Environmental Assessment of Soil for Monitoring. Volume IIa: Inventory & Monitoring

Dominique D. Arrouays, Xavier Morvan, Nicolas N. Saby, Anne C Richer-De-Forges, Christine Le Bas, P.H. Bellamy, A. Freudenschuss, A.R. Jones, R.J.A. Jones, M.G. Kibblewhite, et al.

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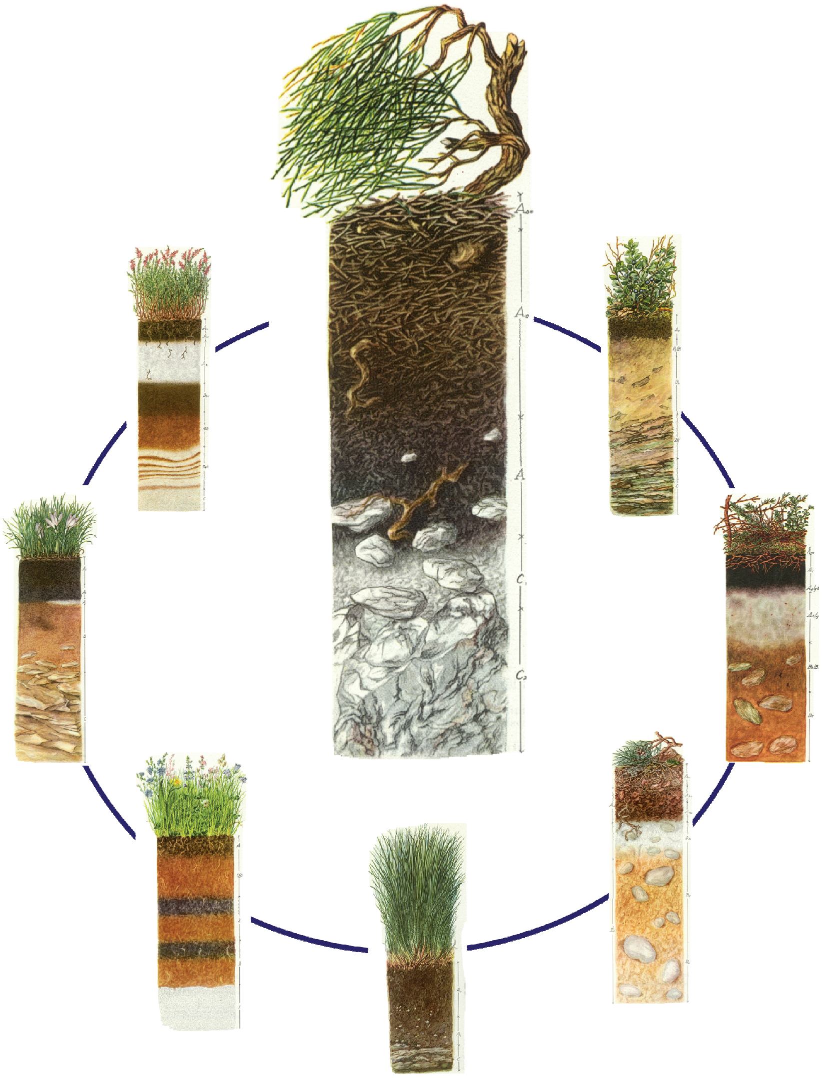

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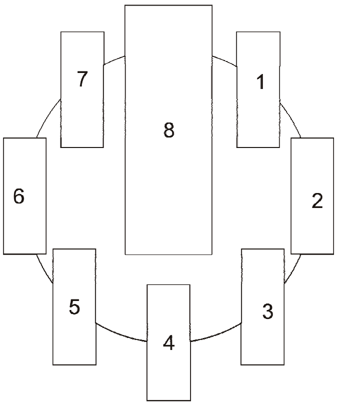

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Volume IIa: Inventory & Monitoring

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Preface

The ENVironmental ASsessment of Soil for mOnitoring – ENVASSO – Project (Contract 022713) was funded, 2006-8, as Scientific Support to Policy (SSP) under the European Commission 6th Framework Programme of Research. The project's main objective was to define and document a soil monitoring system for implementation in support of a European Soil Framework Directive, aimed at protecting the continent's soils. The ENVASSO Consortium, comprising 37 partners drawn from 25 EU Member States, succeeded in reviewing soil indicators and criteria (Volume I) that are currently available upon which to base a soil monitoring system for Europe. Existing soil inventories and monitoring programmes in the Member States (Volume II) were also reviewed and a database system to capture, store and supply soil profile data was designed and programmed (Volume III). Procedures and protocols (Volume V), appropriate for inclusion in a European soil monitoring system have been defined and fully documented by ENVASSO, and 22 of these procedures were evaluated in 28 Pilot Areas in the Member States (Volume IV). Finally, a European Soil Monitoring System (Volume VI) is defined that comprises a network of georeferenced sites at which a qualified sampling process is being or could be conducted.

Volume II has two parts, which together constitute the most comprehensive study to date of the soil inventory and monitoring activities in the European Union. The first part, Volume IIa, identifies the existing soil inventory and monitoring systems in the EU Member States and evaluates the extent to which existing soil monitoring networks adequately represent European soil typological units, land use/cover, specific soil criteria – such as soil organic carbon, bulk density, heavy metal contents – and existing spatial assessments of threats to soil such as soil erosion, compaction and desertification. The second part, Volume IIb Survey of National Soil Monitoring Networks, contains comprehensive fact sheets listing for each national network, its purpose, the sampling strategy adopted, the analytical methods used and the number of monitoring sites. Gaps in the coverage of these existing national networks are identified and the minimum number of new sites that would be needed to provide harmonised coverage at European scale is estimated.

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29 June 2008

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This report was prepared under the supervision of the French Institute for Agricultural Research (INRA) by Dominique Arrouays and Xavier Morvan. Responsibilities for the contents were shared as follows:

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EXECUTIVE SUMMARY

The results presented in this report provide an indication of the status of Soil Monitoring Networks (SMN) in Europe. The stated objectives of this module of ENVASSO are to:

1. provide a description of monitoring networks and their databases,
2. document coverage (over geography and time),
3. list variables and,
4. describe soil sampling and testing protocols.

This Volume II(a & b) constitutes the most exhaustive review on European soil monitoring networks to date.

The survey of monitoring practices was conducted by means of questionnaires. INRA was responsible for the design of the questionnaires and it developed these in collaboration with ENVASSO partners. The questionnaires asked for a description of monitoring activities, geographical coverage, variables, soil sampling and testing protocols, and summary statistics on variables by Member States. A literature review of in-site variability of soil parameters was also conducted.

Site selection and geographical coverage

Official frameworks for comprehensive soil monitoring exist in most countries. However, uniformity in methodology and coverage, albeit existing in some countries, is far from common even among national systems. This review highlights the differences between existing networks. The present geographical coverage is very heterogeneous between and within countries. National and regional networks are much denser in northern and eastern parts of Europe than in southern countries.

The locations for the installation of SMN sites may be selected based on different criteria: grid-based site selection, representativeness (of landform, soil types, land use, specific site-related situations), specific land uses or unusual conditions, documentation and control of land use and practices, or integration of sites into other currently established ecological observation areas.

Most of the soil mapping units and the land use classes of Europe have at least one monitoring site, however the parameters measured are far from homogeneous. The density of sites in soil mapping units of Europe is highly variable. About 10% of the soil mapping units do not have any monitoring site. For land use classes, the greatest density is reported in grasslands, whereas arable lands and forests have lesser, although comparable, site density. Permanent-crop lands (e.g. vineyards, orchards) and open spaces with little or no vegetation are under-sampled in comparison to other land uses.

The median density of sites in 50 km x 50 km cells applied all over Europe is 1 site per 300 km² and is close to the density of the ICP Forest grid. This density is, by definition, already reached for half of the European territory. However, a large variability in site densities is reported when considering various indicators, as the minimum set of parameters measured differs amongst countries.

Converted into a systematic grid, the median density of sites would be equivalent to a 17 km x 17 km grid covering Europe. If we take into account the existing sites and their uneven distribution between countries, to provide all 50 km x 50 km cells having at least this median density would require 4,100 new sites, mainly located in southern countries (Italy, Spain, Greece), and parts of Poland, Germany, the Baltic states, Norway, Finland and France. This number might be a slight overestimate, because some metadata are missing for Italy, Spain and Sweden, and some SMNs are currently being implemented (France). This illustrates the huge differences between countries and the considerable effort needed to reach a common acceptable level. As a 16 km x 16 km grid already exists covering forest soils, reaching this common median density would imply locating new sites only on non-forested soils. Whatever the selection criteria, we recommend that a minimum density of sites is achieved over Europe and we propose the present median density of 1 site per 300 km². Moreover, as already shown (Van-Camp *et al*., 2004), this density enables almost all the soil type and land use combinations in Europe to be covered. Table 1 gives the number of new sites needed to reach this median density in Member States, and the number of new sites to address some specific threats.

Table 1a. Number of new sites needed to reach the minimum density of 1 site per 300 km² for specific threats in Member States

	Soil Compaction		**Decline in Soil Biodiversity**			**Soil salinisation**	
	CP01	**CP02**	**BI01**	**BI02**	**BI03**	**SL01**	**SL02**
Country	**Bulk density**	**Packing density**	**Earthworm diversity**	**Enchytraeid diversity**	**Soil respiration**	**Salt profile content**	**Exchangeable sodium percentage**
Austria	139	139	277	277	252	279	7
Belgium	92	102	102	102	102	102	28
Bulgaria	16	16	370	370	370	370	195
Czech Republic	263	263	263	263	263	263	5
Denmark	107	107	149	149	149	149	2
England & Wales	507	507	507	507	507	507	507
Estonia	130	130	151	151	151	151	49
Finland	407	407	1117	1117	1117	1117	407
France	452	872	1769	1769	1769	1829	452
Germany	546	549	779	780	1189	1189	621
Greece	441	441	441	441	441	441	377
Hungary	0	0	310	310	0	0	0
Ireland	232	232	232	232	232	232	210
Italy	1006	1006	1006	1006	1006	1006	656
Latvia	193	213	195	215	215	215	109
Lithuania	216	216	216	216	216	216	134
Luxemburg	9	9	9	9	9	9	0
Malta	0	0	1	1	1	1	0
Northern Ireland	47	47	47	47	47	47	47
Netherlands	117	117	2	2	2	117	2
Norway	1074	1074	1074	1074	1074	1074	417
Poland	1039	1039	1039	1039	1039	1039	397
Portugal	296	296	296	296	296	295	38
Romania	14	14	793	793	793	170	14
Scotland	261	261	261	261	261	261	4
Slovakia	1	144	163	163	163	163	0
Slovenia	51	51	68	68	68	68	11
Spain	956	956	1663	1663	1663	1616	956
Sweden	1491	1491	1491	1491	1491	1491	407
TOTAL	**10101**	**10697**	**14790**	**14811**	**14886**	**14416**	**6054**

Table 1b. Number of new sites needed to reach the minimum density of 1 site per 300 km² for specific threats in Member States

	Soil Erosion	Decline in Soil Organic Matter		Soil Contamination			Desertification
	ER01	OM01	OM02	CO01	CO01	CO01	DE01
Country	Soil loss measurements	Organic matter or organic carbon content	topsoil organic carbon stocks	Cadmium content	Zinc content	Lead content	Estimated soil loss
Austria	271	0	139	0	0	0	273
Belgium	102	0	92	3	0	1	102
Bulgaria	366	16	16	16	16	16	370
Czech Republic	263	0	263	0	0	5	263
Denmark	149	2	107	107	107	107	149
England & Wales	507	2	507	2	2	2	507
Estonia	151	35	130	49	49	49	151
Finland	1117	209	407	209	209	363	1117
France	1829	452	452	452	452	452	1829
Germany	1180	217	546	209	211	211	1189
Greece	438	333	441	418	404	420	441
Hungary	310	0	0	0	0	0	310
Ireland	232	0	232	210	0	0	232
Italy	1006	656	1006	656	656	656	1006
Latvia	215	89	193	108	110	110	215
Lithuania	216	79	216	79	79	79	216
Luxemburg	9	0	9	0	0	0	9
Malta	1	0	0	1	0	0	1
Northern Ireland	47	0	47	0	0	0	47
Netherlands	117	2	117	2	2	2	117
Norway	1074	417	1074	417	417	417	1074
Poland	1038	248	1039	248	248	248	1039
Portugal	296	38	296	38	38	38	296
Romania	789	14	14	14	14	14	793
Scotland	261	4	261	261	261	261	261
Slovakia	163	0	1	0	0	0	163
Slovenia	68	11	51	11	0	0	68
Spain	1663	914	956	916	916	916	1663
Sweden	1491	407	1491	1491	407	407	1491
TOTAL	**15369**	**4147**	**10101**	**5917**	**4600**	**4775**	**15392**

Site area and sampling strategy

Apart from a few watersheds where erosion is monitored, all sites have areas ranging from 10 m^2 to a few ha and are homogeneous with regard to soil profile development. In most cases, sampling is based upon several subsamples (from 4 to 100) taken within this area. Apart from watersheds, we recommend selecting a small area for sampling, ranging from 100 m^2 to 1 ha and being homogeneous with regard to soil profile development. We recommend taking at least 4 subsamples, and adapting subsampling density by taking from 10 to 100 subsamples depending on the size of the site. It is also recommended that the exact location of cores is clearly recorded in order to avoid re-sampling these locations in future campaigns.

Fixed-depth increments are most often used for core sampling. This method of sampling ensures standardisation between sites. It is also the most relevant approach for assessing some anthropogenic characteristics (e.g. anthropogenic heavy metals, radionuclides, organo-chemicals), and for parameters showing a strong gradient near the surface. Pedogenic horizons are often sampled in soil pits, outside the monitoring area, but close to it. This method of sampling is relevant for some parameters (e.g. particle-size distribution, water retention properties, mineralogy). It is also the most relevant unit to link SMN observations to geographical soil information systems derived from soil mapping activities.

It is very difficult to make recommendations on the depths to adopt. Indeed, changing the depth of a national SMN would make it very difficult to use previous campaigns for the assessment of changes. One way to harmonise reporting at the European scale could be to report the results on the basis of an equivalent mineral mass. We recommend sampling is done so that topsoil concentrations or stocks of elements can be calculated for depths ranging from 0-15 to 0-30 cm.

Parameters monitored and analyses

There is generally a minimum set of mandatory parameters which are systematically measured (at least once) or monitored (with different frequencies). This minimum set differs amongst countries.

Amongst the top three indicators identified in Volume I for each threat to soil, the density of coverage is heterogeneous. Soil organic carbon and pH are the most often measured parameters, whereas some other parameters have a very limited coverage, even if we restrict this evaluation to risk areas concerned by the threat they cover. In particular, indicators related to soil biodiversity and to soil erosion are very seldom measured. Some trace elements are measured in almost all countries (e.g. Pb), whereas others are rarely measured (e.g. Hg). Indicators for soil compaction such as bulk density or packing density are not measured in about half of the Member States. A quite large number of periurban areas are not monitored for contaminants, especially in southern Member States. Areas identified as having the highest heavy metal deposition rates appear not to be sampled with sufficient density, especially where Hg is concerned. Areas with heavy livestock pressures are covered unevenly by appropriate indicator measurements (organic carbon, copper, zinc, phosphorus).

The use of international standards for analytical procedures (where they exist) is far from common among the SMNs reported here. The question of the harmonisation of analytical techniques remains a very difficult issue. Combining several techniques, on all samples or on a subset of samples, would be the best option to ensure data comparability over time and between Member States. It would be useful to use previous campaigns to detect changes, and to establish pedotransfer functions linking the results obtained using different methods. As the main cost in soil monitoring is accounted for by field sampling, adding new determinations would not affect costs greatly.

Most SMNs use inter-laboratory quality control. However, except for the on-going project “Forest Focus Biosoil”, there is no central laboratory acting as a reference for European soil analyses. A central laboratory could help to improve harmonisation at the EU level, by making determinations on a subset of samples, and working on pedotransfer functions to compare results from various methods.

Time interval for re-sampling and minimum detectable changes

Although a broad range of time intervals between sampling campaigns is observed, depending on parameters and on networks, most SMN use time steps equal or less than 10 years. Some SMN recommend adopting shorter time steps at the beginning of monitoring, and then to adapt the re-sampling to the rates of observed changes.

Recommending a maximum time step of 10 years would allow nearly all the SMNs to be incorporated into a common framework. For a large number of indicators, shorter time steps would not reliably demonstrate changes.

Our results suggest that the minimum detectable levels of change differ considerably between both soil monitoring networks and indicators. For some Member States, irrespective of the indicator, considerable effort is needed in order to reach an acceptable density of sites to assure minimum change detection. This density should in nearly all cases be denser than 1 site per 300 km^2. For some indicators such as the topsoil organic carbon, a time interval of about 10 years would enable the detection of some simulated changes. For other indicators, such as heavy metals, detecting changes occurring over such a short time interval is impossible except in the case of gross contamination.

Archiving samples

We recommend archiving samples in order to :

- Re-analyse samples from previous inventories to detect changes linked to analytical protocols
- Allow *a posteriori* analyses of new indicators
- Constitute a soil bank for research and inter-laboratory calibration.

Conclusion

In view of the present heterogeneity of SMNs in Europe, it is clear that harmonisation and co-ordination are necessary. When SMNs are dense enough, this harmonisation could be done by adding measurements for the missing indicators in existing sites. In numerous cases, new sites are also required. Indeed, considerable efforts are still needed to reach a common and acceptable level of soil monitoring in Europe. Yet, it is necessary to provide a framework for a harmonised system that allows comparison of the data provided by monitoring networks and geographical databases. Creating a minimum coverage of one site per 300 km^2 is the least that should be accepted, together with an intensive programme of cross-method validation to permit valid spatial and temporal comparisons both within and between Member States.

1 INTRODUCTION

Soil is one of the fundamental systems for agricultural food production, life and the environment and therefore its functions and quality must be sustainably maintained (EC, 2002). Soil monitoring is the systematic determination of soil variables so as to record their temporal and spatial changes (FAO/ECE, 1994). Soil monitoring is essential for the early detection of changes in soil quality. Such early detection enables action to be taken to control soil processes involved in soil degradation in order to protect and to conserve soils for a sustainable use and for general environmental control.

A soil monitoring network (SMN) is a set of sites/areas where changes in soil characteristics are documented through periodic assessment of an extended set of soil parameters. The use of a harmonised methodology is essential to provide data comparable among sites and between member States.

The stated objectives of this part of ENVASSO are to provide a description of the monitoring networks including their coverage (in space and time), parameters, and sampling and testing protocols. The results presented in this report provide an indication of the status of SMNs in Europe.

One purpose of this report is to review existing SMNs in Europe. To achieve the aim of gathering harmonised and comparable information on European soils, it is essential that the current status of monitoring is understood. Although official frameworks for comprehensive soil monitoring exist in most Member States, uniformity in methodology and coverage is far from common even within national systems. Considering the need to produce comparable and consistent results between Member States, it is important that these differences are highlighted and that ways of overcoming them are identified. Therefore, another aim of this report is to recommend improvements to current systems and/or ways to achieve the necessary improvement.

The survey of monitoring practices was conducted by means of questionnaires. The design of these questionnaires was the responsibility of the French Institut National de la Recherche Agronomique (INRA) who developed them in collaboration with ENVASSO partners. Electronic copies of these questionnaires were distributed to ENVASSO partners in each country. The partners were responsible for either answering the questionnaires, or identifying key contacts within their country to answer the questionnaires.

Spatial variation within monitoring sites may increase the number of samples to be analysed in order to detect a given amount of change. This has consequences for monitoring costs, on the reliability of observed changes, and on the minimum time step necessary to detect a given change. Therefore, we conducted a meta-analysis on soil variability within monitoring sites in order to assess the consequences of this variability on confidence intervals for the mean values of parameters monitored and on the minimum changes detectable given the site density.

Section 1 summarises the description of national and European level networks by describing the geographical coverage of sites and indicators, and by analysing their representativity according to soils, land-uses, and main state, pressure or impact indicators. The description of the questionnaires and the methodology for data collection, harmonisation and analysis are given in section 2 of this report. A summary description of soil monitoring networks (SMNs) in each country is provided in fact-sheets in Volume IIb. Section 4 provides a review of sampling and testing protocols used in SMNs. The exhaustive list of testing protocols is provided in Annex 4 as Tables. Section 5 summarises the main findings of the meta-analysis of the in-site variability and their consequences for minimum detectable changes and recommended time steps. The main findings of this review, and main inputs to the work reported in Volume IV (a & b), are summarised in the Conclusions. A major outcome of our work has been to highlight the urgency of the need for harmonisation and co-ordination of all aspects of soil monitoring in member states if robust intra- and inter-national comparison of soil condition is to be achieved.

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2 DATA COLLECTION, HARMONISATION, PROCESSING AND ANALYSIS

This section describes the data which were used for this report, the way they were obtained, and their processing.

2.1 Soil monitoring network metadata

2.1.1 Questionnaire survey

The metadata collection was conducted by means of a questionnaire. The design of this questionnaire was the responsibility of the French “Institut National de la Recherche Agronomique” (INRA) which developed it in collaboration with the partners involved in the first WP2 meeting in Orléans (3-4 of April 2006). This questionnaire consists of 4 Excel files and a dictionary (see forms in Annex I). Using this questionnaire, information was collected on the national SMNs and their sampling designs, the monitoring sites, the parameters measured and the analytical methods employed.

The first task was to define what constitutes a monitoring site. It was agreed that a site can be considered as a monitoring site, if the following conditions are fulfilled:

- the boundaries of the site are georeferenced with an accuracy better than +/- 10 m; and
- several measurement campaigns have been done, will be done, or can be done on the site.

These are the minimum conditions required to consider a site as a monitoring site. The quality of the SMN is improved, if the following conditions are also fulfilled:

- a composite sample, or several replicates, are sampled at the site in order to take into account the local soil spatial variability;
- the accuracy of the georeferencing of each sample point is very good (<1m) and each subsample is georeferenced; and
- the accuracy of the georeferencing is less than half of the sites shortest side or diameter.

The 4 Excel files were sent, in April 2006, to all the partners who were asked to complete the questionnaire. Fact sheets collated from the responses to the questionnaire, describing all the soil monitoring networks are presented in Annex II.

After the second WP2 meeting (June 2006, Orléans), another request was sent to the partners, who were asked to provide basic statistics (mean, standard deviation, minimum, maximum) for each parameter measured in their SMNs.

2.1.2 International soil monitoring networks: ICP Forests level I and II

The International Co-operative Programme on the Assessment and Monitoring of Air Pollution in Forests began in 1985. It is an integral part of the Co-operative Programme for Monitoring and Evaluation of the long-range transmission of Air Pollutants in Europe (EMEP) of the Long-Range Transboundary Air Pollution (LRTAP) convention. In order to contribute to a better understanding of air pollution and other factors which may influence forest ecosystems, a programme for intensive and continuous monitoring was implemented. An extensive, systematic large scale network (16 km x 16 km grid) was established (ICP Forest level I). Only grid points falling within forested areas were sampled. Level I plots are currently re-sampled for soil, in the framework of the Forest Focus BioSoil study (http://inforest.jrc.it/activities/ForestFocus/biosoil.html). This large scale survey was extended by the intensive and continuous monitoring of the forest ecosystems network (ICP Forest level II) containing crown condition assessments, soil and foliar surveys, increment studies, deposition measurements and the observation of meteorological parameters over a period of at least 15-20 years. In the European Union, Switzerland, Croatia, Serbia and Montenegro, Russia, Moldova and Belarus, 5915 plots have been established.

We only took into account the metadata for the mineral layers. Selection of the measured parameters was based on the mandatory parameters described in the upgrade of the 4th edition of the ICP Forests' Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests, part IIIa (FSCC, 2006) and on the results presented in the report of the FSCC (Vanmechelen, *et al*., 1997). The description of the data collected is presented in Annex II.

2.1.3 National soil monitoring networks

All the known soil monitoring networks are described in fact sheets in Annex II. In this section, we briefly summarise the number of national SMNs for which we received information, and the related number of sites per country.

2.1.3.1 Austria

From Austria, we received information on 12 SMNs having various purposes: environmental soil surveys, soil erosion surveys, and monitoring of soil organic matter.

We collected data for 3315 monitoring sites distributed all over the country; 874 of them have been sampled more than once (287, 2, and 585 of them have been sampled 4, 3, and 2 times, respectively).

2.1.3.2 Belgium

We received information on 13 SMNs in Belgium. For 5 of them, the monitoring sites will not be used in this study for various reasons: the coordinates were not accurate enough, or we were not allowed to use private data, or the resampling did not correspond to the same sites. As for Austria, the objectives of the SMNs are various: soil inventory, assessment of soil fertility, heavy metal monitoring.

We retained 2515 potential soil monitoring sites, none of which have been resampled yet.

2.1.3.3 Bulgaria

We received information on 2 SMNs in Bulgaria. Their purposes are the study of diffuse contamination and the survey of local hot spots. For this last SMN, the access to the data is restricted. Therefore we could not use it. We know that there is another regional SMN in Bulgaria but we did not get metadata for it.

We had access to the coordinates of 407 monitoring sites in Bulgaria, located on a 16 km x 16 km grid. Fourty four of these sites have been sampled 3 times.

2.1.3.4 Czech Republic

We received information on 3 SMNs in Czech Republic. However, we could not get the coordinates of the sites for 2 of them. The remaining SMN has 207 monitoring sites, none of which has been resampled.

2.1.3.5 Denmark

We received information from 4 SMNs in Denmark. We could get the coordinates of the sites for only 1 of these SMNs. Its purpose is the estimation of the farmland nitrogen requirements.

This SMN is made up of 858 monitoring sites located on a 7 km grid. None of them have been resampled.

2.1.3.6 England and Wales

In England and Wales, we received information from one SMN including 6105 monitoring sites located in a 5km grid. Part of them (2358 sites) have been resampled.

2.1.3.7 Estonia

We received information from 3 SMNs in Estonia. Unfortunately, the accuracy of the coordinates of one of these SMNs is not precise enough. Therefore, we retained 2 SMNs for which the coordinates of the sites were available.

From these SMNs, we collected data for 1483 monitoring sites in Estonia; 13 and 4 of them have been sampled 2 and 3 times, respectively.

2.1.3.8 Finland

We received information from 2 SMNs in Finland. Their purpose is the study of heavy metals and nutrient contents in the soil.

These SMNs are made up of 822 sites: 117 of them have been sampled 2 times and the other 705 sites have been sampled 3 times.

2.1.3.9 France

There is one SMN in France, its purpose is a general monitoring of the soil quality.

This SMN is planned to be made up of ca 2200 sites, but only 909 have been sampled to date. The initial sampling campaign is currently ongoing, and should be finished by the end of 2008.

2.1.3.10 Germany

A large number of inventories exists in Germany (see Annex II). But together with the ICP Forest monitoring, there is one other main SMN in Germany, the purpose of which is the survey of soil quality. We received only metadata for this SMN.

This SMN consists of 829 monitoring sites, which have been sampled once.

2.1.3.11 Greece

The 134 monitoring sites in Greece are not a part of a systematic national SMN. They are individual sites having various purposes: soil survey, soil erosion, landslide, soil organic matter, nitrate leaching etc. Most of them have been sampled only once. Only five monitoring sites have been resampled (3 times (1 site), 17 times (2 sites) and 18 times (2 sites)).

2.1.3.12 Hungary

We received information concerning 2 SMNs in Hungary. We got the coordinates of the monitoring sites for these 2 SMNs, which comprise 1235 monitoring sites, which have all been sampled 14 times since 1992.

2.1.3.13 Ireland

We received information from one SMN in Ireland. Its aim is to survey the heavy metals content in the topsoil.

This SMN includes 1310 monitoring sites located on a 7 km grid. All the sites have been sampled once.

2.1.3.14 Italy

In the absence of a partner from Italy, it was not possible provide detailed information on national SMNs. However, it is known that some soil monitoring activities exist or are planned in Italy, for example, Filippi (2005) described a project to establish a total of about 480 sites, giving a density of 1 site per 625 km^2 for Italy.

2.1.3.15 Latvia

We received information from one national SMN in Latvia. Its aim is to monitor the agricultural land. This SMN includes 20 monitoring sites. All sites have been sampled 8 times.

2.1.3.16 Lithuania

We received information from one SMN in Lithuania. This SMN is mainly focused on soil contamination and on other agrochemical properties. It includes 63 monitoring sites which have been sampled twice.

2.1.3.17 Malta

We received information from 5 SMNs in Malta. Their purposes are to make a soil inventory, and survey soil contamination, decline of soil organic matter and soil salinity.

All the coordinates of these SMNs were available. We collected data for 388 monitoring sites. Most of them have been sampled once, except for 31 sites which have been sampled twice.

2.1.3.18 The Netherlands

There are many monitoring activities in the the Netherlands, but we could get the metadata of only one SMN. Its aim is to make a survey of soil biodiversity and contamination.

We collected data for 503 monitoring sites, which have been sampled once.

2.1.3.19 Northern Ireland

We received information from one SMN in Northern Ireland. Its purpose is to create a geochemical database. We collected data for 582 monitoring sites located on a 5 km grid. Most of these sites have been sampled twice.

2.1.3.20 Poland

We received information from one SMN in Poland. Its purpose is to make an inventory of soil chemical properties and to study soil contamination.

This SMN is made up of 216 monitoring sites. Two sampling campaigns have occurred for all these sites.

2.1.3.21 Portugal

We received information from 2 SMNs in Portugal, but one has only one monitoring site. Their purposes are to study soil salinisation and heavy metals in the agricultural soils.
We collected data for 111 monitoring sites in Portugal. They have been sampled once.

2.1.3.22 Romania

We received information from 2 SMNs in Romania. One national systematic grid-based SMN surveys soil contamination and soil chemical and physical states. Four other monitoring sites exist, where soil erosion is monitored.

In total, we collected data for 945 monitoring sites in Romania. The 941 monitoring sites from the systematic SMN have been sampled once.

2.1.3.23 Scotland

We received information from one SMN in Scotland. Its purpose is to characterise and quantify soil distribution and variability at a regional scale.

We collected data for 721 monitoring sites located all over Scotland in a 10km grid, which have been sampled once.

2.1.3.24 Slovenia

We received information from eight SMNs covering Slovenia. Their purpose is the study of soil contamination.

All the coordinates of these SMNs were available. We collected data for 412 monitoring sites. Only one sampling campaign has occurred for most of the monitoring sites; only 6 of them have been sampled twice.

2.1.3.25 Slovakia

We received information from one SMN in Slovakia. The aim of this SMN is to measure the different soil properties according to the different soil threats.

The coordinates of the 318 monitoring sites have been provided. Two sampling campaigns have occurred for this SMN.

2.1.3.26 Spain

We received information from 9 SMNs, all of which were located in Catalonia. However, we know that some other SMNs exist in Spain (Ibáñez *et al*., 2005), but we could not get information about these monitoring activities. We could get coordinates for only 4 of the 9 Catalonian SMNs. We collected data for 110 monitoring sites in that part of Spain. All these sites have been sampled once.

2.1.3.27 Sweden

Several SMNs exist in Sweden on agricultural and forest lands (Olsson, 2005). However, we only got information about one SMN established for forest soils. We collected data for 5410 monitoring sites distributed all over Sweden, except in the centre of the country where there is a huge lack of data. All these sites have been sampled twice.

2.2 EU-wide databases

2.2.1 Soil Geographical Database of Eurasia

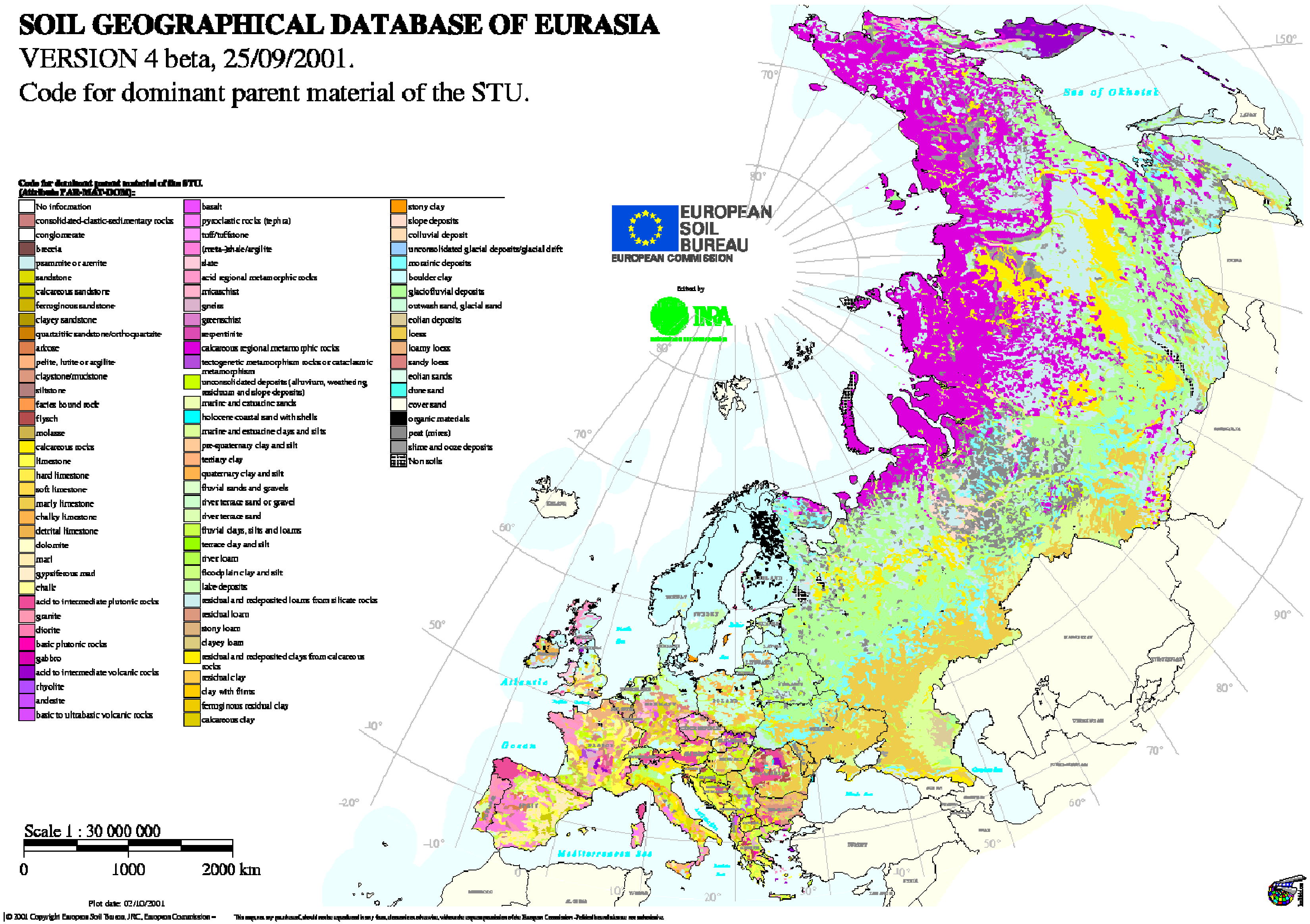
The Soil Geographical Database of Eurasia at a Scale of 1:1,000,000 (Figure 1) is part of the European Soil Information System (EUSIS). It is the product of a collaborative project involving all the European Union and neighbouring countries (King *et al*., 1995). It is a simplified representation of the diversity and spatial variability of the soil coverage. The methodology used to differentiate and name the main soil types is based on the terminology of the F.A.O. legend for the Soil Map of the World at a Scale of 1:5,000,000. This terminology has been refined and adapted to take account of the specificities of the landscapes in Eurasia.

The database contains a list of Soil Typological Units (STU). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example the texture, the water regime, the stoniness, etc. The geographical representation was chosen at a scale corresponding to the 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMU) to form soil associations and to illustrate the functioning of pedological systems within the landscapes.

Harmonisation of the soil data from the Member States is based on a dictionary giving definition for each variable. Considering the scale, the within-SMU variability is very large. Furthermore these variables were estimated over large areas by expert judgement rather than measured on local soil samples. This expertise results from the synthesis and generalisation of national or regional maps published at more detailed scales, for example 1:50,000 or 1:250,000 scales. Delineation of the Soil Mapping Units is also the result of expertise and experience. Quality indices of the information (purity and confidence level) are included with the data in order to guide usage.

Although detailed soil information for Malta exist, the current Soil Geographical Database of Eurasia does not include these data, thus it was not possible to inlcude Malta in our analyses. Iceland did not particpate in the ENVASSO project.

We made an overlay of the soil map with the European monitoring sites in order to check the representativeness of the sites for the soil mapping units. This overlay is explained in Figure 2.



