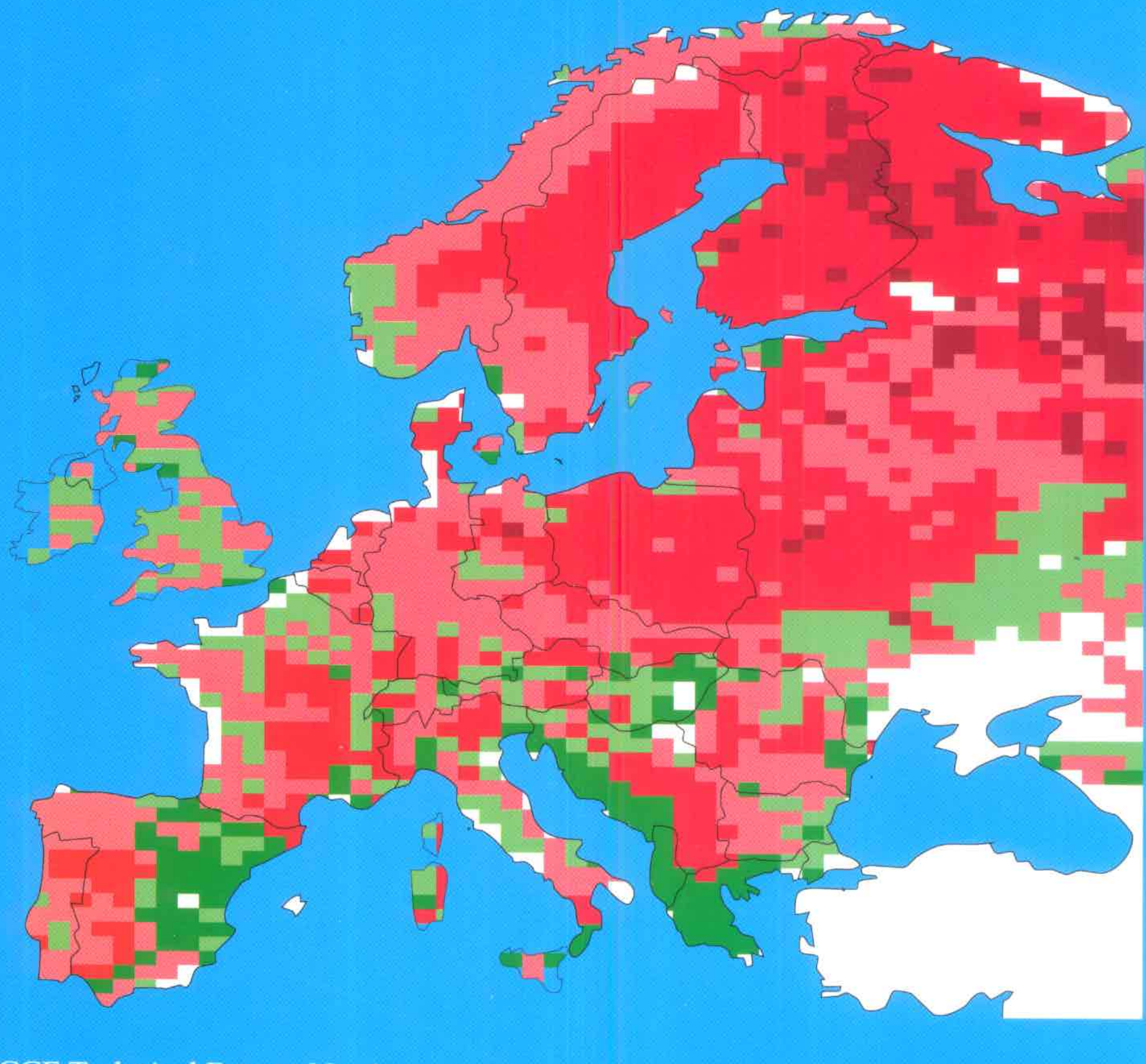
Mapping Critical Loads for Europe

United Nations
Economic Commission for Europe
Convention on Long-Range Transboundary Air Pollution



CCE Technical Report No. 1
July 1991

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COORDINATION CENTER FOR EFFECTS

NATIONAL INSTITUTE OF PUBLIC HEALTH AND ENVIRONMENTAL PROTECTION

MAPPING CRITICAL LOADS FOR EUROPE

CCE TECHNICAL REPORT NO. 1

JULY 1991

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RIVM Report No. 259101001
ISBN No. 90-6960-011-0

PREFACE

This report presents the first maps of critical loads produced as part of the work conducted under the United Nations Economic Commission for Europe (UN ECE) on this subject.

The work plan for the implementation of the UN ECE Convention on Long-Range Transboundary Air Pollution (LRTAP) includes the production of maps of critical loads, critical levels, and exceedances as a basis for developing potential abatement strategies for sulphur and nitrogen. The Coordination Center for Effects (CCE) has been charged with assisting ECE member countries and the Task Force on Mapping in the development of national and European maps of critical levels/loads.

The Coordination Center for Effects was created to assist the Executive Body for the UN ECE LRTAP Convention in the effects-related work conducted under its Working Groups on Effects and on Abatement Strategies and their subsidiary bodies, particularly the Task Force on Mapping. The CCE was first proposed by the Government of the Netherlands at the November 1988 meeting of the UN ECE Executive Body for the LRTAP Convention. The Executive Body welcomed the Netherlands offer, and the Center was established in 1990. It is part of the Bureau for Environmental Forecasting of the National Institute of Public Health and Environmental Protection (RIVM), located in Bilthoven, the Netherlands. Financial support for the Center is provided by the Dutch Ministry of Housing, Physical Planning and Environment (VROM), and by RIVM.

Many UN ECE member countries participating in the critical loads mapping exercise have appointed National Focal Centers (NFCs) which coordinate national mapping efforts. These focal centers are primarily responsible for the development, collection, and review of national data, and the production and/or review of national critical loads and levels maps. The Coordination Center works in close collaboration with these National Focal Centers and the Task Force on Mapping.

As its first major task, the Coordination Center has produced 'best available' integrated European critical load maps of actual acidity, based primarily upon the data supplied by individual countries. In order to avoid gaps in the development of a continent-wide map, and to allow the comparison of national results, the Coordination Center has used various standardized methods to calculate critical loads for some countries who have been unable to produce national maps. The resulting best available integrated European maps of actual acidity, sulphur, and nitrogen produced by the Coordination Center can be found in Chapter 2 of this report. These maps include national data received by the Coordination Center through 7 June 1991.

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ACKNOWLEDGMENTS

The Mapping Manual prepared by the Task Force on Mapping (UN ECE, 1990a) and its annexes provided the conceptual basis for the mapping exercise. Two Training Sessions held by the CCE in 1990 and early 1991 and early versions of the Mapping Vademecum (Hettelingh and de Vries, 1991) were essential in addressing issues which arose in the production of national data and maps, and in proposing solutions to obstacles encountered. The Task Force on Mapping, National Focal Centers, and other participants in these exercises were instrumental in the conceptual and scientific development of the critical loads calculations and resultant maps presented in this report.

In particular, the Coordination Center would like to acknowledge the efforts of:

- Wim de Vries, Winand Staring Center, for assistance with the European data base and the application of the steady state mass balance method.

- Wolfgang Schöpp, IIASA, for providing European data and programming expertise.

- Markus Amann, IIASA, and Leen Hordijk, University of Wageningen, for providing general support.

- Hans Breukers, Arthur van Beurden, Wim Evers, Paul Padding, and Henk Scholten, RIVM; Evert Meijer, Geodan; and Theo Tewisse, RAET-LUM, for their contributions and expertise concerning geographic information systems (GIS).

- Michael Chadwick, Johan Kuylenstierna, and Clair Gough of the Stockholm Environment Institute for assisting in data and map evaluation.

- Maximilian Posch and Juha Kämäri, Finnish Water and Environment Administration, for providing assistance in updating the European data base of soil parameters.

- The Air Directorate of the Dutch Ministry of Housing, Physical Planning, and Environment (VROM), particularly Volkert Keizer, Johan Sliggers, and Harriet Marseille, for funding and support.

- Andre Berends, RIVM, for designing the cover artwork.

In addition, sincere thanks are due to all National Focal Center representatives who provided maps, input data, and/or reports on their national mapping activities. Their contributions over the past year or more form the basis of the critical load maps included in this report.

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EXECUTIVE SUMMARY

The work plan for the implementation of the UN ECE Convention on Long-Range Transboundary Air Pollution includes the production of maps of critical loads, critical levels, and exceedances as a basis for developing potential abatement strategies for sulphur and nitrogen.

The Coordination Center for Effects (CCE) was created to assist the United Nations Economic Commission for Europe (UN ECE) in the effects-related work conducted under its Working Groups on Effects and on Abatement Strategies and their subsidiary bodies, particularly the Task Force on Mapping. Since its start in April 1990, the CCE has produced a Mapping Vademecum and held two training sessions in order to obtain consensus among experts involved in the mapping exercise concerning the methods used.

The first critical load maps presented in this report have the following characteristics:

1. **Application of different methods**: The critical loads maps of Europe have in majority been obtained using one method, i.e., the steady state mass balance method. Only 3 of 13 countries which submitted data applied a different method. The application of different methods has not lead to loss of comparability of displayed results.

   The maps of critical loads of sulphur have been obtained from the critical load map of acidity by applying a fraction computed from actual acid deposition. The maps of critical loads of nitrogen have been obtained by applying the earlier mentioned fraction as well as European data on nitrogen uptake. Therefore the map of critical loads of nitrogen reflects acidifying as well as nutrifying characteristics of nitrogen for forest soils.

2. **Application of different data resolutions**: European soil data are available for 25 countries. National critical load computations using national data were provided by 13 countries. These 13 countries provided critical loads for surface waters, forest soils or a combination of these ecosystems. The remaining 12 countries were mapped using European data for forest soils.

   All critical loads data were aggregated to EMEP grid areas (approximately 150 km x 150 km) by constructing cumulative distributions of critical loads for every EMEP grid cell.

3. **Display of critical loads percentiles**: 1 and 5 percentile maps of critical loads of acidity, sulphur and nitrogen have been produced. The 1 (or 5) percentile map of critical loads reflects the upper bound of the range of critical loads in each EMEP grid cell which covers 1% (or 5%) of the area **in an EMEP grid cell.**

   By choosing a low percentile (i.e., 1 or 5) a large share of sensitive ecosystems, including the most sensitive ones, will be protected. The application of higher percentiles will increase the uncertainty with respect to the area coverage of protected ecosystems. The main reason for the latter is the lack of areal data.

4. **Shading of EMEP grid cells**: The shading of EMEP grid cells is obtained by assigning the 1 and 5 percentile critical loads to one of the following critical load ranges, i.e., 0 - 200 eq ha^{-1} yr^{-1} (dark red), 200.1 - 500, 500.1 - 1000, 1000.1 - 2000, and > 2000 (dark green).

   EMEP grid cells which contain parts of more than one country have been shaded using (1) national data if the grid cell contains a combination of European and national data, or (2) combined data from different countries if the grid cell contains a combination of national data or (3) European data if the EMEP grid cell does not contain national data. Note that an EMEP grid cell may also have been shaded entirely when the cell partly contains shares of countries for which no European nor national data is available.

5. **Map intercomparison**: A comparison of the critical loads map for acidity with the Stockholm Environment Institute map used until now in the activities of the UN ECE Working Group on Abatement Strategies shows an overall similarity, both in the critical loads values and in the distribution of critical loads classes.

   However, quality control of methods and data will be part of an ongoing research process. Users of the first maps provided in this report should be aware of the compromises in quality and resolution made by the participants in the mapping exercise in keeping the tight schedule since the Coordination Center for Effects started its work in 1990. Consequently, future revisions to the enclosed maps will be produced as more detailed and accurate data becomes available.

6. **Computation of critical loads exceedances**: The exceedance of the 1 and 5 percentile critical load of acidity, sulphur, and nitrogen has been estimated using EMEP deposition computations which have been modified to inorporate base cation deposition, base cation uptake, and nitrogen uptake. In addition, filtering factors for forests in an EMEP grid cell have been estimated in order to account for throughfall. Failure to include EMEP depositions with the variables mentioned above will result in an imprecise estimation of the actual exceedance of the critical loads of acidity. A similar conclusion holds when the exceedance of non-modified EMEP computed sulphur (nitrogen) deposition is compared to the critical load of sulphur (nitrogen).

   Country participants have indicated that filtering factors used in this report may be adapted in the future to incorporate effects other than forest throughfall effects, e.g., effects of altitude.

The European maps of critical loads are displayed in Chapter 2 of this report. Attention is especially drawn to the 1 and 5 percentile European maps of actual acidity (respectively Figure 2.1a and 2.2b), and the 1 and 5 percentile sulphur maps (respectively Figure 2.2a and 2.2b).

These results, while preliminary, represents the current state of scientific knowledge which can be provided to discussions concerning the assessment and control of long-range transboundary air pollution. It is expected that these maps will be revised in the future as updates of input data through national contributions (e.g., nitrogen critical loads, sulphur fractions and filtering factors) become available.

It is also necessary to investigate the consequences of differences in critical load estimation more thoroughly, especially since a good understanding is needed for a dynamic assessment of acid (sulphur and nitrogen) abatement scenarios.

CHAPTER 1. INTRODUCTION

J.-P. Hettelingh, R.J. Downing, and P.A.M. de Smet

This first Technical Report of the Coordination Center for Effects (CCE) presents European maps of critical loads of actual acidity, sulphur and nitrogen, and maps displaying European geographical patterns of exceedances* of current deposition over critical loads. Methods and assumptions used to produce these CCE maps are summarized in this report but can be found in more detail in the Mapping Manual (UN ECE, 1990a) and its annexes, as well as the Mapping Vademecum (Hettelingh and de Vries, 1991), of which several drafts were produced during the mapping exercise.

This report also aims to provide an preliminary evaluation of the CCE maps through (1) comparison with the Stockholm Environment Institute sensitivity map which has been used by the UN ECE Task Force on Integrated Assessment Modeling (TFIAM) to assess abatement strategies, and (2) comparison of broad-scale European data to two cases of national data used in the mapping exercise.

Chapter 2 provides 1 and 5 percentile CCE maps of European critical loads of acidity, sulphur and nitrogen and respective exceedance maps. The 1 (and 5, respectively) percentile map of critical loads is the value of the critical loads in each EMEP grid cell which protects 99% (respectively 95%) of the entire EMEP grid cell area, including nationally chosen most sensitive ecosystems, in an EMEP grid cell. Higher percentiles will increase the uncertainty about the share of ecosystems in an EMEP grid cell which are protected, as computed with the currently available data.

The CCE maps provided in Chapter 2 represent the status of national contributions, available European data, and applied methods through 7 June 1991. Since it started its activities in April 1990, the Coordination Center for Effects has made several versions of maps (November 1990; January, March, May 1991) available to participating parties including the UN ECE Task Force on Mapping as national data became available and agreed methods were refined. The CCE maps displayed in this report differ from earlier maps (May 1991 version) by the inclusion of a national contribution of critical loads in the USSR. National contributions were obtained from Austria, Bulgaria, Czech and Slovak Federal Republic, Denmark, Finland, France, Germany, Ireland, the Netherlands, Norway, Sweden, Switzerland, the Union of Soviet Socialist Republics, and the United Kingdom. Remaining countries have been mapped using available European data. Chapter 2 concludes with a map of critical loads obtained by using the latter mentioned data only, and excluding national contributions.

The CCE maps of European critical loads and data presented in Chapter 2 have been transferred to the Task Force on Integrated Assessment Modeling to support ongoing activities for the Working Group on Abatement Strategies.

Chapter 3 provides an overview of the steps taken to produce the CCE maps of European critical loads and summarizes methods used to compute critical loads of acidity and its sulphur and nitrogen derivatives. This chapter also describes briefly the data and its statistical treatment leading to the representation of percentiles.

There have been numerous other regional assessments to map ecosystem sensitivity to acidic air pollutants on a European scale. One notable effort is that of the Stockholm Environment Institute at York (Chadwick and Kuylenstierna, 1990), which has been used recently by the Task Force on Integrated Assessment Modeling in the assessment of abatement strategies. Chapter 4 includes a comparison of

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* The word "exceedance" has been widely accepted in the vocabulary of the parties under the LRTAP Convention to express the excess of current deposition loads over critical loads. This report uses the term "exceedance" in conformity with current practices.

European maps produced by the Coordination Center and the sensitivity map produced by the Stockholm Environment Institute (Section 4.3), and country maps produced by National Focal Centers (Section 4.4). Chapter 5 contains conclusions and discussion of the critical load mapping effort.

Individual country maps and reports produced by National Focal Centers, which form the basis for the integrated European critical loads maps, are contained in Appendix 1 of this report. Other appendices include background information on the sources and calculations used in producing the European critical loads maps.

CHAPTER 2. EUROPEAN CRITICAL LOADS MAPS

J.-P. Hettelingh, R.J. Downing, and P.A.M. de Smet

2.1 Critical Loads of Actual Acidity

Figures 2.1a and 2.1b display the 1 and 5 percentiles, respectively, of critical loads of actual acidity. These maps have been produced on the basis of the steady state mass balance map (Section 2.7), with the inclusion of nationally derived critical load values. The map reflects data for both forest soils and surface waters (i.e., it is a "mixed receptor" map). The following countries provided the Coordination Center with national data on critical load calculations: Austria, Czech and Slovak Federal Republic, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Sweden, Switzerland, Union of Soviet Socialist Republics, and United Kingdom.

Other countries (Bulgaria, France, Poland) indicated improvements to the existing European data bases for input data for their country. In these cases, the Coordination Center has revised these data bases accordingly. Input data values from the European data bases described in Appendix 3 were used for the remaining countries. The 1 and 5 percentile values of critical loads of acidity were computed from national as well as from European data except for the USSR, which provided the CCE directly with 1 and 5 percentile data for critical loads of acidity.

The computation of critical loads and percentile values in EMEP grid cells were produced using the SPANS and ARC/INFO geographic information systems. All maps in this section were produced using GEOMAN data display software, designed by the International Institute for Applied Systems Analysis (IIASA).

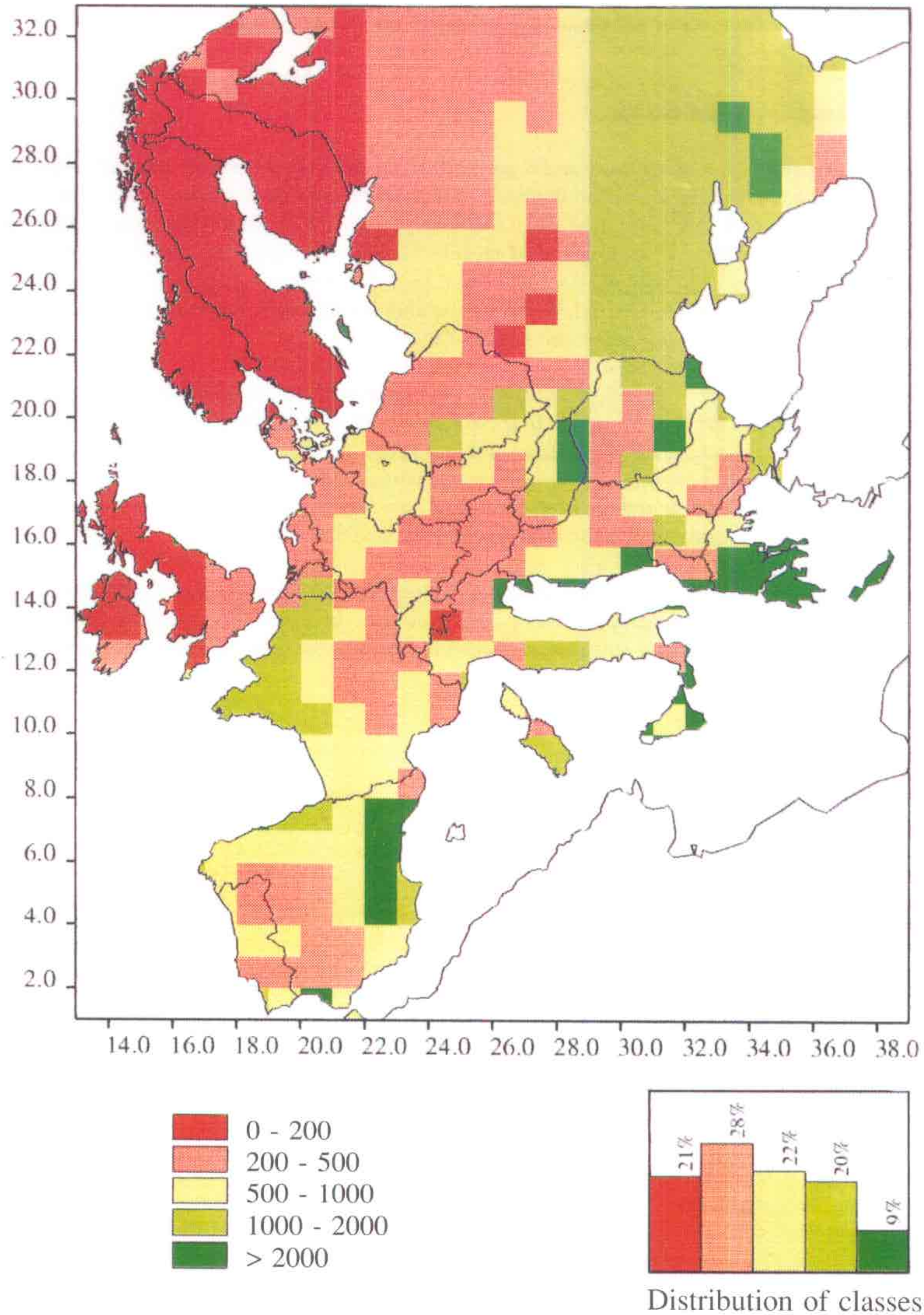


Figure 2.1a. Critical loads of actual acidity using national and European data (1 percentile). Units = equivalents ha^{-1} yr^{-1}.

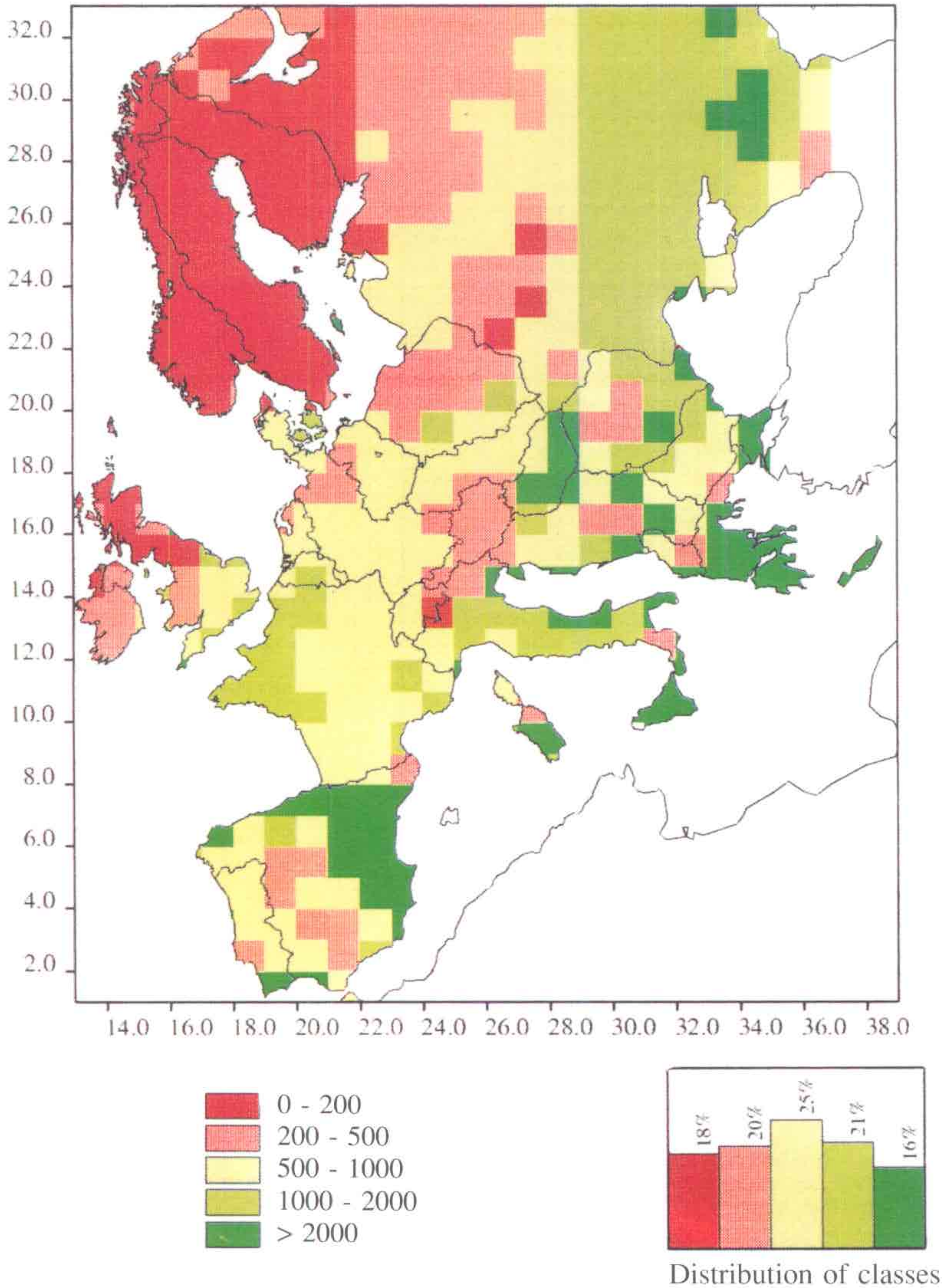


Figure 2.1b. Critical loads of actual acidity using national and European data (5 percentile). Units = equivalents ha^{-1} yr^{-1}.

2.2 Critical Loads of Sulphur

Figures 2.2a and 2.2b display the 1 and 5 percentiles, respectively, of critical loads of sulphur. These maps were produced on the basis of the map of critical loads of actual acidity and incorporate the calculated ratios of the deposition of sulphur as a percentage of total acidity. These maps were produced in response to a request by the UN ECE Executive Body for the LRTAP Convention and its subsidiary bodies for scientific information to be used as scientific input to a new sulphur emissions reduction protocol. Background information on the development of the sulphur fraction can be found in Section 3.3.2.

The 1 and 5 percentile map of critical loads of sulphur were computed from national as well as from European data except for the USSR, which provided the CCE directly with 1 and 5 percentile data for critical loads of sulphur.

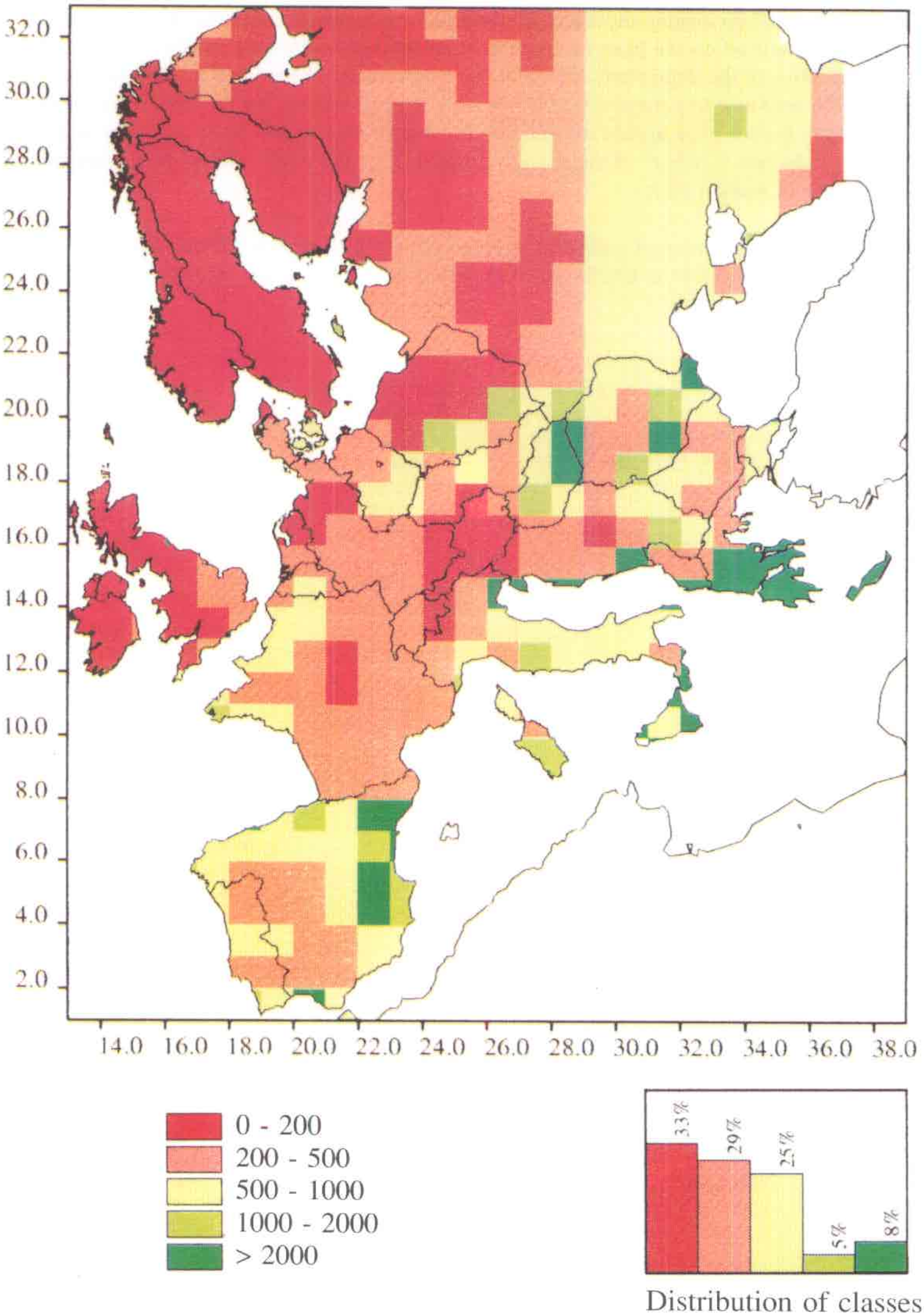


Figure 2.2a. **Critical loads of sulphur using national and European data (1 percentile). Units = equivalents ha^{-1} yr^{-1}.**

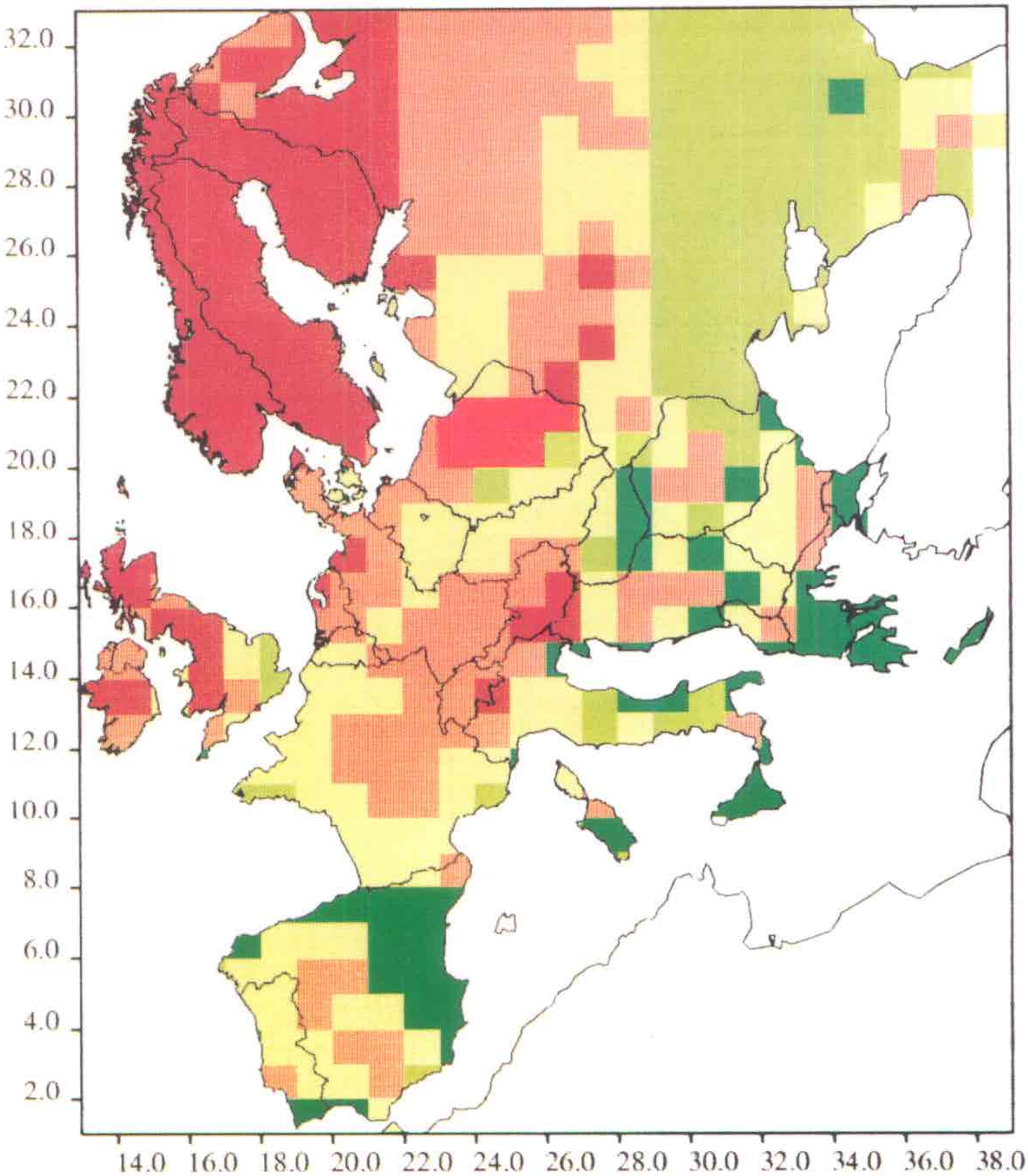


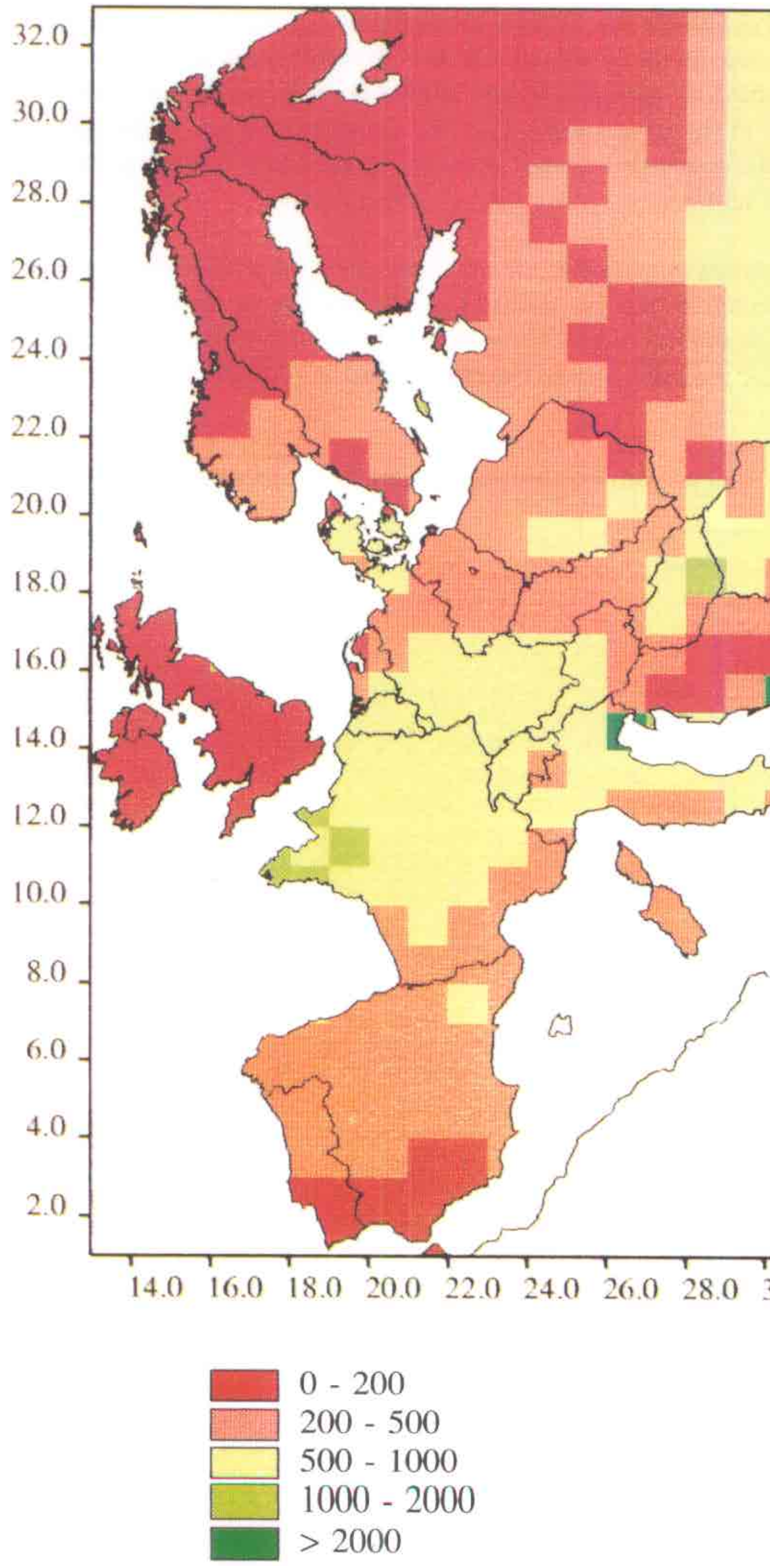
Figure 2.2b. Critical loads of sulphur using national and European data (5 percentile). Units = equivalents ha^{-1} yr^{-1}.

2.3 Critical Loads of Nitrogen

Figures 2.3a and 2.3b display respectively the 1 and 5 percentile of critical loads of nitrogen. The critical load of nitrogen reflects sensitivity of managed forests to nitrification as well as to acidification. The result is obtained by adding nitrogen uptake of managed forests (from the European data base) to the part of the critical load of acidity which is assigned to nitrogen. The latter has been computed by subtracting the computed critical load of sulphur (using the sulphur fraction described in Section 3.3.2) from the critical load of actual acidity.

Future work will incorporate country preferences for the ecosystems for which nitrogen uptake has to be incorporated. The 1 percentile map of the critical load of nitrogen has been computed for all countries except the USSR, which provided the CCE directly with 1 percentile computations for critical loads of nitrogen. The 5 percentile map of the critical load of nitrogen has been computed for all countries.

A discussion of calculation methods used to compute critical loads of nitrogen can be found in Section 3.3.3.



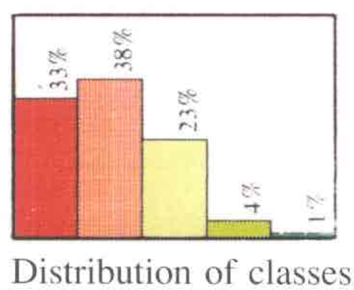


Figure 2.3a. Critical loads of nitrogen using national and European data (1 percentile). Units = equivalents ha^{-1} yr^{-1}.

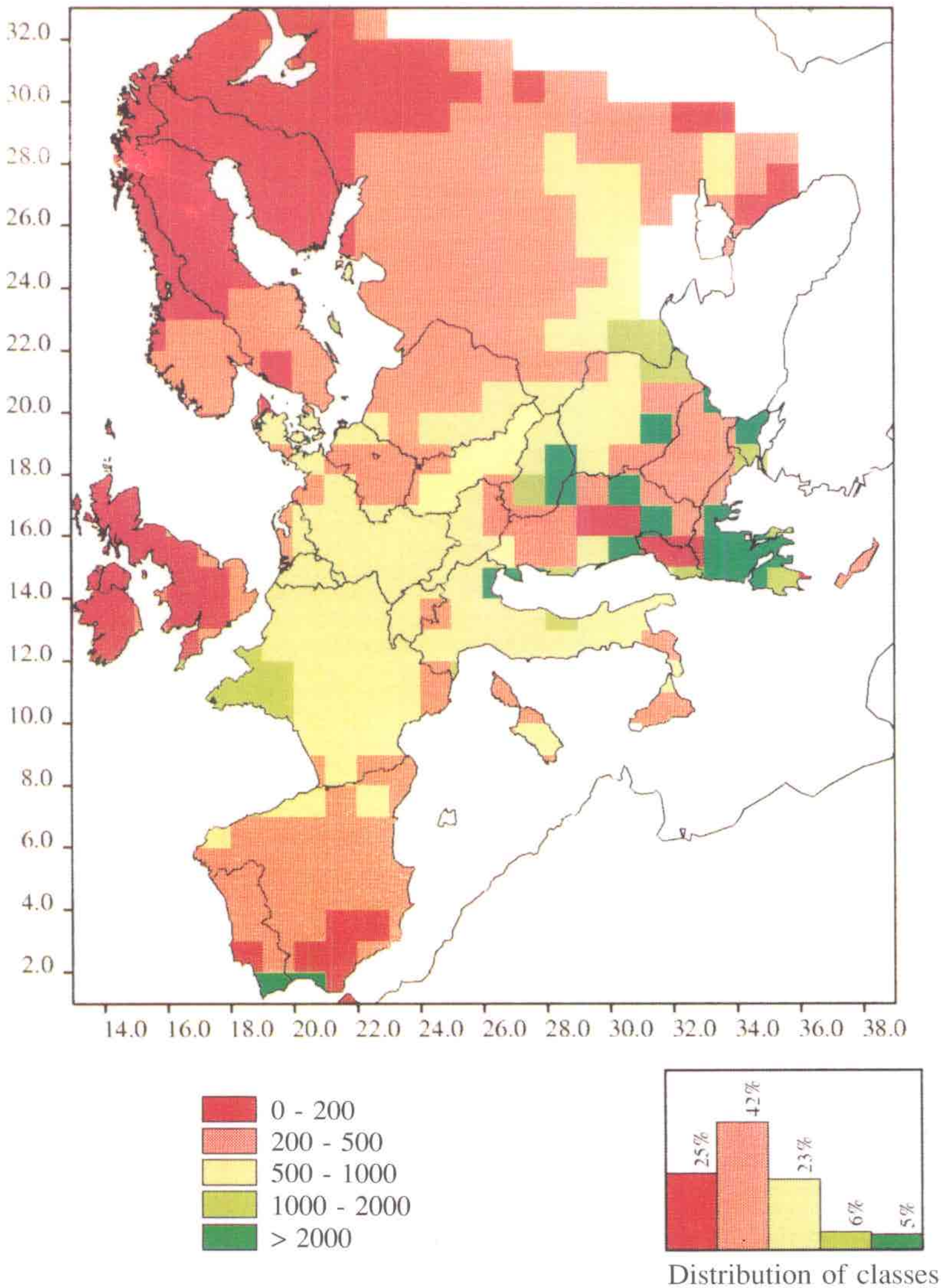


Figure 2.3b. Critical loads of nitrogen using national and European data (5 percentile). Units = equivalents ha^{-1} yr^{-1}.

2.4 Exceedances of Critical Loads of Actual Acidity

An exceedance is defined as the excess of present loads over critical loads. The maps of 1 and 5 percentile exceedances of actual acidity (Figures 2.4a and 2.4b) have been calculated by subtracting the European/national critical loads data contained in Section 2.1 from EMEP present loads data, which have been modified to include base cation uptake, base cation deposition, nitrogen uptake, and filtering factors from European data base to define present loads of acidity, sulphur, and nitrogen. (See Appendix 3 for details on the European data bases used.) The calculations used to compute present loads and exceedances can be found in Section 3.3.4.

It should be noted that the values of the input parameters mentioned above to modify EMEP deposition computations, will be updated as improved information becomes available, and thus that these exceedance maps may change accordingly.

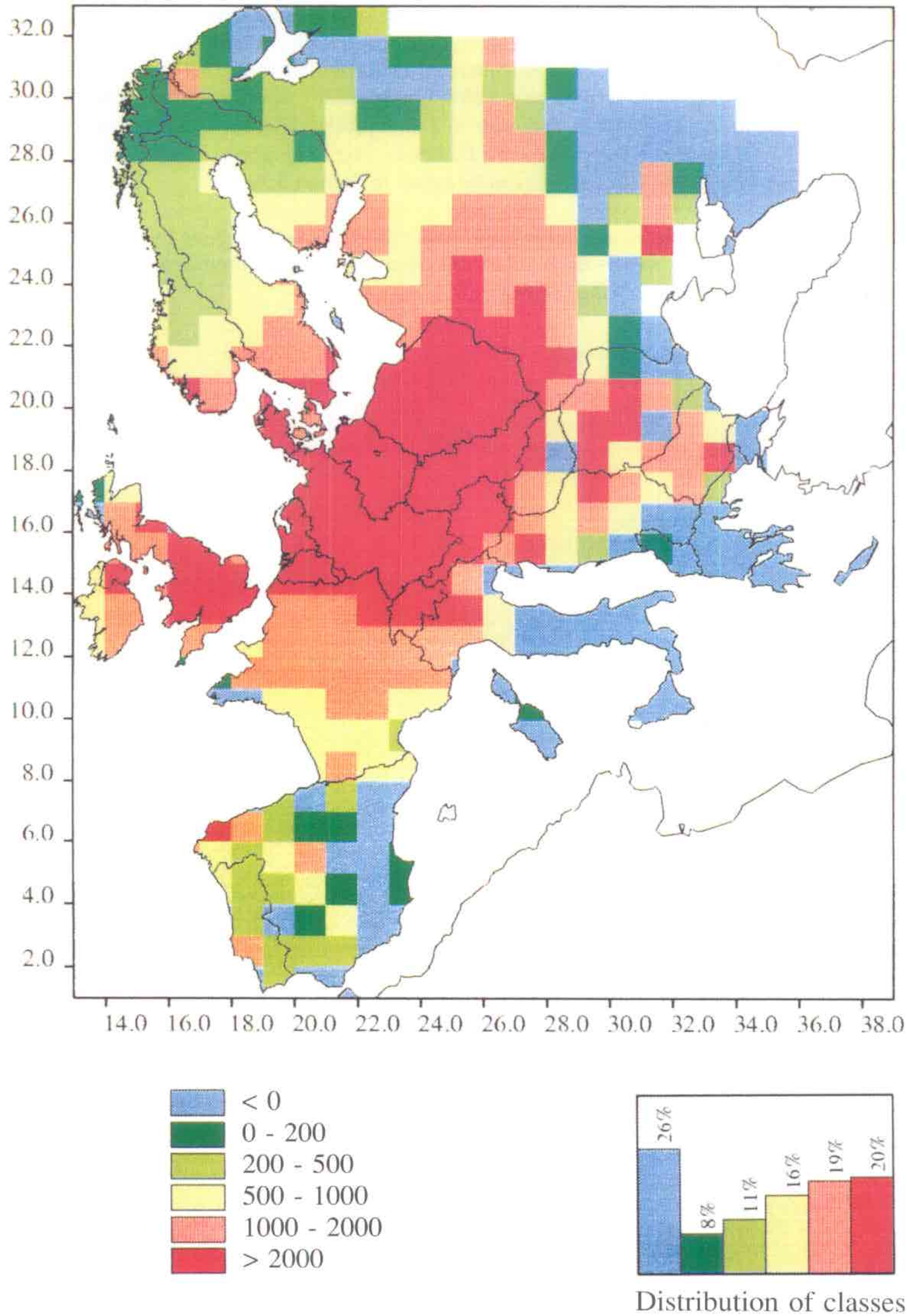


Figure 2.4a. Exceedance of the critical load of actual acidity (1 percentile).
Units = equivalents ha^{-1} yr^{-1}.

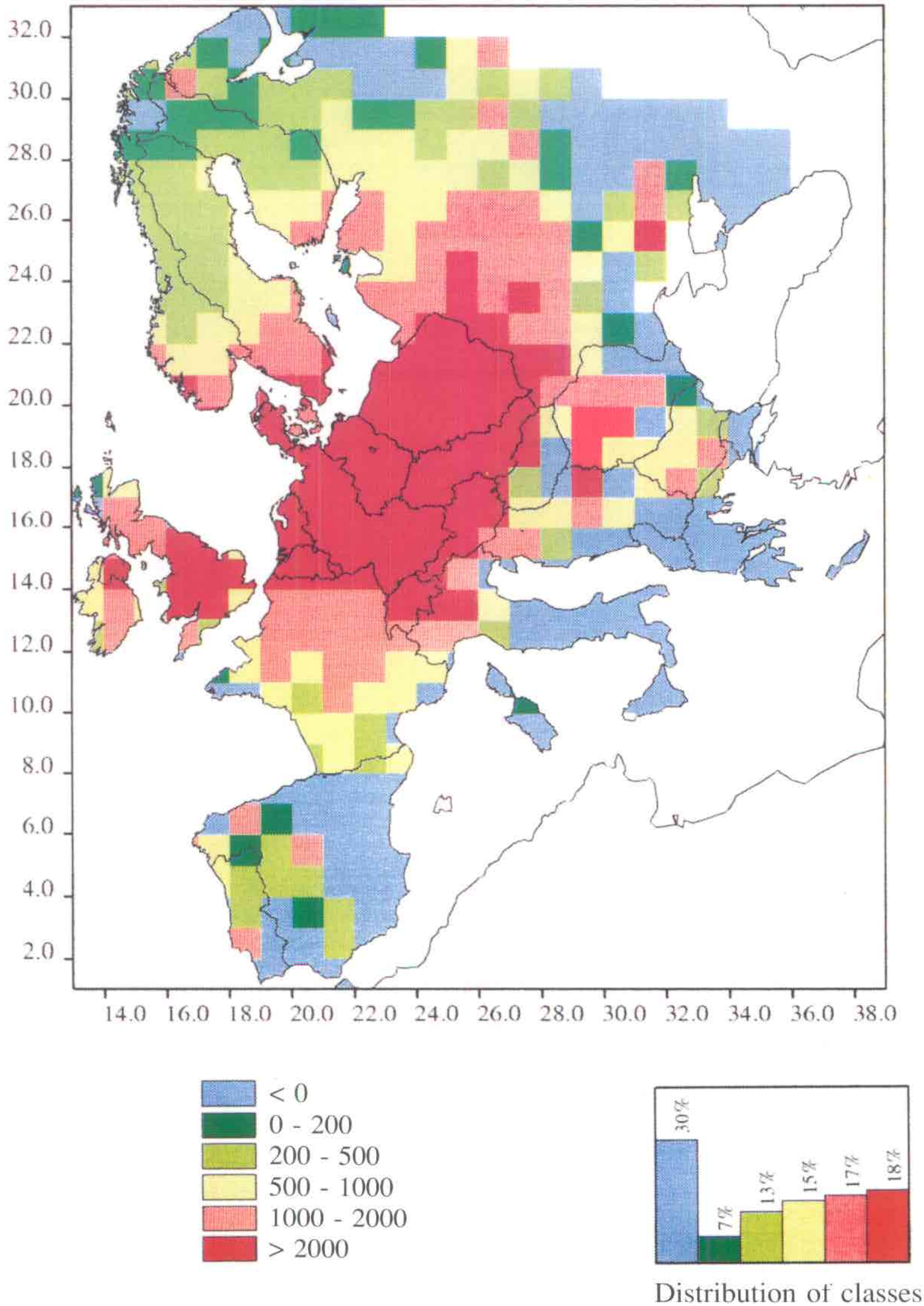


Figure 2.4b. Exceedance of the critical load of actual acidity (5 percentile). Units = equivalents ha^{-1} yr^{-1}.

2.5 Exceedances of Critical Loads of Sulphur

As with critical loads of acidity, the 1 and 5 percentile critical loads of sulphur (from Section 2.2) have been subtracted from EMEP present loads data (from Appendix 2) to produce these maps of exceedances of critical loads of sulphur. The resulting 1 and 5 percentile exceedances are presented in Figures 2.5a and 2.5b.

The calculations used to produce these maps include filtering factors for sulphur and for net base cation inputs. The derivation of the sulphur filtering factor is described in Appendix 4. Data sources for base cation inputs are discussed in Section 3.4.2 and Appendix 3.

It should be noted that the values of the input parameters mentioned above to modify EMEP deposition computations, will be updated as improved information becomes available, and thus that these exceedance maps may change accordingly.

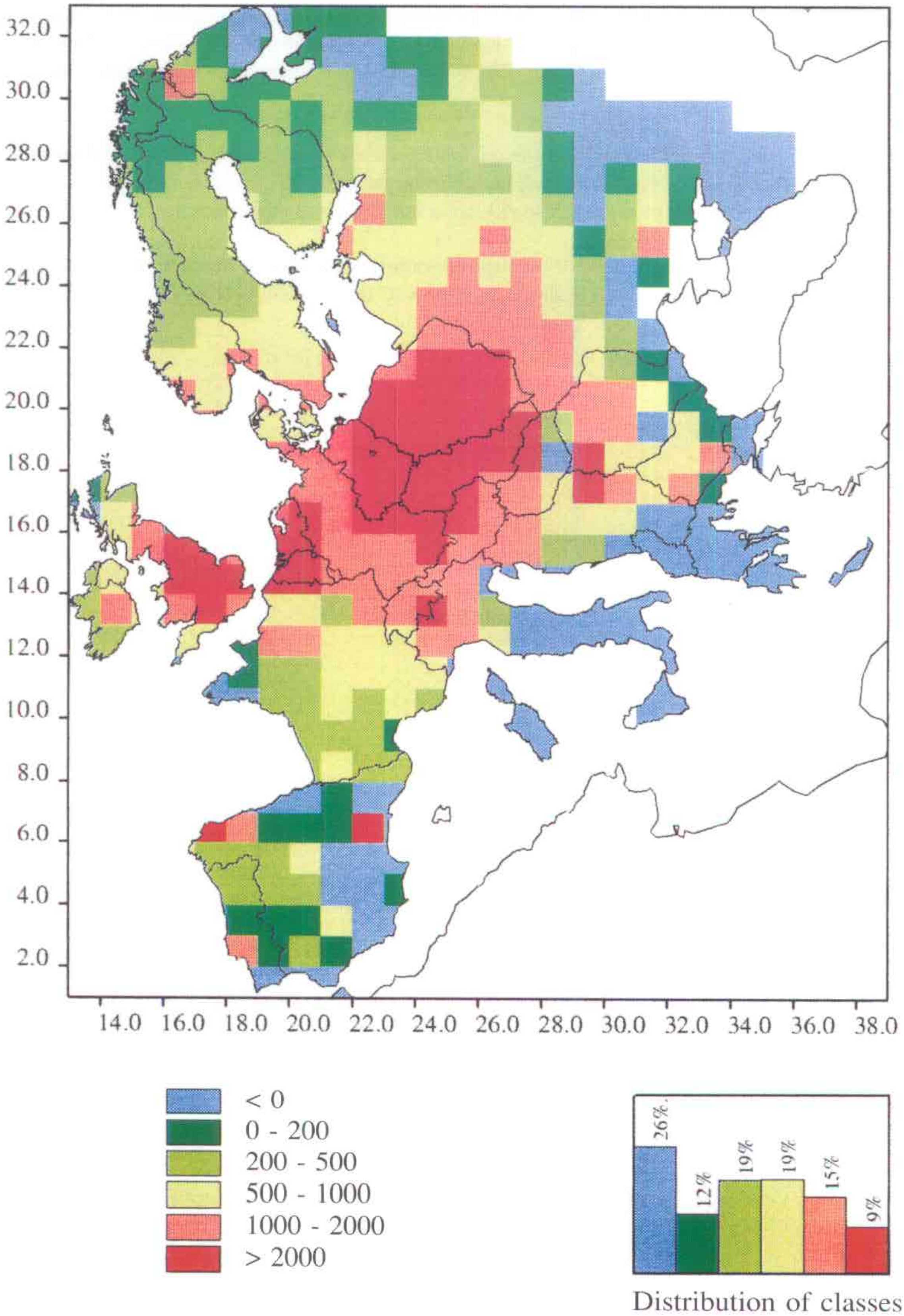


Figure 2.5a. **Exceedance of the critical load of sulphur (1 percentile). Units = equivalents ha^{-1} yr^{-1}.**

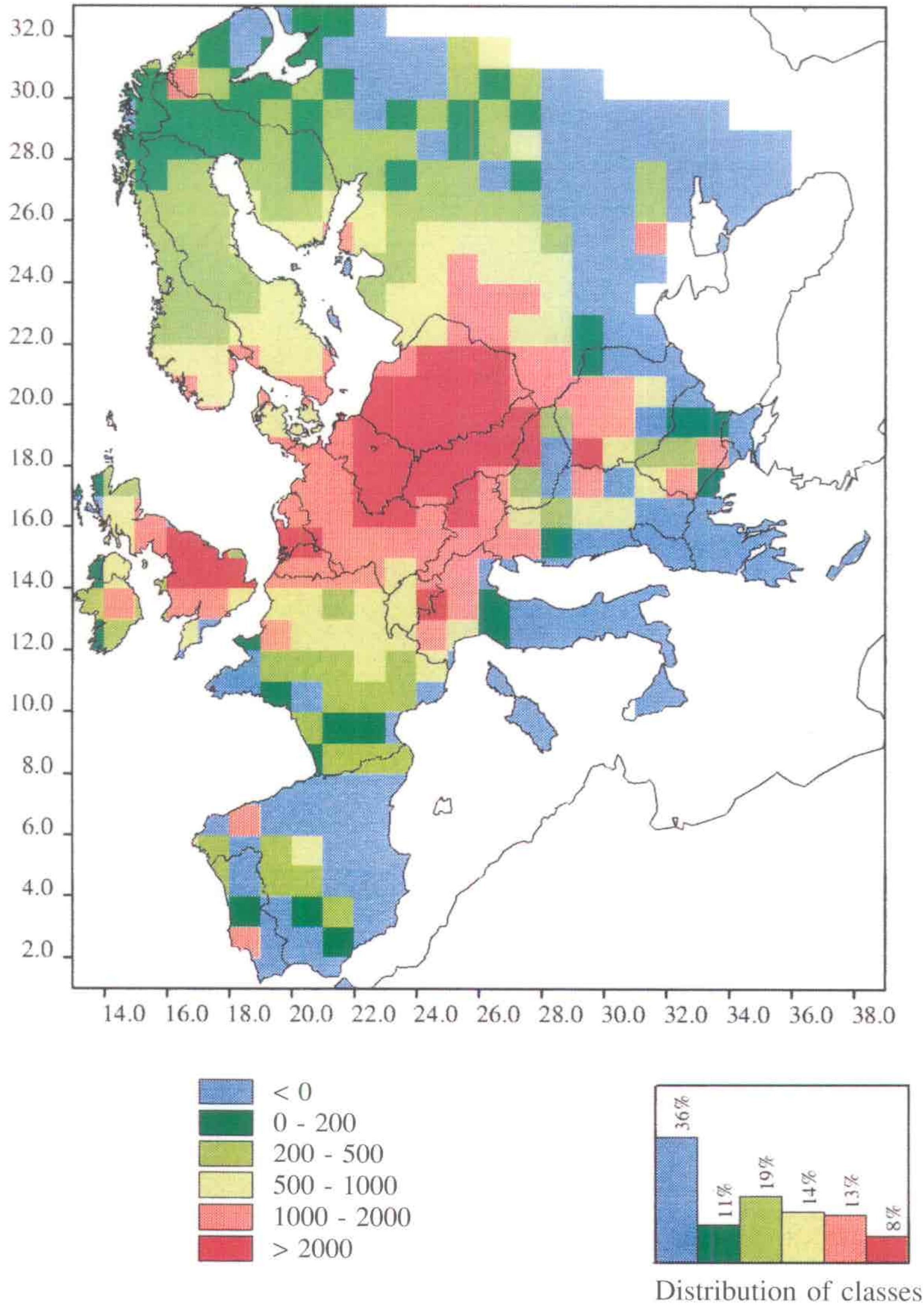


Figure 2.5b. Exceedance of the critical load of sulphur (5 percentile).
Units = equivalents ha^{-1} yr^{-1}.

2.6 Exceedances of Critical Loads of Nitrogen

The 1 and 5 percentile nitrogen exceedance maps (Figures 2.6a and 2.6b) are also derived from the relevant critical loads and present loads data.

The calculations used to produce these maps include filtering factors for nitrogen and for net base cation inputs. The derivation of the nitrogen filtering factor is described in Appendix 4. Data sources for base cation inputs are discussed in Section 3.4.2 and Appendix 3.

It should be noted that the values of the input parameters mentioned above to modify EMEP deposition computations, will be updated as improved information becomes available, and thus that these exceedance maps may change accordingly.

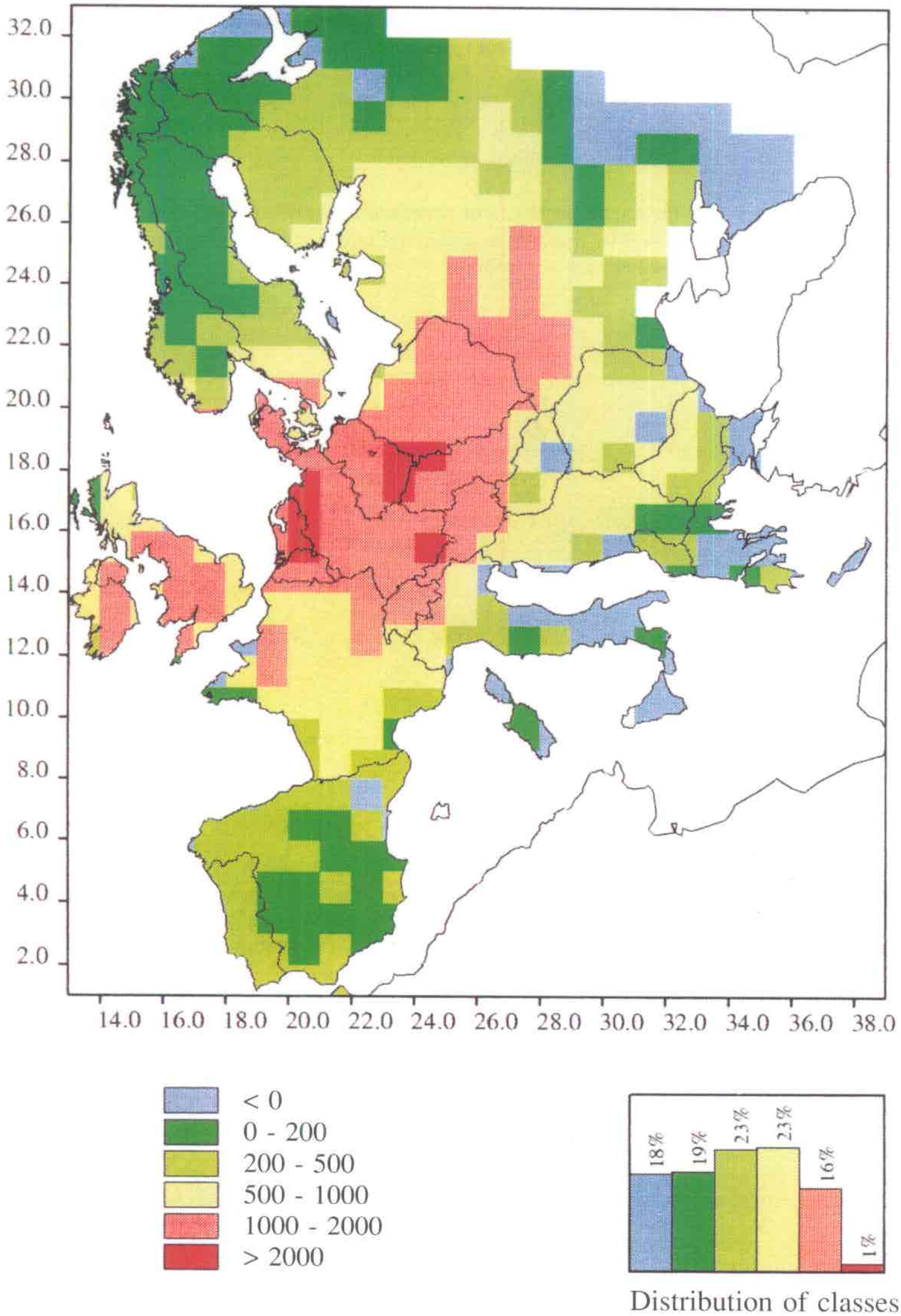


Figure 2.6a. Exceedance of the critical load of nitrogen (1 percentile). Units = equivalents ha^{-1} yr^{-1}.

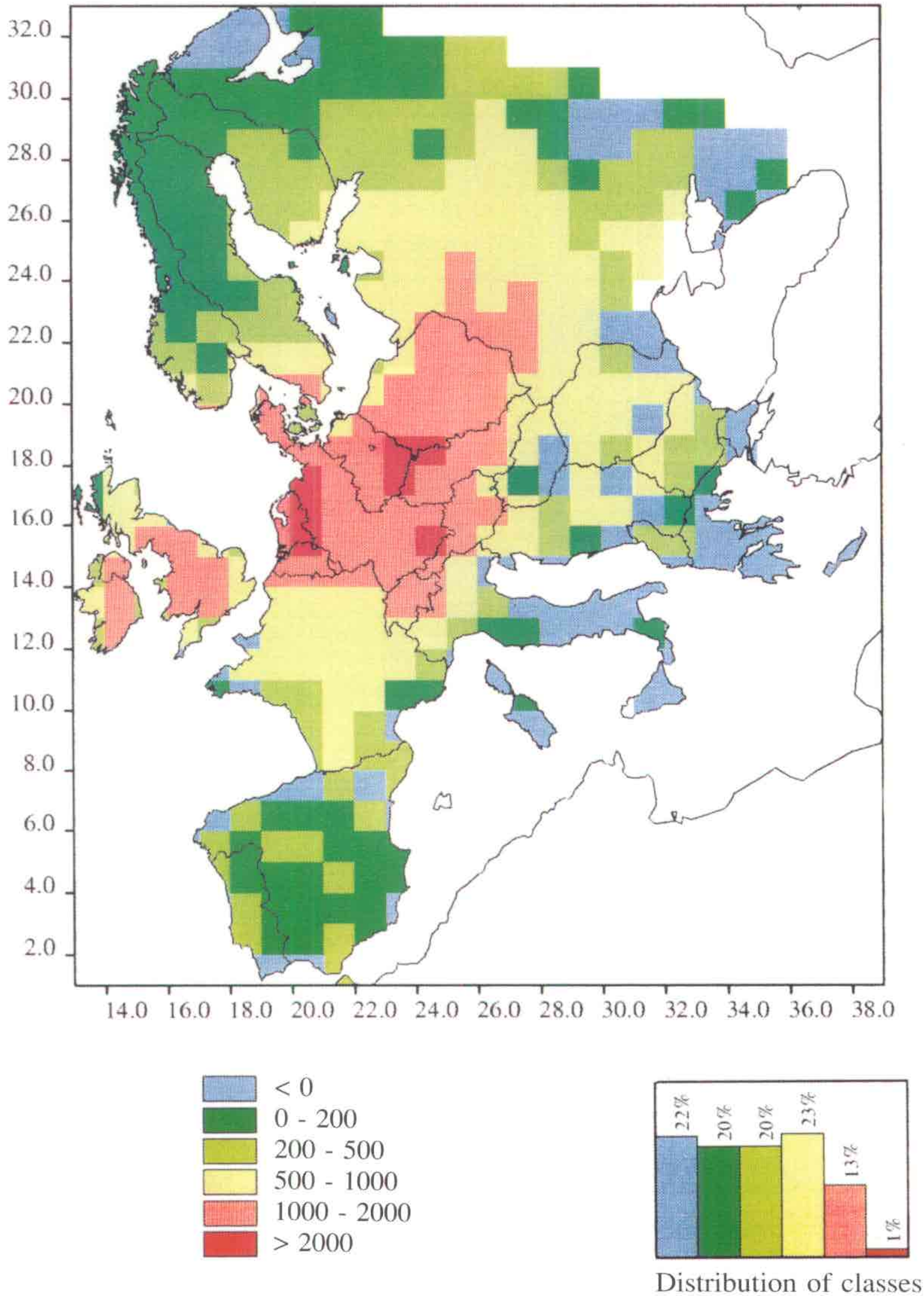


Figure 2.6b. Exceedance of the critical load of nitrogen (5 percentile).
Units = equivalents ha^{-1} yr^{-1}.

2.7 Critical Loads of Actual Acidity: Steady State Mass Balance Map

This map displays the critical loads of actual acidity for forest soils. The map has been produced using only the steady state mass balance method (described in Section 3.3.1.1) and common European data bases. This map forms the basis for "gap filling" for areas in Europe in the absence of other national data on critical loads.

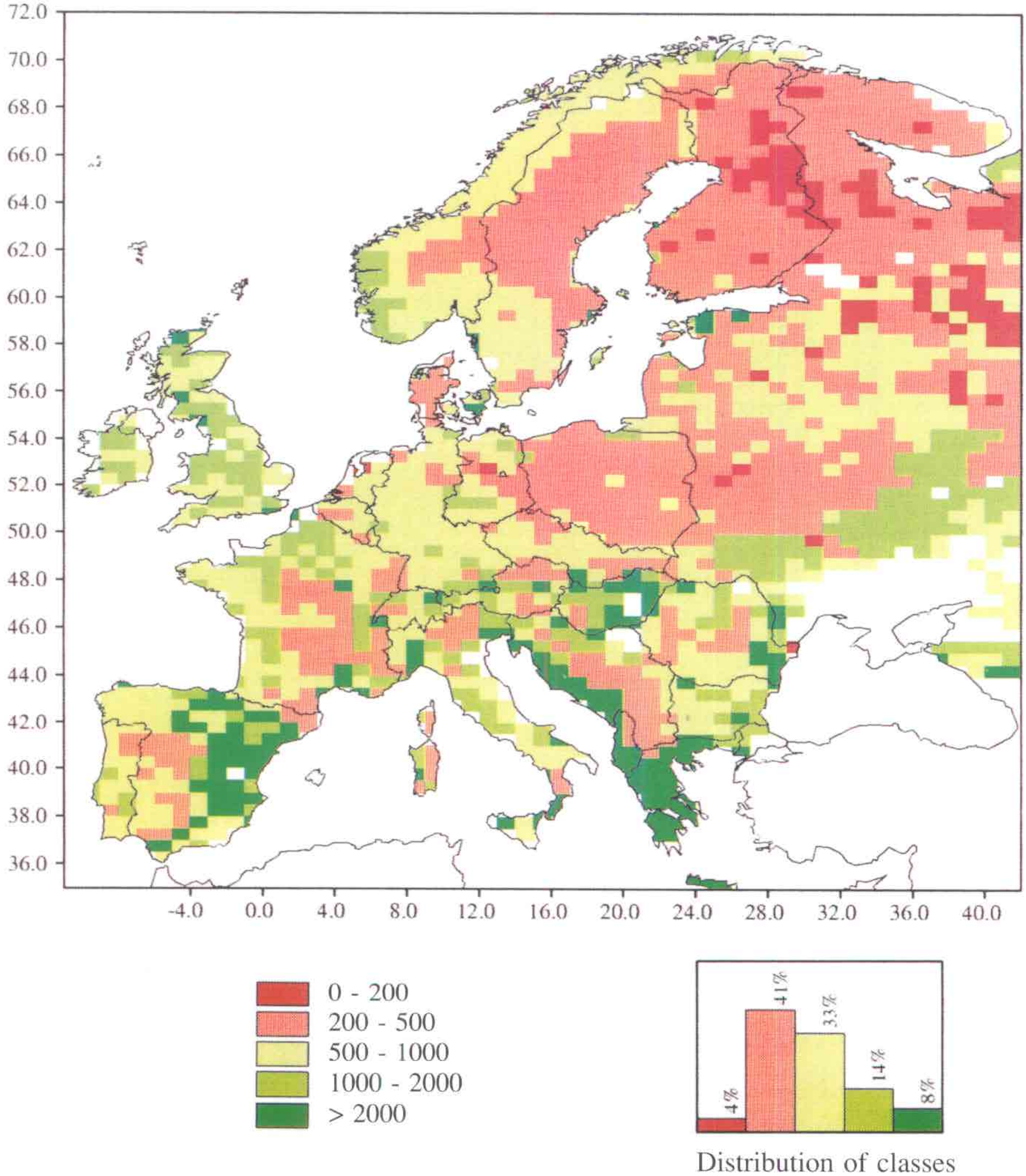


Figure 2.7. **Steady State Mass Balance Map: Critical load of actual acidity for forest soils (1 percentile, using European data only). Units = equivalents ha^{-1} yr^{-1}.**

CHAPTER 3. METHODS AND DATA

J.-P. Hettelingh, W. de Vries[1], W. Schöpp[2], R.J. Downing, and P.A.M. de Smet

3.1 Introduction

This section provides an overview of the methods and data used by the Coordination Center for Effects (CCE) and National Focal Centers to develop the critical loads maps contained in Chapter 2. Section 3.2 describes the criteria used to define critical loads. Section 3.3 discusses the development and use of the mathematical equations used to calculate critical loads, and Section 3.4 describes the origin and uses of input data used in these calculations. Various issues concerning the development of unified European maps of critical loads are discussed in Section 3.5.

The figure below summarizes the steps taken in producing integrated European maps of critical loads.