© 2001 Copyright European Soil Bureau, JRC, European Commission –

Figure 1. Soil geographical database of Eurasia

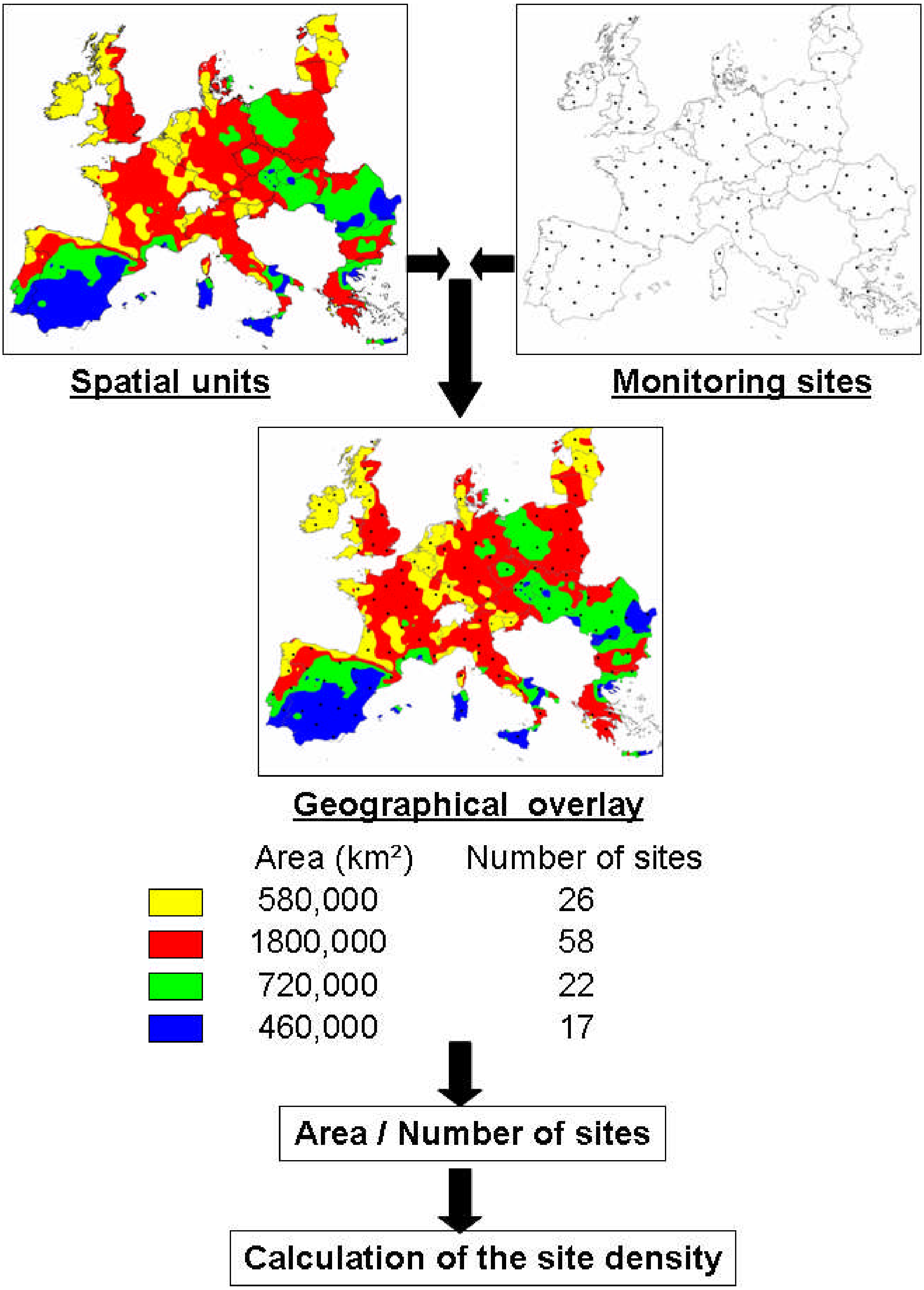


Figure 2. Principle of the overlay of geographical data (e.g. European Soil map, Land Cover map, maps of pressure indicators) with the monitoring sites coordinates

2.2.2 Corine Land Cover 2000

The aim of the CLC database is to provide an inventory of the Earth surface features for managing the environment (Heymann *et al*., 1994). Only features that are relatively stable in time are mapped. CLC is not interested in diurnal changes (e.g. tides), seasonal changes (e.g. vegetation cycles) or short-term changes (e.g. flooding). Computer-aided visual interpretation of satellite images has been chosen as the mapping methodology. The basic choices of scale 1:100,000 minimum mapping unit (MMU) of 25 hectares and minimum width of linear elements of 100 metres represent a trade-off between cost and detail of land cover information. Information is available for two periods, resulting in two databases: CLC1990 and CLC2000. The basic parameters are the same for CLC1990 and CLC2000. However, in CLC1990, some of the Member States had not kept to the 25 ha limit, which made comparison among countries difficult. This limitation was removed with the CLC2000.

The standard CLC nomenclature includes 44 land cover classes (Table 2). These are grouped in a three level hierarchy, having five level-one categories. All national teams had to adapt the nomenclature according to their landscape conditions, following standard criteria. The 44 classes have not changed since the implementation of the first CLC inventory (1986-1998). However, the definition of each nomenclature element was significantly improved (Bossard *et al*., 2000) to facilitate the achievement of comparable results in time and space. A special feature of the nomenclature is the class “Heterogeneous agricultural areas”. It is formed by objects, (e.g. plots of arable land, areas of natural vegetation, etc.) which themselves would be smaller than the minimum mapping unit (25 hectares).

Figure 3 shows the Corine Land Cover 2000 units: Norway is not covered by CLC.

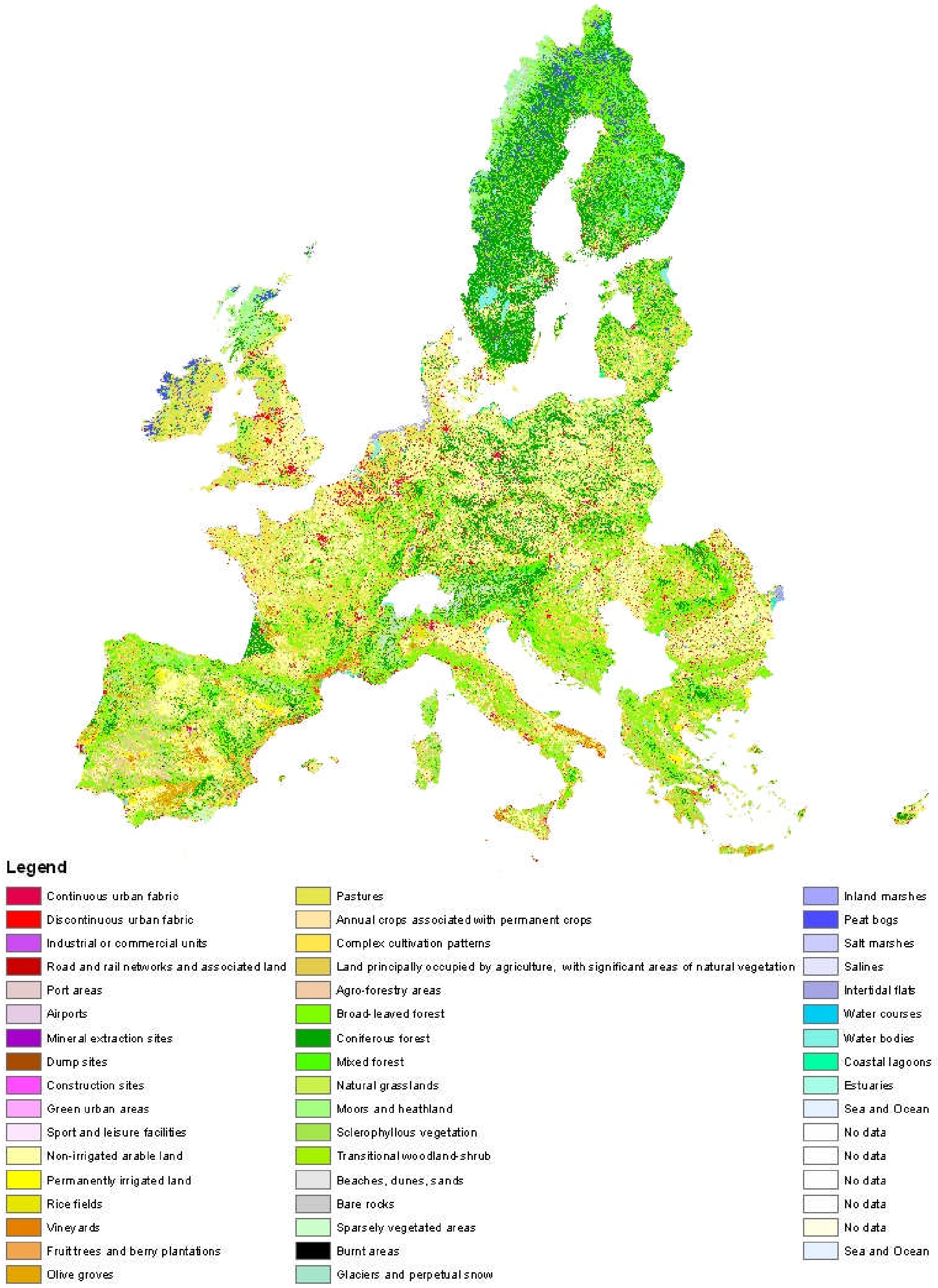


Figure 3. Corine Land cover 2000 (100 m cells)

Table 2. Corine Land Cover codes

CLC code	LABEL1	LABEL2	LABEL3
111	Artificial surfaces	Urban fabric	Continuous urban fabric
112	Artificial surfaces	Urban fabric	Discontinuous urban fabric
121	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units
122	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land
123	Artificial surfaces	Industrial, commercial and transport units	Port areas
124	Artificial surfaces	Industrial, commercial and transport units	Airports
131	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites
132	Artificial surfaces	Mine, dump and construction sites	Dump sites
133	Artificial surfaces	Mine, dump and construction sites	Construction sites
141	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas
142	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities
211	Agricultural areas	Arable land	Non-irrigated arable land
212	Agricultural areas	Arable land	Permanently irrigated land
213	Agricultural areas	Arable land	Rice fields
221	Agricultural areas	Permanent crops	Vineyards
222	Agricultural areas	Permanent crops	Fruit trees and berry plantations
223	Agricultural areas	Permanent crops	Olive groves
231	Agricultural areas	Pastures	Pastures
241	Agricultural areas	Heterogeneous agricultural areas	Annual crops associated with permanent crops
242	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns
244	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas
311	Forest and semi natural areas	Forests	Broad-leaved forest
312	Forest and semi natural areas	Forests	Coniferous forest
313	Forest and semi natural areas	Forests	Mixed forest
321	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Natural grasslands
322	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Moors and heathland
323	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Sclerophyllous vegetation
324	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland-shrub

Table 2. Corine Land Cover codes (cont.)

CLC code	LABEL1	LABEL2	LABEL3
331	Forest and semi natural areas	Open spaces with little or no vegetation	Beaches, dunes, sands
332	Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks
333	Forest and semi natural areas	Open spaces with little or no vegetation	Sparsely vegetated areas
334	Forest and semi natural areas	Open spaces with little or no vegetation	Burnt areas
335	Forest and semi natural areas	Open spaces with little or no vegetation	Glaciers and perpetual snow
411	Wetlands	Inland wetlands	Inland marshes
412	Wetlands	Inland wetlands	Peat bogs
421	Wetlands	Maritime wetlands	Salt marshes
422	Wetlands	Maritime wetlands	Salines
423	Wetlands	Maritime wetlands	Intertidal flats
511	Water bodies	Inland waters	Water courses
512	Water bodies	Inland waters	Water bodies
521	Water bodies	Marine waters	Coastal lagoons
522	Water bodies	Marine waters	Estuaries
523	Water bodies	Marine waters	Sea and ocean
999	No data	No data	No data
990	Unclassified	Unclassified land surface	Unclassified land surface
995	Unclassified	Unclassified water bodies	Unclassified water bodies

2.2.3 Geographical soil regions database

The European Soil Bureau Network (ESBN) developed a soil regions database at a scale of 1:5,000,000 (version 1.0). The revision of this first version became necessary because of new developments in international soil classification, in the availability of improved auxiliary mapping data such as topography, and in evaluations of national soil inventory data. Version 2.0 has been produced under a joint venture between the Federal Institute for Geosciences and Natural Resources (BGR) and the European Soil Bureau Network (ESBN) (Hartwich *et al*., 2006).

The delineation of the soil regions is based on soil maps, geological maps, natural vegetation, topography and ecological and environmental classifications.

We made an overlay of this map with the European monitoring sites (Figure 2). We also combined this map with CLC level 1 and we overlaid this combination with the European monitoring sites.

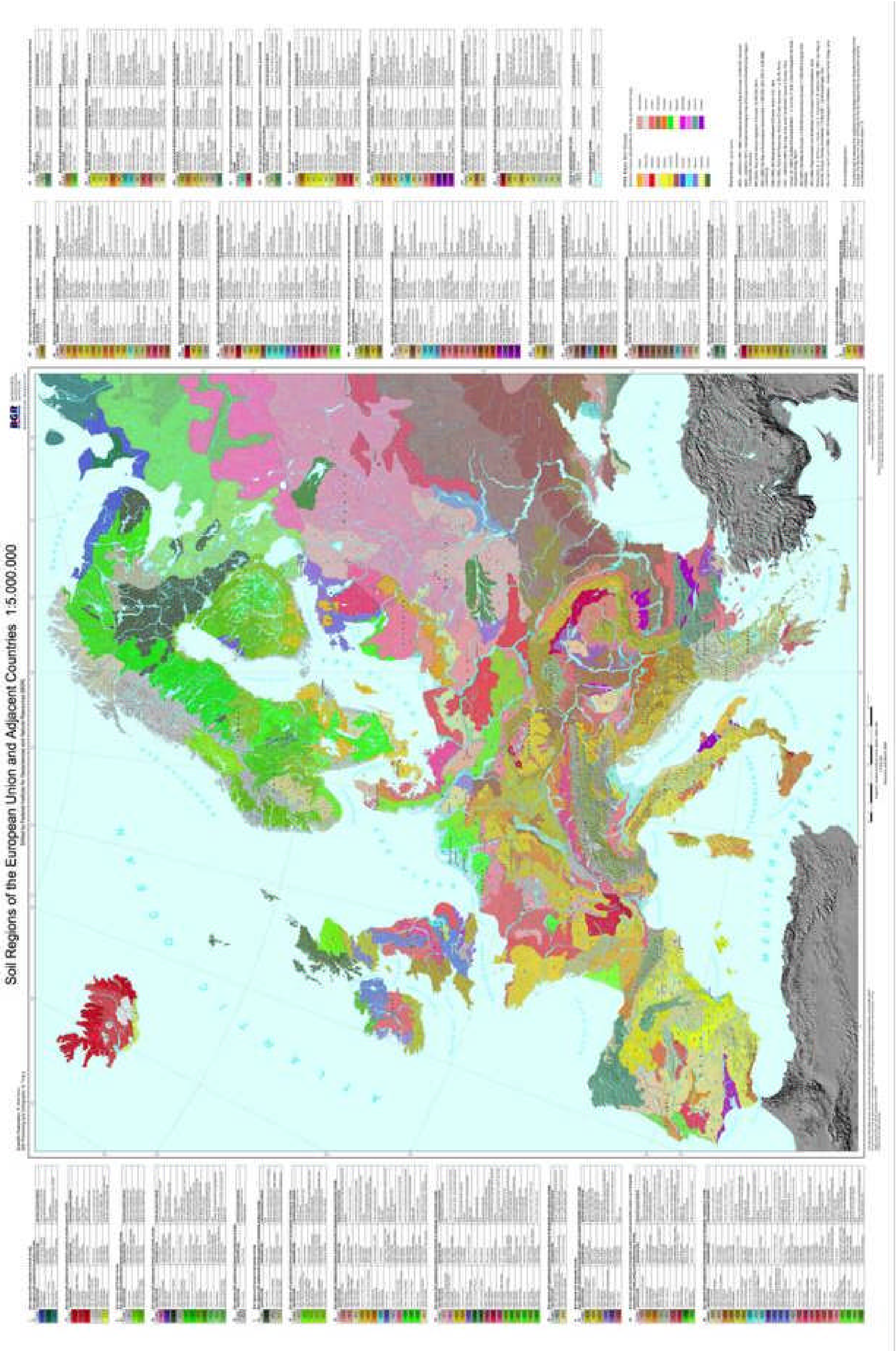


Figure 4. Soil regions of the European Union and adjacent countries 1:5 000 000 (Hartwich *et al*., 2006)

2.2.4 Soil organic carbon and peat maps

Jones *et al*. (2005) describe a methodology for estimating organic carbon contents (%) in topsoils across Europe. The information presented in map form provides policy-makers with estimates of current topsoil organic carbon contents for developing strategies for soil protection at regional level. Such baseline data may be used to estimate regional differences in soil organic carbon (SOC). Processing of data was performed on harmonized spatial data layers in raster format with a 1 km × 1 km grid spacing (Figure 5).

We overlaid this map with the coordinates of SMN sites in order to assess their representativity for organic carbon status in Europe.

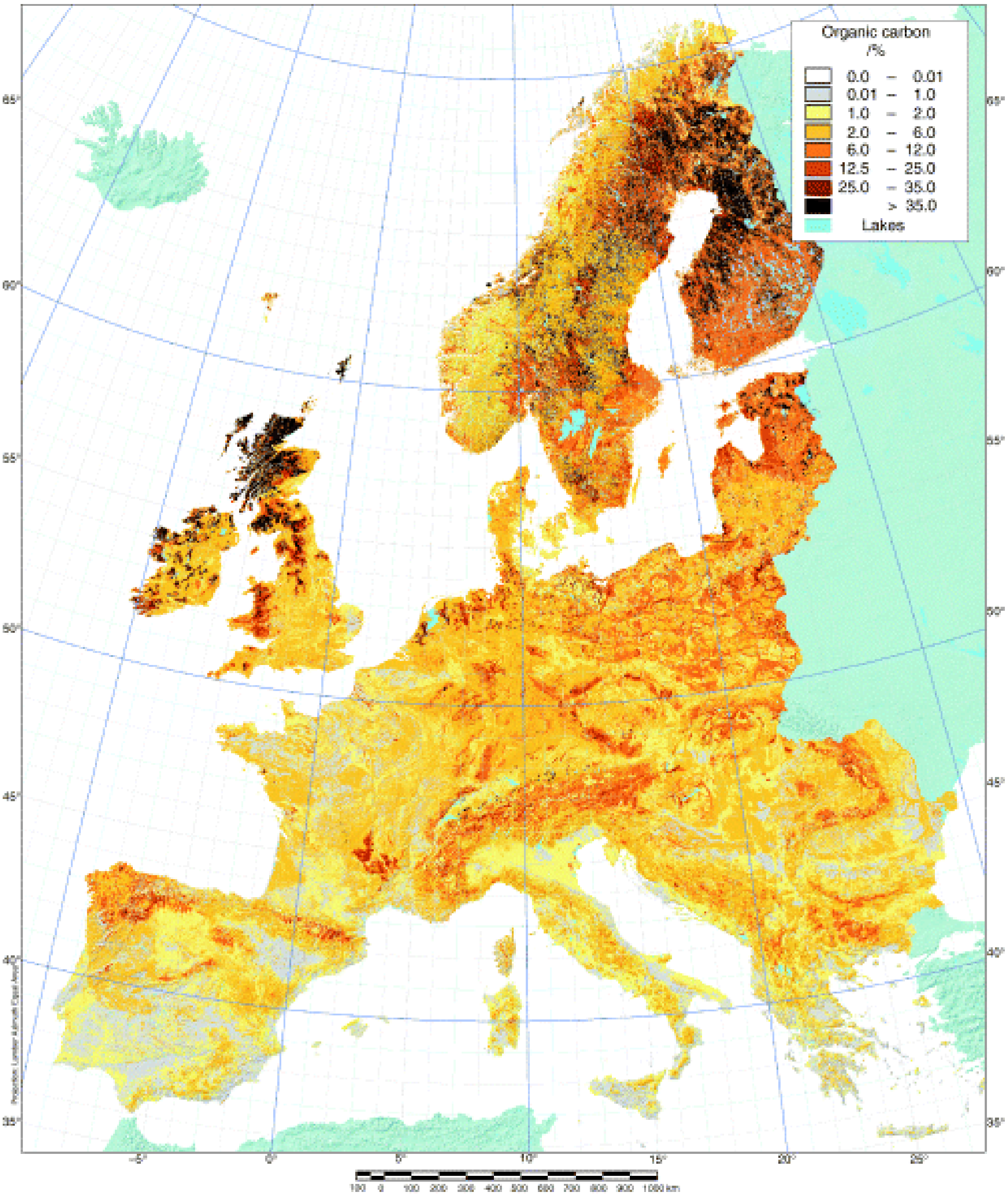


Figure 5. Soil organic carbon map of Europe
(Jones *et al*., 2005)

The peat map is based on the soil organic carbon map. Indeed, the distribution of peat is more accurately portrayed by the map of SOC of Europe (Jones, *et al*., 2005) than by the European Soil Map. Moreover, the map of SOC of Europe with a threshold of 25% SOC (Figure 6) gives more accurate estimates of the area of peatland (peat and peat-topped soils) in Europe than a threshold of 20% SOC with the same spatial data, or the European Soil Database (Montanarella *et al*., 2006).

The map in Figure 6 was overlaid with the European monitoring sites to identify any monitoring sites, reported in this work, that are sited in the large areas of peat and to calculate their density.

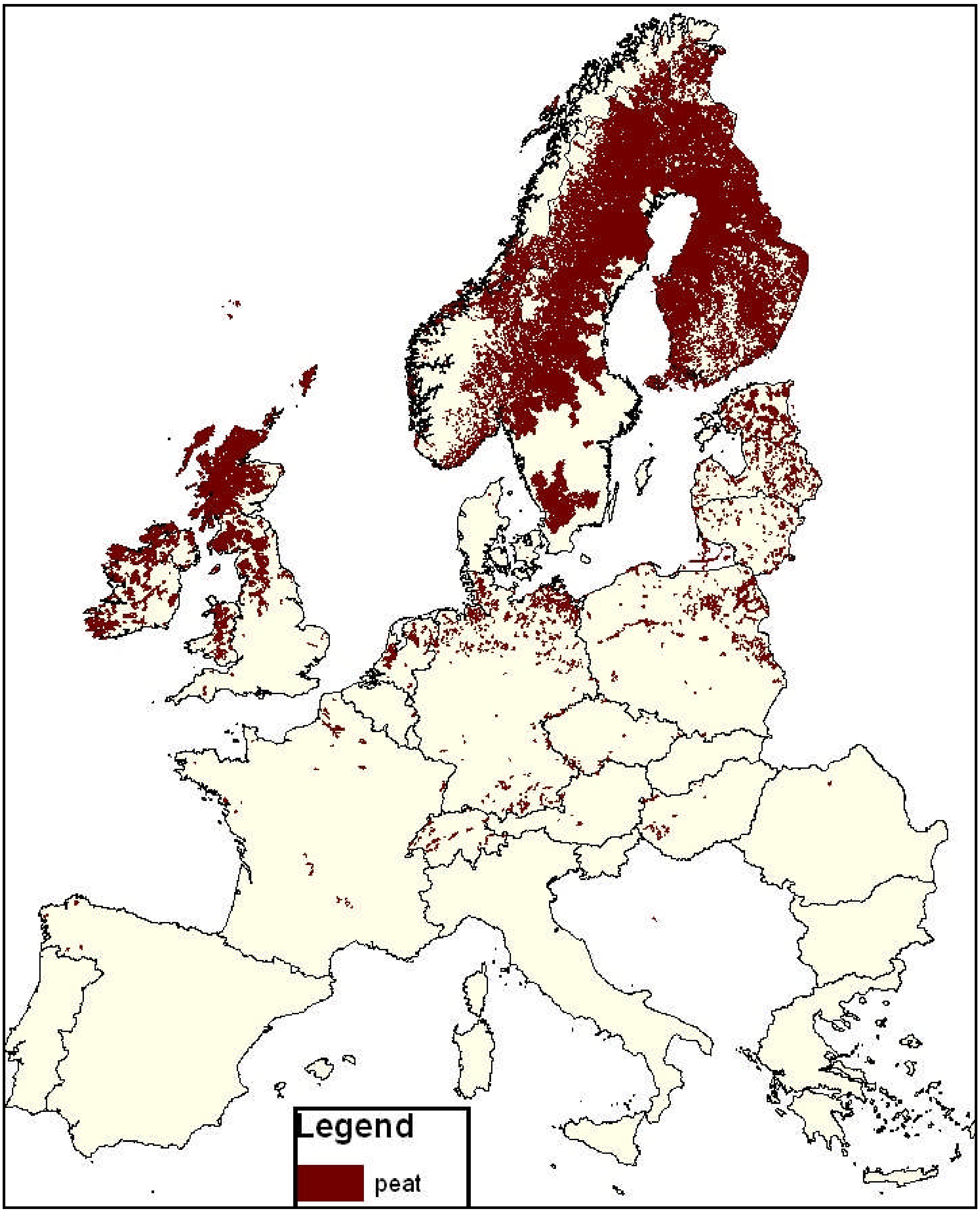
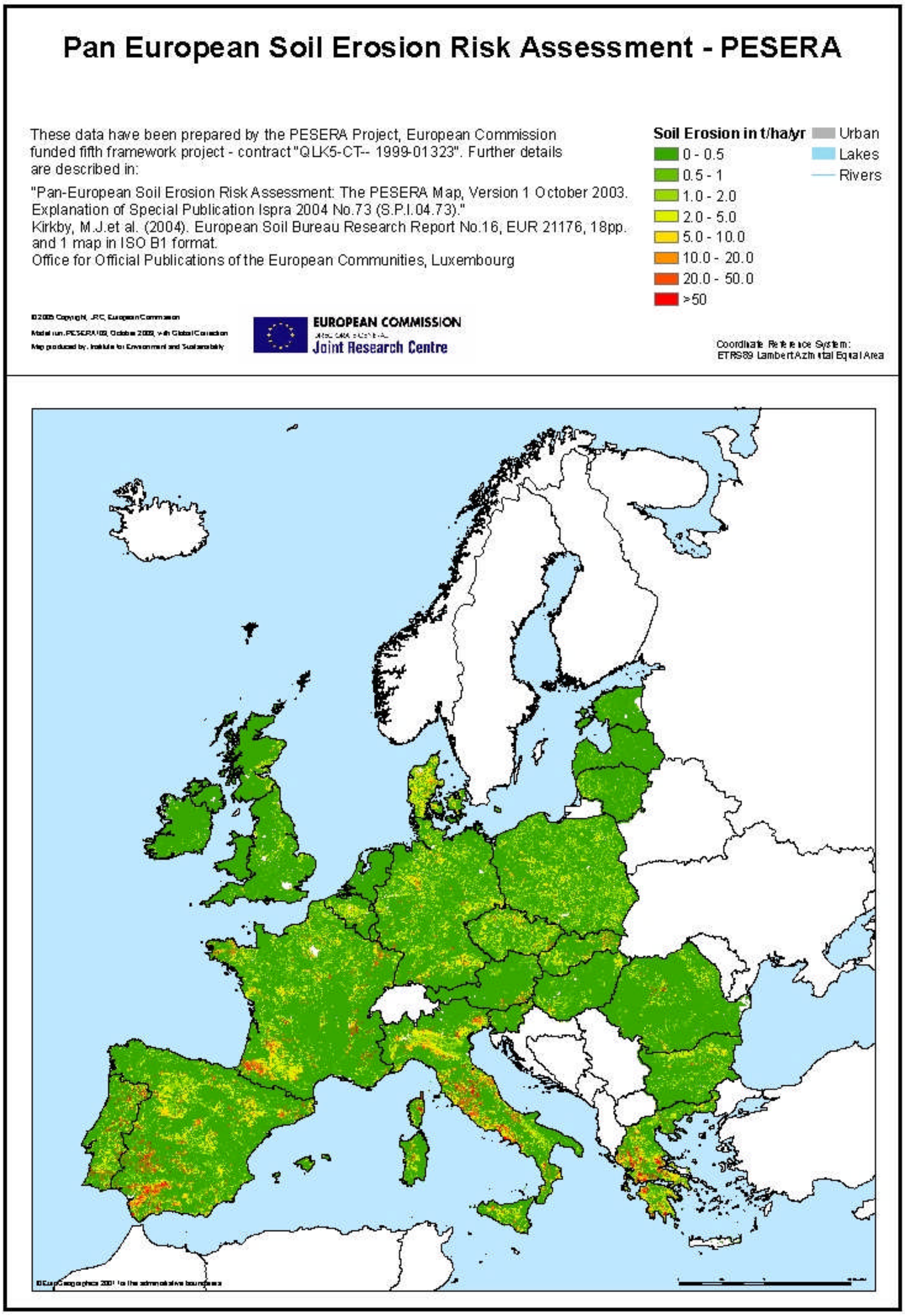


Figure 6. Delineation of the peat & Peaty-topped soils in Europe (after Montanarella et al., 2006)

2.2.5 Soil Erosion Risk Estimates

(Kirkby *et al.*, 2004; S.P.I.04.73., 2004)

Soil erosion by water is a widespread problem throughout Europe. PESERA (Pan European Soil Erosion Risk Assessment) models spatial and temporal data of variable quality and detail to enable the impacts of agricultural policy, land use and climate changes to be assessed and monitored across Europe.



Pan European Soil Erosion Risk Assessment - PESERA

These data have been prepared by the PESERA Project, European Commission funded fifth framework project - contract "QLK5-CT-- 1999-01323". Further details are described in:

"Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73)."
Kirkby, M.J.et al. (2004). European Soil Bureau Research Report No.16, EUR 21176, 18pp. and 1 map in ISO B1 format.
Office for Official Publications of the European Communities, Luxembourg

Figure 7. PESERA map
(Kirkby *et al.*, 2004)

PESERA uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe.

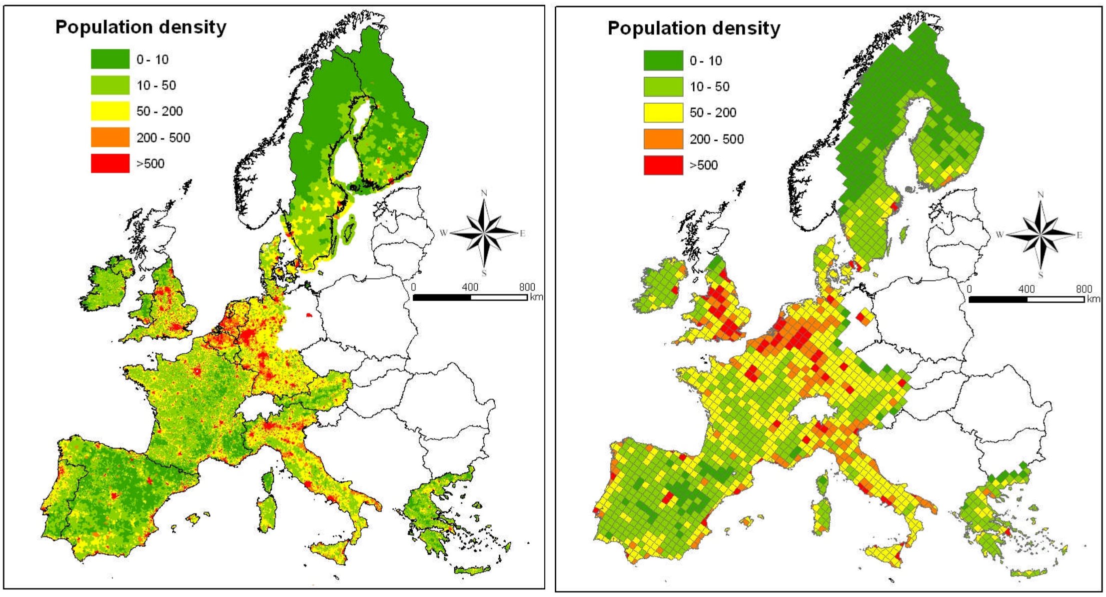
The soil erosion estimates (t $ha^{-1}yr^{-1}$) have been calculated by applying the PESERA grid model at 1 km, using the European Soil Database, CORINE land cover, climate data and a Digital Elevation Model (Figure 7). The resulting estimates are sediment losses from water erosion. The PESERA model produces results that depend crucially on land cover as identified by CORINE and on the accuracy of the interpolated meteorological data.

The PESERA map was overlaid with the European monitoring sites to check if the existing monitoring sites cover the whole variability of the soil erosion estimates.

2.2.6 Population Density

The population density database is a part of the GISCO database (Geographic Information System for the European Commission) and contains population numbers and population density for the regional subdivisions based on the NUTS 5 nomenclature (Nomenclature of territorial units for statistics) defined by SIRE, Infra-Regional Information system (Eurostat) (Figure 8).

This database raises some problems. Firstly, it mainly covers western Europe and such data are not available for the eastern Member States, nor for Scotland, Norway and Malta. Therefore, the representativeness study, based on the population density, was conducted only on that part where data were available. Secondly, the areas of the NUTS5 polygons are very different. Indeed, whereas a NUTS5 area in Sweden may be 20,000 km², the NUTS5 areas in other Member States can be less than 1 km². Moreover, if population density is considered as a pressure indicator, monitoring sites may be located in a low population density area as defined by this database, but adjacent to a significant population centre. Consequently, it was decided to create a grid aggregating in each of its cells the area-weighted mean of NUTS5 density data it included. The grid used is the is a 50 km grid produced by the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) (http://www.emep.int/index_data.html) (Figure 8).



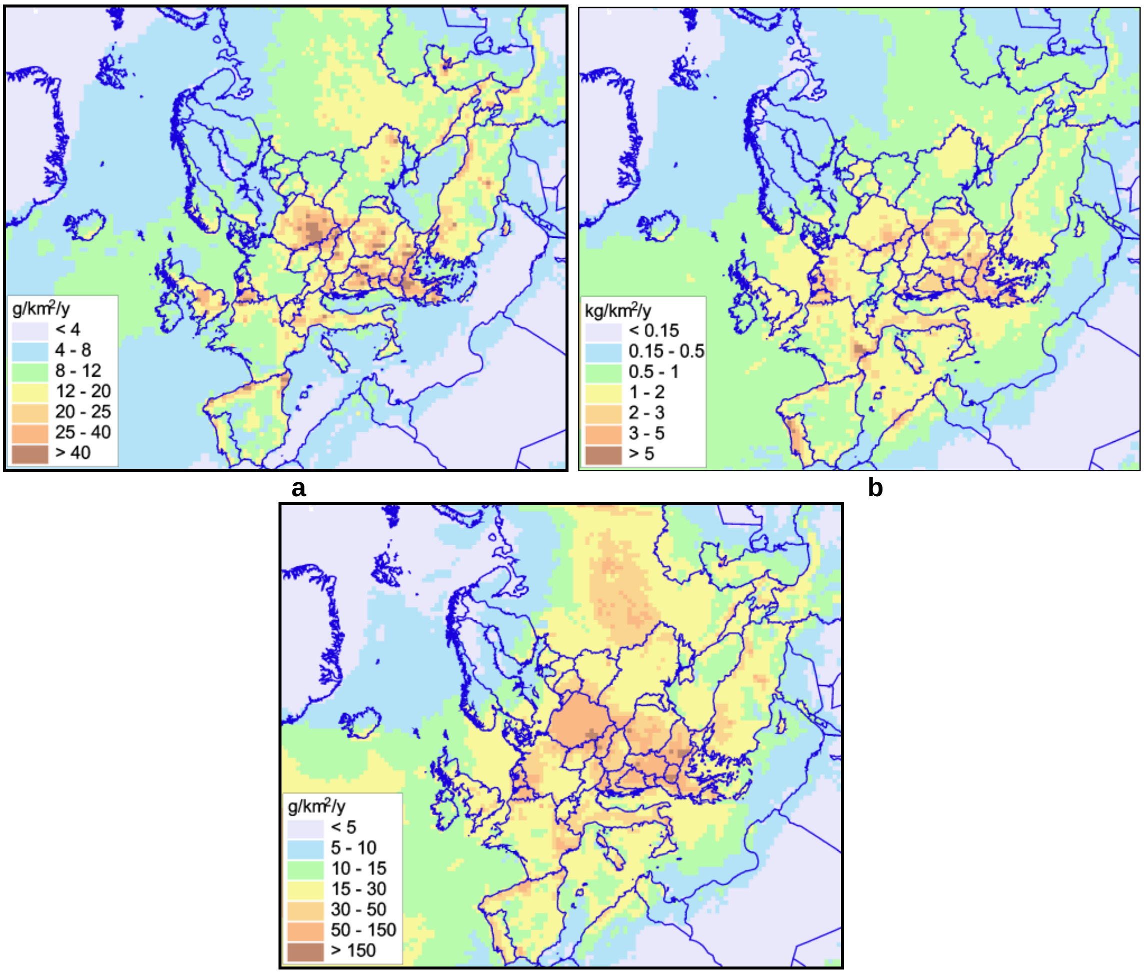
(NUTS5 nomenclature on the left, and data aggregated on the EMEP grid on the right)

Figure 8. Population density in EU15 Europe

2.2.7 Heavy metal emission data (EMEP)

The EMEP programme notably focuses on providing monitoring and modeling data on concentrations, depositions and transboundary fluxes of Heavy Metals (Ilyin *et al*., 2006) and Organic Pollutants (Gusev *et al*., 2006) over Europe. It relies on three main elements: the collection of emission data, the measurements of air and precipitation quality, and the modelling of atmospheric transport and deposition of air pollution. In this study, only the data on heavy metals was used because most of the SMNs do not monitor organic pollutants.

The EMEP programme provides data of annual averages of Pb, Cd and Hg concentrations in the air and annual averages of Pb, Cd and Hg depositions in 2004. These data are available at a spatial resolution of 50 x 50 km. We aquired the data compiled under the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP, http://www.msceast.org/ Section "EMEP Countries").



a

b

c

a) mercury, b) lead and c) cadmium

Figure 9. Spatial distribution of mercury, lead and cadmium depositions in Europe in 2004

The spatial distribution of Hg, Pb and Cd depositions in Europe in 2004 is shown in Figure 9. Generally, mercury depositions in Europe in 2004 were greater than 4 g km^{-2} y^{-1} but rarely exceeded 40 g km^{-2} y^{-1}. The greatest deposition fluxes took place in Poland, Belgium, the United Kingdom, and Balkan countries, where depositions were as large as 25 g km^{-2} y^{-1} and more. Over central parts of the Scandinavian Peninsula and the Arctic the depositions did not exceed 8 g km^{-2} y^{-1}.

The spatial distribution of lead deposition over the EMEP region corresponds to a significant extent to the anthropogenic emission patterns. In general, annual deposition fluxes in Europe range from 0.3 to 3 kg km^{-2} y^{-1}. In the most polluted areas of such countries as Belgium, Germany, Portugal, Poland, Greece and Bulgaria deposition fluxes often exceed 2 kg km^{-2} y^{-1}. In the northern part of Europe (Iceland, north of the Scandinavian Peninsula) deposition fluxes of lead are typically less than 3 kg km^{-2} y^{-1}.

The greatest anthropogenic depositions of Cd were obtained for the former Yugoslav Republic of Macedonia (FYRM), then Slovakia, Bulgaria and Poland. Large depositions in these countries are mainly caused by significant industrial emissions.

2.2.8 Compaction risk

The compaction risk map (Jones *et al*., 2003) is based on the European soil map at the scale of 1:1,000,000 (Figure 10). The map is divided into four compaction risk classes: low, medium, high, and very high. As this map is based on the EU soil map, there is no information for Malta.

This map has been overlaid with the European monitoring sites layer in order to check the density of sites for each class and to highlight the undersampled areas in Europe both for the high and the very high compaction risks.

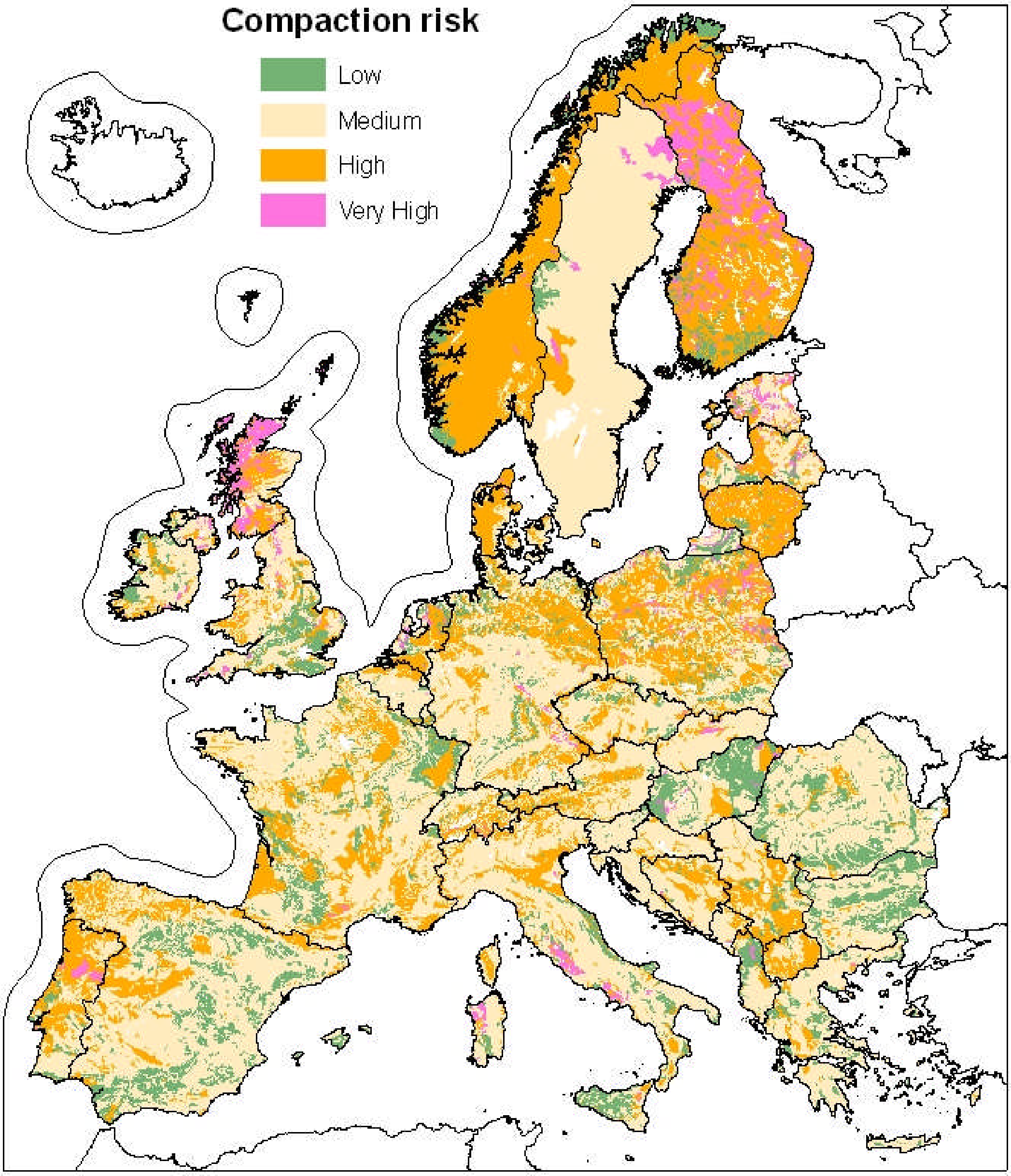
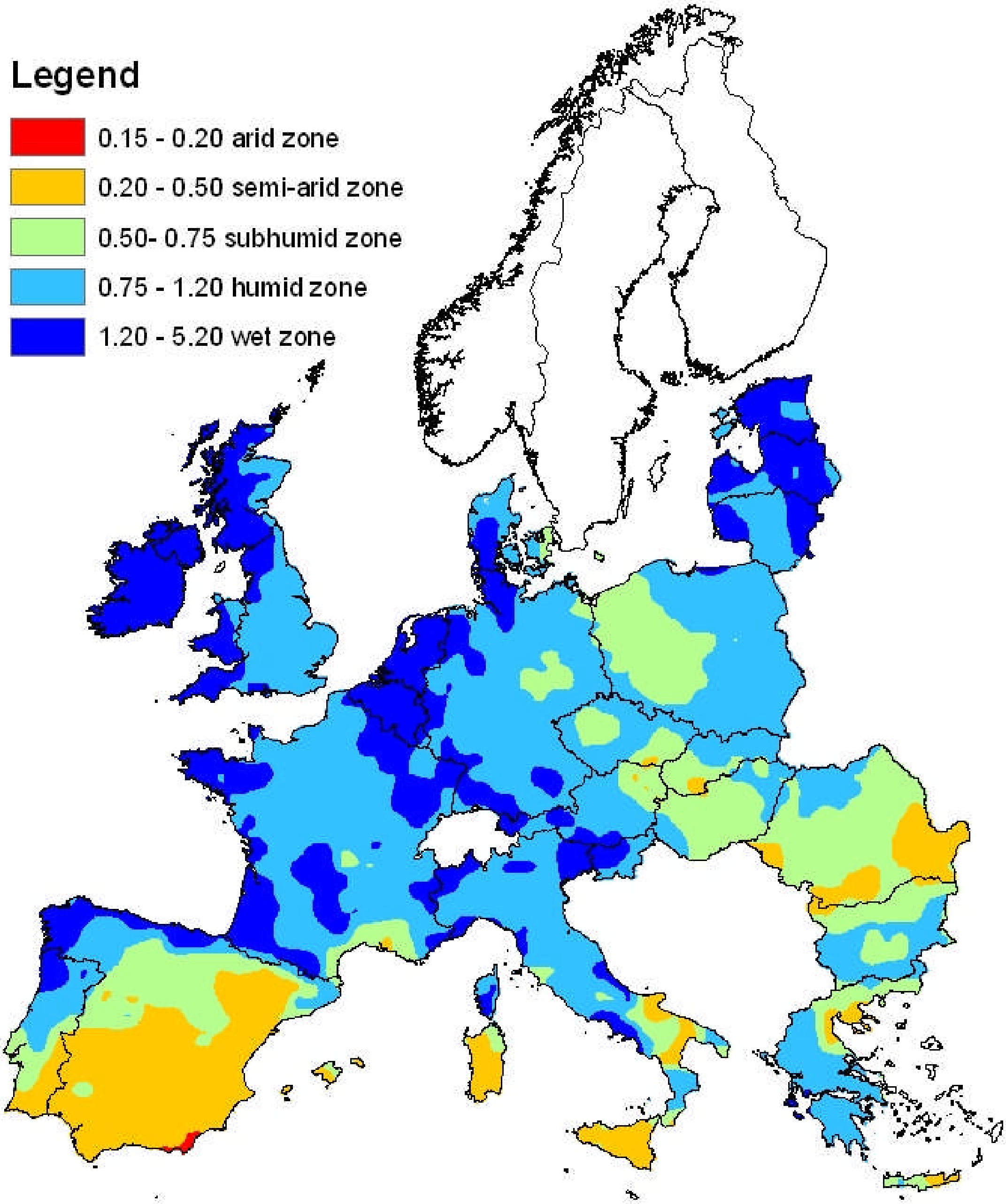


Figure 10. Compaction risk map (after Jones et al., 2003)

2.2.9 Desertification map

The desertification map is based on a 1km grid. This grid is based on the PESERA climate data. A climate index, precipitation/evapotranspiration, has been calculated for each cell. Areas with a climate index below 0.50 can be considered as a semi-arid zone and when the index is below 0.20 the zone is considered as arid (Figure 11). This map does not cover Malta.

For the representativeness study, the areas with a climate index below 0.50 (arid and semi-arid) were considered as at risk of desertification. These areas were overlaid with the monitoring sites coordinates to check their density of sites.



Analysis by R J A Jones from original PESERA Climatic data preparaed by Joel Daroussin INRA Orleans

(Kosmas *et al*., 1999)

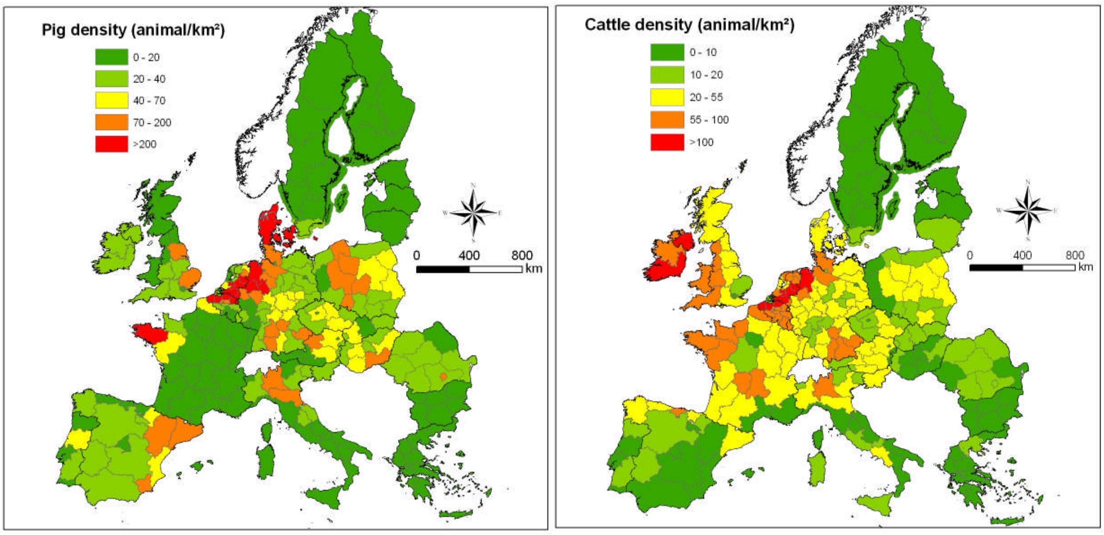
Figure 11. Desertification map in Europe, Climate index of aridity (P/ET)

2.2.10 Livestock numbers

The data on livestock numbers have been downloaded from the Eurostat website (http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136162,0_45572076&_dad=portal&

_schema=PORTAL). This database contains several animal categories and is based on the NUTS2 nomenclature (Figure 12). The NUTS2 polygons are the most precise European-wide information that we could get about livestock. We could not get the information for Norway and Malta. The data used for this study are the mean of the livestock numbers between 1997 and 2005.

The mean pig and cattle population densities during the period from 1997 to 2005 were calculated separately and overlaid with the European monitoring sites layer to assess the site density in those areas characterised by a large livestock population density.



NUTS2 level

Figure 12. Mean pig and cattle population densities between 1997 and 2005 in Europe

2.3 Data processing and analysis

2.3.1 Coordinates of the sites

The coordinates of monitoring sites for this study were supplied in various projection systems. The coordinates of each site were transformed into longitude and latitude decimal degrees according to the WGS1984 ellipsoid.

2.3.2 Metadata

Various analytical methods are used to measure soil parameters (see section 4.7). For instance, a pH measurement can be done with pure water or in solutions of KCl or $CaCl_2$. All the measured parameters and their analytical methods are presented in Annex III. For the representativity study, it was decided to group some measurements in order to have a clear overview of the sites where a given parameter is measured, even if methods were slightly different amongst networks. In particular, we grouped together all pH determinations, total and pseudo-total trace element analyses, and the various methods of organic carbon determination.

2.3.3 Data analysis

2.3.3.1 Geographical overlay

To aggregate the results on a common geographical basis, we chose to use the EMEP grid (http://www.emep.int/index_data.html): the main objective of the EMEP programme (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe) is to provide Governments and subsidiary bodies under the LRTAP Convention with qualified scientific information to support the development and further evaluation of the international protocols on emission reductions negotiated within the Convention. The 50km EMEP grid is available free of charge through the internet

The advantages of using this grid are numerous:

- Its resolution is suitable for the calculation of the density of sites expressed as 1 site per number of km²;
- its resolution is suitable for the production of European scale maps and,
- such aggregated maps could be overlaid directly with estimates of emissions or of depositions of air pollutants provided by EMEP.

Various units of aggregation were used to produce maps, namely: soil mapping units of the 1:1,000,000 soil geographical database of Europe (King *et al*., 1995), soil mapping units of the soil regions database (Hartwich *et al*., 2006), mapping units resulting from the overlay of the soil regions database and Corine Land Cover database (level 1), European peatland database (Montanarella *et al*., 2006), and EMEP grid cells.

2.3.3.2 Assessment of soil monitoring network coverage

Using the overlay of the different databases, maps of gaps in SMN coverage, and maps of density of sites were produced. For all the SMN sites, a median density of sites in cells of the 50 km x 50 km grid, expressed in 1 site per number of km² was calculated. This value was used as a reference to estimate the number of new sites or new measurements required in each country to reach an acceptable common level across Europe.

2.3.3.3 Gaps in coverage

Mapping units and/or classes (for soil, land-use, soil regions and land-use combinations) in which either none of the monitoring sites was present, or in which a selected indicator was not measured were identified. These mapping units and classes were considered as “gaps” in coverage, and mapped.

2.3.3.4 Density of sites

The density of sites was calculated for each mapping unit and/or class, considering all monitoring sites, or only sites at which selected indicators are monitored. In order to assess in which areas of Europe more samples should be taken, the density for various mapping units and classes (soil mapping units, land use classes, cells of the EMEP grid) was calculated. As the median density of sites in the EMEP cells of Europe was 1 site per 300 km², this value was used as a reference to assess oversampled or undersampled areas.

2.3.3.5 Minimum detectable level of change (MDC)

The minimum detectable level of change (MDC) was calculated for a set of indicators using the following methodology:

For any particular sampling scheme of a variable *x*, *n* sites are sampled at time t_0 and again at time t_1. An estimate of the mean change in the variable is

$$\Delta \bar{x} = \sum_{i=1}^{n} (x_{i,t_0} - x_{i,t_1}) / n$$

where $xi_{,t}$ is the measurement at site *i* at time *t*. An estimate of the standard error of $\Delta \bar{x}$ is:

$$\sqrt{\frac{2s^2}{n}}$$

where s^2 is an estimate of the variance of the variable and n is the number of points in the sampling scheme (see Barnett, 2002).

The condition for detection of a change *y* in the mean value for a variable between the two samplings is:

$$y \geq \frac{N_p \sqrt{2} s}{\sqrt{n}},$$

where N_p is the value of the standardised normal distribution at probability *p*. *y* is the MDC. If we turn this equation around we can estimate the number of samples required to measure a particular change i.e.

$$n \geq \frac{N_p^2 \times 2 \times s^2}{y^2}$$ and this is the same as $$n \geq \frac{N_p^2 \times 2 \times s^2 \times 100^2}{x^2 \times \overline{Y}^2}$$

where x is the percentage change we want to detect and $\overline{Y}$ is the mean of the population.

With the assumption that the variable is changing at an estimated rate of change *k* and that this is constant over the whole time interval *t*, then

$$t \geq \frac{N_p \sqrt{2} s}{k\sqrt{n}}$$ to be able to detect that change.

By introducing a measurement error as well as a sampling error it is found that the best estimate of s^2 is a combination of the estimate of the natural variation from previous studies $s^2_{natural}$ and the expected measurement errors (see Ramsey, 1998). All these sources of error can be assumed to be independent so

$$s^2 = s_m^2 + s_s^2 + s_{natural}^2,$$

where s^2_m is the measurement variance and s^2_s is the sampling variance from the sampling of the soil in the field (the within-site variance).

This derivation is based on several strong assumptions: the estimate of the mean change in a variable follows a normal distribution, repeated sampling is carried out by the same method (supposed to be here simple random), and the variance remains the same on successive occasions. It is likely that the first and the third assumptions are false to a greater or lesser degree for different variables, but this is the only way we found to get first estimates with the data we have.

We used the data from the within-site variability review (see sections 2.4 and 5.1) to derive quantitative estimates of the within-site coefficients of variation and variances for some of the most available parameters in SMNs. We established relationships between within-site variance and site area and/or mean values of these parameters. From these relationships we derived estimates of coefficients of variation for all the sites for which the area was known.

Aggregated statistics on existing results from national monitoring networks were assembled. These national statistics (mean, median, standard deviation, variance) were collected for a set of parameters (mainly organic carbon, pH and total contents of some heavy metals) for Austria, Bulgaria, Czech Republic, England & Wales, Greece, France, Ireland, Northern Ireland, Poland, Portugal, Scotland, Slovakia, and The Netherlands. These statistics were used to derive rough estimates of mean coefficients of variation of the above-cited parameters for national monitoring networks. Statistics on these estimates of soil variability were produced to provide information on the levels of variability at national scale. It was not possible to produce statistics for all countries, which made the assessment of minimum detectable level of change impossible for all the EU Member States.

It was decided to focus mainly on two indicators, on the basis of contrasting assumptions which could be made on rates of change: topsoil organic carbon content and topsoil lead content. In addition, calculations for pH, Cd, Cu, Cr and Zn were also performed.

As the study did not have access to real data, the initial mean value of Pb on a fixed date *t* was set to a theoretical European mean value calculated using all available national statistics. For organic carbon, as strong gradients had been previously identified, modelled, and mapped by Jones, *et al*. (2005) at a European scale, it was decided to set the initial value to the value predicted at each site by this map.

In order to estimate national variances we proceeded in two ways:

1. For organic carbon, we calculated, for each country, the variance of the values predicted by the EU map of Jones *et al*. (2005). This variance was calculated on the population of the predicted organic carbon values in all 1 x 1 km cells of the map for each country.

2. For pH and Cd, Cr, Cu, Pb and Zn content, we used real data from the French national soil monitoring network. We overlaid this network with sets of areas of increasing sizes. Then we fitted the relation between the mean calculated variance and area. This relation was used to generate a theoretical variance for each country, on the basis of its area.

We used these figures to:

i. calculate 2 MDCs for national networks, which were the minimum change that the SMN would be able to detect 1) according to the total number of sites and 2) according to the number of sites where an indicator is measured.
ii. simulate the number of sites needed to detect a change in the national means of the indicators.
iii. simulate the time necessary to detect a change occurring at a given rate.

2.4 Review of within-site variability

The spatial variation that may occur within monitoring sites might increase the number of samples that need to be analysed in order to detect changes as it is a component of the estimate of variation used to calculate the MDC. This has consequences for monitoring costs, for the reliability of observed changes, and for the minimum time necessary to detect a given change. Therefore, we conducted a meta-analysis on soil variability within monitoring sites in order to assess the consequences of this within-site variability on confidence intervals for the mean values of parameters monitored.

Data was compiled from a review of the literature (Table 3). The following relevant factors were included in the compilation: area of the site (ranging from 1 m^2 to 20 ha), number of samples, mean values of soil parameters, indication of in-site variability (i.e. variance, or standard deviation, or coefficient of variation). Data on analytical variability was also compiled when available. Literature searches were performed using the electronic database “Web of Science”. In addition, unpublished data were also gathered from ENVASSO partners (mainly from France and Slovakia). We excluded references from tropical soils. In all, we collected data on within-site variability for 120 sites.

The data were used to derive quantitative estimates of the mean values of within-site variances, standard deviations and coefficients of variation for all available parameters. The possible relationships between in-site variability and site area and/or mean values were examined.

Table 3. References used for the meta-analysis

Source	Country	Source	Country
Arrouays, *et al*., 1997	France	Odlare, *et al*., 2005	Sweden
Bourennane, *et al*., 2004	France	Rasmussen, *et al*., 2005	Denmark
Bourennane, *et al*., 2006	France	Reichardt, 1990	Austria
Brouder, *et al*., 2005	USA	Ritz, *et al*., 2004	UK
Burgos, *et al*., 2006	Spain	Shukla, *et al*., 2004	Austria
Cox, *et al*., 2006	USA	Stenberg, *et al*., 2005	Sweden
Homann, *et al*., 2001	USA	Unpublished data	Slovakia
Johnson, *et al*., 1990	USA	Unpublished data	France
Jolivet, 2000	France	Wopereis, *et al*., 1988	France

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3 REPRESENTATIVITY ANALYSIS

In this section, the representativity of existing soil monitoring sites is presented. We first examine the geographical coverage of all sites. Then we review the geographical coverage (i.e. density of monitoring sites) for the main soil status indicators. We study the representativity of the networks with regard to soil mapping units and land-uses of Europe and with regard to some state, pressure and impact indicators.

3.1 Geographical coverage of sites

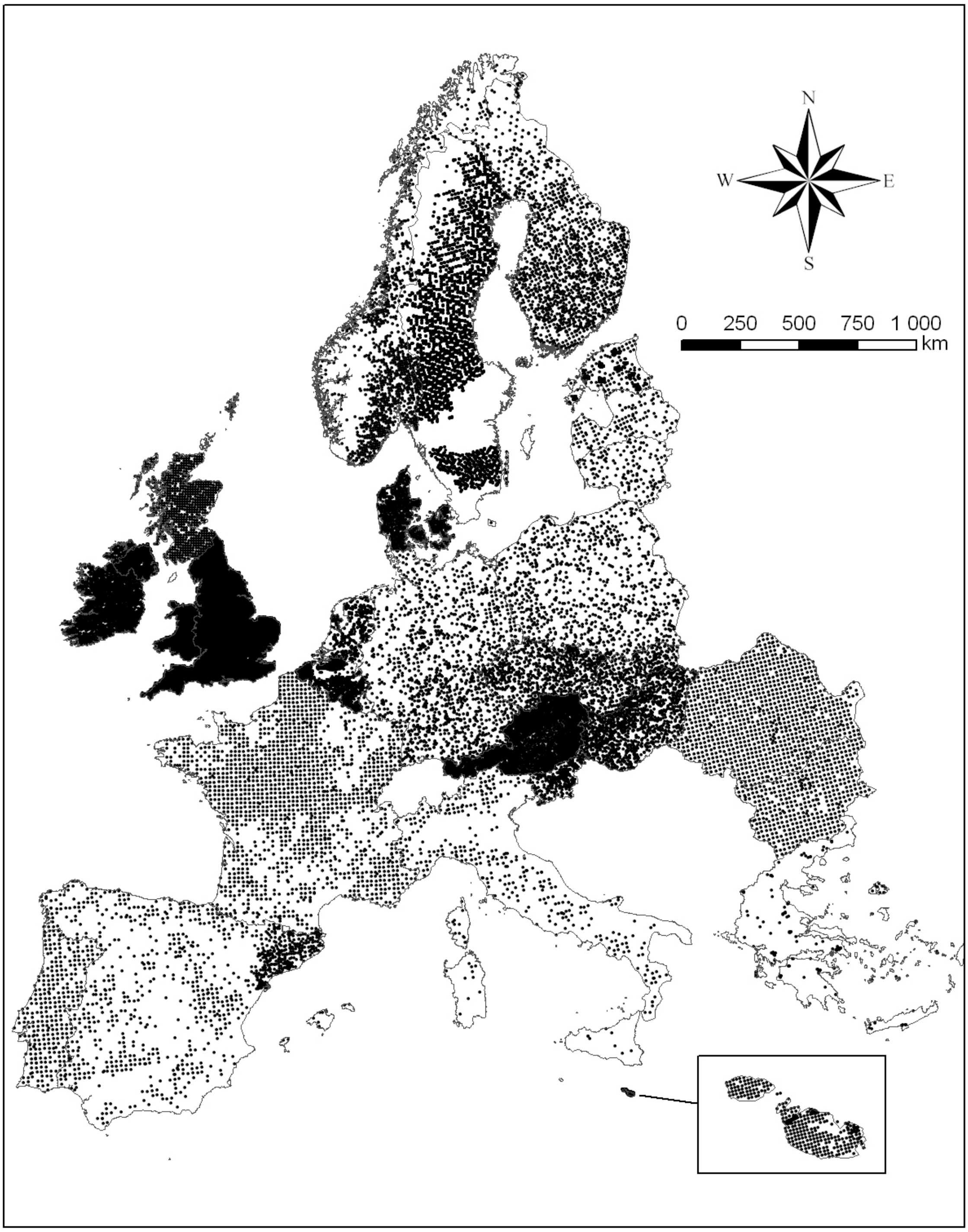


Figure 13. Map of the soil monitoring sites of Europe

The geographical distribution of the soil monitoring sites (SMS) in Europe is very heterogeneous (Figure 13). Some Member States have very dense networks (e.g. England and Wales, Northern Ireland, Austria, Denmark, Malta), whereas in other Member States SMS are quite scarce (Spain, Italy, Greece). Some countries have reported only forest sites, generally belonging to the ICP forests monitoring network.

The situation is in some cases not as it appears in Figure 13: some Member States did not provide coordinates of sites, even though we know that they have implemented SMNs. We did not get detailed information on some projects which were described by Ibáñez *et al*. (2005) for Spain, and by Filippi (2005) for Italy. Part of Sweden is also lacking information on site coordinates.

We should stress that, although most SMNs use databases and GIS to store and process monitoring data and are able to deliver their data in various formats without major technical problems, access to basic data is not yet always possible. In numerous cases, access to data is limited, including access to a metadatabase describing the nature and the origin of the information. Indeed, some SMNs have not yet defined clear rules for data availability. This will be a major concern in reporting on soil status at the EU level.

In spite of this lack of information, the work reported here represents the most exhaustive collection of SMN metadata to date. These metadata have been used to run the representativity analysis, keeping in mind the limitations cited above.

The density of sites, expressed in number of km² for 1 site in EMEP cells, is highly variable over Europe (Figure 14), with some EMEP cells having no site at all. Homogeneous site densities are characterising those countries that sample a completed systematic grid (e.g., England and Wales, Scotland, Northern Ireland, Ireland, Denmark). Heterogeneous site densities reflect a national stratified sampling strategy (e.g, Germany, Poland), the presence of different soil monitoring networks within a country (e.g., Belgium, Spain), or systematic grid sampling in countries where the full national coverage is not yet complete (e.g., France).

Across Europe, the mean density of sites in EMEP cells is 18.7 sites for 2,500 km^2, that is about 133 km² for each site, the median value being 8.4 sites for 2,500 km^2, that is about 295 km^2 for each site. The distribution of the number of sites in the EMEP cells is shown in the Figure 15. The median value avoids the large influence of the maximum values (363, 401 or 616 monitoring sites in an EMEP cell) and is a robust statistic. Therefore, the median value was chosen as a more pertinent statistic to use as a reference in the following study.

Converted onto a systematic grid, this median density (rounded to 300 km²) would be equivalent to a regular 17 km x 17 km grid covering Europe. If we take into account the existing sites, achieving that all 50 km x 50 km cells have at least this median density would require 4,100 new sites, mainly located in southern countries (Italy, Spain, Greece), and parts of Poland, Germany, Baltic countries, Norway, Finland and France (Figure 16). This number might be a slight overestimate, considering that some metadata are missing for Italy and Spain, and that some SMNs are currently being implemented (France).

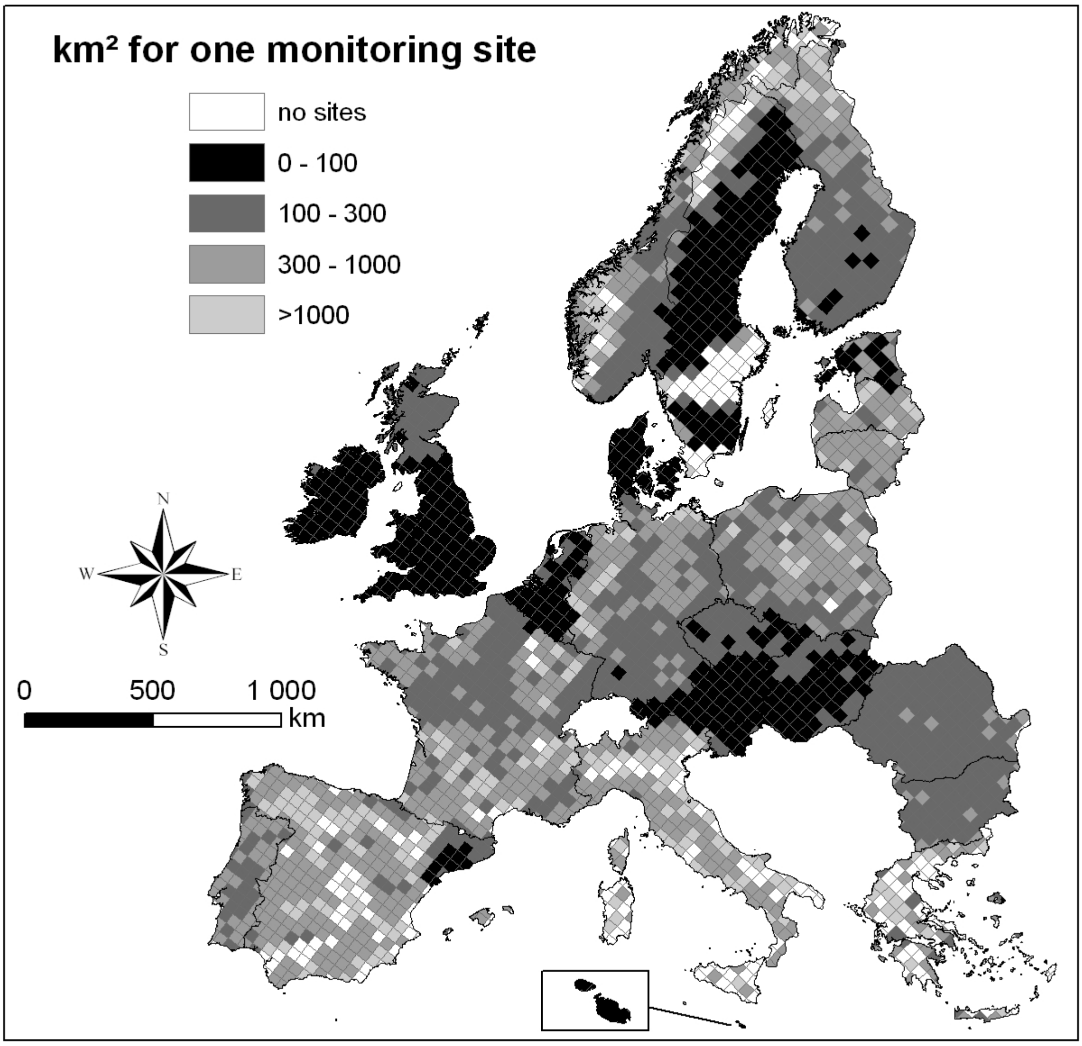


Figure 14. Density of SMNs sites in Europe, number of km² represented by one site

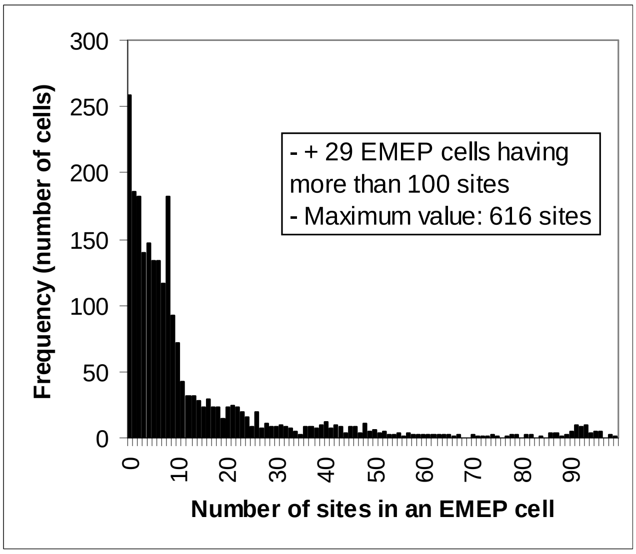
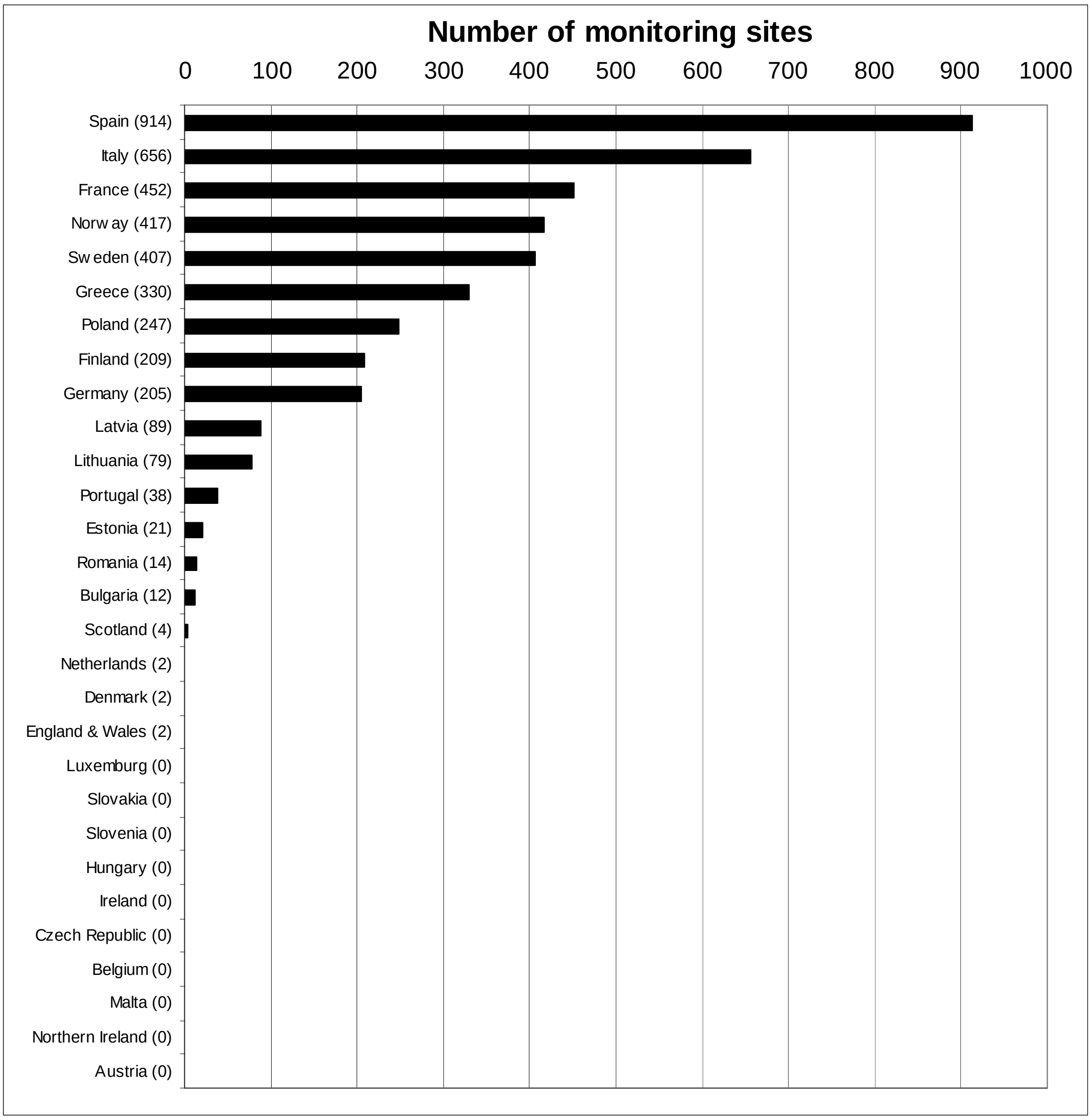


Figure 15. Distribution of the number of monitoring sites in the EMEP cells



(number of sites in the brackets)

Figure 16. Monitoring sites to add in each country to reach the median density in the EMEP cells.

We observed very large differences in the density of monitoring sites existing in Member States. However, a 16 km x 16 km grid is already implemented within an existing SMN for forest soils, so only non-forest soil sites would need to be added to provide complete coverage at better than the median density which is equivalent to a 17 km x 17 km grid. This density has also been shown to be effective when mapping contamination in peri-urban areas (Saby *et al*., 2006).

Table 4. Number of additional monitoring sites required to reach the median density of sites in the EMEP cells, for selected variables

Country	Particle size distribution	pH	Organic matter or organic carbon content	Bulk density or topsoil organic carbon stocks	Nitrogen content or C:N ratio calculation	Estimated soil loss	Soil loss measurements	Earthworm diversity	Enchytraeid diversity	Soil respiration
Austria	4	0	0	139	0	273	271	277	277	252
Belgium	3	0	0	92	15	102	102	102	102	102
Bulgaria	16	16	16	16	16	370	366	370	370	370
Czech Republic	52	0	0	263	5	263	263	263	263	263
Denmark	2	2	2	107	107	149	149	149	149	149
England & Wales	2	2	2	507	507	507	507	507	507	507
Estonia	56	21	35	130	35	151	151	151	151	151
Finland	209	209	209	407	407	1117	1117	1117	1117	1117
France	872	452	452	452	452	1829	1829	1769	1769	1769
Germany	456	210	217	546	223	1189	1180	779	780	1189
Greece	352	337	333	441	402	441	438	441	441	441
Hungary	0	0	0	0	0	310	310	310	310	0
Ireland	232	0	0	232	210	232	232	232	232	232
Italy	969	656	656	1006	656	1006	1006	1006	1006	1006
Latvia	204	89	89	193	108	215	215	195	215	215
Lithuania	208	79	79	216	134	216	216	216	216	216
Luxemburg	6	0	0	9	0	9	9	9	9	9
Malta	0	0	0	0	1	1	1	1	1	1
Northern Ireland	0	0	0	47	0	47	47	47	47	47
Netherlands	94	2	2	117	2	117	117	2	2	2
Norway	1055	417	417	1074	417	1074	1074	1074	1074	1074
Poland	674	248	248	1039	248	1039	1038	1039	1039	1039
Portugal	178	38	38	296	126	296	296	296	296	296
Romania	14	14	14	14	14	793	789	793	793	793
Scotland	4	4	4	261	4	261	261	261	261	261
Slovakia	144	0	0	1	0	163	163	163	163	163
Slovenia	51	11	11	51	11	68	68	68	68	68
Spain	916	914	914	956	930	1663	1663	1663	1663	1663
Sweden	1491	407	407	1491	407	1491	1491	1491	1491	1491
TOTAL	**8262**	**4128**	**4147**	**10101**	**5441**	**15392**	**15369**	**14790**	**14811**	**14886**

Table 5. Number of additional monitoring sites required to reach the median value in the EMEP cells for selected variables

Country	able sodium percentag	Salt profile content	Soil water retention	Saturated hydraulic conductivity	Packing density	Phosphorus content	Cadmium content	Zinc content	Lead content	Mercury content	Chromium content
Austria	7	279	259	258	139	2	0	0	0	20	2
Belgium	28	102	102	102	102	29	3	0	1	52	1
Bulgaria	195	370	370	370	16	16	16	16	16	16	16
Czech Republic	5	263	263	263	263	54	0	0	5	263	263
Denmark	2	149	149	149	107	107	107	107	107	149	149
England & Wales	507	507	507	507	507	2	2	2	2	2	2
Estonia	49	151	151	151	130	58	49	49	49	151	151
Finland	407	1117	1117	1117	407	460	209	209	363	1117	460
France	452	1829	1829	1829	872	956	452	452	452	1829	956
Germany	621	1189	1189	884	549	302	209	211	211	660	552
Greece	377	441	441	441	441	388	418	404	420	441	441
Hungary	0	0	310	310	0	0	0	0	0	0	0
Ireland	210	232	232	232	232	232	210	0	0	0	0
Italy	656	1006	1006	1006	1006	1006	656	656	656	1006	1006
Latvia	109	215	215	215	213	207	108	110	110	215	215
Lithuania	134	216	216	216	216	153	79	79	79	216	153
Luxemburg	0	9	9	9	9	9	0	0	0	9	9
Malta	0	1	1	1	0	1	1	0	0	0	0
Northern Ireland	47	47	47	47	47	0	0	0	0	47	0
Netherlands	2	117	117	117	117	2	2	2	2	2	2
Norway	417	1074	1074	1074	1074	1074	417	417	417	1074	1074
Poland	397	1039	1039	1039	1039	820	248	248	248	1039	820
Portugal	38	295	296	296	296	296	38	38	38	187	38
Romania	14	170	14	14	14	14	14	14	14	793	793
Scotland	4	261	261	261	261	4	261	261	261	261	261
Slovakia	0	163	163	150	144	1	0	0	0	1	1
Slovenia	11	68	68	68	51	68	11	0	0	1	1
Spain	956	1616	1549	999	956	1663	916	916	916	1549	1549
Sweden	407	1491	1491	1491	1491	407	1491	407	407	1491	407
TOTAL	**6054**	**14416**	**14483**	**13614**	**10697**	**8333**	**5917**	**4600**	**4775**	**12590**	**9323**

3.2 Geographical coverage of sites for the main soil status indicators

In this section, we present the geographical coverage for the main soil status indicators. A set of point maps is given in Annex IV.