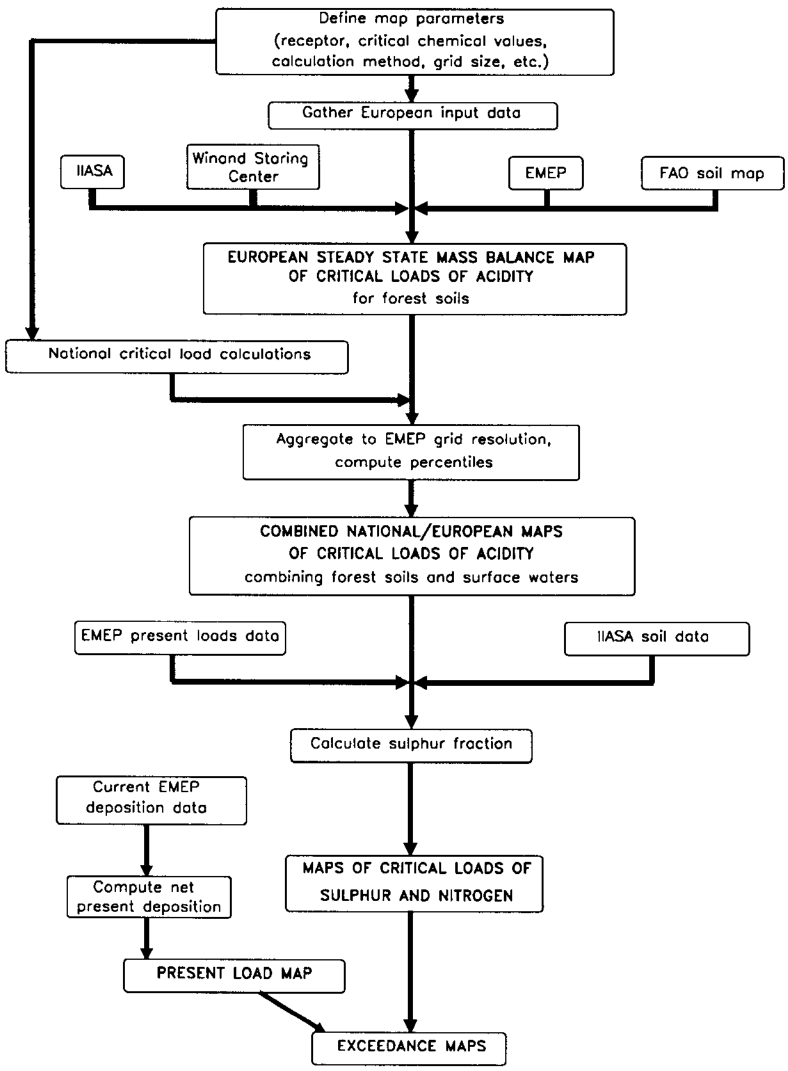


Figure 3.1. Steps in producing CCE European critical loads maps.

1. Winand Staring Center, Wageningen, the Netherlands.
2. International Institute for Applied Systems Analysis, Laxenburg, Austria.

The critical loads maps in Sections 2.1 through 2.6 are mixed maps: they combine national critical loads data for a variety of ecosystems, using various methods, with the critical load calculations of the steady state mass balance map.

The actual production of the maps of critical loads for Europe are the result of basic assumptions described in the Mapping Manual (UN ECE, 1990a) and its annexes, particularly Sverdrup *et al.*, 1990) and of a consequent number of decisions made by the participants of two CCE training sessions. As mapping issues became more specific, more detailed procedures could be followed with respect to the ecosystems to map, the methods to used, the treatment of the data in an EMEP grid cell, etc. A number of these issues were proposed in the Mapping Vademecum (Hettelingh and de Vries, 1991), others were treated in training sessions (see Appendices 6 and 7) and Task Force on Mapping meetings (UN ECE, 1991b). The result is a number of steps that are different from the original decision pathway described in the Mapping Manual. The actual steps taken are outlined in Figure 3.1 and described in the following:

1. **Define map parameters:** The decision was taken by the participants of the National Focal Centers to (a) allow for countries to use their own method, (b) map critical loads of actual acidity for different ecosystems on the same map, (c) apply the steady state mass balance method in European regions for which no national contributions were available, (d) apply a particular formulation of the steady state mass balance method, (d) map European critical loads in EMEP grid cells to ensure compatibility with the EMEP deposition computations, and (e) apply a particular statistical methodology, i.e., construct cumulative distributions (see Appendix 5).

2. **Compute the critical load of actual acidity for Europe as a whole** (the European SMB map): The steady state mass balance method was applied to data from the International Institute for Applied Systems Analysis (Austria) and the Winand Staring Center (The Netherlands). These data are available for $1^{\circ} \times 0.5^{\circ}$ longitude-latitude grid cells and were provided to National Focal Centers for review in November 1990. The results were used for regions in Europe for which no national contributions were available. The SMB method is described in Section 3.3.1.1.

3. **Incorporate national data:** Three types of national data were provided to the CCE: (1) point data of critical loads for forest and surface waters; (2) critical loads assigned to areas in grid cells; (grid cells ranged from very small [1×1 km^2] to EMEP grid cells [150×150 km^2]); and (3) corrections to input data used to apply the steady state mass balance method for forest soils or surface waters. The data received by the CCE are the result of basically two methods, i.e. the steady state mass balance method applied to detailed national data, and the Level 0 method (described in Section 3.3.1.3). An overview of the methods applied by the participants is provided in Section 3.3.1.4.

4. **Assign national data to EMEP grid cells:** The point data (see Point 2 above) were directly assigned to EMEP grid cells. Critical loads provided for areas in grids smaller than the $1^{\circ} \times 0.5^{\circ}$ longitude-latitude grid cells were treated as point data which were assigned to longitude-latitude grid cells. Critical loads for areas in $1^{\circ} \times 0.5^{\circ}$ longitude-latitude grid cells were assigned to areas in EMEP grid cells[1]. The transformation of the European SMB map to the EMEP raster was performed in a similar way. The result of assigning data to EMEP grid cells is a combination of European EMEP grid cells of which each contains either (a) a set of critical load points in, or (2) a set of critical loads assigned to areas (representing ecosystem covers).

   EMEP grid cells which are split by a national border contain critical loads according to one or more of the following three possibilities:

   a. European SMB map data on one side of the border and national data on the other; the shading of the EMEP cell results from national critical loads only and the European SMB data are discarded.

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1. This is done using overlaying techniques of the geographical information system of the CCE/RIVM, which has been provided with the $1^{\circ} \times 0.5^{\circ}$ longitude-latitude raster and with the EMEP raster.

b. National data on both sides of the border; data are mixed to obtain a new cumulative distribution (see Appendix 5).
c. European SMB map data on both sides of the border; the cumulative distribution results from Point 2, above.

5. **Compute percentiles:** Using the cumulative distributions derived above, the 1 and 5 percentile critical loads are derived (see Section 3.5.3 and Appendix 5). Each EMEP grid cell is shaded by assigning the 1 and 5 percentile critical load in an EMEP grid cell to one of the following ranges: Class 1, 0-200 eq ha^{-1} yr^{-1} (dark red); Class 2, 200.1-500; Class 3, 500.1-1000; Class 4, 1000.1-2000; and Class 5, 2000.1 or more (dark green).

6. **Calculate sulphur fraction**: The EMEP computations of deposition of sulphur, nitrogen and preliminary European data on nitrogen uptake for managed forests were used to compute sulphur fractions (described in Section 3.3.2). The critical load map for sulphur represent the share, computed with the sulphur fraction, of acidity which is attributed to sulphur. A similar computation has been used in combination with data on nitrogen uptake to compute the critical load of nitrogen (described in Section 3.3.3).

7. **Compute maps of exceedances of critical loads of acidity, sulphur and nitrogen**: EMEP deposition computations are assumed to be homogeneously distributed over each EMEP grid cell. Participants in the mapping exercise consider it appropriate to distinguish between deposition on open land and remaining areas. For this purpose a preliminary filtering factor has been computed by the CCE following a Task Force on Mapping decision (UN ECE, 1991b). In addition, seasalt-corrected base cation deposition (NILU data), base cation uptake and nitrogen uptake (European database) have been included to EMEP computations of sulphur and nitrogen in order to estimate the net acid deposition. Finally, the 1 and 5 percentile critical loads (acidity, sulphur, nitrogen) were subtracted from the net acid deposition to obtain 1 and 5 percentile exceedance map of critical loads (acidity, sulphur, nitrogen).

3.2 Critical Chemical Values

A critical load has been defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt, 1988). Significant harmful effects are assumed to occur when critical values of chemical compounds in forest soils and freshwaters are exceeded.

Critical chemical values (i.e. for aluminum, aluminum: calcium ratio, pH and alkalinity) are used in the steady state mass balance method for the computation of critical loads. The steady state mass balance method assumes a time-independent equilibrium between the production and consumption of acidic compounds. Basic assumptions underlying the method are described in detail in Sverdrup *et al.* (1990, pp. 16-17). By assuming average thresholds for critical chemical values of pH and aluminum (see Table 3.1), the critical alkalinity can be computed as follows (see also de Vries, 1991).

$$[Alk] = [HCO_3^-] + [RCOO^-] - [H^+] - [Al^{3+}] \qquad (1)$$

where:
$[Alk]$ = alkalinity (acid neutralizing capacity) (mol_c m^{-3})
$[HCO_3^-]$ = concentration of bicarbonates (mol_c m^{-3})
$[RCOO^-]$ = concentration of organic anions (mol_c m^{-3})
$[H^+]$ = concentration of H^+ ions (mol_c m^{-3})
$[Al^{3+}]$ = concentration of aluminum ions (mol_c m^{-3})

The concentration of bicarbonates ($[HCO_3^-]$) and of organic anions ($[RCOO^-]$) can be neglected for soils, assuming that [Al] refers to inorganic aluminum. Assuming gibbsite equilibrium the critical pH can be computed from a given critical aluminum concentration as follows:

$$\mathbf{pH = (\log K_{gibb} - \log[Al]) / 3} \qquad (2)$$

where:
pH = unit for the measurement of $[H^+]$
K_{gibb} = gibbsite equilibrium constant $(mol_c\ m^{-3})^{-2}$
[Al] = aluminum concentration $(mol_c\ m^{-3})$

From Equations 1 and 2, neglecting $[HCO_3^-]$ and $[RCOO^-]$, a critical alkalinity concentration can be computed for forest soils.

For freshwaters the aluminum concentration has been neglected for the computation of critical alkalinity. However, bicarbonates are included since the critical pH is much higher than in forest soils. Bicarbonates can be computed from the critical pH according to:

$$\mathbf{[HCO_3^-] = K_1 \cdot K_H \cdot pCO_2 / [H^+]} \qquad (3)$$

where:
K_1 = first acidity constant $(mol_c\ m^{-3})$
K_H = Henry's law constant $(mol_c\ m^{-3}\ atm^{-1})$
pCO_2 = partial pressure of CO_2 (atm)
$[H^+]$ = concentration of H^+ ions $(mol_c\ m^{-3})$

Substitution of Equations 3 and 2 into Equation 1, neglecting $[RCOO^-]$, leads to the computation of critical alkalinity in freshwaters.

Table 3.1 gives an overview of average critical values that can be obtained from the literature (aluminum, Al/Ca ratio) and by means of Equations 1 to 3 (pH, alkalinity). The average values have been computed from values found in Sverdrup *et al.* (1990) and de Vries (1991). It should be noted that the range in these values may be large, especially for aluminum and Al/Ca ratio in forest soil solutions.

Table 3.1 Critical values used for chemical compounds in forest soils and freshwaters.

Compound	Units	Forest soils	Freshwaters
[Al]	$mol_c\ m^{-3}$	0.2	0.003
Al/Ca	$mol_c\ mol_c^{-1}$	1.5	-
pH	--	4.0[1]	(5.3, 6.0)[2]
[Alk]	$mol_c\ m^{-3}$	-0.3[1]	(0.02, 0.08)[2]

Source: Hettelingh and de Vries, 1991.

1. Assuming log K_{gibb} of 8.0 and [Al]= 0.2. (A pH of 4.0 corresponds to 0.1 $mol_c\ m^{-3}$ of H^+). See Equation 1 for a more general computation of critical alkalinity.
2. A pH of 6.0 relates to peak flow situations and is associated with [Alk] = 0.08 $mol_c\ m^{-3}$. For the computation of critical loads, the alkalinity value of 0.02 $mol_c\ m^{-3}$ (20 $\mu eq\ l^{-1}$) has been used.

3.3 Calculation Methods

3.3.1 Critical Loads of Actual Acidity

In the Mapping Manual (UN ECE, 1990a) a distinction is made among two types of critical loads calculations: Level I: steady state modeling, divided into a water chemistry method and a mass balance method, and Level II: dynamic modeling. In addition, the semi-quantitative Level 0 approach, which uses existing data to assign critical load classes to ecosystems based on ecosystem sensitivity, has been used by some countries.

3.3.1.1 Steady state mass balance method

Steady state modeling approaches assume a time-independent steady state of chemical interactions involving an equilibrium between the soil solid phase and soil solution. Dynamic modeling approaches can be used to assess critical loads in relation to time-dependent processes, thus enabling the assessment of the current and future affects of abatement strategies. The critical loads maps presented in Chapter 2 have been developed using predominantly steady state methods. Individual national mapping approaches used are summarized in Section 3.3.1.4.

The steady state mass balance (SMB) method computes the maximum acid input to the system that will not cause exceedance of the critical alkalinity value. The method can be used to compute critical loads for forest soils, surface waters and groundwater. The mathematical formulation of the steady state mass balance method can be extended with base cation uptake, nitrogen uptake and nitrogen immobilization which leads to the computation of the critical load of potential acidity (see Sverdrup *et al.*, 1990, p. 19; Hettelingh and de Vries, 1991, par. 4.2.1 and Appendix 2). However, uptake and immobilization variables may vary over time as a consequence of land use changes.

Therefore, at the second CCE Training Session, it was decided to use a method which would mainly take ecosystem characteristics into account. This decision also applied to atmospheric-dependent variables (i.e., base cation deposition). The focus on ecosystem characteristics mainly lead to the computation of the critical load of actual acidity.

The steady state mass balance method has been used in the European application (Section 2.7) to derive critical loads of actual acidity for forest soils. These results were used for European regions for which no national contributions were available. Many countries applied the method using more detailed national data (see Section 3.3.1.4).

The critical load of actual acidity, $CL(AC_{act})$, is computed as follows:

$$\mathbf{CL(Ac_{act}) = BC_w - Alk_{l(crit)}} \qquad (4)$$

where:
BC_w = weathering of base cations ($mol_c\ ha^{-1}\ yr^{-1}$)
$Alk_{l(crit)}$ = critical alkalinity leaching ($mol_c\ ha^{-1}\ yr^{-1}$)

Critical alkalinity leaching is defined as follows for acid forest soils:

$$\mathbf{Alk_{l(crit)} = -H_{l(crit)} - Al_{l(crit)}} \qquad (5)$$

where:
$H_{l(crit)}$ = critical hydrogen leaching ($mol_c\ ha^{-1}\ yr^{-1}$)
$Al_{l(crit)}$ = critical aluminum leaching ($mol_c\ ha^{-1}\ yr^{-1}$)

These two terms are in turn defined as:

$$H_{l(crit)} = Q \cdot [H]_{crit} \tag{6}$$

and:

$$Al_{l(crit)} = \begin{cases} Q \cdot [Al]_{crit} & \text{(the Al criterion), or} \quad (7) \\ R(Al/Ca)_{crit} \cdot (BC^*_d + BC_w - BC_u) & \text{(the Al/Ca criterion) *} \quad (8) \end{cases}$$

where:

Q = runoff ($m^3\ ha^{-1}\ yr^{-1}$) **

$[H]_{crit}$ = critical hydrogen concentration (= 0.09 $mol_c\ m^{-3}$) ***

$[Al]_{crit}$ = critical aluminum concentration (= 0.2 $mol_c\ m^{-3}$)

$R(Al/Ca)_{crit}$ = critical aluminum: calcium ratio (= 1.5 $mol_c\ mol_c^{-1}$)

BC^*_d = seasalt-corrected base cation deposition ($mol_c\ ha^{-1}\ yr^{-1}$)

BC_u = uptake of base cations ($mol_c\ ha^{-1}\ yr^{-1}$)

Substitution of Equations 5 through 8 into Equation 4 leads to the following two equations for the critical load of actual acidity:

$$CL(Ac_{act}) = \begin{cases} BC_w + 0.09 \cdot Q + 0.2 \cdot Q & \text{if Equation 7 is used} \quad (9) \\ BC_w + 0.09 \cdot Q + 1.5 \cdot (BC^*_d + BC_w - BC_u) & \text{if Equation 8 is used} \quad (10) \end{cases}$$

The lower of the two values respectively calculated by Equations 9 and 10 has been used.

Equations 9 and 10 indicate that the water flux (runoff) may have a considerable influence on the critical load computation, which varies for different receptors. Critical alkalinity in forest soils is negative (see Table 3.1). A consequence of a negative critical alkalinity is that an increasing water flux will yield a higher critical load. The opposite is true for groundwater and surface water, where the critical alkalinity is positive. The reason is that an increasing water flux will increase the dilution of aluminum. However, since calcium is also diluted the Al/Ca ratio is not affected. Consequently, the Coordination Center has recommended that countries apply both the Al and Al/Ca criteria (see also Sverdrup *et al.*, 1990) and use the minimum of the critical loads computed from Equations 9 and 10.

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* Besides the Al and Al/Ca criteria, a third criterion, the aluminum depletion criterion, may be distinguished as follows: $Al_{l(acc)} = r \cdot BC_w$, where r is the stoichiometric ratio of Al to BC_w. However, the Al/Ca and Al criteria are considered more relevant from an ecosystems point of view.

** Q can be defined as the flow rate through a system. If the system consists of watersheds, then Q is defined as precipitation minus evapotranspiration. If the system consists of soils, then the flow rate should be defined as precipitation minus evapotranspiration minus surface runoff, the result of which is referred to as precipitation surplus (PS). Throughout this report, the terms "Q" and "runoff" will be used even when soils are considered.

*** $[H]_{crit}$ is computed from: $[H]_{crit} = ([Al]_{crit} / K_{gibb})^{1/3}$ (8a)

where:

K_{gibb} = gibbsite solubility constant ($3 \cdot 10^2$ mol $m^{-3})^{-2}$

$[Al]_{crit} = Al_{l(crit)}/Q$ (computed from Equations 7 or 8).

When assuming $[Al]_{crit}$ = 0.2 $mol_c\ m^{-3}$ (see Table 3.1) and K_{gibb} as above, it follows from Equation 8a that $[H]_{crit}$ = 0.09 mol m^{-3}, which in Table 3.1 has been rounded to 0.1 (pH = 4.0).

In Equations 9 and 10 the value of 0.09 has been substituted for $[H]_{crit}$.

In summary, the steady state mass balance approach is the simplest method to assess critical loads and has rather limited data requirements (see Section 3.4, "Input Data"). In cases where more detailed survey data are available it was recommended to use the PROFILE model (Sverdrup and Warfvinge, 1988) or the MACAL model (de Vries, 1991).

3.3.1.2 Steady state water chemistry method

Countries that provided critical loads for surface waters generally used the steady state water chemistry method. The key equation for the steady state mass balance computation of critical loads in freshwaters, according to the water chemistry method (Henriksen *et al.*, 1988, 1990; Sverdrup *et al.*, 1990) is as follows:

$$\mathbf{CL(Ac) = (BC^*_0 - Alk_{l(crit)}) \cdot Q - BC^*_d} \qquad (11)$$

where:

CL(Ac) = critical load of acidity in freshwater ($mol_c\ ha^{-1}\ yr^{-1}$)
BC^*_0 = seasalt-corrected original base cation concentration ($mol_c\ ha^{-1}\ yr^{-1}$)
$Alk_{l(crit)}$ = critical alkalinity leaching ($mol_c\ m^{-3}$)
Q = runoff ($m^3\ ha^{-1}\ yr^{-1}$)
BC^*_d = seasalt-corrected base cation deposition ($mol_c\ ha^{-1}\ yr^{-1}$)

Where the H^+/SO_4 ratio in precipitation is lower than 1 because a part of the SO_4 is balanced by base cations (as in Finland), and if the amounts of nitrate and ammonium are equal, then $H^+ = SO_4 - BC^*_d$. From Equation 11, the critical load for the sum of acid anions can be computed (Henriksen *et al.*, 1990):

$$\mathbf{CL(Ac) = (BC^*_0 - Alk_{l(crit)}) \cdot Q} \qquad (12)$$

Critical loads of nitrogen are not computed in the present form of the water chemistry method.

3.3.1.3 Level 0 method

For those countries which have insufficient existing data to apply "Level I" steady state approaches, or otherwise object to the steady state mass balance approach in the current exercise, "Level 0" approaches have been applied. The Level 0 method was used by Ireland, United Kingdom, Czech and Slovak Federal Republic, and USSR to compute critical loads in both forest soils and surface waters.

"Level 0" approaches are semi-quantitative methods using existing geographical data bases to assess the sensitivity of ecosystems to acidic deposition to which critical loads values may be assigned. An example of a semi-quantitative assessment is the map of relative sensitivity to acidic deposition, which has been produced by the Stockholm Environment Institute (see Section 4.2) to which target loads have been applied on the basis of critical loads information in the literature.

In Nilsson and Grennfelt (1988) soil types are assigned to one of five classes according to mineralogy of parent rock-type (Table 3.2). To each class a critical load is suggested (Table 3.3). Table 3.4 describes how other factors such as land use, amount of rainfall, etc. may modify critical load values as specified in Table 3.3. When a combination of factors listed in Table 3.4 enhances sensitivity of the soil the lower limit of the critical load range from Table 3.3 should be used. Otherwise, (i.e., in the presence of conditions which mitigate soil sensitivity), the upper limit of the ranges should be applied.

Therefore, an approach for a country could be:

1. Assign national soil data to one of the five "Skokloster soil classes" from Table 3.2;
2. Modify the classification by considering the factors suggested in Table 3.4;
3. Assign critical loads given in Table 3.3.

Table 3.2. Mineralogy and petrological classification of soil material.

Class	Minerals Controlling Weathering	Usual Parent Rock
1	Quartz K-feldspar	Granite Quartzite
2	Muscovite Plagioclase Biotite (< 5%)	Granite Gneiss
3	Biotite Amphibole (< 5%)	Granodiorite Greywakee Schist Gabbro
4	Pyroxene Epidote Olivine (< 5%)	Gabbro Basalt
5	Carbonates	Limestone Marlstone

Source: Nilsson and Grennfelt (1988), p. 13.

Table 3.3. Critical loads for forest soils (0-50 cm).

Class	Total Acidity (kmol H^+) km^{-2} yr^{-1}	Equivalent amount of sulphur (kg ha yr^{-1})
1	< 20	< 3
2	20-50	3-8
3	50-100	8-16
4	100-200	16-32
5	>200	>32

Source: Nilsson and Grennfelt (1988), p. 14.

Table 3.4. Conditions influencing critical loads to forest soils.

Factor	Decreasing Critical Load Value	Increasing Critical Load Value
Precipitation	high	low
Vegetation	coniferous	deciduous
Elevation/slope	high	low
Soil texture	coarse-sandy	fine
Soil/till depth	shallow	thick
Soil sulphate adsorption capacity	low	high
Base cation deposition	low	high

Source: Nilsson and Grennfelt (1988), p. 14.

In the United Kingdom and Ireland, national soil data have been assigned to five classes according to the Skokloster report (Nilsson and Grennfelt, 1988), although certain modifications have been made, especially with reference to areas of peat. The United Kingdom has combined land use information with the soil data to modify the critical loads derived. The critical loads derived in this way compare favorably with loads calculated using the Henriksen steady state water chemistry method for the same areas. See Appendix 1, "National Focal Center Reports", for further details on the methods applied.

Other national considerations may be necessary in the creation of the "Level 0" critical loads map. The method could be refined by consulting with the Stockholm Environment Institute. The classifications may need to be modified to take into account local conditions. For example, soils in southern Europe having high sulphate adsorption capacities would lead to a modified classification of soils into weathering rate classes.

One of the differences between the "Level 0" approach and the application of the steady state mass balance is that the Level 0 approach will yield a decreasing critical load as the water flux increases (Nilsson and Grennfelt, 1988). The reason is that an increasing water flux will increase the base cation depletion. However, in the steady state approach, base cation depletion is considered a dynamic process which is not taken into account. (The same applies to sulphate adsorption mentioned in Table 3.4).

3.3.1.4 Summary of national approaches

Table 3.5 summarizes the sources of input data used in the combined maps of critical loads of actual acidity, sulphur, and nitrogen contained in Section 2. The critical loads maps produced by the steady state mass balance method described above used input data from various European data bases, described in more detail in Section 3.4. Table 3.6 summarizes the methods used by countries which provided more detailed input data and/or critical load calculations.

Table 3.5. Sources of Input Data for Critical Loads Maps.

Country	IIASA/WSC[1]	National Data[2]
Albania	x	
Austria		x
Belgium	x	
Bulgaria	x[3]	
Czech and Slovak Federal Republic		x
Denmark		x
Finland		x
France	x[3]	
Germany		x
Greece	x	
Hungary	x	
Ireland		x
Italy	x	
Luxembourg	x	
Netherlands		x
Norway		x
Poland	x	
Portugal	x	
Romania	x	
Spain	x	
Sweden		x
Switzerland		x
Union of Soviet Socialist Republics		x
United Kingdom		x
Yugoslavia	x	

1. Using data from European data bases from the International Institute of Applied Systems Analysis (IIASA) and the Winand Staring Center (WSC).
2. See Table 3.6 and Appendix 1, "National Focal Center Reports", for details on national methods and data sources.
3. Using IIASA/WSC data, with some modifications to input data. See Appendix 1 for details on national data usage and sources.

Table 3.6. Summary of Calculation Methods Used for Producing National Critical Loads Maps.

RECEPTOR: FOREST SOILS

Country	Method Used: SMB	Level 0	Other
Austria	x		
Czech and Slovak Federal Republic		x	
Denmark	x		x[1]
Finland	x		
France	x		
Germany	x		
Ireland		x	
Netherlands	x		
Norway	x		
Sweden	x		x[1]
Switzerland	x		
Union of Soviet Socialist Republics	x	x	
United Kingdom		x	

RECEPTOR: SURFACE WATERS

Country	Method Used: Water Chemistry	Level 0	Other
Finland	x		
Norway	x		x[2]
Sweden (lakes)	x		
Switzerland (alpine lakes)	x		
Union of Soviet Socialist Republics	x	x	
United Kingdom (case study)	x		

1. The PROFILE model was used to calculate weathering rates, dividing the soil into several layers.
2. The dynamic model "Model of Acidification of Groundwater in Catchments" (MAGIC) was used.

3.3.2 Critical Loads of Sulphur *

The UN ECE Working Group on Abatement Strategies has been given the responsibility for developing a draft sulphur protocol. Thus, the Working Group has requested that the first critical loads maps to be produced should show the ecosystem impact of sulphur deposition only. This map could be used as part of the scientific contribution to a new UN ECE protocol for reducing sulphur emissions. The methodology used to produce the map of critical loads of sulphur presented in Chapter 2 is described below.

* The term "sulphur impact load" has been used to stress the fact that no definition could be provided for a critical load of sulphur which would be consistent with the critical load of acidity. However, to facilitate communication, the term "critical load of sulphur" is used in this report to describe a variable which is computed as a portion of the critical load of acidity generated by sulphur.

3.3.2.1 Definition of "critical load of sulphur"

The critical load of sulphur is the contribution of sulphur to the computed critical load of actual acidity. The remaining part of the actual acidity would logically be attributed to the acidifying effects of nitrogen. If it were possible, the sum of the "critical load of sulphur" and the "critical load of nitrogen with respect to acidification" would be equal to the critical load of actual acidity. Unfortunately, the application of the term "critical load of sulphur" is not entirely appropriate because this would imply a unique definition of the "critical load of nitrogen with respect to acidification". However, the critical load of nitrogen is defined with respect to eutrophication. Assumptions are needed to separate the contribution of nitrogen to eutrophication from the contribution to acidification. It has proved difficult to provide scientific grounds and methods for a further refinement of the critical load of actual acidity into contributing components, as the sensitivity of an ecosystem to acidification is invariant to distinctions among acidifying compounds; only total acidification is relevant.

The sulphur fraction was originally part of a larger weighing scheme also incorporating economic and technical constraints proposed in UN ECE discussions, but the latter constraints were considered to be too unrelated to ecosystem characteristics. The use of the sulphur fraction was agreed upon by mapping participants in order to provide policymakers with an operational distinction of the contribution of sulphur and nitrogen to the critical load of actual acidity.

Further information and examples are given in the Mapping Vademecum (Hettelingh and de Vries, 1991). It was decided by the Task Force on Mapping to compute the critical loads of sulphur by defining a ratio, the sulphur fraction, between sulphur deposition and the total sulphur and nitrogen deposition.

3.3.2.2 Derivation of the sulphur fraction and critical load of sulphur

The sulphur fraction is designed to compute the net contribution of sulphur and nitrogen to the critical load of actual acidity. At the second CCE Training Session (see Appendix 7), the sulphur fraction was originally proposed as the ratio of the present load of sulphur to the present load of sulphur, nitrogen and ammonia based on 1988 EMEP emission data. However, if nitrogen deposition is fully taken up, it can be assumed that nitrogen will not lead to acidification. Consequently, a distinction is made between sulphur fractions in EMEP grid cells where nitrogen may lead to acidification and EMEP grid cells where acidification is only due to sulphur. In the latter case the sulphur fraction has been defined equal to one, meaning that the critical load of sulphur is equal to the critical load of actual acidity.

Note that present loads were computed using the latest EMEP source-receptor relationships incorporated in the RAINS model, and were not modified for filtering factors and base cation uptake, nitrogen uptake and seasalt-corrected base cation deposition. The modified EMEP deposition values were used to compute exceedance maps.

Thus, the sulphur fraction is defined as follows:

$$S_f = \begin{cases} \dfrac{\mathbf{PL(SO_x)}}{\mathbf{PL(SO_x) + PL(NO_x) + PL(NH_x) - N_u - N_{i(crit)}}} & \text{if } PL(NO_x) + PL(NH_x) \geq N_u + N_{i(crit)} \\ \mathbf{1} & \text{otherwise} \end{cases} \qquad (13)$$

where:
S_f = sulphur fraction
$PL(SO_x)$ = present load of sulphur ($mol_c\ ha^{-1}\ yr^{-1}$)
$PL(NO_x)$ = present load of nitrogen ($mol_c\ ha^{-1}\ yr^{-1}$)
$PL(NH_x)$ = present load of ammonia and ammonium ($mol_c\ ha^{-1}\ yr^{-1}$)
N_u = nitrogen uptake for managed forests ($mol_c\ ha^{-1}\ yr^{-1}$)
$N_{i(crit)}$ = critical nitrogen immobilization ($mol_c\ ha^{-1}\ yr^{-1}$)

The critical load of sulphur becomes:

$$\mathbf{CL(S) = S_f \cdot CL(Ac_{act})} \tag{14}$$

where:
$CL(S)$ = critical load of sulphur ($mol_c\ ha^{-1}\ yr^{-1}$)
S_f = sulphur fraction
$CL(Ac_{act})$ = critical load of actual acidity ($mol_c\ ha^{-1}\ yr^{-1}$)

According to Equation 13, the sulphur fraction is smaller than 1 when the deposition of nitrogen exceeds nitrogen uptake and immobilization. Thus the impact load of sulphur becomes equal to the critical load of actual acidity when nitrogen acts only as a nutrient. However, if current nitrogen deposition is not fully taken up or immobilized, then the critical load of sulphur becomes smaller than the critical load of actual acidity. Appendix 2 includes maps of the distribution of sulphur fractions for Europe.

3.3.3 Critical Loads of Nitrogen

The critical load of nutrient nitrogen has been defined as "the maximum deposition of nitrogen compounds that will not cause eutrophication or induce any type of nutrient imbalance in any part of the ecosystem or recipients to the ecosystem" (Sverdrup *et al.*, 1990, p. 3). The equation for the computation of the nitrogen critical load includes nitrogen uptake and nitrogen leaching. However, in addition to eutrophication, nitrogen also contributes to acidification. The leaching of nitrate may be viewed from an eutrophication as well as from an acidification point of view. The latter is computed as the complement of the critical load of acidity due to sulphate only (Sverdrup *et al.*, 1990, p. 4).

The reasoning summarized above has been preliminarily applied to the notions of the critical loads of actual acidity and sulphur. Nitrogen uptake for managed forest, for which European data are available, was taken as the maximum allowable eutrophication limit. The contribution of nitrogen to acidification has been computed by reducing the critical of acidity by the critical load of sulphur. The result is the following formulation of the critical load of nitrogen:

$$\mathbf{CL(N) = N_u + (1-S_f) \cdot CL(Ac_{act})} \tag{15}$$

where:
$CL(N)$ = critical load of nitrogen for eutrophication and acidity ($mol_c\ ha^{-1}\ yr^{-1}$)
N_u = nitrogen uptake for managed forests ($mol_c\ ha^{-1}\ yr^{-1}$)
S_f = sulphur fraction
$CL(Ac_{act})$ = critical load of actual acidity ($mol_c\ ha^{-1}\ yr^{-1}$)

Other nitrogen uptake values than those available for managed forest ecosystems may be given priority by mapping participants in future updates of the critical loads of nitrogen. The critical loads of nitrogen computed by the CCE (Figures 2.3a and 2.3b) are merely a first attempt which bears on available data and on a consistent further application of the sulphur fraction.

3.3.4 Present Loads and Exceedances of Critical Loads of Acidity, Sulphur, and Nitrogen

The computation of critical load exceedances basically consist of the difference between present loads of acidity, sulphur, nitrogen and ammonia and the 1 and 5 percentile critical loads of acidity, sulphur and nitrogen, respectively. Ammonia and ammonium deposition are considered to be acidifying according to Sverdrup *et al.* (1990, pp. 4-5, p. 26). The present loads of sulphur and nitrogen (including ammonia) were modified for the effects of throughfall by applying preliminary filtering factors computed by the CCE. (See Appendix 2 for filtering factor values used; Appendix 4 for the derivation of these values.) Processes that affect the level of acidification caused by sulphur and nitrogen deposition, i.e., base cation uptake, nitrogen uptake and seasalt-corrected base cation deposition, were also taken into account. It is expected that the data used to modify present loads will be updated by future national contributions. An example of an unmodified exceedance map for the 1 percentile map of the critical load of actual acidity is provided in Appendix 2 for comparison purposes. The calculations used for computing the critical loads of acidity, sulphur and nitrogen are presented in Equations 4, 14, and 15, respectively. The emission data used to compute deposition patterns are given in Table 3.7.

Table 3.7. Values used for European emissions of SO_x and NO_x (1990), and NH_x (1988) (in kt).

Country	SO_x (as SO_2)	NO_x (as NO_2)	NH_x (as NH_3)
Albania	50	9	24
Austria	104	207	85
Belgium	418	299	94
Bulgaria	1030	150	147
Czech and Slovak Federal Republic	2774	950	200
Denmark	254	252	129
Finland	278	282	43
France	1272	1761	841
Germany (eastern)	5242	1005	242
Germany (western)	1060	2729	380
Greece	500	746	112
Hungary	1084	249	151
Ireland	182	93	139
Italy	2410	1700	426
Luxembourg	12	16	6
Netherlands	254	552	254
Norway	66	226	41
Poland	3910	1480	478
Portugal	208	132	55
Romania	1800	390	350
Spain	3118	950	273
Sweden	210	382	62
Switzerland	68	189	61
Union of Soviet Socialist Republics	9318	4190	3180
United Kingdom	3734	2606	478
Yugoslavia	1650	480	235
Total	**41,006**	**22,025**	**8,486**

With the inclusion of filtering factors (see Appendix 4 for details on their derivation), the most important equations for the computation of these exceedances become:

Exceedance of critical load of actual acidity:

$$CL(Ac_{act})_{exc} = f^{s}_{EMEP} \cdot PL(SO_x) + f^{n}_{EMEP} \cdot (PL(NO_x) + PL(NH_3)) + BC_u - BC^*_d - N_u - N_{i\,(crit)} - CL(AC_{act}) \quad (16)$$

where:

f^{s}_{EMEP} = sulphur filtering factor for an EMEP grid square
$PL(SO_x)$ = EMEP-computed present load of sulphur ($mol_c\ ha^{-1}\ yr^{-1}$)
f^{n}_{EMEP} = nitrogen filtering factor for an EMEP grid square
$PL(NO_x)$ = EMEP-computed present load of nitrogen ($mol_c\ ha^{-1}\ yr^{-1}$)
$PL(NH_3)$ = EMEP-computed present load of ammonia ($mol_c\ ha^{-1}\ yr^{-1}$)
BC_u = base cation uptake ($mol_c\ ha^{-1}\ yr^{-1}$)
BC^*_d = seasalt-corrected base cation deposition (NILU data) ($mol_c\ ha^{-1}\ yr^{-1}$)
N_u = nitrogen uptake ($mol_c\ ha^{-1}\ yr^{-1}$)
$N_{i\,(crit)}$ = critical nitrogen immobilization ($mol_c\ ha^{-1}\ yr^{-1}$)
$CL(Ac_{act})$ = critical load of actual acidity ($mol_c\ ha^{-1}\ yr^{-1}$)

Exceedance of the critical load of sulphur:

$$CL(S)_{exc} = f^{s}_{EMEP} \cdot PL(SO_x) + S_f \cdot (BC_u - BC^*_d) - CL(S) \quad (17)$$

where:

$CL(S)$ = critical load of sulphur ($mol_c\ ha^{-1}\ yr^{-1}$)
S_f = sulphur fraction

Exceedance of the critical load of nitrogen:

$$CL(N)_{exc} = f^{n}_{EMEP} \cdot (PL(NO_x) + PL(NH_3)) + (1-S_f) \cdot (BC_u - BC^*_d) - CL(N) \quad (18)$$

where:

$CL(N)$ = critical load of nitrogen ($mol_c\ ha^{-1}\ yr^{-1}$)

Note that the filtering factors used in Equations 16, 17, and 18 are subject to revision by National Focal Centers. Currently, filtering factors are used for forest soils. Updates may consist of national preferences as appropriate (e.g., filtering factors for altitude).

Also note that exceedances of critical loads may lead to the violation of critical chemical values in the future. The importance of the temporal evolution of chemical values as a result of abatement strategies may become important especially in areas where the estimated critical load is exceeded (Hettelingh *et al.*, 1991).

3.4 Input Data

3.4.1 Requirements

Data requirements differ from model to model, and are described in the following sections of the Mapping Manual (UN ECE, 1990a):

Method / model	Mapping Manual
Steady state mass balance, PROFILE, MACAL	Table 4.5
Steady state water chemistry	Section 4.2.2.1
SMART, MAGIC	Table 4.8

An overview of data acquisition procedures and suggested default values for the most important parameters in several dynamic models is given in Sverdrup *et al.* (1990). The Mapping Vademecum also includes a presentation of different methods. When the necessary input data for PROFILE were available, PROFILE was used for the estimation of weathering rates (i.e., Sweden and Denmark). However, the estimation of the weathering rate requires information on the mineralogy, which reaches a level of detail unachievable by most countries for these first maps. Consequently, a simple estimation procedure for the derivation of weathering rates from soil type information has been used for the European application (Hettelingh and de Vries, 1991, Appendix 3). Several countries also used this approach. A more detailed overview of this estimation procedure, focused on the SMART model, is presented in de Vries (1991).

Data bases for applying the steady state mass balance model at a spatial resolution of $1^{\circ} \times 0.5^{\circ}$ longitude-latitude are available from the Coordination Center (see Appendix 3). However, most inputs are estimated or empirically derived (e.g., the weathering rate) and many of the data requirements need further surveys throughout Europe, and will be updated in the near future.

3.4.2 European data bases

Table 3.8 summarizes the European data bases used to produce the European steady state mass balance maps of critical loads.

These data have been collected primarily by IIASA, and made available to the Coordination Center. The Coordination Center produced preliminary critical loads maps in November 1990, and distributed the maps and the input data used to all National Focal Centers. NFCs were requested to comment on, improve, and/or replace these data with nationally derived information. These data have been used to produce the maps in Chapter 2 for all countries that were unable to provide other sources of data. More detailed information on the European data bases used is given in Appendix 3.

Table 3.8. Available European data for the application of the steady state mass balance method on forest soils.

Data Requirements	Available data bases
Deposition of sulphur, nitrogen and base cations:	
Sulphur and nitrogen	- EMEP source-receptor matrices; used at IIASA in the model RAINS.
Base cations	- EMEP monitoring network - National monitoring networks of wet and dry deposition (throughfall)
Uptake of nitrogen and base cations: [1]	
Average forest yield	- IIASA data sets on coniferous and deciduous wood volume and forested area per grid (Nilson and Sallnäs, 1991)
Element contents in stems and branches	- Winand Staring Center data set based on literature review (de Vries *et al.*, 1990)
Base cation weathering:	- Digitized FAO soil map of Europe available at IIASA [2]
Net precipitation: [3]	
Precipitation	- UNEP/GRID data base
Evapotranspiration	- IIASA data set based on transfer functions with elevation and latitude

Source: Hettelingh and de Vries, 1991.

1. N_u = (average forest yield) · (nitrogen contents).
   BC_u = (average forest yield) · (base cation contents).
2. Soil type information has been used to estimate the weathering rates using a simple transfer function. (Hettelingh and de Vries, 1991; de Vries, 1991).
3. Q = Precipitation - evapotranspiration.

3.5 Mapping Issues

3.5.1 Introduction

The two training sessions (see Appendices 6 and 7) conducted by the CCE addressed many of the technical and logistical issues encountered in the development of national and European critical loads. The Mapping Vademecum (Hettelingh and de Vries, 1991) was written to provide National Focal Centers with practical guidance in conducting national mapping efforts. Major issues related to the mapping effort include:

(a) How to display critical loads in regions for which national contributions would be lacking: It was decided to use European data bases (see Section 3.4.2) in combination with the steady state mass balance method to produce critical loads for all the countries in Europe. This map was distributed by the CCE in November 1990 to enable National Focal Centers to verify the results. Finally, national contributions which become available to the CCE were superimposed on the original CCE results. Countries which have not provided amendments on the computed critical loads remain unchanged.

(b) How to incorporate varying national results of critical load computations into one European map: National computations vary with respect to (1) the amount of samples used to compute critical loads and (2) the method applied. It was decided to compute statistics of the critical loads results provided to the CCE and display the same statistic for the critical loads mapped on a European scale. This issue is treated in more detail in Section 3.5.2.

(c) What should the size be of the grid cells to best reflect national considerations about the importance of domestic ecosystems: The final size of the grid cells should be consistent with the EMEP grid. The importance of the sensitivity of ecosystems is covered by mapping the 1 and 5 percentiles of critical loads of actual acidity, sulphur, and nitrogen. Details on the statistical treatment are provided in Sections 3.5.2 and 3.5.3.

(d) Should the mapping of critical loads of actual acidity be restricted to the most sensitive ecosystems only: It was decided to produce a European map of critical loads for a mixture of forest, surface and groundwater ecosystems. The display of low percentiles (1 and 5) assures that the most sensitive ecosystems are mapped (see Sections 3.5.3 and 3.5.4, and Appendix 5).

(e) How to ensure a map of critical loads which could be used in combination with EMEP deposition computations to quantify critical load excess: It was decided by the Task Force on Mapping (UN ECE, 1991b) to include filtering factors for the computation of throughfall or for taking into account deposition impacts at different altitudes. Appendix 4 describes the methods used to calculate filtering factors for Europe.

3.5.2 Grid resolution

The size of the grids to be used for the mapping of critical should be (1) detailed enough to display the sensitivity of a majority of ecosystems, including the smallest ones, (2) compatible with the EMEP grid to allow for the computation of the excess of acid deposition over critical loads of actual acidity, and (3) compatible with national grid preferences. These requirements conflict because of the large size of an EMEP grid cell (approximately 150 x 150 km^2) and the varying sizes of the grid cells applied nationally (the smallest size used is 1 x 1 km^2). However, the importance of the EMEP grid for the assessment of the excess of deposition of acidifying compounds over critical loads was recognized.

National Focal Centers provided the CCE with critical loads data, if available, using national preferences with respect to resolution. The CCE used a geographic information system (GIS) to:
(1) Assign the data to EMEP grid cells;
(2) Compute the frequency of the occurrence of critical load values in an EMEP grid cell; and
(3) Transform frequencies to cumulative distributions (see following section and Appendix 5).

The choice of ecosystems for which critical loads were to be displayed was made by the National Focal Centers. The European map of critical loads of actual acidity reflects the sensitivity of forest soils and surface waters. The majority of European critical load values reflect the sensitivity of forest soils. Critical loads in Finland, Norway, Sweden, Switzerland, and the USSR reflect forests and surface waters.

3.5.3 Statistical treatment of critical loads data

The critical loads data in the maps consist of (1) critical load values for point measurements, or (2) a percentage of the area within a national grid cell for which a critical load applies, or (3) a critical load value representing a national grid cell.

The CCE processed the data by constructing a cumulative frequency distribution (CDF) of the critical load data for actual acidity within each EMEP grid cell. More details are provided in Appendix 5. A CDF of critical loads in an EMEP grid cell describes what the percentage is of the area corresponding to a particular range of critical loads. The highest percentage (the 99 percentile) of a CDF will display the range of critical loads, including the highest, occurring within an EMEP grid cell. The highest percentile critical loads will correspond to the least sensitive ecosystem. Conversely, the lowest percentage (the 1 percentile) displays the range of the lowest critical loads occurring within the grid cell. Therefore, the lowest percentile corresponds to the most sensitive ecosystem within an EMEP grid cell.

Note that a display of percentiles for large grid cells is less accurate than for small grid cells. A 95% critical load in the entire region of Europe is likely to correspond to a high value. A 95% critical load in a small grid cell will correspond to lower critical load values. Therefore, the display of a particular percentile in the EMEP grid (150 x 150 km^2 grid cells) is likely to display an area of sensitive ecosystems which is smaller than the area displayed for the same percentile in, for example, a $1^\circ \times 0.5^\circ$ longitude/latitude-grid ($\approx$50 x 50 km^2 grid cells).

3.5.4 Percentiles mapped

It was decided to give priority to European maps of critical loads displaying 1 and 5 percentile critical loads. The grid cells are shaded according to the value range to which the 1 percentile (5 percentile) critical load belongs. The 1 and 5 percentile maps display the range of critical loads covering 1% and 5%, respectively, of the area in each EMEP grid cell. Appendix 5 contains detailed information on the calculation of cumulative frequency distributions used to produce the percentile maps.

In addition, maps of 50 percentile critical loads are provided in Appendix 2. An earlier version of the 50 percentile map was displayed by the CCE at earlier meetings under the LRTAP Convention. The Task Force on Mapping has recommended the use of the 1 or 5 percentile map of critical loads of actual acidity in order to ensure that a large share of sensitive ecosystems will be protected.

CHAPTER 4. EVALUATION OF CCE EUROPEAN MAPS AND OTHER MAPS

4.1 Introduction

The aim of this chapter is to provide an evaluation of:

1. **The European maps of critical load of acidity:** The European maps of critical loads produced by the Coordination Center for Effects (CCE maps) is evaluated by comparison with the map of relative ecosystem sensitivity which was produced by the Stockholm Environment Institute (SEI). The reason for this comparison is twofold. First, results of two different methods are compared, i.e., the SEI map obtained with the Level 0 approach and the CCE map which was developed using predominantly the steady state mass balance method applied to detailed national data and European data. Second, insight is obtained in the compatibility between results of using either of the maps for the evaluation of abatement strategies. The SEI map has been used by the UN ECE Task Force on Integrated Assessment Modeling (TFIAM) in recent evaluations of alternative abatement strategies. The CCE critical loads maps and data have been provided to the TFIAM and are currently being used in their work.

2. **The input data:** The CCE map consists of national contributions and the application of European data in regions for which no national contributions were obtained. Differences between European data and national data are evaluated through case studies for the Netherlands and Austria.

Background information on the SEI map is provided in Section 4.2, followed by the comparison between the SEI map and the CCE map in Section 4.3. Section 4.4 illustrates some of the differences between European and national data, and provides some preliminary information on data updates to be expected in the near future.

4.2 The Stockholm Environment Institute Map of Relative Sensitivity to Acidic Depositions in Europe

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4.2.1 Introduction

The Stockholm Environment Institute (SEI) map of relative sensitivity to acidic depositions in Europe (Kuylenstierna and Chadwick, 1989; Chadwick and Kuylenstierna, 1990) has been used to indicate critical loads of acidic depositions in Europe. The SEI map has been used as a preliminary critical loads map in the UN ECE Task Force on Integrated Assessment Modeling (UN ECE, 1990b, 1991a) prior to the production of the European critical loads map, for the examination of abatement strategies. Major environmental factors of sites, relevant to sensitivity to acidic depositions, have been categorized, weighted and combined to give single values of sensitivity which are then ranked. These relative sensitivity classes are then assigned critical load values on the basis of determinations for specific sites, and extrapolations, over Europe. Comparisons to critical load maps of specific countries have been made in a general way and the SEI map used in some exploratory abatement strategy modelling.

4.2.2 Ecological site factors

The factors used to determine the sensitivity of a site to acidic depositions were: (1) bedrock lithology; (2) soil type; (3) land use; and (4) rainfall. These factors were selected because of their relevance to site response to acidic depositions, the general availability of information in a Europe-wide context, their susceptibility to mapping procedures, their overall integrative nature, the relative unambiguous acceptance of what they represent and the relative permanence of applicability to an area. Other factors of importance such as soil depth (Turner *et al.*, 1986; Kinniburgh and Edmunds, 1986) and sulphate adsorption capacity (Cosby *et al.*, 1986) do not meet some of these criteria, and their use was therefore not attempted.

Some of the factors used exhibit a high degree of correlation. However, it was not considered that any one variable alone would give a sufficiently accurate indication of sensitivity (Lucas and Cowell, 1984). For example, the soil type that forms at a site is not only influenced by the parent material but also by climate and land use practices. The response of the soil to acidic deposition may also be modified by these factors. Thus, four site factors appear to be a minimum that need to be employed to arrive at a "finely-tuned" assessment of relative sensitivity. Table 4.1 shows how the four site factors have been divided into categories and also the associated weights used in their combination to arrive at an overall assessment of sensitivity to acidic deposition.

Table 4.1. Division of site factors into categories and associated weights for use in combination.

Factor	Weight	Category		Weighting
Rock type	2	I	siliceous, slow weathering rocks	1
		II	faster weathering rocks	0
Soil type	1	I	major acid buffering < pH 4.5	1
		II	major acid buffering > pH 4.5	0
Land use	3	I	coniferous forest	1
		II	rough grazing	2/3
		III	deciduous forest	1/3
		IV	arable land	0
Rainfall	1	I	> 1200 mm (annual average)	1
		II	< 1200 mm (annual average)	0

4.2.2.1 Bedrock lithology

Rock types have been assigned to one of two categories based on their weathering rates. Since accurate determinations of the weathering rates for many rock types can only be inferred, relative weathering rates from the chemical and mineralogical composition of rocks as well as from catchment studies and laboratory investigations have to be utilized. Table 4.2 shows a classification of rock types according to their ability to buffer acidic inputs. The slow-weathering rock types, Group A in Table 4.2, are those with a low ability to neutralize acids due to rate limitation and these constitute Category I. Sites with these rock types will have a high sensitivity. Unfortunately the International Geological Map of Europe and the Mediterranean Region (UNESCO, 1971) maps sedimentary rocks by age and not type. Rock types of Precambrian and Lower Palaeozoic age have been used to approximate to the slow-weathering sedimentary rocks in Group A (Table 4.2). These are generally slow-weathering and have a low calcium content (Kinniburgh and Edmunds, 1986). The other rock types with a higher ability to neutralize acids (Groups B-D) constitute Category II, as designated in Table 4.1.

Table 4.2. The acid neutralizing ability of rock types.

Group	Acid neutralizing ability	Rock type
A	None - low	Granite, syenite, granite-gneisses, quartz sandstones (and their metamorphic equivalents) and other siliceous (acidic) rocks, grits, orthoquartz, decalcified sandstones, some quaternary sands/drifts
B	Low - medium	Sandstones, shales, conglomerates, high grade metamorphic felsic to intermediate igneous, calcsilicate gneisses with no free carbonates, metasediments free of carbonates, coal measures
C	Medium - high	Slightly calcareous rocks, low-grade intermediate to volcanic ultramafic, glassy volcanic, basic and ultrabasic rocks, calcareous sandstones, most drift and beach deposits, mudstones, marlstones
D	"Infinite"	Highly fossiliferous sediment (or metamorphic equivalent), limestones, dolostones

Source: Norton (1980); Kinniburgh and Edmunds (1986); Lucas and Cowell (1984).

4.2.2.2 Soil type

Soil types have been assigned to categories on the basis of soil chemistry and factors which control soil chemistry. At values below pH 4.5 when soils are at risk of approaching the aluminum buffer range (Garrels and Christ, 1965; Keller, 1957; Hem, 1968; Schofield and Taylor, 1954; Ulrich, 1983), aluminum mobilization increases and calcium: aluminum ratios decrease to levels which have been associated with toxicity to the roots of quite tolerant plant species (Meiwes *et al.*, 1986). Aluminum, which has been mobilized in the soil, may leach to surface waters causing the toxic effects which have been associated with increased aluminum levels in aquatic systems (Wilson, 1986). Therefore, soil types with characteristics which may cause the soil chemistry to approach the aluminum buffer range, under the influence of acidic depositions, will increase site sensitivity and were assigned to Category I. Those soil types, with major acid buffering systems operating above this value, were designated Category II in Table 4.1.

Capacity parameters which influence soil buffering include cation exchange capacity, base saturation and exchangeable calcium content (Ulrich, 1983; Bache, 1983). Soil pH is also considered as this gives an indication of the current soil chemistry (Meiwes *et al.*, 1986). Data for some of these parameters have been collated from the Soil Map of the World, Volume V (FAO-UNESCO, 1981) and the Soil Map of the European Communities (EEC, 1985). Based on this information soil types have been assigned to one of two categories. Mean values for chemical parameters for the soil types in the two categories are shown in Table 4.3.

Table 4.3. A summary of the soil data for the two soil categories.

Soil category		pH	CEC (meq $100g^{-1}$)	Base saturation (%)	Sand (%)	Ca content (meq $100g^{-1}$)
I	Mean	4.2	23	8	61	1.52
	s.d.	0.27	9.5	2.5	21	1.7
	Range	3.8-4.5	14-33	6-13	30-94	0.1-4
II	Mean	6.7	33	57	30	18
	s.d.	1.01	39	31	26	20
	Range	4.9-8.4	2-182	7-100	5-97	0.2-100

s.d. = standard deviation. Source: FAO-UNESCO (1981); EEC (1985).

The soil types assigned to category I are: Rankers, Acid Lithosols, Dystric Cambisols, Dystric Podzoluvisols, Orthic Acrisols, Podzols, and Dystric Histosols. Other soil types have been assigned to Category II. Sites with Category I soil types have higher sensitivity than those with Category II soils.

4.2.2.3 Land use

Of the land use categories shown in Table 4.1, coniferous forest vegetation was considered to increase site sensitivity most. This is due to the way in which such trees confer certain hydrological features to a site (Miller, 1985), and because of the characteristics of the typical acid mor soil organic layer characteristics formed under coniferous forest stands (Mikola, 1985). There is also an increased deposition of pollutants caused by the filter effect of vegetation (Hultberg, 1985), which may be substantial in coniferous forests. This was not taken into account in atmospheric transport models and so influenced the assessment of sensitivity derived here.

Rough grazing and heathland vegetation also produce mor humus and so this type of vegetation was also considered to increase site sensitivity, though to a lesser extent than coniferous forest as the filter effect is not so great (Hultberg, 1985) and hydrological site modification is not so pronounced (Munn *et al.*, 1973).

Deciduous forest vegetation produces less acid, mull humus which has a higher decomposition and lower organic acid production rate than a mor humus (Mikola, 1985). Hardwoods often have deep roots which bring up nutrients from deeper horizons; this may lead to a certain amount of surface soil layer enrichment (Black, 1968). Sites with deciduous forest vegetation therefore have a lower relative sensitivity than sites with vegetation causing the production of a mor humus.

It was assumed that practices such as fertilizer and lime application would artificially maintain pH and base saturation levels on intensively-managed arable and rich grazing land and reduce sensitivity accordingly (Bache, 1983).

4.2.2.4 Rainfall

As amounts of rainfall increase, the base cation, aluminum and other acid ion leaching rates increase due to the enhanced flow of water through the soil (Cresser *et al.*, 1986). In high rainfall areas there is a tendency for more water to flow through the soil surface layers, decreasing the potential for acid neutralization by the mineral soil. This results in a higher discharge of acids to surface waters (Cresser *et al.*, 1986; Kinniburgh and Edmunds, 1986; AWRG, 1986).

The long-term influence of high rainfall will enhance sensitivity of sites and areas with a mean annual rainfall greater than 1200 mm were categorized as having a higher sensitivity than those receiving less (Table 4.1).

4.2.3 Weighting procedures

The weighting procedure should be such that when factors are combined the resultant relative sensitivity matches field observations and experience of such sites. The weighting given to rock type (Table 4.1) reflects the importance of mineral weathering in the neutralization of acidity. Soil is weighted less heavily since part of the effect of soil in neutralizing acids, namely the weathering of minerals, is assumed to be reflected by the bedrock lithology. The large difference between coniferous forest and arable land, in the effect that their typical management regimes have on the soil and the ability to buffer acidic inputs, results in weighting this factor heavily (Table 4.1). The effect of rainfall is not considered to affect sensitivity to the same extent as mineral weathering or land use.

4.2.4 Mapping relative sensitivity

The factors used in the evaluation of relative sensitivity have been digitized so that they may be combined using a geographic information system (GIS). Bedrock types were digitized from the International Geology Map of Europe and the Mediterranean Region (UNESCO, 1971). Soil types were digitized from the Soil Map of the World, Volume V, Europe (FAO-UNESCO, 1981). Land use types were digitized from the Land Use Map of Europe (FAO-Cartographia, 1980); for Russia and Turkey the Types of Agriculture Map of Europe (Kostrowicki, 1984) was used. Reference was also made to the World Forestry Atlas (Weltforstatlas, 1975). Rainfall was digitized from the Climatic Atlas of Europe I (WMO-UNESCO-Cartographia, 1970).

Eight relative sensitivity classes (0-7) were the result of combining the four factors at the range of weightings assigned (Table 4.1). It was postulated that the use of the map as a basis for assigning deposition targets, based on critical loads, was only feasible with a reduced number of classes. The basis of this assumption was the restricted availability of critical load estimates applicable to a range of ecosystems, and the practicability of establishing fine differences in deposition targets with any real expectation that these could be variably achieved. A second-order consideration was the establishment of classes of not inordinately dissimilar total area. The higher sensitivity rankings were combined in pairs (2+3; 4+5; 6+7) and with Classes 0 and 1 gives sensitivity classes 1 to 5 which are shown on the map (Figure 4.1).

4.2.5 Setting critical loads

Once relative sensitivities have been mapped for areas in Europe, it is possible to pin-point ecosystems that have been the subject of study for the purpose of critical load estimation. For example, much of Scandinavia has been designated as exhibiting the highest level of sensitivity (see Figure 4.1). Certain terrestrial and aquatic ecosystems that have been studied in the region (Nilsson, 1986) have been allocated critical load values of about 20 keq H^+ km^{-2} yr^{-1}. The critical load for this sensitivity class, therefore, has been set at this value. By a similar process of comparison of the sensitivity classes derived and the estimates of critical loads that have been worked out (Nilsson, 1986; Nilsson and Grennfelt, 1988), the critical loads shown in Table 4.4 were assigned.

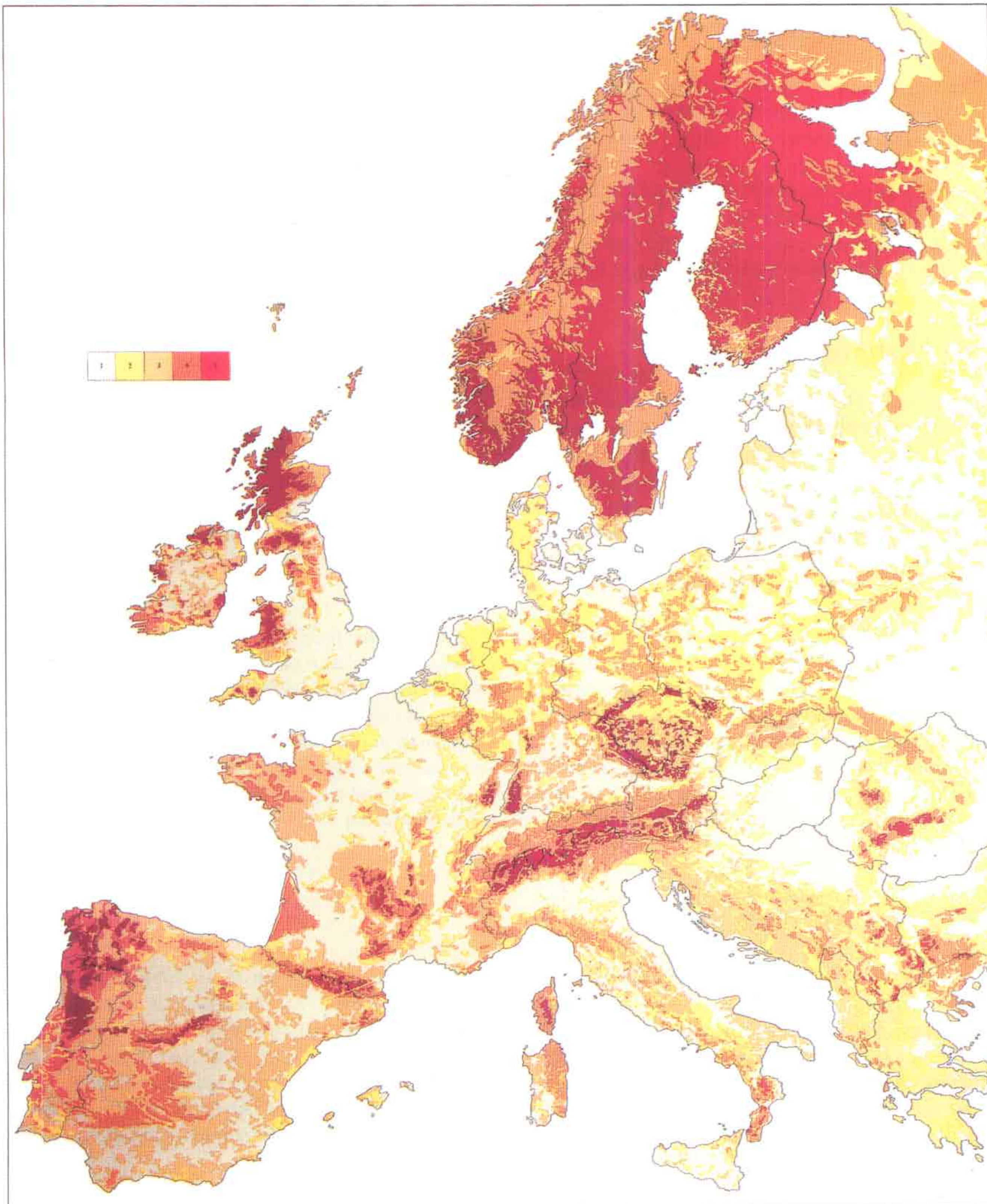

Figure 4.1. The SEI map of relative sensitivity to acidic depositions.

The range shown in Table 4.4 accords with suggestions on critical loads (Nilsson and Grennfelt, 1988) to ensure that acidic depositions should not exceed the weathering rate for groups of soil minerals. Due to the uncertainties involved in the values obtained for the critical loads and the application of targets to relative sensitivity classes, it may be desirable to use different ranges of critical loads and observe the way in which they affect the abatement strategies. Targets may be set at higher levels than the critical loads if a political decision was made to adopt generally acceptable preliminary targets as a feasible, attainable first objective. A review of progress might lead subsequently to the revision downwards of such values. Targets might be set below the critical load if there was evidence that the recovery of a system could be achieved at a faster rate, especially in view of the possible hysteresis effect during the recovery period. By using abatement strategy models it is possible to evaluate cost differences associated with various target values. Ultimately dose-response relationships are required to evaluate damage caused by deposition loads.

Table 4.4. Target deposition levels applied to the relative sensitivity classes.

Relative sensitivity class	Critical loads (keq H^+ km^{-2} yr^{-1})
1	>160
2	160
3	80
4	40
5	20

The total sulphur deposition may be compared to critical loads. Estimates of the total deposition of sulphur compounds may be derived from measurements and the results extrapolated, or the deposition may be estimated by using emission estimates calculated from the fuel use in every country, the sulphur content of the fuel, together with sulphur retention factors during combustion, and use of transfer coefficients resulting from calculations using atmospheric transfer models. The atmospheric transfer model that covers all regions in Europe is the model developed by the Co-operative Programme for Monitoring and Evaluation of The Long-Range Transmission of Air Pollutants in Europe (EMEP). This model produces country to EMEP square transfer coefficients by year, taking into account the weather patterns typical of the year (Eliassen *et al.*, 1988). The pattern of total sulphur deposition shown in Figure 4.2 as estimated for 2000 is derived from emission estimates for all countries in Europe in 2000 calculated at the Stockholm Environment Institute at York using the mean of 1988 and 1989 EMEP country-to-square transfer coefficients. Figure 4.3 indicates the excess of depositions over the critical load values established in the sensitivity map.

Acid deposition resulting from nitrogen sources is not described here but is treated as an input after allowing for uptake and immobilization by Chadwick and Kuylenstierna (1990).

4.2.6 Use of the sensitivity map

The excess of deposition over critical loads may be used as a comparison of deposition over the derived, fine-scale distribution of sensitivity (Figure 4.3), but when the critical loads are used in emission abatement strategy modelling in Europe it is necessary to assign a value to an EMEP (150 x 150 km) square. This necessity derives from the fact that the EMEP transfer coefficients are the only ones which cover the whole of the European region. There are possibilities to carry out optimization procedures in a model which aim to bring deposition levels to or below critical loads, as far as possible, in the most efficient cost-effective manner. In order to do this it is necessary to compare the deposition calculated from the transported emission with a value given to the square. In terms of a strict critical loads

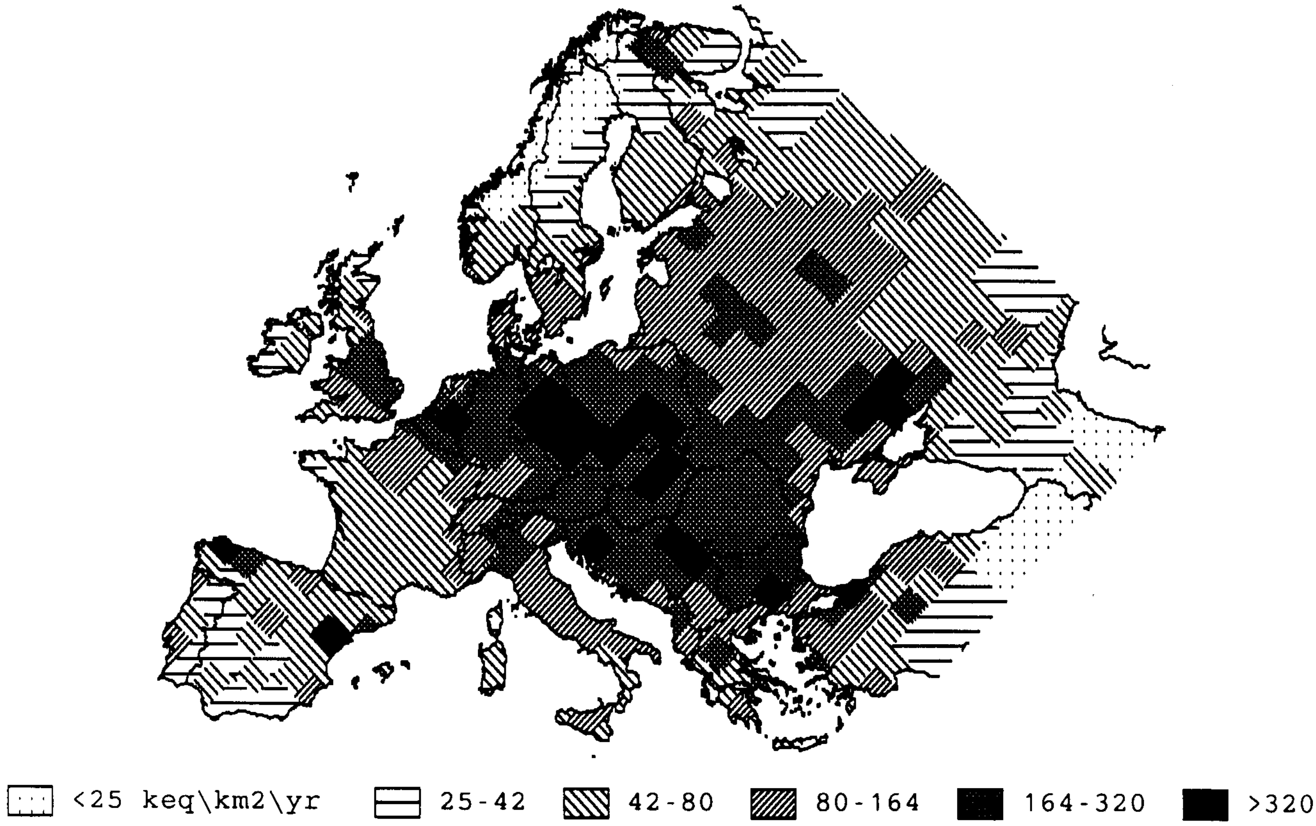

Figure 4.2. **Deposition of S in 2000 with no abatement, expressed as acid equivalents. (SEI emission; EMEP transfer coefficients.)**

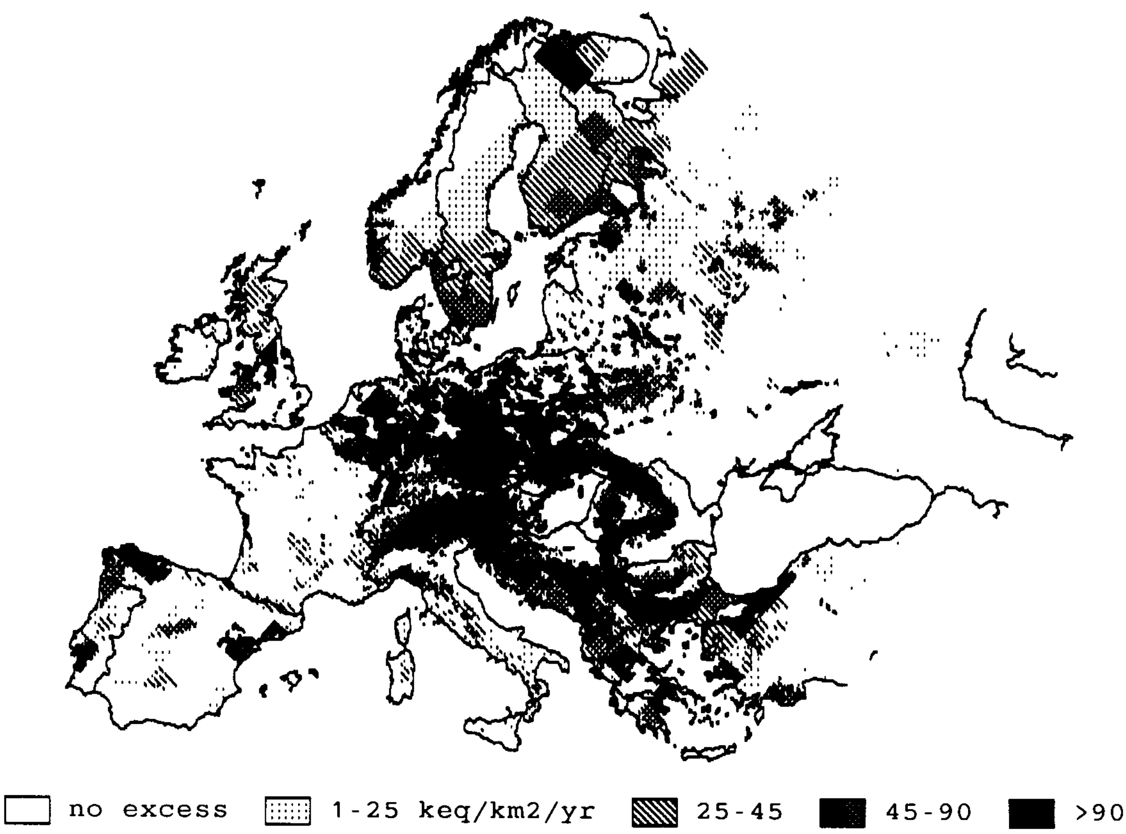

Figure 4.3. **Amount of excess deposition of S in 2000, using the SEI sensitivity map.**

approach it would be necessary to reduce depositions to or below the critical load of any ecosystem, however small, in each EMEP square in order to ensure that there will be no deleterious changes. This may be considered to be setting a value for the square based on the maximum sensitivity, or minimum value, within the square. It is necessary to be pragmatic, however, in the application of a value to an EMEP square. The map resolution and inherent inaccuracies in the input data and maps used to derive the critical loads means that uncertainties surround the presence (or absence) of sensitivity classes in a square. Additionally, it is not sensible to attempt control of emissions, and hence depositions, from an operational point of view, at very high levels of spatial resolution. It would seem sensible, therefore, to have a minimum area of ecosystems with a certain critical load in a square which determines the target assigned to that square. Section 4.3 illustrates the effect of choosing different cut-off criteria for the presence of an area that would designate the sensitivity of a square (5 percent and 50 percent, or the median), respectively.

It can be seen that by choosing criteria to assign an overall sensitivity (and hence critical load) to squares, which is not based on the maximum that the smaller, widely dispersed areas of high sensitivity in central Europe become under-represented whereas the highly sensitive areas in Scandinavia are still well-represented. Clearly, there would be a large effect of the choice of method to assign a target to an EMEP square on the resulting abatement strategy designed to reduce depositions below targets (see Section 4.3.4).

The area covered by each sensitivity class, and therefore the critical load, changes using these different methods to assign an overall class to a square. The changes in area are illustrated in Figure 4.4. The area of the most sensitive class decreases, the medium sensitivity classes change little, and the least sensitive area increases as the stringency is relaxed.