3.2.1 Soil organic matter indicators

Topsoil organic carbon is one of the most widely available indicators in Europe and measurements of topsoil organic carbon content are available in all countries (Figure 17). The median density of sites for the topsoil organic carbon indicator in 50 x 50 km cells is 1 site per 306 km². Ensuring that all 50 km x 50 km cells have at least the median density of sites measuring OC over all Europe (1 per 300 km²) would require 4147 new sites at which topsoil organic carbon is measured, mainly located in southern countries (Italy, Spain, Greece) and in Ireland and Baltic countries (Table 4). Among these 4147 new measurements of OC, 47 could be done at already existing sites in which this indicator is not currently measured.

As a noticeable number of countries do not determine soil bulk density, topsoil carbon stocks cannot be accurately monitored in the United Kingdom, Italy, Portugal, Greece, Poland, Sweden, Norway, Czech Republic, Lithuania, The Netherlands, and in parts of Austria (Figure 17). However, some pedotransfer functions can be used to get estimates of carbon stock changes (see for example Bellamy, *et al*., 2005) from SMN results. Nevertheless, as bulk density and organic carbon are correlated, and as changes in bulk density may induce changes in the mineral mass of soil collected down to a given depth, it would be worthwhile to determine bulk density on all sites.

Nearly all Member States measure both carbon and nitrogen except for England and Wales, Greece and Malta.

3.2.2 Heavy metal content indicators

The density of heavy metal measurements strongly depends on the element considered. Some elements are measured quite widely (e.g., Pb, Cu) whereas some others are only measured in a few Member States (e.g., Hg, Tl) (Figure 18, Figure 19 and Figure 20).

A way to harmonise the density of measurements in Europe may be to fix a given minimum number of sites per 50 x 50 km cell. Considerable effort would be needed to raise all cells to the density of one site for 300 km². For instance, to reach that density, 4600, 5917, 9323 and 12590 new measurements of zinc, cadmium, chromium and mercury content respectively would have to be made all over Europe (Table 5).

The relevance of these measurements will be studied later in this chapter with the representativeness of the actual SMNs based on the areas with high population or livestock densities.

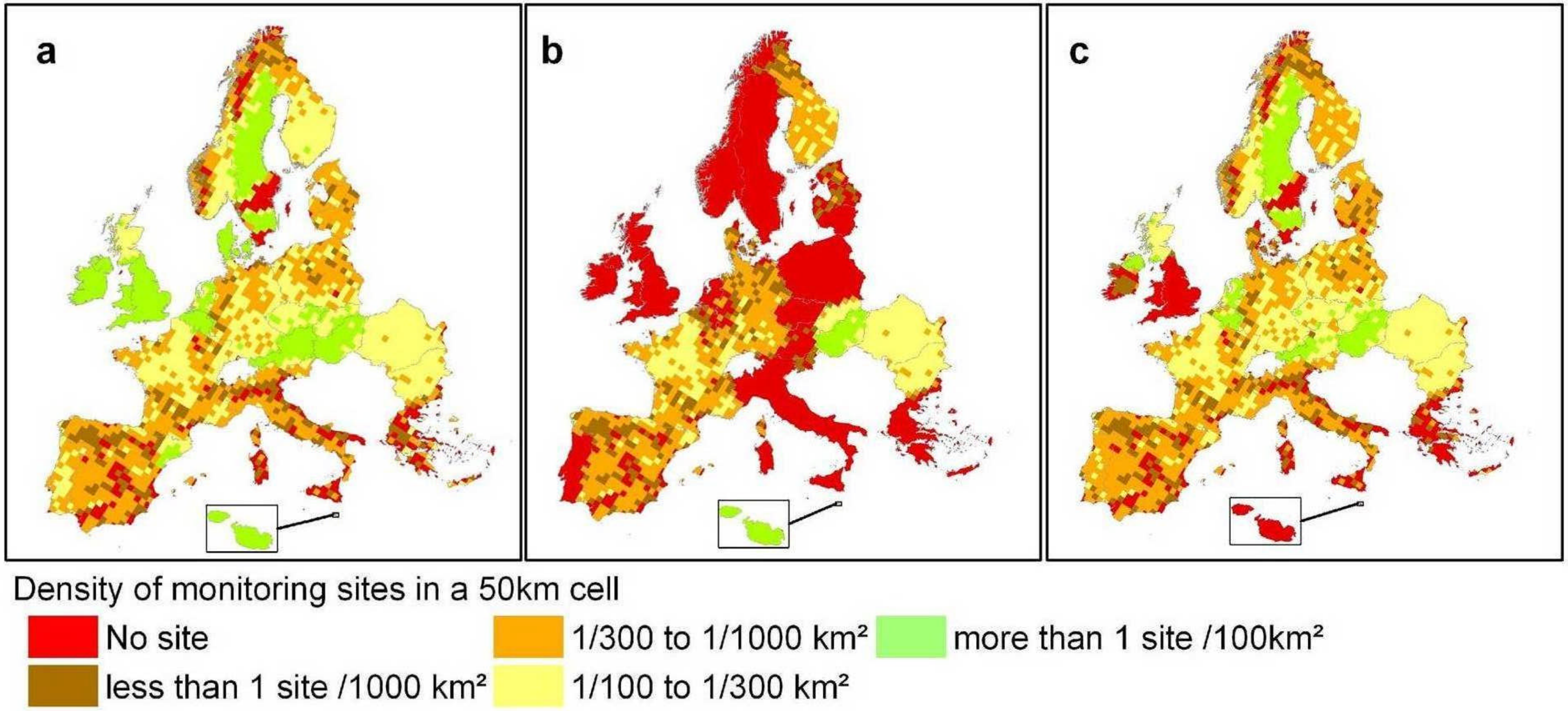


Figure 17. Maps of density of sites at which a) topsoil organic carbon content is measured, b) topsoil organic carbon stocks and c) C:N ratio in topsoil can be calculated

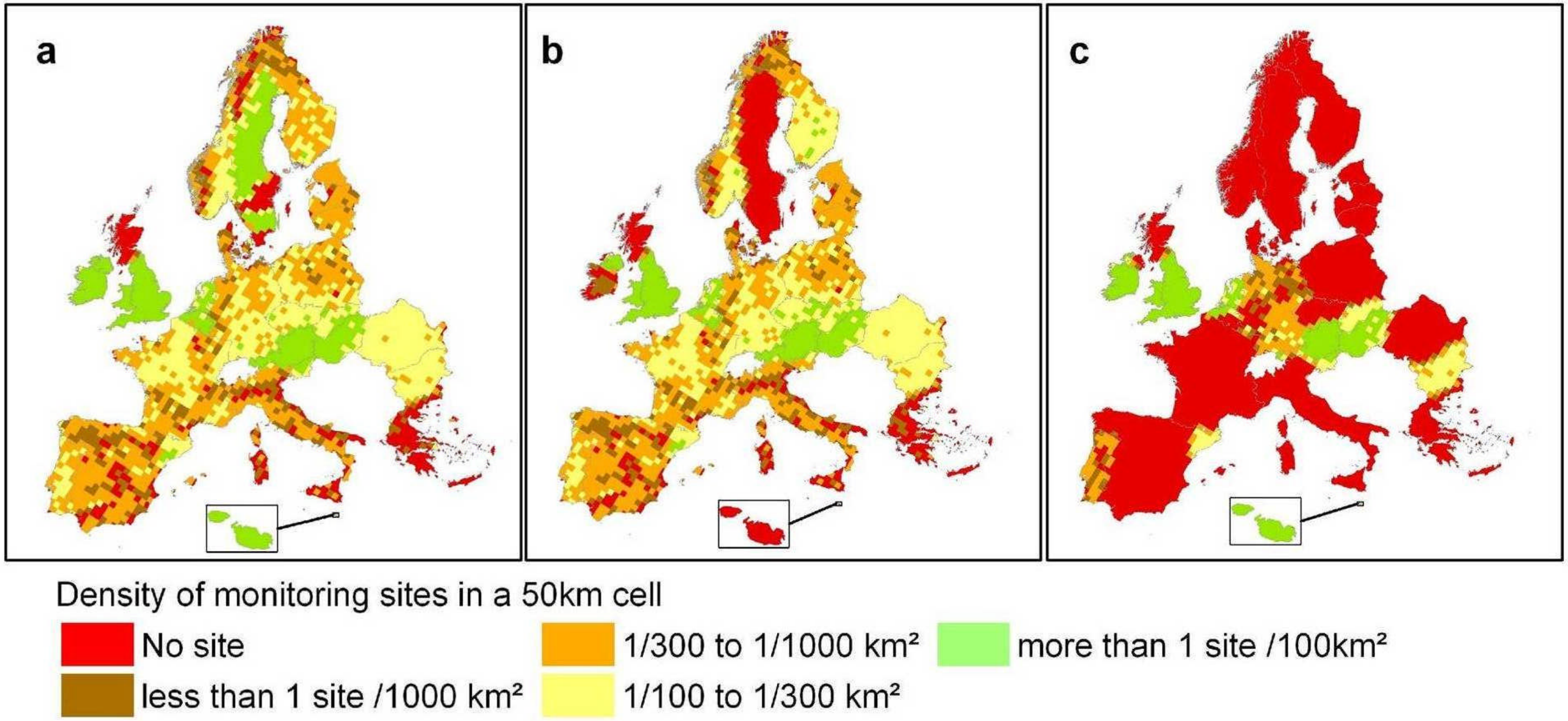


Figure 18. Density of total or pseudo-total measurements of a) Pb content, b) Cd content, c) Hg content

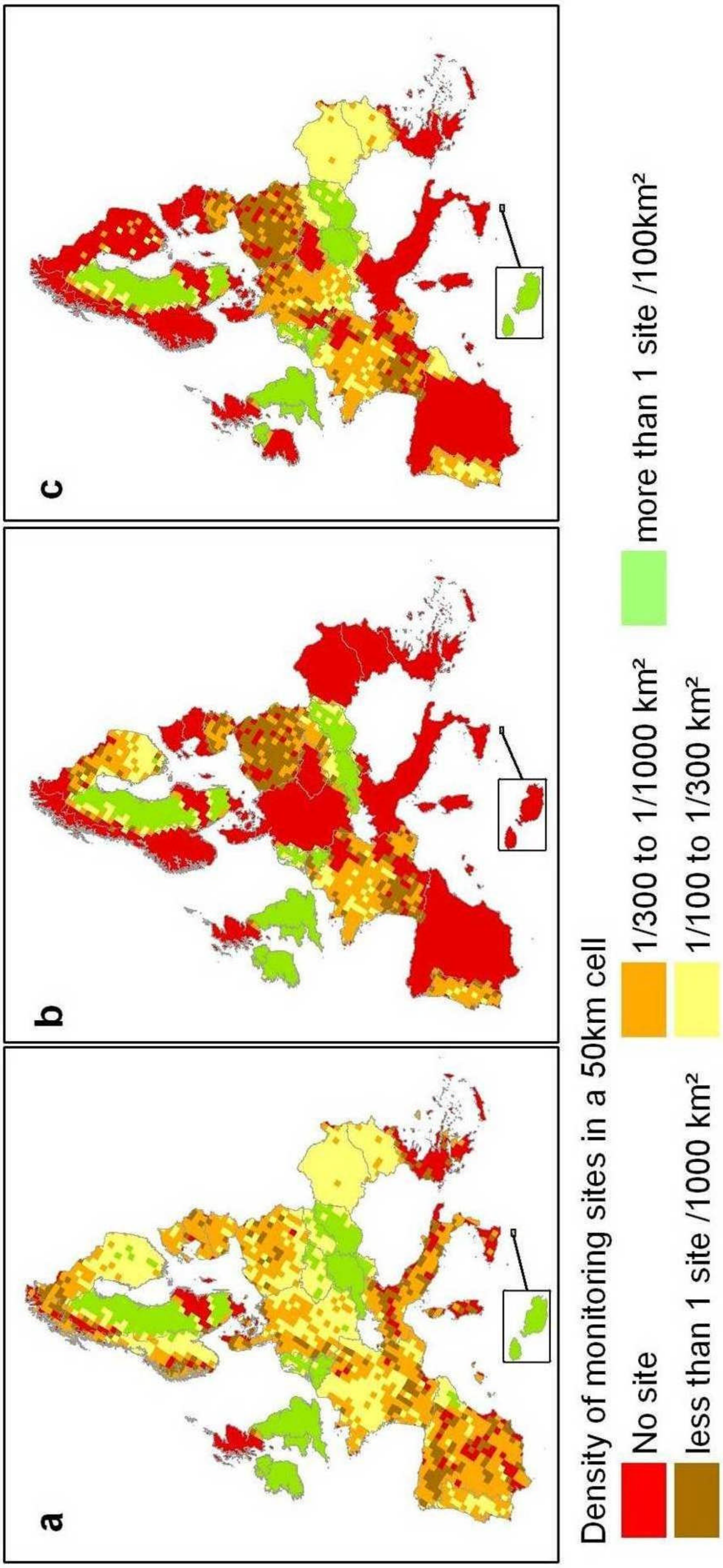


Figure 19. Density of total or pseudo-total measurements of a) Cu content, b) Fe content, c) Ni content

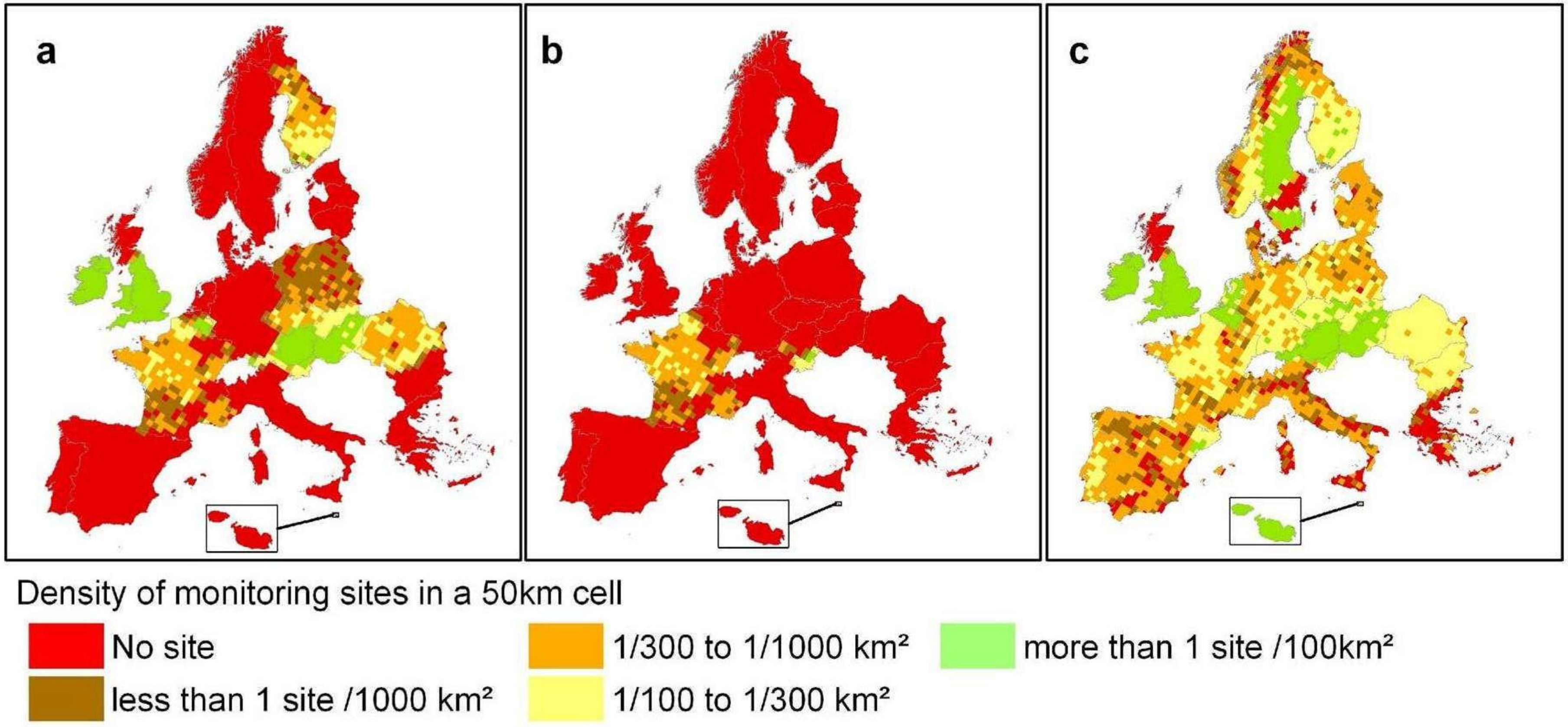


Figure 20. Density of total or pseudo-total measurements of a) Co content, b) Tl content, c) Zn content

3.2.3 Sulphur and nitrogen

By contrast with nitrogen, very few Member States measure sulphur content at their sites.

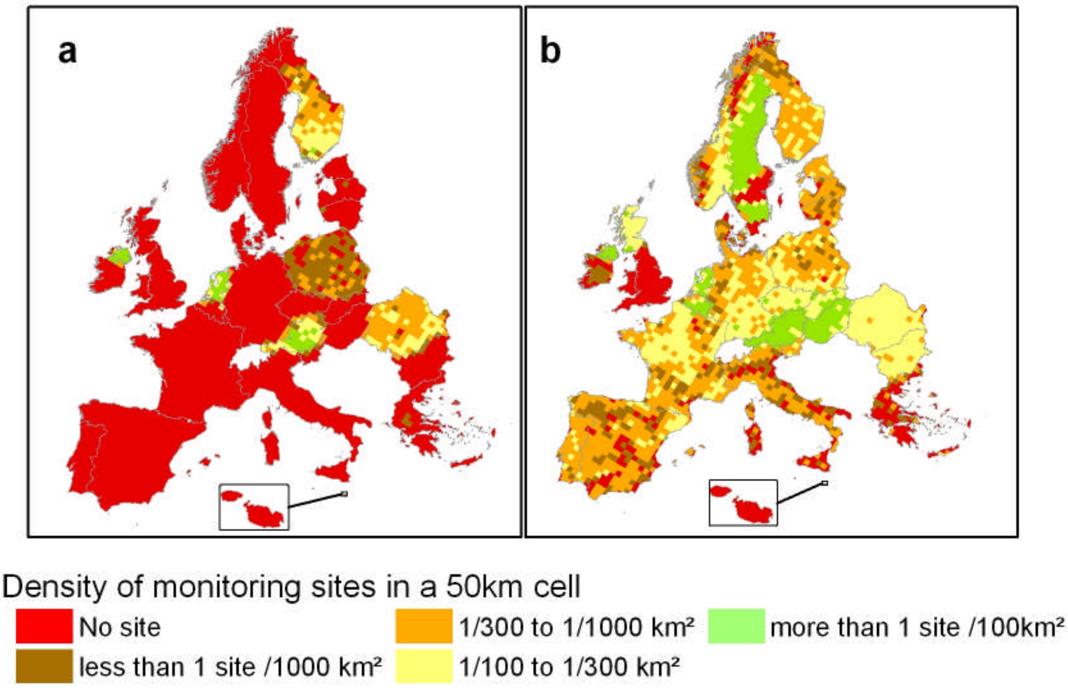


Figure 21. Density of SMN sites at which a) sulphur, b) nitrogen, are measured

3.2.4 pH and cations

pH is widely measured in almost all the soil monitoring sites (Figure 22). However, the method employed differs amongst Member States (see section 4). Its geographical distribution is very close to the distribution of all SMN sites. In order that all 50 x 50 km cells have at least the density of one site for 300 km² would require 4,128 new sites at which pH is measured (Table 4). Nearly all of these new measurements of pH would have to be done at new sites.

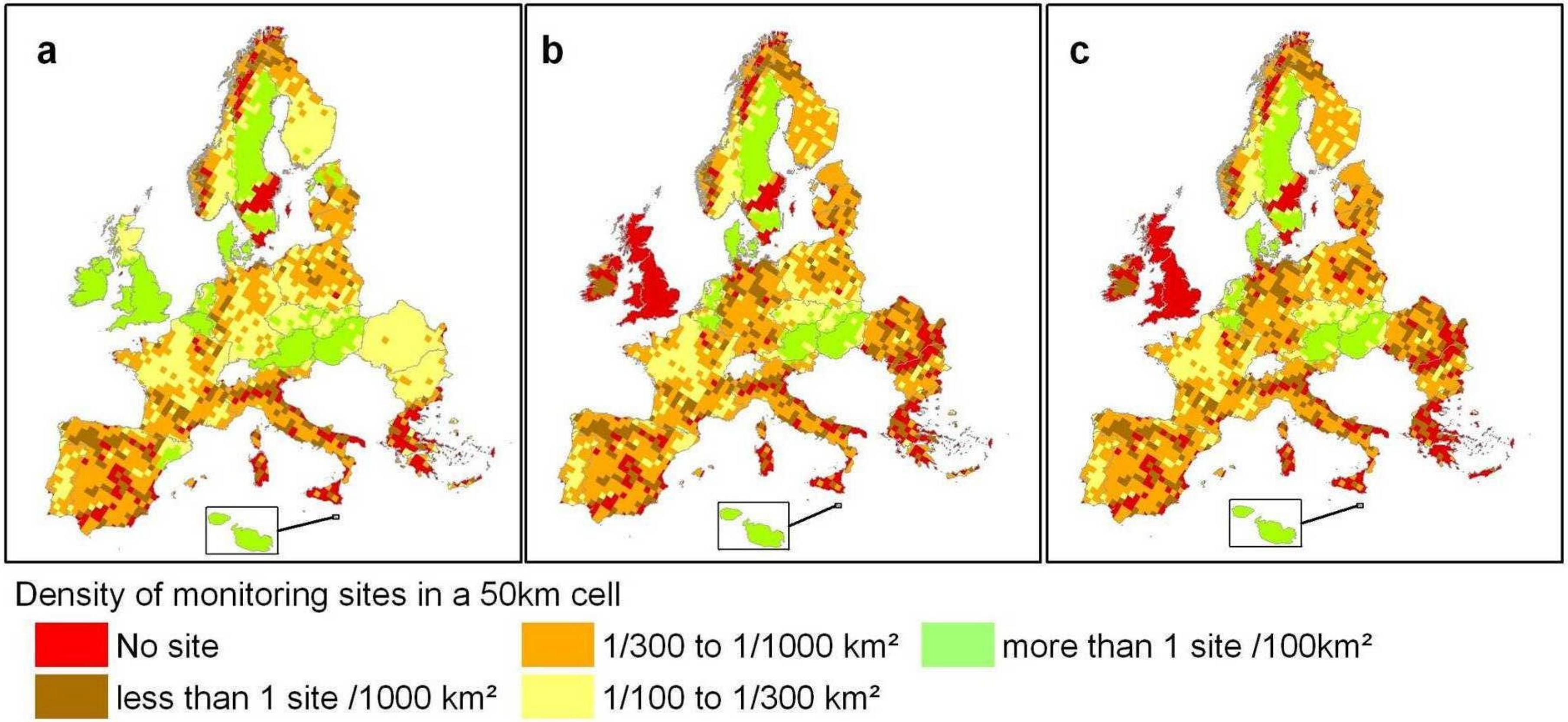


Figure 22. Density of measurements of a) pH, b) cation exchange capacity, c) base saturation

3.2.5 Indicators of erosion

In our meta-database, the sites where indicators of soil erosion are measured are very scarce (Figure 23). However, we know that these maps largely underestimate the number of sites at which erosion rates are measured. For instance in Spain, Ibañez *et al*. (2005) reported a programme on erosion (RESEL) that includes 60 experimental stations.

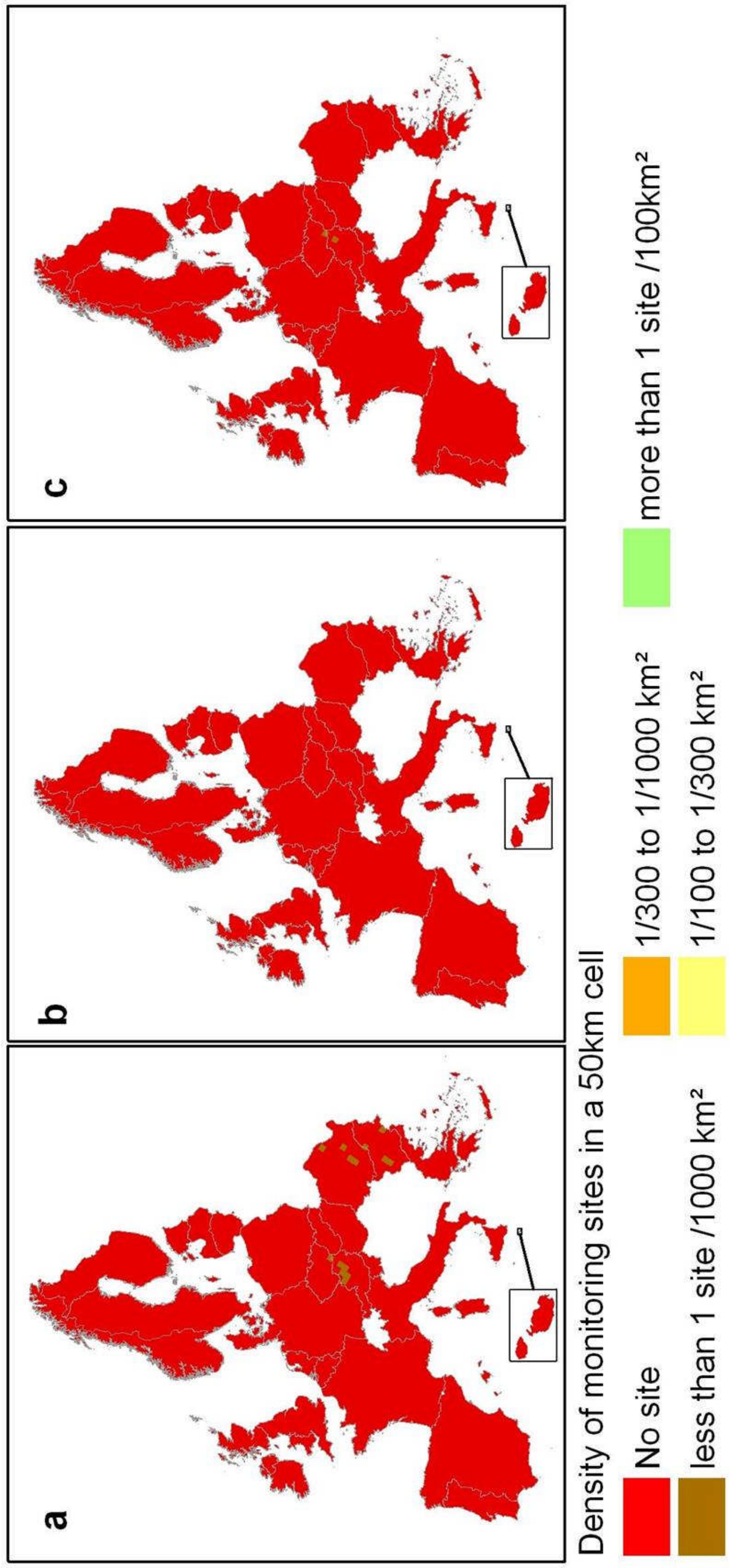


Figure 23. Density of SMN sites at which a) actual water erosion, b) actual wind erosion, c) actual tillage erosion, are monitored

3.2.6 Indicators of salinisation

Calculation of exchangeable sodium percentage is possible in nearly all the SMNs except for England and Wales (Figure 24). Other parameters related to salinisation are determined in countries where this threat is thought to be of real concern. Surprisingly, there is no site in southern Spain. This could be due to missing information.

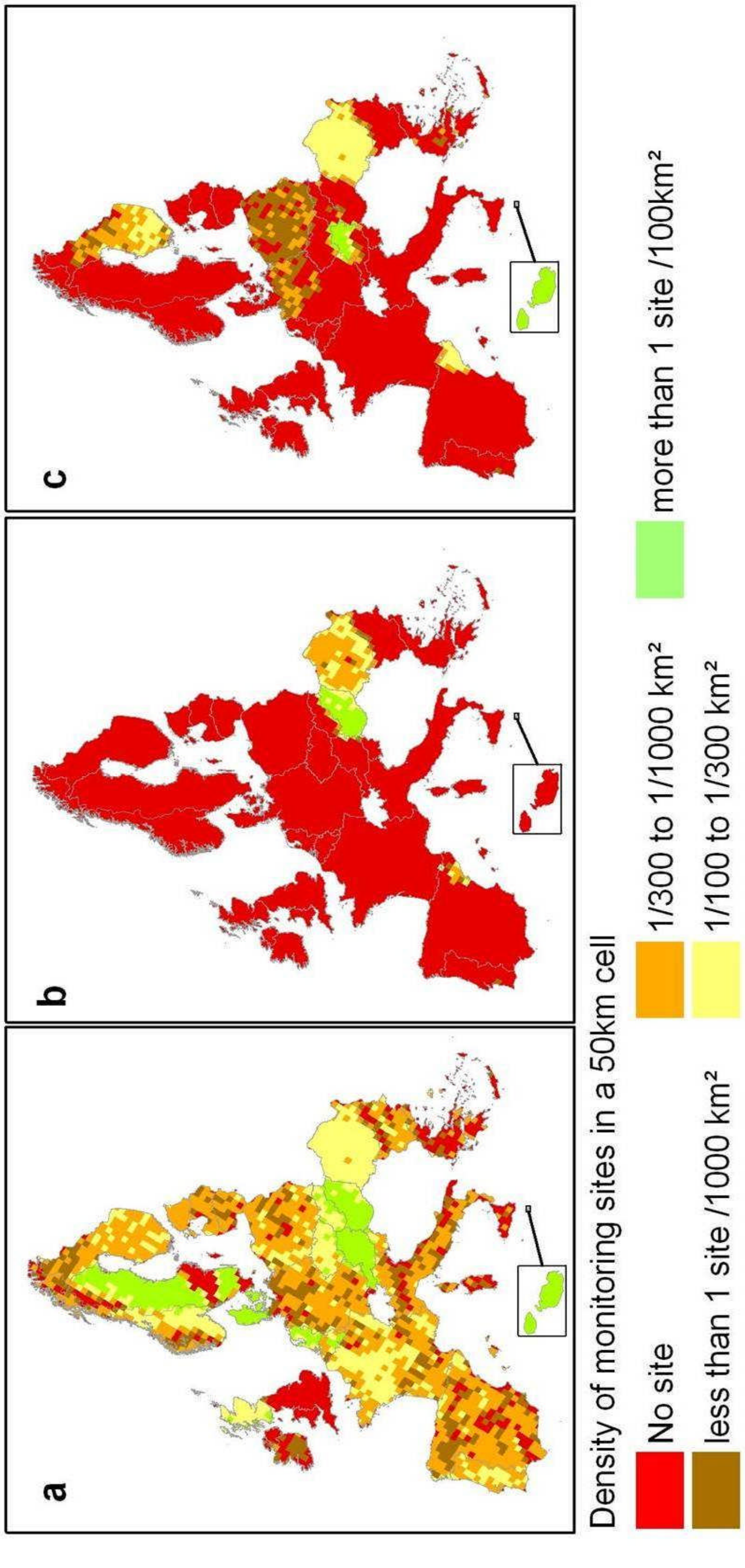


Figure 24. Density of SMN sites at which a) exchangeable sodium percentage can be calculated, b) and at which salt content and c) electrical conductivity are measured

3.2.7 Indicators of soil compaction

Particle-size distribution is widely measured in soil monitoring networks (Figure 25). However, in order to reach a density of one site for 300 km², 8262 new measurements have to be made, especially, in Norway, Sweden, Baltic countries, Ireland and Italy. Reaching a density of one site for 300 km² would require 10,101 new measurements for the bulk density measurements. As particle-size distribution is missing in some SMNs for which bulk density is measured, the maps of bulk density and of packing density do not coincide exactly (see differences in Latvia, and in parts of Belgium and France).

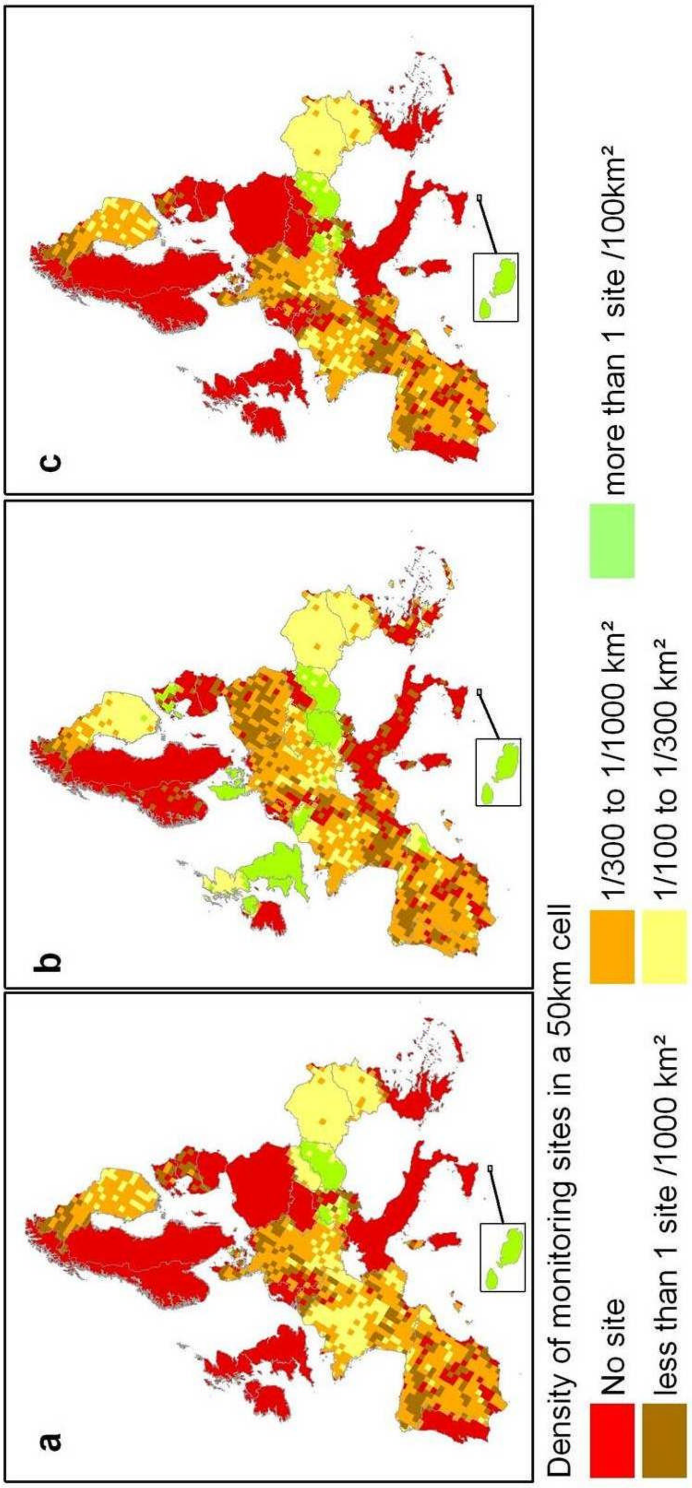


Figure 25. Density of SMN sites at which a) bulk density, b) particle-size distribution are measured, c) and where packing density can be calculated

3.2.8 Indicators of soil biodiversity

Very few SMNs determine soil biodiversity indicators (Figure 26). Earthworm and Enchytraeids diversity and soil respiration are only monitored in Netherlands and in Brittany in France. Some other country like Germany or Hungary only monitor some of them. Reaching a density of one site for 300 km², would require respectively 14790 and 14811 new observations of earthworm and Enchytraeid diversity and 14886 new measurements of soil respiration.

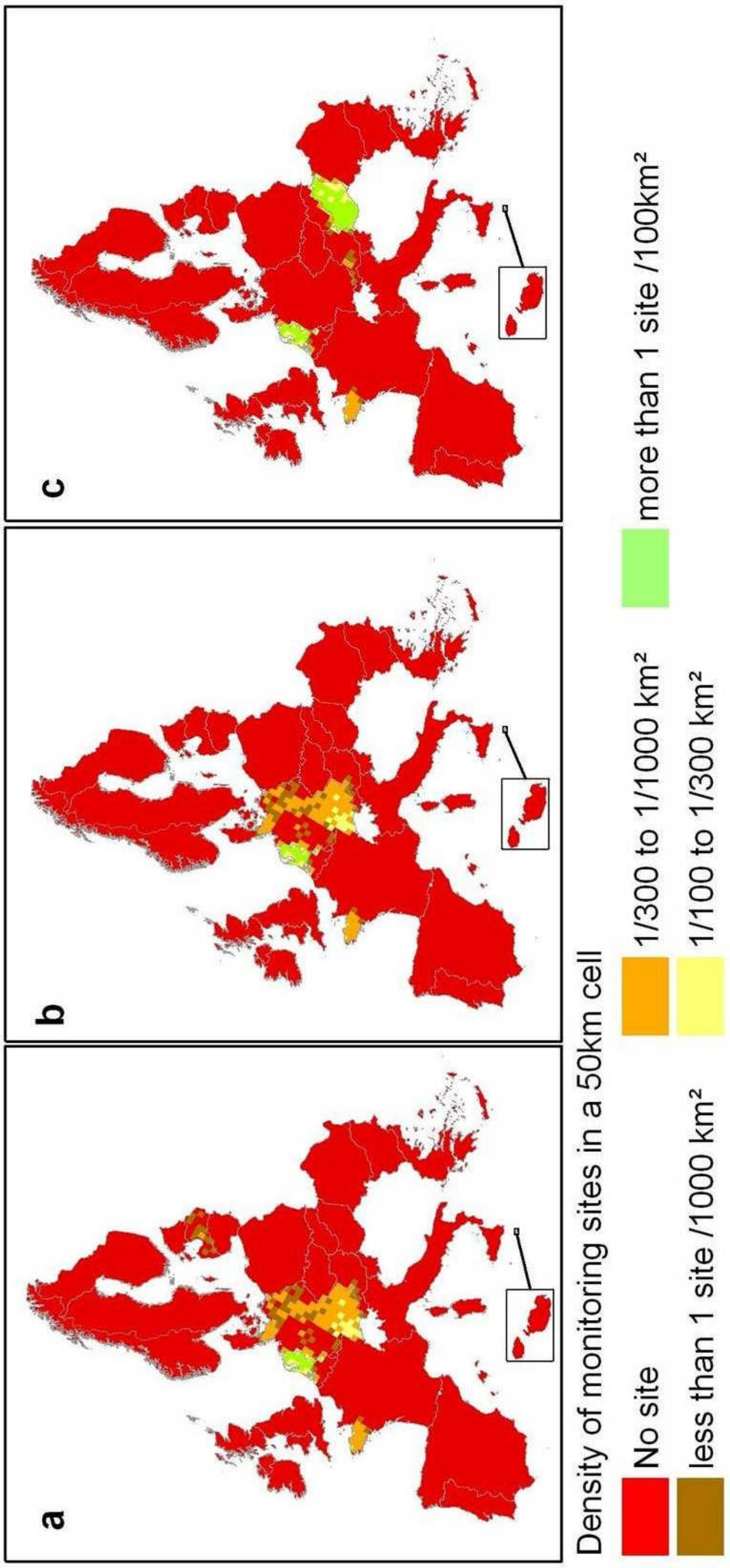


Figure 26. Density of sites at which a) earthworm diversity, b) Enchytraeid diversity c) Soil respiration are measured

3.3 Geographical coverage for soil mapping units

In this section we examine if the existing SMN sites cover the variability of soils mapping units of Europe. We overlaid the 1:1,000,000 soil geographical database of Europe with the coverage of existing sites, and we mapped gaps in site coverage of soil mapping units, and calculated the density of sites per soil mapping unit.

3.3.1 Gaps in coverage for soil mapping units

3.3.1.1 Gaps in soil monitoring network coverage for soil mapping units

If we consider all monitoring sites, 349 out of 1585 soil mapping units, representing 22%, are not sampled at all. These soil mapping units represent 6.6% of the land area (Figure 27, Figure 28). However, some of the big gaps observed are likely to be related to SMNs for which we did not receive information, even though we know that some monitoring activities exist in these areas (for example in Sweden, and probably in parts of Italy). Some of these gaps will be filled within the next few years by ongoing programmes (for example in France). Therefore, we can consider that nearly all the soil mapping units of Europe are already sampled, or will be sampled in the near future.

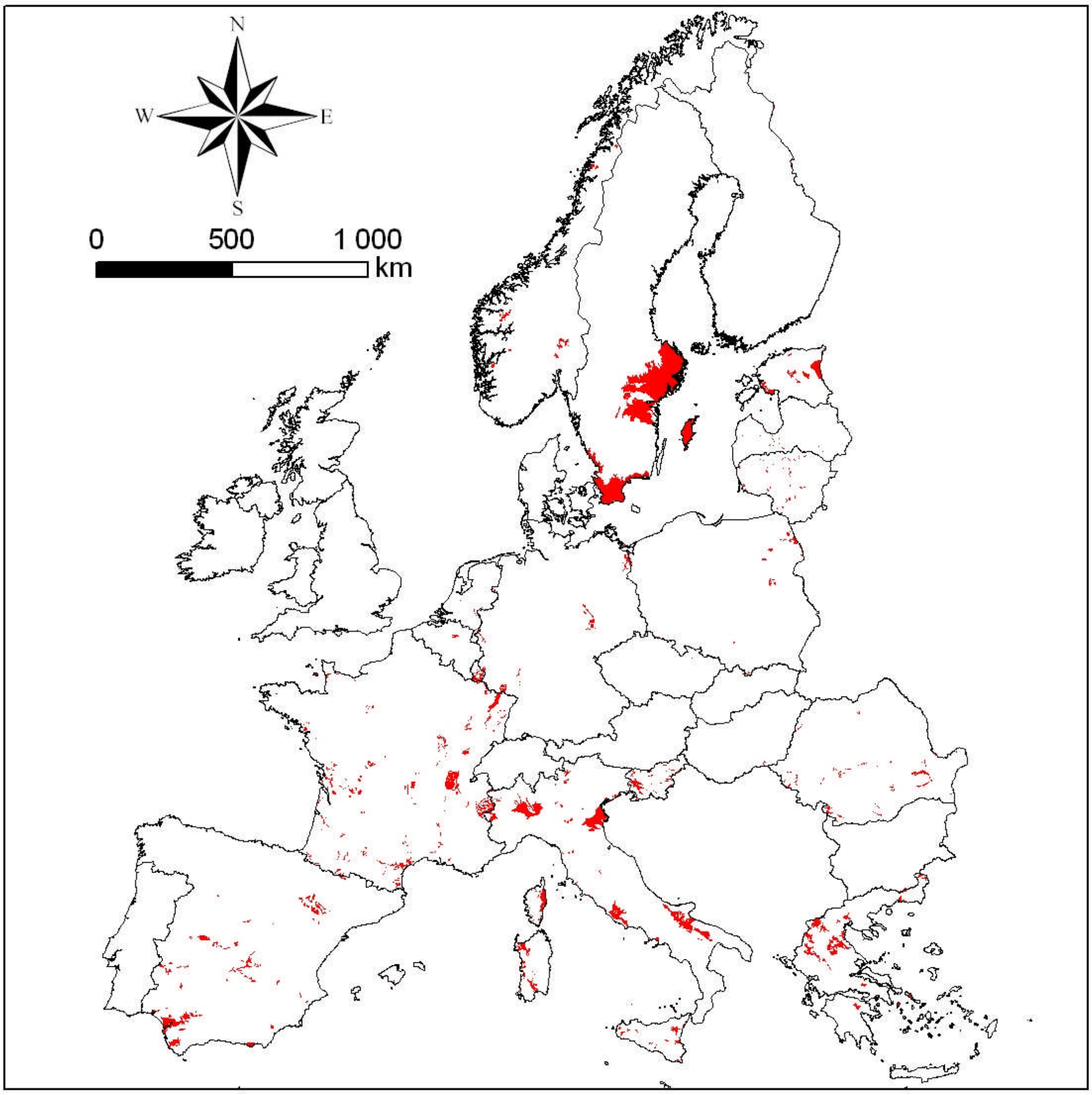


Figure 27. Unsampled soil mapping units of Europe, all sites
[as Malta is not in the 1:1 000 000 soil database, it is not represented on the map]

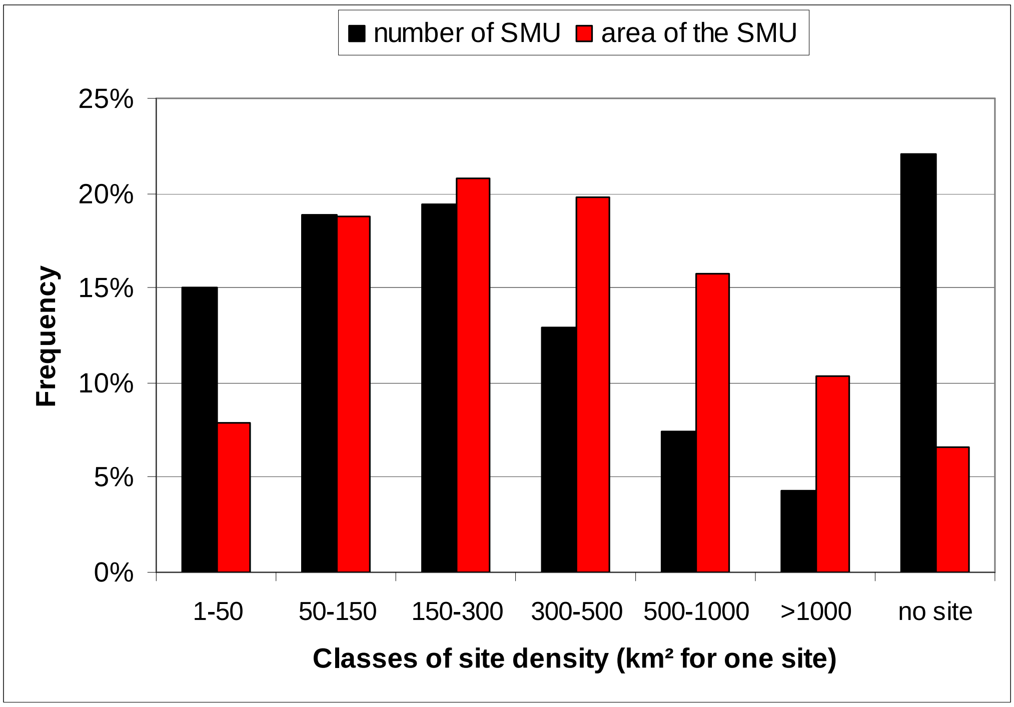


Figure 28. Frequency of the classes of site density in the soil mapping units

3.3.1.2 Gaps in indicator coverage for soil mapping units

In this section we map all the soil mapping units of Europe which do not include any measurement for a set of indicators.

A large proportion of soil mapping units have at least one site measuring topsoil organic carbon (Figure 29) in each Member State. The main difference with the previous figure (coverage for all sites) is for Slovenia. The situation differs when considering the indicator "topsoil organic carbon stocks" for which a large number of soil mapping units do not have any measurement.

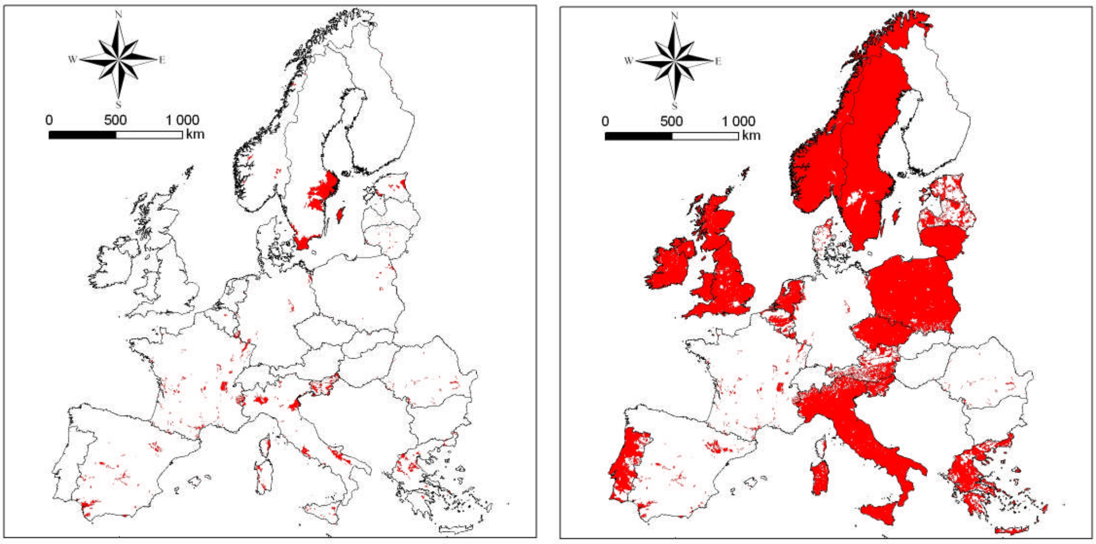


Figure 29. Unsampled soil mapping units of Europe; measurement of topsoil soil organic carbon content (left) and measurement of topsoil organic carbon stocks (right) [as Malta is not in the 1:1 000 000 soil database, it is not represented on the map]

The sampling in soil mapping units for total or pseudo-total trace element contents in topsoils shows various gaps depending on the element considered. Unsampled soil mapping units for Zn and Cu are almost the same, except for Greece where unsampled soil mapping units are more frequent for Cu (Figure 30).

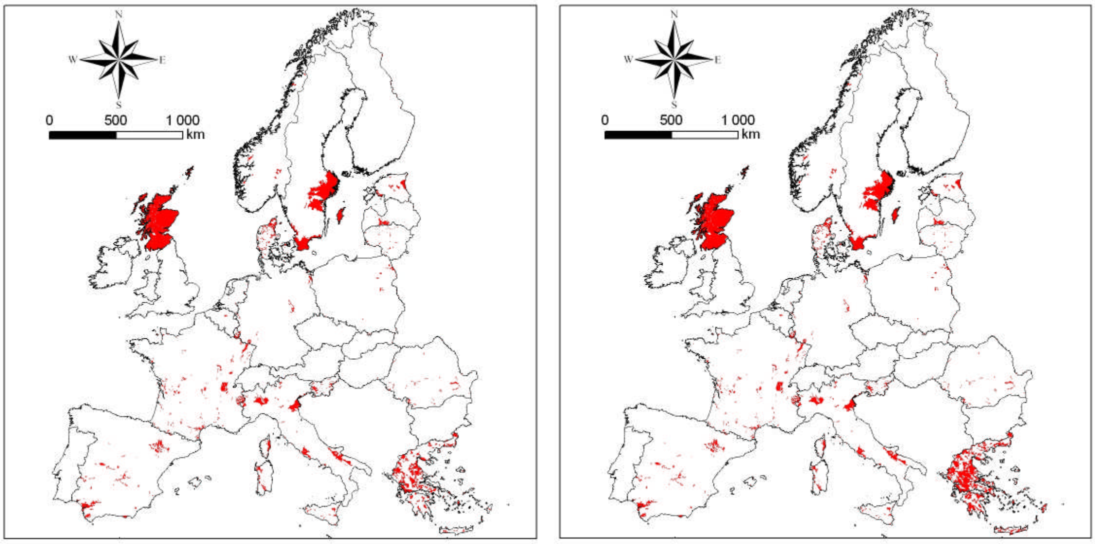


Figure 30. Unsampled soil mapping units of Europe; measurement of topsoil total Zn content (left) and measurement of topsoil Cu content (right)
[as Malta is not in the current 1:1 000 000 soil database, it is not represented on the map]

Unsampled soil mapping units are also very similar for Pb (Figure 31). However, some total and pseudo-total contents of trace elements, like Cr (Figure 31), Hg, or Ni (Figure 32), are much less sampled. An extreme situation is the distribution of unsampled soil mapping units for Hg. Nearly all northern parts of Europe do not have any measurement of Hg content in their soil mapping units, and only 11 countries have most of their soil mapping units characterised by at least one measurement. The situation is somewhat better for Ni but some countries still lack measurement sites for this element, for all their soil mapping units, or for a large proportion of them.

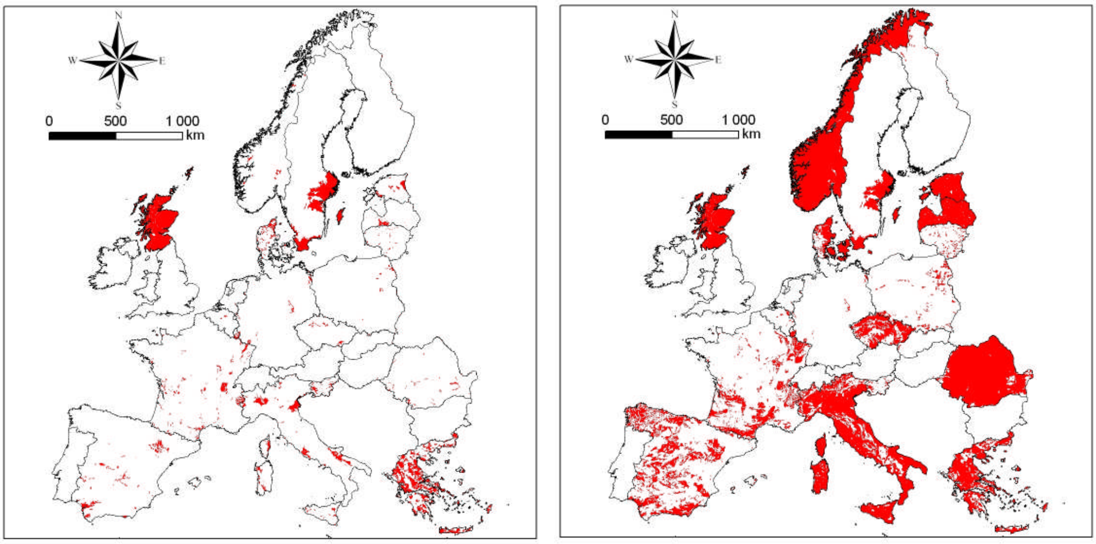


Figure 31. Unsampled soil mapping units of Europe; measurement of topsoil total Pb content (left) and measurement of topsoil Cr content (right)
[as Malta is not in the current 1:1 000 000 soil database, it is not represented on the map]

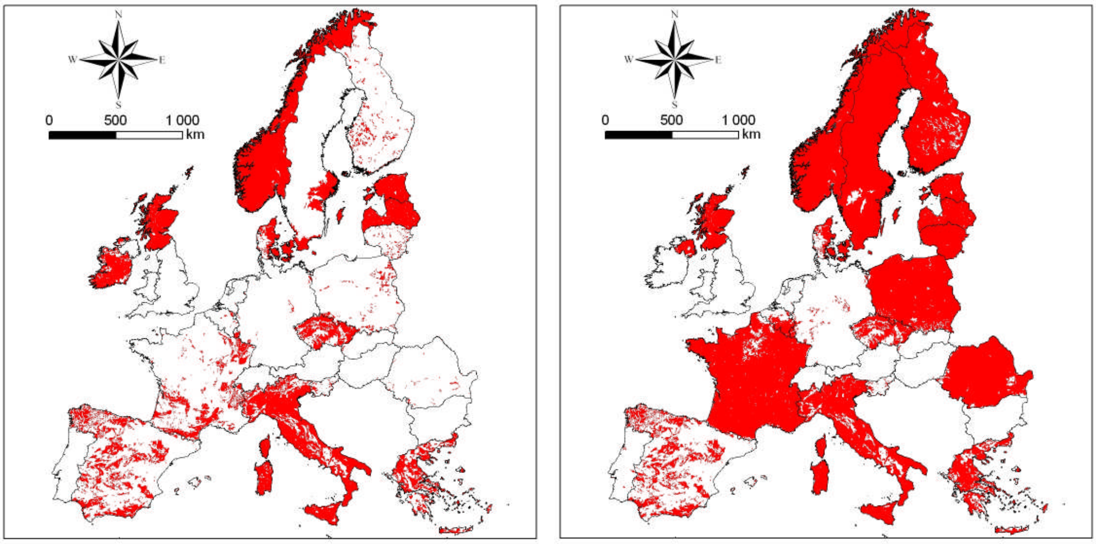


Figure 32. Unsampled soil mapping units of Europe; measurement of topsoil total Hg content (left) and measurement of topsoil Ni content (right)
[as Malta is not in the current 1:1 000 000 soil database, it is not represented on the map]

3.3.2 Density of soil monitoring sites in soil mapping units of Europe

In this section we produce an estimate of the density of soil monitoring sites in the soil mapping units of Europe. The density of the sites where some indicators are measured is presented in Annex V.

Amongst the sampled soil mapping units, about 53% of them have a density of soil monitoring sites > 1 site per 300 km² (Figure 33). If we consider the area the soil mapping units cover, it is 48% of the studied area that have at least one site for 300 km².

The density of sites in soil mapping units of Europe is highly variable (Figure 33). Contrary to soil mapping units of southern Europe and northern Europe, the soil mapping units of the central Europe are very well sampled.

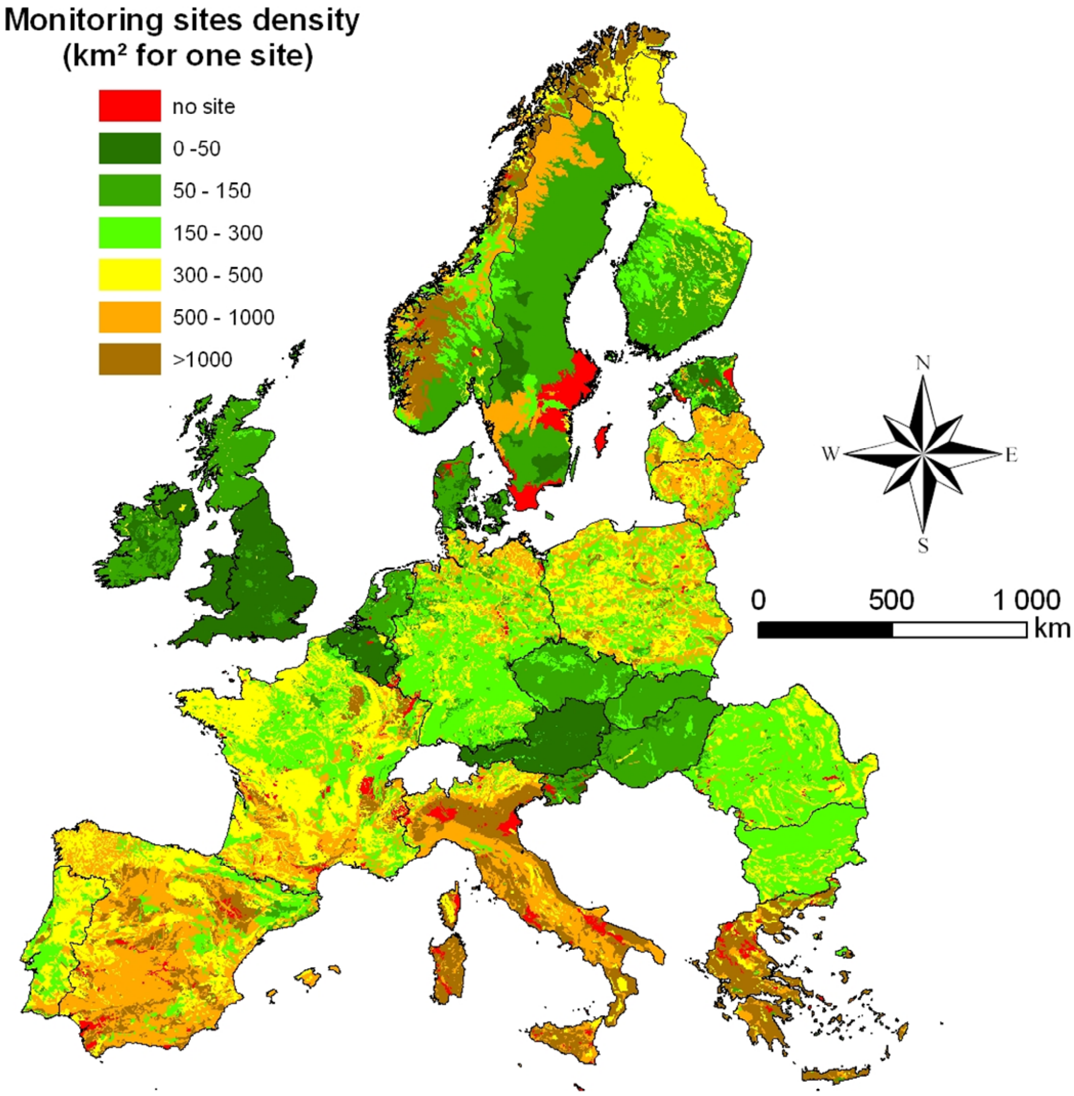


Figure 33. Density of sites in soil mapping units of Europe

3.4 Geographical coverage for land-use

We overlaid the Corine Land Cover (CLC) map with the coverage of sites. For each land use class, we calculated the average site density expressed in km² for 1 site. Figure 34 shows the distribution of the density of sites according to the main land uses. The greatest density (smallest area per site) is for pasture, whereas arable lands and forests have a comparable site density. Permanent crops (excluding permanent grass) and open spaces with little or no vegetation are under sampled in comparison to other land uses. This is due to the small number of monitoring sites in Mediterranean regions. Table 6 gives the distribution of site density according to the detailed CLC classification. These figures should be used with caution, given the low accuracy of the CLC and site mapping.

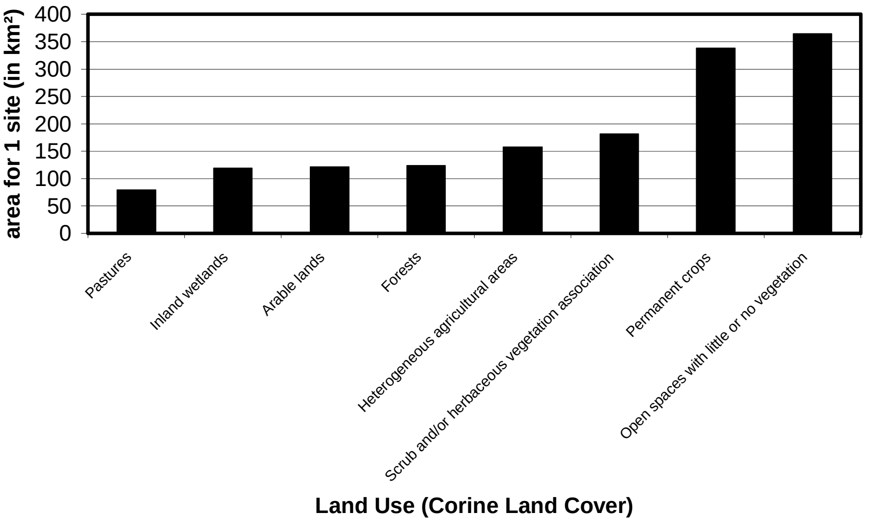


Figure 34. Density of soil monitoring sites for the main land-uses in Europe

Table 6. Number, area and density of sites in km^2 site^{-1} aggregated according to three CORINE Land Cover classes

	CLC	Number of sites	Area (km²)	km²/site
Green urban areas	141	49	2875.73	58.7
Continuous urban fabric	111	100	5893.91	58.9
Sport and leisure facilities	142	119	8091.91	68.0
Road and rail networks and associated land	122	25	1919.84	76.8
Pastures	231	4724	375557.2	79.5
Coniferous forest	312	6802	648314.8	95.3
Discontinuous urban fabric	112	1274	132490.6	104.0
Peat bogs	412	654	71372.9	109.1
Non-irrigated arable land	211	9037	1072265	118.7
Natural grasslands	321	966	118491.9	122.7
Airports	124	23	2901.21	126.1
Dump sites	132	8	1078.97	134.9
Mixed forest	313	2143	291062.4	135.8
Complex cultivation patterns	242	1839	259222.6	141.0
Industrial or commercial units	121	139	20001.29	143.9
Moors and heathland	322	584	90580.28	155.1
Mineral extraction sites	131	39	6151.76	157.7
Land principally occupied by agriculture, with significant areas of natural vegetation	243	1275	206855.3	162.2
Transitional woodland-shrub	324	1375	239420.8	174.1
Broad-leaved forest	311	2297	454503.8	197.9
Water courses	511	47	10637.96	226.3
Vineyards	221	169	39328.53	232.7
Inland marshes	411	46	12057.2	262.1
Construction sites	133	4	1167.74	291.9
Sparsely vegetated areas	333	132	39366.25	298.2
Burnt areas	334	5	1492.01	298.4

Table 6. (cont.)

	CLC level2	Number of sites	Area (km²)	km²/site
Fruit trees and berry plantations	222	84	25101.7	298.8
Salt marshes	421	10	3113.51	311.4
Agro-forestry areas	244	92	31934.61	347.1
Water bodies	512	277	99157.37	358.0
Rice fields	213	16	5874.86	367.2
Beaches, dunes, sands	331	10	3765.31	376.5
Permanently irrigated land	212	67	31708.08	473.3
Bare rocks	332	37	20709.5	559.7
Annual crops with permanent crops	241	17	9909.91	582.9
Estuaries	522	5	3244.74	648.9
Olive groves	223	56	40020.08	714.6
Salines	422	1	741.58	741.6
Intertidal flats	423	11	10391.15	944.7
Port areas	123	1	1026	1026.0
Sclerophyllous vegetation	323	86	98568.26	1146.1
Coastal lagoons	521	2	5630.24	2815.1
Glaciers and perpetual snow	335	0		
Sea and ocean	523	0		
out of CLC layer		1530		

	CLC level2	Number of sites	Area (km²)	km²/site
Artificial, non-agricultural vegetated areas	14	168	10968	65.3
Pastures	23	4724	375557	79.5
Urban fabric	11	1374	138385	100.7
Inland wetlands	41	700	83430	119.2
Arable land	21	9120	1109848	121.7
Forests	31	11242	1393881	124.0
Industrial, commercial and transport units	23	188	25848	137.5
Heterogeneous agricultural areas	24	3223	507922	157.6
Mine, dump and construction sites	13	51	8398	164.7
Scrub and/or herbaceous vegetation association	32	3011	547061	181.7
Permanent crops	22	309	104450	338.0
Inland waters	51	324	109795	338.9
Open spaces with little or no vegetation	33	184	67066	364.5
Maritime wetlands	42	22	14246	647.6
Marine waters	52	7	9043	1291.9
out of CLC layer		1530		

	CLC level1	Number of sites	Area (km²)	km²/site
Artificial surfaces	1	1781	183599	103.1
Agricultural areas	2	17376	2097778	120.7
Wetlands	4	722	97676	135.3
Forest and semi natural areas	3	14437	2008008	139.1
Water bodies	5	331	118839	359.0
out of CLC layer		1530		

3.5 Geographical coverage for soil regions-land use combinations

At their most detailed level, the overlays of geographical information for soil and land-use in Europe generate too many combinations, and an enormous number of polygons which are impossible to handle properly with geographical information systems. Therefore, we chose to simplify these coverages by using the soil regions map of Europe (Hartwich, *et al.*, 2006), and level 1 of Corine Land Cover classification for soils and land use respectively. By overlaying these two coverages, we arrived at 203 unique combinations which were used to produce maps of average site density in soil region-land use combinations (Figure 35).

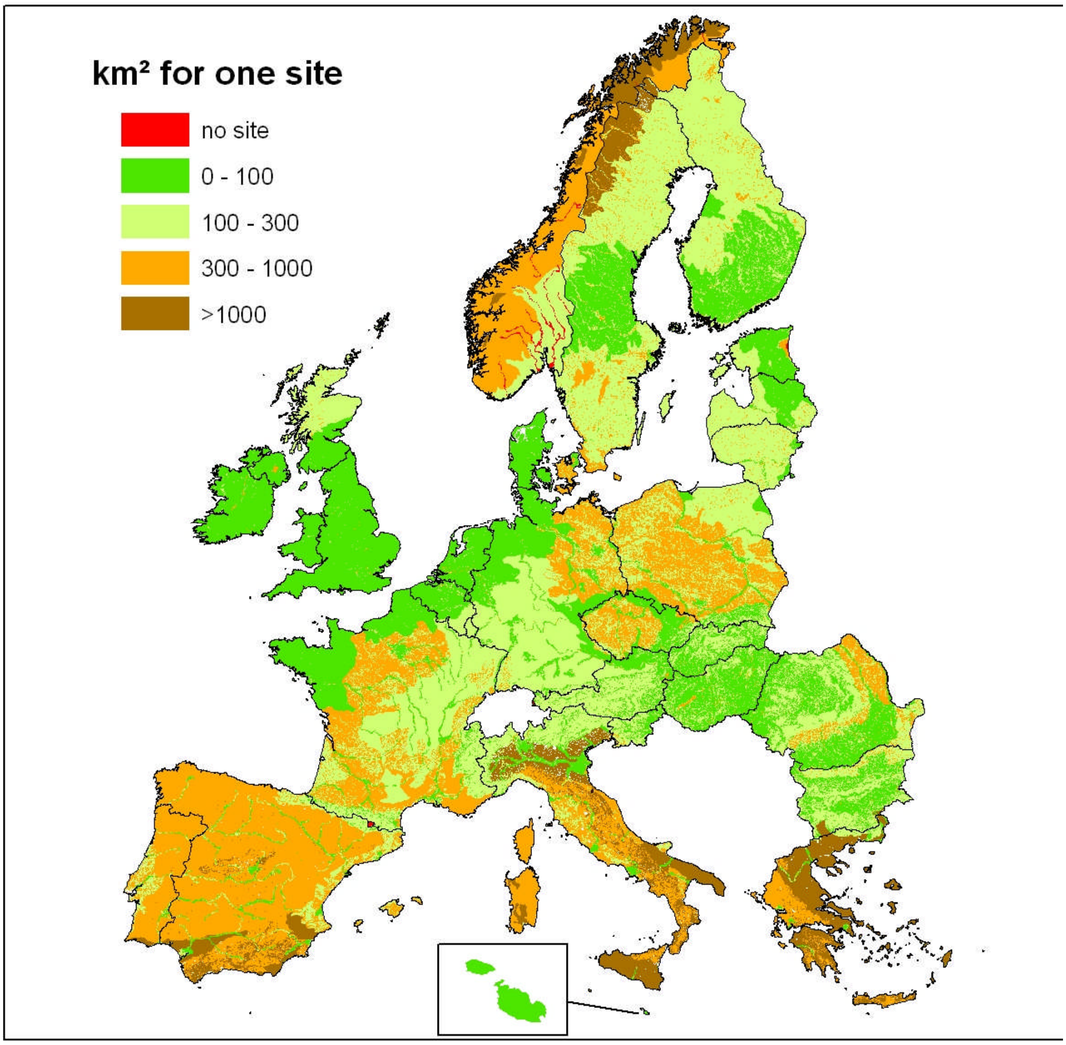


Figure 35. Density of monitoring sites in soil regions-land use combinations.
A zero value (in red) indicates that there is no site in the combination

The map shows that Mediterranean regions are generally undersampled. Undersampling is also seen in some northern regions (i.e. Norway) and in parts of France, Germany, Poland, Czech Republic and Romania (Figure 36, Figure 37, Figure 38). When considering sites at which some indicators are measured, the maps show considerable variations linked to the density of measurements of the indicator.