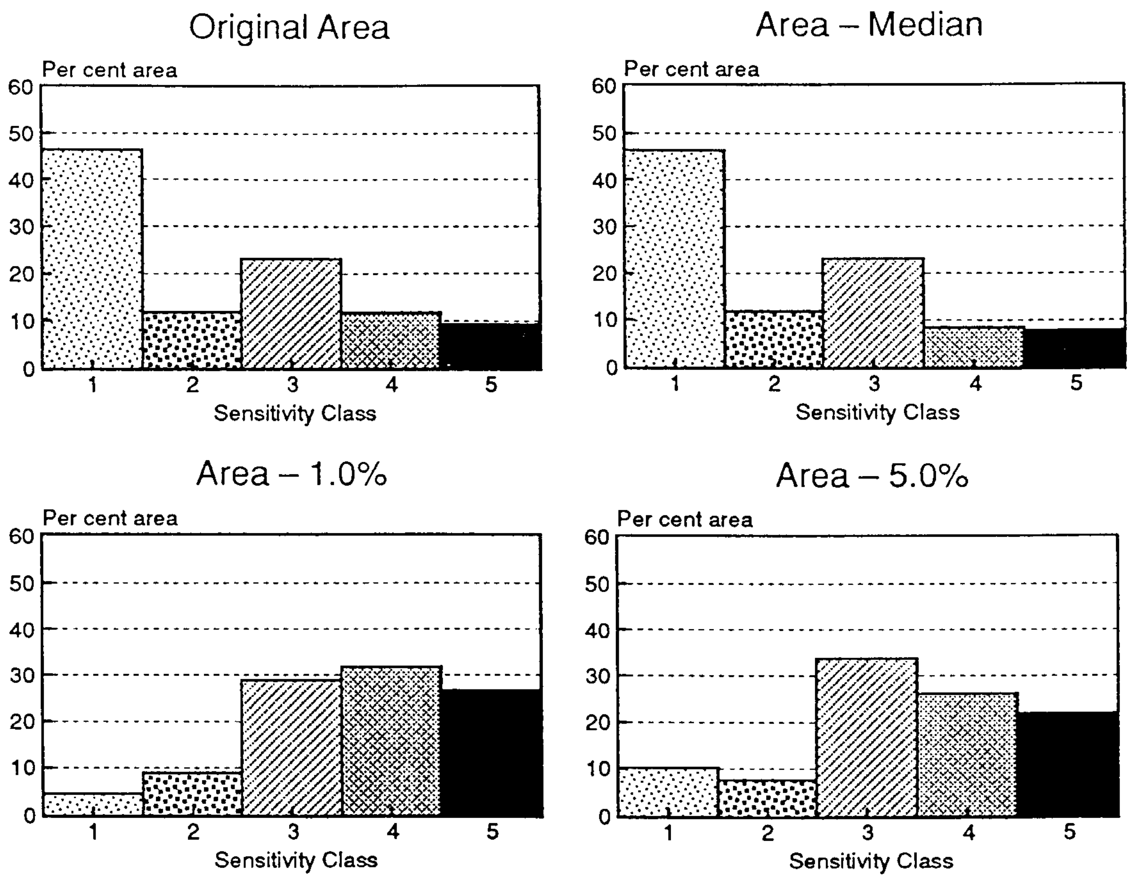

Figure 4.4. Percentage area of each relative sensitivity class in land areas of Europe on the basis of four criteria for determining the overall sensitivity for each EMEP square.

4.3 Comparison of the Stockholm Environment Institute Critical Loads Map and the CCE Critical Loads Map Based on European and National Data

Johan C.I. Kuylenstierna[1], *Clair A. Gough*[1], *Michael J. Chadwick*[1],
Jean-Paul Hettelingh, Robert J. Downing, and Peter A.M. de Smet

4.3.1 Introduction

The assessment of regional critical loads, based on relative sensitivity mapping, carried out at the Stockholm Environment Institute (SEI) has been used as a preliminary map by the UN ECE Task Force on Integrated Assessment Modeling (UN ECE 1990b, 1991a) for evaluation of some abatement strategies using SEI's CASM and IIASA's RAINS models. CASM and RAINS use critical loads maps for comparison with sulphur and nitrogen deposition resulting from given abatement strategies, or use the critical load values to influence the distribution of abatement in "targeted" abatement strategies. The CCE critical loads map, based on European and national data (the CCE map) will now be available for use in integrated assessment models and it is thus of interest to see how the maps compare. This comparison will show where and by how much the maps differ, and to what extent these differences will affect targeted abatement strategies. Limited explanation of the basis of the differences between the maps will be given.

The maps used in this comparison are the 1 and 5 percentile maps by EMEP square. Both the SEI map (Figure 4.1) and CCE European maps (Section 2) are available at higher resolution than EMEP grid squares, but the abatement strategy models require data at this resolution, this being the resolution of the EMEP atmospheric transfer model. The CCE and SEI 1 and 5 percentile maps used in this comparison are shown in Figures 4.5 to 4.8. The critical loads are shown as classes where 1 is least sensitive (high critical loads) and 5 most sensitive (low critical loads). The area covered by the different maps does not exactly correspond since the SEI map covers part of Turkey and a greater area in the USSR (to the EMEP boundaries) than the CCE map. The critical loads for the five classes of the CCE map are described as ranges (Table 4.5) and although critical load values are calculated for each grid square this data has not yet been used, so for the purposes of this comparison a single critical load value has been assigned to each critical load class which is equivalent to the upper value of the range. Single critical load values for the SEI map are also shown in Table 4.5. All critical loads in this section are quoted in the form of keq km^{-2} yr^{-1} (1 keq km^{-2} = 10 eq ha^{-1}).

The comparison describes the size and distribution of the differences in critical loads by using maps and histograms. Europe has been divided into five regions (Figure 4.9) so that the regional differences in Europe may be illustrated.

The comparison undertaken here is carried out by examining:
1. differences between distributions of critical loads;
2. differences in exceedance of critical loads;
3. the effect of the maps on integrated assessment model results.

These three aspects constitute a full comparison of the maps and their use. The first part considers the critical loads maps by comparing firstly their predicted pattern of sensitivity and secondly the critical loads values; the second part compares the exceedance by acidic deposition which is one important way in which the critical loads maps are used to assess the success of abatement strategies; the third part analyses the use of the critical loads maps to drive "targeted" abatement strategies which is another important way in which the critical loads will be used. In this way differences relevant to policy will be brought to light.

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1. Stockholm Environment Institute, Stockholm, Sweden.

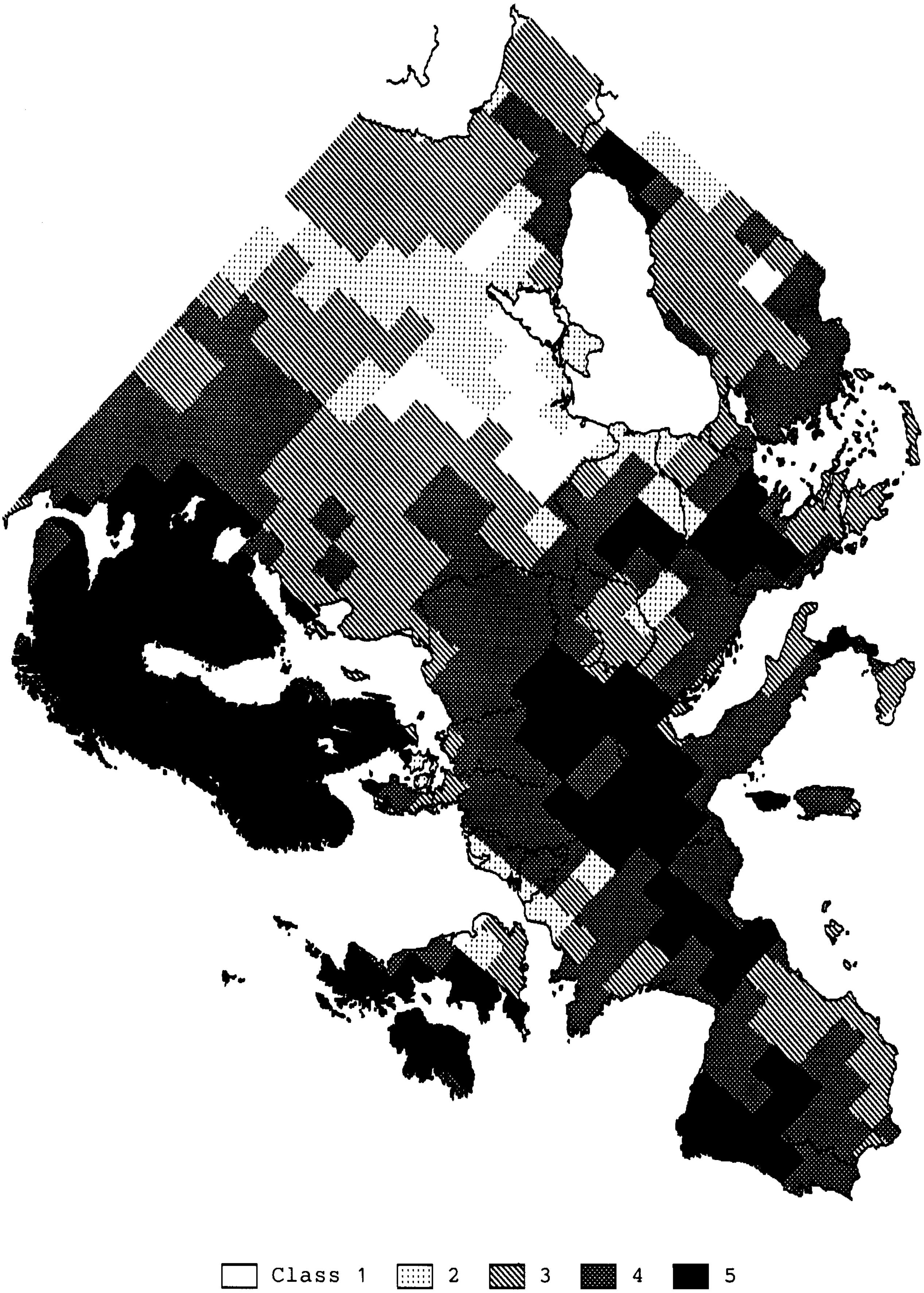


Figure 4.5. The Stockholm Environment Institute 1 percentile critical loads map presented as classes.

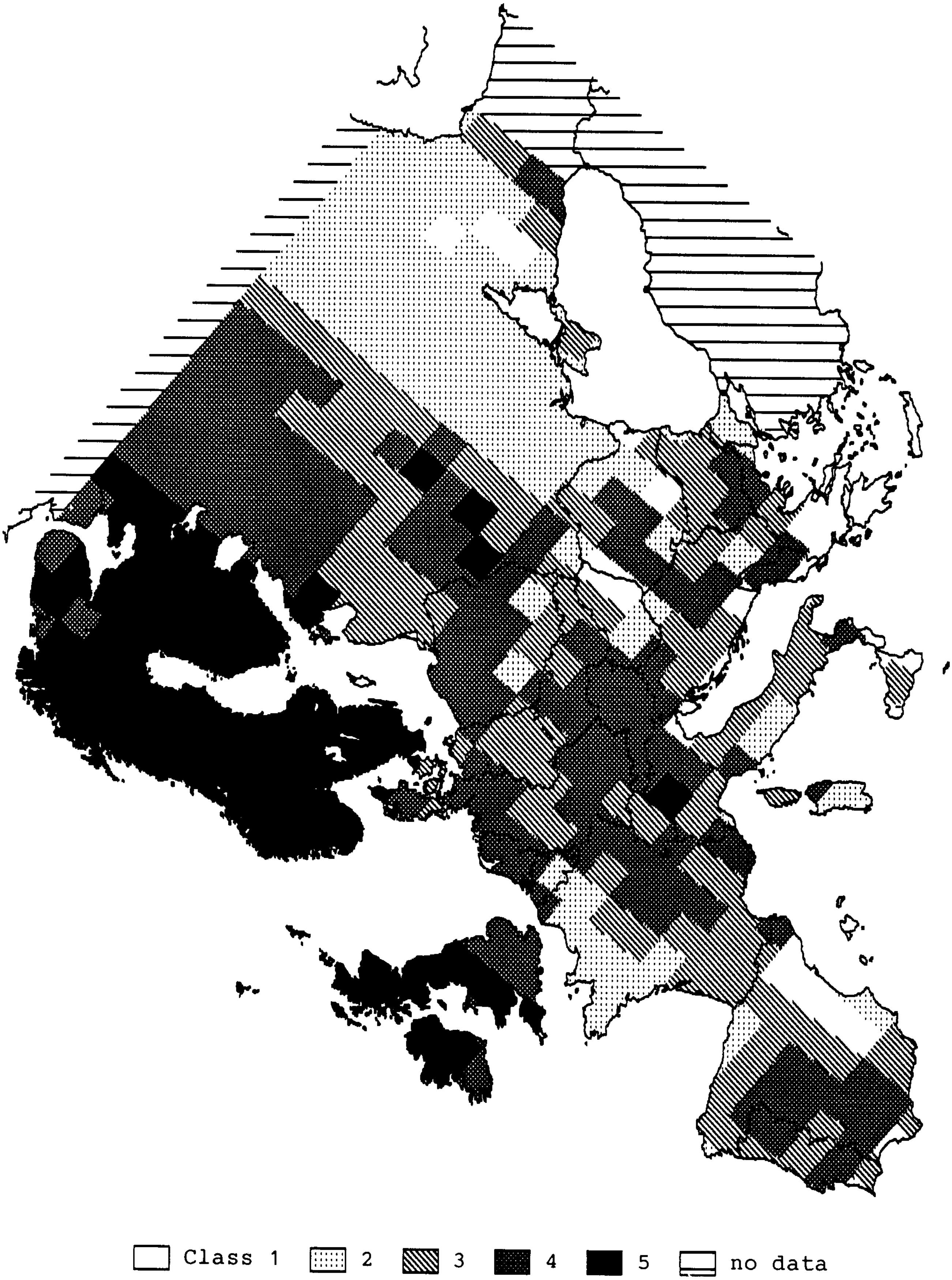


Figure 4.6. The CCE 1 percentile critical loads map based on national and European data presented as classes.

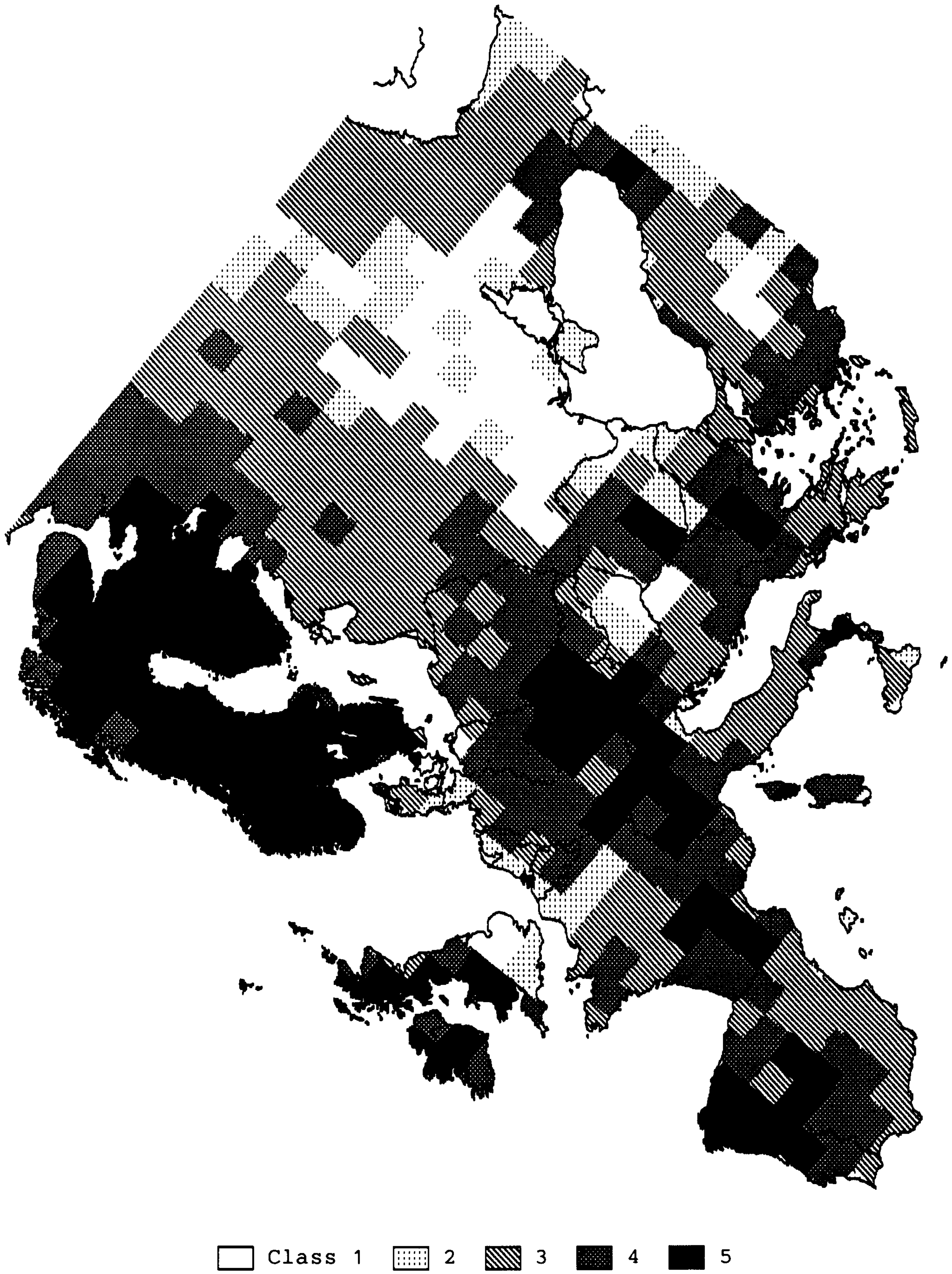


Figure 4.7. The Stockholm Environment Institute 5 percentile critical loads map presented as classes.

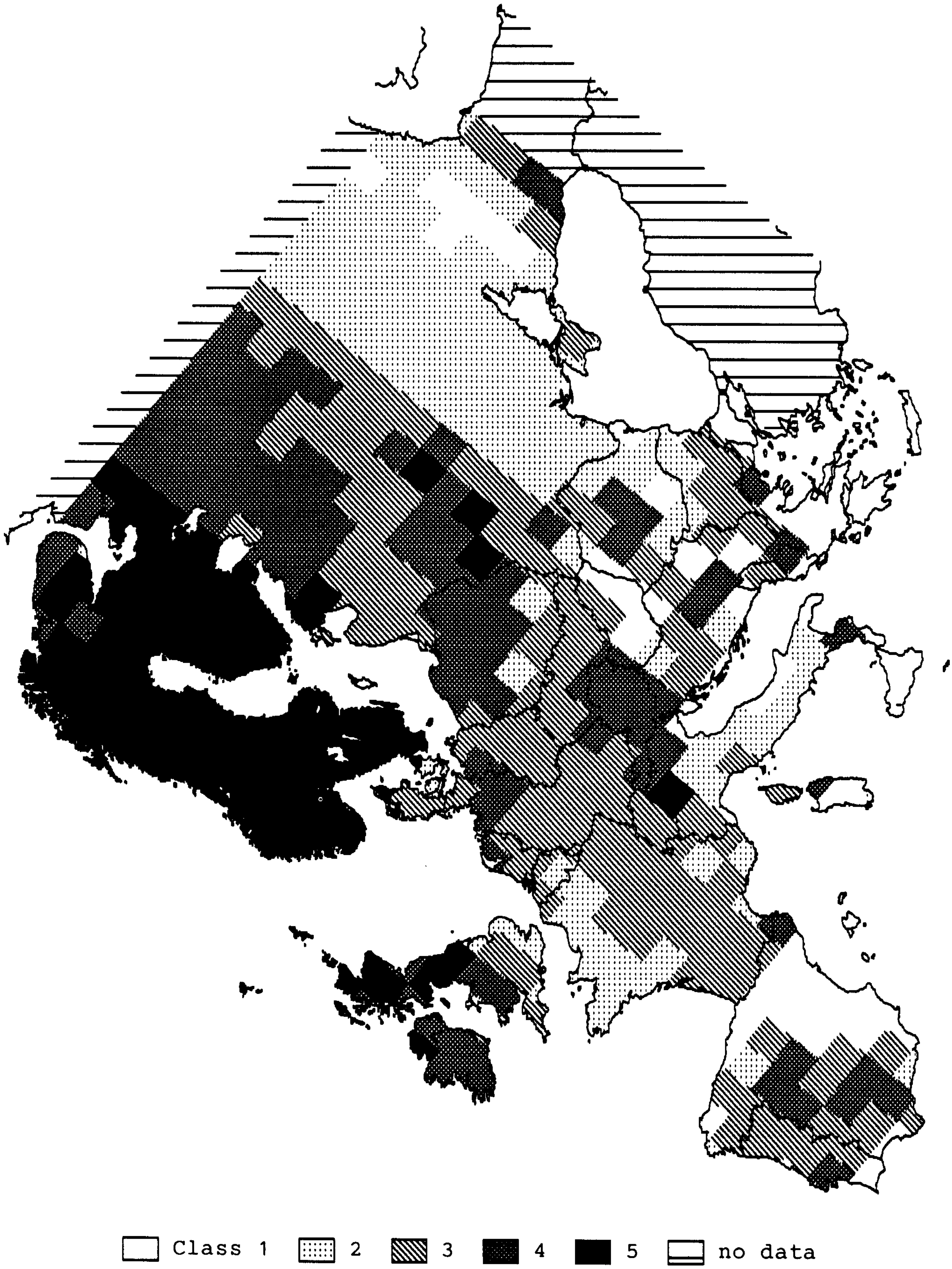


Figure 4.8. The CCE 5 percentile critical loads map based on national and European data presented as classes.

Table 4.5. **The critical loads used with the different maps in this comparison (keq km^{-2} yr^{-1}).**

CCE EUROPEAN MAPS			SEI MAPS	
Class	Critical load range	Critical load value	Class	Critical load assigned
5	0-20	20	5	20
4	20-50	50	4	40
3	50-100	100	3	80
2	100-200	200	2	160
1	>200	>200	1	>160

N.B.: 1 keq km^{-2} = 10 eq ha^{-1}.

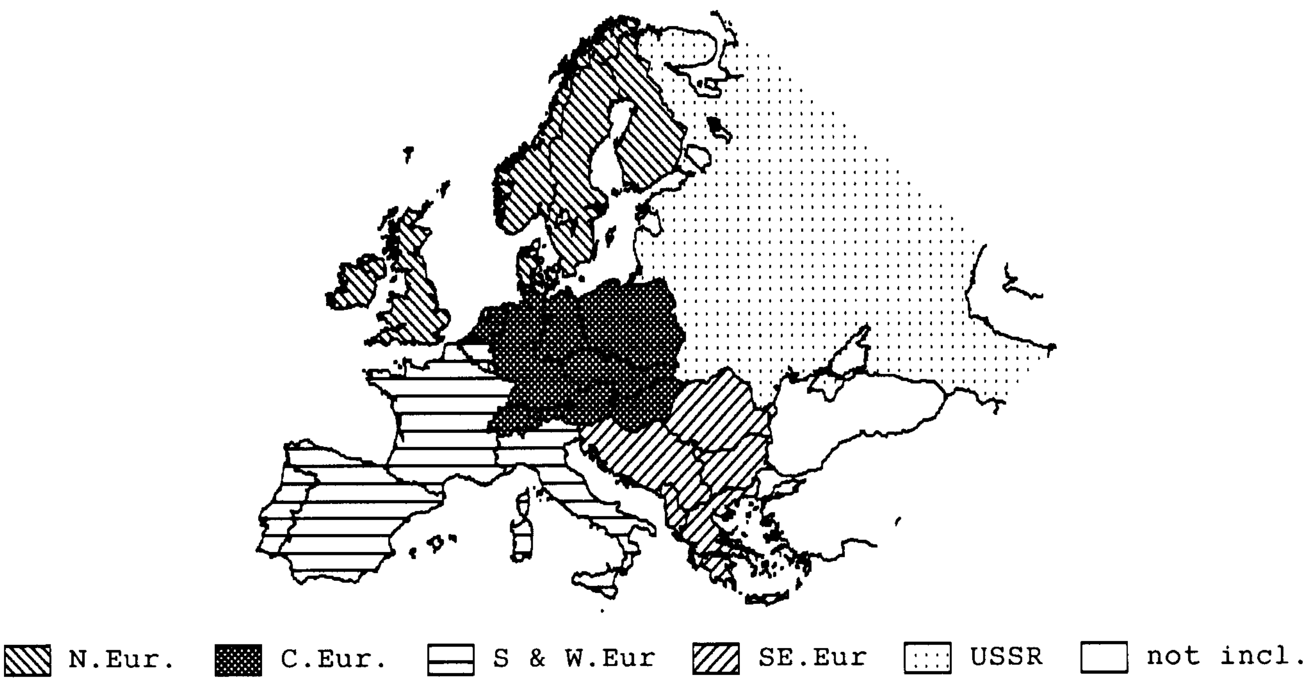
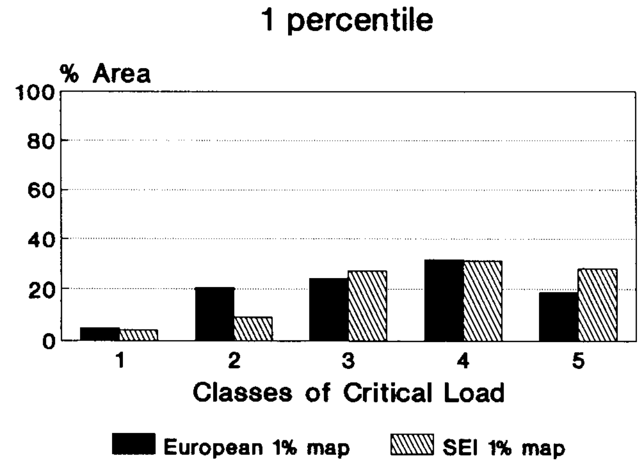


Figure 4.9. The five regions used for the purposes of comparison.

4.3.2 Differences between the critical loads distributions

The comparison of the SEI and CCE 1 and 5 percentile maps excludes Turkey. Over the whole area under comparison it can be seen from Figure 4.10 that the SEI maps has higher coverage of the lower critical load classes than the CCE maps. As would be expected, the 1 percentile tends to increase the area of the lower critical loads (Figure 4.10).

Regional dissimilarities are investigated by taking into account the difference in critical load classes in each square (showing the divergence in the pattern of critical loads), and differences between the critical load values in each square (relevant to targeted abatement strategy formulation). From Table 4.5 it is evident that the critical load values set for each class are not equivalent due to overlap between the classes. For this reason the comparison by classes only considers critical load classes in EMEP squares which differ by two or more classes, as these will definitely represent different critical loads. Critical loads differences greater than 60 keq km^{-2} yr^{-1} are considered, as smaller values are of less consequence; this procedure highlights the major differences.



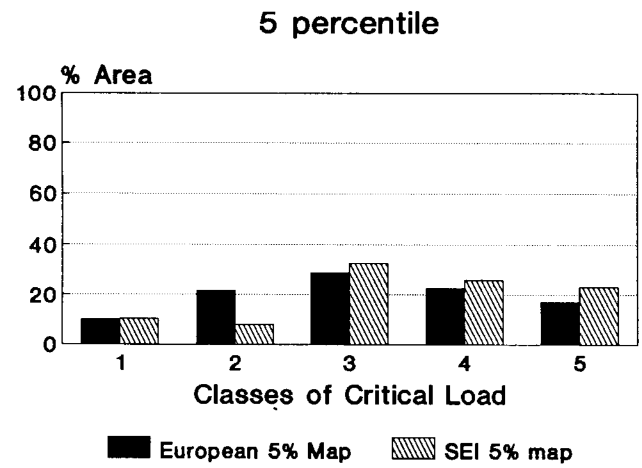


Figure 4.10. Percentage area covered by the critical load classes in the 1 (upper graph) and 5 (lower graph) percentiles of the CCE and SEI critical loads maps (Class 1 = high critical loads; Class 5 = low critical loads).

For the 1 and 5 percentile, 14% and 20% of Europe differs by two or more critical load classes (Figures 4.11 and 4.13) and the greatest area of difference is in South and West and Southeast Europe (Figure 4.15). The greatest similarities are in Northern Europe and the USSR. The difference in critical load values (>60 keq km^{-2} yr^{-1}) shows a similar picture but emphasizes further the similarity in Northern Europe and the differences in the South and West and Southeast. Differences in the southern USSR, especially around the Caspian Sea, appear in the comparison of critical load values, although the maps only differ by one critical load class (Figures 4.12, 4.14 and 4.15). Since the critical loads in the CCE maps have been assigned to the highest value in the range (Table 4.5), and since the CCE critical loads are generally higher than the SEI values, the use of actual CCE critical loads calculated for a square would decrease the dissimilarities between the maps.

No critical loads are set for the least sensitive areas (Class 1, Table 4.5), which leads to many of the large differences shown in Figures 4.12 and 4.14 compared to Figures 4.11 and 4.13, where one or the other map has an "infinite" critical load and the other has a critical load set. In other areas critical loads are 100 keq km^{-2} yr^{-1} different for only one change in critical loads class. Such areas will show up in Figures 4.12 and 4.14 but not in Figures 4.11 and 4.13. The total area under comparison where the 1 and 5% maps differ by > 60 keq km^{-2} yr^{-1} is 36% and 45% respectively, of which 8% and 18% is due to one or other of the maps having an "infinite" critical load. The 1 percentile maps are more similar than the 5 percentile as would be expected since the representation of the low critical load areas increases with a lower percentile cut-off. The differences in Spain, Italy and the USSR are all diminished.

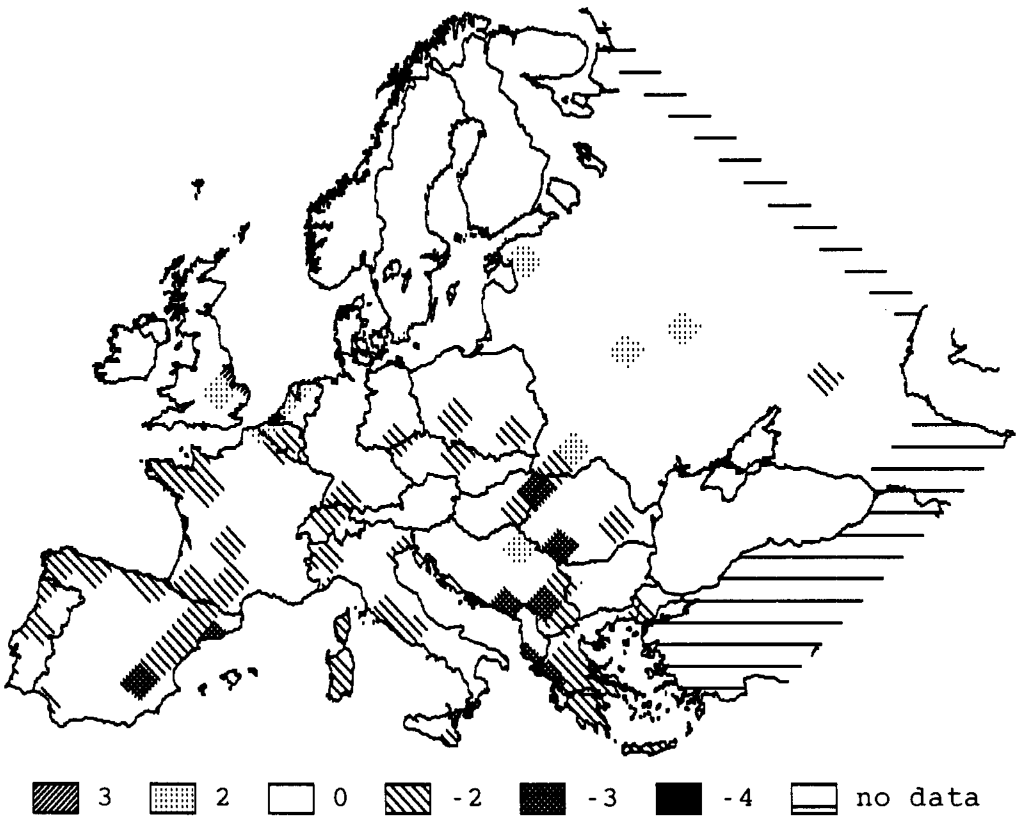


Figure 4.11. The distribution of areas which differ by two or more critical loads classes in the 1 percentile maps. The values shown indicate the difference in class number between the two maps. Positive numbers indicate a higher CCE class number.

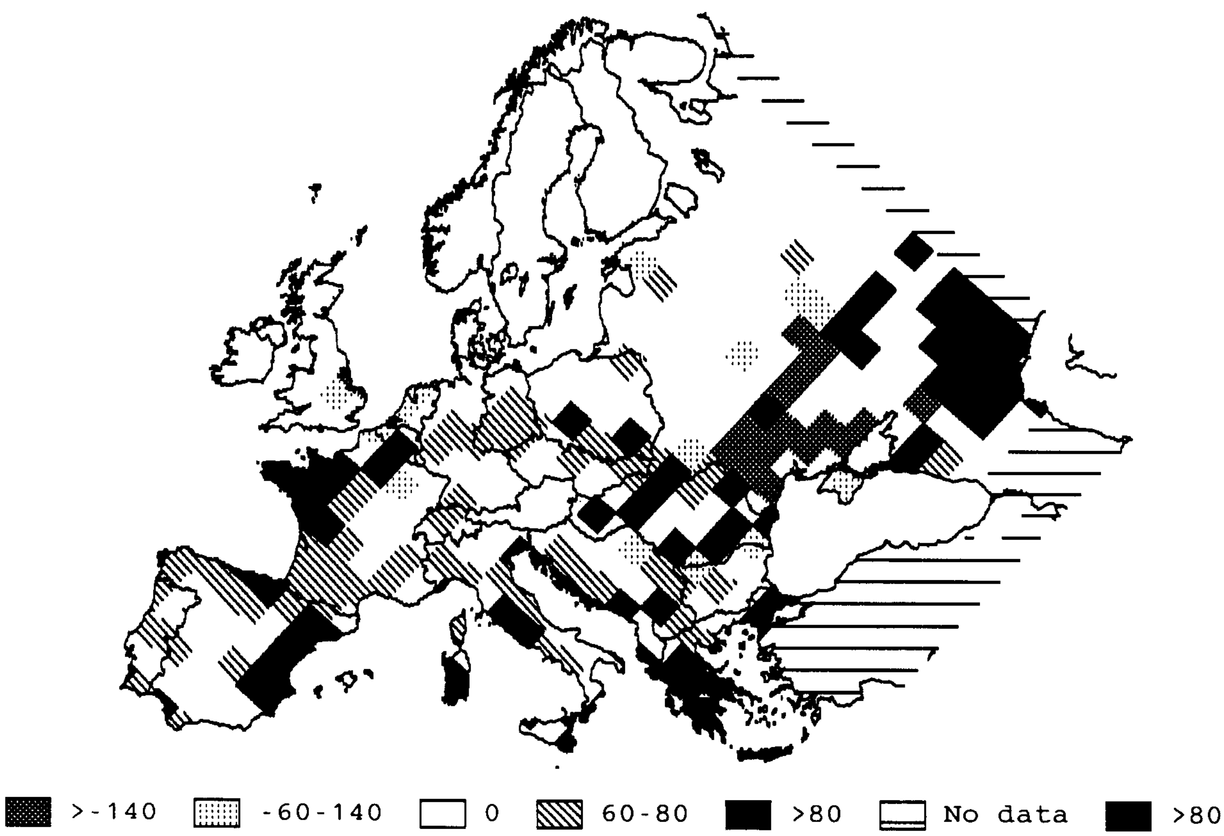


Figure 4.12. The distribution of areas where the 1 percentile critical loads differ by >60 keq km^{-2} yr^{-1} (in keq km^{-2} yr^{-1}). Positive values indicate higher critical loads in the CCE map.

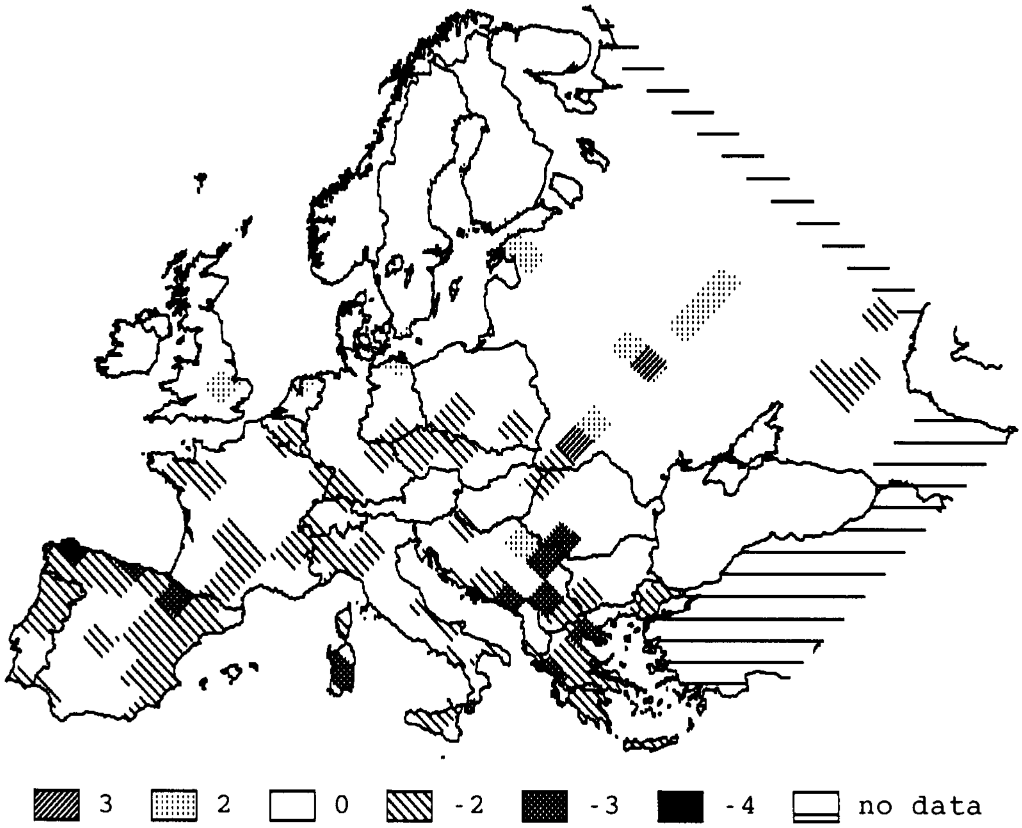


Figure 4.13. The distribution of areas which differ by two or more critical loads classes in the 5 percentile maps. The values shown indicate the difference in class number between the two maps (positive numbers indicate a higher CCE class number).

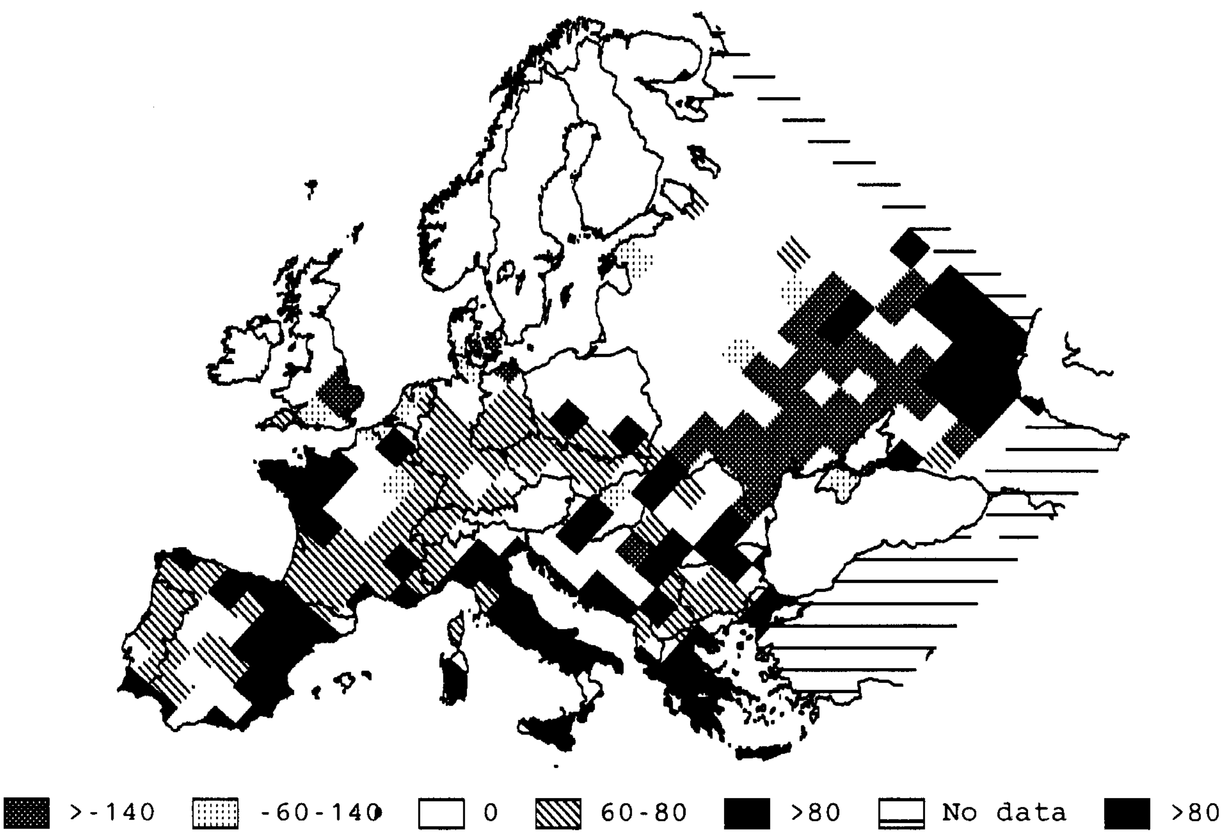


Figure 4.14. The distribution of areas where the 5 percentile critical loads differ by >60 keq km^{-2} yr^{-1} (in keq km^{-2} yr^{-1}). Positive values indicate higher critical loads in the CCE map.

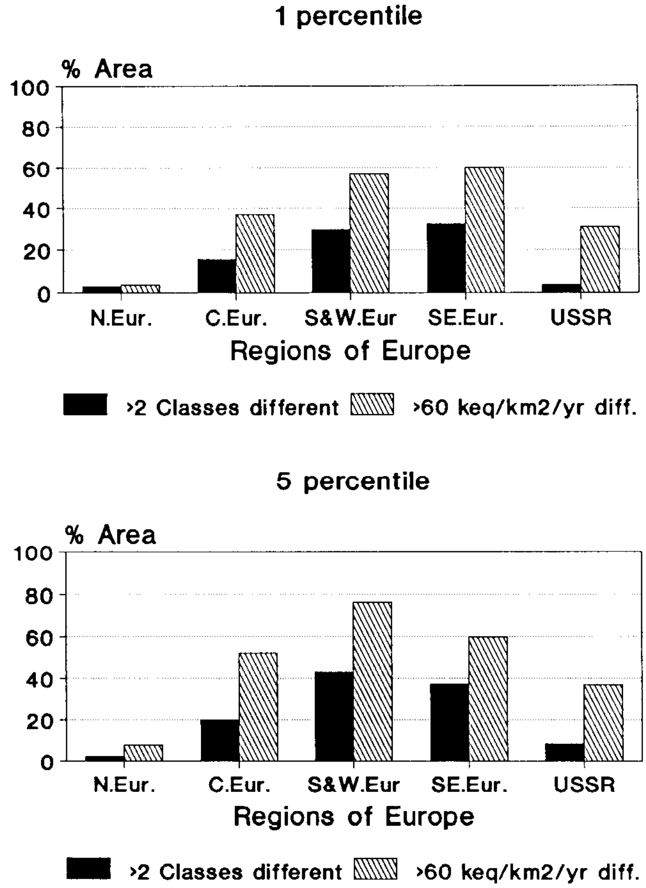


Figure 4.15. **The area over which the SEI and CCE 1 (upper graph) and 5 (lower graph) percentile critical load maps differ by two or more classes and by more than 60 keq km^{-2} yr^{-1}.**

4.3.3 Differences in exceedance

The exceedance of critical loads is an important way of assessing the success of an abatement strategy and is relevant to the "targeted" abatement strategies, since if there is no critical load exceedance, then there will be little pressure to carry out abatement in emissions causing depositions in these areas. The exceedance calculated for this comparison makes the following assumptions:

1. critical loads of acidity are compared directly to sulphur deposition alone (critical loads of sulphur are not calculated);
2. nitrogen deposition is not included;
3. base cation uptake is not included;
4. base cation deposition is not included.

The total unabated sulphur deposition in 2000 (Figure 4.2 in Section 4.2) is calculated from projected SEI emission estimates for each country (including Turkey) and the mean of the latest EMEP 1988 and 1989 atmospheric transfer coefficients. The 2000 emissions are estimated from official energy use projections, the sulphur contents of the fuels, and the retention factors. The background deposition of sulphur as calculated by EMEP has also been included.

The comparison of the exceedance is carried out by considering the amounts of exceedance over the whole European area (including Turkey) and the exceedance in the five regions of Figure 4.9. The exceedance over the SEI high-resolution map (Figure 4.3) is included in the comparison.

The pattern of exceedance is similar over both SEI and CCE maps (Figures 4.16 and 4.17), although there is a larger area of exceedance over the SEI maps (Figure 4.18) due to the greater area of low critical loads in South and West and Southeast Europe. The total area of exceedance over the high-resolution map is naturally less than the 1 or 5 percentile maps (Figure 4.18) but shows a similar distribution of exceedance to all percentile exceedance maps. The area of exceedance shown by the SEI and CCE maps is very similar in North and Central Europe, but differ to a greater extent in South and West and Southeast Europe (Figure 4.19). This is consistent with the analysis of the difference between the critical loads maps which noted the greater difference assigned to the critical loads in these areas. The area of exceedance in the USSR is greater using the CCE map due to lower critical loads in the southern parts, especially around the Black Sea.

4.3.4 Differences in the SEI CASM integrated assessment model results using the different maps

Abatement strategies may concentrate on reducing depositions causing exceedance of critical loads and therefore the use of differing critical loads maps will lead to different distributions of abatement. The effect of using the different maps in this respect may be investigated by using integrated assessment models which will find the optimum allocation of abatement to satisfy a specified objective based on the critical loads. For this purpose the SEI Co-ordinated Abatement Strategy Model (CASM) has been used. CASM uses critical loads maps (as percentiles of EMEP squares) to drive "targeted" abatement strategies whereby abatement is carried out in order to reduce critical loads exceedance in a cost-effective manner. The runs of the model described here have been carried out for comparison purposes and use the same parameters and inputs except for the different critical loads maps.

The model has been run for this comparison by calculating the cost of an arbitrary uniform 50 per cent reduction (50% UPR) of emissions relative to 1980 in all countries from total cost curves of abatement. These cost curves, produced at SEI, refer to the cost of building and running "bolt-on" technologies in all the major sulphur-producing sectors of each country. The cost is allocated optimally to satisfy a specified objective. The model (CASM) finds the optimal solution whereby the minimum number of tonnes of sulphur exceeding critical loads ("Exceedance Minimization") is derived subject to the cost constraint (cost of 50% UPR) by using the different country cost curves. If there is no exceedance of critical loads in one region then the allocation of finances will shift towards another part of Europe where emissions do lead to depositions which exceed critical loads.

The results of the optimization are shown in three ways:

1. the amount of sulphur abated in each of the 5 regions;
2. the cost of abating the sulphur in each country; and
3. the area of critical load exceedance over the SEI high-resolution critical loads map (to show differences in deposition/exceedance patterns relative to a common map) in each region.

The amount of sulphur abated in each of the five regions is similar (Figures 4.20 and 4.21), but the distribution of abatement varies slightly so that when the CCE European critical loads maps are used, the allocation of abatement shifts northwards, causing more abatement in Northern and Central Europe and the USSR and consequently less in the Southeast and South and West Europe, compared to when the SEI critical loads maps are used in the model.

Due to the greater degree of abatement in Northern and Central Europe and the USSR (using the 5 percentile map), more of the financial resource is shifted to these areas when using the CCE critical loads map (Figures 4.20 and 4.21). The high cost per tonne sulphur abated in Northern and Central Europe is due to the relatively high cost of abatement in those countries where the extra abatement is carried out.

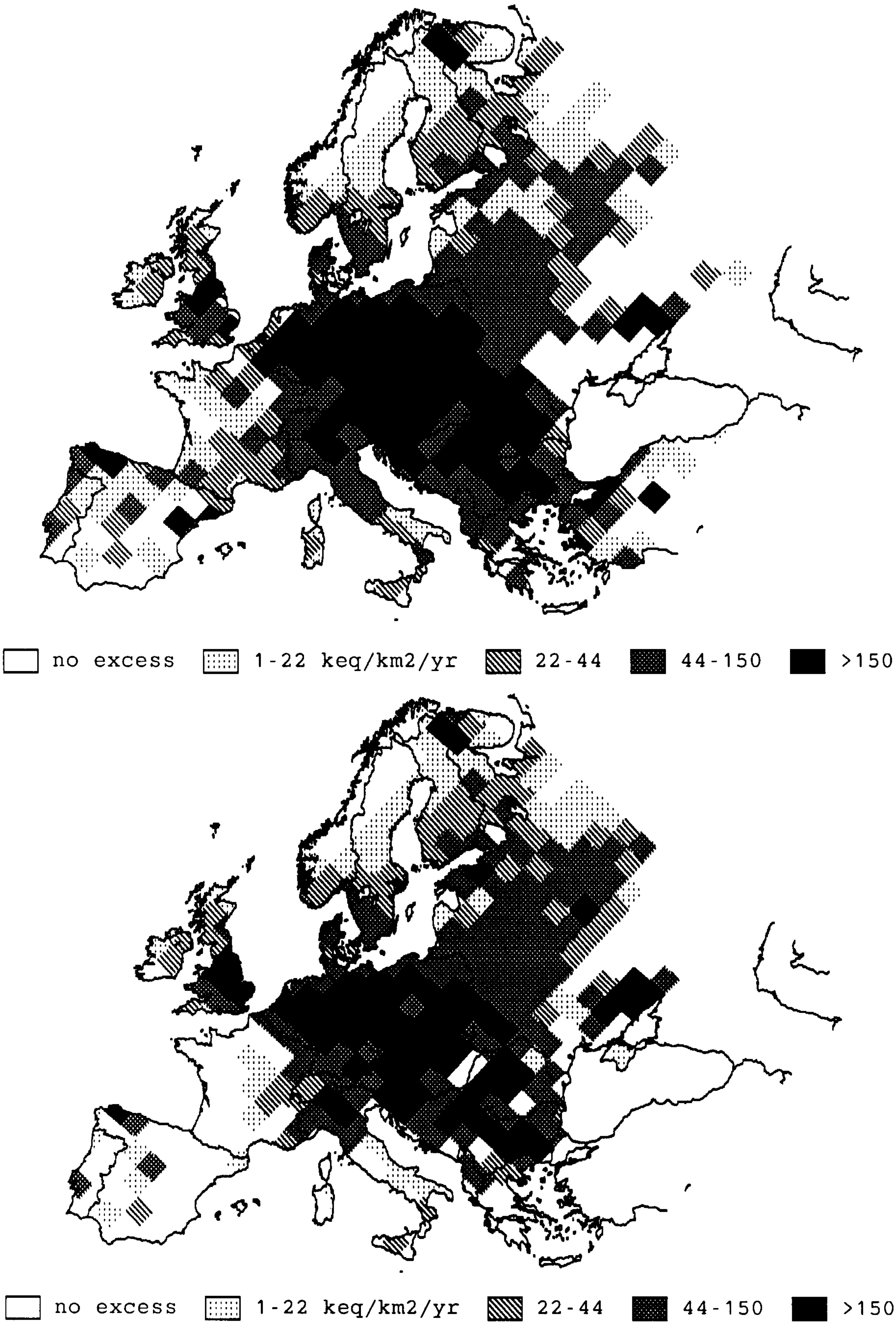
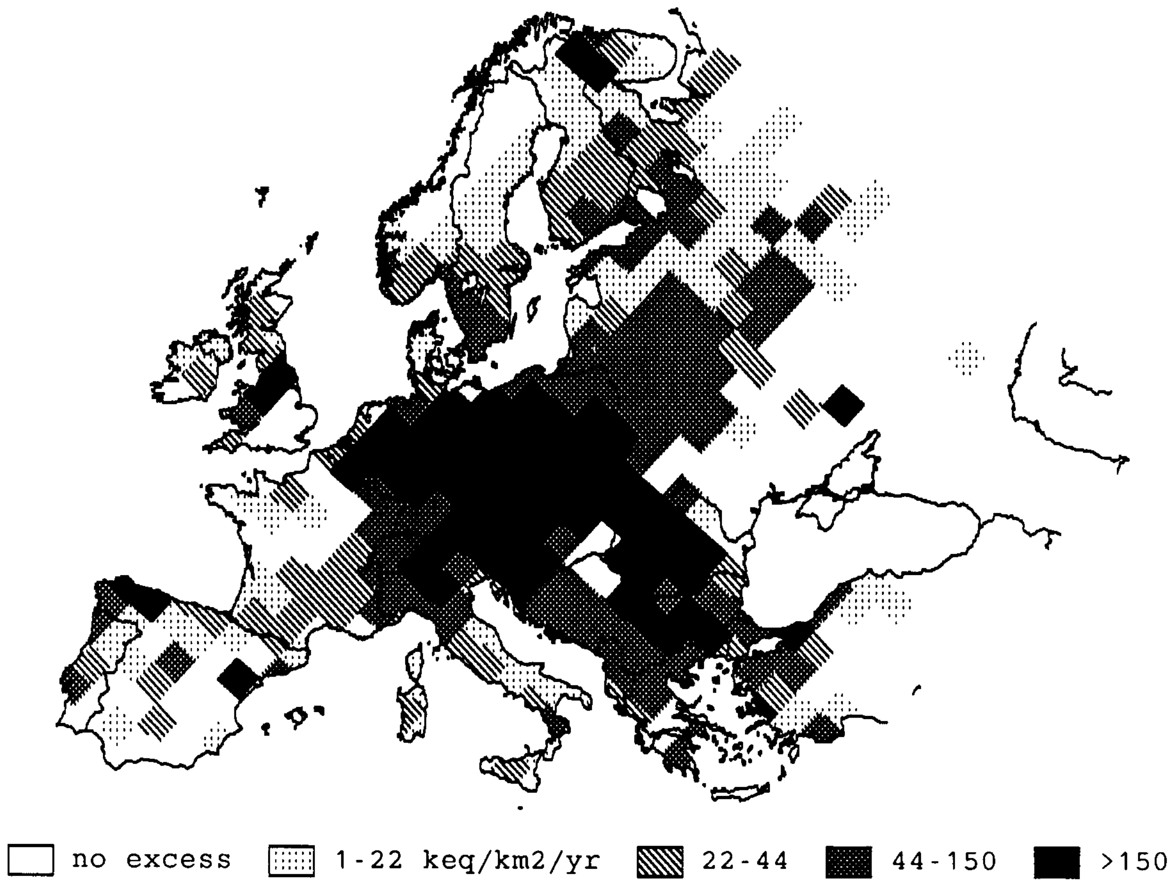


Figure 4.16. The exceedance of the SEI (upper map) and CCE (lower map) 1 percentile critical loads by the 2000 sulphur deposition (calculated using SEI emission estimates and EMEP transfer coefficients).



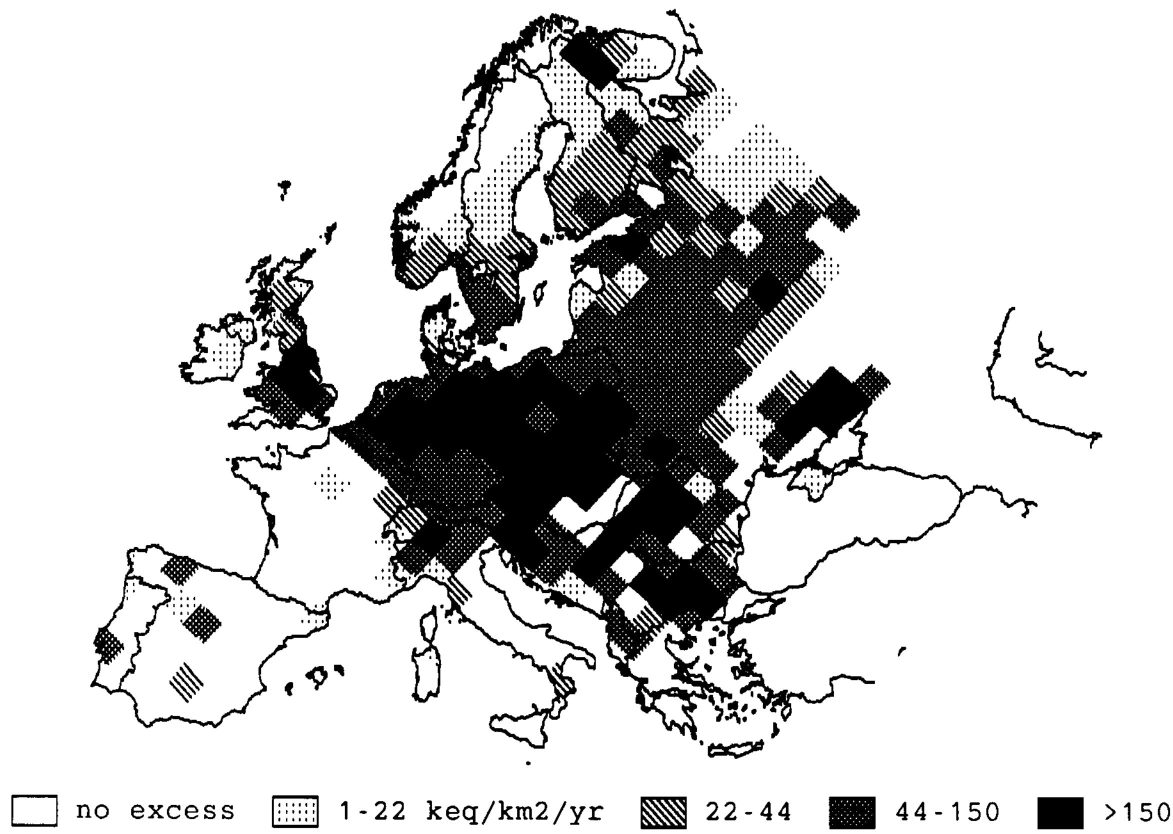
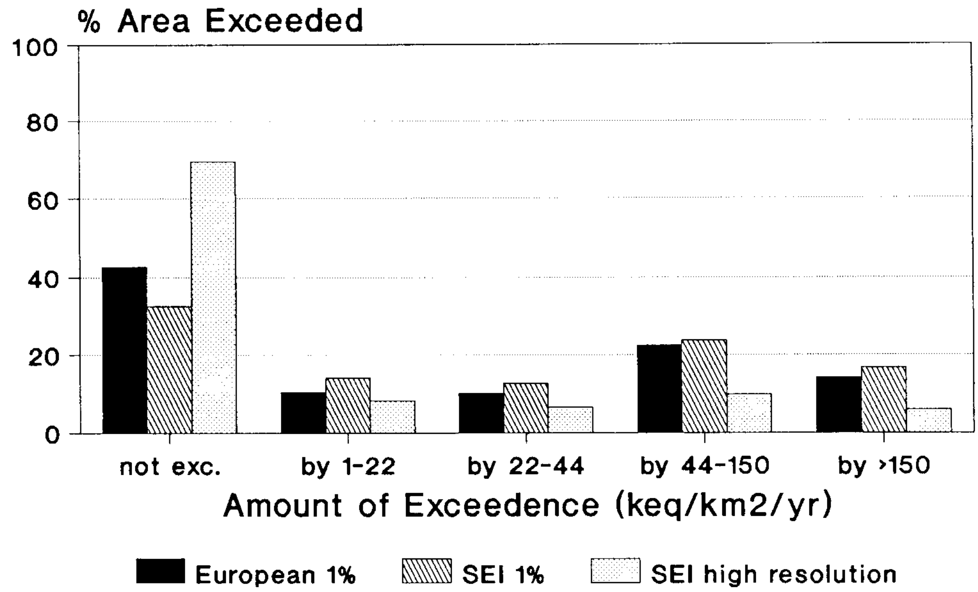


Figure 4.17. **The exceedance of the SEI (upper map) and CCE (lower map) 5 percentile critical loads by the 2000 sulphur deposition (calculated using SEI emission estimates and EMEP transfer coefficients).**



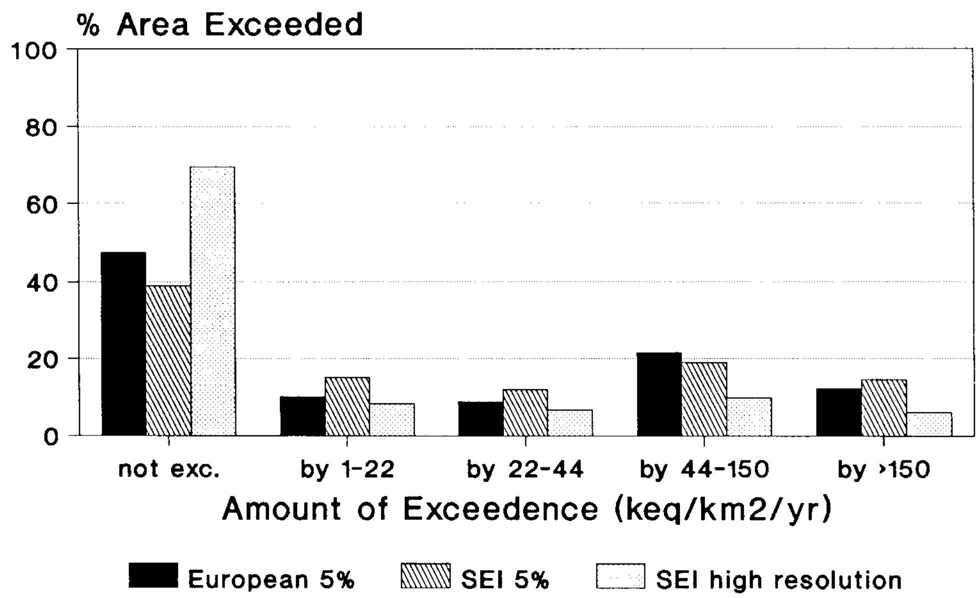
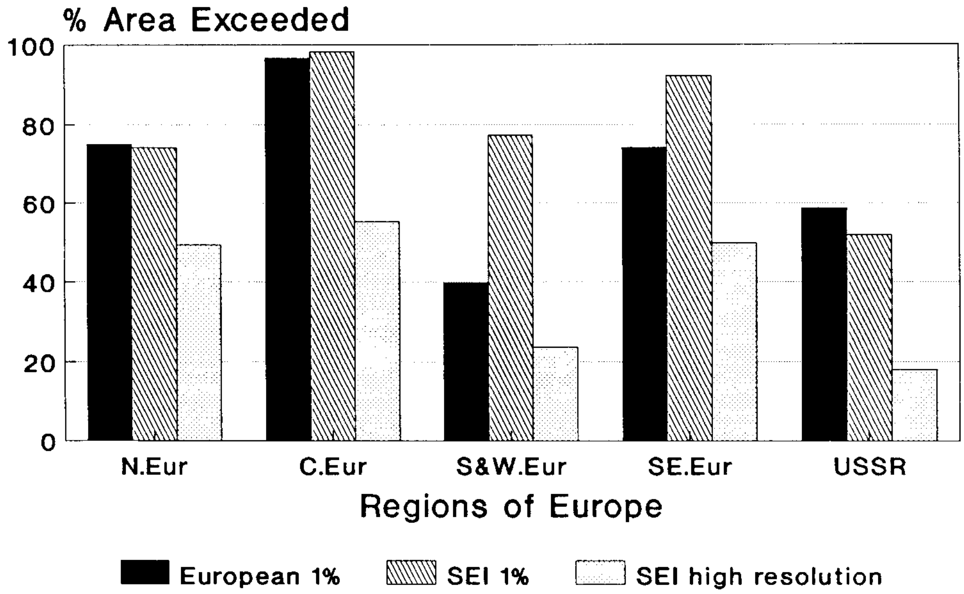


Figure 4.18. Area of amount of exceedance of the European and SEI 1 (upper) and 5 (lower) percentile critical loads by the projected 2000 sulphur deposition (SEI emission estimates; EMEP transfer coefficients).

Figures 4.20 and 4.21 show the exceedance of deposition over the SEI high-resolution critical loads map which is used as a common base for comparison of the changes in deposition and exceedance caused by using the different critical load maps to run targeted abatement strategies. As would be expected from the pattern of abatement, the greater proportion of resources allocated to Northern and Central Europe



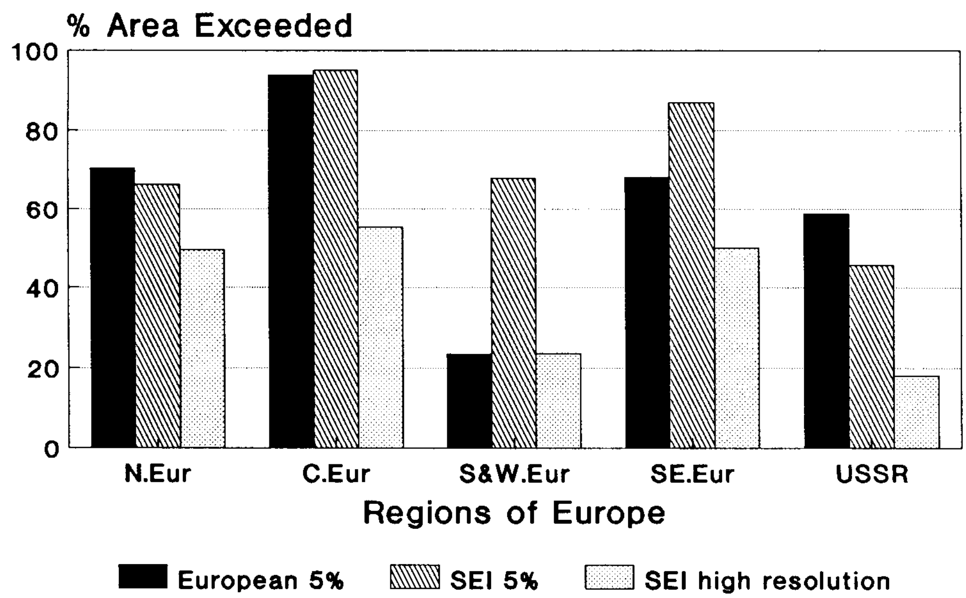


Figure 4.19. **Area of exceedance in five regions of Europe by the projected 2000 sulphur deposition over the 1 (upper graph) and 5 (lower graph) percentile CCE and SEI critical loads as compared to the SEI high-resolution critical loads.**

using the CCE critical loads maps results in a lower amount of critical load exceedance in this region. Also consistent with this is the greater area of exceedance of critical loads in the Southeast and South and West Europe using the CCE map rather than the SEI map.

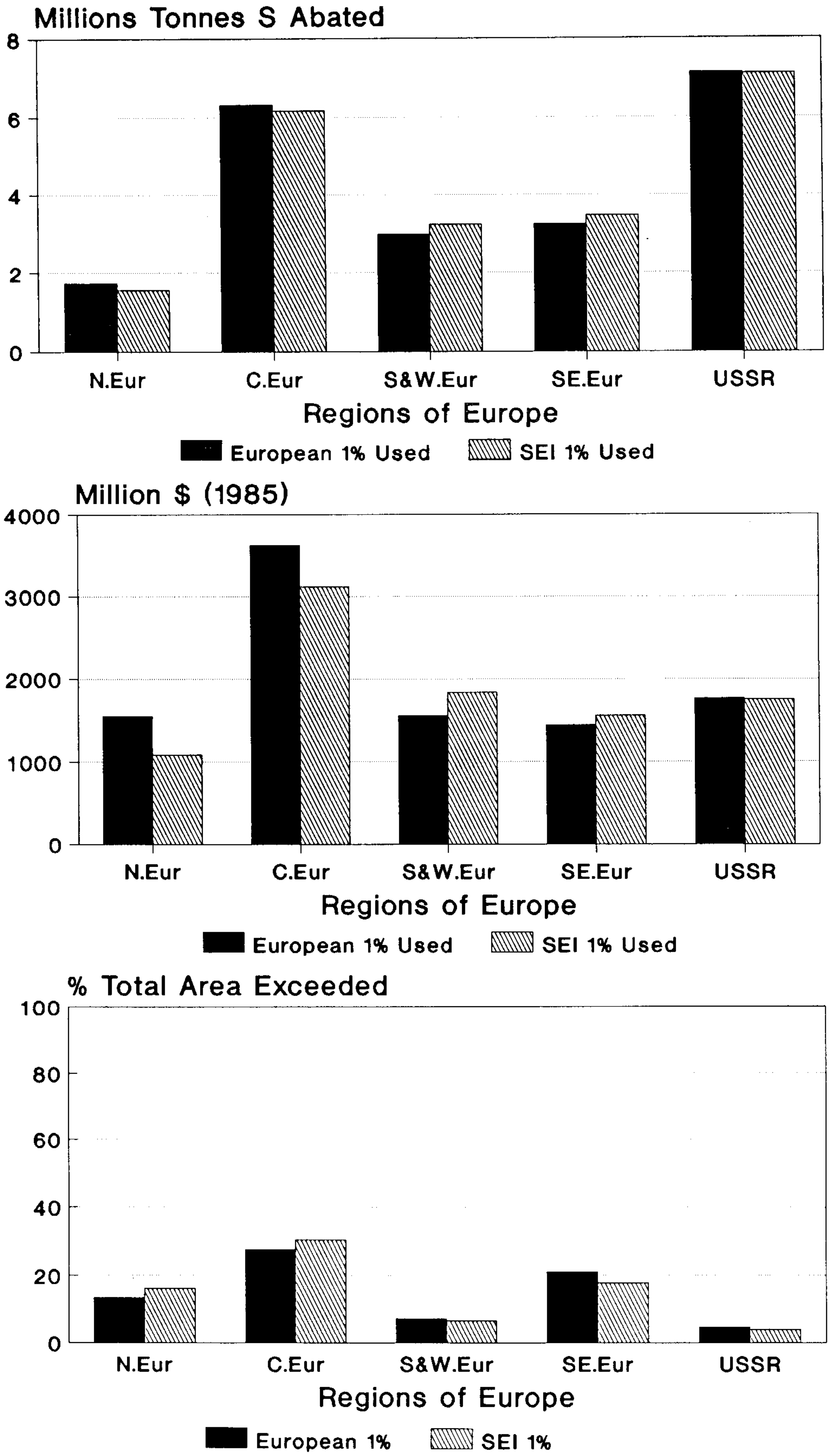


Figure 4.20. The amount of sulphur abated; the cost of abatement, and the exceedance of resulting deposition over SEI high-resolution targets using the 1 percentile SEI and CCE critical loads for an exceedance minimization at the cost of a uniform 50% reduction in emissions (using CASM).

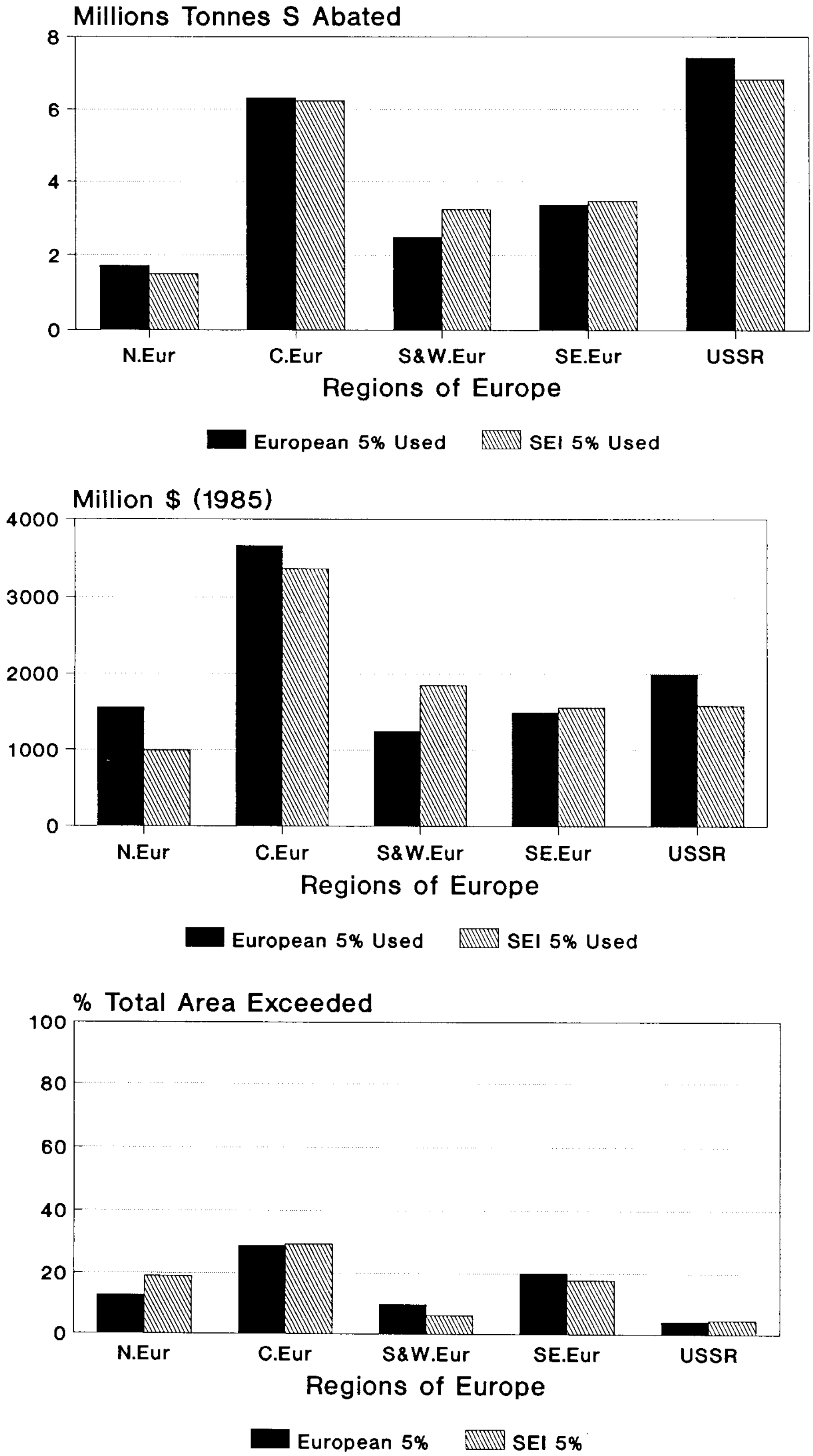


Figure 4.21. The amount of sulphur abated; the cost of abatement, and the exceedance of resulting deposition over SEI high-resolution targets using the 5 percentile SEI and CCE critical loads for an exceedance minimization at the cost of a uniform 50% reduction in emissions (using CASM).