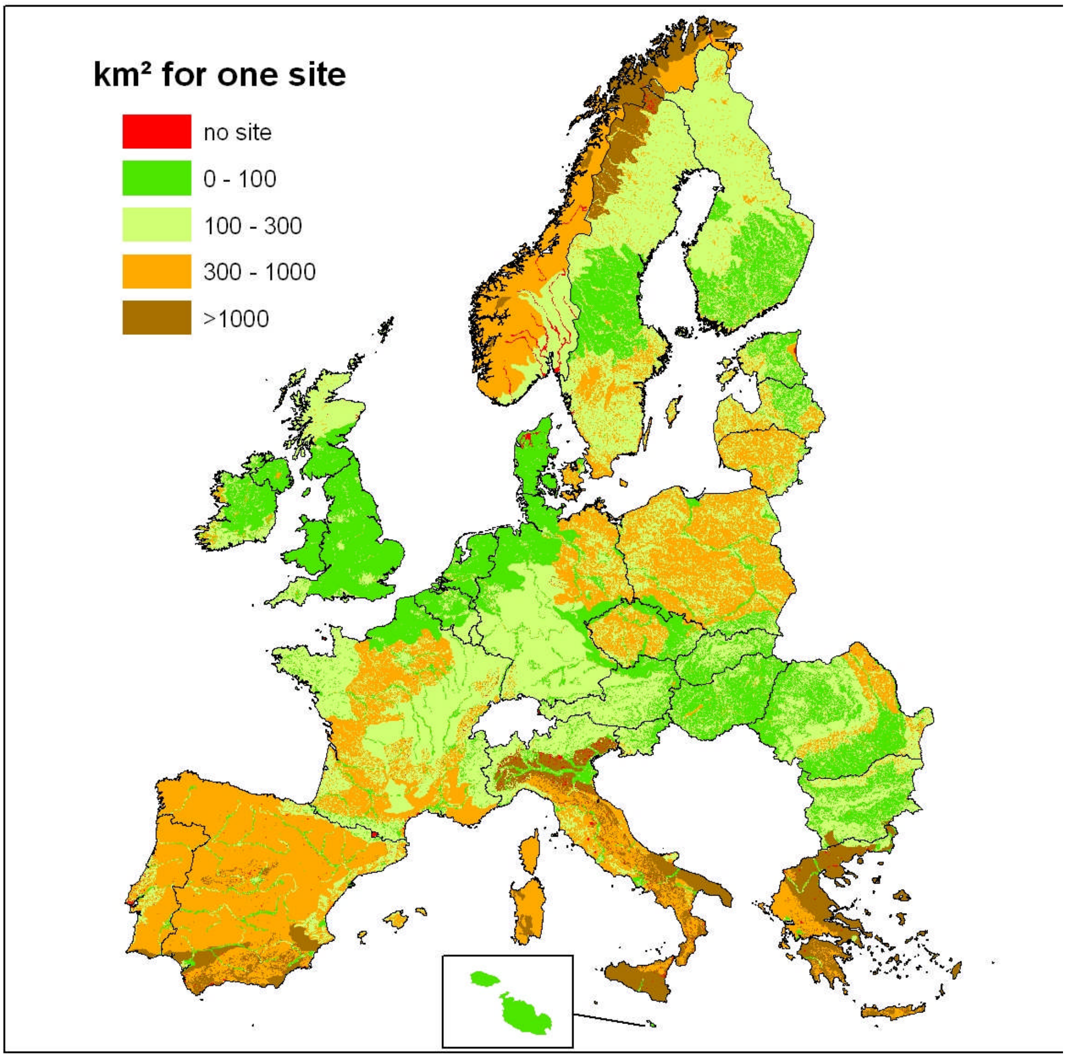


Figure 36. Density of monitoring sites where organic carbon or organic matter is measured, in the soil region-land use combinations of Europe

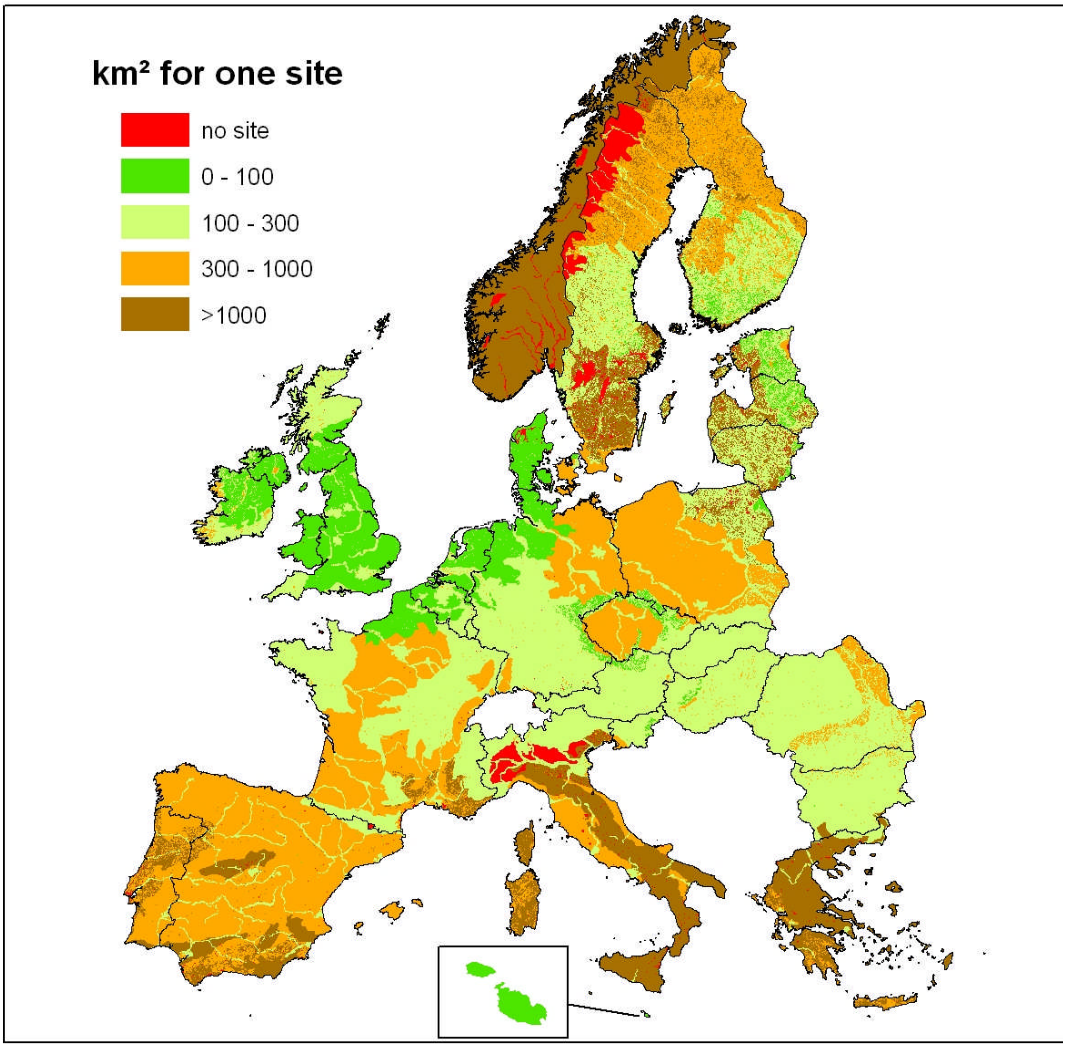


Figure 37. Density of monitoring sites where particle size distribution is measured, in the soil region-land use combinations of Europe

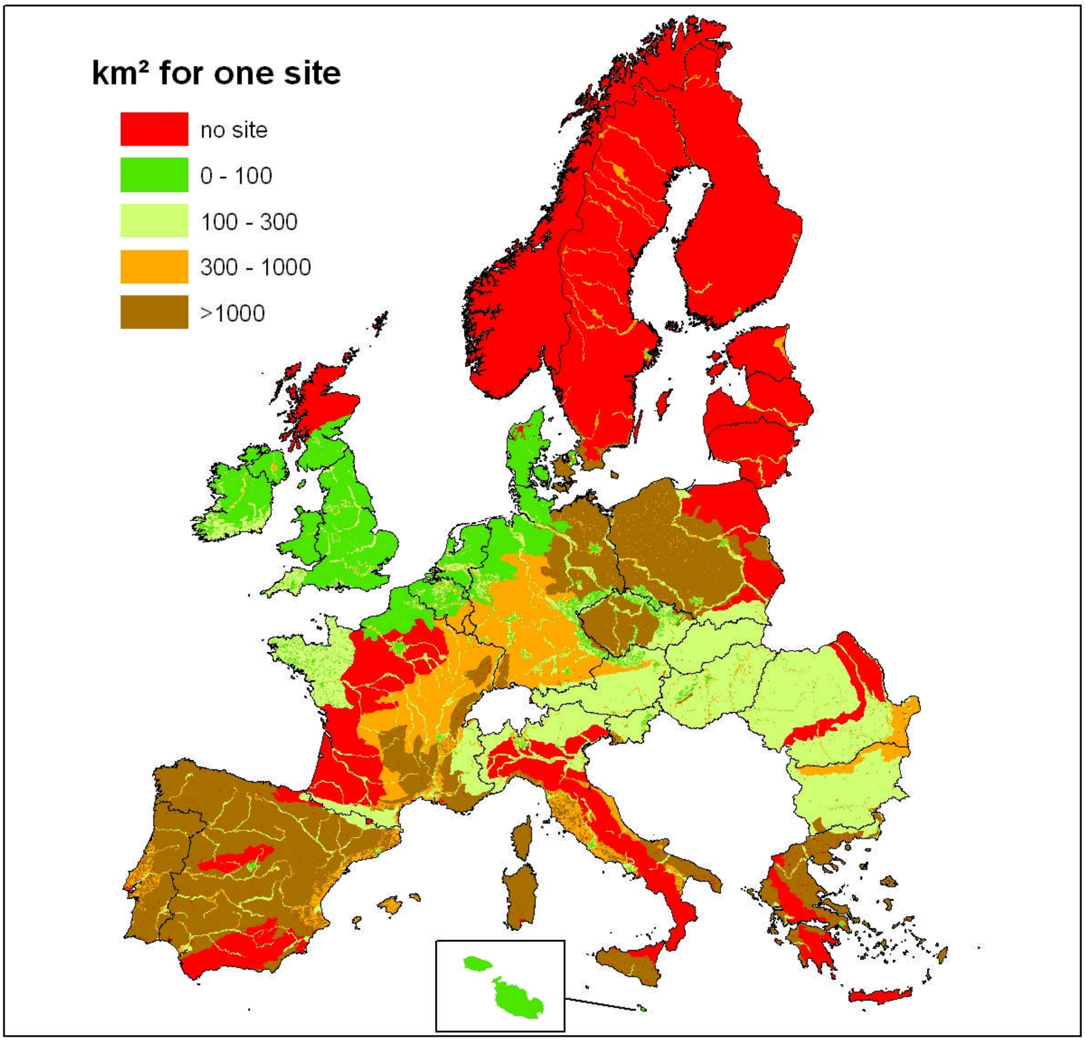


Figure 38. Density of monitoring sites where topsoil total Hg is measured, in the soil region-land use combinations of Europe

3.6 Geographical coverage for some state, pressure and impact indicators

3.6.1 Representativity and geographical coverage for soil organic carbon content

We overlaid the organic carbon grid map produced by Jones *et al*. (2005) with the coordinates of the SMN sites in order to assess their representativity for organic carbon status in Europe. We assigned to each monitoring site a theoretical value corresponding to the organic carbon content predicted for its location by the map of Jones *et al*. (2005). Then, we compared the frequencies and the cumulated frequencies of theoretical organic carbon contents calculated on the whole topsoil organic content of the 1 x 1 km grid map of Europe and on several subsets corresponding to all the soil monitoring sites or to the monitoring sites where given indicators are measured.

When overlaying the organic carbon map with all the monitoring sites, the two cumulated frequencies appear to be similar (Figure 39 and Figure 40). However, a Kolmogorov–Smirnov test was computed and indicated that the 2 distributions were significantly different ($p<0.01$). Low organic carbon contents are undersampled by existing networks when compared to the theoretical distribution. This is mainly attributable to the low density of sites in southern countries.

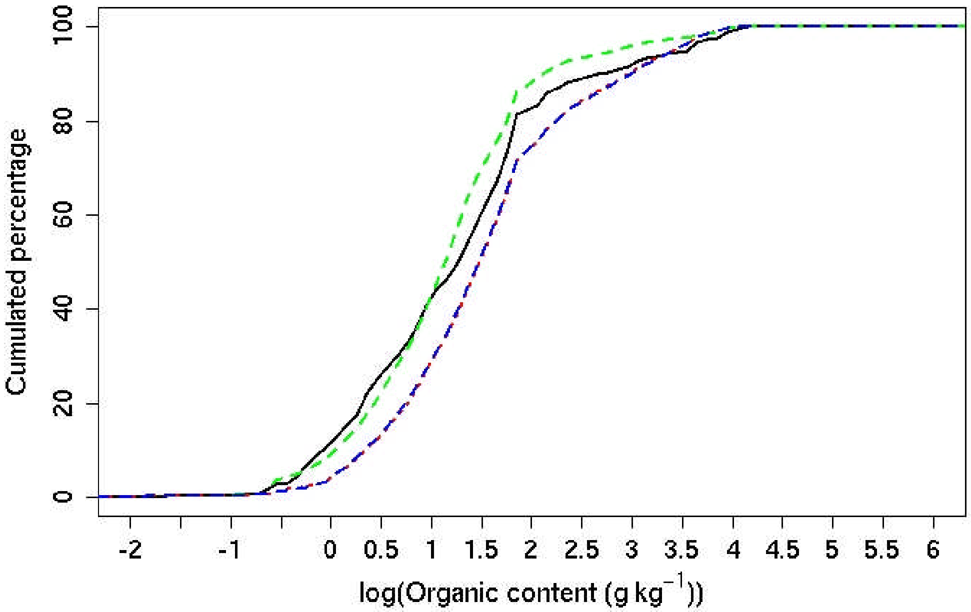


Figure 39. Comparison of the cumulative frequencies of estimated organic carbon contents calculated on the whole topsoil organic content grid map of Europe (in black), on a subset corresponding to the soil monitoring sites (in red), on a subset corresponding to the soil monitoring sites where organic carbon or organic matter are measured (in blue) and on a subset corresponding to monitoring sites where organic carbon stocks are measured (in green)

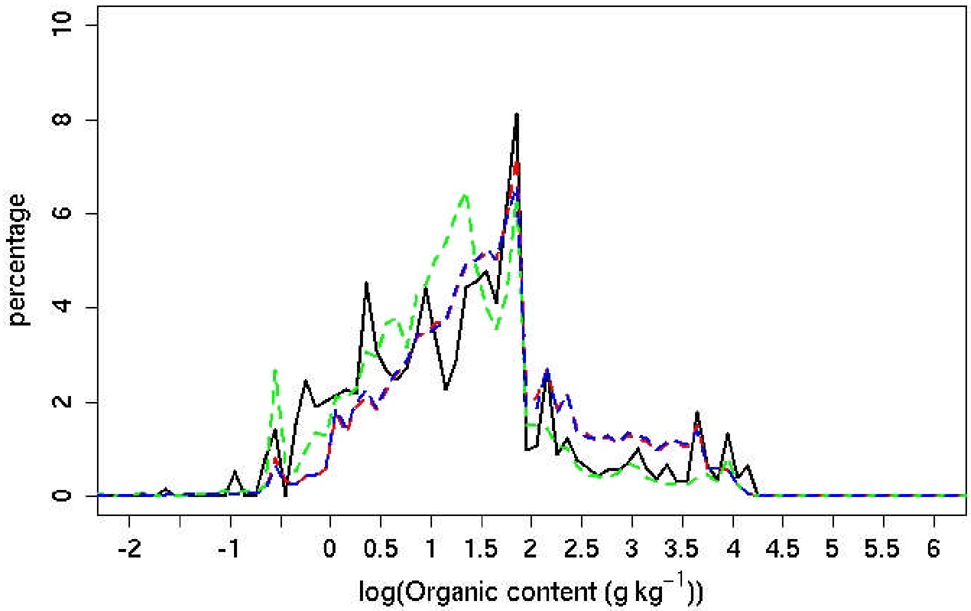


Figure 40. Comparison of the frequencies of estimated organic carbon contents calculated on the whole topsoil organic content grid map of Europe (in black), on a subset corresponding to the soil monitoring sites (in red), on a subset corresponding to the soil monitoring sites where organic carbon or organic matter are measured (in blue) and on a subset corresponding to monitoring sites where organic carbon stocks are measured (in green)

When considering the sites where organic carbon is measured by various methods, or the sites where organic matter is measured by the loss-on-ignition method, the shape of the curve is almost the same than the one with all the monitoring sites (Figure 39 and Figure 40). However, the 2 distributions are still significantly different from the theoretical one (Kolmogorov–Smirnov test, $p<0.01$). The difference for high organic values is attributable to loss-on-ignition measurements in northern countries.

The distribution of sites where these measurements are made is not homogeneous across Europe. The northern parts of Europe are much better characterised for organic matter content than the other parts.
However, from the population of sites at which this indicator is measured, it would be possible to extract a representative population by subsampling according to organic carbon content classes.

If we do the same exercise with sites where organic carbon stocks are measured, which are much less numerous, the cumulative frequencies of the populations become very close (Figure 39 and Figure 40). However the 2 distributions remain significantly different (Kolmogorov–Smirnov test, $p<0.01$). Nevertheless, the relative “over-sampling” in northern Europe disappears, as some northern countries (Ireland, Lithuania, Norway, Sweden, United Kingdom) do not measure bulk density (Bd).

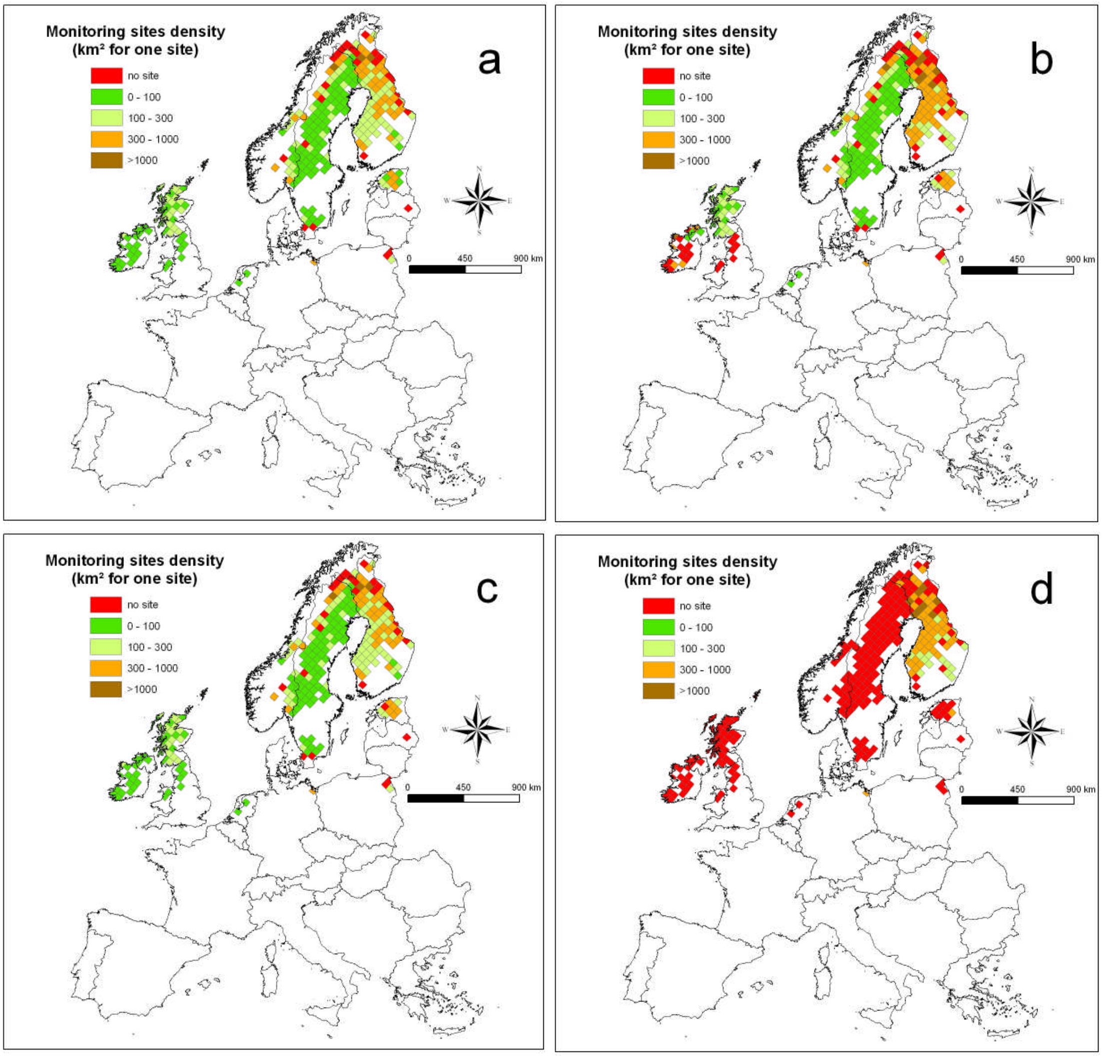
3.6.2 Representativity and geographical coverage for peats

Peats play an essential role for greenhouse gas exchanges with the atmosphere, dissolved organic carbon transport to water, and biodiversity. The delineation of the peat is explained in section 3-2-4. By overlaying the map of peatlands (Montanarella, *et al*., 2006) and the point map of soil monitoring sites, we selected the sites which were inside the peat areas delineated by Montanarella *et al*. (2006). We also selected the EMEP cells in which the total peat area was greater than 300 km². Then, we calculated the number of km² of peat for one site in each selected cell in order to map where new monitoring sites had to be implemented to monitor peat changes.

For the parts of Europe having large areas of peats, the density of monitoring sites is quite high (median, corresponding to 1 site for 110 km²); 116 new sites would be enough to reach the 1 site to 300 km² density in all large areas of peat (Table 7, Figure 41). Most of them are located in Finland. As organic carbon or organic matter content is measured at almost every monitoring site, these variables would have to be measured in 119 new sites, 3 of them already existing in Estonia. For the other indicators of soil organic matter, C:N ratio and organic carbon stocks, 222 and 619 new measurements would have to be done, respectively. These measurements are mainly located in Finland, Sweden and Scotland.

Table 7. Monitoring sites to add per country in the peat area, according to the “decline of organic matter” indicators

Country	Monitoring sites	Organic carbon or organic matter content measurement	C:N ratio calculation possible	Organic carbon stocks calculation possible
Estonia	2	5	5	14
England & Wales	0	0	12	12
Finland	81	81	145	145
Germany	0	0	0	0
Ireland	0	0	27	33
Latvia	2	2	2	2
Netherlands	0	0	0	3
Northern Ireland	0	0	0	2
Norway	4	4	4	27
Poland	3	3	3	4
Scotland	0	0	0	112
Sweden	24	24	24	264
TOTAL	**116**	**119**	**222**	**619**



[as there is no peat in Malta, it is not represented on the maps]

Figure 41. Density of monitoring sites in the peat areas (a), monitoring sites where C:N ratio calculation is possible (b), where organic matter or organic carbon content is measured (c) and where organic carbon stock calculation is possible (d)

Small areas of peat in other parts of Europe are not delineated in the peat map from Montanarella *et al*. (2006), given its scale. They are likely to be undersampled, especially for SMNs using relatively large spacing systematic grids.

3.6.3 Representativity and geographical coverage for soil erosion risk

We received very little information concerning sites or watersheds where indicators of erosion are measured however we know that a few watersheds are monitored in some countries (for instance in Spain). This general lack of information seems to indicate that the geographical coverage of watersheds monitored for erosion is very limited, and almost non-existent in many countries.

We overlaid the map of the soil erosion estimates produced by PESERA, with the coordinates of the SMN sites in order to assess their representativity for soil erosion status in Europe. We assigned to each monitoring site a theoretical value corresponding to the soil erosion predicted for its location by the PESERA map. Then, we compared the cumulated frequencies of theoretical soil erosion calculated on the whole PESERA 1 x 1 km grid map of Europe and on a subset corresponding to the soil monitoring sites.

When overlaying the map of the soil erosion estimates with all the monitoring sites, the two cumulated frequencies are very close (Figure 42). A Kolmogorov–Smirnov test was computed and indicated that the 2 distributions are significantly different ($p<0.01$). However the differences mainly correspond to the low PESERA values which are under represented by the monitoring sites.

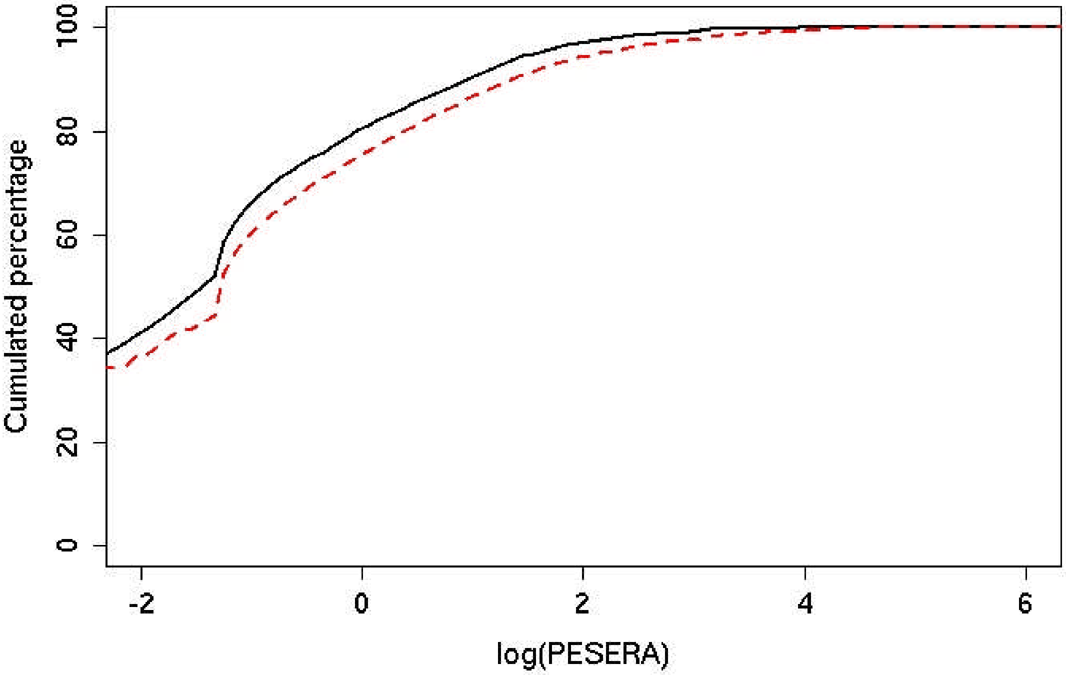


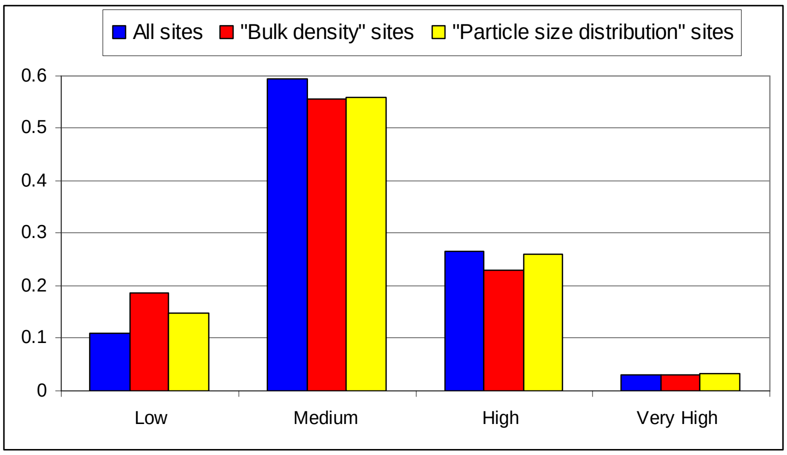
Figure 42. Comparison of the cumulated frequencies of theoretical PESERA value calculated on the whole grid map of Europe (in black) or on a subset corresponding to all the monitoring sites (in red)

3.6.4 Representativity and geographical coverage for soil compaction risk

The map of soil compaction risk of Jones, *et al*. (2003) has been overlaid with the point map of all SMN sites. In order to study the representativeness of the monitoring sites in these areas, we kept only the sites in the high or very high compaction risk areas. As for the study of the peat, we selected the EMEP cells where the total of the high or very high compaction risk areas were greater than 300 km². According to classes of compaction risk, the relative distributions of frequency of sites measuring or not measuring some compaction indicators are quite similar (Figure 43).

Reaching a density of 1 site per 300 km² in areas at high and very high risk of compaction would need the addition of about 1161 sites to the existing ones (Table 8). 74% of those sites are located in two Baltic countries, Finland and Norway, and in the southern Europe, France, Italy and Spain (Figure 44). Some of them will be implemented in France in the next 2 years.

For particle-size distribution, 2624 new measurements would have to be made, 1461 of these measurements could be made in existing sites. For the other soil compaction indicators, a lot of new measurements need to be made. Indeed, as numerous existing sites do not measure bulk density or do not observe soil structure (Figure 45), measurements of bulk density and observation of soil structure would have to be made on 3358 and 3941 sites, respectively, to reach the density of one site for 300 km². For the soil water retention and saturated hydraulic conductivity measurements, 4650 and 4471 new measurements have to be made, respectively.

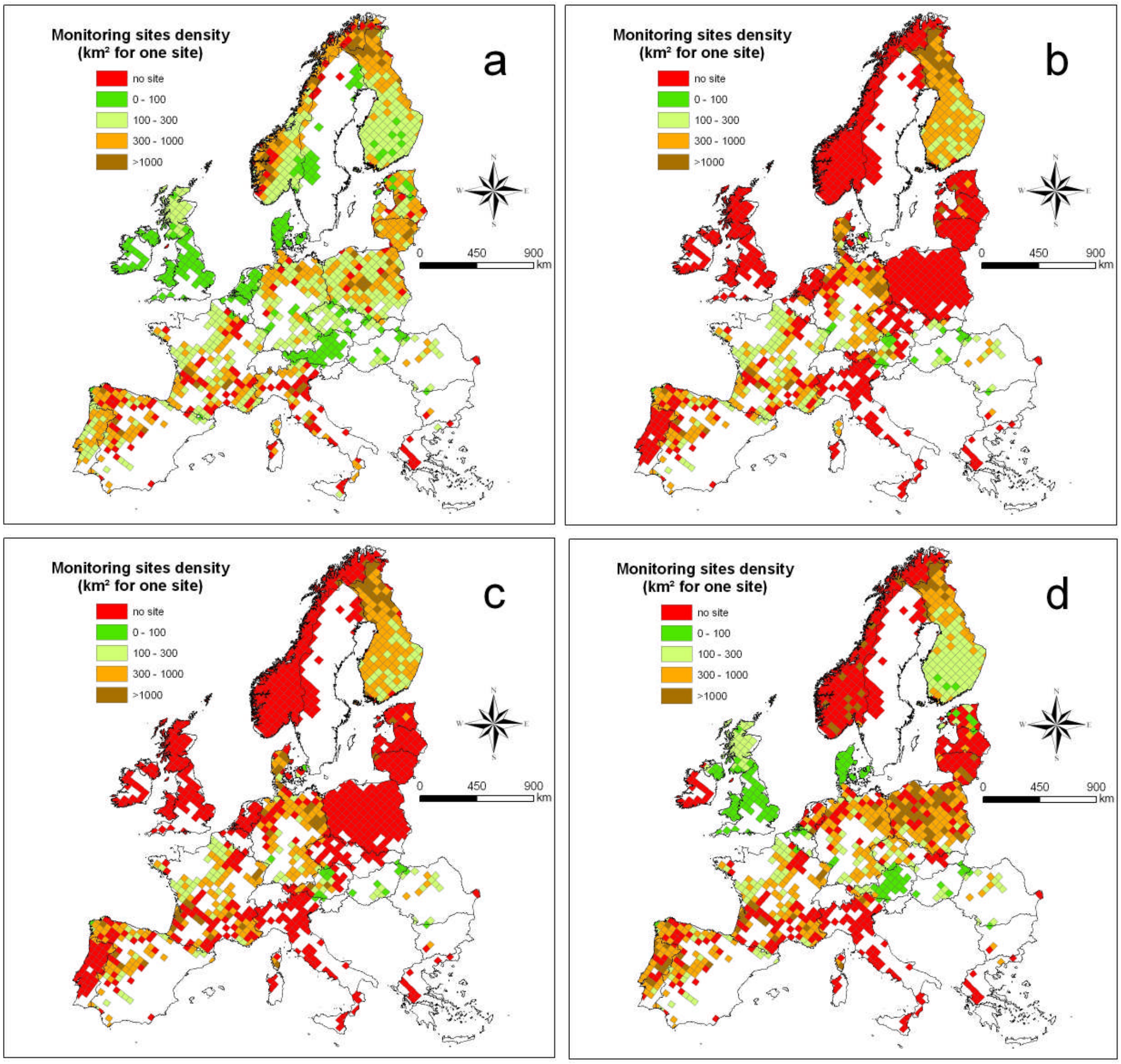


Low (L), medium (M), high (H) or very high (VH) risk areas for compaction

Figure 43. Frequencies of all monitoring sites where bulk density is measured, and of sites where soil texture is measured, in units of soil compaction risk

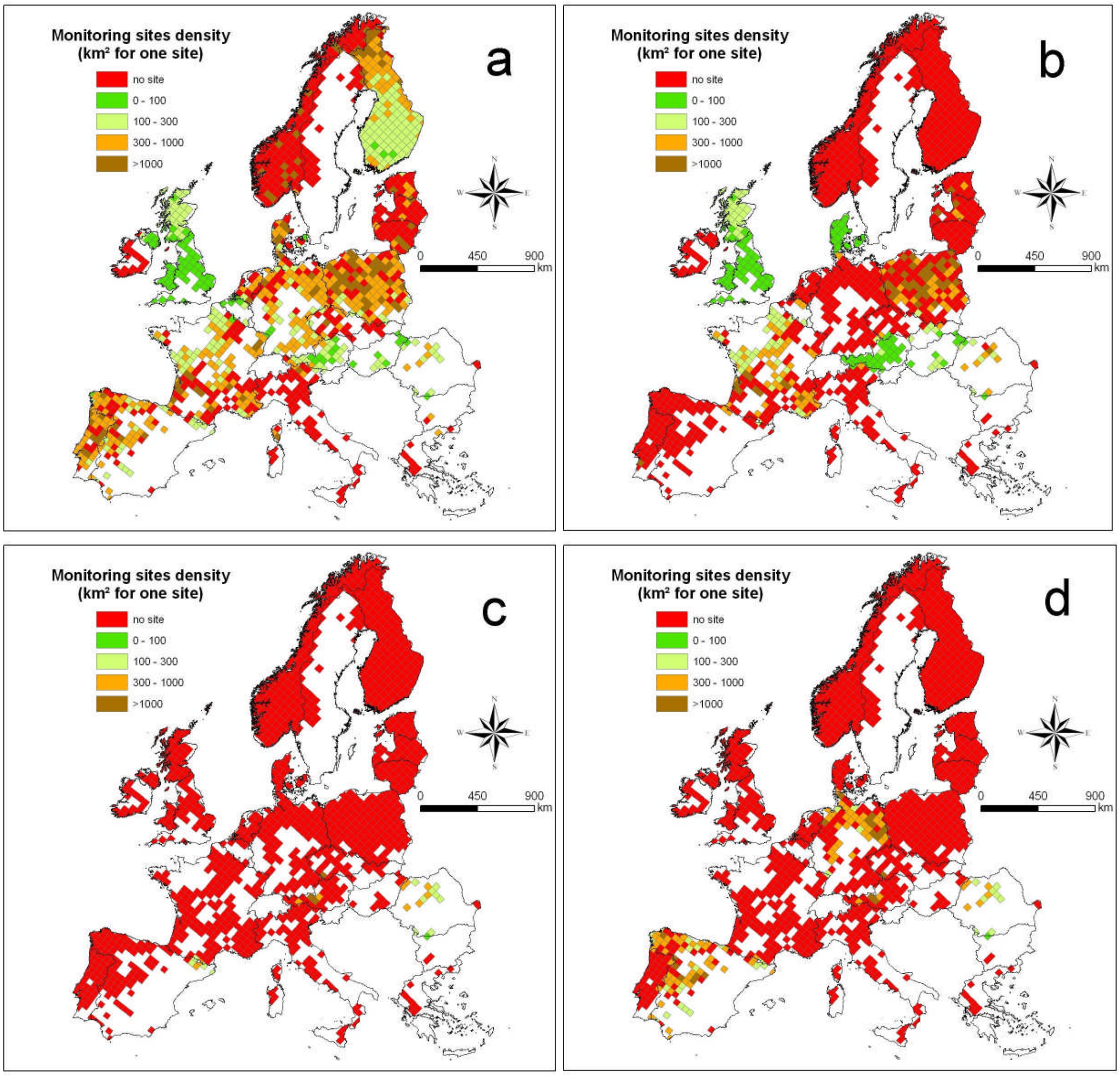
Table 8. Monitoring sites to add per country in the areas with a high or very high risk of compaction, depending on the "soil compaction" indicators

Country	**Monitoring sites**	**Bulk density measurements**	**Packing density calculation possible**	**Particle size distribution measurements**	**distribution and organic carbon content**	**Soil structure observation**	**Soil water retention measurements**	**Saturated hydraulic conductivity measurements**
Austria	0	45	45	3	5	0	79	79
Belgium	1	11	17	1	1	10	17	17
Bulgaria	2	2	2	2	2	3	3	3
Czech Republic	1	48	48	19	41	48	48	48
Denmark	0	57	57	0	57	0	84	84
England &Wales	1	86	86	1	1	1	86	86
Estonia	8	53	53	32	48	53	55	55
Finland	203	353	353	203	203	977	977	977
France	124	124	235	235	235	257	417	417
Germany	51	165	165	136	138	297	297	228
Greece	16	17	17	16	16	17	17	17
Hungary	0	0	0	0	0	0	32	32
Ireland	0	36	36	36	36	36	36	36
Italy	115	164	164	162	162	164	164	164
Latvia	29	74	82	79	79	75	83	83
Lithuania	63	177	177	170	170	177	177	177
Netherlands	0	54	54	40	40	54	54	54
Northern Ireland	0	10	10	0	0	10	10	10
Norway	313	861	861	843	843	861	861	861
Poland	97	493	493	337	337	420	493	493
Portugal	23	152	152	105	105	151	152	152
Romania	3	3	3	3	3	9	3	3
Scotland	0	182	182	0	0	0	182	182
Slovakia	0	0	12	12	12	0	12	12
Spain	109	111	111	109	109	240	230	119
Sweden	2	79	79	79	79	79	79	79
TOTAL	**1161**	**3358**	**3494**	**2624**	**2723**	**3941**	**4650**	**4471**



(a) monitoring sites where bulk density is measured
(b) monitoring sites where packing density calculation is possible
(c) monitoring sites where particle-size distribution is measured
(d) white areas are classified as low or medium risk areas for compaction

Figure 44 Density of monitoring sites with high or very high compaction risk



(a) where soil structure is observed (b) where soil water retention is measured (c) and where white areas are classified as low or medium risk areas for compaction

Figure 45. Density of monitoring sites in the areas with high or very high compaction risk where both particle-size distribution and organic carbon content are measured

3.6.5 Representativity and geographical coverage for population density

The population density may be considered as a pressure indicator for soils. It may act as a pressure through emissions and subsequent depositions of pollutants (see for example, Saby *et al*., 2006), or by other pressures such as urban waste spreading, soil sealing and uptake, landscape fragmentation, etc. Population density is highly variable in Europe. We aggregated statistics on population density on a 50km x 50km grid. We selected the cells having a high population density (>200 km²). As the GISCO database on the population density (http://eusoils.jrc.it/gisco_dbm/dbm/toc.htm) has no information on Scotland, Norway and most of the Eastern Europe countries, these parts of Europe are not mapped in the Figure 46 and the Figure 47.

The maps show that some areas with a high population density do not have any monitoring sites, especially in Spain, France, Italy, Greece and Sweden (Figure 46). To reach the density of one site per 300 km², 401 new monitoring sites have to be implemented (Table 9). Most of them are located in Italy. However, some areas with high population density are quite well covered with monitoring sites (mainly in the UK and Belgium).

Moreover, the situation differs amongst potential pollutants. Maps for Zn and Pb exhibit a rather small number of empty cells whereas large areas are not covered for Ni, Hg and Cr (Figure 46, Figure 47). For instance, only 411 new measurements of lead content would be needed, whereas 854 and 1285 new measurements of mercury and thallium, respectively, would be necessary.

Diffuse pollution around a big city like Paris has been shown to induce strong gradients to distances ranging from 60 to 100 km (Saby *et al*., 2006). Our maps show that the present monitoring sites in some high population density parts of Europe are not dense enough to cover this kind of peri-urban threat everywhere in Europe.

Table 9. Monitoring sites to add per country in the area with a population density >200 ha km^2 based on the ‘heavy metal’ indicators

Country	**Monitoring sites**	**Cadmium content**	**Cobalt content**	**Chromium content**	**Copper content**	**Mercury content**	**Nickel content**	**Lead content**	**Thallium content**	**Zinc content**
Austria	0	0	0	0	0	0	0	0	14	0
Belgium	0	3	42	3	0	28	3	3	70	0
Denmark	0	3	8	8	3	8	8	3	8	3
England & Wales	0	0	0	0	0	0	0	0	222	0
Finland	0	0	0	0	0	10	10	3	10	0
France	30	30	72	72	30	177	72	30	72	30
Germany	61	61	323	150	61	179	142	61	323	61
Greece	9	9	14	14	12	14	9	9	14	9
Ireland	0	7	0	0	0	0	7	0	7	0
Italy	213	213	284	284	213	284	284	213	284	213
Luxemburg	0	2	4	4	2	4	4	2	4	2
Netherlands	2	2	85	2	2	2	2	2	85	2
Northern Ireland	0	0	0	0	0	10	0	0	10	0
Portugal	5	5	32	5	5	22	5	5	32	5
Spain	67	67	116	103	67	103	103	67	116	67
Sweden	14	14	14	14	14	14	14	14	14	14
TOTAL	**401**	**415**	**993**	**658**	**408**	**854**	**662**	**411**	**1285**	**405**

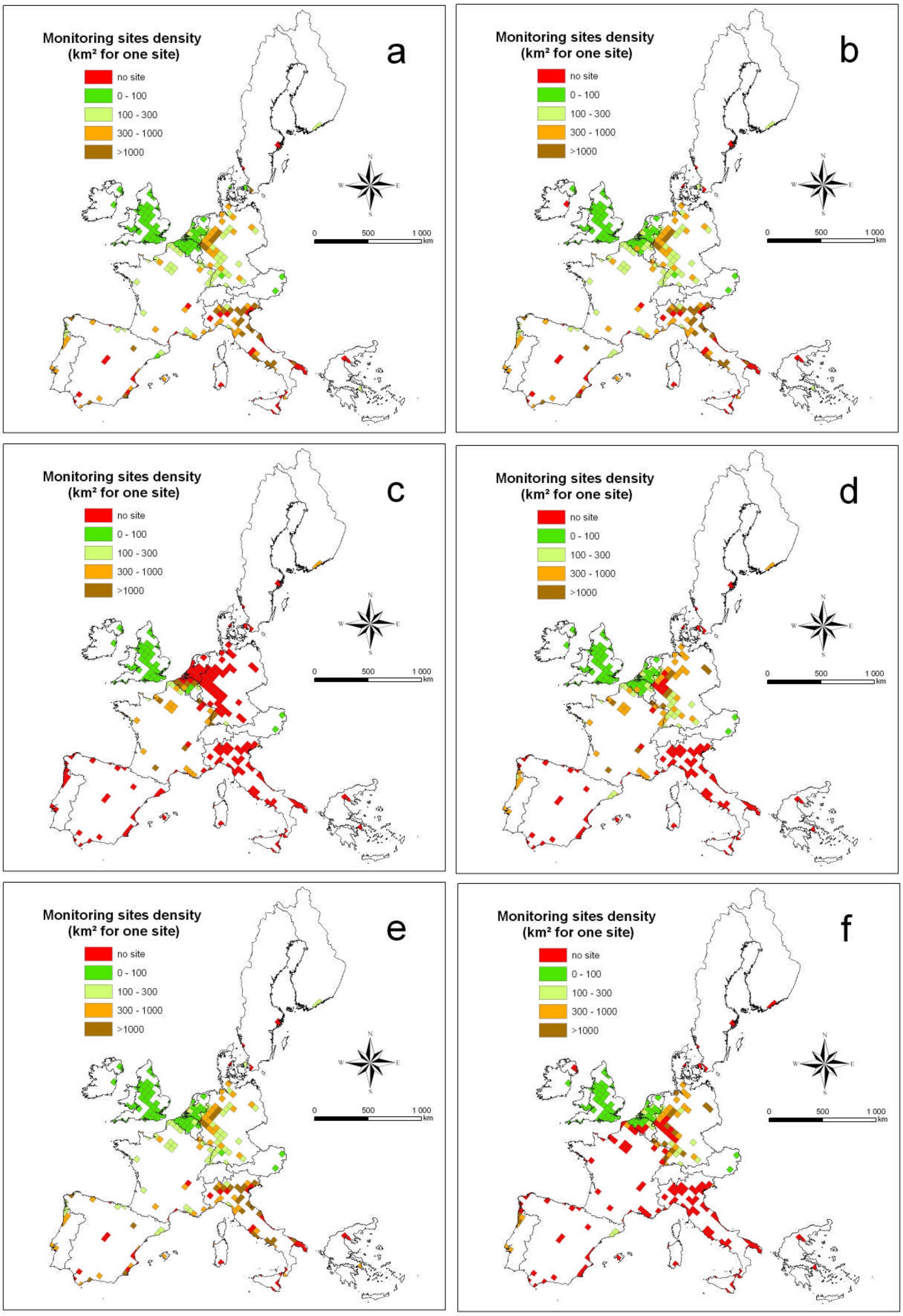


Figure 46. Density of monitoring sites in the high population density areas (a), and where (b) Cd, (c) Co, (d) Cr, (e) Cu and (f) Hg total or pseudo-total contents are measured (missing countries correspond to those for which population density data are not available)

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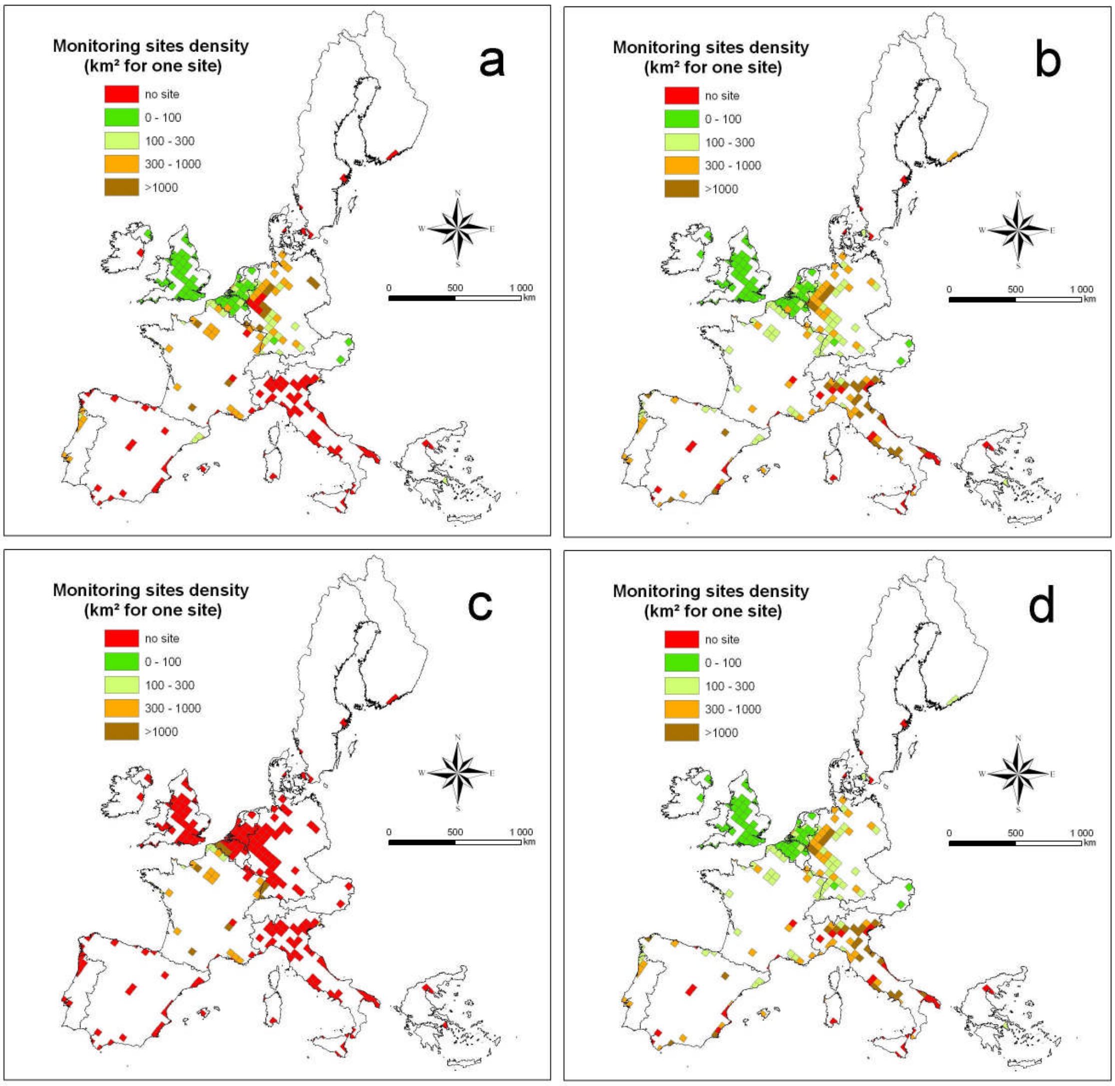


Figure 47. Density of monitoring sites in the high population density areas
where (a) Ni, (b) Pb, (c) Tl, (d) Zn contents are measured

3.6.6 Representativity for desertification risk

The areas identified as arid or semi-arid have been selected. After having selected the monitoring sites in these areas, we selected the EMEP cells where the total arid or semi-arid area was greater than 300 km². In order to reach a density of 1 site per 300 km² in all these cells, 789 new monitoring sites are needed: 72% and 21% of them are located in Spain and Italy respectively (Table 10, Figure 48). However, we know that some data are still missing from these two countries.

As organic carbon (OC) or organic matter content are measured at many sites throughout Europe, new OC measurements would have to be made only at the 789 new monitoring sites that would need to be implemented to reach the minimum site density. On the other hand, 1264 new measurements of the salt profile content would be needed, 84% of them being located in Spain and Italy.

Table 10. Additional monitoring sites needed in the arid or semi-arid area, based on the “soil desertification” indicators

Country	Monitoring sites	Organic carbon or organic matter content	Salt profile content
Austria	0	0	2
Bulgaria	2	2	16
Czech Republic	0	0	3
France	1	1	4
Greece	34	34	35
Hungary	0	0	0
Italy	163	163	186
Portugal	9	9	66
Romania	14	14	23
Slovakia	0	0	9
Spain	566	566	919
TOTAL	**789**	**789**	**1264**

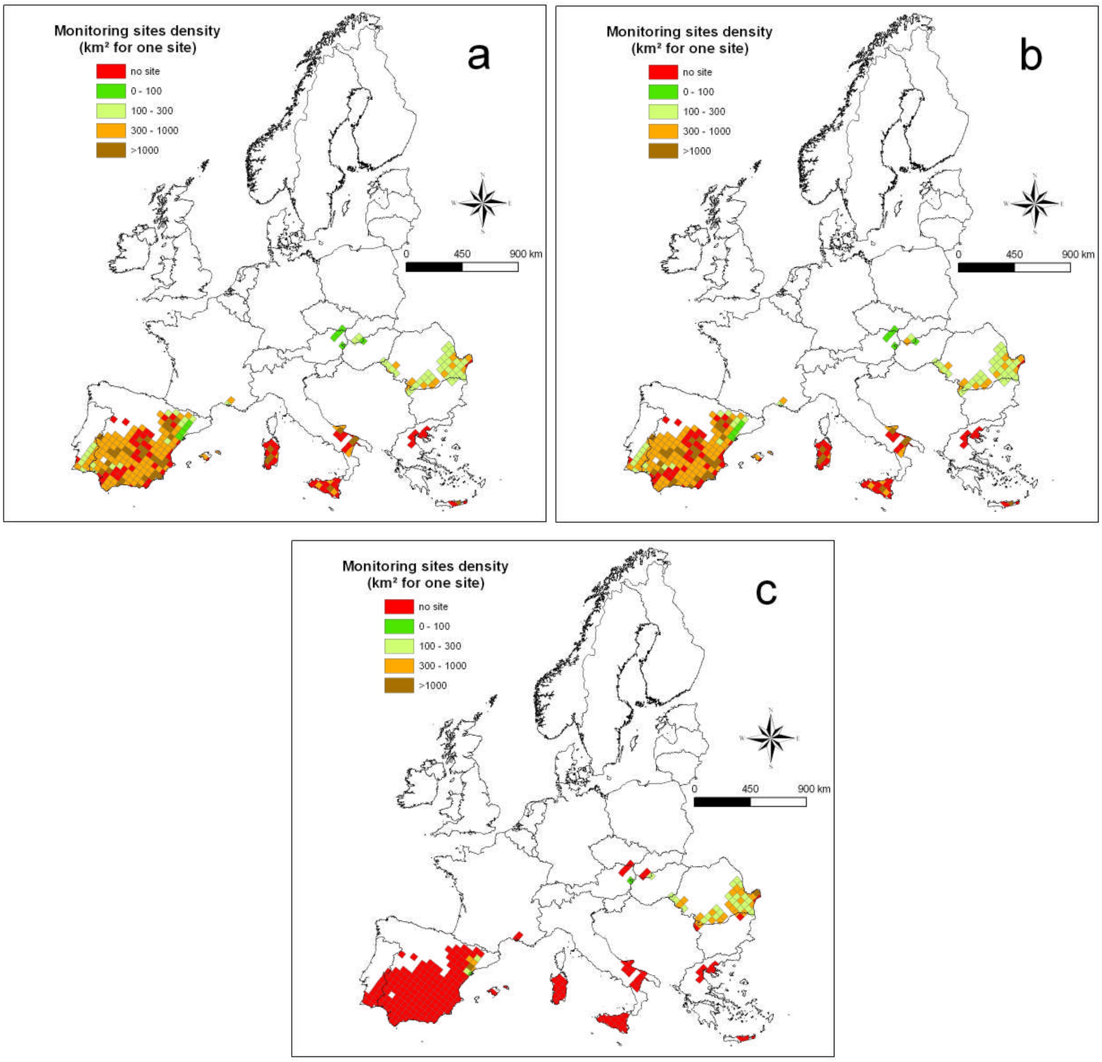


Figure 48. Density of monitoring sites in the arid or semi-arid areas (a), and (b) where organic matter or organic carbon content are measured (c) where salt profiles are measured.

3.6.7 Representativity for livestock

The livestock may be considered as a pressure indicator for soils. Indeed, it may act as a pressure through application of slurry for instance.

Densities of pigs and cattle in Europe were aggregated separately on the 50 x 50 km grid (Figure 49). On the basis of the maps and of the frequency distribution of cattle and pig populations in Europe (Figure 50), we fixed a level of high livestock density of 70 pigs km^{-2}, and 55 cattle km^{-2}. We selected the EMEP cells having a livestock density greater than these thresholds. The relevant indicators we chose were topsoil organic carbon or organic matter content, organic carbon stocks, total Cu and Zn content, and P content.

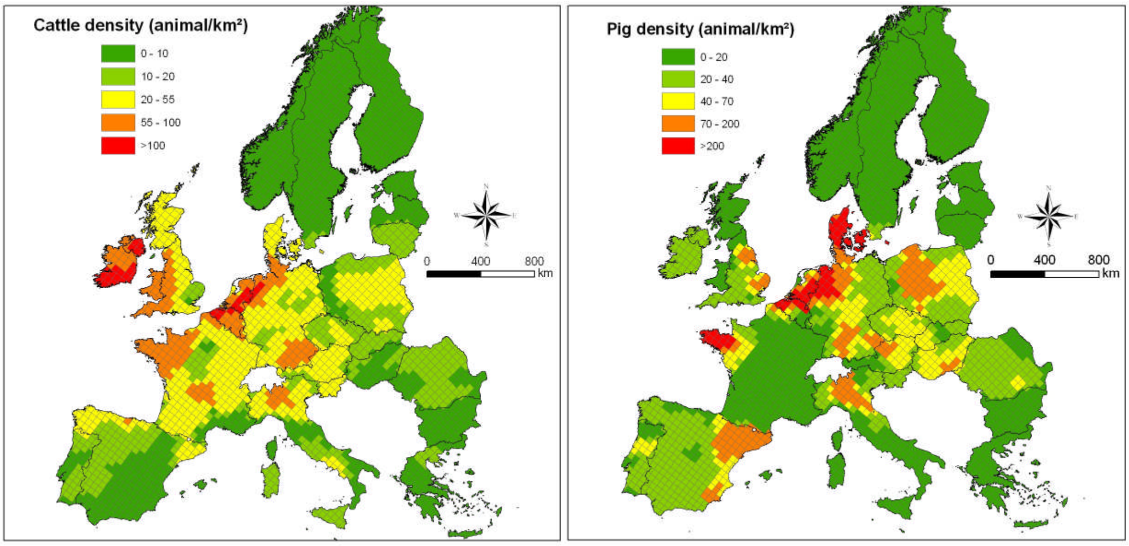


Figure 49. Cattle and pig populations in Europe, aggregated on a 50km x 50km grid (expressed in number of animals per km²)

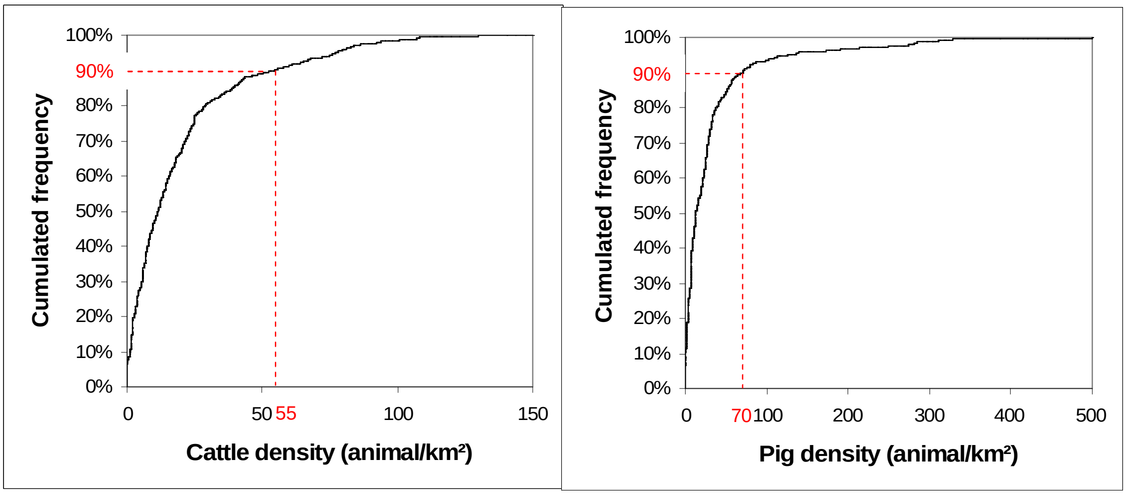


Figure 50. Cumulated frequency of the cattle and pig densities in the EMEP cells

Areas with high livestock density are quite well covered by SMN sites, except for the western and the central parts of France, the north of Italy, small regions of Spain and parts of Germany (Figure 51) for cattle, and except for Brittany in France, and regions of Poland, Spain and Germany for pigs (Figure 52). The situation is expected to change in France within the next two years as the SMN implementation is ongoing in the regions concerned. We know that some data are missing in Italy.

In order to reach the density of one site for 300 km², 184 and 398 monitoring sites would have to be implemented to monitor the areas with high livestock density of cattle and pig respectively (Table 11, Table 12). Most of those sites are located in France, Germany and Italy for cattle, and in Poland and France for pigs (Figure 51, Figure 52).

Table 11 gives the number of sites which would have to be added, depending on indicators.

Table 11. Monitoring sites to add per country in the area with high cattle density based on the decline of soil organic matter and soil contamination indicators

Country	Monitoring sites	Organic carbon or organic matter content	Organic carbon stocks	Copper content	Zinc content	Phosphorus content
Austria	0	0	4	0	0	0
Belgium	1	1	85	1	1	33
Denmark	0	0	2	2	2	2
England & Wales	0	0	235	0	0	0
France	61	61	61	61	61	116
Germany	63	68	145	68	68	92
Ireland	0	0	224	0	0	224
Italy	52	52	82	52	52	82
Luxemburg	2	2	6	2	2	6
Netherlands	1	1	99	1	1	1
Northern Ireland	0	0	47	0	0	0
Spain	4	4	4	4	4	8
TOTAL	**184**	**189**	**994**	**191**	**191**	**563**

Table 12. Additional Monitoring sites needed in the area with high pig density based on the decline of soil organic matter and soil contamination indicators

Country	Monitoring sites	Organic carbon or organic matter content	Organic carbon stocks	Copper content	Zinc content	Phosphorus content
Austria	0	0	37	0	0	0
Belgium	1	1	39	1	1	33
Denmark	0	0	94	94	94	94
England & Wales	0	0	74	0	0	0
France	29	29	29	29	29	44
Germany	86	91	187	87	87	118
Hungary	0	0	0	0	0	0
Italy	91	91	136	91	91	136
Netherlands	1	1	88	1	1	1
Poland	72	72	291	72	72	235
Spain	118	118	158	120	120	299
TOTAL	**398**	**404**	**1134**	**496**	**496**	**960**

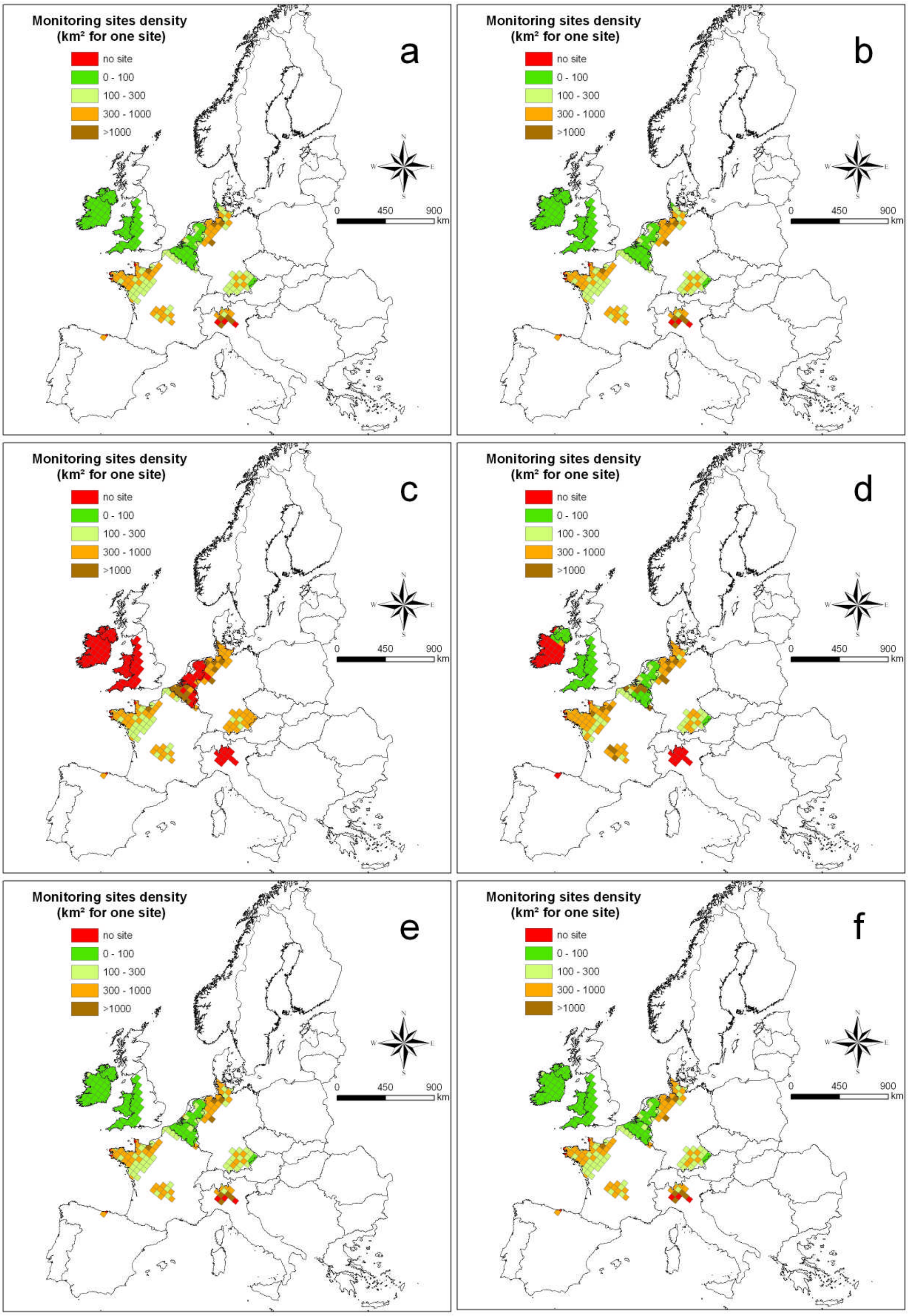


Figure 51. Density of monitoring sites in the area with high cattle density (a), and (b) where organic matter or organic carbon content is measured, (c) where organic carbon stock calculation is possible, (d) where P, (e) Zn, and (f) Cu content are measured

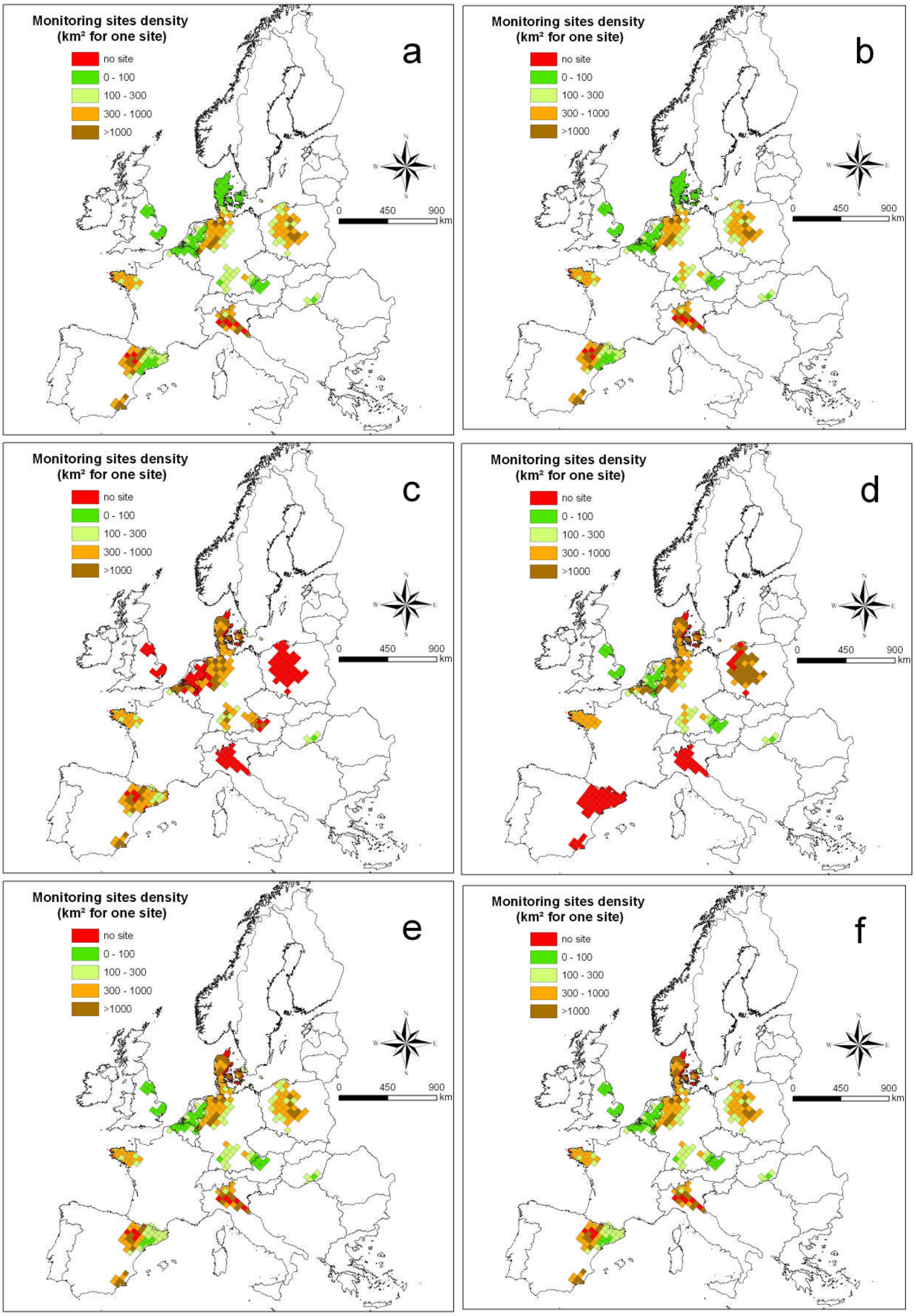


Figure 52. Density of monitoring sites in the area with high pig density (a),
And (b) where organic matter or organic carbon content is measured, (c) where organic carbon stock calculation is possible, where (d) P (d), (e) Zn, and (f) Cu content are measured

3.6.8 Representativity and geographical coverage for EMEP Heavy Metals data

We assessed the representativity and geographical coverage for EMEP Heavy Metals (HM) data in two ways.

Firstly, we overlaid the EMEP grid map with the coordinates of the SMN sites. We assigned to each monitoring site a theoretical deposition value corresponding to the HM data predicted for its location by the EMEP data. Then, we compared the cumulated frequencies of theoretical EMEP data calculated on the whole EMEP grid map of Europe and on a subset corresponding to the soil monitoring sites, or to soil monitoring sites measuring a given indicator.

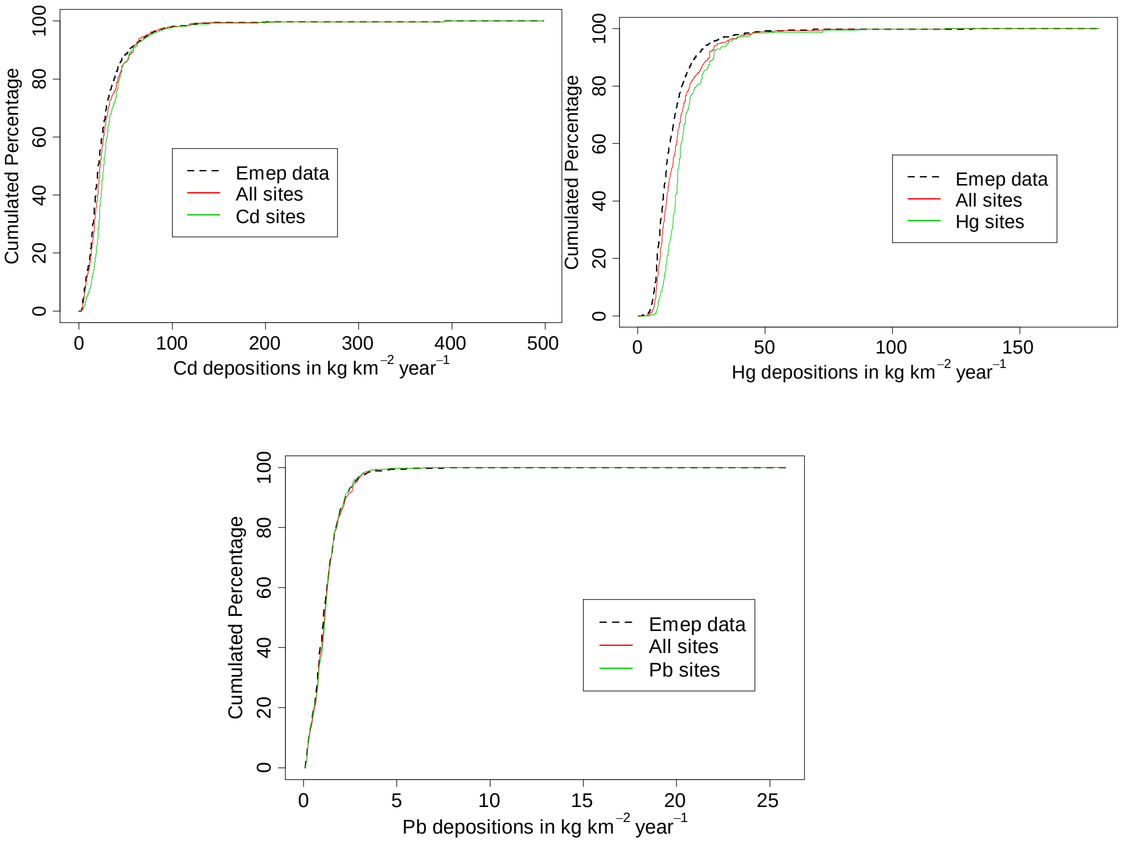
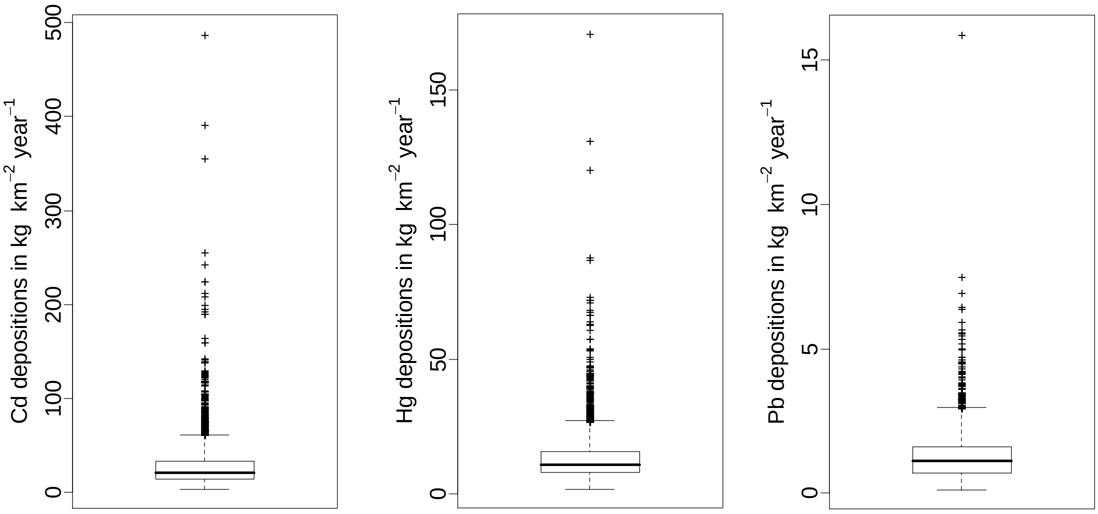


Figure 53. Comparison of the cumulated distributions of theoretical HM EMEP data calculated on the whole EMEP grid (in black) or on a subset corresponding to all the monitoring sites (in red) or on a subset corresponding to the monitoring sites where HM indicators

A Kolmogorov–Smirnov test was computed and indicated that the distributions were not significantly different for Cd and Pb. Figure 53 complete and confirm these results. From this result, we can conclude that the coverage of monitoring sites, and of the monitoring sites where Pb and Cd are measured, are representative of the statistical distribution of EMEP heavy metals deposition rates. This is not the case for Hg for which we have shown that the distribution of sites is very heterogeneous (see Fig. 18).

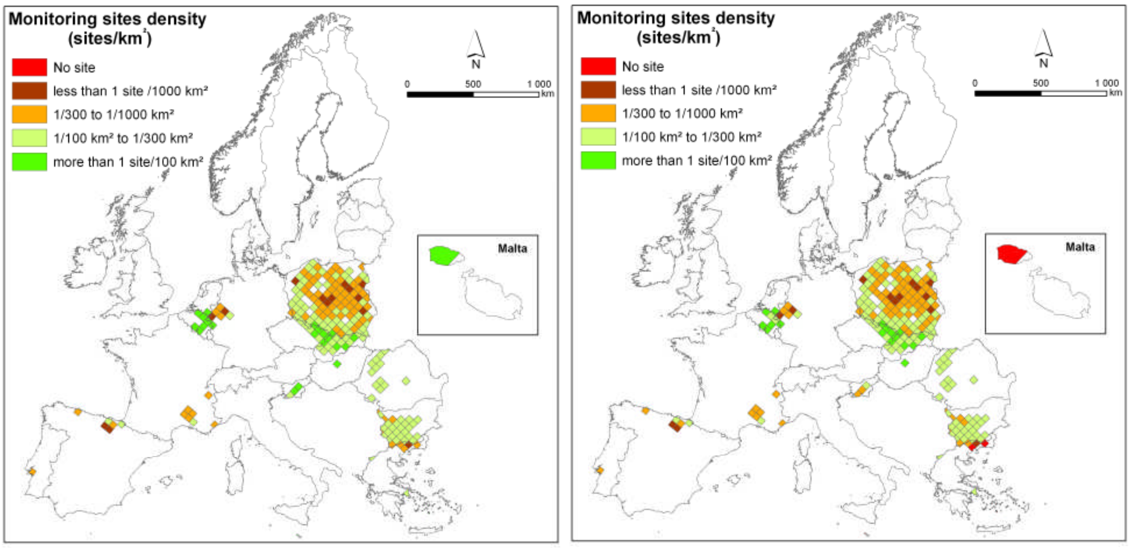
Secondly, we mapped the density of sites in EMEP 50km x 50km cells having high values of HM deposition data. To determine these ‘outlier’ cells, we used exploratory data analysis (Tukey, 1977). This method allows, without any assumption on the data, to calculate a threshold value to determine outliers. This threshold value corresponds to the upper whisker of the boxplot. A boxplot (also known as a box-and-whisker diagram) is a convenient way of graphically depicting the five-number summary, which consists of the smallest observation, lower quartile (Q1), median, upper quartile (Q3), and largest observation; in addition, the boxplot indicates which observations, if any, are considered unusual, or outliers. Thus, any data observation which lies over 1.5*(Q3-Q1) higher than the third quartile is considered as an outlier. The upper whisker indicates the largest value that is not an outlier.

Figure 54 shows that quite a large number of deposition values could be considered outliers. For Cd depositions, 229 cells are considered as outliers over a total of 2947, e.g. 7.77%. For Hg depositions, 166 cells are considered as outliers over a total of 2947, e.g. 5.63%. Finally, For Pb depositions, 100 cells are considered as outliers, e.g. 3.39%.



The threshold values for selection of outliers' cells are: 61.65 g km^{-2} year^{-1} for Cd, 27.17 g km^{-2} year^{-1} for Hg and 2.97 g km^{-2} year^{-1} for Pb

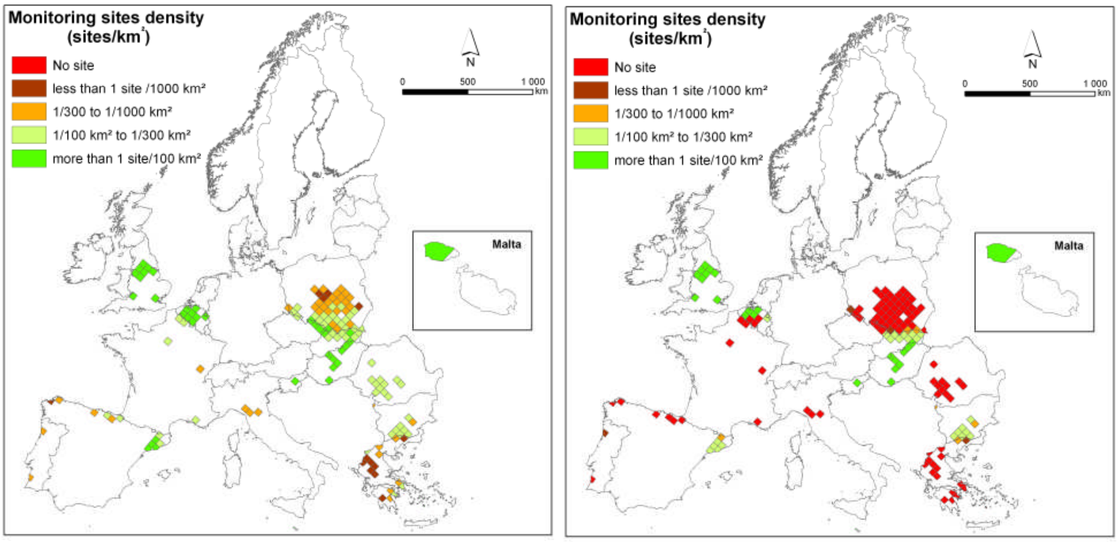
Figure 54. Boxplots of Cd, Hg and Pb depositions observed on the whole EMEP grid data of Europe.



a b

(a) all monitoring sites and (b) monitoring sites where soil Cd content is measured

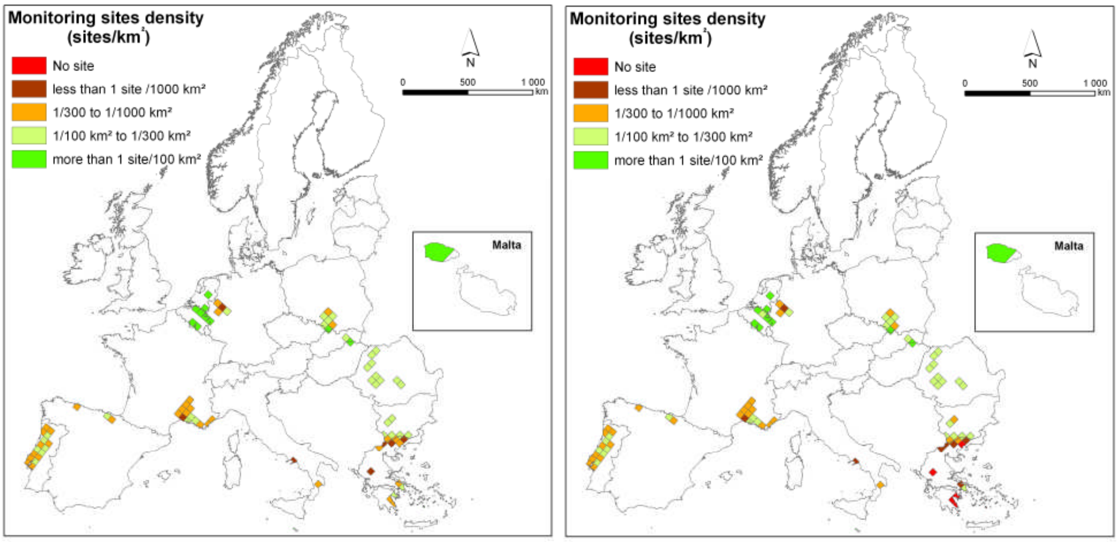
Figure 55. Density of monitoring sites, in area with high amount of Cd deposition predicted from EMEP



a b

(a) all monitoring sites and (b) monitoring sites where soil Hg content is measured

Figure 56. Density of monitoring sites, in areas with high amount of Hg deposition predicted from EMEP



a b

(a) all monitoring sites and (b) monitoring sites where Pb content is measured

Figure 57. Density of monitoring sites, in area with high amount of Pb deposition

For Cd, outlier deposition values are mainly located in eastern Europe: Poland and Slovakia, and parts of Romania and Bulgaria (Figure 55). Some high values are also observed in the Benelux and in the Ruhr regions. About half of these high deposition areas have monitoring site densities less than one site for 300 km^2. The situation is worse for Hg (Figure 56), for which the majority of high deposition areas have no site measuring this parameter. Pb deposition exhibits fewer outlier values, but nearly half of the high Pb deposition areas have less than 1 site for 300 km^2 (Figure 57).