4.3.5 Discussion

The differences between the critical loads maps which show up in South and West and Southeast Europe, and which affect the allocation of abatement, may be explained by examining the methods and data used to produce the critical load values. For most countries in Southern Europe (Southeast and South and West), in the absence of a map prepared nationally, the Steady State Mass Balance (SMB) method was used. It would seem from an examination of the input data for this method that where the differences between the CCE map and the SEI map are greatest, there is a very high weathering rate used as input to the SMB method, there is high base cation deposition or high runoff values, or a combination of these. Using the SEI method the land use alone can give rise to a classification of medium sensitivity, but in dry areas of very high weathering rate, such as in the southeast of Spain, Greece, and the USSR around the Caspian Sea, the SEI method may overestimate sensitivity.

The base cation deposition is used in the SMB method in order to calculate the critical aluminum: calcium ratio and where this is high, the critical load will also be high. The base cation deposition is high in Southern Europe and will explain some of the differences between maps in the critical loads assigned to these areas. The base cation deposition is not included in the SEI calculations of critical loads.

The SMB and SEI methods consider the effect of water flux in different ways: the SEI method tries to include the long-term effect of a high water flux which will give rise to a build-up of organic matter and an increase in ecosystem sensitivity; the SMB method considers the short-term dilution of aluminum in acid soils, thus reducing its toxicity and decreasing sensitivity. These discrepancies may give rise to the differences in critical loads on the north coast of Spain and in Brittany which both methods agree have low weathering rates but which receive relatively high rainfall.

The resolution of input data is much greater in some countries than the primary source maps used by the SEI. This explains the lower critical loads in the southeast of England in the CCE maps, which are based upon a 1 km^2 resolution and therefore detect many of the small sensitive areas not shown on the larger-scale maps.

4.3.6 Conclusions

Overall the SEI and CCE European critical loads maps are similar, both in the critical loads values and in the distribution of the critical loads classes. The 1 percentile maps agree better than the 5 percentile maps. The differences are negligible in Northern Europe and greatest in South and West and Southeast Europe. Reasons for these differences have been suggested which include the use of base cation deposition in the SMB method, areas of high weathering rates used in the SMB approach and differences in the approach to the effect of water flux on the critical loads.

The critical load exceedance maps show a greater degree of similarity than the critical loads maps due to the common pattern of acidic deposition. The exceedance differs most in South and West and Southeast Europe.

The amount and distribution of targeted abatement required in Europe to approach critical load values are similar using the different maps although the differences in the distribution of critical loads and exceedance have an effect. The financial resources that need to be allocated are distributed differently. Nevertheless, the SEI and CCE critical loads maps, even though produced using different methodologies, do result in broadly similar abatement strategies. This should promote confidence in the use of critical load maps.

4.4 Comparison of National Critical Load Maps and the CCE Critical Loads Map Based on European Data Only

Wim de Vries[1], *Wolfgang Schöpp*[2], *and Jean-Paul Hettelingh*

This section describes causes of differences that occur between the critical load map of Europe obtained with the steady state mass balance (SMB) method (Section 2.7) and the European map of critical loads including national contributions (Section 2.1). Figure 4.22 and Table 4.6 respectively provide a geographical and numerical overview of these differences. It can be seen from these figures that about 34 percent of the grids have SMB critical loads which are higher than the European critical loads which include national contributions. Twenty-six percent of the grids have critical loads which have been computed with the SMB (difference of 0) and about 40 percent of the grids contain higher European critical loads.

Table 4.6. Percentage of grids in which differences in critical loads of acidity ($mol_c\ ha^{-1}\ yr^{-1}$) between the 5 percentile SMB map and the 5 percentile European map are classified.

Percentage difference of grids	Critical Loads Lower bound		Upper Bound
7.14 %	-2500.0	to	-500.0
16.59 %	-500.0	to	-200.0
13.24 %	-200.0	to	-0.01
26.26 %	-0.01	to	0.0
0.00 %	0.0	to	0.01
8.40 %	0.01	to	200.0
10.71 %	200.0	to	500.0
13.87 %	500.0	to	2500.0
0.84 %	2500.0	to	5000.0

The following section discusses the causes of these differences by: (1) investigating some European data base characteristics, and (2) case studies of national data from Austria and the Netherlands.

Differences between critical loads maps produced by individual countries in the European application of the steady state mass balance (SMB) method are due to a number of factors, including:

1. Differences in the methods used: Ireland, Czech and Slovak Federal Republic, USSR, and United Kingdom used the Level 0 approach, which is based on a somewhat different concept that the SMB model. In addition, Denmark and Sweden used the PROFILE model, which differentiates among soil layers, to calculate weathering rates.

2. Differences in the receptor mapped: While the SMB method is applied to forest soils, Norway's national critical loads data is for lakes, and Finland and Sweden mapped both forest soils and surface waters.

3. Differences in the spatial resolution of input data: The grid resolution of input data for the SMB is 1° longitude by 0.5° latitude, whereas individual country resolutions are generally much finer, e.g., 10 x 10 km for the Netherlands, or even 1 x 1 km for Switzerland and (western) Germany. individual countries have also included more detail in the distinction of tree species and soil types.

1. Winand Staring Center, Wageningen, the Netherlands.
2. International Institute for Applied Systems Analysis, Laxenburg, Austria.

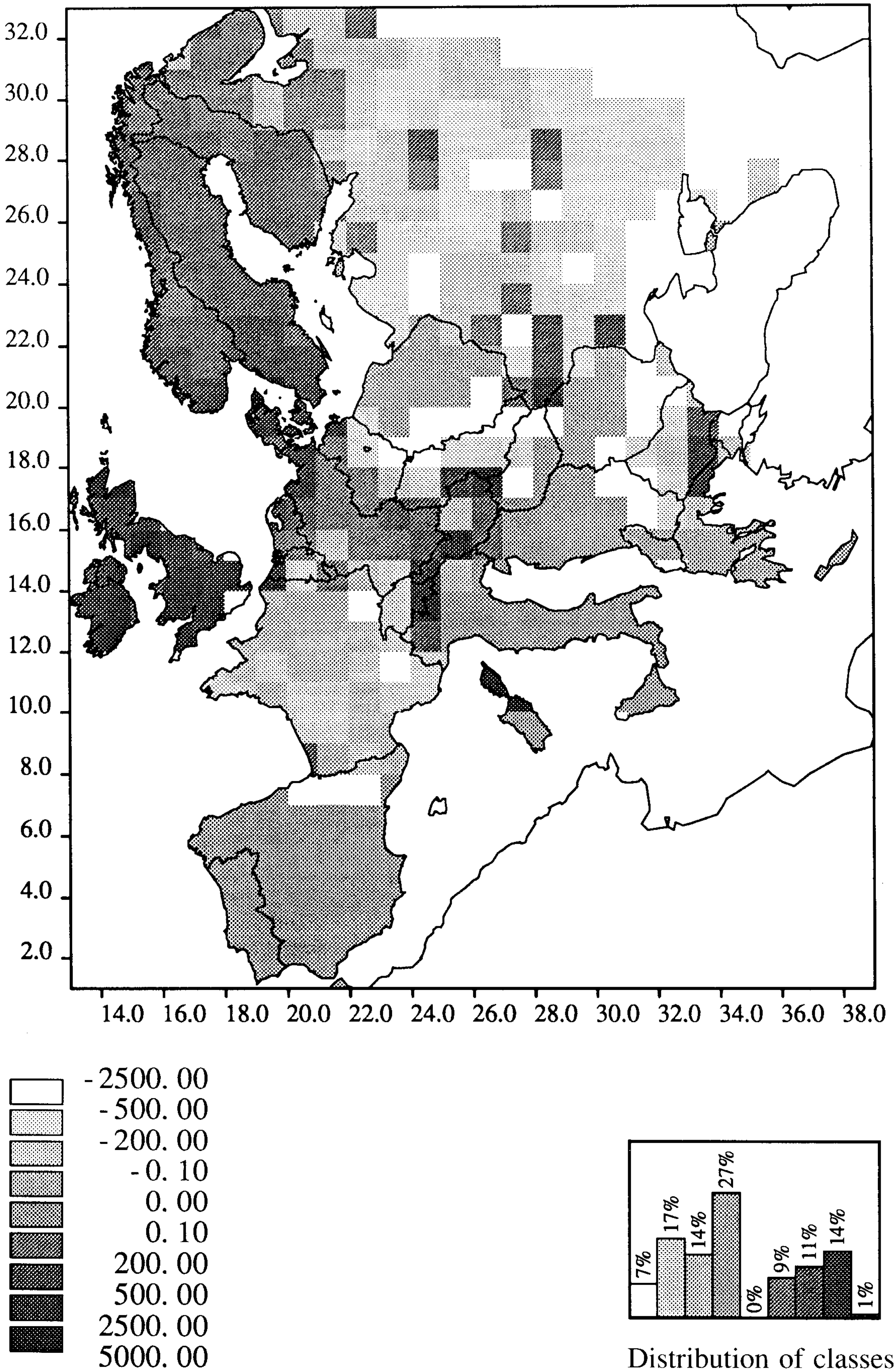


Figure 4.22. **Differences in critical loads computed using European versus national data. Units = equivalents ha^{-1} yr^{-1}.**

For example, the Netherlands distinguishes twelve tree species and 18 non-calcareous soils, whereas the SMB method differentiates only between coniferous and deciduous trees, and two non-calcareous soils for the Netherlands. These differences will lead to lower critical loads for individual countries at low percentile values, since the spatial resolution is not averaged as greatly as in the European application.

4. Differences in assumptions about forest uptake: In the SMB method, it is assumed that whole-tree removal is the common forestry practice, since uptake refers to both stems and branches. In some countries (the Netherlands, Finland, and Switzerland) uptake is restricted to stems only, since stemwood removal is the common practice in these countries.

5. Differences in input data: In the SMB approach, data on weathering, uptake, and runoff are based on simple transfer functions with soil type (for weathering), tree type (uptake), and latitude and elevation (runoff). On a national basis, more detailed information has been used including:
   - the influence of temperature and/or mineralogical composition on the weathering rate (i.e., Denmark, Finland, the Netherlands, Sweden, and Switzerland).
   - the influence of soil type on the uptake rate (the Netherlands)
   - the influence of tree species, slope class and/or soil type on the runoff (Austria, the Netherlands, and Switzerland).

6. Differences in the criteria used: In the European application, the minimum of the aluminum concentration criterion (0.2 $mol_c\ ha^{-1}\ yr^{-1}$) and an aluminum: calcium ratio of 1.5 $mol_c\ mol_c^{-1}$ was used. However, some countries (Denmark and Sweden) used only the Al/Ca ratio criterion, while others (the Netherlands) also included the aluminum depletion criterion. In addition, critical values for the criteria were modified by some countries (France).

7. Differences in the regionalization method: The SMB method has been made by using soil and forest maps with a complete land use coverage. However, several countries have calculated critical loads for individual plots which were then aggregated to regional scales (Denmark, Finland, and Sweden).

Comparisons of the 1 and 5 percentile values for critical loads of **potential** acidity and the various input data (weathering, uptake, and runoff) have been made for Austria and the Netherlands.

The Netherlands:

- Weathering rates from national data and the SMB method are nearly equal. National values are somewhat lower.
- National data on uptake rates are lower than those of the European data. This is mainly due to the difference in stemwood vs. whole-tree removal assumptions. Furthermore, the variation in uptake rates is much higher in the Netherlands due to the inclusion of many more tree species. Slow-growing trees determine the 1 and 5 percentiles of the distribution of uptake rates in the Netherlands. The uptake rates in the European data base are generally higher due to a less detailed distinction between tree species.
- National data for runoff are generally lower than those available in the European data base. The reason is that similar to the reasons described with respect to the uptake data, the inclusion of many more tree species in the national data base. The distribution of a wide variety of tree species affects the evapotranspiration rate. The latter leads to a larger variation in runoff than in the European data base.

Austria:

Only those grids are compared in which Austria's share is more than 30 percent.

1. Weathering rates: Comparing soil types, the Austrian map generally has a larger percentage of soils within the smallest weathering rate class. This can be traced back to 3 reasons:
   a. Different soil classification: Austria has its traditional classification of soils, where it is sometime difficult to find a corresponding FAO soil type.
   b. Information about alluvial land, moraines or soils build by glaciers are not contained in sufficient detail in the FAO soil map.
   c. The exact location of soils in granite bedrock (Bohemian mass) and the end of the alpine region towards the eastern part of Austria are not well represented in the FAO map.

2. Precipitation: The data of the European data base differ in the average over Austria by +5 percent. For single grids, there can be much larger discrepancies (+400 to -200 mm). The Austrian data are based on a dense hydrographic net. The European map has been generated by interpolation of point information. No additional information like altitude or windward/leeward orientation of mountains has been used to improve the result. Stations are not located on points favorable for interpolation, so it is quite likely that some non representative points may influence the results over a large area. The interpolation optimizes for a scale of 150 km, while results on a finer scale may contain large random errors at conditions found in alpine regions.

   One can draw the conclusion that the interpolation method should be used with more care on complex terrain. The results improve in the north and east of Austria where Austria has less variation in altitude.

3. Evapotranspiration data: For evapotranspiration, a model for all Europe has been used. The most important factor in that model seems to be the radiation. There is no strong altitude dependence or other factors for mountain region taken into account. For large parts of Austria this model does not seem to be appropriate.

   The average difference between the European map and the Austrian map is +200 mm. It appears that the Alps have not been taken into account, because in this region the discrepancies are largest. Approximately 100 mm. of the systematic difference can be explained by the different attitude towards interception in both maps.

4. Runoff: Runoff is calculated in both maps as the difference of precipitation and evapotranspiration. The systematic error is balanced out, so that the values for the flat areas of Austria are comparable. In the alpine region great local variation can be found, which results from the uncertainties of precipitation and evapotranspiration. Large-scale data sets should incorporate quite detailed information about precipitation and evapotranspiration in regions with complex topography or the topography characteristics have to be integrated in the model structure. For other regions the approach used may be useful.

The different data base items are spatially correlated. In the calcareous parts of the Alps, the precipitation is higher than in the central alpine region, thus the high critical load of calcareous soils get even higher. But as logical consequence there is less precipitation on non-calcareous soils, and thus these soils will become more sensitive. It is hard to take this fact into account in a coarse grid. As a consequence countries or regions like Austria with a complex topography should handle regional environmental data using a resolution that implies the most prominent features of this topography.

CHAPTER 5. CONCLUSIONS AND DISCUSSION

J.-P. Hettelingh, R.J. Downing, and P.A.M. de Smet

5.1 General Conclusions from CCE Mapping Activities

The Mapping Manual and Annexes, and the Mapping Vademecum have provided the scientific and technical basis for producing the critical loads maps presented in this report. The mapping exercise led to the production of critical loads maps for acidity, sulphur, and nitrogen. The critical load map of nitrogen reflects the sensitivity of ecosystems with respect to eutrophication by using the European data for nitrogen uptake, and acidity by using the CCE map of critical loads of acidity in combination with the sulphur fraction.

Two Training Sessions organized by the Coordination Center for national mapping experts provided a forum for discussion and resolution of theoretical and practical problems in the mapping exercise. (Appendices 6 and 7).

The European critical loads maps consist of national contributions and critical loads computed by using a European data base for countries unable to provide national data. The critical loads maps reflect the sensitivity of a mixture of forest soils and surface water ecosystems.

The map of critical loads of sulphur is derived from the critical loads map of actual acidity by using a sulphur fraction, i.e., the ratio of sulphur deposition to the net deposition of sulphur and nitrogen. The map of nitrogen critical loads reflects the sensitivity of ecosystems to both eutrophication and acidity by using respectively the European data for nitrogen uptake of managed forests, and the share of the critical load of acidity attributed to nitrogen.

Cumulative distributions of critical loads were computed for every EMEP grid cell on the basis of national and European data. These cumulative distributions represent the cumulative percentage of area coverage for each critical load in an EMEP grid cell. The 1 and 5 percentiles chosen reflect the upper bound of the range of critical loads in each EMEP grid cell which covers 1% (5%) of the area in an EMEP grid cell.

A homogeneous distribution within an EMEP grid cell is assumed for each percentile. By choosing a low percentile (i.e., 1 or 5) a major share of most sensitive ecosystems will be protected. The application of higher percentiles will increase the uncertainty with respect to the area coverage of protected ecosystems. These assumptions concerning the distributions of critical loads within a grid cell, however, allow for the comparison of critical loads with EMEP-computed present deposition data in the production of exceedance maps.

Exceedance maps were produced as the difference of the 1 and 5 percentile critical load maps from EMEP deposition computations using the RAINS model. EMEP deposition values were modified to include base cation uptake, nitrogen uptake, seasalt-corrected base cation deposition (from the European data base) and filtering factors.

These results, while preliminary, represent the current state of scientific knowledge which can be provided to discussions concerning the assessment and control of long-range transboundary air pollution.

5.2 Preliminary Conclusions from Mapping Intercomparison

The critical loads maps contained in the present report will be used by the Task Force on Integrated Assessment Modeling (TFIAM) in computing the efficiency of abatement strategies.

The TFIAM has used qualitative ecosystem sensitivity maps produced by the Stockholm Environment Institute in previous exercises. An intercomparison of the present European maps with the SEI maps showed a general agreement of patterns of sensitive areas. A large part of the differences between the two maps can be explained by differences in assumptions and data.

5.3 Future Activities

It is expected that the Coordination Center will produce revised versions of the present maps as a result of:

- improved weathering rates corrected for temperature
- improved uptake rates on the basis of temperature corrections
- improved data on precipitation surplus based on more weathering stations
- inclusion of denitrification for wet soils
- country contributions with respect to basic data, nitrogen critical loads, sulphur fractions and filtering factors.
- the results of case studies which may suggest amendments;
- the comparison of methods and the results for different receptors;
- the preparation of other maps described in the Mapping Manual;
- the inclusion of data from countries which have not yet conducted mapping programs but which submit data in the future; and
- a planned Training Session in January 1992.

The Coordination Center will also assist the UN ECE Working Group on Effects and Task Force on Integrated Assessment Modeling in the production of target load and target load exceedance maps. It is expected that NFCs will provide information on nationally derived target loads to the Coordination Center for this exercise.

Mapping activities on critical levels will also be undertaken by the Coordination Center. The CCE has requested NFCs to submit information on available national base maps, and has begun to acquire background maps for implementation in its geographic information system. The Coordination Center will propose a work plan and distribute it to all NFCs for review.

In addition to its work on critical loads mapping of acidity and sulphur, there are discussions on other pollutants (e.g., nitrogen, VOCs, heavy metals), under the Convention, and the future need for mapping appropriate receptors and/or critical loads for these.

Quality control of methods and data will be part of an ongoing research process. Users of the first maps provided in this report should be aware of the compromises in quality and resolution made by the participants in the mapping exercise in keeping the tight schedule since the Coordination Center for Effects started its work in 1990. Consequently, future revisions to the enclosed maps will be produced as more detailed and accurate data becomes available.

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APPENDICES

APPENDIX 1. NATIONAL FOCAL CENTER REPORTS

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RECEPTOR MAPPED: Forest soils.

CALCULATION METHOD: Steady state mass balance.

GRID SIZE: 2.75 x 2.75 km; approximately 11,000 receptor points, nearly 8000 of which are (partially) covered by forest.

DATA SOURCES:
Geographical:
A number of regional parameters are required to determine the critical load for a given ecosystem. To date the following data bases were identified as being useful for the model purpose:
- The inventory of soil types in Austria based upon Fink (1978).
- Geological data extracted from the "Geological Map of Austria" from the Austria Atlas.
- Soil types according to FAO classification have been derived by overlaying the above mentioned maps.
- Forest data have been taken from the "Austrian Forest Inventory 1971-80" on a 2.75 x 2.75 km grid.
- Precipitation patterns have been estimated on information provided by the Technical University Vienna (Behr, 1989).
- Evapotranspiration has been estimated by applying empirical relationships between altitude and evapotranspiration in the Alpine regions (Baumgartner *et al.*, 1983).

Ion deposition:
Due to its orography, major local variations in acid deposition occur throughout Austria. Therefore, data on acid deposition had to be derived on a small scale for all of Austria. Relevant information is available from the Institute for Analytical Chemistry at the Technical University Vienna (Kovar *et al.*, 1991). However, in order to derive the local deposition from the EMEP-computed average grid deposition the following approach had been developed:

Wet deposition: The measured sulphur and nitrogen concentrations in precipitation were spatially interpolated and superimposed on a map of local precipitation. This precipitation maps was based on measurements and a digital surface model. Within this project, the described method has been tested and compared with the measured deposition at some EMEP measuring sites.

Dry deposition: The measured concentrations of air pollutants in rural areas have been spatially interpolated. Using empirical exponential functions, the altitude was taken into account in the calculations. Based on this regional distribution, dry deposition has been calculated with the aid of a velocity factor.

Occult deposition: Because of the lack of measurements, deposition loads from fog and clouds in forest are estimated by adding 50 % of wet deposition values to total deposition (Kovar *et al.*, 1991).

Evapotranspiration according to Baumgartner *et al.* (1983) has been corrected for deciduous (±240 mm/yr) and coniferous (±120 mm/yr) forests; for northward-oriented slopes (±67.5° from the north) with an inclination larger than 30%, a 30% lower evapotranspiration rate has been assumed. The corrections were adapted with a constant value so that the total water balance for Austria did not change.

Runoff: For slopes with an inclination larger than 30%, a surface runoff of 20% of the precipitation has been assumed. The runoff used in critical load calculation is therefore reduced by that amount. Runoff values are then checked to ensure that they are always positive.

Soil characteristics: The procedure for deriving soil characteristics applicable to the suggested modelling approach was discussed at an international expert meeting held at IIASA in spring 1990. The results of this meeting not only influenced the design of this study, but have directly been incorporated into the Mapping Vademecum (Hettelingh and de Vries, 1991).

Table A1.1 is based on the guidelines outlined in the Mapping Vademecum. Data were checked and adapted for Austria together with Assistant Prof. Solar from the Universität für Bodenkultur, Vienna. This table enables the derivation of the model input data for soil characteristics from the available soil map. Since comprehensive soil monitoring is currently being undertaken in Austria, a later stage of the project will test, improve or partly replace this preliminary table with more precise information.

The values for the various weathering classes in this table are based on the report of the workshop on "Critical Loads for Nitrogen and Sulphur" held in Skokloster, Sweden (Nilsson, 1986). In order to reflect the very thin organic soil layers in high alpine regions -- with in fact very little contact to the calcareous bedrock material -- a very slow weathering rate was assumed for these soil types in altitudes above 1500 m above sea level (Stöhr *et al.* 1989; see Table A1.1).

Biomass Uptake: Biomass uptake of base cations and nitrogen can be estimated based on the canopy type by multiplying the annual biomass increment (from Nilson and Sallnäs, in press) with the proper element contents (from de Vries, 1988; see Table A1.2). These data are available for trees in areas with moderate (or low) concentrations of elements in soil. At very high or very low concentrations of base cations or nitrogen in soil water, additional processes become important, that may lead to systematic errors. In order to provide consistency for low concentrations, the computed potential uptake has been checked against the availability of nutrients in the soil. The base cation input minimum value was assumed as 50 (rather than 100) mol_c ha^{-1} yr^{-1}, which seems more appropriate for Austrian conditions.

Table A1.1. Soil characteristics in Austria.

Soil Type			FAO Soil Code	Weathering Class
Lithosol a. Kalk	Eutric Lithosols	Ie	488	10
Lithosol a. Kalk	Eutric Lithosols	Ie	488	1 (>1500m a.s.l.)
Lithosol sonst.	Dystric Lithosols	Id	493	2
Regosols	Calcaric Regosols	Rc	312	3
Rendsina (alpin)	Orthic Rendzinas	Eo	160	6
Rendsina (alpin)	Orthic Rendzinas	Eo	160	1 (>1500m a.s.l.)
Rendsina sonst.	Rendzinas	E	168	2
Parabraunerde	Orthic Luvisols	Lo	327	4
Schwarzerde	Chernosem	Ch	678	4
Braunerde a.K.	Eutric Cambisols	Be3	3	10
Braunerde sonst.	Dystric Cambisols	Bd1	320	1
Braunlehm, Rotlehm	Eutric Cambisols	Be1	319	4
Reliktboden a.K.	Eutric Cambisols	Be2	316	5
Reliktboden sonst.	Dystric Cambisols	Bd2	2	3
Podsol	Orthic Podsol	Po	570	1
Pseudogley + Rel. Pg.	Gleyic Luvisols	Lg	705	5
Semipodsol	Leptic Podsols	Pl	559	1
Paratschnernosem	Luvic Phaeozems	Hl	39	3
Feuchtschwarzerde	Haplic Phaeozems	Hh	676	2
Hochmoore	Dystric Histosols	Od	959	0
Niedermoore	Eutric Histosols	Oe	955	0
Auböden, grau	Eutric Fluvisols	Je	996	10
Auböden, braun	Dystric Fluvisols	Jd	998	3
Gleye a. Kalk	Eutric Gleysols	Ge	972	10
Gleye sonst.	Dystric Gleysols	Gd	707	5

Table A1.2. Data on element contents in trees for Austria.

Species	Forest increment (m^3 ha^{-1} yr^{-1})	Stem density (kg m^{-3})	Stem Content %				Branch Content %				Ratio Br/Stem
			N	Ca	Mg	K	N	Ca	Mg	K	
Scotch pine	5.0	490	0.11	0.09	0.02	0.05	0.40	0.24	0.05	0.20	0.15
Douglas fir	8.9	410	0.08	0.05	0.01	0.05	0.31	0.50	0.06	0.26	0.10
Norway spruce	10.0	450	0.10	0.12	0.02	0.06	0.57	0.34	0.07	0.37	0.15
Oak	7.0	740	0.19	0.20	0.05	0.13	0.37	0.50	0.05	0.19	0.38
Beech	7.0	860	0.13	0.09	0.03	0.09	0.44	0.27	0.03	0.16	0.23
Coniferous	10.0	500	0.10	0.08	0.02	0.05	0.35	0.35	0.05	0.25	0.15
Deciduous	7.0	700	0.15	0.10	0.04	0.10	0.45	0.50	0.05	0.20	0.20

FIGURES:

A1.1. Austria: Critical loads of actual acidity.
A1.2. Austria: Exceedance of critical loads of actual acidity.
A1.3. Austria: Sulphur fraction of critical loads of acidity.
A1.4. Austria: Precipitation surplus.

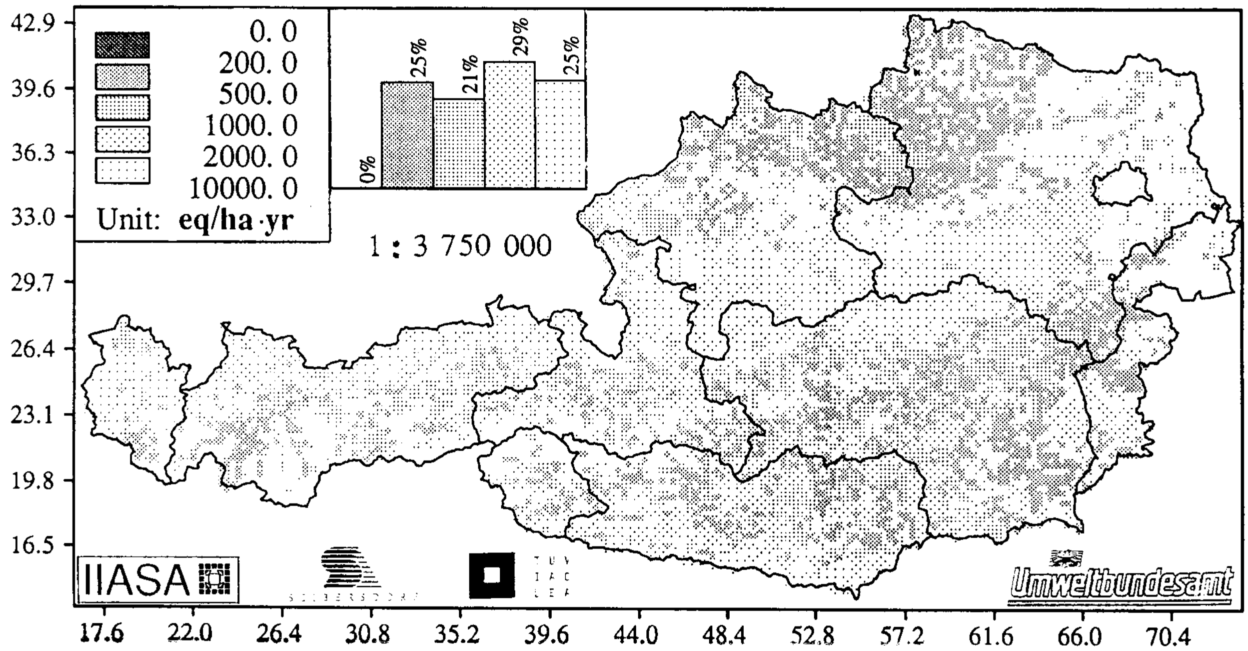

Figure A1.1. Austria: Critical loads of actual acidity.

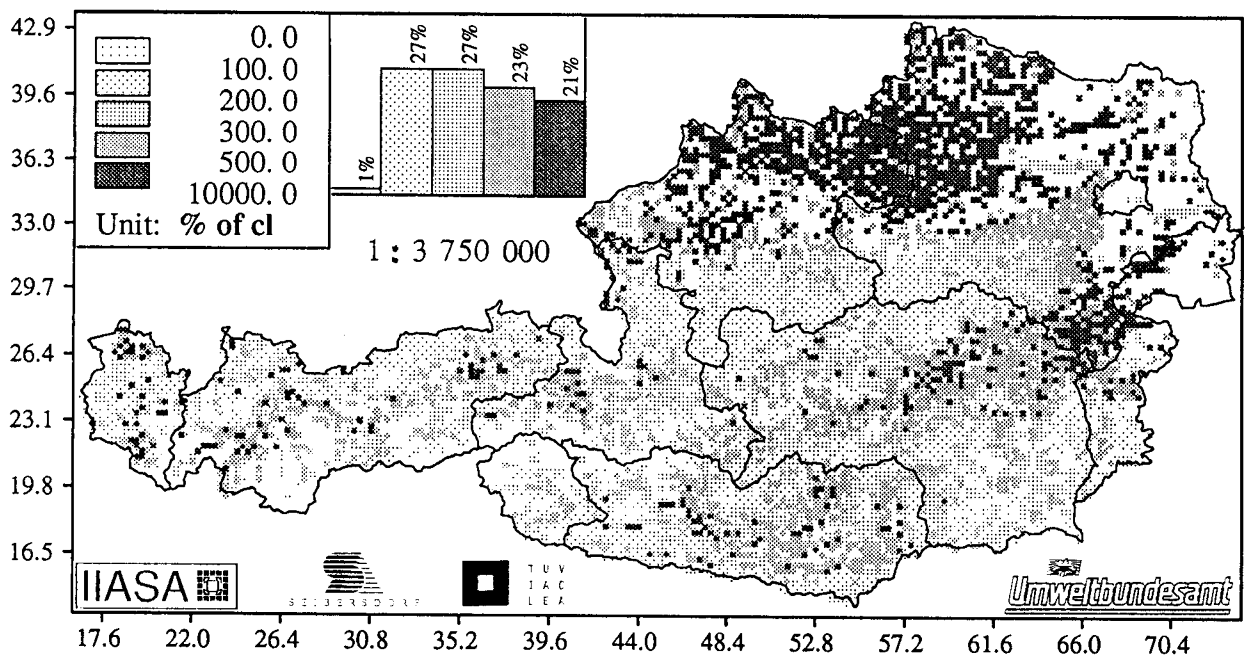

Figure A1.2. Austria: Exceedance of critical loads of actual acidity.

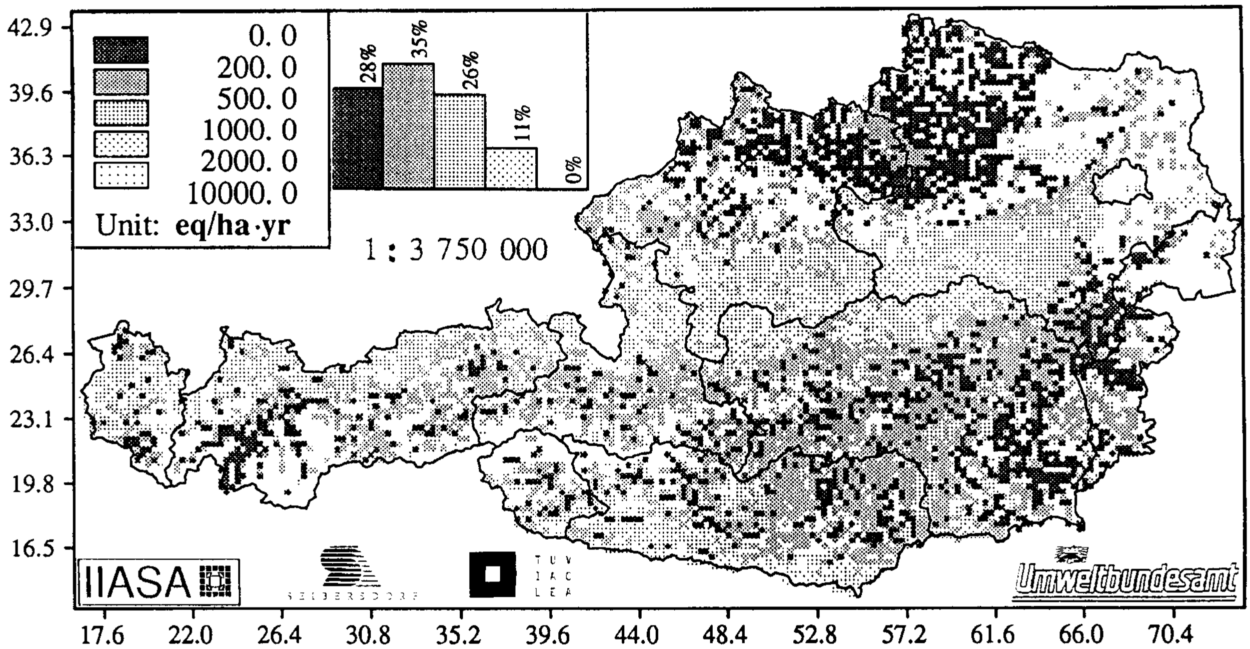

Figure A1.3. Austria: Sulphur fraction of critical loads of acidity.

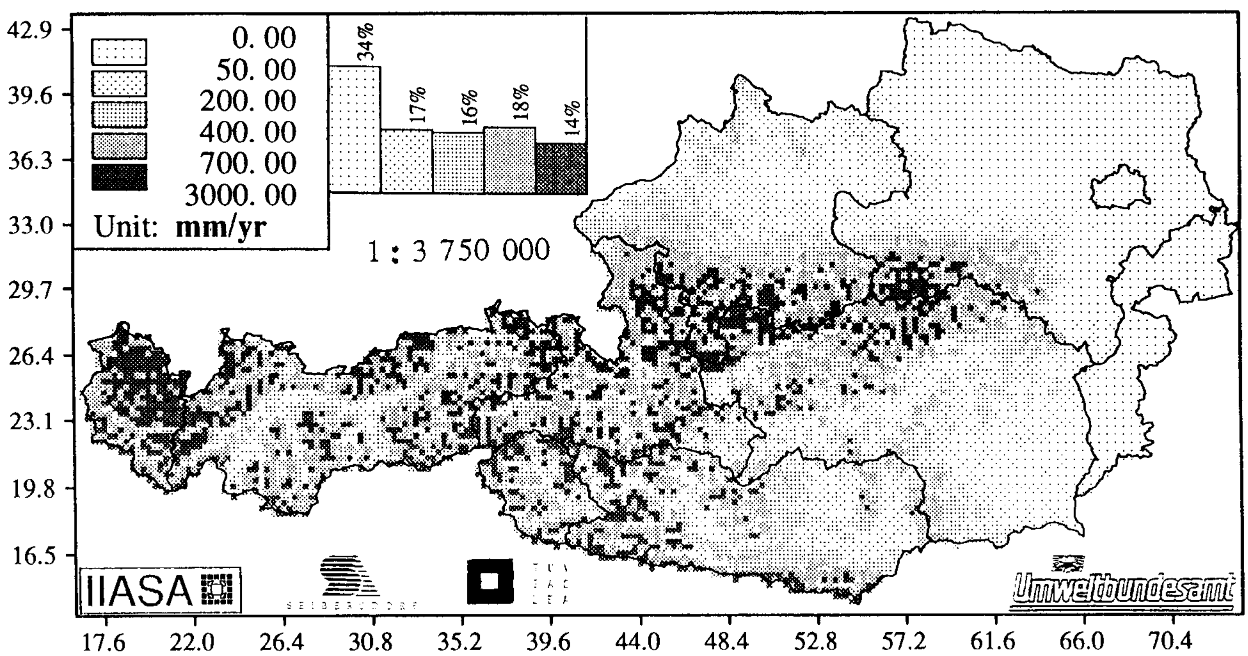

Figure A1.4. Austria: Precipitation surplus.

BULGARIA

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RECEPTOR MAPPED: Forest soils.

CALCULATION METHOD: Steady state mass balance.

DATA SOURCES: The input data supplied by the Coordination Center for Effects, from IIASA and the Winand Staring Center were used, with the following modifications:

Soil Type and Number: The list of FAO soil types was increased approximately 50 percent.

Slope Class: Some corrections have been made to describe more precisely the slope class of the soils.

Text Class: All figures have been corrected taking into account recent national soil information.

Parent Material Class: The corrected figures are derived from the 1989 Geological Map of Bulgaria (scale 1:500,000), following procedures outlined in the Mapping Vademecum.

Percentage of soil type in grid: Calculations are based on 1968 national soil map (scale 1:400,000).

Percentage of forest type on each soil: Calculations are made using the recent maps of vegetation types for Bulgaria and recommendations in the Mapping Vademecum.

CZECH AND SLOVAK FEDERAL REPUBLIC

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RECEPTOR MAPPED: Forest soils.

CALCULATION METHOD: Level 0.

Critical load values were estimated for rock and soil types, the area of the rock/soil types in each EMEP and longitude-latitude grid cell were measured, and distributions and average values calculated. It was not possible to introduce greater accuracy in the methods applied by the early 1991 deadlines. The mineralogical method of determining the soil properties to be used in connection with the PROFILE model is currently being developed. The maps will gradually be improved by using other methods of determining critical loads.

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RECEPTOR MAPPED: Forest soils.

CALCULATION METHOD: Steady state mass balance.

The PROFILE model has been used to calculate critical loads. The mapping of critical loads for Denmark is based on the model result of weathering rates and loss of acid neutralizing capacity (ANC) for different soils, and on area data for soil, forest and deposition.

Modifications: The calculation of the PROFILE model has been modified on two points according to the Mapping Manual (UN ECE, 1990a), which states that the soil criteria have to be maintained everywhere in the root zone. In order to simulate the internal nutrient cycle from litterfall, the soil criteria have only to be maintained just below the root zone. This change in concept increases the critical load for clay soils, while there is no significant change on sandy soils.

For base cation deposition total deposition of non-marine Ca, Mg, and K, plus marine Ca was used. The PROFILE model uses the (Ca + Mg + K) / Al ratio instead of the Ca/Al ratio. Budget studies for Danish forests based on deposition, growth uptake and weathering of Ca, Mg, and K showed that the best estimate for the Ca/Al ratio with the PROFILE model was based on a base cation deposition comprising non-marine Ca, Mg, and K plus marine Ca.

Deposition measurements in spruce forests in Denmark indicate that the sulphur deposition is about a factor of 2 above the calculated EMEP deposition values. The deposition to beech forests appears to be equal to the EMEP calculated deposition.

In order to eliminate these differences, the deposition of all elements has been estimated on the basis of the air concentrations of pollutants. The following data have been used:

SO_2-S:	EMEP calculation for 1985
SO_4-S:	EMEP calculation for 1985
NO_2-N:	EMEP measurement for 1986
NO_3-N:	EMEP measurement for 1986
NH2-N	Asmann's calculations for long-range transport of ammonia/ammonium
NH4-N	in Europe for 1980

DATA SOURCES:

Deposition: The deposition constants used in the critical load calculations are evaluated based on throughfall data and air concentrations from 10 sites in Denmark and southern Sweden (Skåne). The deposition constant for spruce is twice the EMEP-calculated value. For beech, the constant is the same as EMEP values.

The concentration of non-marine base cations in precipitation has been estimated to 20 μg/l based on bulk deposition data from Denmark and southern Sweden. The total non-marine base cation deposition has been calculated by multiplying the wet deposition by the ratio of the amount of sodium in throughfall to precipitation for spruce and beech. The marine deposition of Ca, Mg, and K has been calculated based on an empirical relation between throughfall of sodium and the distance to the North Sea coast in Denmark.

Soil Criteria: Critical load calculations are extremely sensitive to the soil criteria chosen. In Denmark, it is not possible to set reasonable soil criteria based on the present knowledge of soil parameters, their variation and their influence on forest growth. A pH criteria will not be reasonable either, as pH depends on the organic content in the soil profile. In order to establish a first approach criterion, the Ca/Al ratio of 1.0 has been used.

Nitrogen: In the western part of Denmark, the acid load is significantly reduced by the ammonia emissions; however, the potential acid load will be high due to the potential ammonia deposition. The production of acids in soils from nitrogen turnover will be essential for the computations of the exceedance of the critical load for sulphur and acidity.

In the PROFILE model, all nitrogen which is not removed from he forest will be leaching, and thereby produce acidification to the soil. This seems not to be realistic for the present status of Danish soils. Essentially, PROFILE calculates the critical load of potential acidity due to the concept agreed upon at the second Training Session.

Vegetation: At each site calculations have been made for a spruce and a beech stand, respectively. The production classes used are representative for the area in which the site is located. The assumed values for root depth and nutrient content in biomass are given below:

	Root depth m	**Mg + Ca + K** eq/tons	**N** eq/tons
Spruce	0.50	75	72
Beech	0.75	120	160

In the most acidification sensitive areas of Denmark, the native tree species is oak. As oak has a deeper root system and lower growth rate than beech, the critical loads for these areas will be less than estimated by the model. No calculations for oak have been made.

The growth uptake of nitrogen and base cations is almost equal for spruce. The acidity produced by the growth uptake is therefore zero.

Mineralogy: The geology of the Danish top soils is shown in Figure A1.5. The southwestern part of Denmark was not covered by the last glaciation. It is assumed that the most acidification sensitive areas are located here.

In Denmark, the mineralogy of the top soil at 28 sites has been evaluated. On 23 sites, the mineralogy analyses have been made on both clay, silt and sand fractions in 4 to 8 layers in the soil profile. This is different from the Swedish approach, where the mineralogy analyses are based on one unseparated soil sample. The Danish mineralogy samples make it possible to calculate both a weight and a surface per cent for each mineral. Calculations with the PROFILE model show that the surface approach gives a weathering rate that is 1-3 times higher than the weight approach.

RESULTS:
The critical load has been calculated for the 28 selected sites. Spruce forest is the most sensitive due to its higher deposition rate and lesser root depth compared to beech. Only results based on mineralogy surface are reported.

Tree species	Potential acid deposition	Relative weathering
Oak	130	4.5
Beech	160	2.2
Spruce	310	1

The critical load for spruce is 600-1000 $mol_c\ ha^{-1}\ yr^{-1}$ on sandy soils and 2000-4000 $mol_c\ ha^{-1}\ yr^{-1}$ on clayey soils. For beech the critical load is 600-1400 $mol_c\ ha^{-1}\ yr^{-1}$ on sandy soils, and 2800-8000 $mol_c\ ha^{-1}\ yr^{-1}$ on clayey soils.

The calculated weathering rates have been compared to budget studies on base cation turnover on three sites and with laboratory studies of weathering rates on five sites. The experimental data and the model results are quite in agreement.

The following relationship between the model calculated critical load, weathering rate and alkalinity in runoff was found:

$$Cl = BC_w + Q \cdot alk$$
$$= BC_w + a\,(BC_w + BC_d - BC_u)$$

The parameter "a" for spruce was 1.4 with a remarkably small variance. For beech, the parameter varied from 0.9 on poor sandy soil to 1.3 on clayey soils.

The relationship has been used to make the maps of critical load and exceedances for Denmark (Figures A1.6 to A1.9). The sulphur impact load has been calculated from the critical load by using a sulphur fraction based on the evaluated deposition of sulphur and nitrogen in Denmark. The sulphur impact load has been reduced by the ratio of (EMEP-calculated deposition) / (evaluated deposition of sulphur) to make it comparable to the EMEP-calculated depositions.

The sulphur impact load has been calculated for three different rates of nitrogen immobilization (Figures A1.10 to A1.15). The average sulphur impact load for spruce is 0.6 $g\ S\ m^{-2}\ yr^{-1}$ with no immobilization, 0.8 $g\ S\ m^{-2}\ yr^{-1}$ when all surplus nitrogen is immobilized.

FIGURES:
A1.5. Denmark: Surface geology.
A1.6. Denmark: Critical load of potential acidity for spruce.
A1.7. Denmark: Exceedance of critical load of acidity for spruce.
A1.8. Denmark: Critical load of potential acidity for beech.
A1.9. Denmark: Exceedance of critical load of acidity for beech.
A1.10. Denmark: Sulphur impact load (EMEP) for spruce when 100% of surplus nitrogen is leached.
A1.11. Denmark: Sulphur impact load (EMEP) for spruce when 50% of surplus nitrogen is leached.
A1.12. Denmark: Sulphur impact load (EMEP) for spruce when 0% of surplus nitrogen is leached.
A1.13. Denmark: Sulphur impact load (EMEP) for beech when 100% of surplus nitrogen is leached.
A1.14. Denmark: Sulphur impact load (EMEP) for beech when 50% of surplus nitrogen is leached.
A1.15. Denmark: Sulphur impact load (EMEP) for beech when 0% of surplus nitrogen is leached.

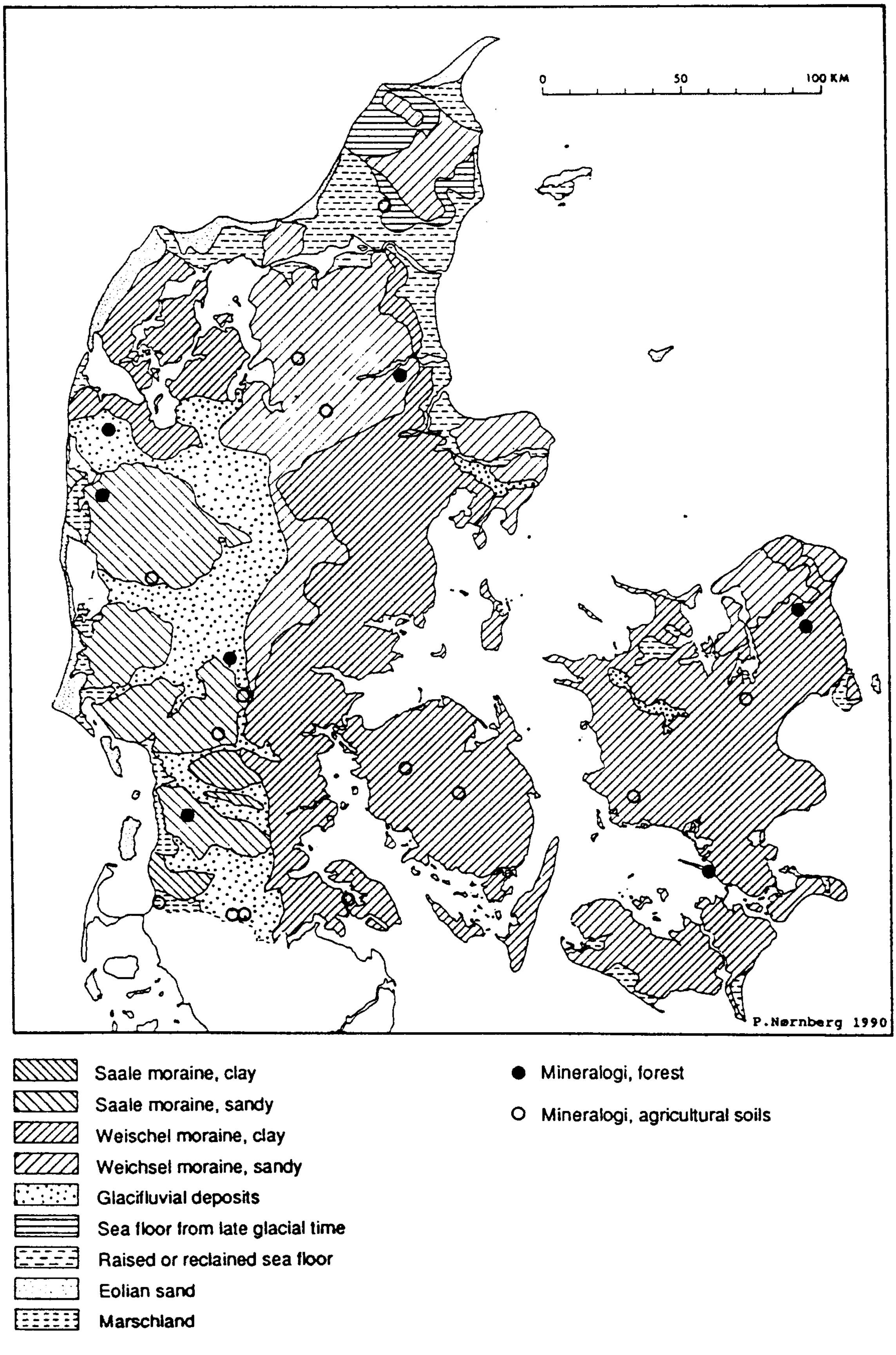

Figure A1.5. Denmark: Surface geology.

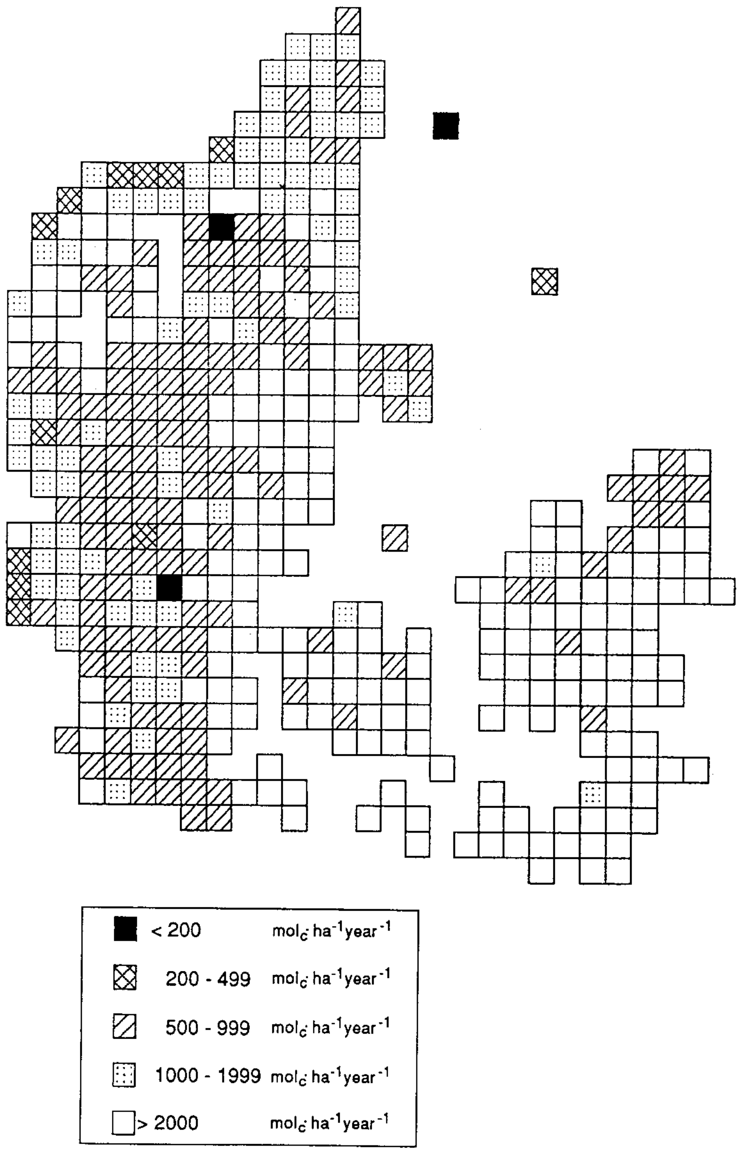

Figure A1.6. Denmark: Critical load of potential acidity for spruce.

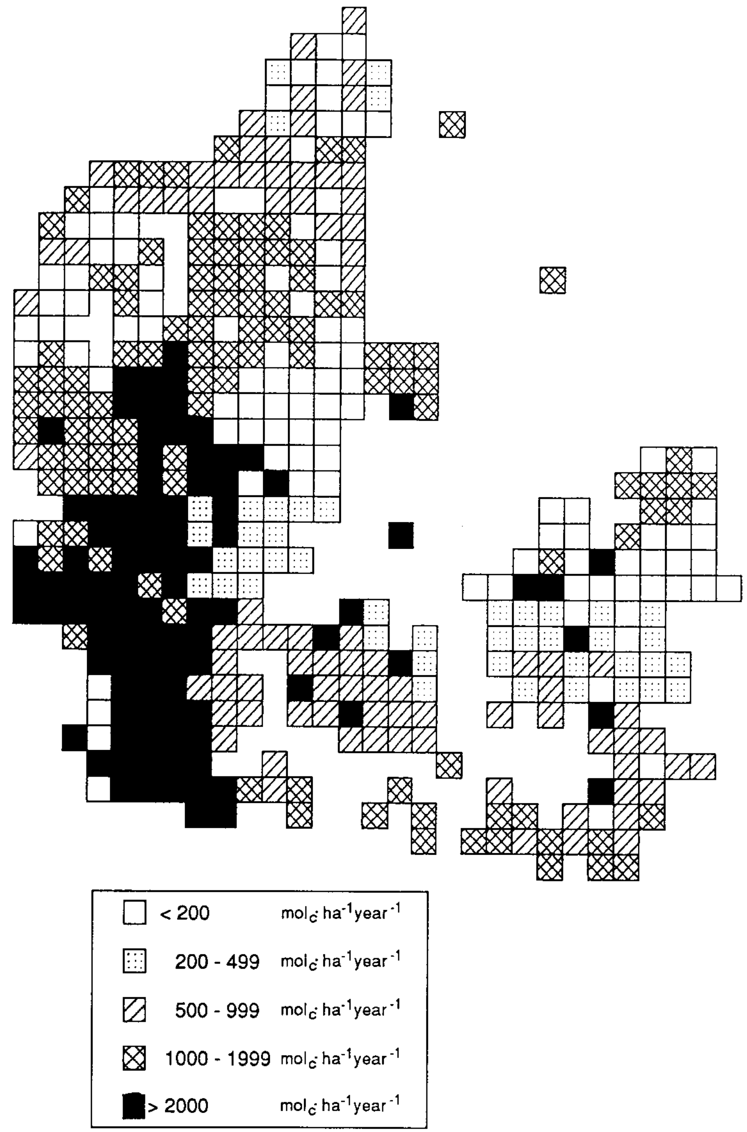

Figure A1.7. Denmark: Exceedance of critical load of acidity for spruce.

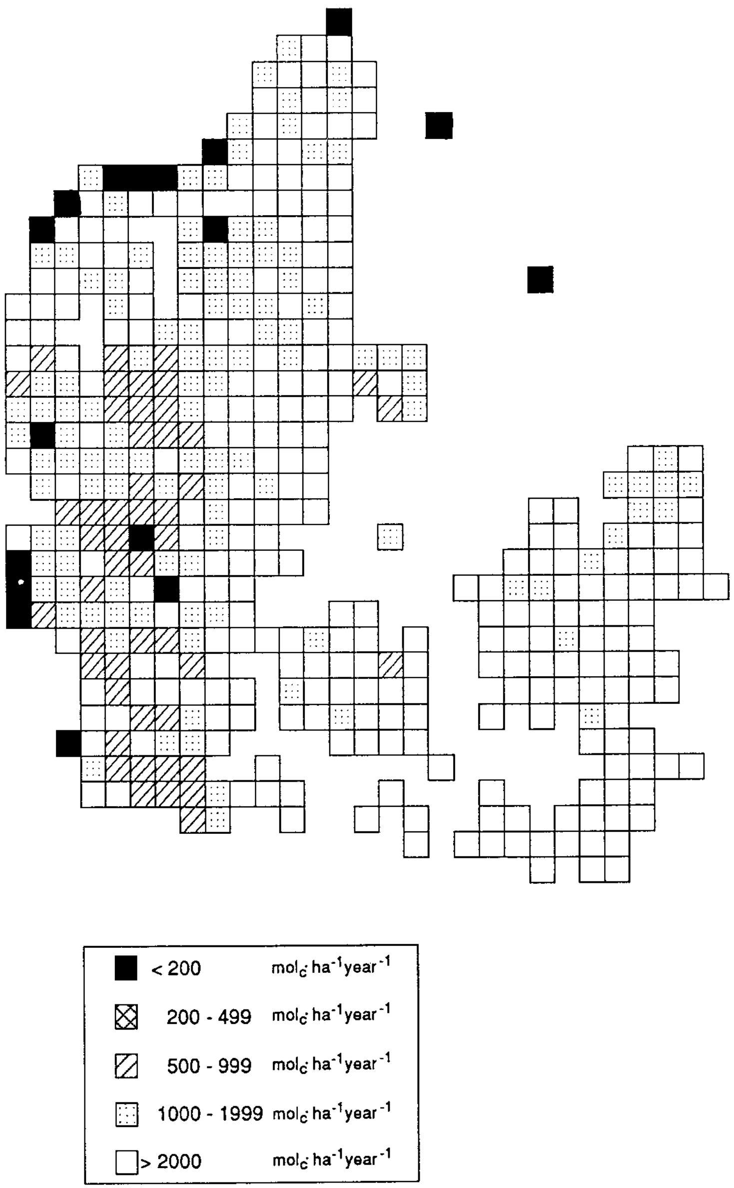

Figure A1.8. Denmark: Critical load of potential acidity for beech.

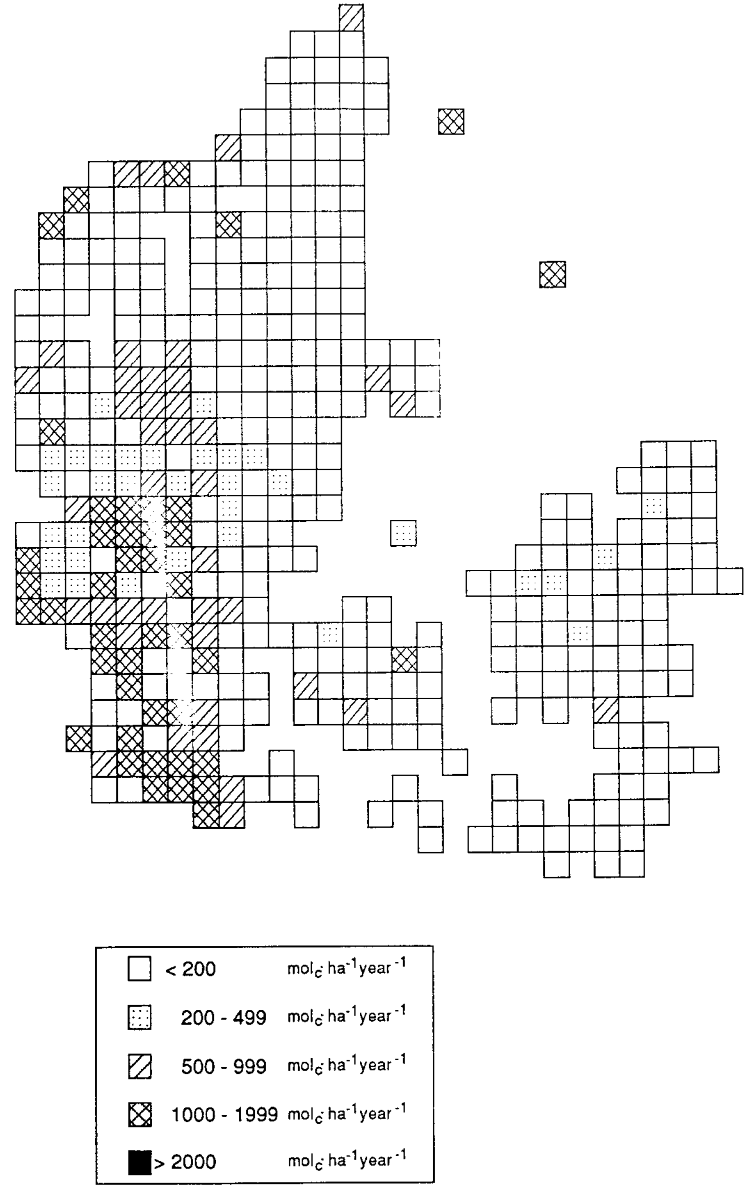

Figure A1.9. Denmark: Exceedance of critical load of acidity for beech.

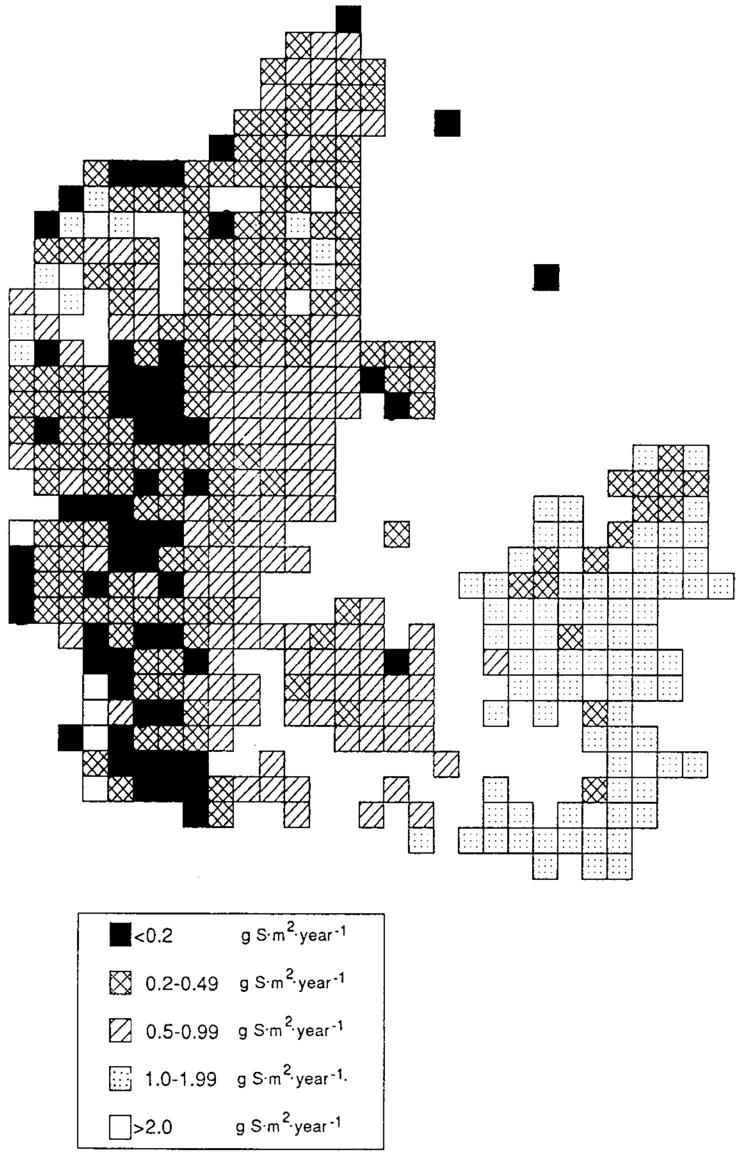

Figure A1.10. Denmark: Sulphur impact load (EMEP) for spruce when 100% of surplus nitrogen is leached.

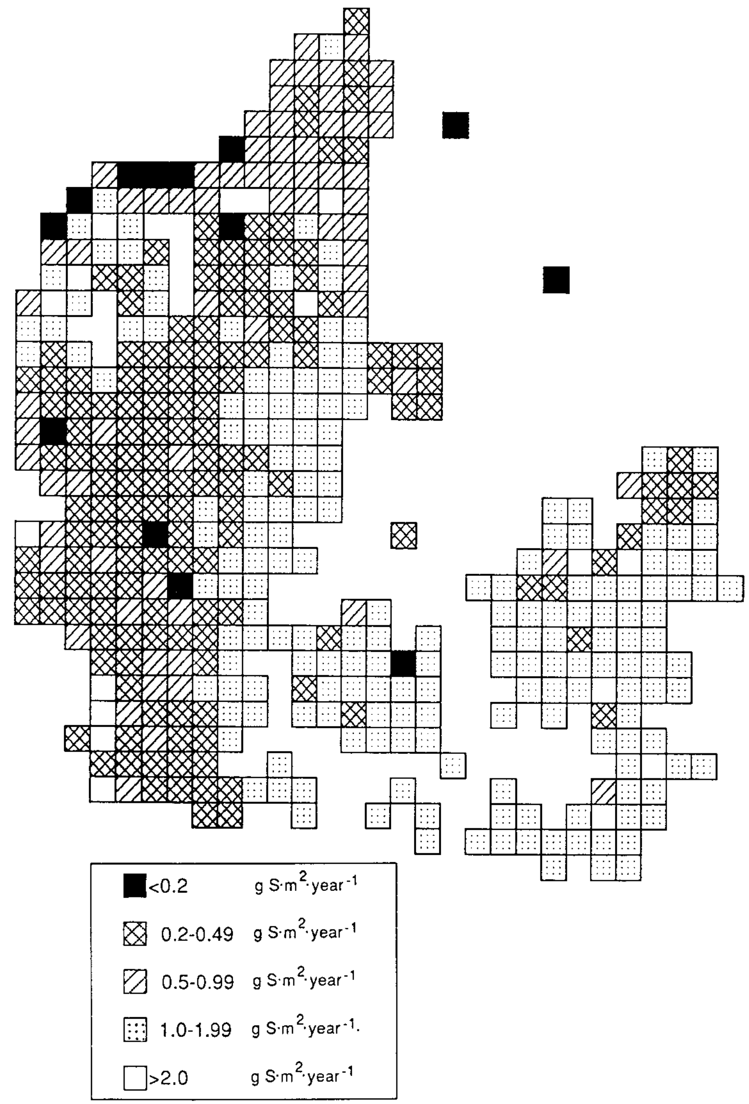

Figure A1.11. Denmark: Sulphur impact load (EMEP) for spruce when 50% of surplus nitrogen is leached.

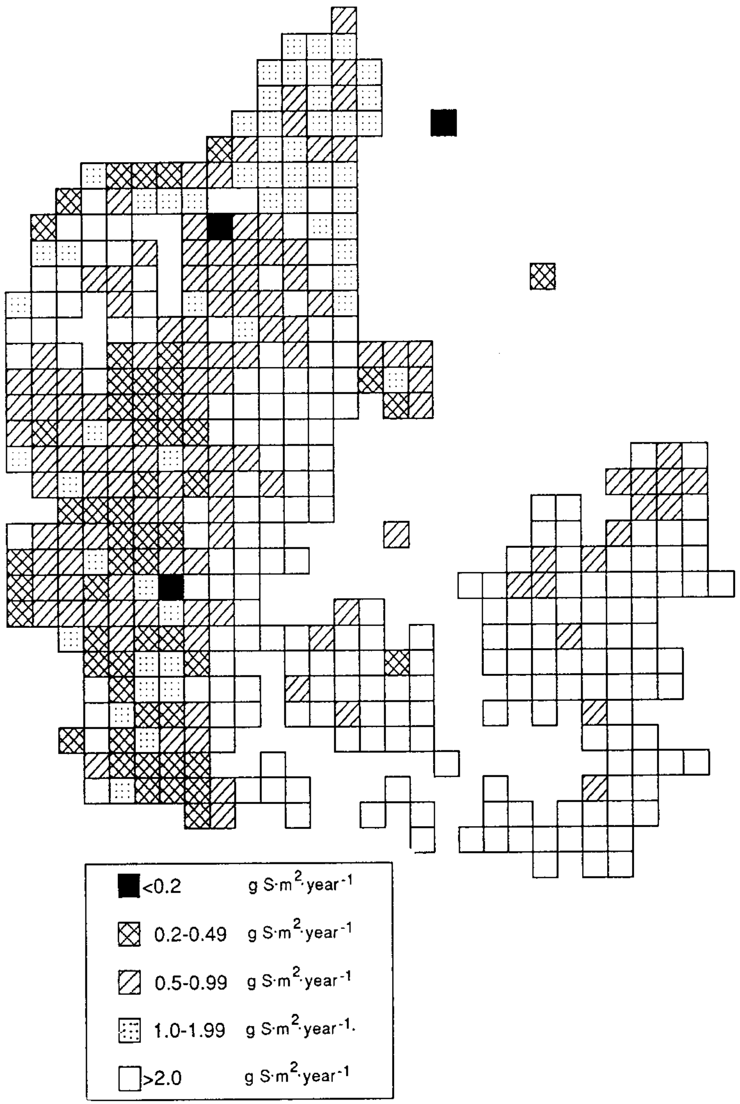

Figure A1.12. **Denmark: Sulphur impact load (EMEP) for spruce when 0% of surplus nitrogen is leached.**

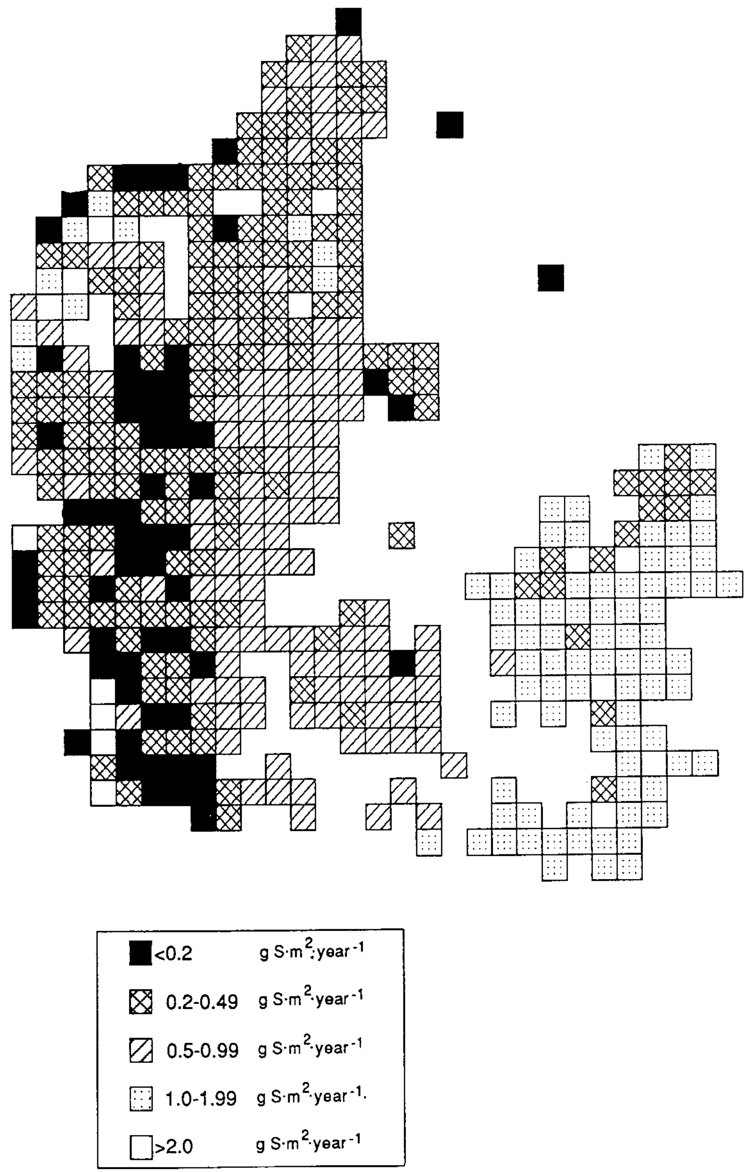

Figure A1.13. **Denmark: Sulphur impact load (EMEP) for beech when 100% of surplus nitrogen is leached.**

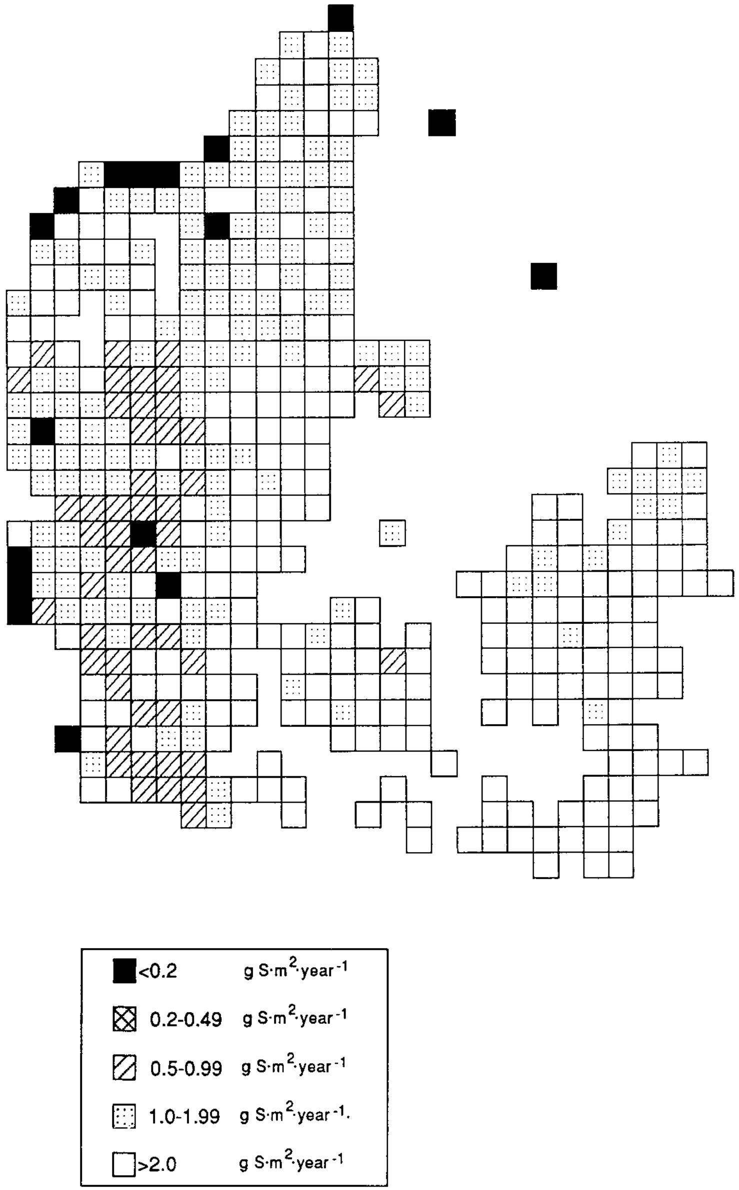

Figure A1.14. Denmark: Sulphur impact load (EMEP) for beech when 50% of surplus nitrogen is leached.

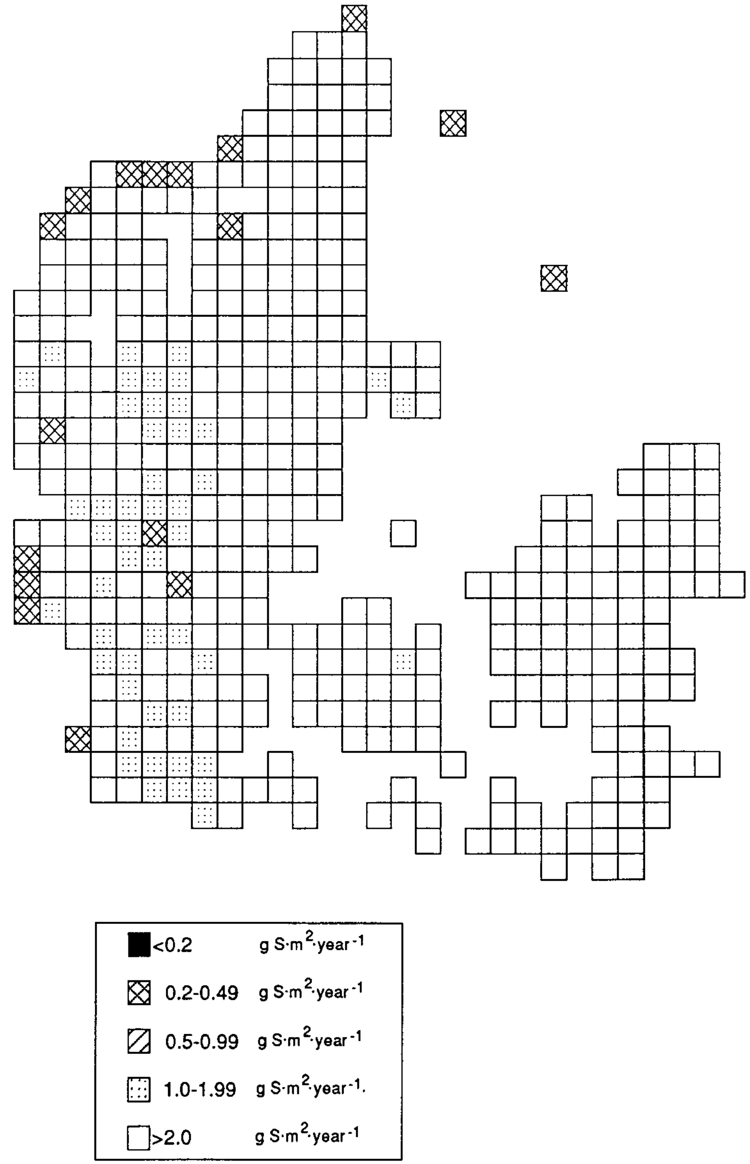

Figure A1.15. Denmark: Sulphur impact load (EMEP) for beech when 0% of surplus nitrogen is leached.

FINLAND

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RECEPTORS MAPPED: Surface waters, forest soils.

CALCULATION METHODS: Steady state water chemistry (surface waters), steady state mass balance (forest soils).

A. DEPOSITION

CALCULATION METHOD: Total deposition of sulphur was mapped at the Finnish Meteorological Institute on the basis of a wet deposition monitoring network and throughfall measurements. Different dry deposition velocities were calculated for different receptors based on throughfall data. Dry deposition was then calculated from ambient air concentrations, and wet deposition was derived from bulk deposition measurements. A weighted average deposition value for each NILU grid (a 3 x 3 subdivision of the EMEP grid) was computed by taking land use into account. The total deposition of oxidized and reduced forms of nitrogen were mapped in a similar way.

Base cation deposition was derived from results of a nationwide network of bulk deposition stations. Results from stations with a significant anthropogenic contribution were not included. A dry deposition factor, varying linearly from 1.0 to 2.1 according to the open area fraction of the grid cell, was assigned to the bulk deposition values. Results from the included stations were interpolated to a longitude-latitude grid using the values of the three nearest stations, weighted according to their inverse distance from the grid cell center. Analysis of throughfall data is being carried out as Nordic cooperation in order to obtain more accurate estimates for the dry deposition of base cations.

GRID SIZE: Sulphur deposition: NILU grid (3 x 3 subdivision of EMEP grid).
Base cation deposition: long-lat grid ($1/4^{\circ}$ longitude by $1/8^{\circ}$ latitude).

DATA SOURCES: Bulk deposition data were obtained from the national monitoring networks of the Finnish Meteorological Institute and the National Board of Waters and Environment. Dry deposition calculations were based on throughfall measurement data collected by the Swedish Environmental Research Institute. Land use data were obtained from the Finnish Forest Research Institute.

Base cation deposition: The amount of deposition from bulk precipitation is estimated from a nationwide network of stations measuring deposition of different compounds (Järvinen and Vänni, 1990). The sampling method is monthly bulk precipitation from open collectors. Values from the years 1986-1988 are used. A seasalt correction is made to the measured data. The results from the measuring stations were interpolated for each HAKOMA grid element using the values of three nearest stations weighed according to their distance from the element center. The results are in accordance with EMEP measurement data for wet precipitation of base cations.

When calculating critical loads, the bulk precipitation deposition is assumed to be of natural origin and to represent the external effective deposition from outside to the forest ecosystem. Therefore, such results from stations where a significant anthropogenic contribution was noticed, were not taken into account. As a significant part of the deposition is apparently coming from the oil shale burning in Estonia, this contribution was clearly seen in the increasing levels on the southern coast and in southwest Finland. Moreover, stations near cultivated fields and in the immediate neighborhood of roads were not taken into account.

B. SURFACE WATERS

CALCULATION METHOD: The steady state water chemistry method as described in the Mapping Manual (UN ECE, 1990a) was used to prepare maps for critical loads of acidity as well as critical load exceedances. Point data were aggregated for the NILU grid and for the EMEP grid. Harmonized maps were prepared for all of Fennoscandia showing frequency distributions on the EMEP grid and colored classes on the NILU grid. These maps are described and contained in the national report of Norway.

GRID SIZE: Point data, aggregatable to any grid. (NILU and EMEP have been used.)

DATA SOURCES: Lake chemistry data consisted of national survey data of 945 lakes sampled in 1987, together with additional data of 429 lakes from northern Finland supplied by the Water and Environment District of Lappland. Runoff data was obtained from the Hydrological Office of the National Board of Waters and the Environment.

C. FOREST SOILS

CALCULATION METHOD: Steady state mass balance.

The minimum of the aluminum and Al/Ca criteria was computed for 1057 plots covering the whole of Finland. Weathering rate estimates were computed as a function of total analysis measurements of Ca and Mg and effective temperature sum (ETS). Base cation uptake and nitrogen uptake were calculated based on growth estimates and element content measurement measurements from bark and stem. Forest growth estimates were based on forest site type and effective temperature sum. Base cation deposition data is described above.

GRID SIZE: Point data, aggregatable to any grid size. The following longitude-latitude grids have been used: 1/4° longitude by 1/8° latitude (HAKOMA grid), and 1° longitude by 1/2° latitude (IIASA grid).

DATA SOURCES:

Base cation and nitrogen net uptake: The average net uptake of these nutrients by forests is assumed to depend on the tree growth, which is related to the forest site type and the effective temperature sum, and the element content concentration is stem and bark. This dependency is derived from national forest inventory results of the Finnish Forest Research Institute.

Information on the element content concentrations in bark and stem were obtained from the Finnish Forest Research Institute. Values for calcium, potassium and nitrogen are available. The annual increments of overbark volume and nutrient mass are known. From these we get base cation (now only calcium and potassium, valences of 2 and 1 respectively) net uptake in meq m^{-2} yr^{-1} for unit growth (overbark) of 1 m^3 ha^{-1} yr^{-1} and for nitrogen (assuming valence of 1) 2.4. Assuming that Mg constitutes 20% from the total nutrient content in biomass, we get the base cation net uptake value 2.7 meq m^{-2} yr^{-1} per unit growth.

Effective temperature sum means the amount of degree days, when the threshold level is daily mean temperature of +5°C. The geographical distribution of ETS is calculated at the Finnish Forest Research Institute according to the meteorological data from the weather stations of the Finnish Meteorological Institute. For each grid element also its location in latitude, altitude and distance to sea were taken into account.

Weathering Rate: The weathering rate is calculated according to the total Ca and Mg content in soil multiplied with effective temperature sum (ETS) and then using a correlation derived from field experiments. The dependency for a 0.5 meter profile (in meq m^{-2} yr^{-1}) is:

$$BC_w = 3.68 \cdot 10^{-3} \cdot [(X_{Ca} + X_{mg}) \cdot ETS)] - 0.37$$

where:

$$X_{ca} + X_{mg} = Ca(\text{mass-\%}) \cdot 2 / 40.08 + Mg(\text{mass-\%}) \cdot 2 / 24.30$$
$$= Ca(\text{mass-\%}) / 20.04 + Mg(\text{mass-\%}) / 12.15$$

Using this equation the result is in keq ha^{-1} yr^{-1} for one meter profile. Conversion to 0.50 m profile and meq m^2 yr^{-1} is made by multiplying the previous result by 50 (1 keq/ha = 100 meq/m^2). The part of the linear relationship for BC_w supported by Swedish field data was applied for Finnish forest soils. The data for total soil analysis is obtained from the Geological Survey of Finland. The sampling took place in 1984-1985. The total of about 1057 plots were fairly well and evenly scattered around Finland.

The weathering rate map was applied as such for rich mineral soils. This is because the field data is derived from similar soils. For poor mineral soils the values were scaled down due to lower fine fraction content in these soils. Soil survey results of the Finnish Forest Research Institute (Tamminen and Starr, 1990) suggest that in poor mineral soils the amount of fine fraction is about 3/5 compared to the rich forest soils. Based on this and on an assumption that the fine fraction largely determines the weathering rate and the coarse fraction is rather inactive, the weathering rate in poor mineral soils was assumed to be 60% compared to the value in rich mineral soils.

FIGURES:

A1.16. Finland: Five percentile critical loads of acidity calculated with the steady state water chemistry method for Finnish lakes (left) and the five percentile critical loads of potential acidity calculated with the steady state mass balance method for forest soils (right).

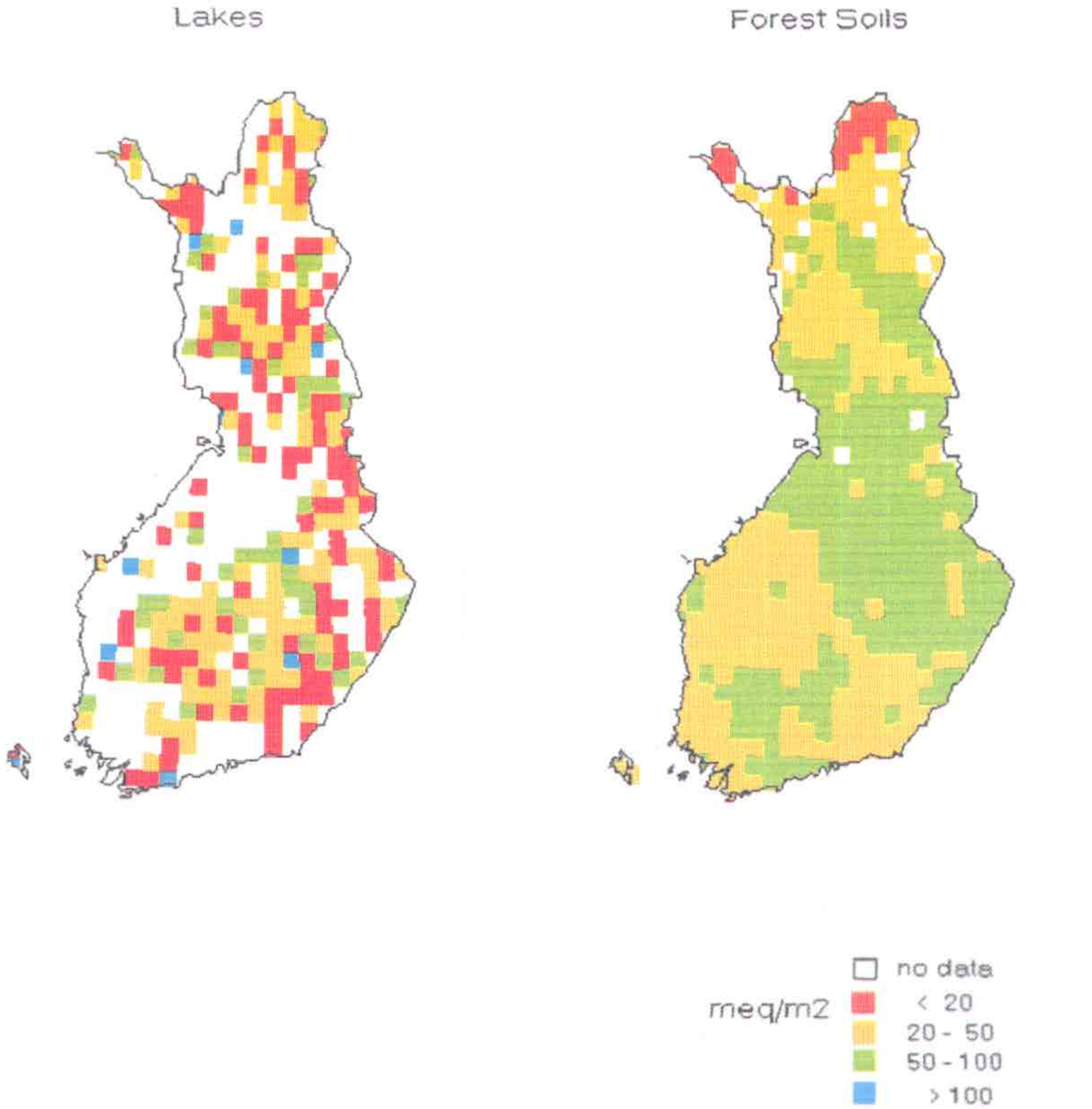

Figure A1.16. **Finland: Five percentile critical loads of acidity calculated with the steady state water chemistry method for Finnish lakes (left) and the five percentile critical loads of potential acidity calculated with the steady state mass balance method for forest soils (right).**

FRANCE

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RECEPTOR MAPPED: Forest soils.

CALCULATION METHOD: Steady state mass balance.

The data from the IIASA and Winand Staring Center data bases were used, with some modifications. The value for acceptable alkalinity leaching (0.09) obtained by the methods outlined in the Vademecum appear high for French conditions, especially in mountainous regions that receive a large amount of precipitation (more than 1200 mm/year) and are considered particularly sensitive. Based on knowledge of the Vosges mountains ecosystems, a value of 0.04, which corresponds to a pH of 4.4 at root depth, has been suggested. Where the precipitation surplus is greater than 500 mm/year, the acceptable Al/Ca ratio has been modified from 1.5 to 1.2.

There has been little study in France on the functioning of the western plain forest ecosystems developed on sandy or loamy soils. Consequently, for these areas, the values and methods proposed by the Mapping Manual, Mapping Vademecum, and other European countries should be used. The minimum realistic pH value at root depth is 4.2.

Weathering rates were also modified for several grid cells in France.

Sulphur is retained in most of the soils in the Mediterranean regions in France. Therefore, the steady state mass balance method will lead to underestimations in critical load values.

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Dr. Gerhard Smiatek
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RECEPTOR MAPPED: Forest soils.

CALCULATION METHOD: Steady state mass balance.
Critical loads of acidity and potential acidity for forest soils were calculated using the simple mass balance method as required by the Mapping Manual (UN ECE, 1990a). Table A1.3 specifies the data and geographical resolution of maps used in the mapping exercise. Some differences still exist concerning the accuracy and resolution of data used for mapping in the eastern and western parts of Germany.

Table A1.3. Data Used in Germany for Calculating Critical Loads for Forest Soils.

Parameter	Maps Used	Resolution	Items	Source	Comments
Weathering rate	soil map	1km x 1km	soil type, soil parent material, soil texture	BFANL	1:1,000,000 soil map (western part of Germany).
	soil map	30" x 30"	soil type	GRID	FAO soil map for eastern part.
	soil map	0.5° x 0.25°	soil type	Atlas GDR	Case study.
Forest	forest map	1km x 1km		INS	Made using classification of NOAA/AVHR imagery. No distinction between different forest types has been made.
	forest map (1:750,000)	10km x 10km	deciduous, coniferous	Atlas GDR	Case study.
Base cation uptake	temperature	1km x 1km	annual mean temperature	BFANL	Base cation uptake as a function of temperature as given in the Mapping Manual.
Nitrogen uptake	temperature	1km x 1km	annual mean temperature	BFANL	As a function of temperature.
Runoff		1° x 0.5°	runoff	IIASA	
Precipitation surplus	maps of total runoff (1:200,000)	2.5km x 2.5km	precipitation, evapotranspiration	Inst. for Water Mgmt.	Case study.
Base cation deposition		1° x 0.5°		NILU	

BFANL = Federal Research Institute for Nature Conservation and Landscape Ecology.

Following the guidelines from the CCE, mapping was performed based on different equations for critical loads of acidity and potential acidity (Hettelingh and de Vries, 1991). The lowest of the resulting values was used for each grid (grid size 1 x 1 km and/or 0.5° longitude x 0.25° latitude) covered by forest.

One major problem occurs in areas with high annual precipitation. When calculating critical loads using the recommended criteria for acceptable ANC leaching, areas with high precipitation always show high critical loads. Experience with sensitive regions in Germany contradicts this result. Therefore the critical loads maps of Germany may change in the future.

Case studies and scientific discussions have been started to calculate the acid neutralizing capacity using the base content and the effect of exchange buffer in the soil. This "base deficit" approach better reflects the forest soil endangering by acidification in Germany and may be verified in other European countries.

Another difficulty arises from the method for the estimation of weathering rates. The recommended method does not consider the annual mean temperature. This may bias the estimated weathering rates, especially in high-elevation areas.

RECOMMENDATIONS: For countries that experience differences in annual precipitation, a possible solution is to use a base deficit approach. Germany will demonstrate a case study.

FIGURES:
A1.17. Germany: Critical loads of acidity for forest soils (1 x 1km grid).
A1.18. Germany: Critical loads of acidity for coniferous forests (0.5° x 0.25° grid).

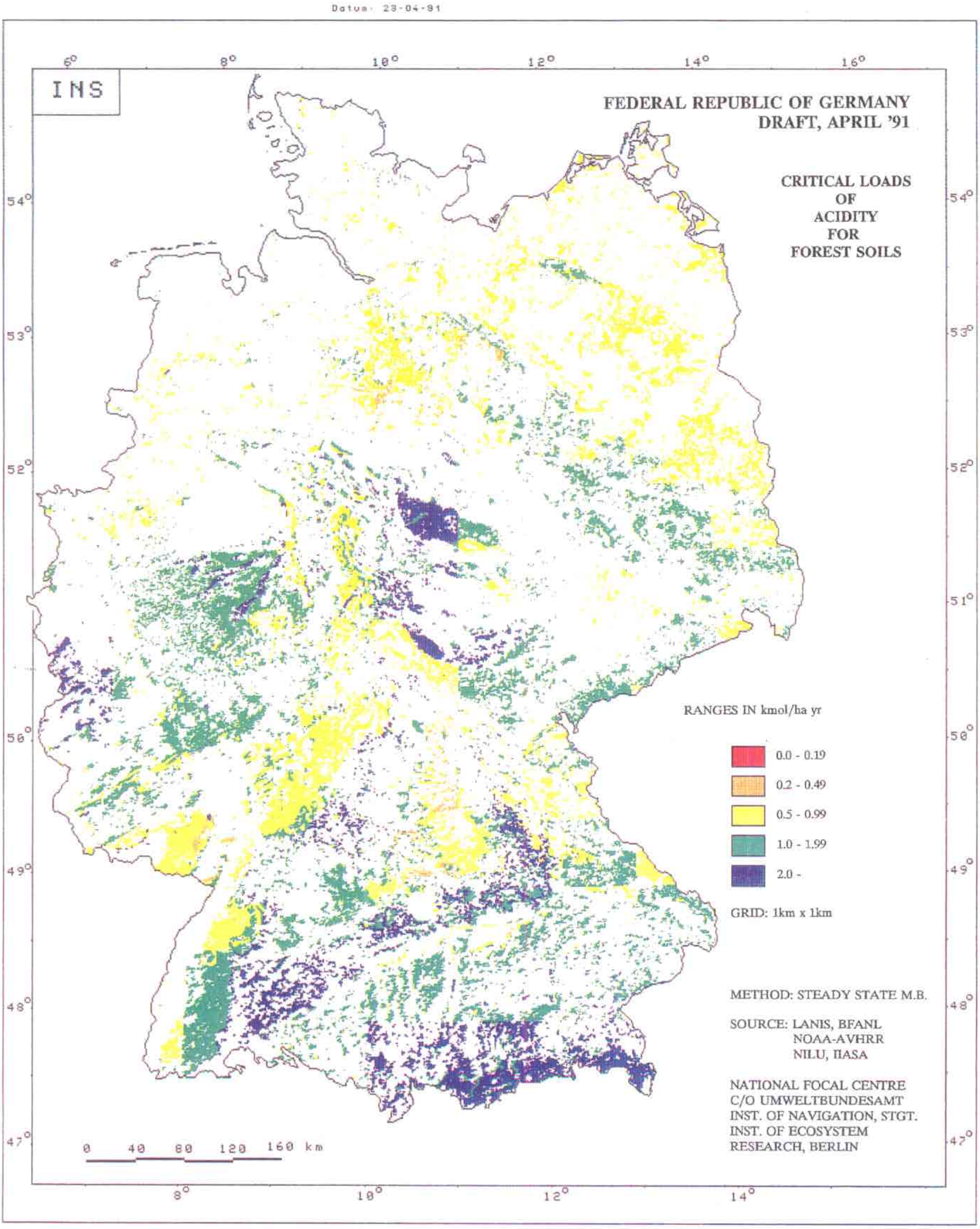

Figure A1.17. Germany: Critical loads of acidity for forest soils (1 x 1km grid).

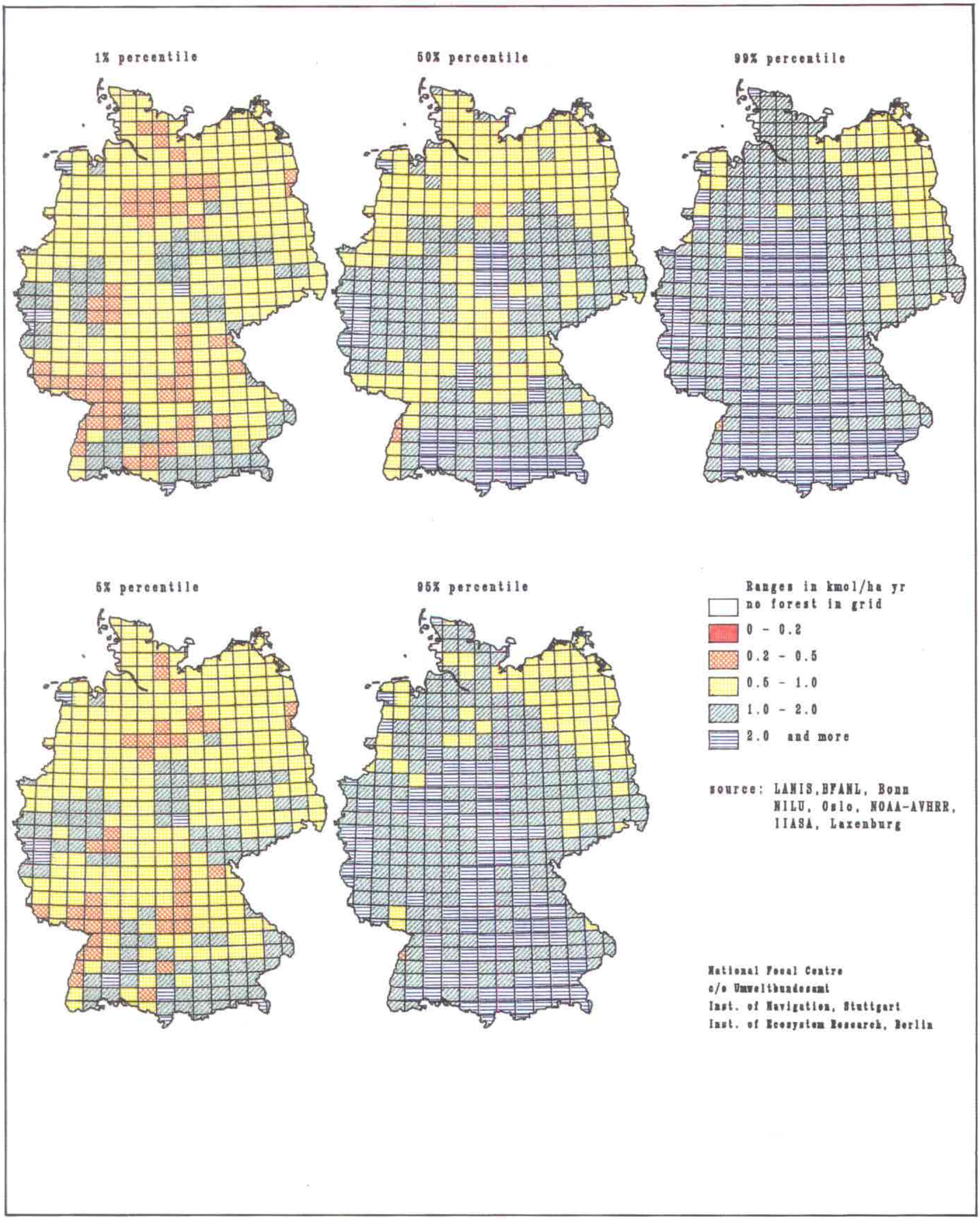

Figure A1.18. Germany: Critical loads of acidity for coniferous forests (0.5° x 0.25° grid).

IRELAND

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RECEPTOR MAPPED: Soils.

CALCULATION METHOD: Level 0. The adoption of this approach was determined by:
- the desire to submit a map based on some form on national data as opposed to a map produced by the Coordination Center using European data;
- limited resources at the National Focal Center;
- the scarcity of data for the application of higher-level methods; and
- the constraints imposed by the mapping timetable.

The Level 0 approach was therefore considered to be the only realistic method which could be applied to produce a national critical loads map by the February 1991 deadline.

Mapping units were developed by dividing each 1° longitude by 1/2° latitude grid into 64 subgrids (approximately 7 x 8 km). Cumulative distributions by sensitivity class have been calculated for (a) each 1° by 1/2° grid square and (b) each EMEP grid square.

DATA SOURCES: The basic data used was a combination of national geological and soil maps and reference to the CEC soil map of the European Communities (EEC, 1985). The national soil data was assigned an upper limit of one of the five Skokloster critical load classes (Nilsson and Grennfelt, 1988). This modification was prompted by: (a) the need for a single absolute critical load value for calculating exceedances, and (b) the need for consistency with the United Kingdom for a realistic combination of data in several EMEP grid squares. The values used are as follows:

Class	Total acidity kEq/ha/yr	Sulphur equivalent kg S/ha/yr
1	0.20	3
2	0.50	8
3	1.0	16
4	2.0	32
5	4.0	64

The occurrence of peat is widespread in the Republic of Ireland. Based largely on the results of studies carried out in the United Kingdom, blanket peats were assigned to Class 2 and deep peats were assigned to Class 4.

At present no reliable quantitative data can be submitted regarding nitrate uptake and immobilization or sulphur fractions based on the ecosystem approach.

FUTURE ACTIVITIES: During 1991 it is likely that work relating to critical loads/levels will attain higher priority in Ireland. A summary of the mapping activities planned to be undertaken is set out below.

<u>Critical loads</u>:
- improvement and validation of the Level 0 map;
- production of critical loads maps for surface waters;
- application of the steady state mass balance method for forest soils; and
- production of critical load exceedance maps.

Critical levels/receptors:
The production of critical levels maps is largely dependent on the availability of good receptor maps. For Ireland, significant effort must now be directed towards obtaining suitable maps of forests, crops, and natural vegetation. When these are made available it will be a simple task to produce critical levels and exceedance maps, as the levels of pollutants to be mapped are very low in the country.

Deposition loads and exposure levels maps:
Attempts will be made to deliver all the maps required under this heading in the Mapping Manual.

FIGURE:
A1.19. Ireland: Critical loads of acidity for soils.

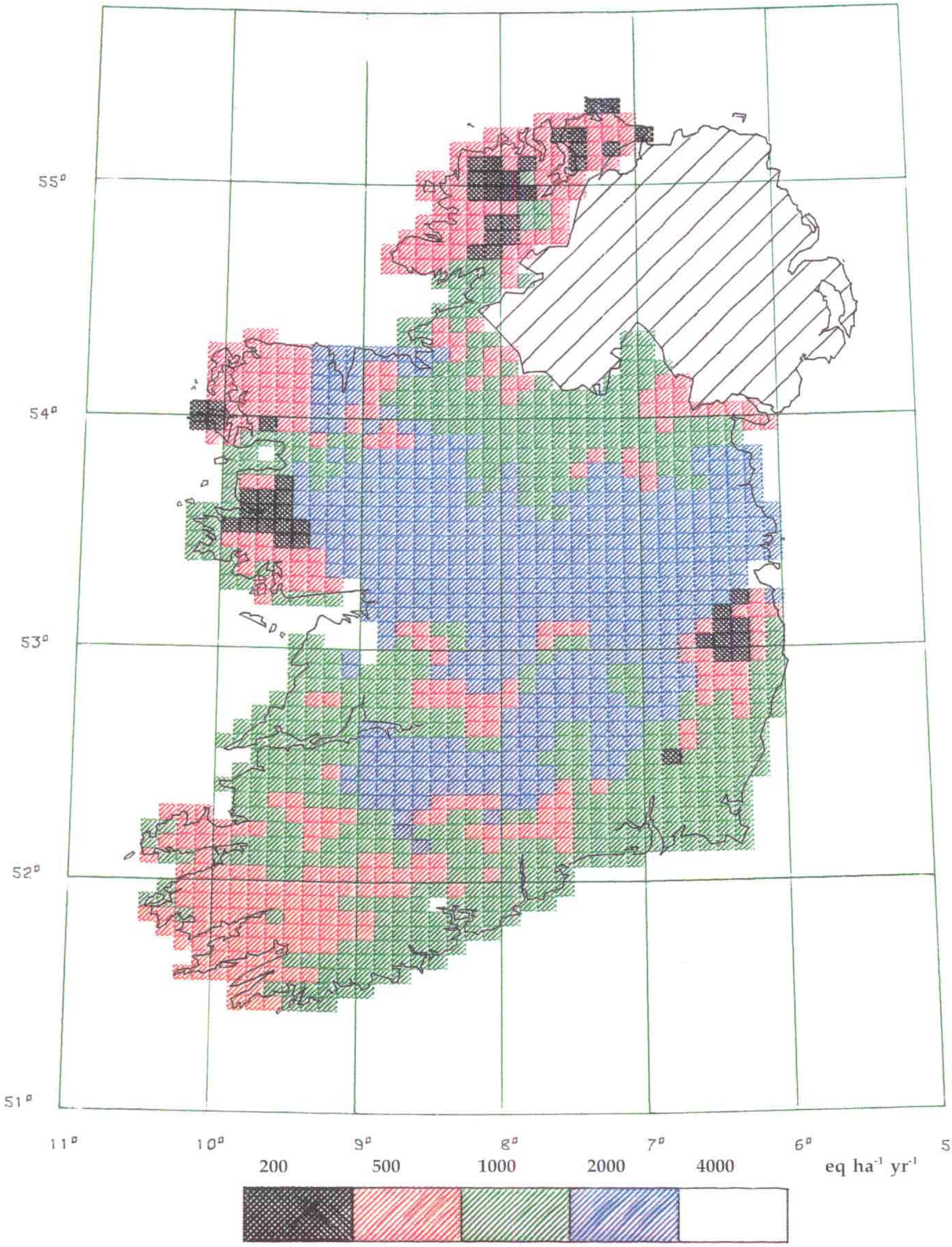

Figure A1.19. Ireland: Critical loads of acidity for soils.

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RECEPTORS MAPPED: Forest soils.

CALCULATION METHOD: Steady state mass balance method, according to:

$$CL\ (Ac_{pot}) = BC^{*}_{dd} - BC_{gu} + BC_{w} + N_{gu} + N_{i}(crit) + Ac_{le}(crit) \qquad (A1.1)$$

where:
$CL(Ac_{pot})$ = critical load of potential acidity
BC^{*}_{dd} = dry deposition of base cations not balanced by chloride
BC_{gu}, N_{gu} = growth uptake (net uptake needed for forest growth) of base cations and nitrogen respectively
BC_{w} = base cation weathering
N_{i} (crit) = long-term nitrogen immobilization
Ac_{le} (crit) = critical leaching flux of acidity
The element fluxes in the above equation are all given in $mol_c\ ha^{-1}\ yr^{-1}$.

In the Netherlands, the load of potential acidity is defined as the sum of SO_x, NO_x and NH_x, corrected for the bulk deposition of base cations not balanced by Cl. Consequently, the dry deposition of base cations has been included in the calculation of the critical load. In the Mapping Vademecum the potential acid load is defined as the sum of SO_x, $N)_x$ and NH_x corrected for the total deposition of base cations not balances by Cl. Using this definition, BC^{*}_{dd} is not included in the critical load calculation.

The critical acidity leaching flux is calculated as the sum of aluminum leaching and H leaching. The three options for calculating the critical aluminum leaching flux described in Section 3.3.3.1 was used, and the minimum value was taken.

The critical H leaching flux is calculated as:

$$H_{le}(crit) = FW \cdot [H](crit) \qquad (A1.2)$$

where FW is the water flux in $m^3\ ha^{-1}\ yr^{-1}$.

The critical H concentration is related to the critical aluminum concentration according to:

$$[H](crit) = ([Al](crit)\ /\ K_{gibb})^{1/3} \qquad (A1.3)$$

where K_{gibb} is the gibbsite equilibrium constant in $mol_c^{-2}\ m^6$. For K_{gibb} a value of $3 \cdot 10^2\ mol_c^{-2}\ m^6$ (= $10^8\ mol^{-2}\ l^2$) was used.

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* Based on de Vries *et al.*, 1991, available from the Coordination Center for Effects.

The value of the critical aluminum concentration is determined by the critical aluminum leaching flux divided by the water flux.

Separate critical loads for N and S have been calculated according to:

$$CL(N) = N_{gu} + N_{im}(crit) + NO_{3,le}(crit) \qquad (A1.4)$$

and

$$CL(S) = BC^{*}_{dd} - BC_{gu} + BC_{w} + Ac_{le}(crit) - NO_{3,le}(crit) \qquad (A1.5)$$

Summation of the critical loads for N and S gives the critical load for potential acidity (from Equations A1.1, A1.4 and A1.5). Again, the value of BC^{*}_{dd} was not included in Equation A1.5 when the potential acid load is corrected for the total deposition of base cations.

The amount by which critical loads for N and S are exceeded was calculated by subtracting critical loads from present loads. Present loads were calculated as:

$$PL(N) = PL(NO_x) + PL\ (NH_x) \qquad (A1.6)$$

$$PL(S) = PL(SO_x) - BC^{*}_{dw} \qquad (A1.7)$$

As with critical loads, the summation of the present loads for N and S gives the present load for potential acidity.

DATA SOURCES: Deposition areas have been defined by seeking for an optimum between the number of areas and the spatial variability within each area. For The Netherlands a 10 x 10 km grid has been used because detailed information regarding tree species and soil types exists at this scale. The number of grids containing forests equal 434.

A distinction has been made in twelve tree species and 23 soil types. Tree species included are *Pinus Sylvestris* (Scotch Pine), *Pinus Nigra* (Black Pine), *Pseudotsuga Menziesii* (Douglas Fir), *Picea Abies* (Norway Spruce), *Larix Leptolepis* (Japanese Larch), *Quercus Robur* (Oak), *Fagus Sylvatica* (Beech), *Populus Spec* (Poplar), *Salix Spec* (Willow), *Betula Pendula* (Birch), *Fraxinus Nigra* (Ash) and *Alnus Glutinosa* (Black Alder). Soil types were differentiated in 18 non-calcareous sandy soils (mainly podzolic soils), calcareous sandy soils, loess soils, non-calcareous clay soils, calcareous clay soils and peat soils on the basis of a recent 1 : 250 000 soil map of The Netherlands.

Information on the area (distribution) of each specific forest-soil combination in a grid was derived by overlaying the digitized forest- and soil database. This was done by a grid-overlay of the digitized 1:250,000 soil map with a spatial resolution of 100 x 100 m and a data base with tree species information with a spatial resolution of 500 x 500 m for each 10 x 10 km grid.

The total number of forest/soil combinations for all grids was 17,102 (12,514 on non-calcareous sandy soils and 4588 on all other soils). The number of forest/soil combinations in a grid varies between 1 and 125.

Data that are needed to map critical loads and exceedances are the deposition, weathering and uptake of elements and the water flux. Long-term nitrogen immobilization has been neglected. These data are collected as a function of location, tree species and soil type as shown in Table A1.4.

Table A1.4. The influence of location, tree species and soil type on input data as considered in the Dutch application. ("x" = considered, "-" = not considered)

	Deposition	Weathering	Uptake	Precipitation Surplus
Location	x	-	-	x
Tree species	x	-	x	x
Soil type	-	x	x	x

An overview of the collection of the data determining the various fluxes of elements and water is given below.

Deposition: Dry deposition of base cations has been calculated by multiplying the bulk deposition with a dry deposition factor. The bulk deposition of base cations (Ca, Mg, K and Na) and Cl has been derived from 22 weather stations in the Netherlands using interpolation techniques to get values for each grid. Dry deposition factors for base cations and chloride on each tree species have been derived from available data on Na in throughfall and bulk deposition.

The total deposition of N and S on forests has been calculated by multiplying average deposition values for each grid by forest filtering factors for SO_x, NO_x and NH_x. Average deposition values are based on calculations with the TREND model (an emission/deposition model from the RIVM) for the year 1985. Filtering factors are based on a comparison of average annual deposition and throughfall data.

Weathering rates: Base cation weathering rates are based on a correlation with total base cation contents. This correlation has been derived for nine non-calcareous sandy soils and six loess soils in the Netherlands. Weathering rates are based on information on base cation depletion rates in soil profiles, budget studies and on column and batch experiments, which have been conducted during five years on the most relevant non-calcareous sandy soils in The Netherlands. For clay and peat soils an indicative value has been derived from literature.

Uptake: Uptake rates are determined by forest growth and element contents in stems. Forest growth estimates for all relevant combinations of forest and soil type and contents of the elements N, K, Ca and Mg in stems are based on a literature survey for all tree species included.

Precipitation surplus: Precipitation surpluses are determined by the precipitation rate minus the sum of interception, evaporation and transpiration (evapotranspiration). Precipitation estimates have been derived from 280 weather stations in The Netherlands, using interpolation techniques to obtain values for each grid. Interception fractions, relating interception to precipitation, have been derived from literature data for all tree species considered. Data for evaporation and transpiration have been calculated for all combinations of tree species and soil type with a separate hydrological model.

The range in model inputs for non-calcareous soils in The Netherlands is given in Table A1.5. The table shows that N uptake is the most important proton sink in peat soils. However, the uptake of nitrogen (proton sink) is largely compensated by base cation uptake (proton source). Consequently uptake is an unimportant proton sink. In sandy soils, the critical acidity leaching is the most important proton sink. For clay soils, the weathering rate is most important. However, this value is rather arbitrary. As with peat soils the weathering rate of clay soils has been assigned on the basis of vary few data. Consequently, values have not been varied (see Table A1.5). In loess soils the dry deposition of base cations and the N uptake is nearly as important as acidity leaching. The large input of base cations (mainly Ca) on loess soils is due to their locations in the neighborhood of limestone quarries in the southern part of The Netherlands.

Table A1.5. 5%, 50% and 95% values of input data ($mol_c\ ha^{-1}\ yr^{-1}$) for Dutch forests on non-calcareous soils.

	BC* dry deposition			BC weathering			BC uptake		
Soil type	5%	50%	95%	5%	50%	95%	5%	50%	95%
Peat	145	220	570	200	200	200	118	256	366
Sand	147	231	554	180	300	580	187	311	545
Loess	172	541	1370	500	500	500	270	456	707
Clay	145	220	685	1000	1000	1000	118	396	994
All	146	229	602	200	300	1000	178	304	586

	N uptake			NO_3 leaching			Acidity leaching		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Peat	136	567	1142	39	191	251	114	304	520
Sand	221	409	680	39	223	323	116	419	746
Loess	309	557	918	58	234	321	173	635	941
Clay	136	507	1142	38	184	249	113	533	735
All	210	418	829	39	216	313	116	421	744

RESULTS: An overview of the results for The Netherlands as a whole is given in Table A1.6.

Table A1.6. 5%, 50% and 95% values of critical loads and exceedances for Dutch forests on non-calcareous sandy soils (in $mol_c\ ha^{-1}\ yr^{-1}$).

	Critical loads			Present loads - critical loads		
Element	5%	50%	95%	5%	50%	95%
N	325	640	1030	1195	3430	6100
S	150	500	1250	860	1855	2860
Acid	700	1115	2055	2370	5320	8670

Using deposition data based on 1985 emissions, a reduction of approximately 80% is needed to approach the median critical loads for forest in The Netherlands.

The variation in critical load and the amount by which they are exceeded is determined by tree species and soil type. Results for the effect of tree species are shown in Table A1.7.

Table A1.7. Median values for critical loads and exceedances for coniferous and deciduous forests on non-calcareous sandy soils in The Netherlands ($mol_c\ ha^{-1}\ yr^{-1}$).

	Critical loads			Present loads - critical loads		
Forest type	N	S	Acid	N	S	Acid
Coniferous	484	654	1150	4478	2221	6771
Deciduous	721	360	1095	2973	1720	4761
All	638	503	1117	3429	1856	5329

The critical N loads for deciduous forests are higher than for coniferous forests because of higher values for uptake and critical NO_3 leaching, whereas the present loads (not shown) are lower because of a lower filtering for dry deposition. Consequently, the excess in critical N loads is much less for deciduous forests.

Contrary to N, the critical S load for deciduous forests is lower because of a lower input of base cations by dry deposition. However, the present S load is also less because the dry deposition of this element is lower as well. Consequently, the difference in the excess in critical S loads for both types of forests is relatively small.

Results for the effect of soil type are shown in Table A1.8.

Table A1.8. Median values for critical loads and exceedances for forest on various non-calcareous sandy soils in The Netherlands.

	Critical loads			Present loads - critical loads		
Soil type	N	S	Acid	N	S	Acid
Peat	666	212	910	2747	1825	4703
Sand	616	474	1068	3544	1920	5524
Loess	794	1018	1771	2829	1807	4762
Clay	689	1187	1941	2746	1151	4004
All	638	503	1117	3429	1856	5329

The critical N loads are generally in the same order of magnitude for all soils. However, it should be noted that the values for peat- and clay soils are an underestimate, because the occurrence of denitrification is neglected. The effect of this process is likely to be high in these soils, unless nitrification is inhibited. For these soils, a separate N load could also be derived on the basis of critical concentration levels for NO_x. However, it is dangerous to use these (much higher) N loads to derive an acid load, unless a separate critical S load is given as well. Table A1.8 shows that the highest excess in critical N loads occurs for sandy soils. This is not because the critical N loads are lower (compare Table A1.9) but because the present N loads are higher on these soils which are mainly located in areas with intensive animal husbandry.

The critical loads for S and potential acid increase in the direction peat < sand < loess < clay. The relative high critical S load for clay soils is due to its greater weathering rate (compare Table A1.5). For loess soils it is due to the effect of dry deposition of base cations. However, for international comparison the effect of BC^*_{dd} should be excluded.

The range in critical loads for N and S and potential acid for the various non-calcareous soils are shown in Table A1.9.

Table A1.9. 5%, 50% and 95% values of critical loads for nitrogen, sulphur and potential acid (mol_c ha^{-1} yr^{-1}) for Dutch forests on various non-calcareous sandy soils.

	Critical N load			Critical S load			Critical acid load		
Soil type	5%	50%	95%	5%	50%	95%	5%	50%	95%
Peat	237	666	1363	162	212	774	661	910	1546
Sand	386	616	980	148	474	1011	693	1068	1762
Loess	542	794	1121	198	1018	1777	941	1771	2449
Clay	237	689	1360	481	1187	1615	1159	1941	2477
All	324	638	1032	152	503	1250	698	1117	2056

An overview of the amount by which the critical loads on the various soil types are exceeded is given in Table A1.10.

Table A1.10. 5%, 50% and 95% values of present minus critical loads (mol_c ha^{-1} yr^{-1}) for nitrogen, sulphur and potential acid for Dutch forests on non-calcareous sandy soils.

	N excess			S excess			Acid excess		
Soil type	5%	50%	95%	5%	50%	95%	5%	50%	95%
Peat	1313	2747	5680	970	1825	2847	2730	4703	8078
Sand	1357	3544	6223	1039	1920	2892	2721	5524	8781
Loess	1453	2829	5109	1330	1807	2883	2916	4762	7645
Clay	696	2746	5828	36	1151	2195	1065	4004	7552
All	1196	3429	6099	858	1856	2862	2368	5329	8669

EVALUATION: Average critical loads of potential acid on Dutch forests which have been derived earlier for non-calcareous soils by use of Equation A1.1 vary between 1100 and 1700 mol_c ha^{-1} yr^{-1}. The lower limit is close to the median value given in Table A1.6.

For the derivation of a European critical load map the use of 5 percentile values have been suggested. However, it should be noted that use of a 5 percentile critical load value based on a simple mass balance model is a very strict criterium. Use of this model implies that the critical Al-concentration and Al/Ca ratio is applied at the bottom of the root zone whereas most fine roots are concentrated in the topsoil. Values for these parameters in the forest topsoil are generally lower because of nutrient (Ca) cycling, transpiration and Al-mobilization with depth.

An indication of these effects on the critical load value has been derived by applying the Al-concentration criterion in the middle of the root zone and assuming a uniform weathering, transpiration and nutrient uptake with depth. Furthermore, the value for K_{gibb} was adapted to 10^7 mol^{-2} l^2. 5%, 50% and 95% values for the critical load of potential acidity thus derived equal 1484, 2077 and 2558 mol_c ha^{-1} yr^{-1} respectively. This is nearly a doubling of the 5% and 50% values given in Table A1.6, which is due to a much larger critical acidity leaching. The 5% value is in accordance with applications with the dynamic multi-layer model RESAM, which showed that an acid load near 1400 mol_c ha^{-1} yr^{-1} hardly caused any exceedance of a critical Al-concentration or Al/Ca ratio in the forest topsoil. Consequently, using a standard SMB model calculation, a 50 percentile critical load value seems more appropriate than a 5 percentile.

FIGURES:

A1.20. Netherlands: Critical loads of potential acidity for soils (minimum, 5, 50, and 95 percentile).
A1.21. Netherlands: Critical loads of sulphur for soils (minimum, 5, 50, and 95 percentile).
A1.22. Netherlands: Critical loads of nitrogen for soils (minimum, 5, 50, and 95 percentile).

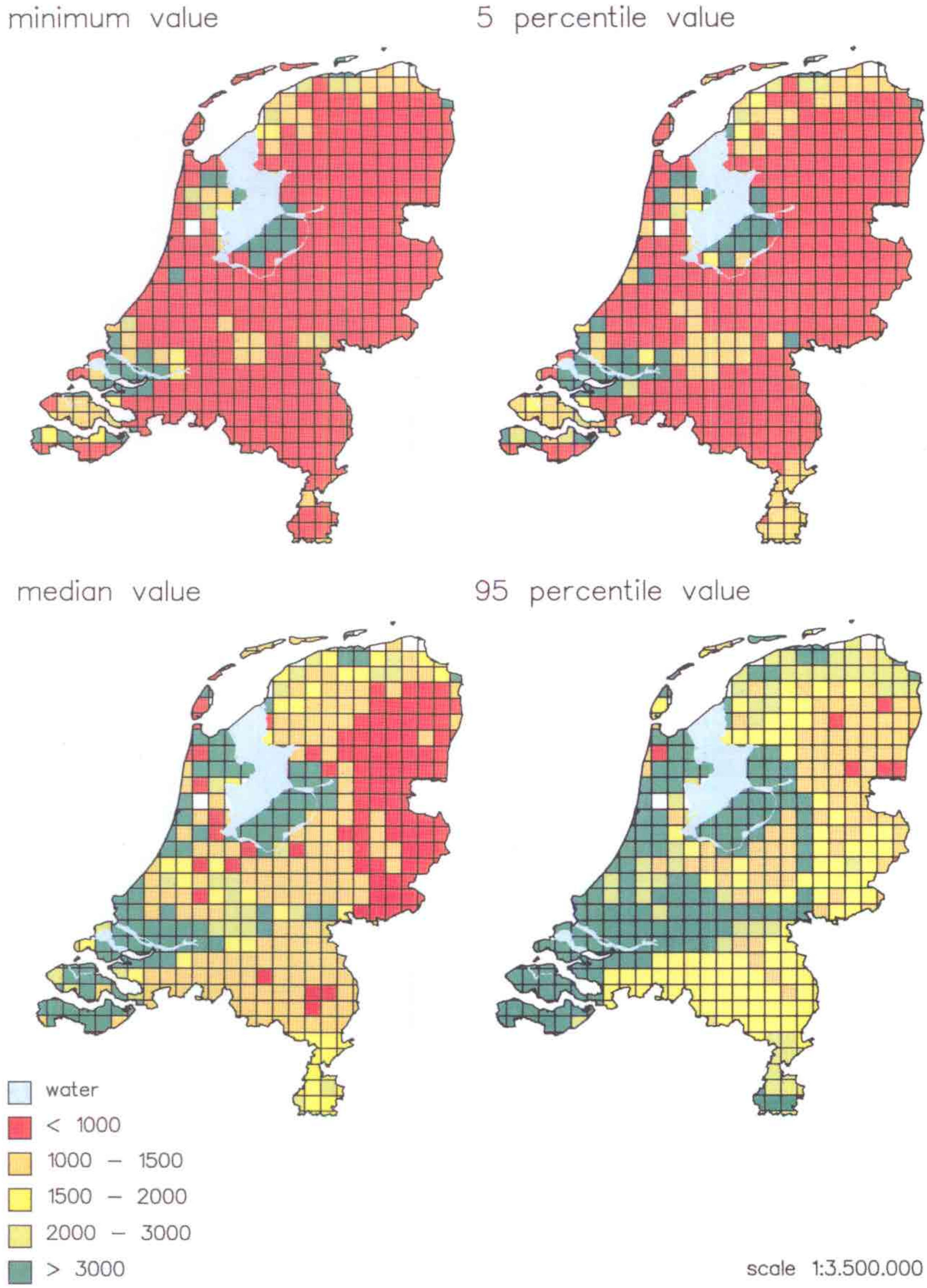

Figure A1.20. Netherlands: Critical loads of potential acidity for soils (minimum, 5, 50, and 95 percentile).

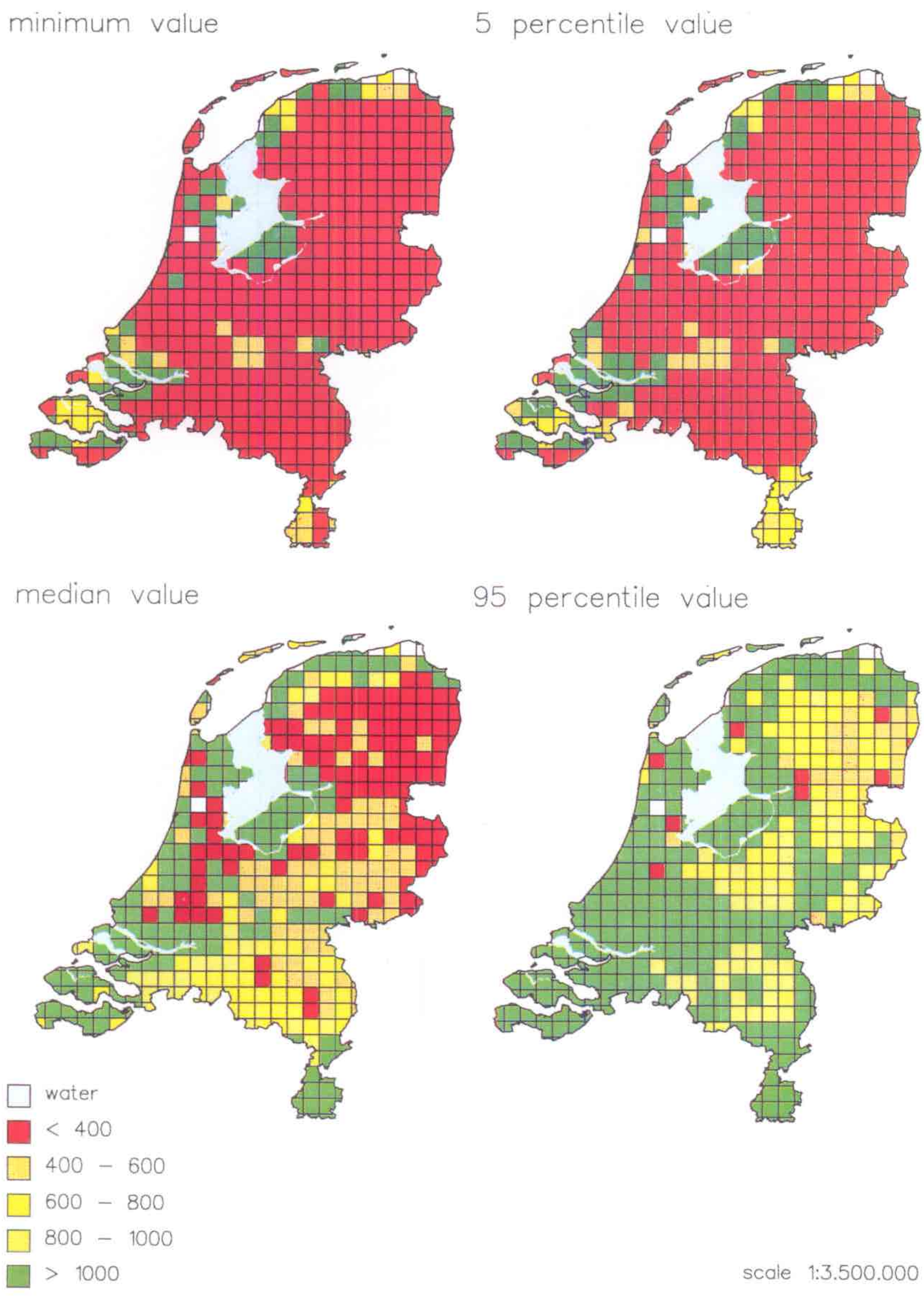

Figure A1.21. Netherlands: Critical loads of sulphur for soils (minimum, 5, 50, and 95 percentile).

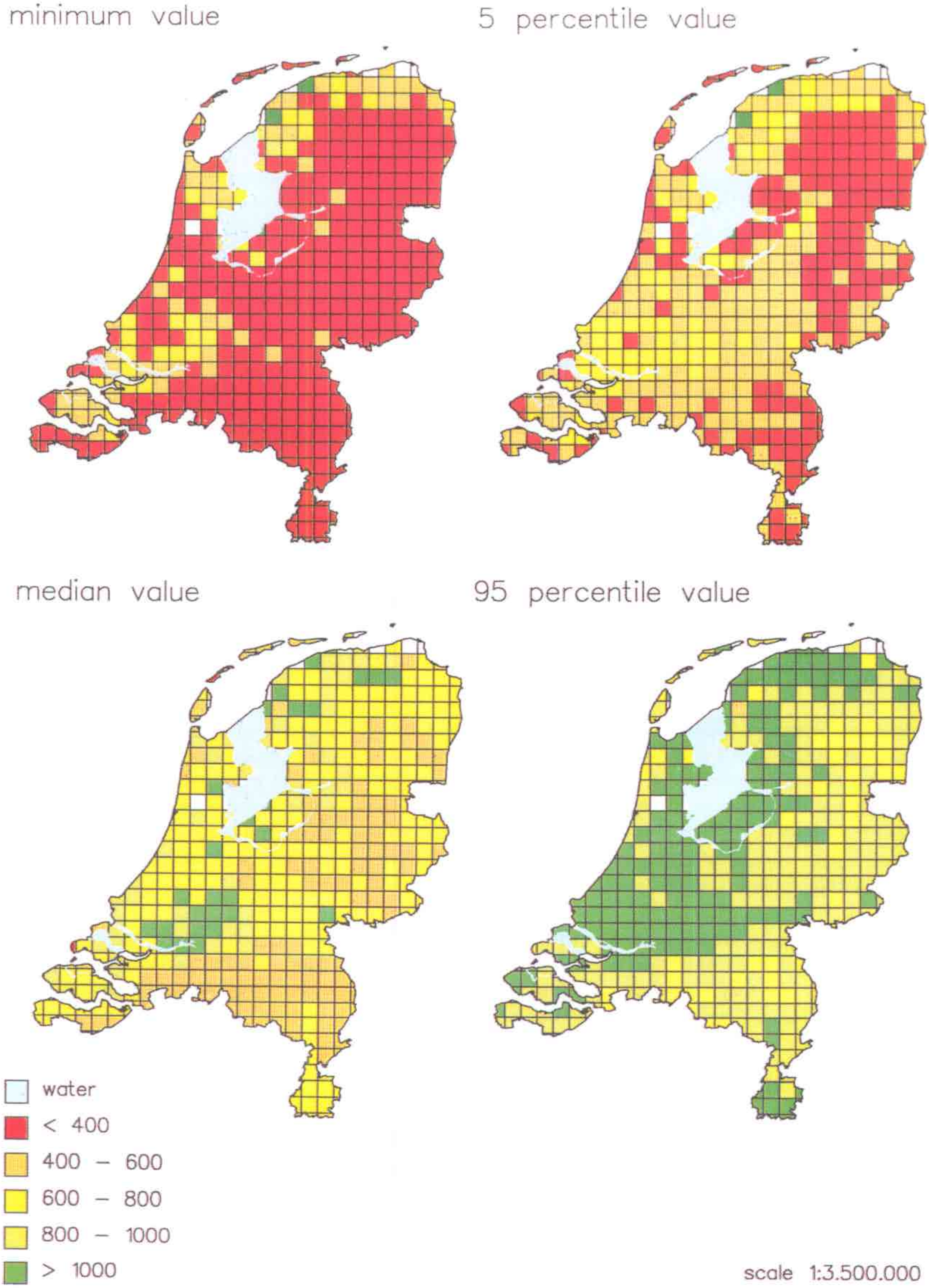

Figure A1.22. Netherlands: Critical loads of nitrogen for soils (minimum, 5, 50, and 95 percentile).

NORWAY

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RECEPTORS MAPPED: Surface waters, forest soils.

A working group was established in 1990 by the Nordic Council of Ministers, Group on Effects of Air Pollutants, to study the variability of deposition and critical loads of acidity to surface waters within EMEP grids, and to work out "harmonized" maps for the Nordic countries. The results have been reported in Henriksen *et al.*, 1991.

Harmonized maps for deposition of sulphur and nitrogen have been prepared for Finland, Sweden and Norway on the basis of wet deposition and throughfall measurements. Different dry deposition velocities have been calculated for different receptors based on throughfall measurements. Dry deposition has then been calculated from ambient air concentrations, and wet deposition has been derived from bulk deposition measurements. A weighted average deposition value for each NILU grid (a 3 by 3 subdivision of an EMEP grid) has been calculated taking land use data (coverage of different receptors) into account (Lövblad *et al.*, 1991).

Harmonized maps for critical loads to surface waters (lakes) have been prepared for Finland, Sweden, and Norway using the steady state water chemistry method. Also, critical load exceedance maps have been prepared. The maps have been produced on the basis of water chemistry measurements from 6509 lakes for the whole of Fennoscandia (Henriksen *et al.*, 1991).

A. SURFACE WATERS

CALCULATION METHOD: The steady state water chemistry method was used to produce maps of acidity, critical load exceedance for sulphur and sulphur runoff for Southern Norway. Maps for the whole of Norway will be produced in May 1991. (Critical load and critical load exceedance maps have been prepared for Fennoscandia based on frequency distribution within EMEP grids, and color maps based on NILU grids.)

Each 1° longitude by 0.5° latitude grid was divided into 16 subgrids, each covering an area of approximately 12 x 12 km in southern Norway. This basic unit is used for all maps. The water chemistry method assumes that sulphate is a mobile anion and that the acidity of precipitation is equivalent to the concentration of sulphate in precipitation; i.e., that there are equal amounts of H^+ ions and SO_4 ions in precipitation, as is the case in Norway (Henriksen *et al.*, 1990). Thus, the acidity of precipitation can be traced directly via the sulphate concentrations in runoff water. The ratio of these ions must be taken into account when applying the water chemistry method in other areas.

In order to compute the chemistry of surface water within a subgrid, the water chemistry of lakes and rivers located within the grid and with acceptable data was compared. The chemistry of the lake that was judged to be the most typical was chosen to represent the grid. If there were wide variations within a subgrid, the most sensitive area was selected, if it amounted to more than 25% of the grid's area. Sensitivity was evaluated on the basis of water chemistry, topography, and bedrock geology. The variation in chemistry within one typical square might be quite small (Henriksen *et al.*, 1990).

GRID SIZE: A 4 x 4 subdivision of 1° longitude x 1/2° latitude grids, coordinates of grid center defined.

DATA SOURCES: National regional surveys.

Precipitation: The harmonized maps prepared for the Fennoscandian countries (see below) were used to assess the deposition values for each 4 by 4 subdivision of the 1° longitude by 0.5° latitude grid.

Water: Data from the 1000 Lakes Survey and the monitoring program were used together with data from reports from NIVA and other institutions. Data from samples collected in the autumn after water circulation were preferred, but in some cases data from samples collected at other times of the year were also used. This was done for grids with low sensitivity to acidic precipitation located in areas where inputs of acidic precipitation are small. Data for each subgrid are stored in a ND-5100 personal computer in the Researchers Archive (RESA) system at NIVA. Additional stored data includes precipitation chemistry, runoff amounts, and dominant geology of each grid. Mean annual runoff data is from runoff maps prepared by the Norwegian Water and Energy Works. The geology was determined from the geological map of Norway (1:1,000,000) prepared by the Norwegian Geological Survey.

B. FOREST SOILS (Maps to be produced by August 1991)

CALCULATION METHOD: Steady state mass balance, MAGIC (Model of Acidification of Groundwater in Catchments) dynamic model

DATA SOURCES: National monitoring data.

FIGURES:

A1.23. Fennoscandia: Critical loads of acidity for lakes: (a) minimum, (b) 25th percentile, and (c) median, in each NILU grid.
A1.24. Fennoscandia: Cumulative frequency distribution for critical loads for lakes in each EMEP grid.
A1.25. Fennoscandia: Exceedance of critical loads of acidity for lakes: (a) minimum, (b) 25th percentile, and (c) median, in each NILU grid.
A1.26. Fennoscandia: Cumulative frequency distribution of critical loads exceedance in each EMEP grid.
A1.27. Fennoscandia: Estimated present sulphur deposition in each NILU grid.

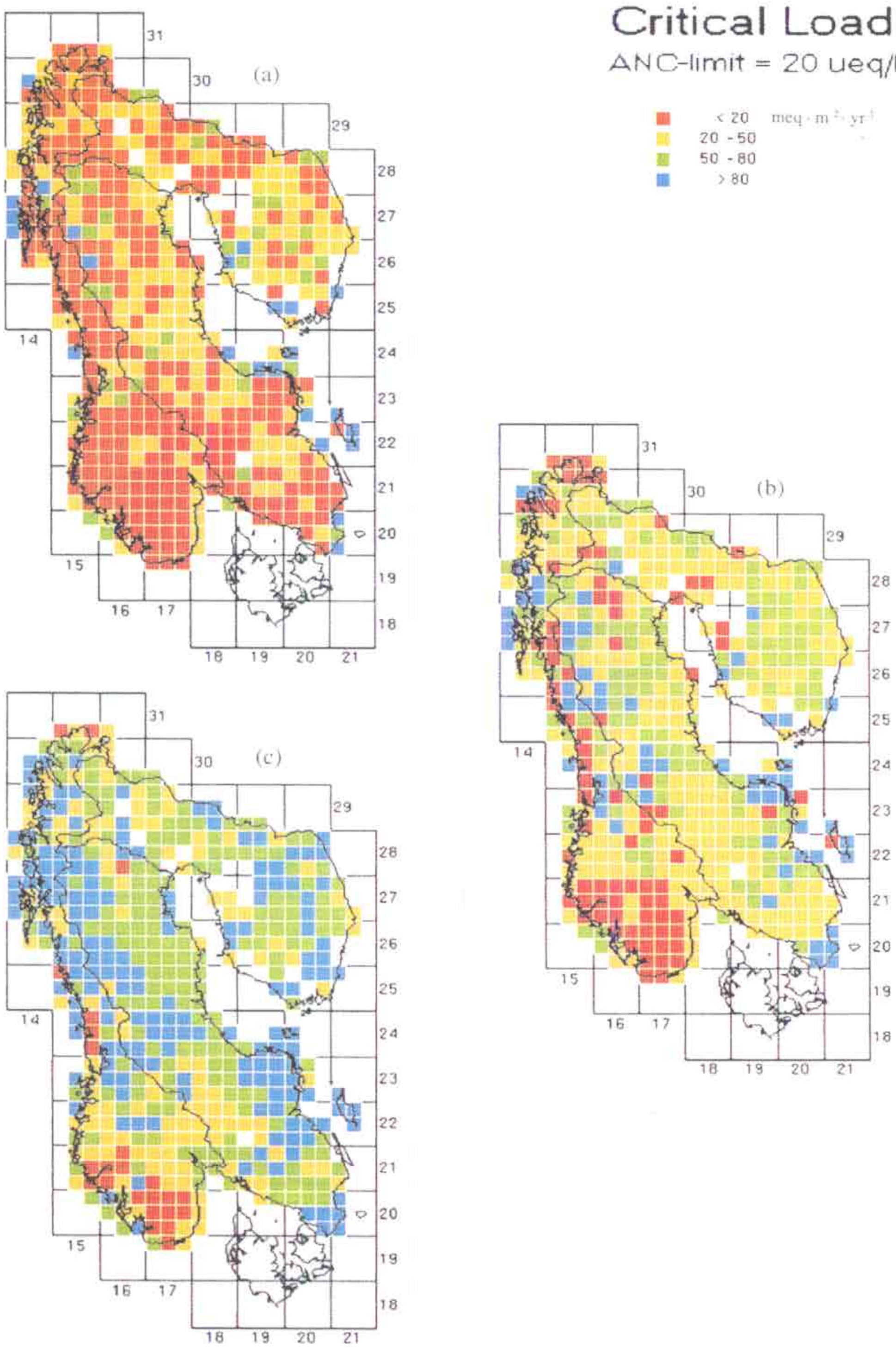

Figure A1.23. Fennoscandia: Critical loads of acidity for lakes: (a) minimum, (b) 25th percentile, and (c) median, in each NILU grid.

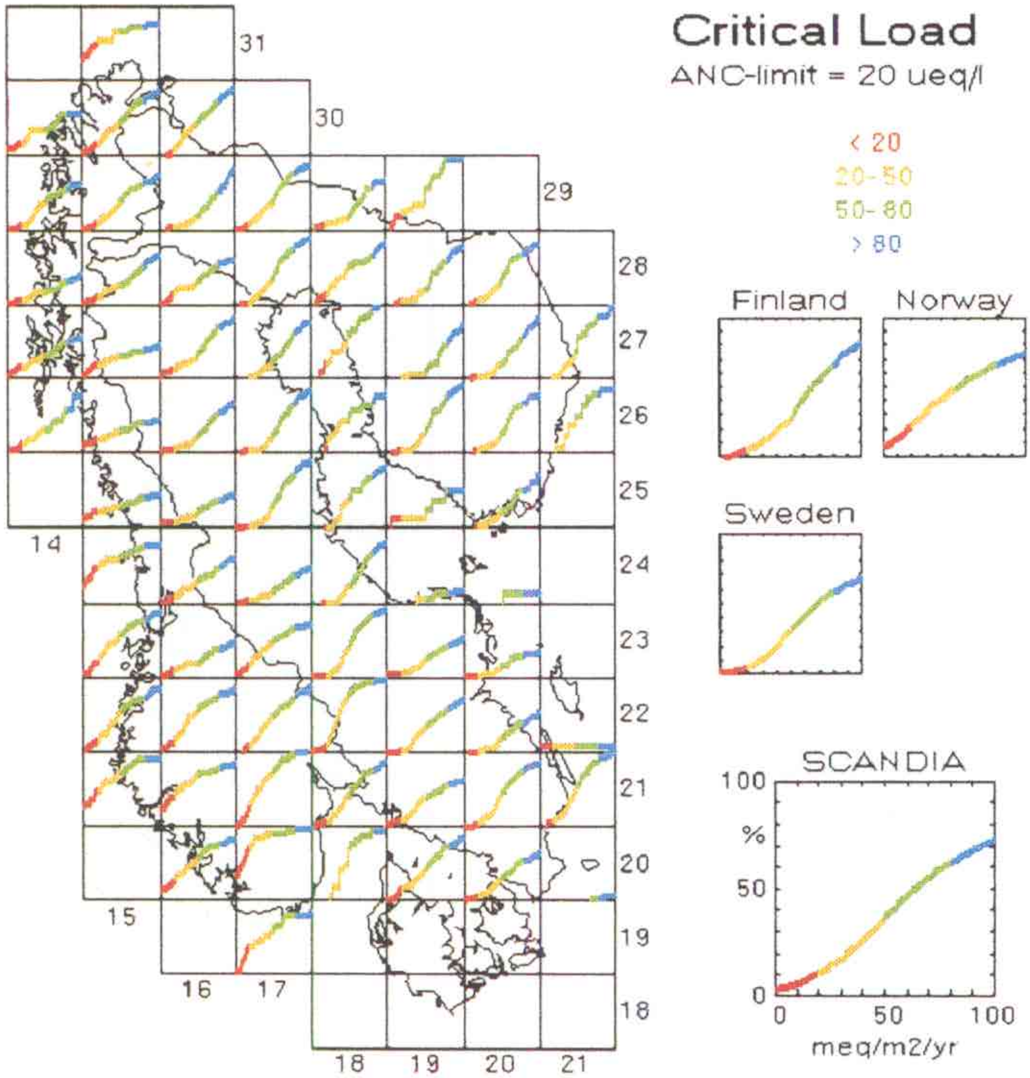

Figure A1.24. Fennoscandia: Cumulative frequency distribution for critical loads for lakes in each EMEP grid.

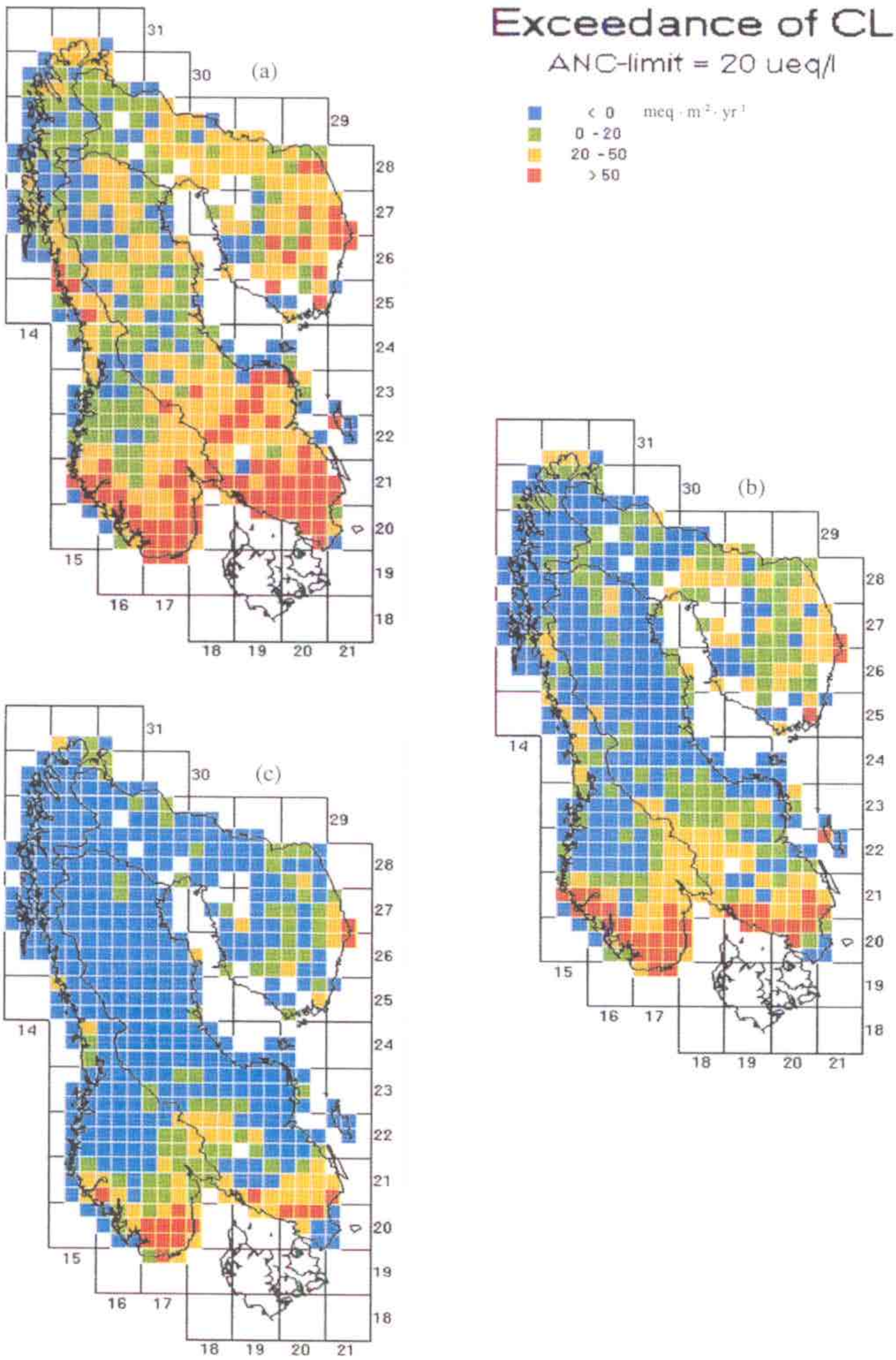

Figure A1.25. Fennoscandia: Exceedance of critical loads of acidity for lakes: (a) minimum, (b) 25th percentile, and (c) median, in each NILU grid.

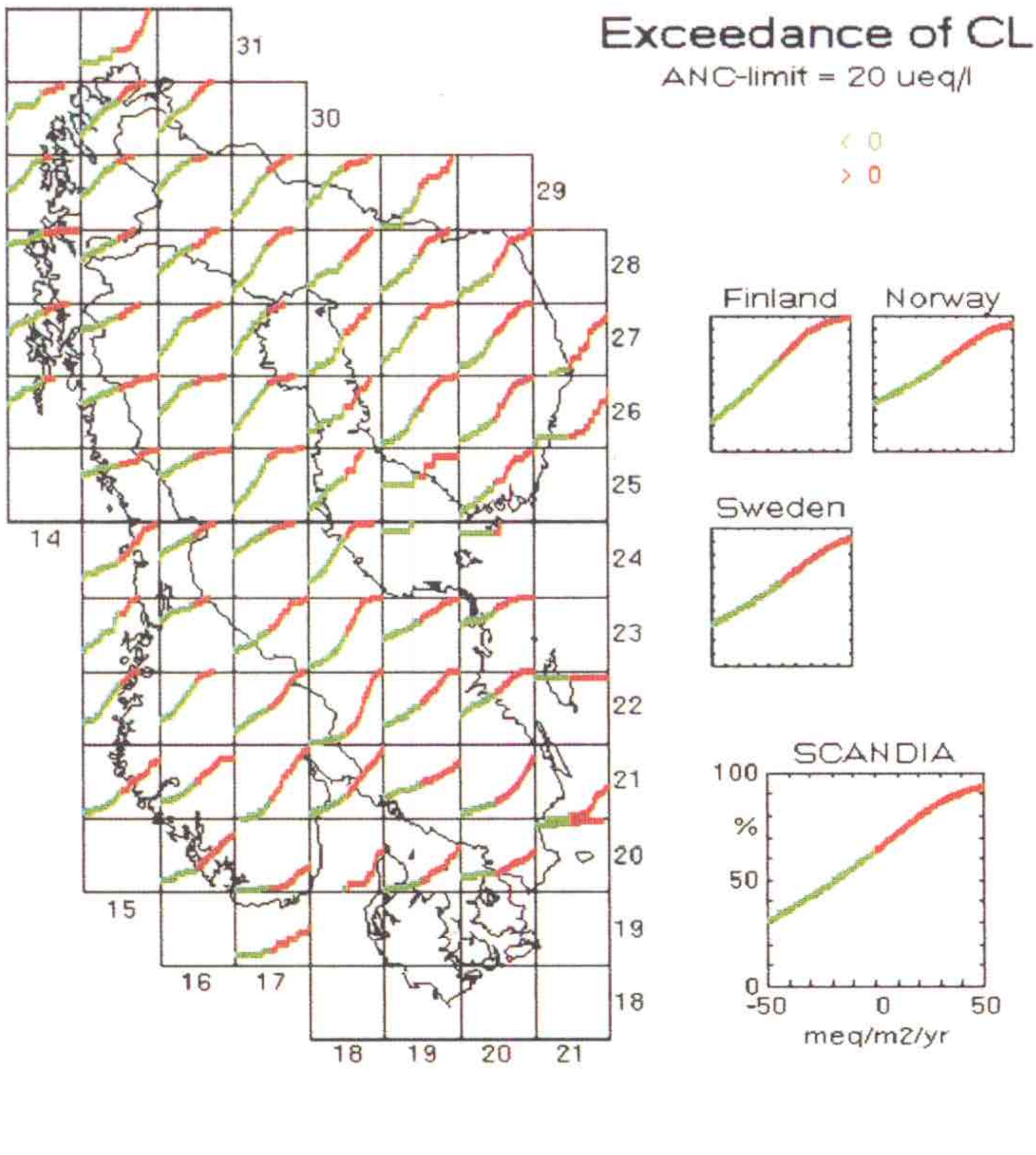

Figure A1.26. Fennoscandia: Cumulative frequency distribution of critical loads exceedance in each EMEP grid.

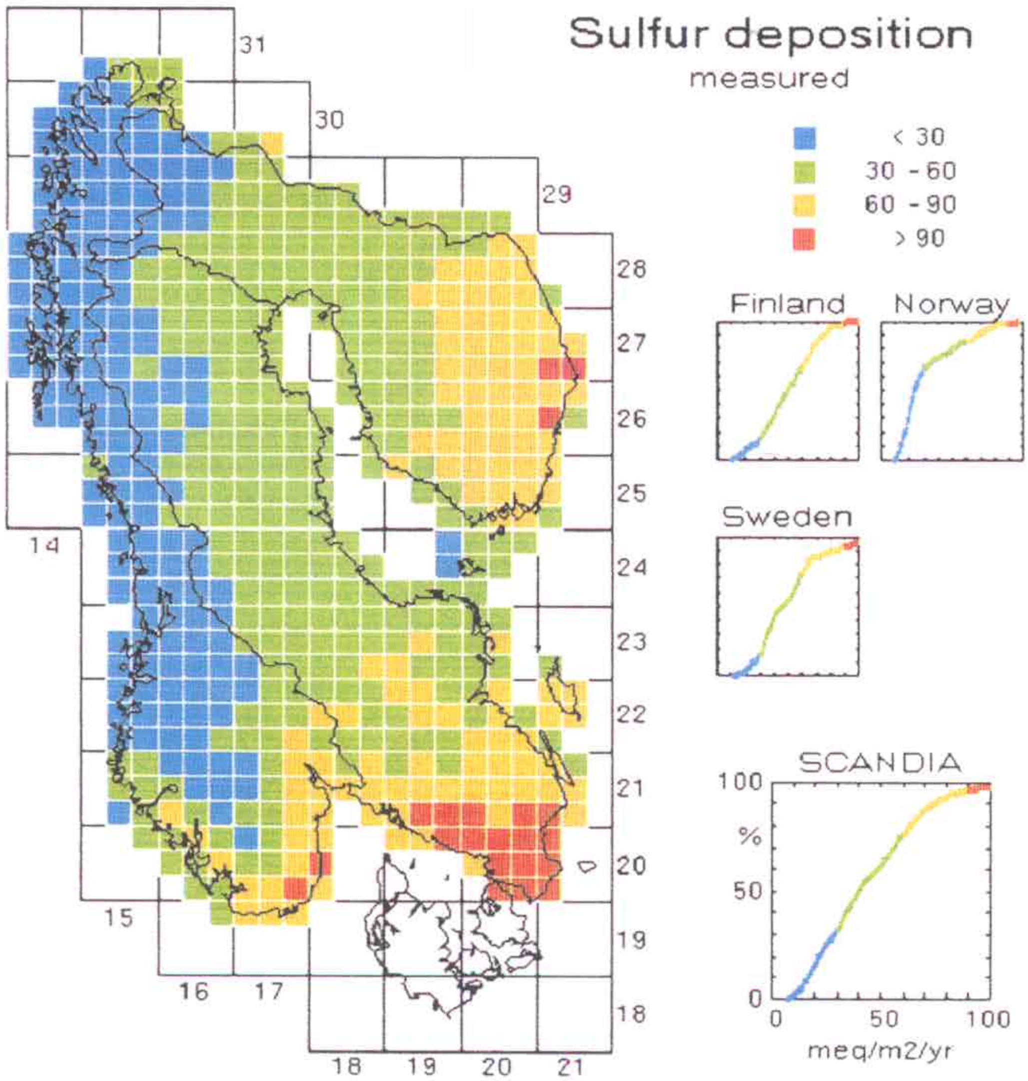

Figure A1.27. Fennoscandia: Estimated present sulphur deposition in each NILU grid.

POLAND

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RECEPTORS MAPPED: Forest soils (European maps), surface waters (case study).
A case study is presented based on seven selected impoundments and river cross-sections representing the most typical conditions that may occur in the Upper Silesia region.

CALCULATION METHOD: Steady state mass balance (European maps); steady state water chemistry (case study).

GRID SIZE: 10 x 10 km grid.

DATA SOURCES: Water quality data derive from the Center of Environmental Investigations (CEIC) in Katowice and are related to the mean concentrations for 1989.

Base cations: Direct measurements of Ca^{2+} and Mg^{2+} are rather sporadically conducted. The majority of Ca^{2+} and Mg^{2+} concentrations are represented by the values of water hardness measured systematically by CEIC. Concentrations of Na^+ and K^+ are not measured at all by the Center. Instead, an empirical factor is used that increases the total concentration of Ca^{2+} and Mg^{2+} by about 10%. It is that ratio at which the total of Na^+ and K^+ to Ca^{2+} and Mg^{2+} in some Silesian surface waters occur, according to the results of the Environmental Pollution Abatement Center in Katowice.

Acid anions: The strong acid anions SO_4^{2-}, Cl^- and NO_3^- are directly monitored in impoundments and rivers.

Average annual runoff: The average annual runoff is determined by the Institute of Meteorology and Water Management and published in the Hydrological Yearbook of Surface Waters.

REMAINING UNCERTAINTIES:
- There is a general lack of Na^+ and K^+ monitoring in surface waters in Poland. For current calculation needs, approximate value concentrations of Na^+ and K^+ have been applied. For future work on critical load mapping, a measurement program for the two ions in surface waters should be undertaken.
- Another type of uncertainty arises from the use of conversion functions, where the desired parameter value is taken from a correlation to an already known parameter; e.g., the F-function and the function for assessing the $[SO_4^{2-}]_0$ concentration. Both empirical functions should be established for Poland.
- A specific problem arises in the heavily industrialized and densely populated Upper Silesia region, where the surface water quality is mostly determined by industrial and wastewater discharges. Especially coal mine drainage waters, containing huge loads of Cl^- and sulphate, undermines the sense of evaluation of the airborne acidity loads in Silesian surface waters.

In that context, the calculation and mapping of critical loads should be restricted to those sites where the acidification problem is apparent and can be evaluated by the use of the recommended methods.

FIGURES:
A1.28. Poland: Critical loads of acidity for surface waters (case study, Southern Poland).
A1.29. Poland: Exceedance of critical loads of acidity for surface waters (case study, Southern Poland).

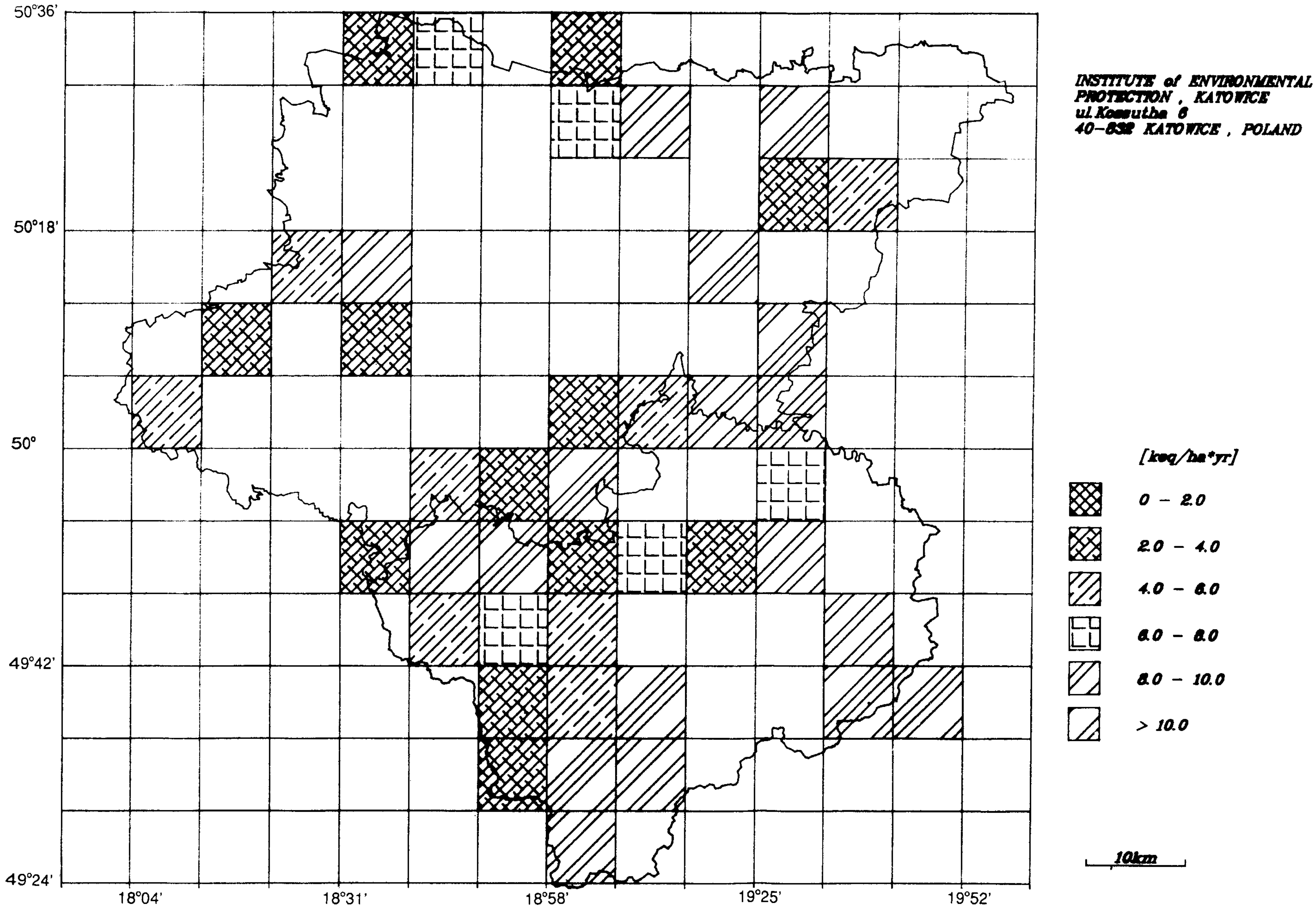

Figure A1.28. Poland: Critical loads of acidity for surface waters (case study, Southern Poland).

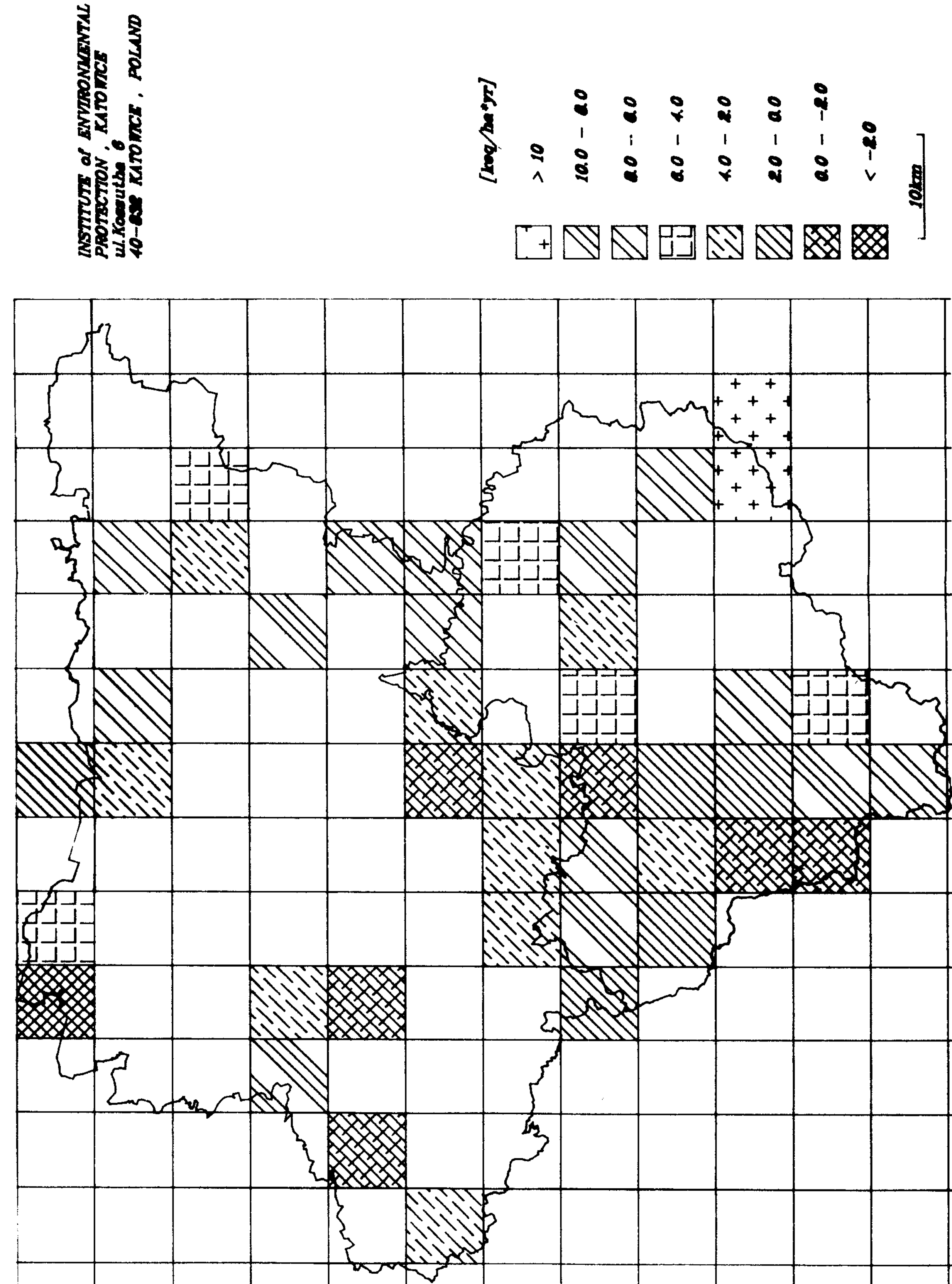

Figure A1.29. Poland: Exceedance of critical loads of acidity for surface waters (case study, Southern Poland).

SWEDEN

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RECEPTORS MAPPED: The present forest critical loads map applies to all types of forests on moraine only. At the present time, sedimentary soils have been omitted, but will be included in later 1991 updates. The forest vegetation includes the Southern Swedish deciduous forest, the coniferous forest and the northern birch forest.

A. DEPOSITION (Gun Lövblad)

CALCULATION METHOD: The deposition over Sweden has been mapped in cooperation with other Nordic countries. The main purpose of the joint Nordic effort was to obtain deposition estimates as close as possible to what is observed by monitoring (throughfall measurements). Another main goal was to harmonize the national maps ion order to avoid discrepancies along national borders.

Deposition of sulphur and nitrogen was estimated based on monitoring results of wet deposition. Dry deposition was calculated from air pollution concentrations and dry deposition velocities. For sulphur deposition, velocities were derived from throughfall results, and for nitrogen from literature data.

Deposition was mapped to specific ecosystems in order to compare it to critical loads. Deposition to forest ecosystems was calculated to be compared to critical loads for forest spoils. For the comparison with critical loads for surface waters, the deposition to an integrated area of forest, open land, and lake surfaces has been estimated. A comparison with the EMEP model results has been made, since this model will be used for abatement strategy calculations over Europe. For this comparison the integrated deposition over all types of areas within the EMEP grid square were computed.

DATA SOURCES: Data used for calculating deposition of sulphur and nitrogen are:
1. Wet deposition monitoring data from the national monitoring network, 30 stations for precipitation chemistry and 700 for precipitation amount.
2. Air concentration data from the six Swedish EMEP stations.
3. Throughfall monitoring results from a network in southern Sweden (around 80 stations).
4. Snow cover data from the national meteorological network.
5. Land use data from the Swedish University of Agriculture (Rosén)

B. ACIDITY IN FOREST SOILS (Harald Sverdrup)

CALCULATION METHOD: Steady state mass balance approach, implemented as the Apple MacIntosh version of the PROFILE model. Units used are keq ha^{-1} yr^{-1} if not otherwise specified. The soil profile is divided into 4 layers, using input data for the thickness of each soil layer (O, A/E, B, C). The criteria were applied in the 0-50 cm of the soil, assumed to be the tree rooting depth in Sweden.

CRITERIA: The criteria Ca:Al > 1.0 was used for the calculation of critical loads. In the model base cation uptake will occur from each layer, but uptake is stopped if the base cation soil solution concentration falls below 15 μeq/l. Residual uptake is then moved to the next layer.

DATA SOURCES: The calculations are based on 1395 individual points with longitude and latitude coordinates. The soil and vegetation data was taken from the data base of the Swedish National Forest Survey. For each site the net long term uptake is specified, based on the measurements in the survey of base cation and nitrogen contents of stem and branch, combined with site specific estimates of net long term forest growth. Each tree is considered separately, and the total uptake weighted together for each calculation point.

The weathering rate is calculated internally in the PROFILE model, basically form mineralogy and texture. The soil mineralogy was derived for 124 sites by measurement. For the remaining of the 1395 sites the soil mineralogy was calculated using the total analysis, backchecked against the 124 accurate mineralogy determinations. Texture was measured by granulometry and BET/adsorption. The texture for the remaining 1271 sites were read from the correlation using the field classification.
Annual average air temperature, precipitation and runoff was taken from the official statistics of the Swedish Meteorological Institute, for each NILU grid (3 x 3 subdivision of EMEP).

Other input data were derived strictly in accordance with Sverdrup *et al.* (1990) and the Mapping Vademecum (e.g., gibbsite coefficients, CO_2 soil pressure, typical soil densities, and uptake distribution within the soil profile).

C. NITROGEN AND MANAGED FOREST SOILS (Kaj Rosén)

CALCULATION METHOD: The nitrogen nutrient mass balance method described in the Mapping Manual (UN ECE, 1990a) and annexes. The method implies whole-tree harvesting of biomass and assumes that biological nitrification and denitrification to be negligable. Biomass production was calculated according to the HUGIN model.

CRITERIA: Nitrogen concentration in runoff water > 21 mmol m^{-3} (0.3 mg l^{-1}).

DATA SOURCES: Data from more than 21,000 sites distributed all over Sweden. The sites represent managed forests where the annual increment exceeds 1 m^3 ha^{-1} of stemwood.

D. LAKES (Anders Wilander)

CALCULATION METHOD: Steady state water chemistry. Harmonized maps of Fennoscandia with frequency distributions on the EMEP grid and colored classes on the NILU grid have been produced and are included in the National Focal Center report of Norway.

CRITERIA: ANC_{limit} = 20 μeq/l, agreed on by the Nordic countries. The limit used for national purposes is 50 μeq/l.

DATA SOURCES: Chemistry data from about 4,000 lakes sampled in January-April 1990. The lakes were first separated into 5 size classes. For each of the 24 counties in Sweden, up to 120 lakes within each size class were randomly chosen. If random choice had been applied instead of size class choice, a considerably higher number of small lakes (0.01 - 0.1 km^2) would have been included in the survey. This would have decreased mean and 5 percentile values considerably. Corrections for liming have been made.

FIGURES:

A1.30. Sweden: Critical load of acidity for forest soils (1 percentile).
A1.31. Sweden: Critical load of acidity for forest soils (5 percentile).
A1.32. Sweden: Critical load of acidity for forest soils (50 percentile).
A1.33. Sweden: Exceedance of critical load of acidity for forest soils (1 percentile).
A1.34. Sweden: Exceedance of critical load of acidity for forest soils (5 percentile).
A1.35. Sweden: Exceedance of critical load of acidity for forest soils (50 percentile).
A1.36. Sweden: Critical nitrogen nutrient load (5 percentile; EMEP grid).
A1.37. Sweden: Critical nitrogen nutrient load (5 percentile; Swedish national grid).
A1.38. Sweden: Exceedance of critical load of nitrogen at current nitrogen deposition.
A1.39. Sweden: Exceedance of critical load of nitrogen, expressed in percent area exceeded.

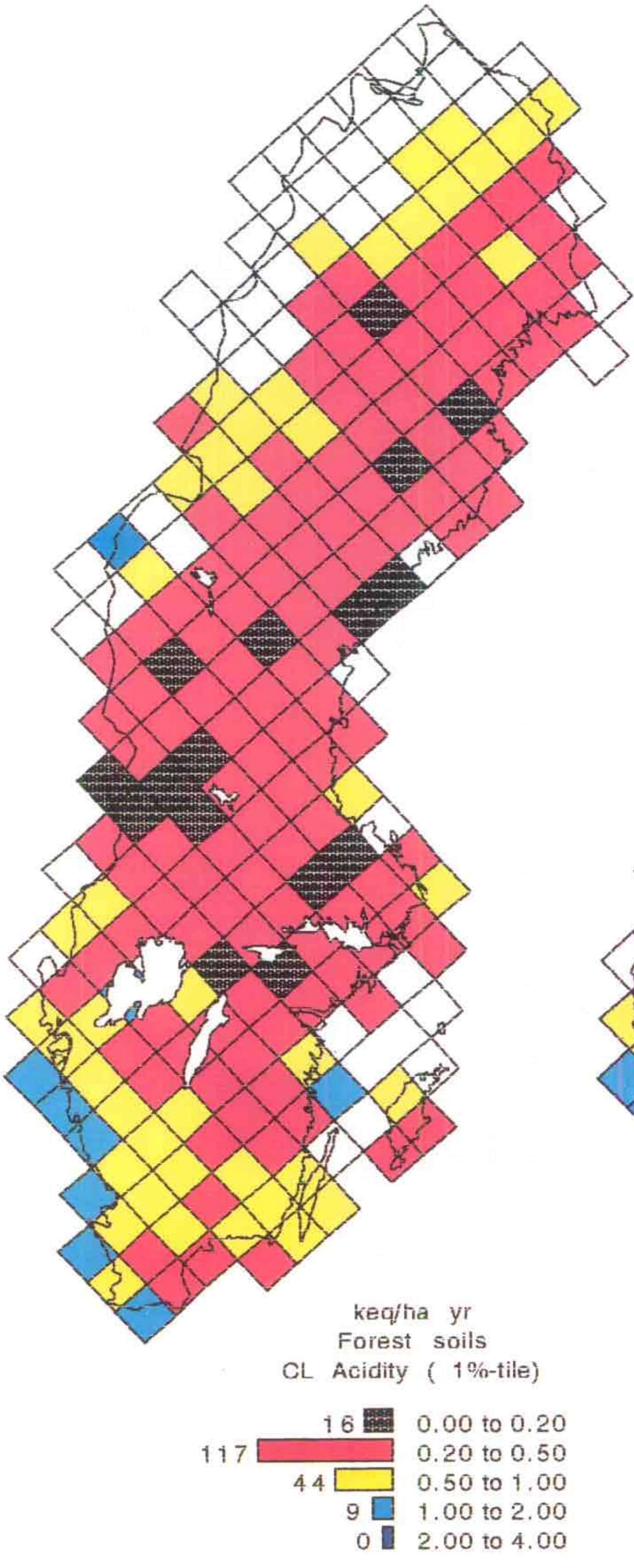


Figure A1.30. Sweden: Critical load of acidity for forest soils (1 percentile).

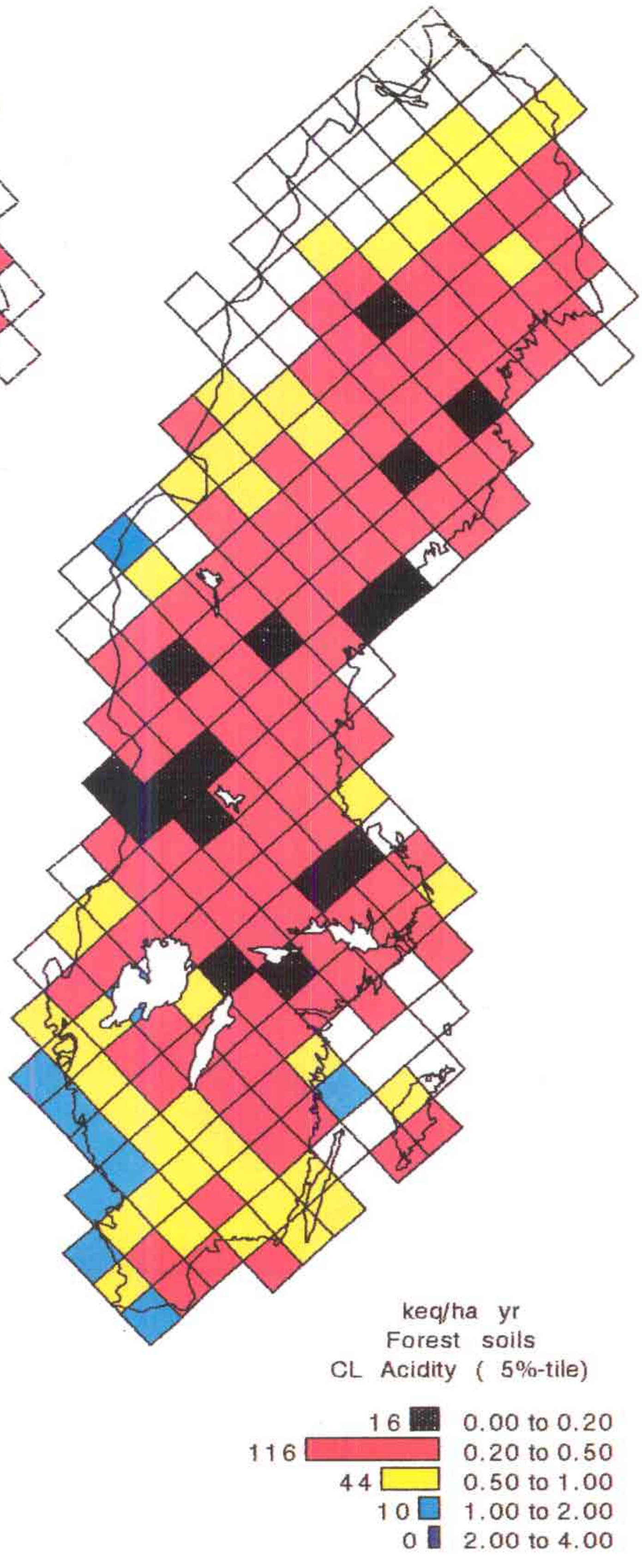
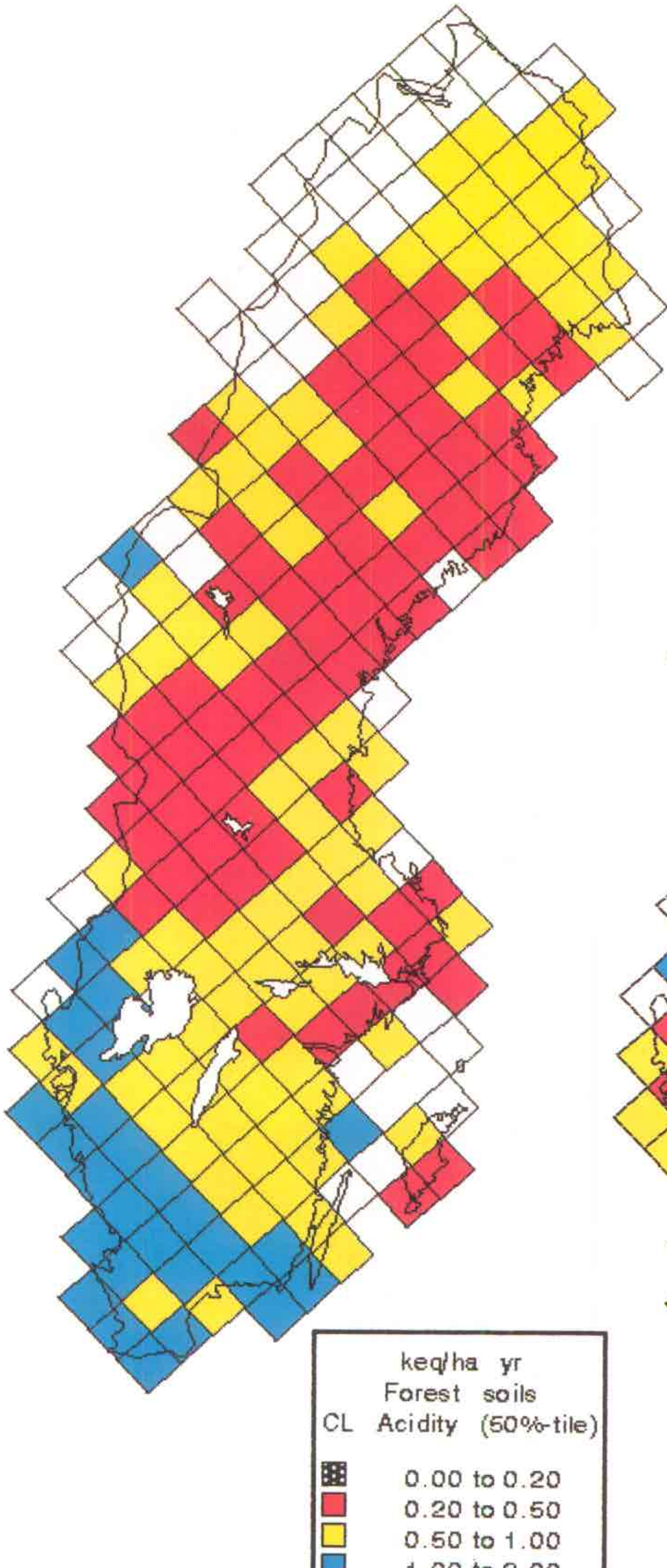


Figure A1.31. Sweden: Critical load of acidity for forest soils (5 percentile).



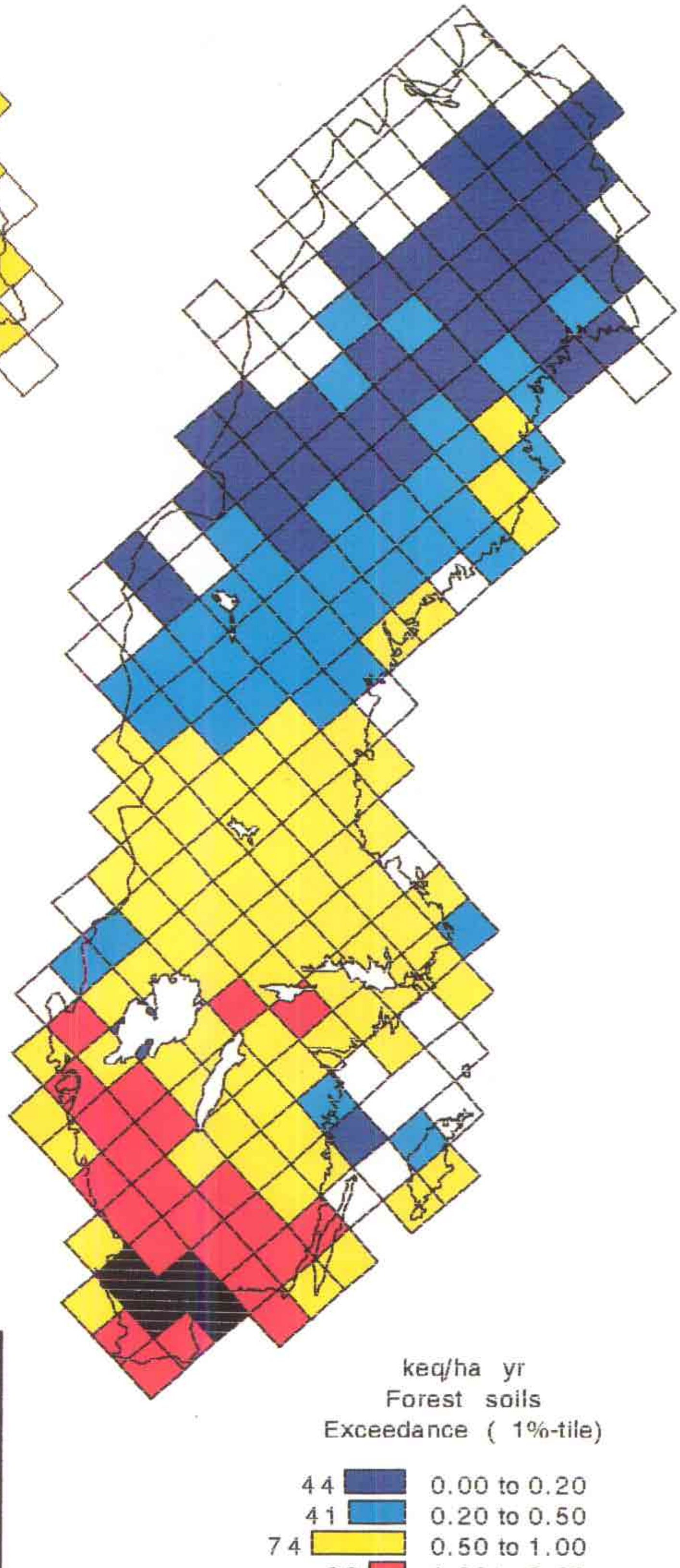


Figure A1.32. Sweden: Critical load of acidity for forest soils (50 percentile).

Figure A1.33. Sweden: Exceedance of critical load of acidity for forest soils (1 percentile).

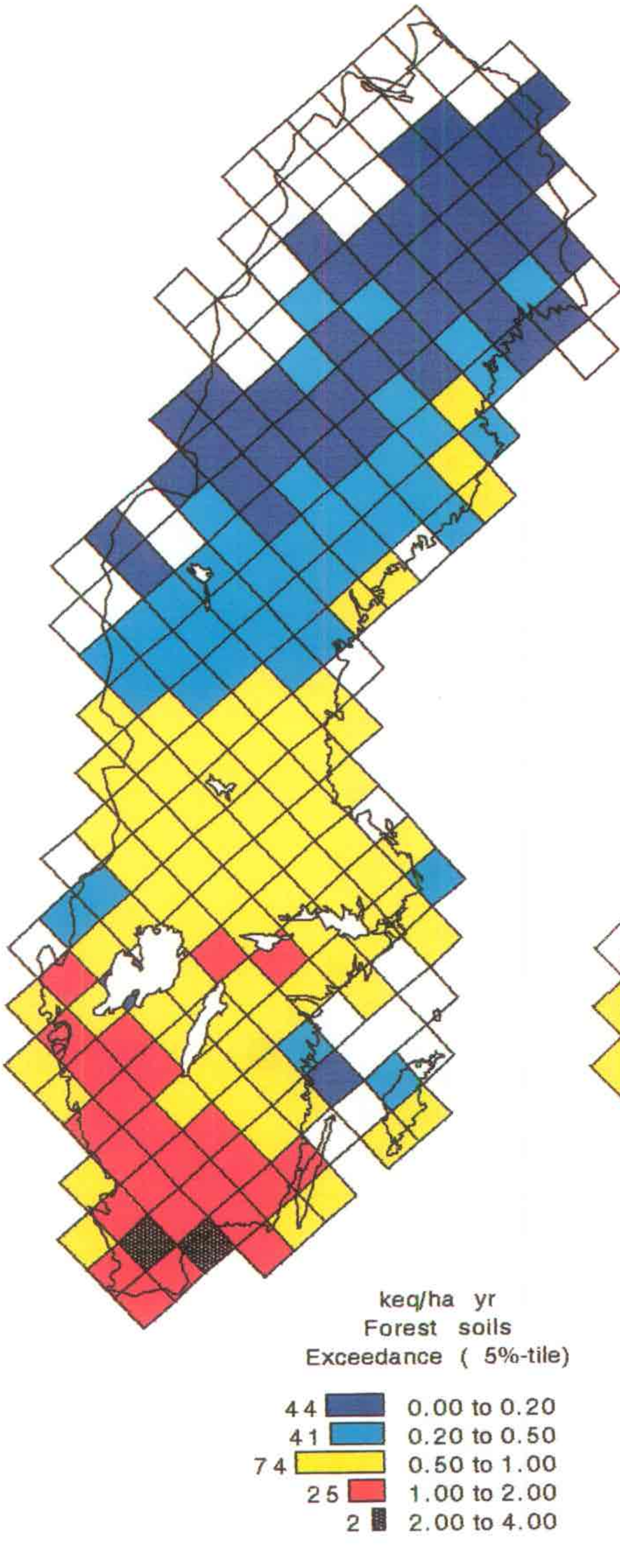


Figure A1.34. Sweden: Exceedance of critical load of acidity for forest soils (5 percentile).

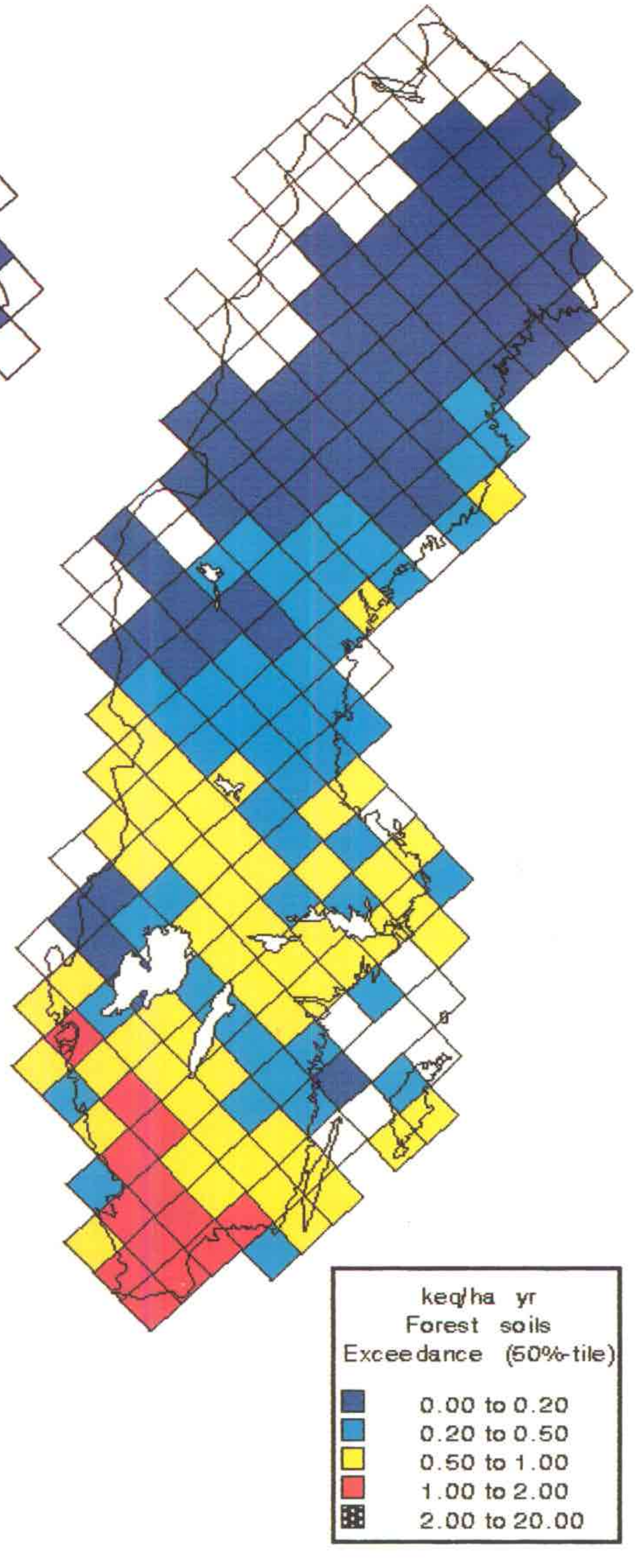


Figure A1.35. Sweden: Exceedance of critical load of acidity for forest soils (50 percentile).

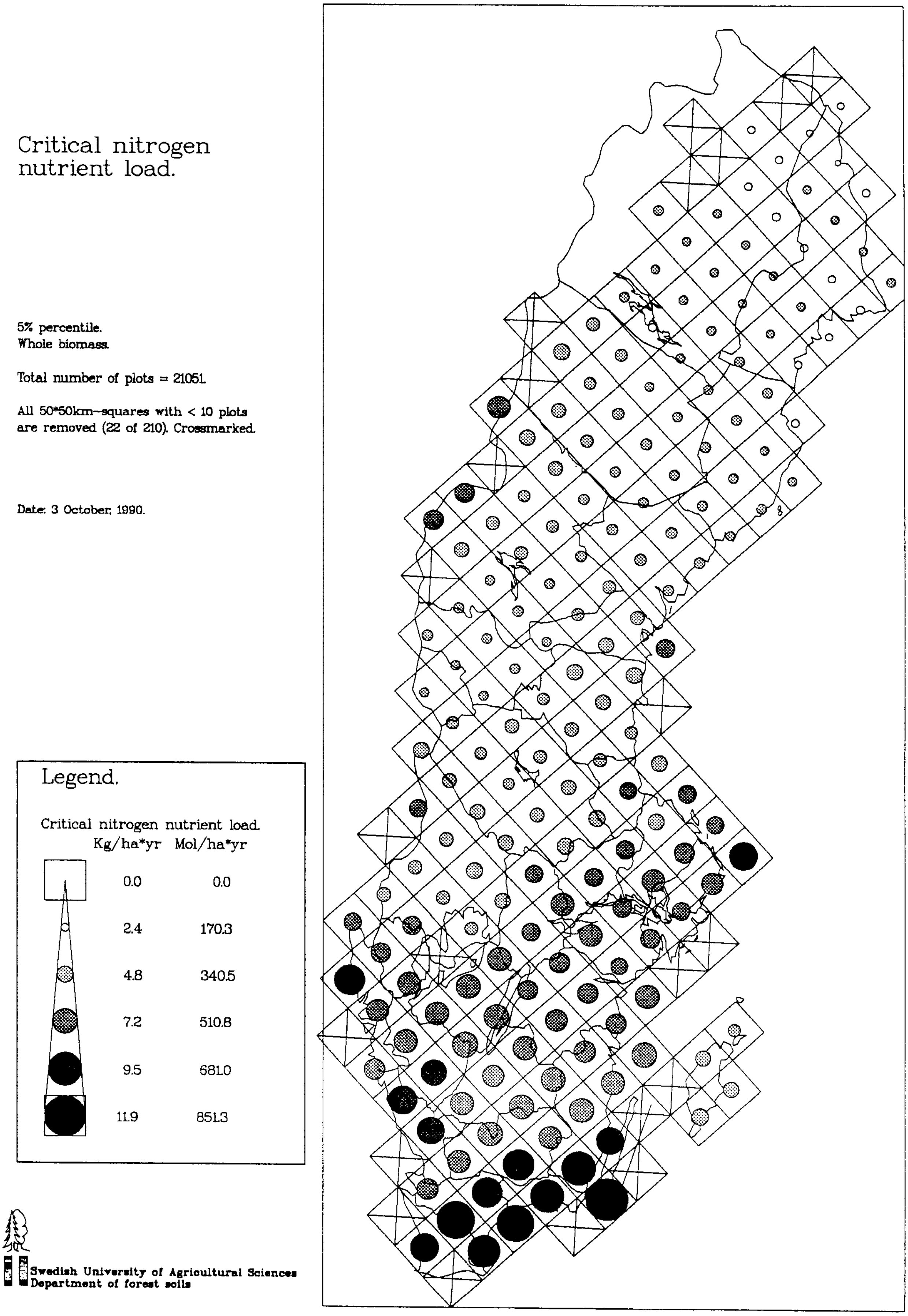


Figure A1.36. Sweden: Critical nitrogen nutrient load (5 percentile; EMEP grid).

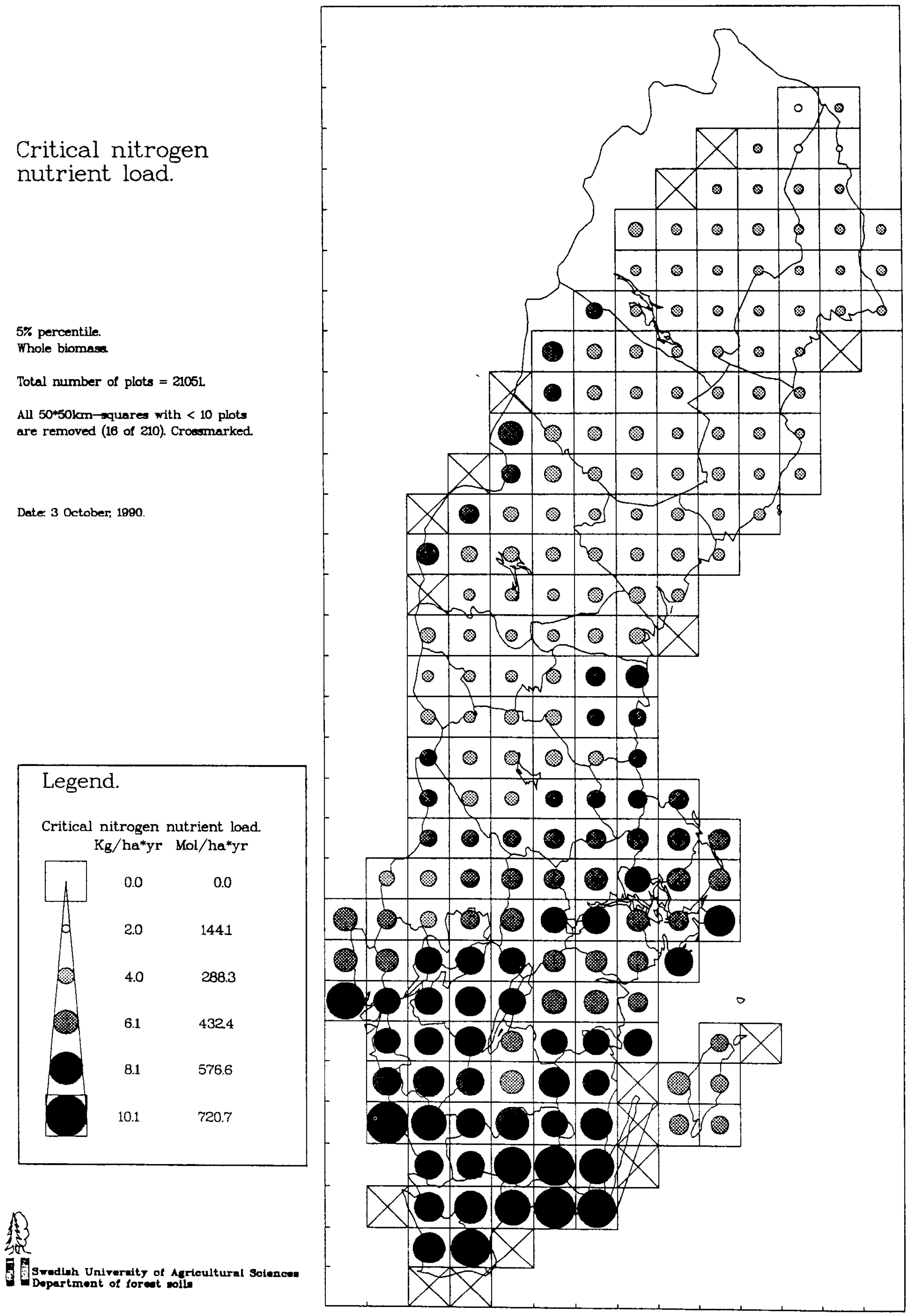


Figure A1.37. Sweden: Critical nitrogen nutrient load (5 percentile; Swedish national grid).

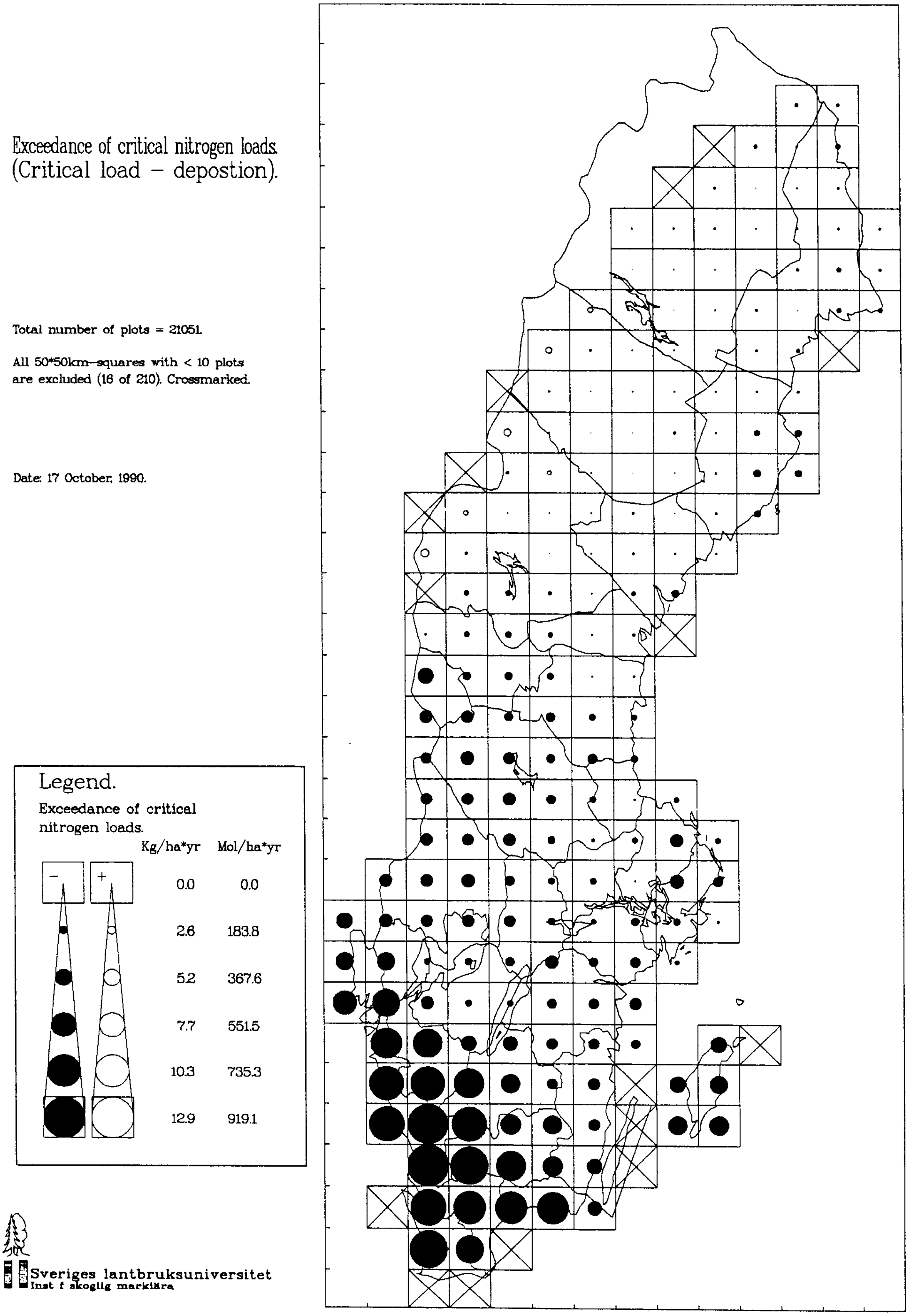


Figure A1.38. Sweden: Exceedance of critical load of nitrogen at current nitrogen deposition.

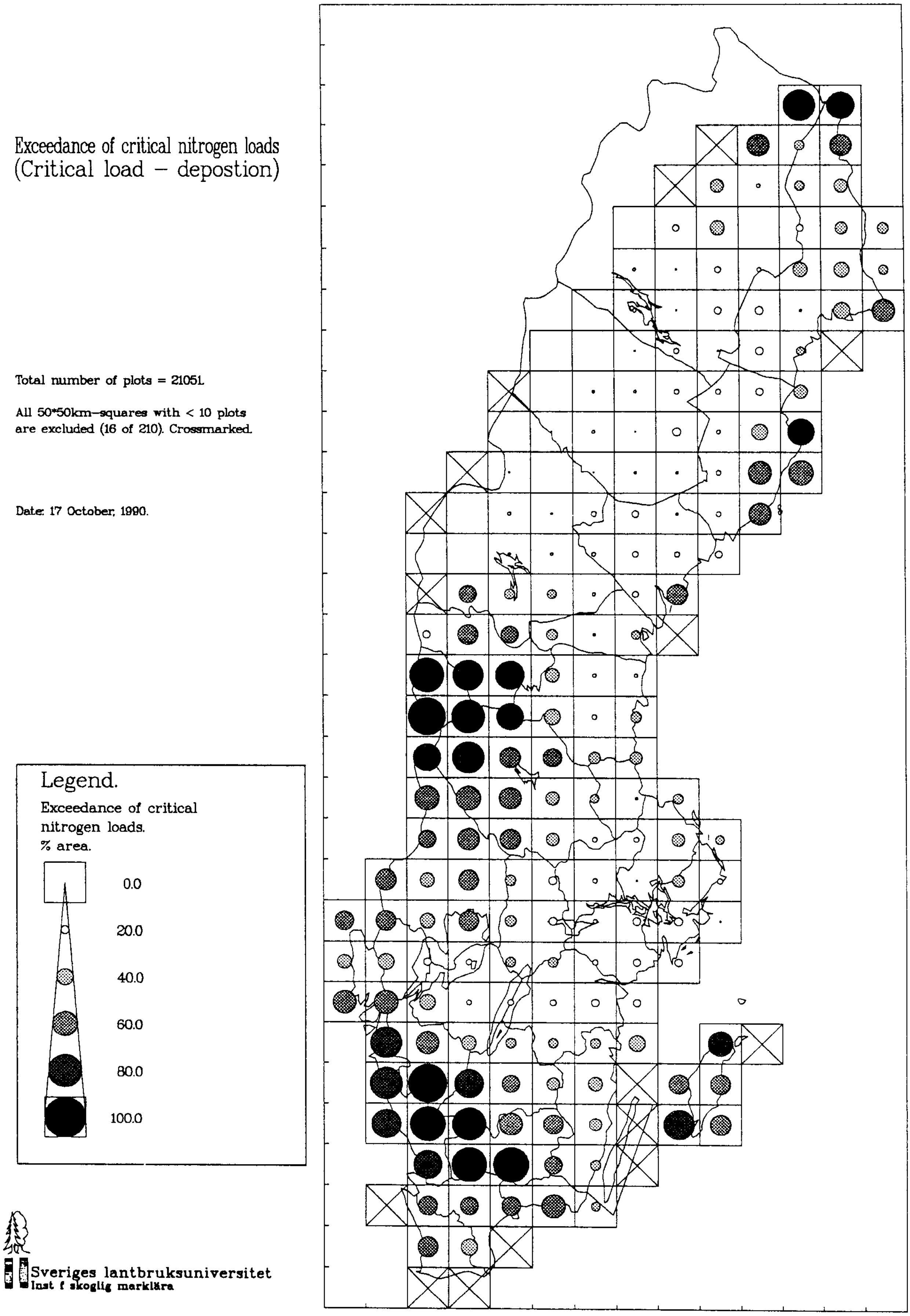


Figure A1.39. Sweden: Exceedance of critical load of nitrogen, expressed in percent area exceeded.

SWITZERLAND

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RECEPTORS MAPPED: Forests (coniferous, deciduous, and unmanaged); sensitive alpine lakes. In general, surface waters and ground waters are well-buffered in Switzerland. However, there are some alpine areas on slow-weathering bedrocks where lakes are sensitive to acidic deposition. These alpine lakes are situated between 1200 and 2800 m above sea level.

CALCULATION METHOD: Steady state mass balance.

GRID SIZE: 1 x 1 km; 11,148 receptor points covering the total forested area and sensitive alpine lake catchments (together 25% of the total area of Switzerland).

CRITERIA: Both the Al and Al/Ca criteria have been applied and the minimum of the critical load computed has been used.

DATA SOURCES:

Spatial distribution of receptors: The land use database of the Federal Office of Statistics, with a resolution of one hectare, was aggregated to a 1 x 1 km grid. As this database contains only one forest category, information from the National Forest Inventory (NFI) was used to make a distinction among the three forest types. Alpine lakes were digitized from 1:25,000 maps and then generalized to the 1 x 1 km grid of sampling points.

Weathering rate: The 23 categories of the 1:500,000 soil map "Atlas der Schweiz", edited by the Federal Office of Topography, are assigned to weathering rate classes as proposed in the Mapping Vademecum. Some categories were not suitable to distinguish calcareous and non-calcareous soils. Therefore, soil acidity values from the NFI were used to recognize calcareous soils (surface pH > 6.2). Then the weathering rate, which is assigned to a certain weathering rate class, is corrected by the influence of soil temperature. The temperature is estimated by a linear regression with the altitude for two different climate zones.

Base cation and nitrogen uptake: The harvesting rate (from the NFI) and values for the element content in stems (proposed by the CCE) are multiplied. Branches are not included.

Annual average growth: Actual measurements from the national forest inventory. Current harvesting rates are low in the mountains and near zero in the southern Alps. (Eventually this point will be readdressed.)

Precipitation surplus: Precipitation minus evapotranspiration.

Precipitation: 1 x 1 km grid supplied by the Swiss Meteorological Institute, produced by processing a large set of measurements with kriging interpolation methods.

Evapotranspiration: Empirical linear regression with altitude. Three climate zones are distinguished. Evapotranspiration values are then increased by 240 mm/yr. for coniferous forests, 120 mm/yr for deciduous forests, and decreased by 30% for shady regions, which are evaluated on a digital elevation model.

Base cation deposition: EMEP data and dry deposition factors from the CCE.

Data processing: The main part of the database is contained in ARC/INFO point coverage, which can by overlaid by the EMEP or longitude-latitude grids for statistical analysis. Maps are plotted after classification and point-to-polygon aggregation in a scale of 1:1,000,000.

Modifications: In many cases the steady state mass balance method returned slightly negative critical load values for alpine lakes, even at unmanaged sites. This may result from inaccurate input data and effects that are not included in the present model. Where this occurred, the critical load was set arbitrarily to a value of 100 mol_c ha^{-1} yr^{-1}.

REMARKS: The critical loads of acidity obtained for forest soils in alpine areas by applying the steady state mass balance method need further scientific discussion. Therefore, the results will be rediscussed in Switzerland, and later alterations may be possible.

FIGURES:

A1.40. Switzerland: Critical loads of actual acidity.
A1.41. Switzerland: Precipitation surplus (runoff).
A1.42. Switzerland: Weathering of base cations.

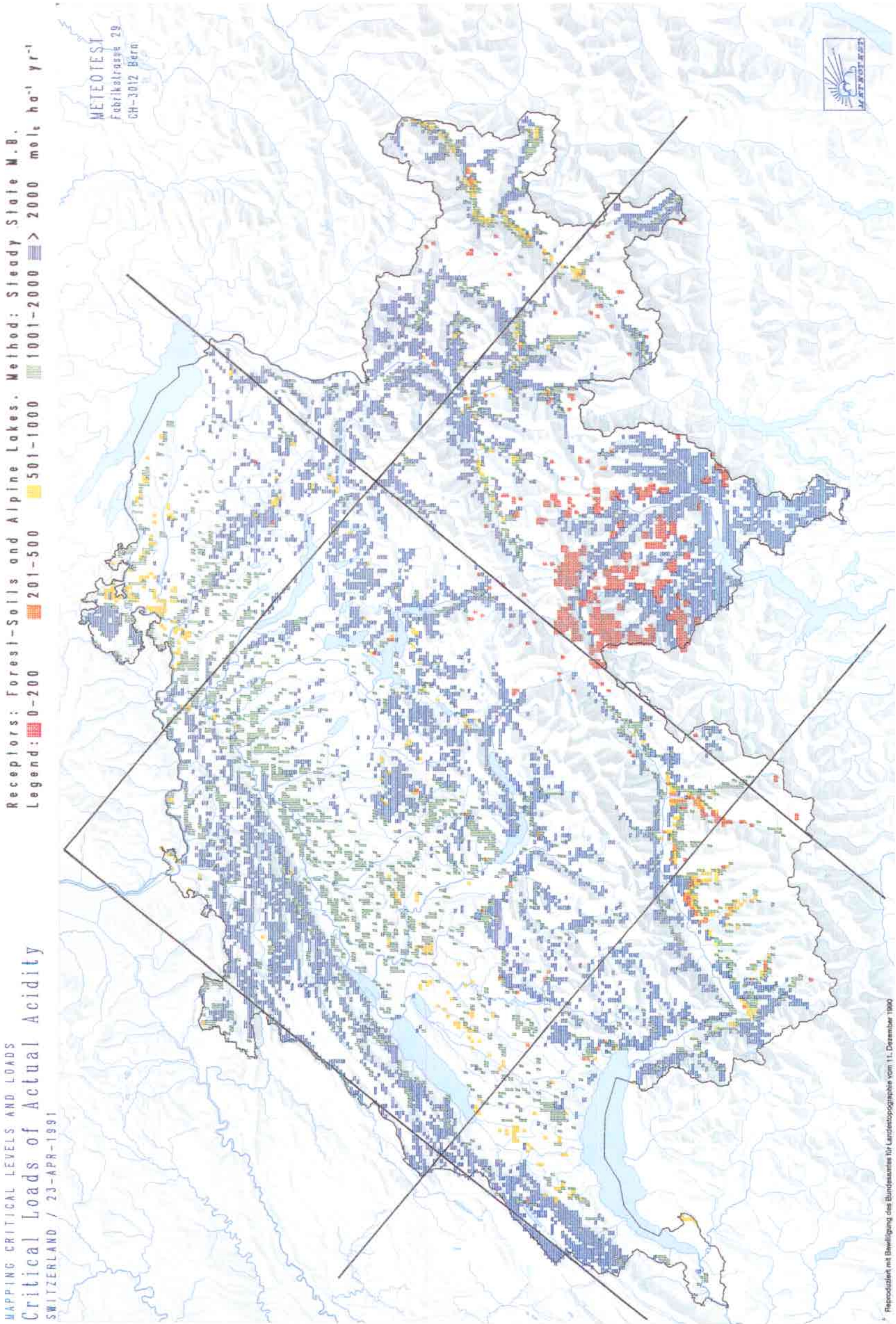

Figure A1.40. Switzerland: Critical loads of actual acidity.

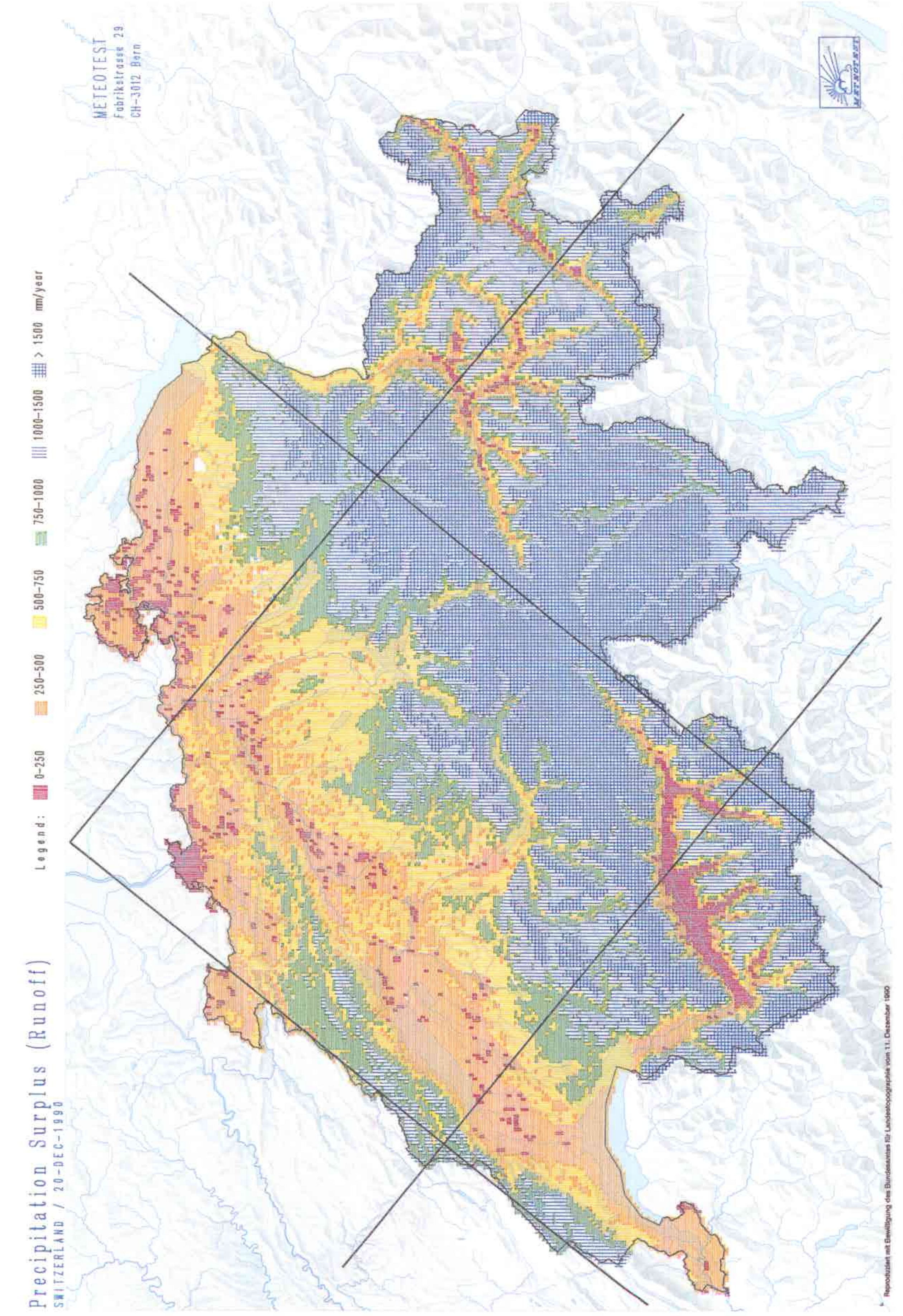

Figure A1.41. Switzerland: Precipitation surplus (runoff).

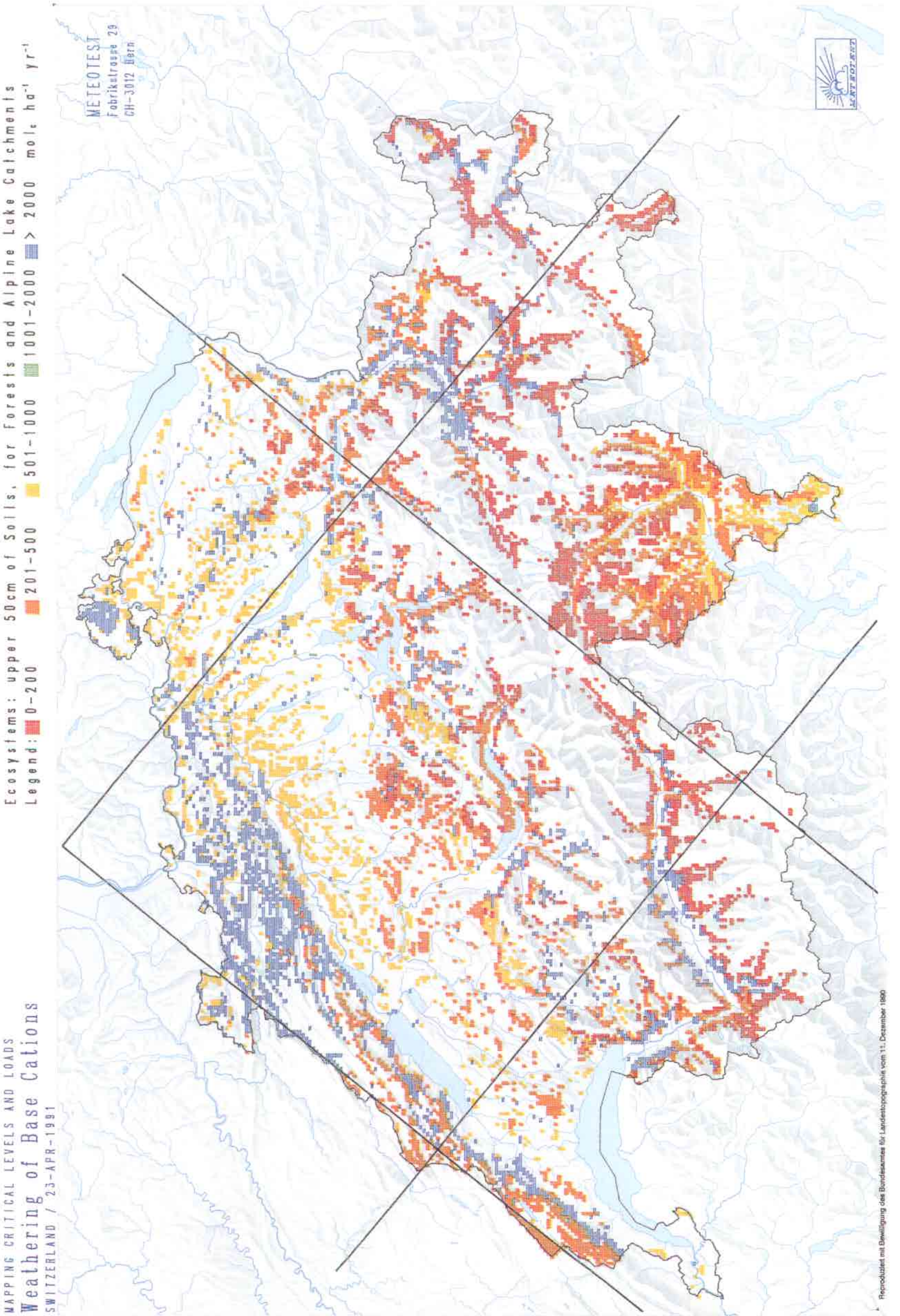

Figure A1.42. Switzerland: Weathering of base cations.

UNION OF SOVIET SOCIALIST REPUBLICS

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RECEPTORS MAPPED: Surface waters, forest ecosystems.

PERCENTILES MAPPED: 5 and 50 (preliminary results).

GRID SIZE: 150 x 150 km.

A. FOREST ECOSYSTEMS

Critical Loads of Acidity: CL(Ac):

CALCULATION METHOD: "Level 0" approach and simple mass balance, according to the Mapping Manual (UN ECE, 1990a). The five "Skokloster soil classes" for the European part of the Soviet Union (EPSU) were obtained by the "Level 0" approach. Modification and testing of the classification were carried out by the simple mass balance method.

$$CL(Ac) = BC_w - BC_u - ANC_l - AC_n \qquad (A1.8)$$

BC_w = 0.4 - 2.8 kEq ha^{-1} yr^{-1}. The maximum values of weathering rate (for calcareous soils) were accepted as conditional values.

BC_u = 0.1 - 1.0 kEq ha^{-1} yr^{-1}. The base cation uptake values in net growth of biomass were calculated for the productivity classes of forest stands. This parameter must be saved, in order to not disturb the balance of "input - output".

ANC_l = 0 - 0.3 kEq ha^{-1} yr^{-1}. The precipitation surplus (Q) was defined as precipitation minus evapotranspiration minus surface run-off. An acceptable limit for forest ecosystems was taken for the "groundwater" criteria ([Alk] crit = 0.1 mEq l^{-1}), because we suggest that the subterranean water is the most sensitive receptor inside forest ecosystems.

AC_N = 0. The acidity in soil associated with nitrogen was accepted equal to zero, because NH_4^+ and NO_3^- ions balances enter in considering ANC.

DATA SOURCES: The values of precipitation, evapotranspiration and surface runoff were taken from data of the Hydrometeorological Service of the USSR.

Weathering rates were estimated based on four parameters:
- Class of geochemical landscape. Data were used from the map of geochemical landscapes (Hauka, 1989)
- Soil type. (Map of soil types from the USSR Forest Atlas, 1973).

- Predominant parent material. (Data from the USSR Atlas, 1986); and
- Texture of soils. (State soil map of the USSR).

On the EPSU map (1:15,000,000), regions were separated into five weathering rate classes (Table A1.11). Values assigned are in Table A1.12.

Table A1.11. Estimated values of weathering rates in forest soils in the EPSU.

Class	Class of geochemical landscape	Soil types	Parent material	Soil texture
1	Acidic, acidic gley	Bog-podzolic, gley-podzolic, peat	Granite, quartz	Sandy
2	Low acidic, acidic	Podzolic	Gniess, granite	Sandy loam
3	Transitional from acidic to calcitic	Soddy-podzolic, gray forest	Granodiorite, gabbro, aspidic shale	Clay loam
4	Calcium-sodium, alkalined	Meadow, brown forest, alkalined brown earth	Gabbro, basalt	Clay loam
5	Carbonaceous, gypseous	Soddy-carbonaceous, black earth, chestnut	Limestone, clay limestone	Clay

Table A1.12. Values of input parameters for calculating critical loads of acidity.

Weathering Class	Base cation weathering rate (BC_w)	Base cation uptake in net growth (BC_u)	Critical rate of leaching (ANC_l)	Critical load of acidity CL(Ac)	Critical load of sulphur: CL(S) kg S ha^{-1} yr^{-1} (5 percentile)
1	0.4 - 0.6	0.1	0.1 - 0.2	0.1 - 0.2	1 - 2
2	0.6 - 1.0	0.2 - 0.4	0.1 - 0.2	0.2 - 0.5	2 - 6
3	1.2 - 1.6	0.4 - 0.6	0.1 - 0.3	0.5 - 1.0	6 - 12
4	1.8 - 2.2	0.6 - 1.0	0.1 - 0.3	1.0 - 2.0	12 - 25
5	2.4 - 2.8	0.1 - 0.6	0.0 - 0.1	> 2.0	25 - 35

In each 150 x 150 km cell, the weathering rate was accepted as the lowest weathering rate class to be represented for this cell. The values used for calcareous soils were > 2.2 kEq ha^{-1} yr^{-1}, as the weathering rate here is defined by the acid load.

Base cation uptake in net growth of biomass (BC_u) was calculated for the classes of productivity (Table A1.12). Content of Ca, Mg and K in wood was established from literature sources (Larcher, 1980; Kimmins, 1987).

The acceptable rate of alkalinity leaching (ANC_l) was determined by the formula:

$$ANC_l = 0.01 \cdot [ANC]_{limit} \cdot Q \qquad (A1.9)$$

where:
$([ANC]_{limit}$ = Acceptable concentration of alkalinity in groundwater (mEq l^{-1})
Q = delayed runoff of water (mm yr^{-1})

As a criterion for estimating $[ANC]_{limit}$, the Skokloster value of critical groundwater alkalinity of 0.10 - 0.14 mEq l^{-1} was used. The criterion of soil acidity ($[ANC]_{limit}$ = > -0.30 mEq l-1), corresponding to a critical acidity of soil of pH 4.0 - 4.2, was rejected for the following reasons:
- it does not protect soils having a pH from > 4.0 to 4.2;
- it admits very high load on acidic soils which have a pH from < 4.0 to 4.2;
- it does not protect the most sensitive receptor of forest ecosystems, i.e., groundwater, against acidification in contradiction to the critical load concept.

Thus the values for ANC_l varied from 0.0 to 0.3 kEq ha^{-1} yr^{-1}, depending on runoff.

The in-soil acid generation from nitrogen compounds, AC_n, was assumed to be zero, as necessary data on NH_4^+ and NO_3^- content in soil solution was unavailable. As the balance of these ions is included in the calculation of ANC (Sverdrup *et al.*, 1990), then Equation A1.8 resembles the water chemistry method, which assumes the full uptake of nitrogen compounds by vegetation. Probably the necessity of including AC_n or N_u into the equation requires further investigation and more reliable generalization. We support the proposal of the Stockholm Environment Institute to use the formula $CL(Ac) = BC_w - (Q \cdot [Alk]_{crit})$.

The most characteristic values obtained are shown in Table A1.12. The geographical distribution of critical loads for acidity in the EPSU is shown in Figure A1.43. The data obtained are in good agreement with the SEI map (Chadwick and Kuylenstierna, 1990). There are discrepancies between our data and the CCE maps produced using the European data base.

Critical Loads of Sulphur (CL(S)):

CALCULATION FORMULA: $CL(S) = 16 \cdot CL(Ac) \cdot S_f$ (A1.10)

where:

$$S_f = \frac{CL(Ac)}{NO_3 \text{ deposition} + CL(Ac)} \qquad (A1.11)$$

Here NO_3 is nitrate deposition which is averaged for each weathering rate class. The calculations showed that the value of the sulphur fraction ranges from 0.7 to 0.9. The geographical distribution of critical loads for sulphur in the EPSU is shown in Figure A1.44.

We believe that the role of ammonium (NH_4^+) in acid deposition needs more definite evidence.

DATA SOURCES: The N (NO_3) deposition values (1985) were borrowed from the papers of the EMEP MSC-W.

Critical Loads of Nutrient Nitrogen (CL(NN)):

CALCULATION FORMULA: $CL(NN) = Nu + N_i + N_l$ (A1.12)

N_u = 3-40 kg ha^{-1} yr^{-1}. The nitrogen uptake in net growth of biomass was calculated for the productivity classes of forest stands. The hoard of biomass was established based on Bazilevich (1984) and the forest atlas of the USSR.

The carbon content in the biomass is accepted in an amount of 45% and a nitrogen : carbon ratio = 1:40 (Larcher, 1980; Kimmins, 1987; see Table A1.13).

Table A1.13. Calculation of nitrogen uptake values in net growth of biomass.

Productivity Class	Biomass hoard, t yr^{-1} (dry basis)	Net growth of biomass, t yr^{-1} (dry basis)	Net growth of biomass, t yr^{-1} carbon (45%)	Nitrogen uptake in net growth, kg/N ha^{-1} yr^{-1}
1	25 - 90	0.2 - 0.4	0.1 - 0.2	3 - 5
2	100 - 200	0.6 - 1.5	0.3 - 0.7	8 - 18
3	200 - 250	2.0 - 2.5	0.9 - 1.1	20 - 28
4	250 - 300	2.5 - 3.0	1.1 - 1.4	28 - 35
5	300 - 350	3.0 - 3.5	1.4 - 1.6	35 - 40

N_i = 1-3 kg ha^{-1} yr^{-1}. The long-term immobilization of nitrogen values were accepted according to the proposals of the Skokloster workshop (1988).

N_l = 0-3 kg ha^{-1} yr^{-1}. The acceptable nitrogen leaching was calculated according to:

$$N_l = 0.01 \cdot Q \cdot N_{limit} \quad \text{(A1.13)}$$

where N_{limit} = critical content of mineral nitrogen in groundwater (mg N l^{-1}).

The value for Q was calculated by the water balance equation:

$$Q = P - E - R \quad \text{(A1.14)}$$

where:
P = mean annual rainfall
E = evapotranspiration in forest ecosystems
R = surface runoff

The values for P, E, and R were taken from departmental and literature values (Moltchanov, 1973, Water Resources, 1980; L. Hydrometeoizdat, 1981). Depending on physical/geographical conditions, delayed runoff ranges from 100 - 300 mm yr^{-1} in forest and partially wooded steppe. Runoff approaches zero in arid zones.

A critical content of nitrogen in delayed runoff, equal to 1.0 mg N/liter, has been conditionally accepted. This value is most representative for delayed runoff in the forest ecosystems of "clean" (background) EPSU regions. It appears that the "acceptable" limit $[NO_3]$ crit = 50 mg/l is extremely high. Moreover, nitrogen in nitrate (NO_2^-) and ammonium (NH_4^+) is also a factor in the eutrophication of groundwater, and the critical level was established at a very low value (Zenin and Belousova, 1988). Rosén (1991) used the value of NO_3^- critical content in range of 0.3 mg l^{-1}. The range of values offered is rather wide. Thus, N_l values for Equation A1.13 ranged from 0 to 3 kg ha^{-1} yr^{-1}.

Table A1.14 and Figure A1.45 show the most representative values of critical loads for nitrogen for forest ecosystems in the aspect of eutrophication.

The calculations did not consider the differences in consumption of nitrogen by coniferous and deciduous stands, nor the nitrogen discharge caused by wood felling, for the following reasons:
- in cells of any dimensions (even 10 x 10 km), both coniferous and deciduous stands will nearly always be present;
- in cells of any dimension, one can not separate the areas where wood felling is done or not.

Table A1.14. Values of the parameters in Equation A1.12 for calculating critical loads of nitrogen.

Productivity Class	uptake in net growth (N_u)	acceptable accumulation in soil (N_{imm})	acceptable rate of leaching (N_l)	critical load of nitrogen (50 percentile)
1	3 - 5	3	0 - 1	6 - 8
2	8 - 18	3	0 - 1	10 - 20
3	20 - 28	2	1 - 2	20 - 30
4	28 - 35	1	2 - 3	30 - 40
5	35 - 40	1	2 - 3	40 - 45

B. SURFACE WATERS

CALCULATION METHOD: The steady-state water chemistry method.

CALCULATION FORMULA: $CL = ([BC]^*_0 - ANC_{limit}) \cdot Q - BC^*_d$ (A1.15)

where:
CL = sulphate critical load
$[BC]^*_0$ = pre-acidification non-marine basic cation concentration
ANC_{limit} (Alk crit) = the critical ANC level
BC^*_d = atmospheric deposition of non-marine basic cations

The result of calculations was the critical load value in kg S ha^{-1} yr^{-1} or in keq ha^{-1} yr^{-1}.

REMARKS:

Peculiarities of the estimation of CL: In order to calculate the CL values the background values of the chemical characteristics were used. (The only exception was the territory of Kola peninsula near the Norway boundary). That is why technogenic atmospheric depositions of basic cations (BC^*_d) were not taken into account.

Each EMEP grid (150 x 150 km) was divided into 4 subgrids (75 x 75 km) and, for the Kola peninsula, into 36 subgrids (25 x 25 km). The maps of subgrids were used as a base for selection of lakes and rivers. Among the lakes and rivers inside each subgrid there were selected the most sensitive ones. Sensitivity was evaluated on the basis of water chemistry, soils, topography and bedrock geology. For the estimation of critical loads the characteristics of about 1,000 lakes and rivers were used. For the subgrids of the northern and central parts of the EPSU the results of field research were used. For some parts of arid territories the method of approximation was used. The results of the estimations of critical load values in the subgrids were generalized into EMEP grids (150 x 150 km).

DATA SOURCES: For the calculation of critical load values there was used the data on chemical characteristics of the surface waters of the EPSU, collected by Hydrometeorological Service of the USSR, the data of the Ministry of Fishing Industry, the data collected by the Institute of Nature Conservation and Reserves, and the data collected by different regional institutes of the system of Academy and Science of the USSR.

C. CRITICAL LOAD EXCEEDANCES

Figures A1.46 and A1.47 show the total deposition (dry and wet) of nitrogen and sulphur in 1985. These data are from the EMEP Meteorological Synthesizing Center - West. The comparison of nitrogen critical loads (Figure A1.45) with nitrogen deposition reveals that there was no exceedance in any cell. This fact is evidence of high uptake capacities of forest ecosystems and confirms our assumption about the minor contribution of nitrogen deposition to direct soil acidification.

Figure A1.48 shows the exceedance of critical loads of sulphur which were obtained as a quotient of dividing deposition by the critical load values. It permits to outline risk areas on the EPSU, forecast the conditions of forest ecosystems, and develop a scenario of reducing emissions of sulphur compounds.

In conclusion, it is worthwhile to point out that the exceedance of the SO_2 critical level (20 $\mu g\ m^{-3}$) was detected in only one EMEP grid cell (number 32/27) in the region of Donetsk. This shows that critical loads are more strict and perhaps more precise tools for LRTAP Convention purposes. However, essential disagreements in estimations of the effect caused by critical loads and critical levels to forests require more detailed explanations.

FIGURES:

A1.43. USSR: Distribution of critical loads of acidity.
A1.44. USSR: Distribution of critical loads of sulphur.
A1.45. USSR: Distribution of critical loads of nutrient nitrogen.
A1.46. USSR: Total nitrogen deposition in 1985 (MSC-W, 1990).
A1.47. USSR: Total sulphur deposition in 1985 (MSC-W, 1990).
A1.48. USSR: Forest areas where critical loads of sulphur were exceeded in 1985. (sulphur deposition:sulphur critical loads.)

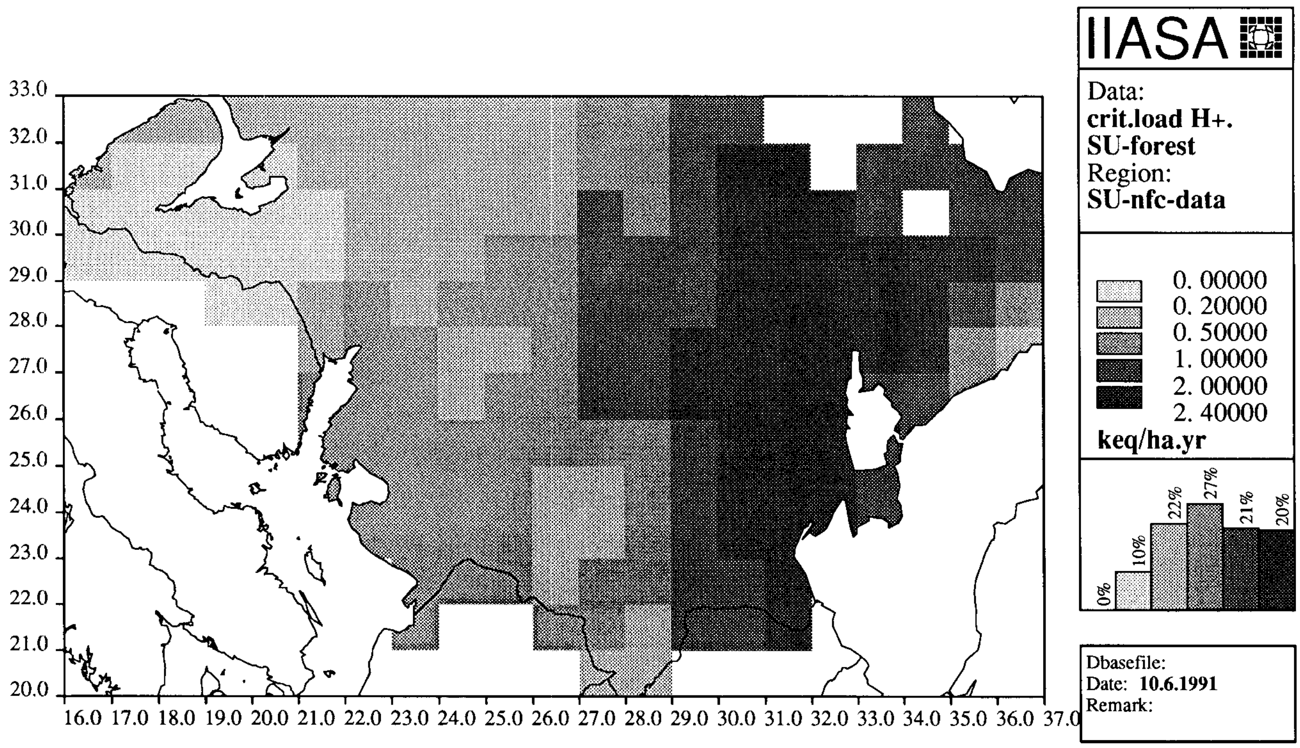

Figure A1.43. USSR: Distribution of critical loads of acidity.

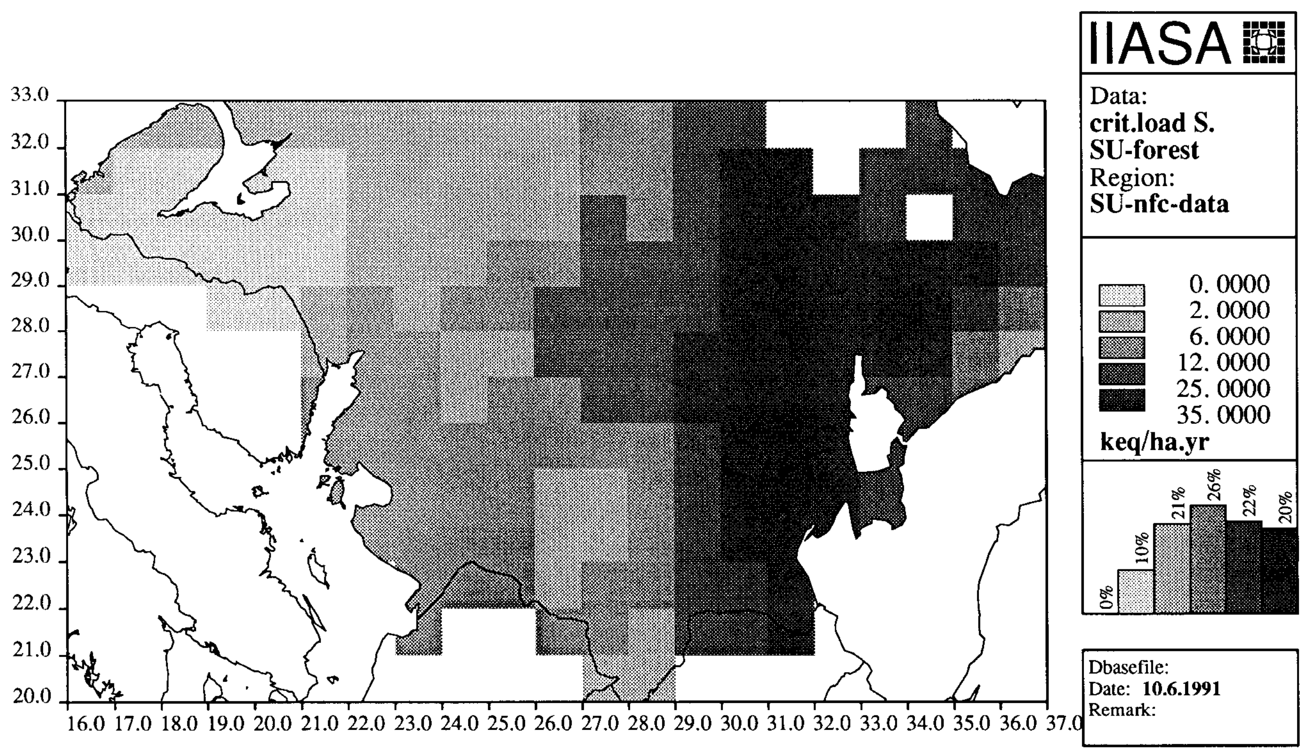

Figure A1.44. USSR: Distribution of critical loads of sulphur.

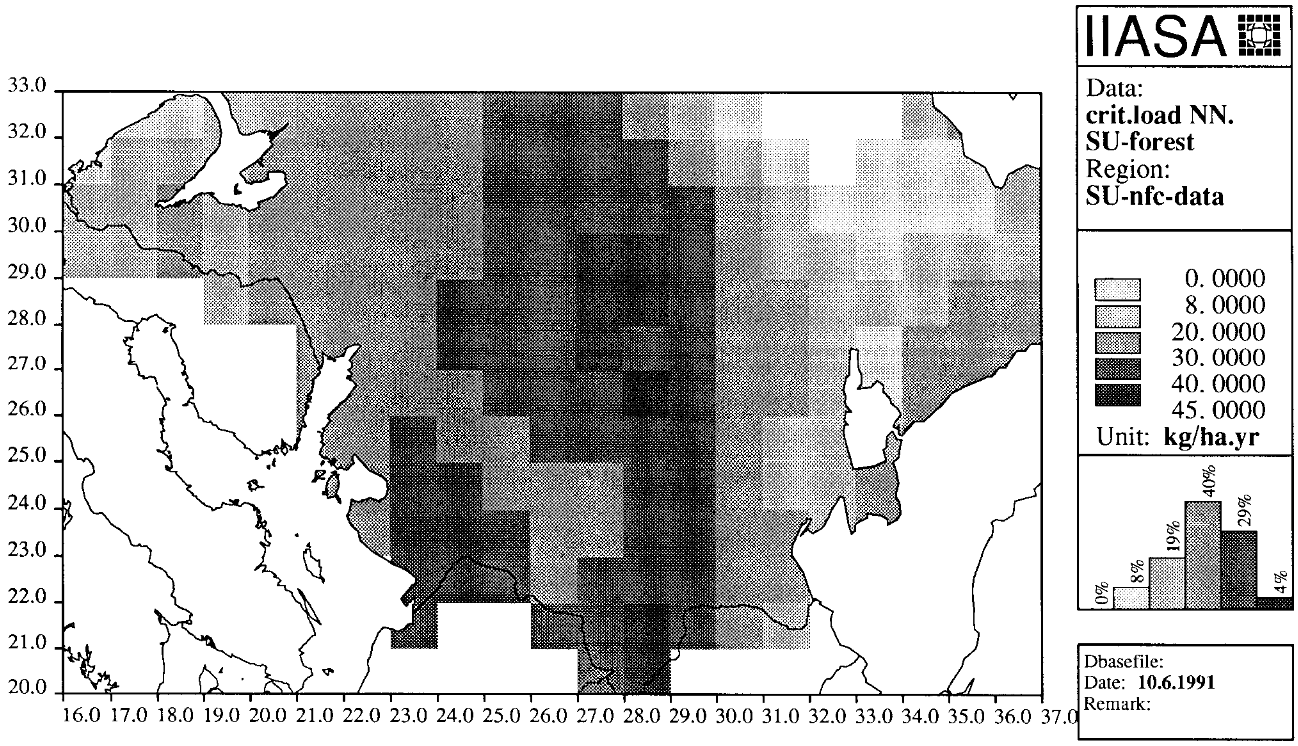

Figure A1.45. USSR: Distribution of critical loads of nutrient nitrogen.

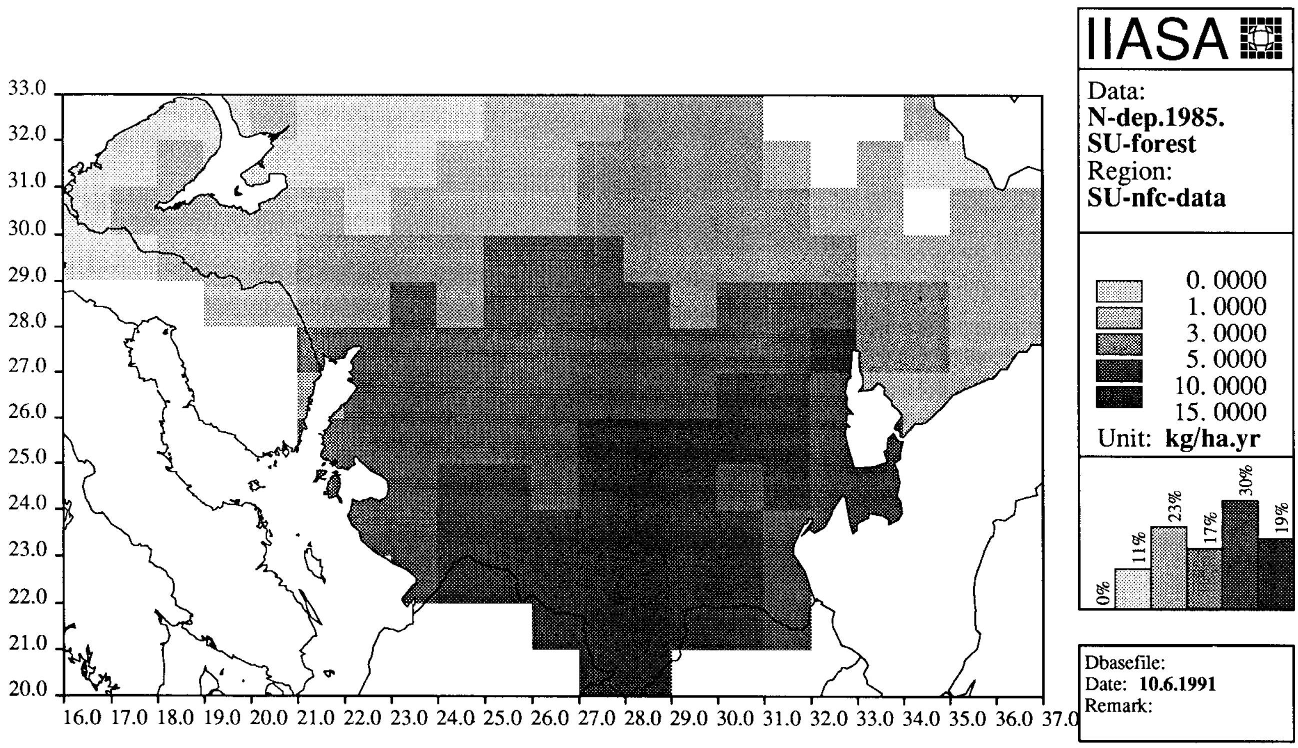

Figure A1.46. USSR: Total nitrogen deposition in 1985 (MSC-W, 1990).

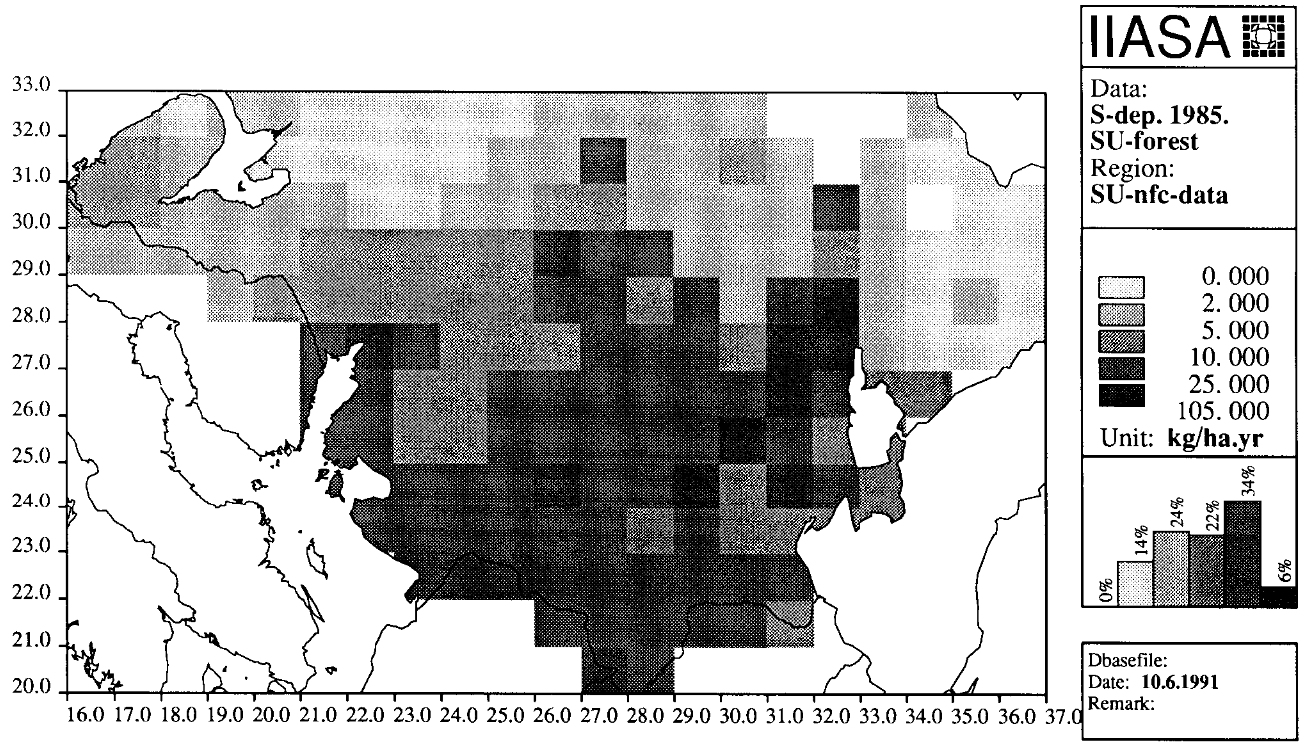

Figure A1.47. USSR: Total sulphur deposition in 1985 (MSC-W, 1990).

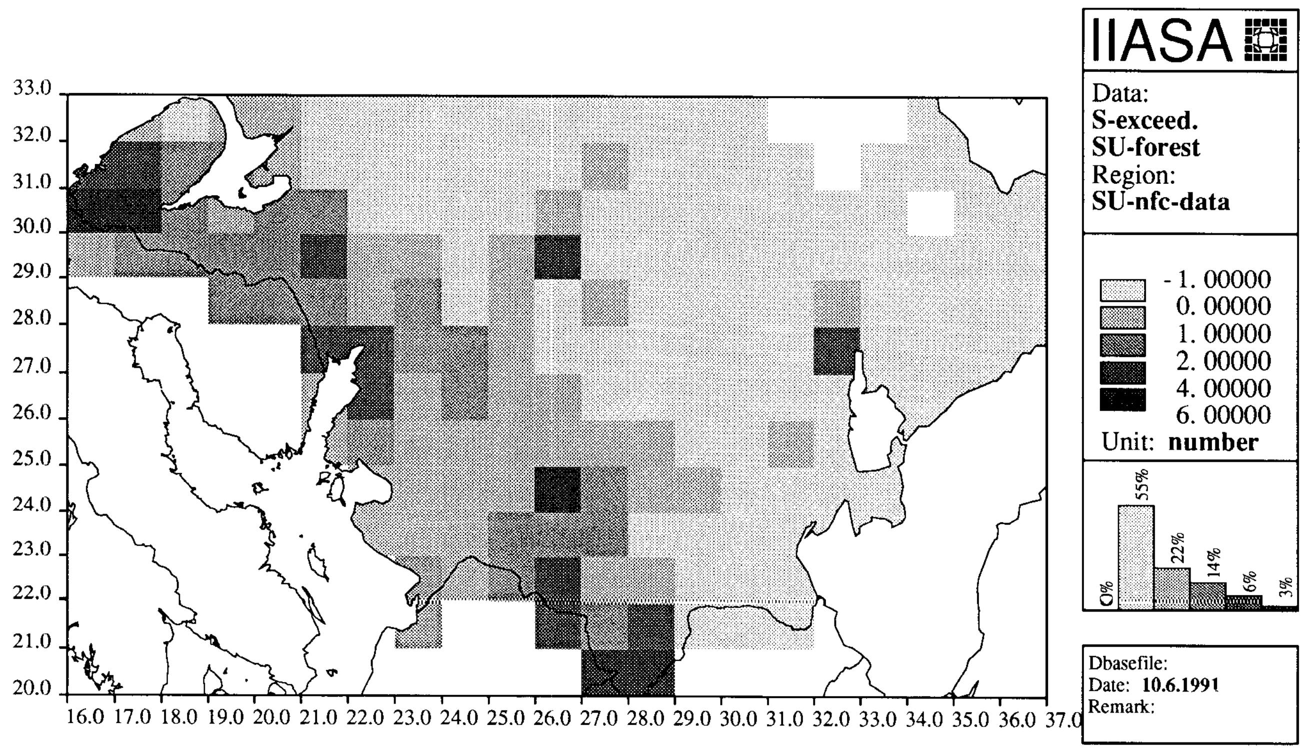

Figure A1.48. USSR: Forest areas where critical loads of sulphur were exceeded in 1985. (sulphur deposition: sulphur critical loads.)

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RECEPTORS MAPPED: Forest soils, freshwaters (case study).

CALCULATION METHOD: Level 0, as described in Section 3.3.1.3. The map is based on 1-km squares of the UK Ordnance Survey national grid and on 1:250,000 scale soil maps, and supporting data bases. The soil maps for England and Wales were produced and published by the Soil Survey and Land Research Center (1983), and for Scotland by the Macauley Land Use Research Institute (1981). Each 1-km square was assigned a critical load for total deposited acidity on the basis of the critical load of the soil map unit which occupied the largest proportion of the square. The map units were assigned a critical load following their allocation to one of five Skokloster soil classes (from Nilsson and Grennfelt, 1988), based on soil mineralogy. The soil classes in this map have been assigned a single critical load value; the upper limit of the Skokloster bands. This has been done to facilitate the production of exceedance maps showing areas where the critical loads are exceeded.

On the soil maps covering Scotland, the map units, which are identified by number, comprise groups of soils, from a given soil association, occurring within a distinct landscape/morphological unit. The associations are assemblages of soil series formed on a given parent material. The maps were initially allocated to one of the five Skokloster soil classes on the basis of available information on the mineralogy of the parent material of the relevant soil association. This initial allocation was then modified, where necessary, using modifiers based on soil depth, texture and drainage as suggested at Skokloster. Thus, where a map unit was dominated by shallow soils on slopes, the soil class based on mineralogy was decreased by one class. Conversely, in units dominated by deep soils or soils inundated regularly the class was increased by one.

The map units on the maps covering England and Wales are soils associations, which are groups of soil series occurring within defined, distinct landscape/geomorphological units. The parent material can vary within the association, but only within narrow limits. The associations with England and Wales are named after the most widespread soil series within the association. The map units were initially allocated to a soil class on the basis of the mineralogy of the most widespread soil series within the association. This initial allocation was modified, where necessary, after making allowances for variations in soil depth, texture and drainage conditions, as with the units on the maps covering Scotland.

Organic soils cannot be allocated to one of the Skokloster classes on the basis of mineralogy. An approach has been developed in the Department of Plant and Soil Science, University of Aberdeen has therefore been used. Map units dominated by base-poor peats were allocated to one of the five soil classes on the basis of the H^+ load (as H_2SO_4) which would result in a pH reduction in the surface layers of the peats, in the given location, of > 0.2; it is assumed that reductions in pH of < 0.2 would not have significant ecological consequences. The boundaries between classes have been set using the results of laboratory equilibration studies, and data on the relationship between changes in surface horizon pH of peats in Scotland over the last 20 years and inputs of acidic deposition over that period. The input of acidity over the last 20 years has included both nitric and sulphuric acid. In order to assign the peats to one of the five classes based on sulphur alone, it has been assumed that 70% of the input of acidity was as sulphuric acid and 30% as nitric acid. Where 30% of recent input; i.e., the nitric acid portion, has produced a reduction in pH of > 0.2, the peat unit is allocated to the most sensitive class, Class 5. Where 30% of recent input would produce a reduction in surface pH of < 0.2, then the critical load has been based on the "acceptable load" of sulphuric acid, over and above the existing nitric acid load.

Finally, a land use modifier was applied to the complete map using a data base developed by the Institute of Terrestrial Ecology (Bunce and Heal, 1984). For each 1-km square, the critical load class of the dominant soil was decreased by one unit if the dominant land use for that area was arable or improved pasture. It was assumed that in these areas lime would be added to the soil, where necessary, to maintain the pH within the optimal range for arable crops or high-yielding grass varieties. This would clearly increase the "effective critical load".

REMARKS:
A number of points must be stressed about the maps produced using the above procedures:

1. The map units portrayed on the 1:250,000 soil base maps can encompass considerable variation in soil type, although the soils within any one map units are usually related to each other by one or more important factors. However, not all soil types within a given geographical area may have been recorded at this mapping scale and not all of the ones recorded occupy a sufficiently large area to be delineated. Thus, the most sensitive soil may have been omitted because it occupies only a very small area of land.

2. The soil properties assessed as the basis for producing the critical loads maps were those of the most widespread soil (the "dominant" soil) within the soil map unit on the 1:250,000 soil map. this may not be the most sensitive of the soils forming the association which corresponds to that map unit.

3. The 1-km squares are assigned a critical load of the most widespread soil map unit within the square: in practice, the most widespread soil type within the map unit.

4. The maps are "Level 0" maps; i.e., the critical loads assigned to the soil mapping units have not been calculated using a mass balance approach, dynamic modelling or determinations of weathering rates for specific UK sites.

5. The critical loads assigned to the soil mapping units are still being validated.

The resultant maps are best seen as providing an indication of the regional distribution patterns of soils ranked in terms of a series of critical load/sensitivity classes.

FIGURES:

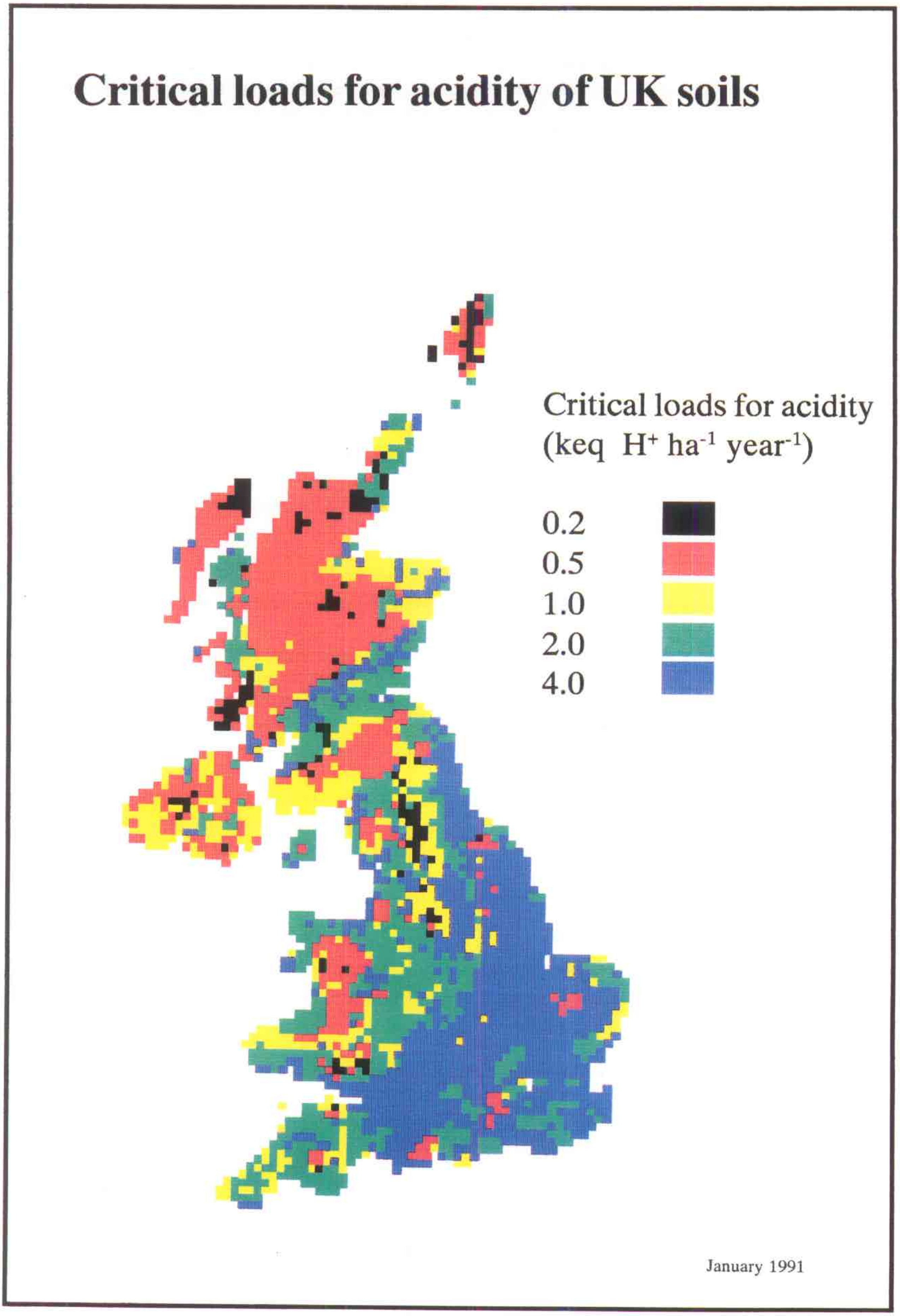

Figure A1.49. United Kingdom: Critical loads of acidity for soils.

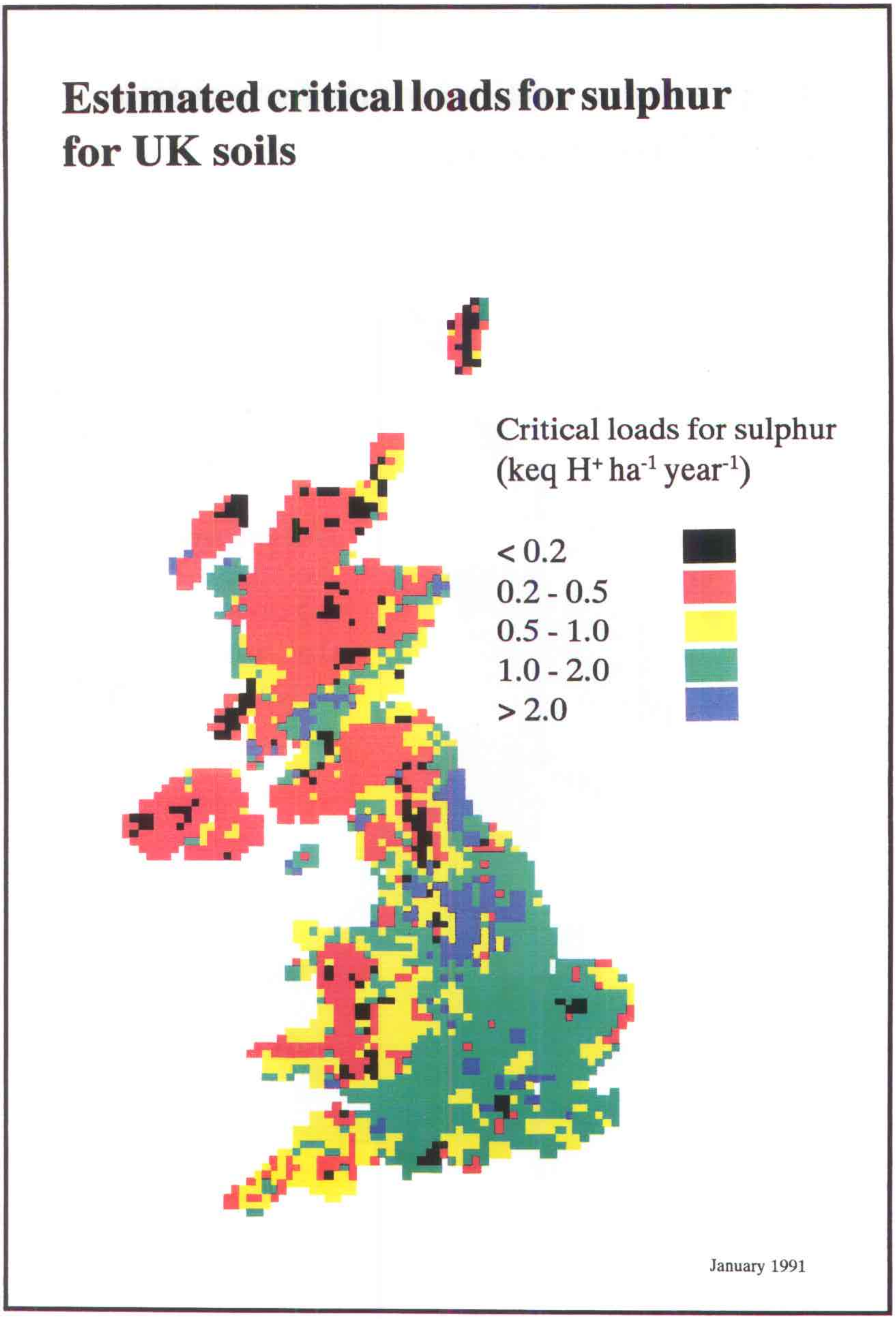

Figure A1.50. United Kingdom: Estimated critical loads for sulphur for soils.

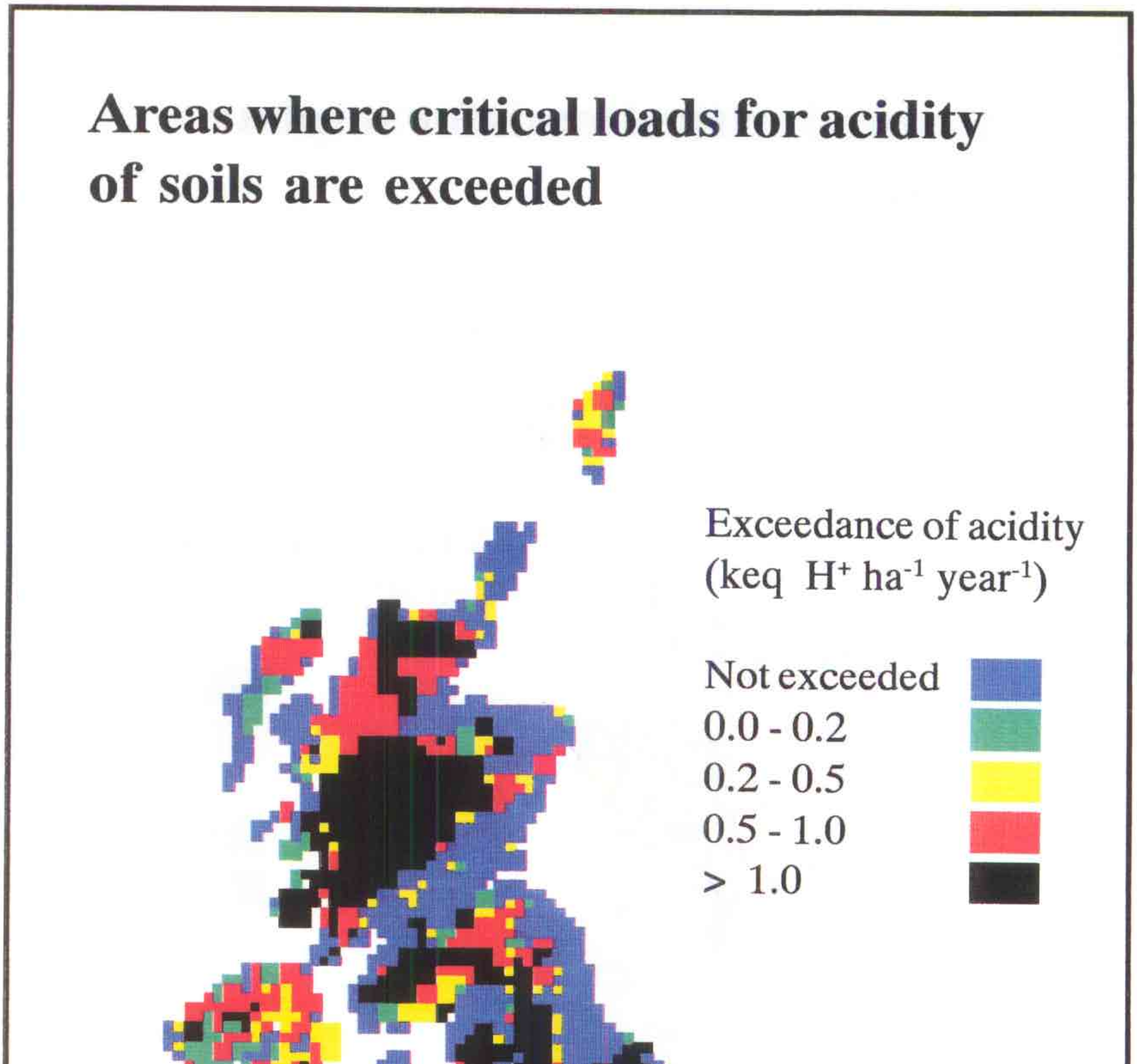

Figure A1.51. United Kingdom: Areas where critical loads for acidity for soils are exceeded.

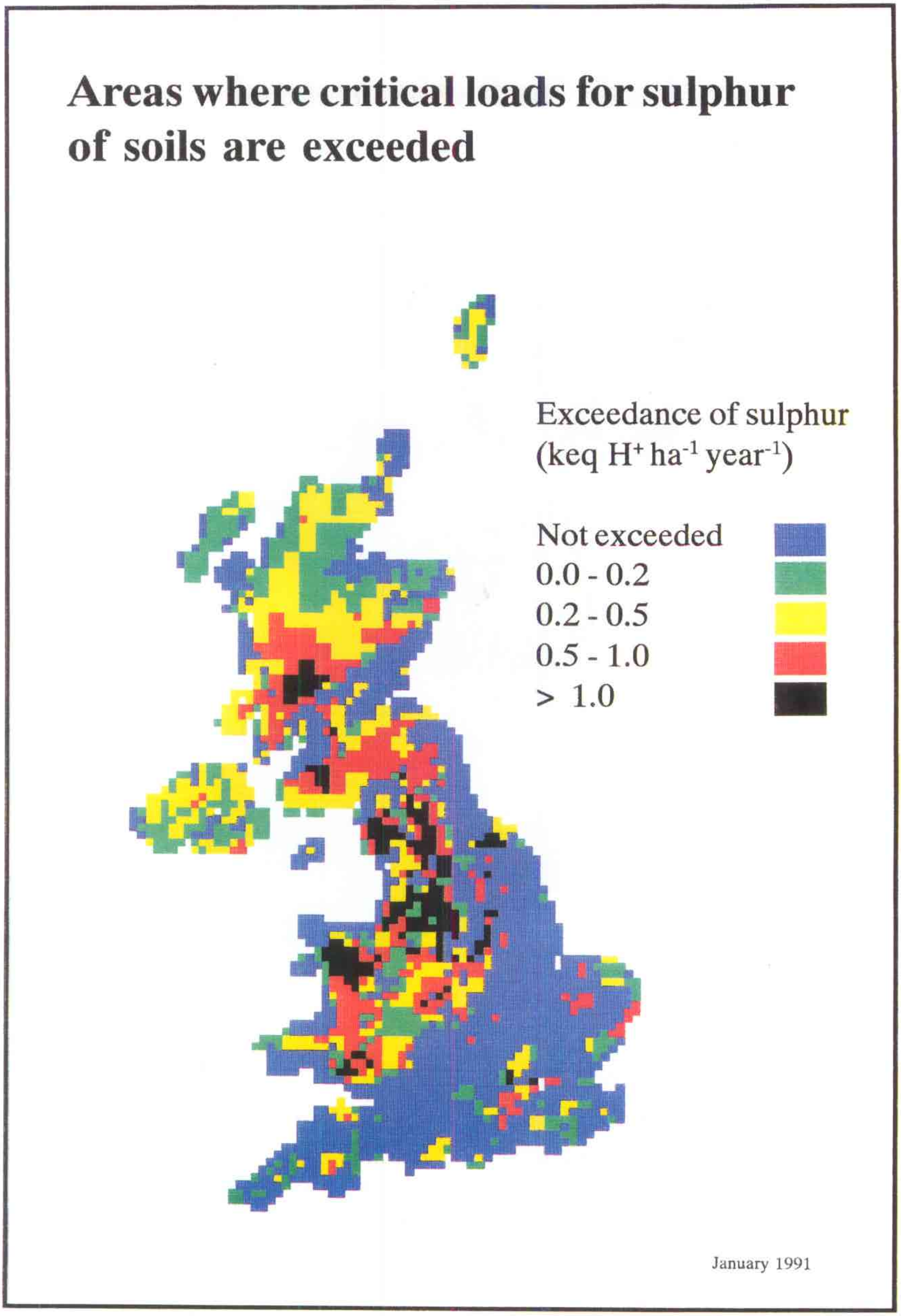

Figure A1.52. United Kingdom: Areas where critical loads for sulphur for soils are exceeded.

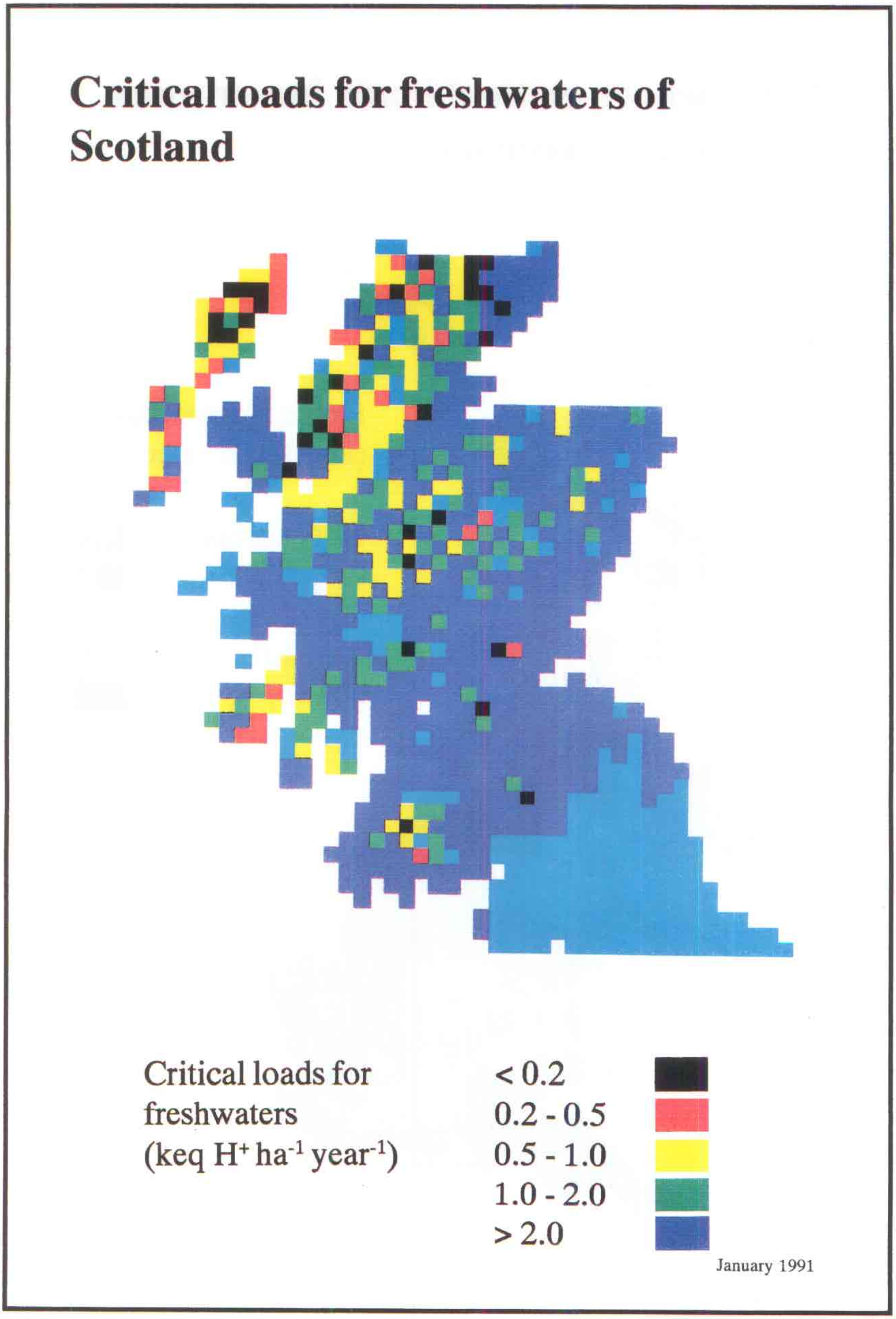

Figure A1.53. Critical loads for freshwaters (Scotland case study).

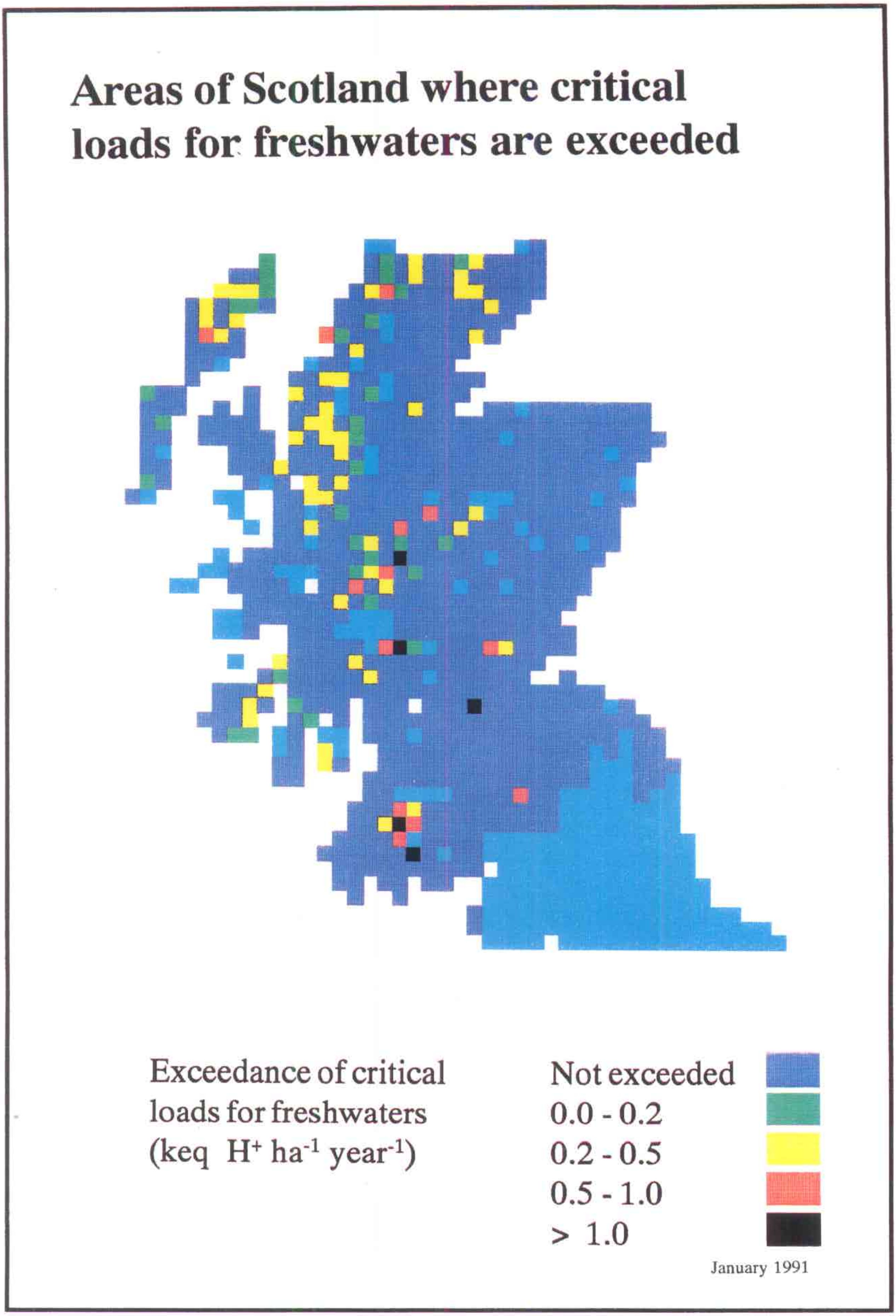

Figure A1.54. Areas where critical loads for freshwaters are exceeded (Scotland case study).

APPENDIX 2. ADDITIONAL MAPS OF CRITICAL LOADS AND BACKGROUND DATA

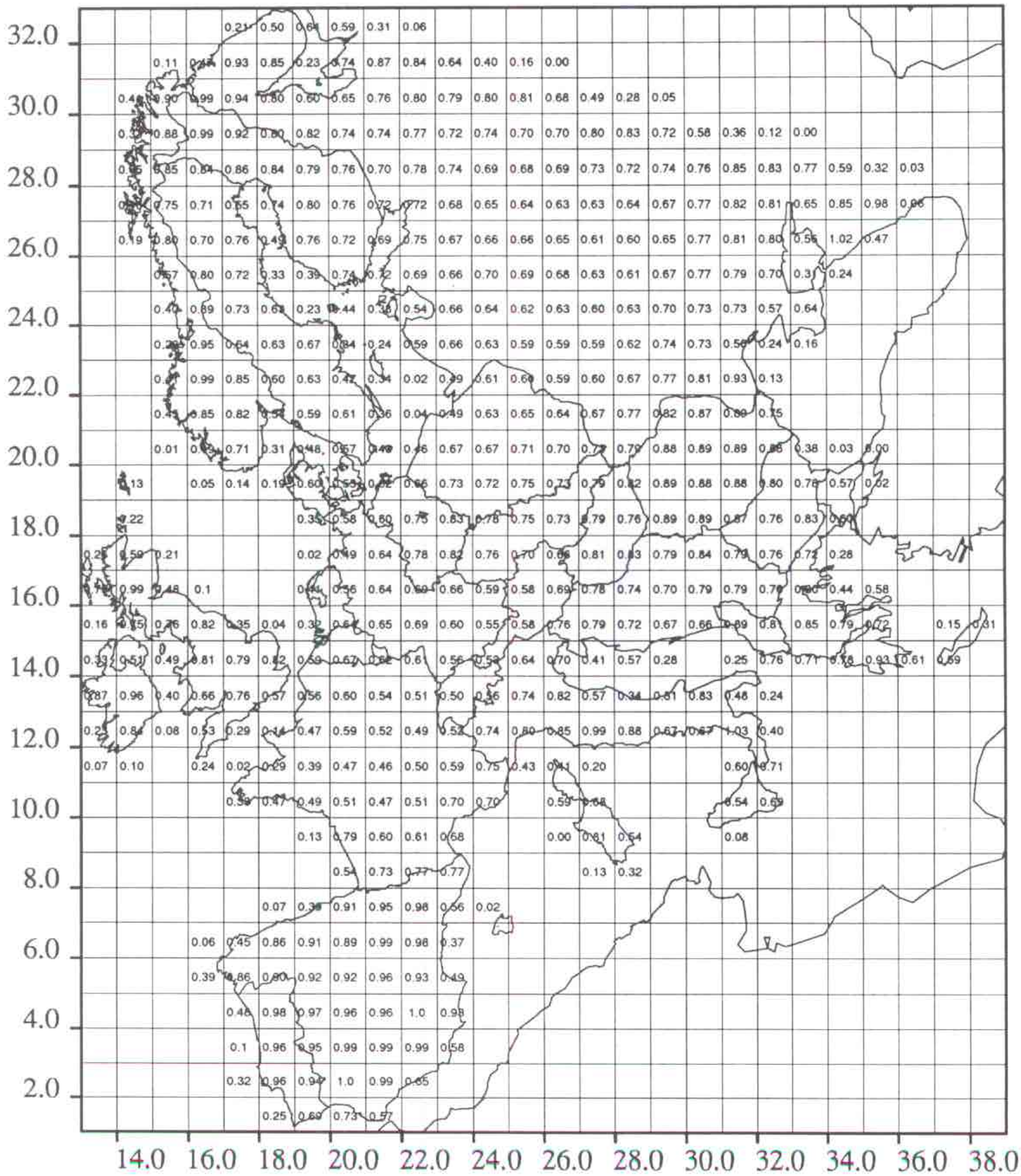

Figure A2.1. Preliminary CCE sulphur fractions computed for each EMEP grid cell.

(See Section 3.3.2 for information on the development of the sulphur fraction.)

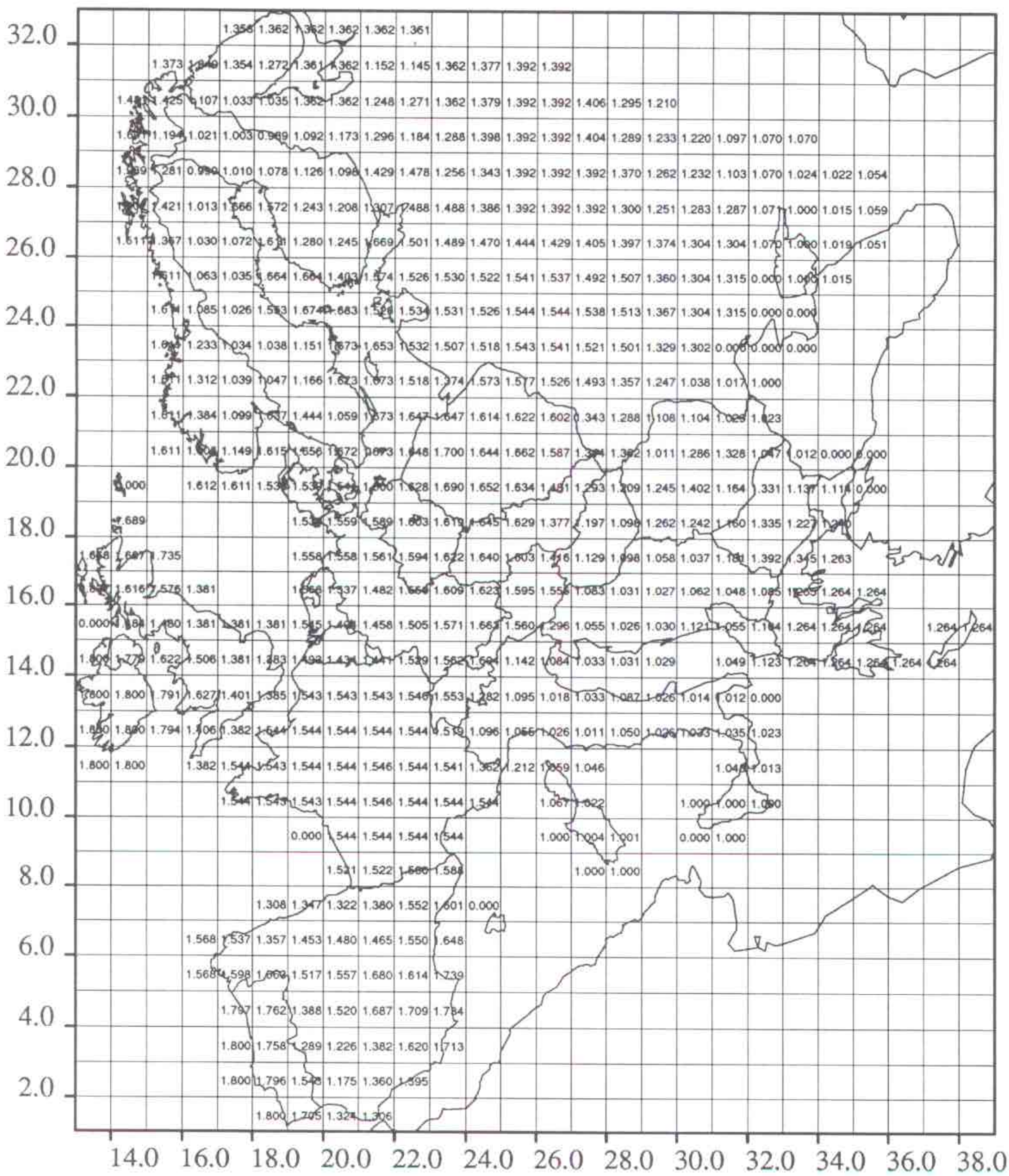

Figure A2.2. Preliminary CCE sulphur filtering factors used for the modification of EMEP deposition values in order to estimate the effect of throughfall.

(See Appendix 4 for a description of the development of filtering factors. See Appendix 3 for information on the European data base.)

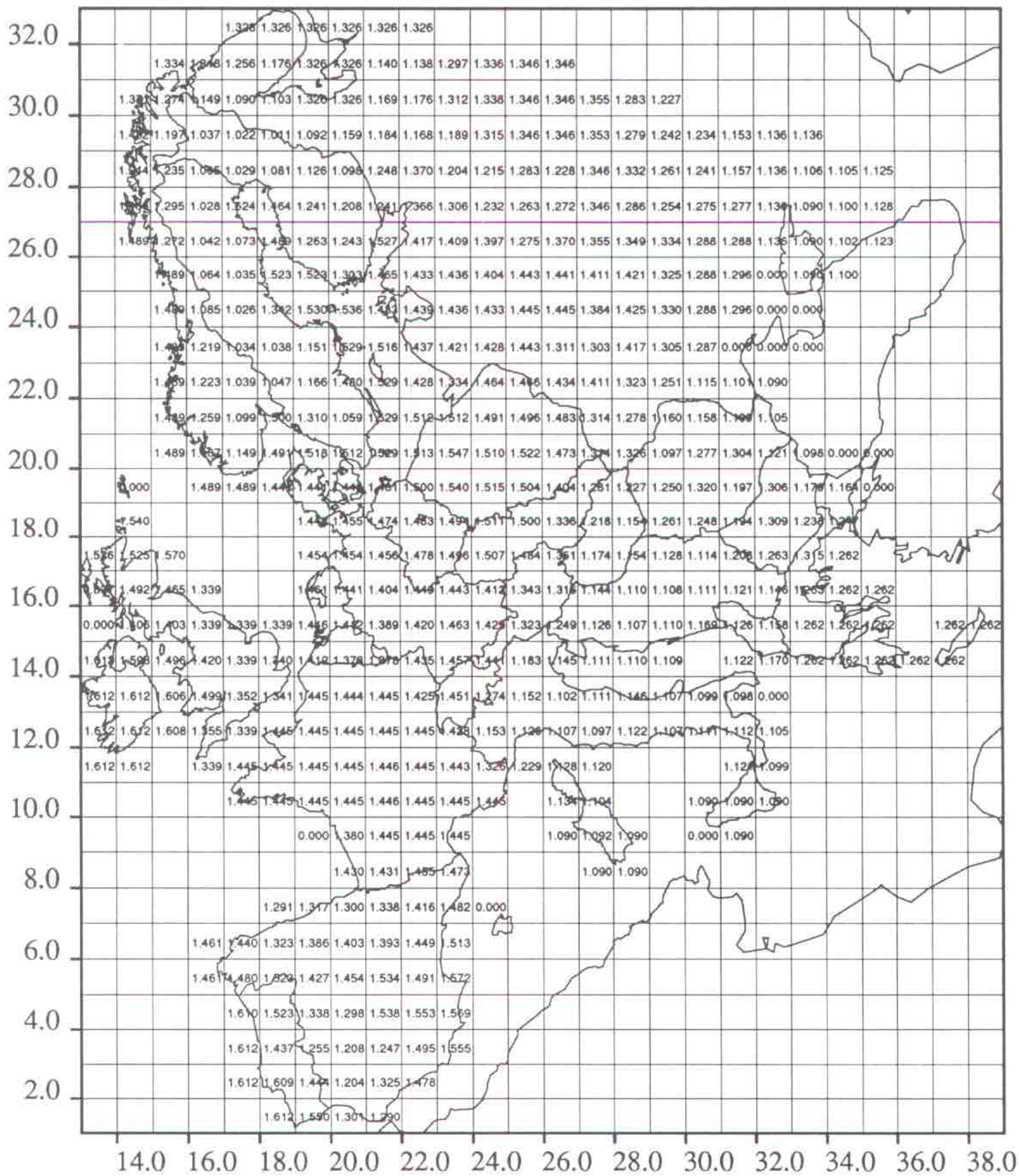

Figure A2.3. Preliminary CCE nitrogen filtering factors used for the modification of EMEP deposition computations in order to estimate the effect of throughfall.

(See Appendix 4 for a description of the development of filtering factors. See Appendix 3 for information on the European data base.)

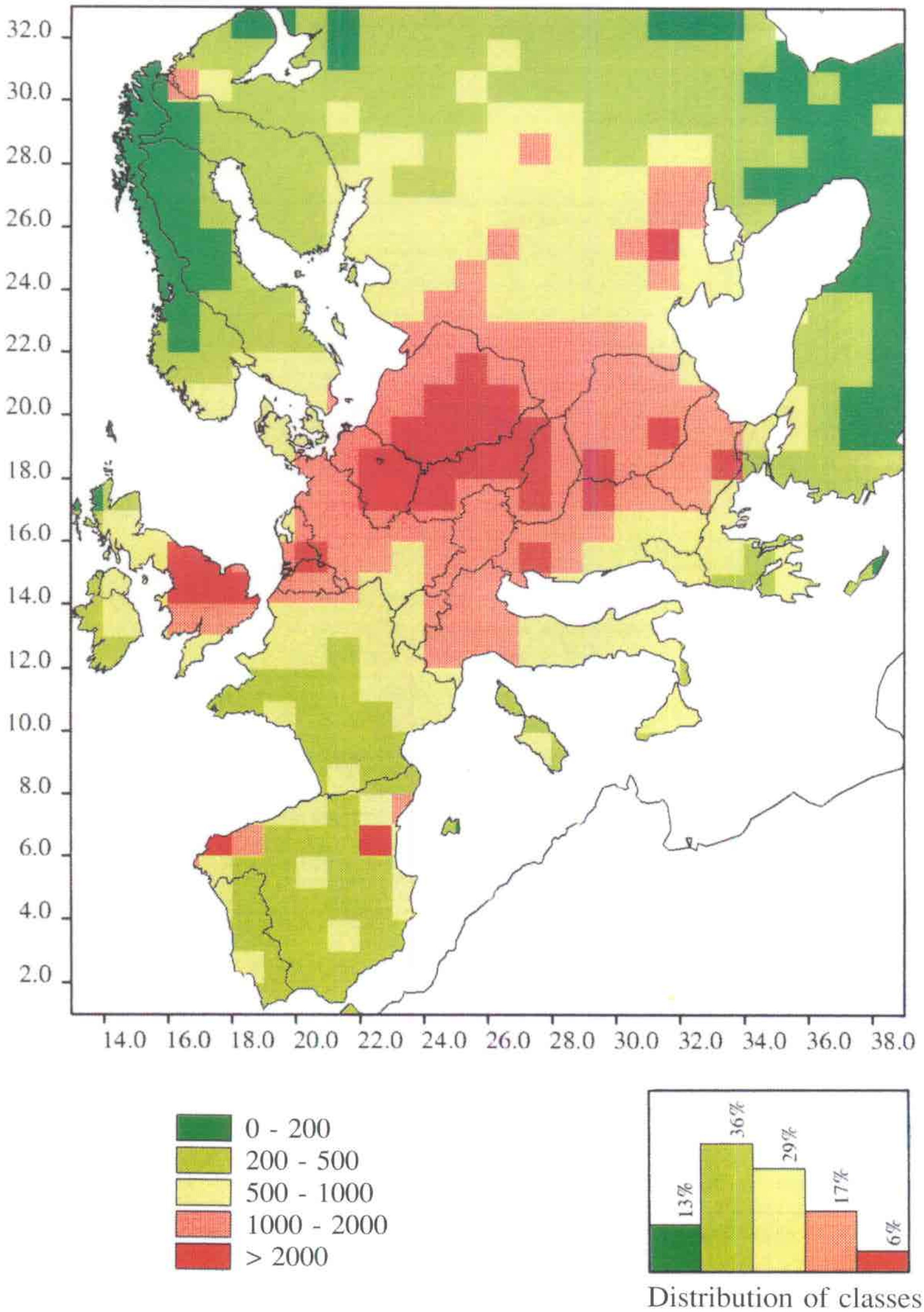

Figure A2.4. **Present load computation of sulphur using the 1988/1989 EMEP source-receptor matrix.**

Computations for this map have **not** been modified for filtering factors, base cation uptake, nitrogen uptake and seasalt-corrected base cation deposition.

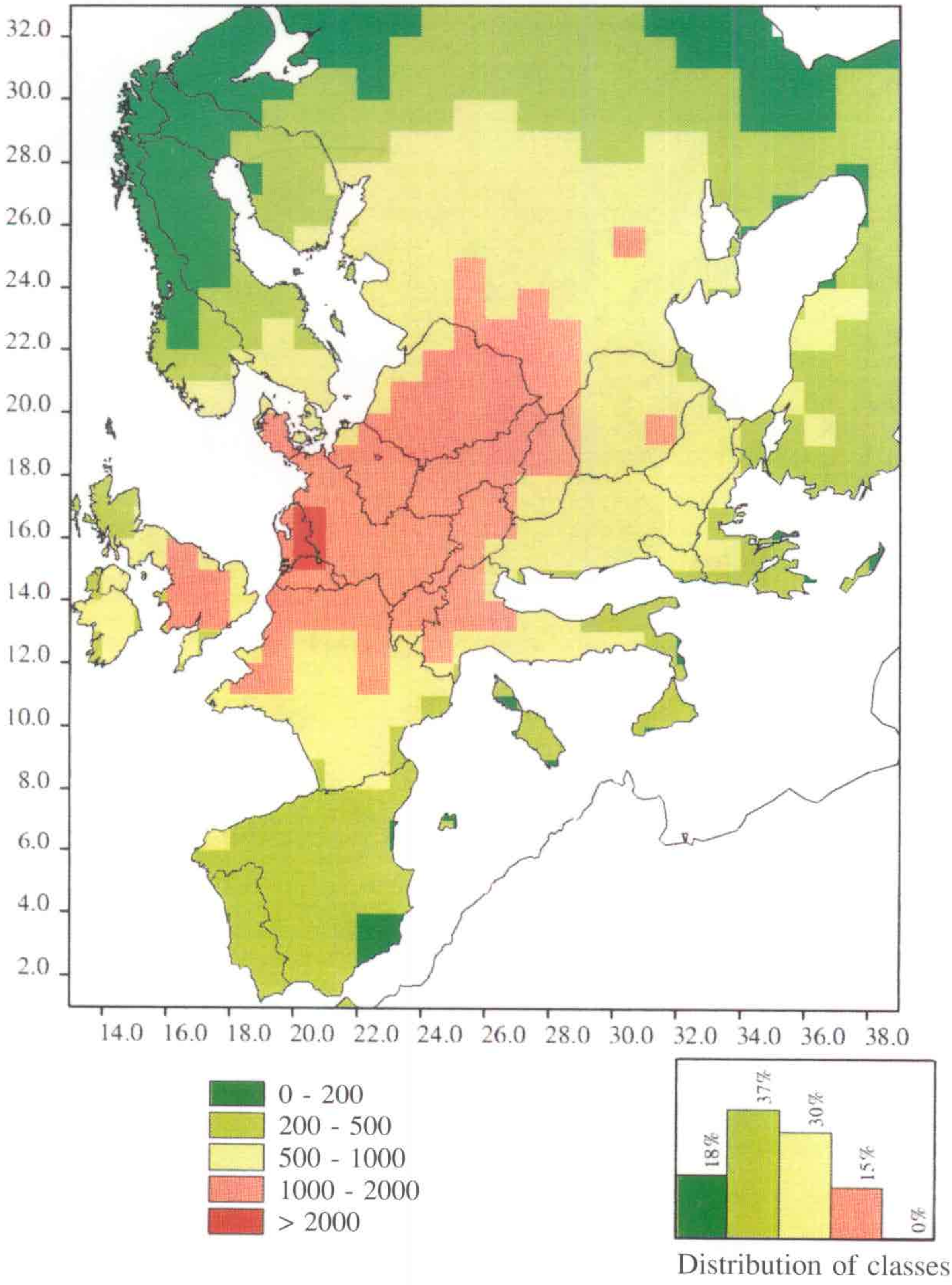

Figure A2.5. **Present load computation of nitrogen (NO_x+NH_x) using the 1988/1989 EMEP source-receptor matrix.**

Computations for this map have **not** been modified for filtering factors, base cation uptake, nitrogen uptake and seasalt-corrected base cation deposition.

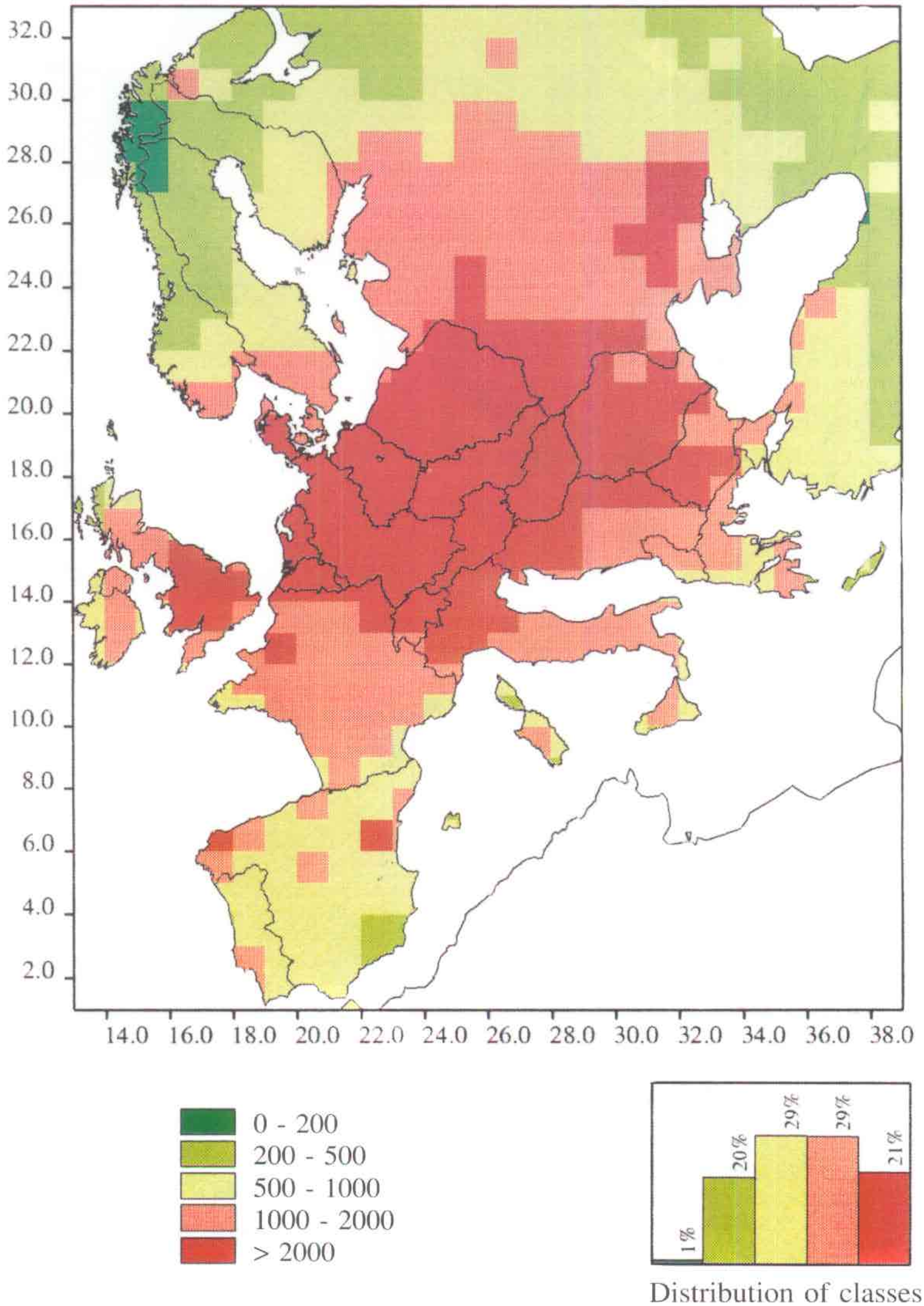

Figure A2.6. Present load computation of acidity using the 1988/1989 EMEP source-receptor matrix.

Computations for this map have **not** been modified for filtering factors, base cation uptake, nitrogen uptake and seasalt-corrected base cation deposition.

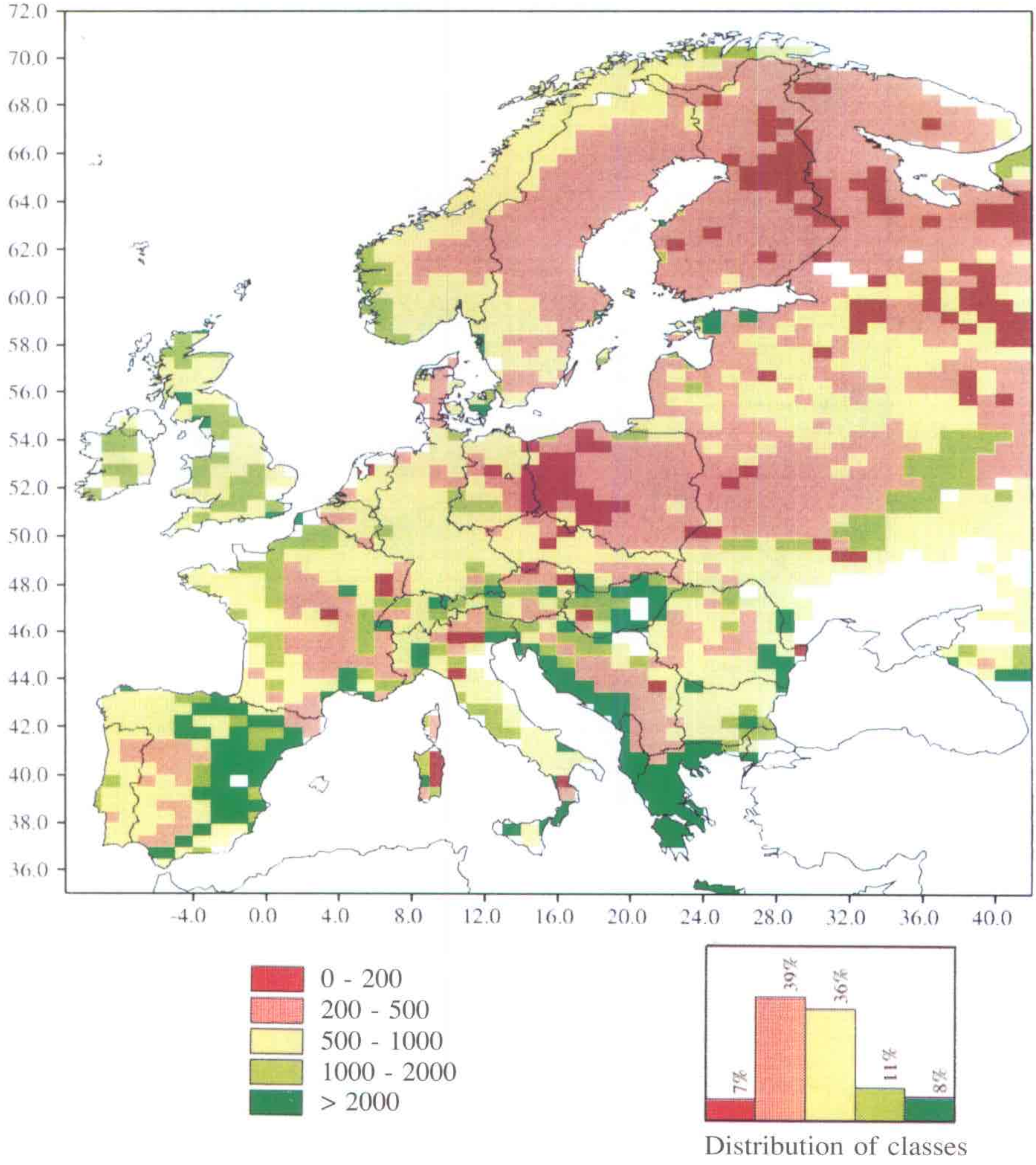

Figure A2.7. 1 percentile critical load map of potential acidity. (See Sverdrup *et al.*, 1990).

The critical load of potential acidity includes base cation uptake, nitrogen uptake, and nitrogen immobilization. Since these parameters may change due to land use alterations, it was decided during the second CCE training session (Appendix 7) to account for these parameters in the computation of present loads.

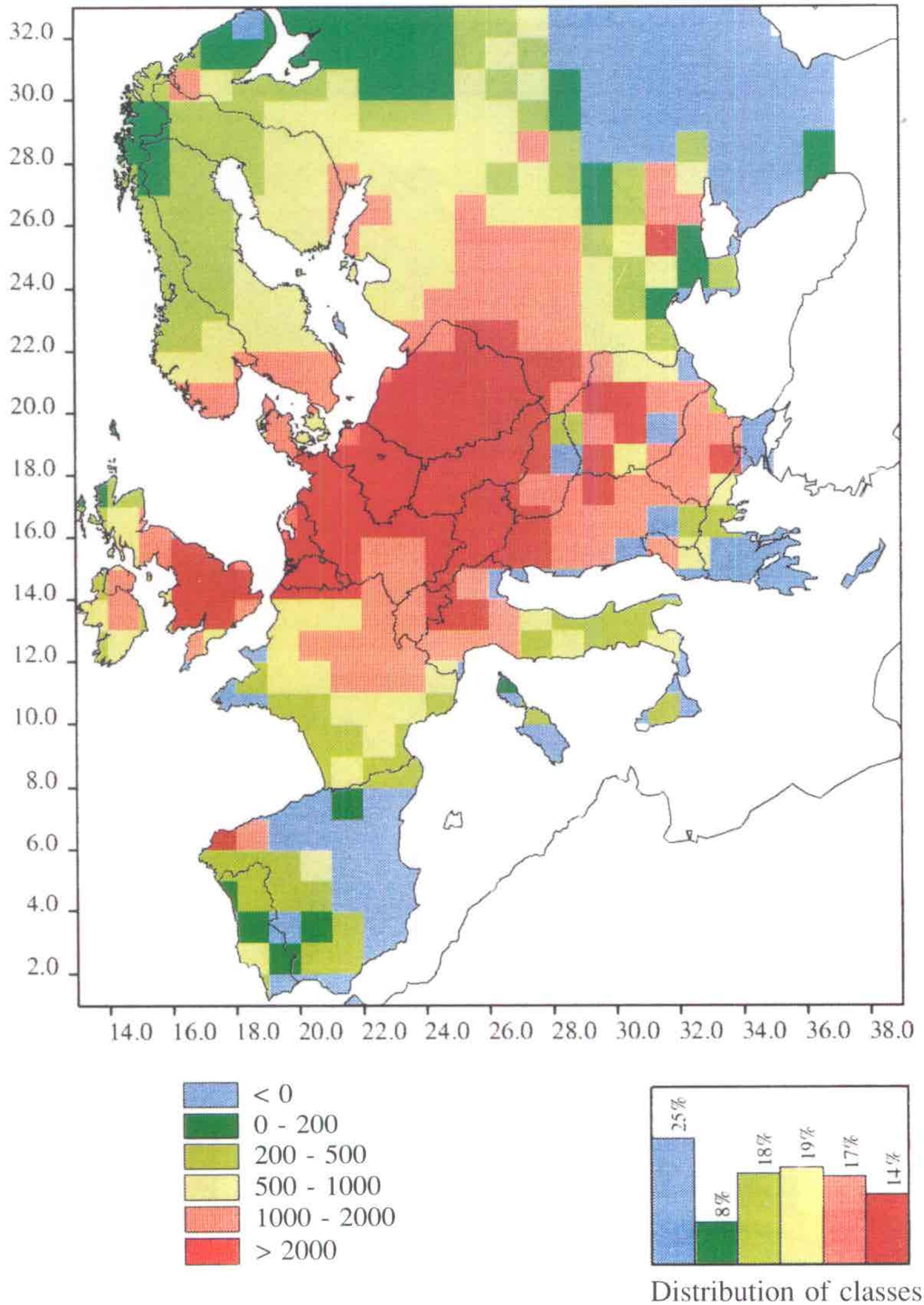

Figure A2.8. Exceedances of unmodified EMEP deposition of acidity to the 1 percentile critical load of acidity.

This map is included to provide insight in the effect of including filtering factors, seasalt-corrected base cation deposition, base cation uptake, and nitrogen uptake on the computation of exceedances which are presented in Chapter 2.

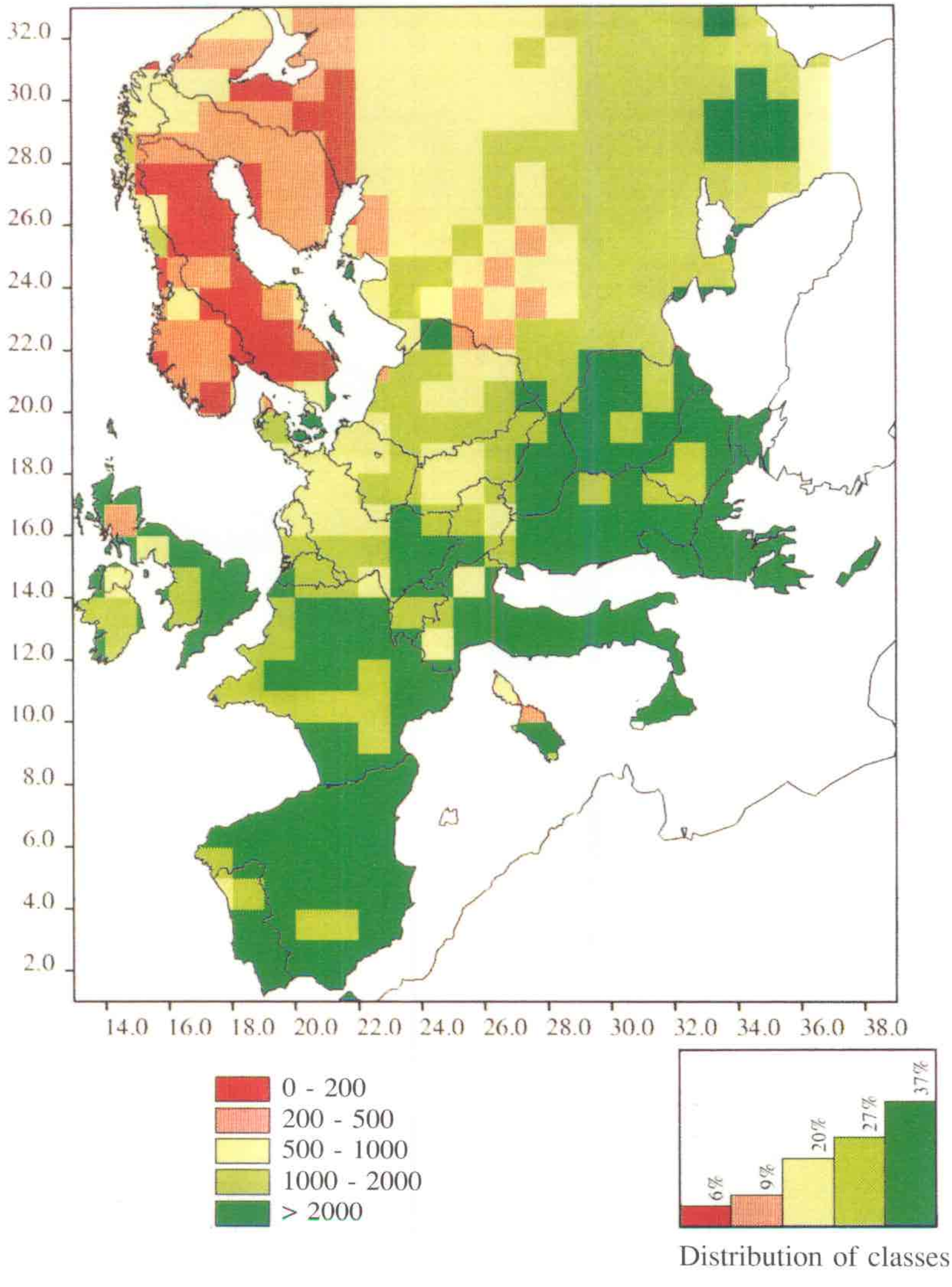

Figure A2.9. **The 50% critical load of acidity.**

An earlier version of this map was displayed by the CCE at earlier meetings under the LRTAP Convention. The Task Force on Mapping has recommended the use of the 1 or 5 percentile map of critical loads of actual acidity in order to ensure that a large share of sensitive ecosystems will be protected.

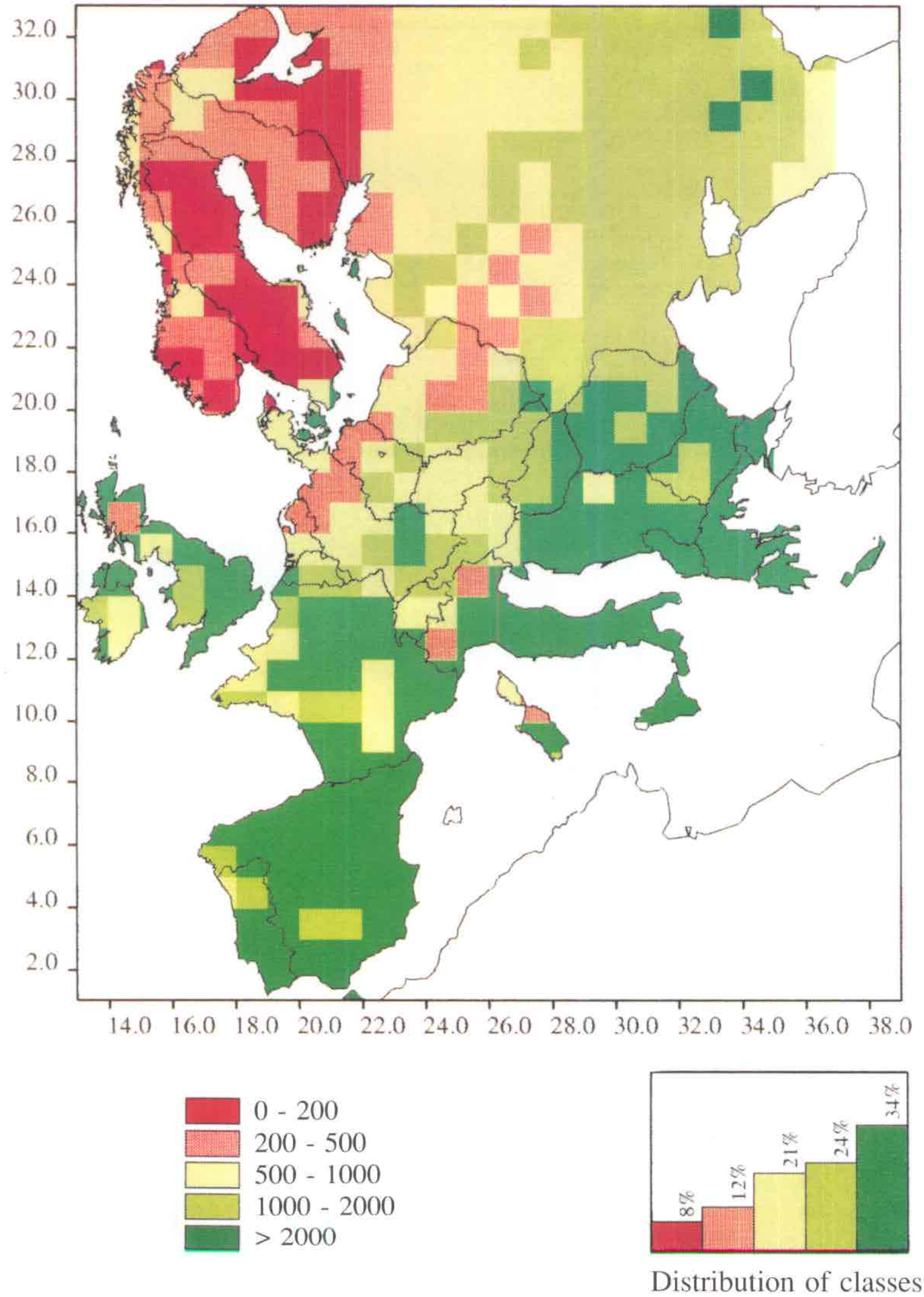

Figure A2.10. The 50% critical load of sulphur.

An earlier version of this map was displayed by the CCE at earlier meetings under the LRTAP Convention. The Task Force on Mapping has recommended the use of the 1 or 5 percentile map of critical loads of sulphur in order to ensure that a large share of sensitive ecosystems will be protected.

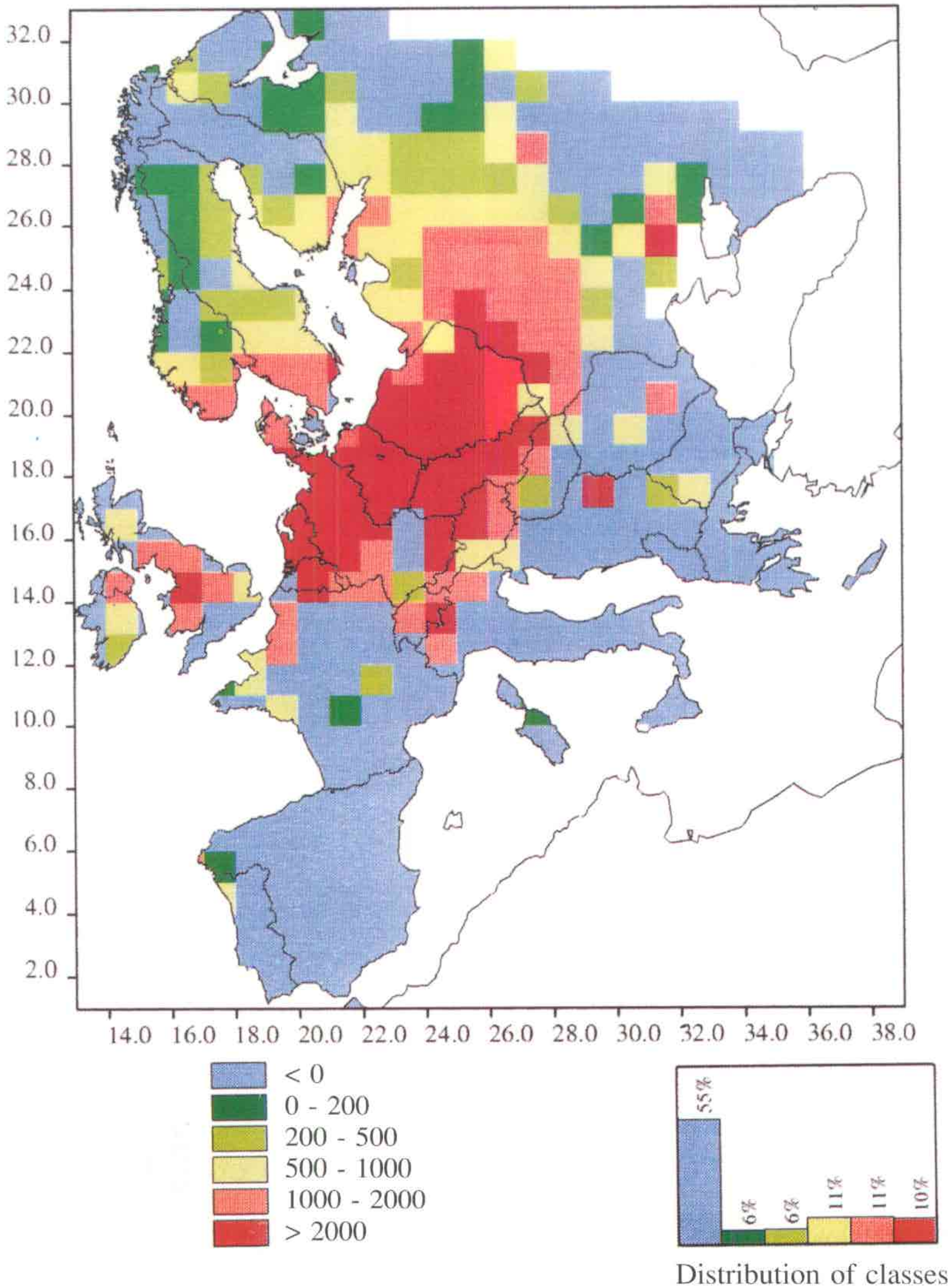

Figure A2.11. The exceedance of the 50% critical load of acidity.

An earlier version of this map was displayed by the CCE at earlier meetings under the LRTAP Convention. The Task Force on Mapping has recommended the use of the 1 or 5 percentile map of critical loads of actual acidity in order to ensure that a large share of sensitive ecosystems will be protected.

APPENDIX 3. INPUT DATA USED IN THE STEADY STATE MASS BALANCE MAPS OF CRITICAL LOADS IN EUROPE

This appendix provides an overview of the sources and specifications of the input data used to produce the European steady state maps of critical loads. The input data used for the steady state mass balance maps of Europe are contained in three dBase III+/IV data bases: **FOREST.DBF**, **SOIL.DBF** and **GLOBAL.DBF**. Paper or disk copies of data for all grid cells for individual countries are available from the Coordination Center. Data have been produced on a grid of 1° longitude by 0.5° latitude, since most national data is produced on similar geographical scales.

These data have been collected by IIASA and the Winand Staring Center, and made available to the Coordination Center. The Coordination Center produced preliminary critical loads maps in November 1990, and distributed the maps and the input data used to all National Focal Centers. NFCs were requested to comment on, improve, and/or replace these data with nationally derived information. These data have been used to produce the maps in Chapter 2 for all countries that were unable to provide other sources of data (See Table 3.5).

GLOBAL.DBF:

This file contains general information to calculate uptake data for nitrogen and base cations; i.e., the wood density (kg m^{-3}), branch-to-stem ratio, and element contents (%) of N, Ca, Mg, and K in stems and branches of coniferous and deciduous tree species. The data are based on a literature review (de Vries *et al.*, 1990). The data base also contains the dry deposition factor for base cations used to calculate total deposition from bulk data. The structure of this file is given in Table A3.1.

FOREST.DBF:

This data base contains all data that are both grid- and forest-dependent; i.e., data on areal occurrence, uptake, deposition and runoff. Regarding forests, distinctions are made among coniferous (CON), deciduous (DEC), and unmanaged (UNM) forests. Regarding the types of data, distinctions have been made between basic (B) and derived (D) data. A description of the data base with information on the sources is given in Table A3.2.

SOIL.DBF:

This file contains basic data that are both grid- and soil-dependent; i.e., the percentage of the considered FAO soil types in each grid with its inherent characteristics (partly basic and partly derived). Furthermore, it contains derived data on the area of the various forest types on each soil type in each grid, based on an assignment procedure for combining forests and soils as described in de Vries *et al.* (in press). A description of the data base with information on the sources is given in Table A3.3.

Table A3.1. Structure of Data Base File GLOBAL.DBF

				Stem contents (%)				Branch contents (%)			
Type	fdd[1]	WD[2]	rbs[3]	N	Ca	Mg	K	N	Ca	Mg	K
coniferous	2.5	500	0.15	0.10	0.08	0.02	0.05	0.35	0.35	0.05	0.25
deciduous	1.5	700	0.25	0.15	0.20	0.04	0.10	0.45	0.50	0.05	0.20

1. fdd = dry deposition factor for base cations.
2. WD = wood density (kg m^{-3}).
3. rbs = ratio of branches to stems.

Table A3.2. Structure of Data Base File FOREST.DBF

Field No(s).	Field Name	Description	Units	Data Type*	Source
1-2	**LONGITUDE-LATITUDE**		degrees		
	1 LONG	Longitudinal coordinate of south-west corner of grid cell.			
	2 LAT	Latitudinal coordinate of south-west corner of grid cell.			
3-7	**AREAL STATISTICS FOR THE GRID**		km^2	B	IIASA, based on information from aeronautic maps.
	3 AGRID	Total area of the grid cell.			
	4 ACON	Total area of coniferous forests per grid cell.			
	5 ADEC	Total area of coniferous forests per grid cell.			
	6 AUNM	Total area of unmanaged forests per grid cell.			
	7 AALL	Total area of all forest types per grid cell. (= ACON + ADEC + AUNM)			
8-9	**GROWTH OF CONIFEROUS AND DECIDUOUS FORESTS**		$m^3\ ha^{-1}\ yr^{-1}$	B	IIASA, based on information compiled by Nilsson and Sallnäs (1991).
	8 GCON	Annual average growth rate of coniferous forests.			
	9 GDEC	Annual average growth rate of deciduous forests.			
10-13	**NITROGEN AND BASE CATION UPTAKE**		$mol_c\ ha\ yr^{-1}$	D	Calculated from growth data and global data.
	10 NUPCON	Rate of nitrogen uptake for coniferous forests.			
	11 NUPDEC	Rate of nitrogen uptake for deciduous forests.			
	12 BCUPCON	Rate of base cation uptake for coniferous forests.			
	13 BCUPDEC	Rate of base cation uptake for deciduous forests.			
14	**BASE CATION DEPOSITION (BCDEP)**		$mol_c\ ha\ yr^{-1}$	B	EMEP
15	**WET:TOTAL DEPOSITION RATIO (WETOTOT)**			B	EMEP
16-18	**HYDROLOGIC DATA PER GRID CELL**		$mm\ yr^{-1}$	B	IIASA
	16 PRECIP	Annual average precipitation per grid cell.			
	17 RUNOFFGRID	Annual average runoff per grid cell.			
	18 EVAPGRID	Annual average evapotranspiration per grid cell.			
19-22	**HYDROLOGIC DATA PER FOREST TYPE**		$mm\ yr^{-1}$	D	calculated according to de Vries *et al.* (in press).
	19 EVAPCON	Annual average evapotranspiration for coniferous forests.			
	20 EVAPDEC	Annual average evapotranspiration for deciduous forests.			
	21 RUNOFFCON	Annual average runoff for coniferous forests.			
	22 RUNOFFDEC	Annual average runoff for deciduous forests.			

* B = Basic data.
D = Derived data.

Table A3.3. Structure of Data Base File SOIL.DBF

Field No(s).	Field Name	Description	Units	Data Type*	Source
1-2	**LONGITUDE-LATITUDE**		degrees		
	1 LONG	Longitudinal coordinate of south-west corner of grid cell.			
	2 LAT	Latitudinal coordinate of south-west corner of grid cell.			
3-6	**SOIL TYPE, NUMBER, SLOPE AND TEXTURE CLASS**		-	B	Description based on FAO soil map.
	3 SOILTYPE 4 SOILNUMBER 5 SLOPECLAS 6 TEXTCLAS	[Explanations on the derivation of these values can be found in the Mapping Vademecum, Appendix 3.]			
7-8	**PARENT MATERIAL AND WEATHERING RATE CLASS**		-	D	Derived from soil type and texture class.
	7 PARWMATCLAS 8 WRCLAS	[Explanations on the derivation of these values can be found in the Mapping Vademecum, Appendix 3.]			
9	**WEATHERING RATE (WRATE)** (for a depth of 0.5 meters)		$mol_c\ ha^{-1}yr^{-1}$	D	Derived according to procedures described in the Mapping Vademecum, Appendix 3.
10	**PERCENTAGE OF EACH SOIL TYPE IN GRID (SPERCENT)**		%	B	IIASA, based on FAO soil map.
11	**SOIL NUMBER IN THE FOREST SOIL ASSIGNMENT (RANK)**		-	-	Assignment procedure described in de Vries *et al.* (in press).
12-15	**PERCENTAGE OF FOREST TYPES ON EACH SOIL**		%	D	Derived according to assignment type in grid procedure.
	12 FPERCON	Percentage of coniferous forest on each soil type per grid cell.			
	13 FPERDEC	Percentage of deciduous forest on each soil type per grid cell.			
	14 FPERUNM	Percentage of unmanaged forest on each soil type per grid cell.			
	15 FPERALL	Percentage of total surface area of all forest types per grid cell. (= FPERCON + FPERDEC + FPERUNM).			

* B = Basic data.
D = Derived data.

APPENDIX 4. DEVELOPMENT OF FILTERING FACTORS FOR SULPHUR DIOXIDE, NITROGEN OXIDES, AND AMMONIA

Critical loads exceedances may be underestimated when computed deposition in an EMEP grid is used as the basis for present load calculations, since throughfall has been measured to be larger than computed deposition. In order to account for this discrepancy, EMEP computations have been modified by means of forest filtering factors, following a procedure proposed by the Task Force on Mapping (UN ECE, 1991b). This appendix discusses a similar but more recent method (see de Vries, 1991) which has been applied to compute filtering factors for the computation of critical load exceedances.

This appendix discusses the equations used to compute filtering factors per land use type (coniferous forests, deciduous forests, and open land/sea), and for each of the acidifying pollutants (SO_x, NO_x, NH_3). Appendix 2 contains maps with the filtering factor values for sulphur and nitrogen used to produce the exceedance maps.

The basic equation is:

$$\mathbf{d_{EMEP} = a_c \cdot d_c + a_d \cdot d_d + a_o \cdot d_o} \qquad \text{(A4.1)}$$

where:

d_{EMEP} = computed SO_x, NO_x or NH_3 deposition for an EMEP grid E
a_c = percentage area[1] of coniferous forests in E
d_c = SO_x, NO_x or NH_3 deposition on coniferous forests in E
a_d = percentage area of deciduous forests in E
d_d = SO_x, NO_x or NH_3 deposition on deciduous forests in E
a_o = percentage area of open land in E
d_o = SO_x, NO_x or NH_3 deposition on open land in E

The deposition on the different land use types are defined as follows:

$$\mathbf{d_c = f_c \cdot d_{EMEP}} \qquad \text{(A4.2)}$$

$$\mathbf{d_d = f_d \cdot d_{EMEP}} \qquad \text{(A4.3)}$$

$$\mathbf{d_o = f_o \cdot d_{EMEP}} \qquad \text{(A4.4)}$$

where:

f_c = filtering factor for coniferous forests
f_d = filtering factor for deciduous forests
f_o = filtering factor for open land

Substitution of Equations A4.2 through A4.4 into Equation A4.1 leads to:

$$\mathbf{(a_c \cdot f_c) + (a_d \cdot f_d) + (a_o \cdot f_o) = 1} \qquad \text{(A4.5)}$$

Furthermore, it is assumed that there exists a constant ratio between f_c and f_d as follows:

$$\mathbf{f_c = C \cdot f_d} \qquad \text{(A4.6)}$$

1. Note that $a_c + a_d + a_o = 1$.

where:
C = 1.8 when sulphur and ammonia filtering is computed
C = 1.3 when nitrogen filtering is computed

and:

f_d = 1.0 when sulphur and nitrogen filtering is computed
f_d = 1.3 when ammonia filtering is computed

To avoid that d_c and d_d exceed d_{EMEP} resulting in an unrealistically low deposition (i.e., below the wet deposition) on open land, the filtering factor for open land is computed as follows from Equations A4.5 and A4.6:

$$\mathbf{f_o = (1 - a_c \cdot f_c - a_d \cdot f_d) / a_o} \qquad \text{(A4.7)}$$

If, from Equation A4.7, $f_o < d^w{}_{EMEP} / d_{EMEP}$, then:

$$\mathbf{f_o = d^w{}_{EMEP} / d_{EMEP}} \qquad \text{(A4.8)}$$

where:
$d^w{}_{EMEP}$ = wet deposition

and f_d is recomputed from Equations A4.6 and A4.8 by:

$$\mathbf{f_d = (1 - a_o \cdot f_o) / (a_c \cdot C + a_d)} \qquad \text{(A4.9)}$$

Finally, f_c is computed by substituting Equation A4.9 into A4.6.

Filtering factors for forests (deciduous and coniferous) in each EMEP grid (f_{EMEP}) are computed by:

$$\mathbf{f_{EMEP} = (f_c + f_d) / 2} \qquad \text{(A4.10)}$$

Preliminary maps displaying the result of Equation A4.10 in each EMEP grid are provided in this report. These filtering factors should be adapted by NFC's, as was decided on the second CCE training session (see Appendix 7) to incorporate the effects of altitude or other appropriate national assumptions.

APPENDIX 5. CUMULATIVE FREQUENCY DISTRIBUTIONS FOR CRITICAL LOADS

Cumulative distribution functions (CDFs) are used to describe the cumulative occurrence of an ascending sequence of critical loads, $x_1, ..., x_n$, in an EMEP grid cell as follows:

$$F(x) = \begin{cases} 0 & \text{for } x < x_1 \\ \sum_{x_i \leq x} w_i & \text{for } x_1 \leq x_i \leq x < x_n \\ 1 & \text{for } x \geq x_n \end{cases} \quad \text{(A5.1)}$$

where:
F(x) = the probability of the event of a critical load being smaller than critical load x (the CDF of x; $x = x_1,...,x_n$)
x_1 = the smallest critical load in an EMEP grid cell
w_i = the weight assigned to critical load x_i
x_n = the largest critical load in an EMEP grid cell (n is finite)

The weight w_i is computed as follows:

$$\mathbf{w_i} = \begin{cases} \mathbf{1/m} & \text{when m critical loads are provided as point data } (x_1,...,x_m) \\ \mathbf{f_i} & \text{when critical load } x_i \text{ is assigned to a percentage of forest area in an EMEP grid cell } (x_i = x_{m+1},...,x_n) \end{cases} \quad \text{(A5.2)}$$

where:
m = the number of critical loads given as point data in EMEP grid cell E
f_i = the percentage of the forest soil combinations in an EMEP grid cell having a critical load of x_i

The critical loads computed for forest soil combinations were based on a 1° x 0.5° longitude-latitude grid cell resolution in countries which did not provide national contributions.* The aggregation of forest areas from a 1° x 0.5° longitude-latitude grid cell, L, to an EMEP grid cell, E, is obtained as follows:

$$\mathbf{f_i} = \mathbf{f_{iL} \cdot S_{LE}} \quad \text{(A5.3)}$$

where:
f_{iL} = The percentage of a forest soil combination with critical load x_i in the area of a longitude latitude grid cell L.
S_{LE} = The percentage of EMEP grid cell E which is covered by longitude-latitude grid cell L.

From Equations A5.2 and A5.3 it follows that a set of critical loads in an EMEP grid may consist of a mixture of weights; e.g., an EMEP grid containing parts of two or more different countries may contain

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* Data were obtained from the International Institute for Applied Systems Analysis (Austria) and the Winand Staring Center (The Netherlands).

both point and areal data.* In the special case that all critical loads in an EMEP grid cell are given as data points, Equation A5.3 does not apply, and Equation A5.2 reduces to $w_i = 1/n$. On the other hand, note that national critical load contributions prevail in the case of an EMEP grid covered both by a country that provided data and by a country that did not. In other words, the entire EMEP grid cell containing a border between national contributions and steady state mass balance calculations from the CCE using a European data base is shaded according to CDF's computed from nationally provided critical loads.

By means of Equations A5.1, A5.2, and A5.3, CDF's are defined for the whole range of critical loads $x_1,...,x_n$ to which a complete set of cumulated weights $w_1,...,w_n$ is assigned. Often, it is interesting to investigate the critical load value for a cumulative subset $w_1,...,w_k$ of the weights $w_1,...,w_n$ ($w_k \leq w_n$). In other words, the question is what the value is of the critical load exceeding the fraction ($w_1 + w_2 + ... + w_k$) of all the critical loads in EMEP grid cell E. This fraction is called a quantile. The q-th quantile of critical loads or of the corresponding distribution of critical loads in an EMEP grid cell E is denoted x_q and is the smallest critical load x satisfying $F(x_q) = q$ ($0 \leq q \leq 1$). The set of quantiles in an EMEP grid cell E is defined as follows:

$$\mathbf{q} = \begin{cases} \mathbf{F(x_1)} & \text{for } q \leq F(x_1) \\ \mathbf{F(x_q)} & \text{for } F(x_1) < F(x_{q-1}) < q < F(x_{q+1}) < F(x_n) \ ^{**} \\ \mathbf{F(x_n)} & \text{for } q \geq F(x_n) \end{cases} \qquad \text{(A5.4)}$$

Percentiles are computed by scaling quantiles to 100, e.g., the p-th percentile corresponds to the (p/100)-th quantile.

The p-th percentile critical load ($x_{p/100}$) is the upper bound of the critical load range in each EMEP grid cell which covers p% of the EMEP grid cell area. The shading of the grid cells, in the European map of critical loads, follows by assigning $x_{p/100}$ to the appropriate of the five critical load classes, i.e., 0-200 (dark red), 200.1 - 500, 500.1 - 1000, 1000.1 - 2000, and larger than 2000 (dark green) eq ha^{-1} yr^{-1} for every EMEP grid cell. In other words, the p-th percentile critical load protects 100-p % of the area or data points covering an EMEP grid cell. As is illustrated by means of examples presented below, it is recommended to use low percentiles, i.e., 1 and 5 percentiles. Higher percentiles, i.e., the 50th percentile, will increase the uncertainty about the share of ecosystems which are protected in an EMEP grid cell.

Caveats

Note that it is not possible to say that p% of the most sensitive ecosystems in every EMEP grid is displayed in the p-th percentile European critical loads map. This is due to the definition in Equation A5.4 of the highest, $F(x_n)$, and the lowest, $F(x_1)$, quantiles, and is explained in the following example. Therefore it should not be concluded that in the p-th percentile critical load map of Europe (100-p%) of the ecosystems is protected.

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* Note that for notational simplicity, Equation A5.2 is formulated such that the first m critical loads are data points followed by (n-m) critical loads for forest soil combinations. In reality the ranking of critical loads in ascending order may result in a different sequence of weight definitions, as in the case where an EMEP grid contains both point and areal data.

** The q-th quantile may be interpolated linearly between the two nearest quantiles which are computed around q in a grid cell E (denoted by x_{q-1} and x_{q+1} in Equation A5.4).

The following examples will be used to illustrate how critical load percentiles should be interpreted. As mentioned earlier low percentiles should be used rather than high percentiles if it is the aim to protect the most sensitive ecosystems. The reason is due to the type of data used as input to formulate cumulative distributions of critical loads in each of the EMEP grid cells. As mentioned earlier, two types of data were used:

(1) critical load values for point measurements in an EMEP grid cell.
(2) critical load values assigned to percentages of the area in an EMEP grid cell.

The essence is that the actual distribution of ecosystem sensitivity may be different from the distribution expressed in cumulative distributions of the two types of data just mentioned.

Example 1 (using point data):

- Assume that 100 point measurements $CL_1,...,CL_{100}$ are available (equally distributed) in an EMEP grid cell. The cumulative distribution of these 100 data points is displayed as the thin solid line in Figure A5.1.

- Assume further that the actual distribution of the ecosystems sampled with these 100 points only cover 20% of an EMEP grid cell. (This type of information was generally not available). The cumulative distribution of the 100 data points only covering 20 percent of the area is displayed as a thick solid line in Figure A5.1.

It can be seen from Figure A5.1 that the 50 percentile critical load is equal to CL_{50} when the solid cumulative distribution is used, but is equal to CL_{100} when the dotted cumulative distribution is used. It can also be seen that low percentiles, i.e., the 1 and 5 percentile, are equal to CL_1 for both cumulative distributions.

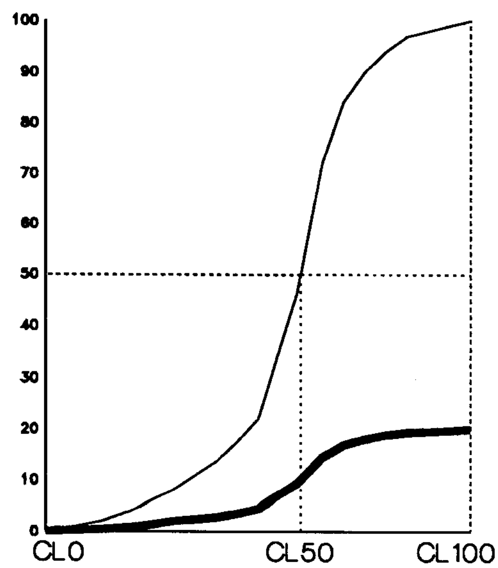

Figure A5.1. Cumulative distribution functions for 100 point data representing (a) an equal distribution of critical loads over 100% of an EMEP grid cell (solid line) and (a) an equal distribution over 20% of the EMEP grid cell actually covered by sensitive ecosystems (dotted line).

Example 2 (using data on area covered):

- Assume that the critical load values are assigned to two forest soil combinations A and B in an EMEP grid cell. Forest soil combination A is assumed to cover 5% of the EMEP grid cell whereas forest soil combination B covers 20% of the grid cell. Assume further that the critical load of forest soil combination B (CL_B) is lower than the critical load CL_A of forest soil combination A.
- The cumulative distribution is plotted in Figure A5.2. Note that the cumulative distribution does not represent critical loads outside of the range between CL_B and CL_A. This assumption implies that an EMEP grid which is covered for 75% by agricultural area is not assumed to have critical loads exceeding CL_A even though agricultural land is not sensitive. Also, note that the cumulative distribution has been interpolated between CL_B and CL_A.

It can be seen from Figure A5.2 that the 50 percentile critical load is equal to the 25 percentile critical load, i.e., CL_A.

When the percentage of the EMEP grid cell cover of the forest soil combinations A and B are scaled up the actual ecosystem cover, i.e., A and B represent 100%, a result is obtained which is displayed in Figure A5.3. From Figure A5.3 it can be seen that the 50 percentile critical load is equal to CL_B (as compared to CL_A in Figure A5.2). However, Figures A5.2 and A5.3 illustrate that a low percentile will be equal, i.e., CL_B.

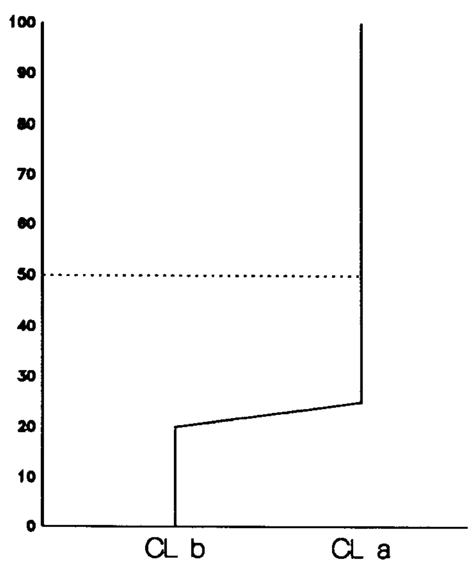

Figure A5.2. Cumulative distribution function of critical loads assigned to cover an EMEP grid cell by 20% of forest soil combination B and by 5% of forest soil combination A.

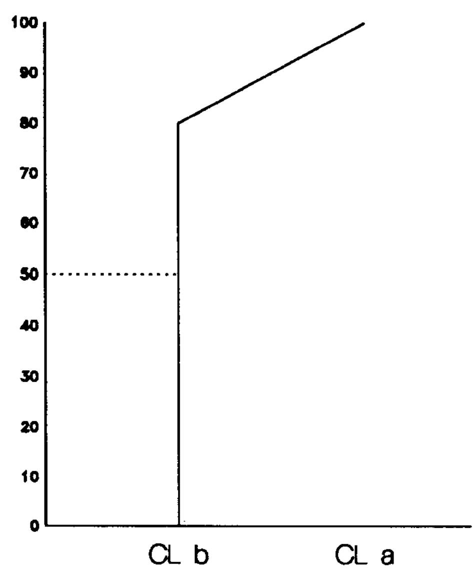

Figure A5.3. Cumulative distribution function of critical loads assigned to 100% of forest soil combinations A and B.

The general conclusion is that the application of high percentiles increases the uncertainty about the area in an EMEP grid cell which is actually protected. The application of low percentiles reduces the uncertainty. It is recommended to use the 1 and the 5 percentile to protect the most sensitive of the ecosystems chosen by countries. The few cases for which the 1 and 5 percentile lead to erroneous interpretations is considered marginal.

Note that uncertainties assigned to the application of high percentiles (higher than 5), as illustrated above, may decrease in future updates of the critical load maps as more and better data becomes available. National Focal Centers will, for example, be requested to provide weightings for the different ecosystems mapped (e.g., weigh the forest soil combinations A and B to cover the entire EMEP grid, i.e., from 0% to 100%; or assign 70% to the point data for forests and 30% to the point data for surface waters).

Conclusions:

Uncertainty about the protection of most sensitive ecosystems is minimized by using a low (1 or 5) percentile CCE map of European critical loads.

Finally, it should be kept in mind that the final aim of the critical loads exercise is to compute the excess of critical loads by actual deposition. To that end, a p-th percentile critical load in an EMEP grid cell is compared to a deposition which is also assumed homogeneously distributed in the same EMEP grid cell.

APPENDIX 6. REPORT FROM THE FIRST CCE TRAINING SESSION: 25-27 June 1990

INTRODUCTION:

The following summarizes the results of the discussions which were held during the training session. Most of the results were typed as a document distributed on the last day of the meeting. Details about the grid resolution, which was discussed only on the last day, have been added herein. This report basically follows the format which was presented at the Working Group on Abatement Strategies (WGAS) in July, and which will be presented at the Working Group on Effects (WGE) in August 1990.

1. At the third session of the Working Group on Abatement Strategies it was announced that the Coordination Center for Effects - West was operational (EB.AIR/WG.5/6, paragraph 11).

2. A training session for experts involved in national mapping of critical loads and levels was arranged by the Center from 25 to 27 June 1990. In view of the large differences in the current directions of the individual mapping programmes and the pressing time scale, the Task Force on Mapping, at its second meeting in May 1990, requested the Center to assist in preparing a condensed list of first priority maps for submission to the Executive Body in 1991 (EB.AIR/WG.5/R.12, paragraph 11).

3. The purpose of the meeting was to enable participants to become acquainted with, and choose between alternatives of, methods and data requirements which are described in the draft manual on mapping critical loads and levels prepared by the Task Force on Mapping.

4. The Training Session was attended by 44 participants from 19 countries, i.e., Austria, Bulgaria, Czechoslovakia, Denmark, Finland, France, German Democratic Republic, Federal Republic of Germany, Hungary, Ireland, Netherlands, Norway, Poland, Portugal, Soviet Union, Sweden, Switzerland, United Kingdom, United States.

5. A document ("Mapping Vademecum") which had been prepared by the Coordination Center provides an overview of items that were discussed. These included (a) the kind of map to be prepared by early 1991, (b) the receptor, (c) ecosystem parameter values, (d) the method to use (e) the grid resolution of the European map (f) the computation and display of statistics for each grid square, (g) alternatives to avoid gaps in the European display of critical loads, and (h) a method to enable intercomparison between maps.

6. The meeting consisted of (a) general presentations on mapping and computation methods, (b) country presentations about the national status of mapping with respect to the items mentioned in section 5 above, (c) presentations of models (RAINS, PROFILE and MACAL) and (d) a continued general discussion.

RESULTS

7. The meeting agreed that priority should be given to the production of a critical loads map for Europe (free acidity and potential acidity) to enable the continued evaluation of abatement strategies by the Working Group on Abatement Strategies. Taking into account necessary time to submit reports and maps to the TFM, TFIAM, WGAS and WGE it was decided to choose February 1991 as a deadline to produce a European map of critical loads. The continued effort after February 1991 will be aimed at the improvement of the European map of critical loads.
A description of the difference between free and potential acidity has been added to the updated Mapping Vademecum.

8. The meeting noted that each of the participating countries will have distinct policy requirements for the production and display of critical loads. Therefore a distinction has been made between national maps and the European map of critical loads. It was agreed that two European maps of critical loads should be produced by the Coordination Center:

One European map should display the preference of each nation with respect to (a) the choice of the receptor, and (b) the method used to obtain a national map of critical loads. This map becomes the actual critical load map of Europe.

Critical chemical values, as chosen by the countries, should reflect an annual average. The country is free to choose the soil depth considered for application in a multi-layer model (e.g., PROFILE or MACAL).

National data of base cation deposition should be used. With respect to weathering the mineralogy correlation method (pp. 101, 102 in Sverdrup *et al.*, 1990) should be used. An annex (Appendix 3) has been added to the Mapping Vademecum to clarify this method. In addition an explanation of the so-called "Level 0" approach (Appendix 1) is presented. With respect to uptake the management practice considered (whole tree harvesting or stemwood removal only) should guide a country's choice.

The variability in data within a defined receptor (e.g., certain forest-soil combinations) will be considered if possible. However, as a start, mean values will be used.

The second European map of critical loads should be produced based on the usage of one method (the steady state mass balance method) and similar soil and surface water parameters. The primary purpose of the second European map would be to enable the intercomparison of results between countries (See Mapping Vademecum Appendix 4 for an overview of the currently available data).

The Steady State Mass Balance method should be applied by all participants to enable such a European Intercomparison. An annex (Appendix 2) has been added to the updated Mapping Vademecum reflecting elements of the Steady State Mass Balance Method for which clarification was required during the training session. With respect to surface waters both the Water Chemistry method as well as the Steady State Mass Balance Method should be applied.

With respect to chemical values, choices were made based on the Mapping Manual and its annexes, and presented below:

(a) similar critical (acceptable) chemical values. These values are given in Table A6.1.

Table A6.1. Critical chemical values to be used to allow national intercomparisons.

	Forest soil	Groundwater	Surface water
alkalinity	-0.3 meq/l	0.14 meq/l	0.02 meq/l*
Al/Ca	1.0 mol/mol	-	-

When the critical load computed from the two criteria of Table 8.1 differs, the lowest critical load should be mapped.

(b) similar depth: the depth of the root zone should be taken.

* Not equal to the background document which proposes 0.05, but based on recent data of Arne Henriksen.

9. The meeting noted further that large differences exist between countries with respect to the availability of methods, data and an infrastructure to produce maps of critical loads. This may lead to an incomplete mapping of critical loads in Europe.

It was agreed that gaps in a European map should be avoided. Therefore countries may apply: (1) available data (see Appendix 4 of the Mapping Vademecum) in combination the Steady State Mass Balance method (as is currently done at the Winand Staring Center for Integrated Land, Soil and Water Research and IIASA), (2) apply a European regional model which is in development at both institutes mentioned above (3) use an available qualitative map (Stockholm Environment Institute) or (4) apply another qualitative method (e.g., the "Level 0" approach (see Appendix 1 of the Mapping Vademecum) to produce a national contribution to the European map of critical loads.

10. The intercomparison of methods and results leading to a European map of critical loads will be based on (a) national maps, (b) the regional map from the Winand Staring Center/IIASA model, and (c) the map of the Stockholm Environmental Institute.

11. The discussion (see sections 8 and 9 above) leads to the notion that the first (February 1991) European map of critical loads for potential acidity (See Appendix 2 of the Mapping Vademecum) will consist of nationally selected receptors with calculations of critical load values using the appropriate, recommended methods. In addition, a similar map will be obtained displaying (free) acidity.

12. With respect to the grid to be chosen the meeting noted that many countries may have particular requirements with respect to the size of the grid squares. It was also noted that the EMEP grid is particularly important for the production of critical loads exceedance maps in Europe but less imperative for the production of European maps of critical loads. The reason is that the latter are computed on the basis of ecosystem characteristics rather than on current deposition levels.

It was agreed that all the critical load data should be generated at nationally decided scales and provided to the Coordination Center including the geographical (longitude, latitude) location of each of the data points. If possible, the data should be transformable to EMEP grid squares, preferably by the countries themselves. The Coordination Center will be in the position to display any grid resolution, provided that all the national critical load data are made available. Maps will clearly indicate the statistic which is displayed in all grid squares (e.g., the mean critical load in each grid square; other statistics could be the 5%, the 50% or the 95% of a grid square area).

13. The Task Force on Mapping and the Task Force on Integrated Assessment Modelling, both meeting in November 1990, could be a good forum to discuss the statistics (see section 12) which are to be displayed on the maps.

14. For the computation and the production of a current critical load exceedance map it was noted that the years for which throughfall deposition is monitored vary over the countries. It was decided that a first current exceedance map of critical loads should be using best available data and mean values for several years where the data are available.

UNSOLVED ISSUES

15. For the production of critical load exceedance maps it was noted by some participants and agreed upon by all, that computed acid deposition is lower than measured throughfall due to filtering effects of forests. This leads to a discrepancy between the deposition computed by EMEP and measured throughfall data. Debate is needed on the deposition values to apply in producing critical load exceedance maps for European scenario analysis.

16. The time horizon within which countries have measured throughfall deposition varies over the countries. The meeting felt that discussion is needed on the reference year to be taken to produce a European map of critical load exceedances which is compatible between countries.

17. Discussion was felt to be needed on the choice of reference years for emissions on the basis of which depositions, to be used in the scenario analysis of critical load exceedances, should be computed.

18. Debate is needed on the EMEP source-receptor matrices to be used in view of the remarks in sections 15 to 17.

19. For the computation of future deposition, meteorological effects may be reduced by using a long-term average source-receptor matrix. Discussion is required on the source-receptor matrix to be used.

NEXT TRAINING SESSION

20. A second training session is planned for 14, 15 and 16 January 1991 in Bilthoven in The Netherlands. This meeting will consist of scientific evaluation of the first quantitative European map of critical loads (see section 8), as obtained from national contributions.

APPENDIX 7. REPORT FROM THE SECOND CCE TRAINING SESSION: 14-16 January 1991

INTRODUCTION:

1. The Coordination Center for Effects - West (CCE-W) held a second training session on mapping critical levels and loads from 14 to 16 January 1991 at the National Institute of Public Health and Environmental Protection (RIVM) in Bilthoven, The Netherlands.

2. The meeting was attended by 52 experts from 16 countries (Austria, Bulgaria, Czechoslovakia, Denmark, Finland, France, Germany, Hungary, Ireland, The Netherlands, Norway, Poland, Soviet Union, Switzerland, Sweden, and the United Kingdom). In addition, representatives from the Secretariat of the U.N. Economic Commission for Europe (UN ECE), the Task Force on Mapping (TFM), the Task Force on Integrated Assessment Modelling (TFIAM), the European Communities, the International Institute for Applied Systems Analysis (IIASA), and Greenpeace were also present.

3. The purpose of the meeting was to reach consensus about the production of a unified European map of critical loads, and for the development of a sulphur map. The meeting consisted of: (a) reports on national mapping activities from country representatives, (b) presentations of computer modeling software, including the RIVM's geographic information system (GIS) to be used for producing final maps, (c) discussion periods to reach resolution on unresolved issues concerning the development of critical loads maps, and (d) a short concluding discussion on future activities.

4. The representative of UN ECE Secretariat and the chairmen of the Task Forces on Mapping and on Integrated Assessment Modeling reported on recent activities relevant to the Training Session. All speakers emphasized the high priority of the work of the Coordination Center to the activities of the UN ECE subsidiary bodies, and stressed the importance for stated deadlines to be met by all parties. A timetable of relevant UN ECE meetings and activities, adapted from the Task Force on Mapping report was developed.

5. The decisions taken at the first Training Session in June 1990 were summarized. These included: (a) the type of maps to be produced; (b) the method used to fill gaps in national contributions (steady state mass balance method); and (c) general map characteristics (mixed ecosystems, percentiles to be mapped, use of the EMEP grid, etc.).

6. Preliminary European maps of critical loads (displaying 1, 5, 50, and 95 percentiles) of potential acidity were presented by the Coordination Center. Copies of these maps were distributed by the CCE-W to National Focal Center representatives.

7. Short reports on national mapping activities, including a comparison of national results to the maps provided by the CCE-W, were presented by all countries in attendance. A list of technical issues resulting from country presentations was developed for later discussion and resolution.

8. A schedule of the delivery of national critical loads data to the Coordination Center was developed from country presentations.

RESULTS: CALCULATIONS AND METHODS

9. The Coordination Center for Effects - West (CCE-W) and National Focal Centers maps to be submitted to the UN ECE bodies will display acidity rather than potential acidity. It was

considered inappropriate to include the acidification potential of nitrogen since this value is dependent on deposition rather than ecosystem characteristics.

10. Some countries noted receiving different values depending on the selection of one of three equations proposed by the Coordination Center in November 1990. It was decided to use two methods of calculating alkalinity leaching (the aluminum and the Al/Ca ratio criteria), and to use the lower of the two resulting values.

The base equation to be used for calculating the critical load of acidity is:

$$\mathbf{CL(Ac) = BC_w - ANC_l} \qquad \text{(A7.1)}$$

where:
CL(Ac) = critical load of acidity ($mol_c\ ha^{-1}\ yr^{-1}$)
BC_w = base cation weathering rate ($mol_c\ ha^{-1}\ yr^{-1}$)
ANC_l = alkalinity leaching ($mol_c\ ha^{-1}\ yr^{-1}$)

For acid forest soils, ANC_L is defined as:

$$\mathbf{ANC_l = - H_l - Al_l} \qquad \text{(A7.2)}$$

where:
H_l = hydrogen ion leaching ($mol_c\ ha^{-1}\ yr^{-1}$)
Al_l = aluminum leaching ($mol_c\ ha^{-1}\ yr^{-1}$)

11. Two options have been selected for calculating the acceptable Al leaching, $Al_{l(acc)}$ (see Sverdrup *et al.*, 1990; pp. 21-22) of which the minimum should be taken:

a) the Al criterion:

$$\mathbf{Al_{l(acc)} = Q \cdot [Al]_{acc}} \qquad \text{(A7.3)}$$

b) the Al/Ca criterion:

$$\mathbf{Al_{l(acc)} = R(Al/Ca)_{acc} \cdot (BC^*_d + BC_w - BC_u)} \qquad \text{(A7.4)}$$

where:
Q = runoff in $m^3\ ha^{-1}\ yr^{-1}$ (equal to $mm\ yr^{-1} \cdot 10$)
$[Al]_{acc}$ = acceptable Al concentration (0.2 $mol_c\ m^{-3}$)
$R(Al/Ca)_{acc}$ = acceptable Al/Ca ratio (1.5 $mol_c\ mol_c^{-1}$)
BC^*_d = seasalt-corrected deposition of base cations ($mol_c\ ha^{-1}\ yr^{-1}$)

The acceptable H leaching, $H_{l(acc)}$, is calculated according to:

$$\mathbf{H_{l(acc)} = Q \cdot [H]_{acc}} \qquad \text{(A7.5)}$$

Where:
$[H]_{acc}$ = acceptable H concentration (= 0.09 $mol_c\ m^{-3}$)

12. Substituting Equations A7.2 through A7.5 into A7.1 leads to the following two equations for the computation of the critical load of acidity:

$$\mathbf{CL(Ac) = BC_w + 0.09 \cdot Q + 0.2 \cdot Q} \quad \text{(A7.6)}$$

$$\mathbf{CL(Ac) = BC_w + 0.09 \cdot Q + 1.5\ (BC^*_d + BC_w - BC_u)} \quad \text{(A7.7)}$$

The lower of the two values calculated by Equations A7.6 and A7.7 is to be used.

13. The sulphur impact map requested by the Working Group on Abatement Strategies will be based on the critical load of acidity, as follows: The portion of sulphur in total acid deposition ("S-fraction") is computed for each grid. Using 1988 values for sulphur, nitrogen, and ammonia emissions, sulphur impact loads will be calculated by multiplying the "S-factor" by the critical load of acidity.

$$S_f = \frac{\text{S deposition}}{\text{S deposition + N deposition}} \quad \text{(A7.8)}$$

$$\mathbf{CL(S) = S_f \cdot CL(Ac)} \quad \text{(A7.9)}$$

where:
S_f = sulphur fraction
CL(S) = sulphur impact load

Obviously, in cases where the nitrogen deposition is lower than nitrogen uptake, S_f should be made equal to 1. The computation of the sulphur fraction and sulphur impact load by this method have been conducted by the CCE-W.

14. The TFIAM computations of the excess of critical loads of acidity consist of the following equations:

$$\mathbf{CL(Ac)_{exc} = PL(Ac) - CL(Ac)} \quad \text{(A7.10)}$$

$$\mathbf{PL(Ac) = PL(SO_x) + PL(NO_x) + PL(NH_x) - BC^*_d + BC_u - N_u - N_i} \quad \text{(A7.11)}$$

where:
$CL(Ac)_{exc}$ = excess of the critical load of acidity
PL(Ac) = present load of acidity (EMEP result)
CL(Ac) = critical load of acidity (see Equations A7.6 and A7.7)
$PL(SO_x)$ = present load of sulphur (EMEP result)
$PL(NO_x)$ = present load of ammonia and ammonium (EMEP result)
BC^*_d = seasalt-corrected base cation deposition
BC_u = base cation uptake
N_u = nitrogen uptake
N_i = nitrogen immobilization

Computation of the excess of the sulphur impact load by the present load of sulphur follows from:

$$\mathbf{CL(S)_{exc} = PL(SO_2) - CL(S)} \quad \text{(A7.12)}$$

15. The effect of water flux (runoff) on critical load calculations was discussed. It was agreed that for some cases the treatment of runoff in the steady state mass balance method may be less appropriate (e.g., seepage lake water balance). It was felt that the Stockholm Environment Institute map is more appropriate for some grids. National Focal Centers should evaluate whether computations for particular ecosystems (grids) require adaptations.

INPUT DATA:

16. Where countries have no data available, the figures for base cation deposition from IIASA, interpolated from the Norwegian Institute for Air Research (NILU) should be used. These data were distributed by the CCE-W to all National Focal Centers in November 1990.

17. Calcareous soils have been assigned the following values in the IIASA data base: a weathering rate class of 40, and a weathering rate of 10 keq ha^{-1} yr^{-1} (i.e., 10^5 mol_c ha^{-1} yr^{-1}).

18. Where weathering rates are calculated according to Appendix 3 of the Mapping Vademecum (Hettelingh and de Vries, July 1990, p. 54), the **highest** value of the ranges given for a particular weathering rate class should be used. As these figures are for a soil depth of one meter, all values should then be multiplied by 0.5 to calculate the value for a depth of 0.5 meters. If other soil depths are more appropriate (as defined by an NFC), other factors may be used.

MAPS AND REPORTS TO BE PRODUCED:

19. The CCE-W maps of critical acid loads to be presented to the UN ECE will consist of the 5 and 50 percentile values for each grid cell. Sulphur impact loads will be computed using the 5 and 50 percentile values of the critical load for acidity (see Equation A7.9).

20. The critical load maps of acidity for Europe will consist of various ecosystems and will be obtained using various methods, depending on national preferences.

ACTIVITIES IN THE NEAR FUTURE:

21. The CCE-W will produce a report for the Working Group on Effects on the results of its activities to date. The first draft of this report will be produced in February 1990, and will include contributions from the National Focal Centers. The CCE-W will provide assistance to the Task Force on Mapping in the production of its report.

22. Updates of the current European maps provided to all NFCs in November 1990 will be made before mid-February 1991. NFCs are urged to submit updates and national contributions to the CCE-W before the end of January.

23. NFCs are requested to send data on national critical loads of acidity as well as of potential acidity, including data leading to these results. In particular, data on nitrogen uptake, nitrogen immobilization, base cation uptake, and base cation deposition is needed to be able to assist the TFIAM in computing exceedance maps (see Equations A7.10 through A7.12, para. 14).

24. Future work on critical levels was discussed. The Coordination Center requested NFCs to submit information on available national base maps. The CCE-W will propose a work plan and distribute it to all NFCs for review.

A 1991 publication of the
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