3.7 Conclusion on SMN representativity

Official frameworks for comprehensive soil monitoring exist in most countries. However, uniformity in methodology and coverage, albeit existing in some countries, is far from common even among national systems. This review highlights the differences between existing networks. The present coverage is very heterogeneous amongst countries. National and regional networks are much denser in northern and eastern parts of Europe than in southern countries. Areas under desertification risks seem to be under-sampled in comparison to others.

The median site density of sites in 50 x 50 km cells applied all over Europe is about 1 site per 300 km². Such a density is close to the density of the ICP Forest grid. This density is, by definition, already reached for half of the European territory. However, the situation differs when considering various pressure indicators (Table 13) or the parameters measured.

Table 13. Monitoring sites to add per country based on different pressure indicators

Country	Total	Peat area	Compaction risk	High Population density	Desertification risk	High cattle density	High pig density
Austria	0	-	0	0	0	0	0
Belgium	0	-	1	0	-	1	1
Bulgaria	12	-	2	-	2	-	-
Czech Republic	0	-	1	-	0	-	-
Denmark	2	-	0	0	-	0	0
England & Wales	2	0	1	0	-	0	0
Estonia	21	2	8	-	-	-	-
Finland	209	81	203	0	-	-	-
France	452	-	124	30	1	61	29
Germany	205	0	51	61	-	63	86
Greece	330	-	16	9	34	-	-
Hungary	0	-	0	-	0	-	0
Ireland	0	0	0	0	-	0	-
Italy	656	-	115	213	163	52	91
Latvia	89	2	29	-	-	-	-
Lithuania	79	-	63	-	-	-	-
Luxemburg	0	-	-	0	-	2	-
Malta	0	-	-	-	-	-	-
Netherlands	2	0	0	2	-	1	1
Northern Ireland	0	-	0	0	-	0	-
Norway	417	4	313	-	-	-	-
Poland	247	3	97	-	-	-	72
Portugal	38	-	23	5	9	-	-
Romania	14	-	3	-	14	-	-
Scotland	4	0	0	-	-	-	-
Slovakia	0	-	0	-	0	-	-
Slovenia	0	-	-	-	-	-	-
Spain	914	-	109	67	566	4	118
Sweden	407	24	2	14	-	-	-
TOTAL	**4100**	**116**	**1161**	**401**	**789**	**184**	**398**

Note: country not concerned by the pressure indicator is indicated by -

Converted into a systematic grid, the median density of sites would be equivalent to a 17 x 17 km grid covering Europe. Whatever the selection criteria may be, we recommend that a minimum density of sites is achieved across Europe and we propose the present median density of 1 site per 300 km². Moreover, as shown previously (Van-Camp *et al*., 2004), this density would enable a SMN to cover almost all the soil type and land use combinations in Europe. If we take into account the existing sites, achieving at least this median density in all 50km x 50km cells would require 4,100 new sites, mainly located in southern countries (Italy, Spain, Greece), and part of Poland, Germany, the Baltic countries, Norway, Finland and France. This number might be a slight overestimate, considering that some metadata are missing for Italy, Spain and Sweden, and that some SMNs are currently being implemented (France). This illustrates the huge differences between countries, and the considerable effort which would be needed to reach a common acceptable level. As a 16x16 km grid already covers the forest soils, reaching at least this common median density would imply setting new sites only on non-forested soils.

Amongst the top three soil quality indicators identified in ENVASSO Volume I, the density of the indicator coverage is heterogeneous. Soil organic carbon and pH are the most often measured parameters, whereas some other parameters have a very limited coverage, even if we restrict this evaluation to risk areas concerned by the threat they cover. In particular, indicators related to soil biodiversity and to soil erosion are very rarely measured. The coverage for compaction indicators is very heterogeneous. Some trace elements are measured in almost all the countries (i.e. Pb), whereas others are not (i.e. Hg). Indicators for soil compaction, such as bulk density and packing density, are not measured in about half of the countries. A quite large number of peri-urban areas are not monitored for contaminants, especially in southern countries. Areas identified as having the highest heavy metal deposition rates appear not to be sampled with enough density, especially concerning Hg. Areas with high livestock pressures are unequally covered by related indicator measurements.

Approximately 90% of the soils and the land uses of Europe have at least one monitoring site. However, the density of sites and of the parameters measured is far from homogeneous. The density of sites in soil mapping units of Europe is highly variable. About 7% of the area covered by soil mapping units does not have any monitoring site. The highest density is for pastures, whereas arable lands and forests have less, but comparable, site densities. Permanent crops (e.g. vineyards, orchards) and open spaces with little or no vegetation are under-sampled in comparison to other land uses.

In view of this situation, it is clear that harmonisation and co-ordination are necessary. When SMNs are dense enough, this harmonisation could be done by adding the missing measurements of indicators in existing sites. In numerous case, it would also require new sites.

3.8 References

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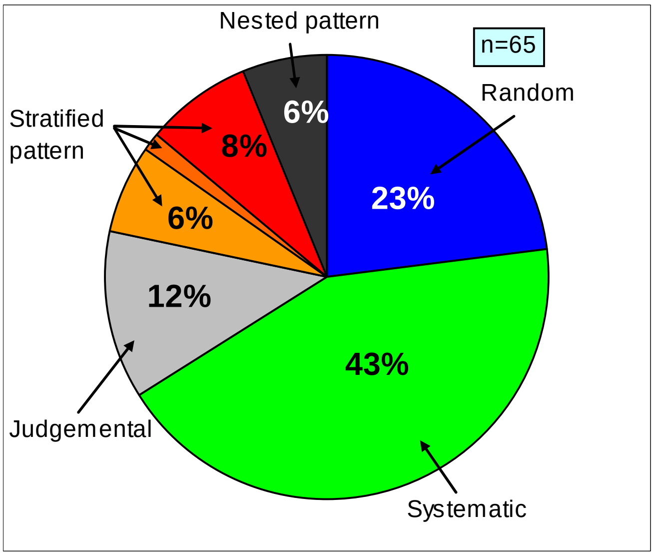
4 REVIEW OF SAMPLING AND TESTING PROTOCOLS

Collecting European harmonised information on changes in soil quality implies the adoption of a common methodology for sampling and testing. This task is difficult as most countries have long established national Soil Monitoring Networks (SMNs). Therefore, changing protocols will undoubtedly impede comparison with previous data. In this section, we summarise the main findings of the review of sampling and testing protocols used in current soil monitoring networks. We give recommendations on the adoption of common methodologies or on the way to make different methodologies comparable. One way forward would be to recommend a programme of cross-method validation allowing comparisons both within and between countries.

4.1 Site selection

The locations for the installation of SMN sites may be selected using different criteria: grid-based site selection, representativeness (of landform, of soil types, of land use, of specific site-related situations); specific land uses or specific unusual conditions; documentation and control of land use and practices; integration of sites into other currently established ecological observation areas.

About 40% of the SMNs use a grid-based site selection (Figure 58). This is the easiest way to ensure a wide and regular coverage of large areas. Most SMNs using this scheme often state that this enables the production of unbiased estimates of background values and/or changes. However, this statement is not entirely correct, as specific site-related changes might not be detected through this selection procedure. Indeed, some sites of specific interest and/or potentially subject to large changes (hot spots for biodiversity, peats, industrial contaminated sites...) might not be covered by a systematic grid.



(n corresponds to the number of SMNs for which the information was available on 30 October 2006)

Figure 58. Relative proportion of the site selection criteria of the soil monitoring networks.

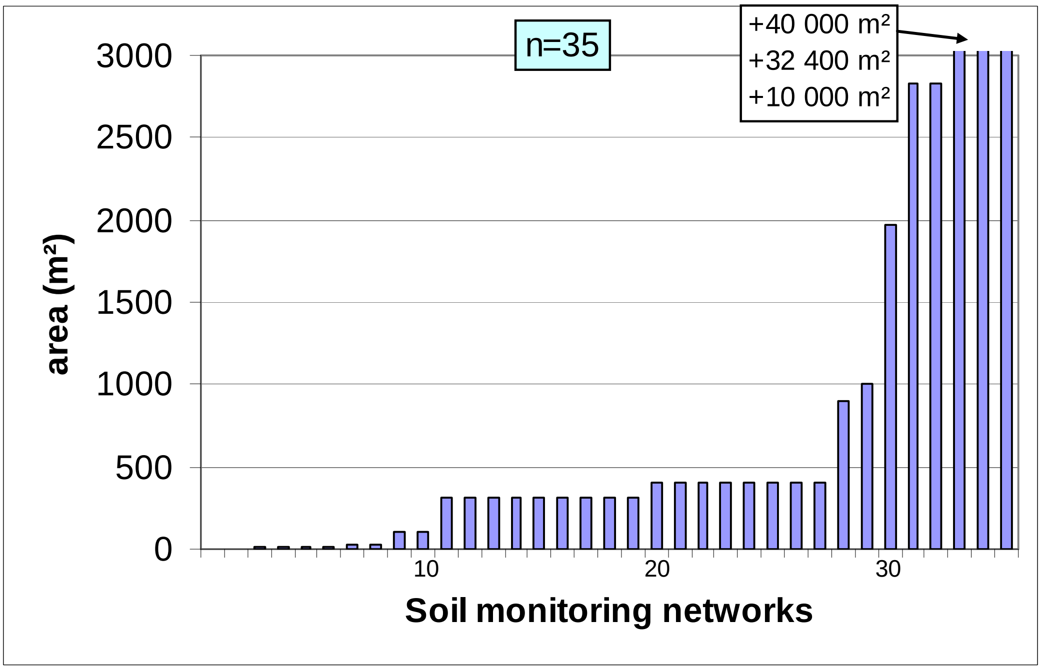
Other SMNs use random location (about 20%) or numerous other criteria for site selection. Representativeness is the first criterion which is cited (of landform, of soil types, of land use, of specific site-related situations). Specific land uses or unusual conditions are also used as criteria in some cases. Another important point that is sometimes cited, is to have complete documentation and control for land use and practices. This means that the areas chosen for monitoring should be available over the long-term and therefore protected in some way. A final criterion is the integration of sites into other currently established ecological observation areas. Judgemental strategies may enable account to be taken of specific site-related situations and may ensure all soil types and land-uses are covered. However, the judgemental strategies might not be relevant to monitor gradients of diffuse contamination if they are not dense enough.

4.1.1 Recommendation

We recommend that SMNs should be dense enough to capture most soil types, to capture all land-uses and to be able to detect diffuse gradients. SMNs could also be denser in parts of Europe where such gradients are suspected (for instance around urban and industrial areas). From the representativity study (see Section 1), we concluded that if we choose to have a minimal density of sites corresponding to its present median value (1 site for ca 300 km²) all over Europe, 4100 sites will have to be added to current networks (see Table 13 and Section 3.1). However, this number might be an overestimate, as we still lack information on some site locations.

4.2 Site area

As far as the soil is concerned, nearly all SMNs require a "homogeneous" area for sampling. The objective - even if it is not always clearly stated - is to have as little spatial variability as possible with regard to temporal variations which are to be monitored. If this is to be achieved, prior soil mapping must be carried out, and the area must usually be of small size. Noticeable exceptions are the watersheds monitored for erosion processes. Apart from these watersheds, all sites have areas ranging from 10 m^2 to a few ha and are homogeneous with regard to soil profile development.



(n corresponds to the number of SMNs for which the information was available on 30 October 2006).

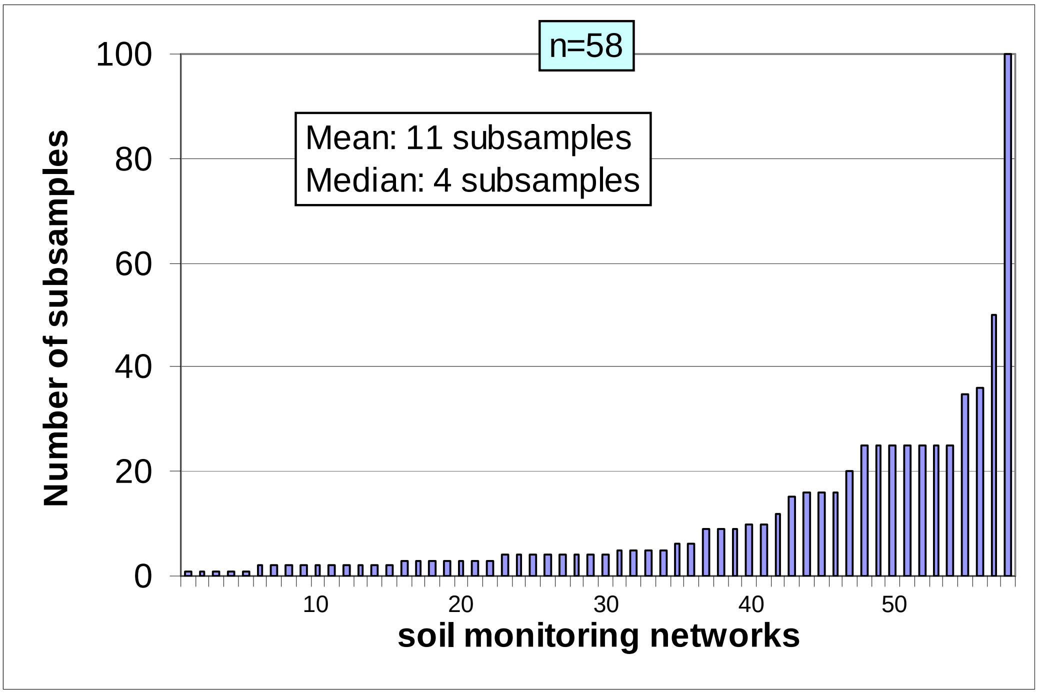
Figure 59. Sampling areas (sorted by increasing area) of the monitoring sites of SMNs.

4.2.1 Recommendation

We recommend adopting a site area >100 m², as repeated sampling over time in smaller site areas may induce changes linked to the effect of the sampling itself. On the contrary, as shown by the meta-analysis of in-site variability, adopting areas >1 ha would, generally, considerably increase the spatial variability and would require much more effort in sampling (see Section 5.1).

4.3 Subsamples

In most cases, sampling is based upon several subsamples (from 4 to 100) taken in the site area. The exact location of cores should be known in order to avoid these locations in a further re-sampling procedure.



(n corresponds to the number of SMNs for which the information was available on 30 October 2006)
Mean and median are to nearest whole number

Figure 60. Number of subsamples taken in the site area.

Most SMNs do not analyse each individual sample, instead they bulk them to make a composite sample. Often, the sampling design is based upon a systematic grid (most often square or rectangular, in some cases circular or hexagonal). The grid is used to locate samples at its nodes or to delineate cells in which clusters are sampled.

The question on what should be the general framework for a harmonised sampling design remains. The choice should be optimal with respect both to the objectives and to technical and financial considerations. But it should ideally also depend on the degree of homogeneity and on the spatial structure of soil attributes. However, the variability of soil properties is usually unknown and its estimation may often be one of the main objectives of a study. Moreover, if the spatial structure is to be studied, this may lead to a huge number of determinations for estimating the variograms at short lags. One would expect that the larger the sampled area, the larger the number of subsamples. Surprisingly, it is not so (Figure 61).

More details on the effects of the size of the site and of the number of subsamples on the accuracy of mean estimates are given in Section 5.1.

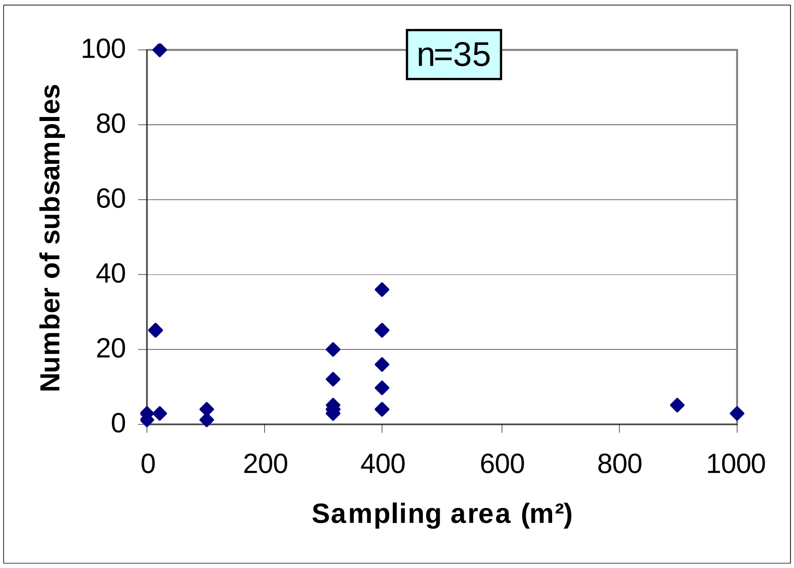


Figure 61. Number of subsamples vs sampling area

4.3.1 Recommendation

We recommend avoiding extreme situations (i.e. very dense sampling in a small area or very few subsamples in a large one). In any case, a unique sample should be avoided if the aim is to monitor changes on a given site. We recommend taking at least 4 subsamples, and preferably adapting the subsampling density by taking from 10 to 100 subsamples depending on the size of the site. It is recommended that the exact location of cores is known in order to avoid these locations in further re-sampling campaigns. Subsampling density could also be adapted to known spatial heterogeneity of soil type and/or pas land management and land use (if the data exists).

4.4 Time steps for re-sampling

A broad range of time intervals is found, depending on parameters and on networks [from several times a year (for indicators very sensitive to short-term changes) to every 20 years (for very stable properties such as texture or mineralogy for instance)].

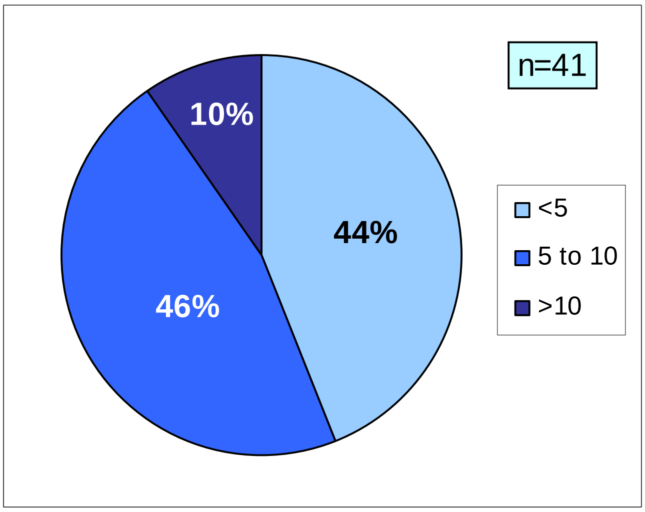


Figure 62. Time intervals used in SMNs (years)

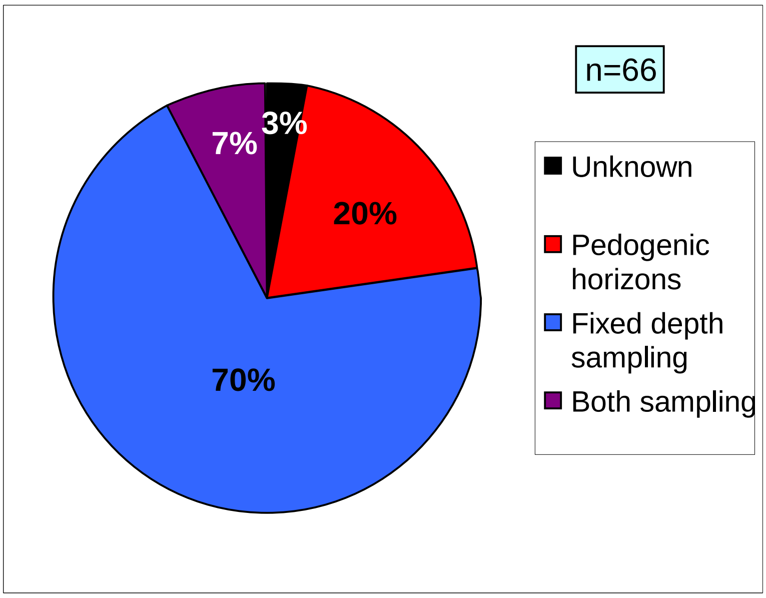
Time steps ranging from 1 to 10 years are used for most fairly stable properties of soils. Most SMNs use time steps 5 to 10 years (Figure 62). Some SMNs recommend adopting shorter time steps at the beginning of the monitoring, and then to adapt the re-sampling rates to observed changes. Obviously, certain very stable parameters (e.g. particle size distribution, if neither erosion nor deposition occur), would only need to be measured once. However, re-measuring them would enable one to verify that samples from different time steps are really comparable.

4.4.1 Recommendation

Recommending a maximum time step of 10 years would enable incorporating nearly all the SMNs. Moreover, the minimum detectable changes study (see section 5), shows that for some indicators a time step of 10 years is efficient, but that for a large number of indicators, shorter time steps would not reliably demonstrate changes.

4.5 Vertical sampling

Fixed depth increments are predominantly used for core sampling (Figure 63). This sampling method ensures standardisation between sites. It is also the most relevant for some anthropogenic characteristics (e.g. anthropogenic heavy metals, radionuclides, organo-chemicals), and for parameters showing a strong gradient near the soil surface which are often sampled with smaller increments near the surface.



(n corresponds to the number of SMN where the information is available)

Figure 63. Vertical sampling used in SMNs

Pedogenic horizons are often collected in soil pits, outside the monitoring area, but close to it. This method of sampling is relevant for some parameters (e.g. particle-size distribution, water retention properties, mineralogy). It is also the most relevant unit to link SMN observations to geographical soil information systems derived from soil mapping activities.

4.5.1 Recommendation

For nearly all the SMNs, the organic layers at the soil surface are sampled separately from the underlying organo-mineral soil.

For organo-mineral layers, we recommend adoption of systematic depths in order to :

- Avoid subjectivity in sampling
- Harmonise sampling protocols

- Facilitate comparisons between SMNs

The best practice would be to sample both by depth increments in the site and by pedogenic horizons in soil pits, outside the monitoring area, but close to it.

We examined, for each SMN, the depths to which indicators are measured or can be calculated, using the calculation rules detailed in Table 14.

Table 14. Derivation of depths to which indicators are measured or can be calculated

Depth of sampling used	Depth to which indicators are measured or can be measured
0-15 cm; 15-25 cm; 25-50 cm	15 cm, 25 cm, 50 cm
0-30 cm; 30-50 cm	30 cm, 50 cm
0-20 cm; 40-60 cm	20 cm
Pedogenic horizon	unknown

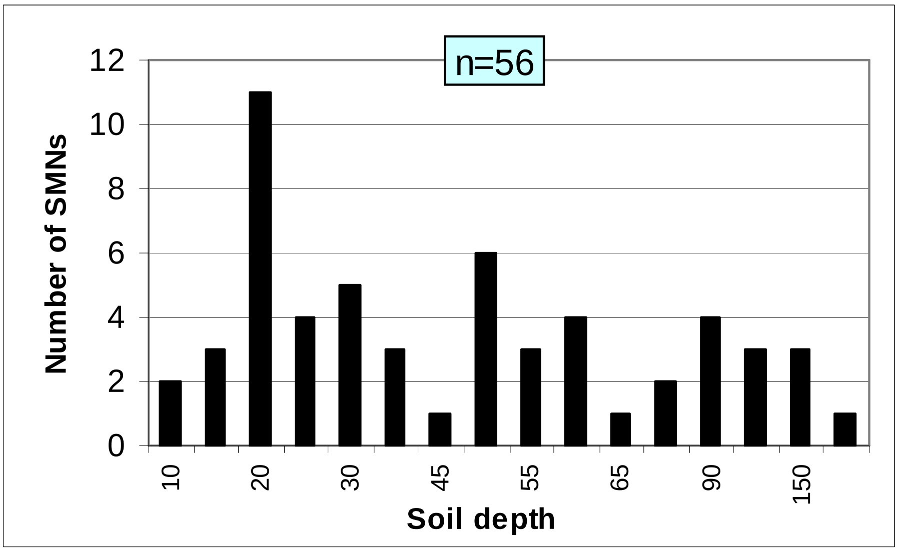


Figure 64. Depth (in cm) to which indicators are measured or can be calculated

The depths to which indicators are measured or can be calculated are highly variable amongst SMNs (Figure 64).

Another way to compare vertical sampling is to calculate for each SMN the maximum depth to which sampling is realised. The frequency of the maximal depths for sampling decreases with depth (Figure 65). About 90% of the SMNs provide information down to 20 cm, whereas nearly 65% of the SMNs reach at least 30 cm.

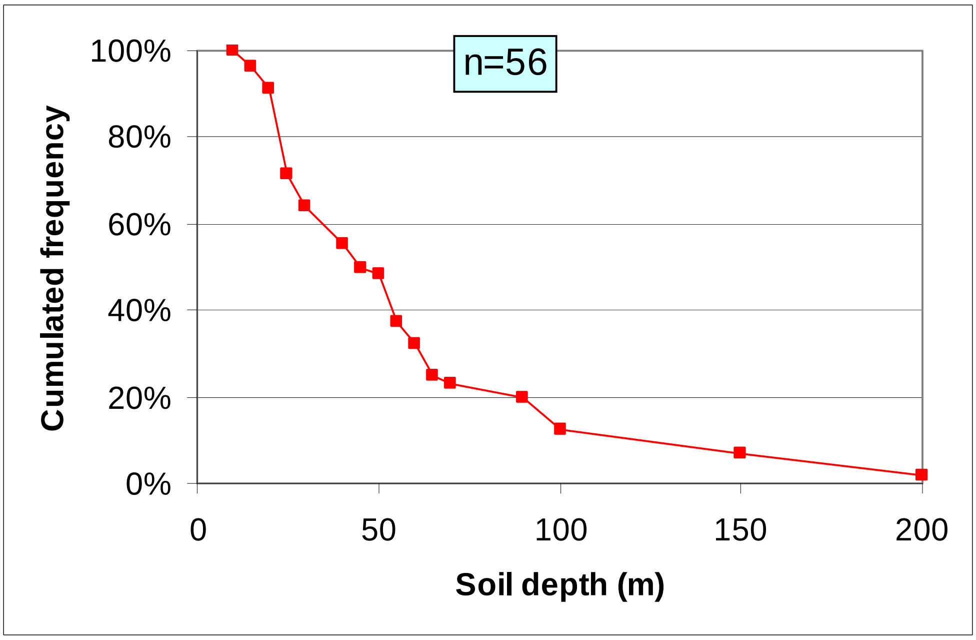


Figure 65. Frequency of maximal depths to which soils are sampled in SMNs

4.5.2 Recommendation

It is very difficult to make recommendations on the depths to adopt. Indeed, changing systematic depths for a national SMN might in some cases make it very difficult to use previous campaigns for the assessment of changes (for example, how would it be possible to compare indicators based on a 0 to 15 cm sampling with the same indicators based on a 0 to 30 cm re-sampling ?). One way to harmonise reporting at the EU level could be to report the results on the basis of a same equivalent mineral mass (Ellert & Bettany, 1995). However, this would require determination of bulk density at all sites and at each sampling date.

We recommend the sampling is done so that concentrations or stocks of elements can at least be calculated for depths ranging from 0-15 to 0-30 cm.

4.6 Sample weight and sample preparation

The minimum weight of each composite sample should be large enough for all analyses and for making possible repetitions or further reanalysis. This is essential in order to be able to re-analyse former samples when new methods or new analytical standards are available. We recommend that at least 10% of “old” samples are re-analysed in parallel with future campaigns. This has strong implications in terms of the total number of samples to be analysed and on related costs. Using the French soil monitoring network, we can simulate the implications of this re-measurement (Table 15).

Table 15. Number of samples to analyse when re-analysing 10% of the samples available from previous campaigns.

	Campaign 1	**Campaign 2**	**Campaign 3**	**Campaign 4**
Number of samples	2000	2000	2000	2000
10% of campaign 1		200	200	200
10% of campaign 2			200	200
10% of campaign 3				200
TOTAL	**2000**	**2200**	**2400**	**2600**

Example from topsoil samples of the French soil monitoring network

The ISO 11464 method recommends a sample size of at least 500 g. However, we recommend to sample and store larger quantities (from 3 to 10 kg) as we do not know which quantities future determinations will require.

Nearly 95% of the SMNs that analyse dried samples use temperatures ≤ 40°C to dry soils (Figure 66).

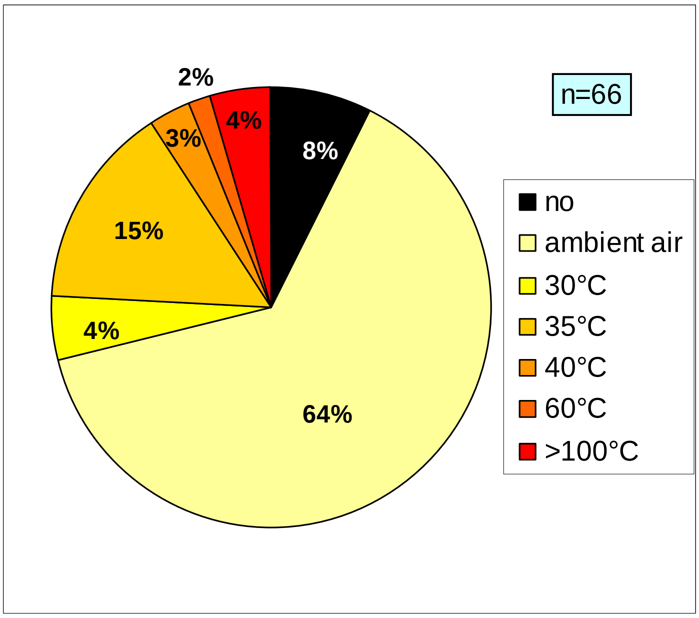


Figure 66. Temperature used for drying samples in SMNs

4.6.1 Recommendation

For drying, we recommend not to exceed 40°C as it has been shown that drying using higher temperatures considerably affects the speciation of trace elements, and may noticeably modify the soil pH (Martínez *et al.*, 2003), and other soil properties (i.e., water retention properties).

Most of the SMNs use sieving through a 2 mm mesh before analysis. Because 2 mm is recognized worldwide, we recommend use of this size limit to separate fine earth from coarse fragments. The particles >2 mm esd should be weighed separately for the determination of the coarse fragment content, and kept separately.

4.7 Analytical techniques

The question of which analytical techniques to recommend is complex. Most countries have long established SMNs, and use specific analysis methods. Changing these methods to a different set of methods would impede data comparison with previous results, unless parallel analyses, using both national and new reference methods, are performed.

There is generally a minimum set of mandatory parameters which are measured systematically (at least once) or monitored (with different frequencies). This minimal set differs amongst countries (see maps in section 1).

Annex II reports the information on soil analytical techniques that was gathered by ENVASSO partners. However, in many cases, the applied analytical procedures were not sufficiently detailed. The information provided was, in some cases very vague, even after several requests. Sometimes partners reported only the extractant used or only the equipment (see tables in ANNEX III). Nevertheless, for SMNs for which this information was available, the analytical methods showed numerous differences, indicating that the use of international standards (when existing) is far from common among the systems. Indeed, as numerous international standards for soil analysis are still lacking, standardisation will be one of the main issues in setting up a SMN at the European level.

Here, we report the analytical techniques used for the main indicators which are measured. We give some recommendations on the adoption of common methodologies or on the way to make them comparable.

4.7.1 Topsoil organic carbon content

Topsoil organic carbon content is measured using various methods which can be grouped in three broad categories.

- Wet oxidation in an acid dichromate solution, followed by various measurements such as titration of the remaining dichromate, or photometric determination, or collection and determination of the evolved CO_2.
- Dry oxidation of organic carbon at various temperatures, followed by collection and determination of the evolved CO_2.
- Loss on ignition at various temperatures (usually for OC> 15%, (Bellamy *et al.*, 2005)).

Some of these methods are known not to measure all the organic C present, but only its easily oxidisable part, by various methods of wet digestion such as Walkley-Black, Walkley Black modified, Anne, Tjurin methods, used by about half of the SMNs.

For dry combustion, when temperatures below 500°C are used in order to allow the determination of organic carbon in the presence of carbonates, some humic material may resist combustion.

The measurement of total organic C by dry combustion at high temperatures (>900°C) by an automated C analyser, is known to be better at recovering all organic C in soils. It is used by about half of the SMNs. Samples containing carbonates must be pre-treated with acid.

Loss on ignition is mainly used for C content measurement in organic layers.

Table 16 summarises the analytical methods used in each country.

Table 16 Analytical methods used in each country for organic carbon or organic matter determination

Country	Dosing method						
	Wet oxidation					**Dry oxidation**	**Loss on ignition**
	unspecified method	Walkley-Black	Walkley-Black modified	Anne	Tjurin method		
Austria	X					X	
Belgium		X				X	
Bulgaria	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*
England & Wales	X						
Estonia					X		
Finland						X	
France						X	
Germany	X					X	
Greece			X				
Hungary	X						
ICP France				X			
ICP						X	
Ireland						X	
Latvia						X	
Malta		X					
Northern Ireland						X	X
Poland					X		
Portugal						X	
Romania			X				
Scotland	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*
Slovakia						X	
Sweden	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*	*unknown*
The Netherlands						X	

4.7.1.1 Recommendation

The best international scientific agreement for organo-mineral layers is to measure the total organic C by dry combustion at high temperatures using an automated C analyser. We recommend this for future harmonised measurements at the EU level. However, combining techniques would be useful in order to be able to use previous campaigns to detect changes, and to establish pedotransfer functions linking the results obtained using one method to those obtained with another (e.g. Lowther *et al.*, 1990; Wang *et al.*, 1996; Jolivet *et al.*, 1998; Hegymegi *et al.*, 2007; Spiegel *et al.*, 2007).

4.7.2 Heavy metals

Determinations of total or pseudo-total content of heavy metals mainly differ with regard to the method of digestion. Nearly half of the SMNs use Aqua Regia, whereas others use digestion with various acids used alone or in combination (various mixtures of nitric, perchloric or hydrofluoric acids). There is no consensus on a method to recommend, even though Aqua Regia is the most widely used, although it is known not to extract the exact total content.

4.7.2.1 Recommendation

Using Aqua Regia would enable harmonisation with the unique existing pan-European soil monitoring network ICP Forest Survey.

For these elements, combining several techniques would be the best option in order to be able to use previous campaigns to detect changes, and to establish pedotransfer functions that link the results obtained using one method to those obtained with another.

Several SMNs use gentler extractions (DTPA, EDTA, ammonium acetate, $BaCl_2$) which might be useful to assess more mobile forms of these elements. Whatever the method, we recommend using ISO standards.

4.7.3 pH

Three main aqueous matrices are used for pH determination, distilled or demineralised water, KCl, and $CaCl_2$. pH in water is the most frequently used method. Some SMNs use two methods (Austria, Hungary, ICP, Northern Ireland, Scotland, Sweden, The Netherlands) and a few countries use three (Belgium, Germany, Latvia, Slovakia).

Table 17. pH measurements made for national SMNs

	pH KCl	pH water	pH $CaCl_2$
Austria		x	x
Belgium	x	x	x
England & Wales		x	
Estonia	x		
Finland		x	
France		x	
Germany	x	x	x
Greece		x	
Hungary	x	x	
ICP		x	x
Ireland		x	
Latvia	x	x	x
Lithuania	x		
Northern Ireland		x	x
Poland	x	x	
Portugal		x	
Romania		x	
Scotland		x	x
Slovakia	x	x	x
Sweden		x	x
The Netherlands	x	x	

Differences are also found regarding the soil-to-aqueous-matrix dilution factor. This last point was not very well documented in the answers we got (see for instance the percentage of unknown soil-to-liquid ratio for pH $CaCl_2$ in Table). However, it seems that, at least for pH water and pH KCl, the 1:5 dilution factor predominates. We recommend to use accepted international standards, such as 1:5 for pH water.

Table 18. Dilution factors for pH determinations

pH KCl		
dilution	n	%
1/5	10	**59**
1/2.5	4	24
unknown	3	18
pH water		
dilution	n	%
unknown	14	40
1/5	11	31
1/2.5	9	26
1/1	1	3
pH $CaCl_2$		
dilution	n	%
unknown	19	49
1/5	18	46
1/2	1	3
1/2.5	1	3

4.7.3.1 Recommendation

As pH is not an expensive measurement, and as the three methods provide complementary information we would recommend to use all three methods.

4.7.4 Bulk density, packing density and stocks of elements

Very few partners described the method for bulk density in detail. This might be due to the fact that the method used can vary significantly amongst sites of a given SMN, especially between soils having coarse fragments or not.

In some SMNs, bulk densities are estimated by using pedotransfer functions being based on statistical relationships between bulk density and other available data such as particle size fractions, coarse fragments and organic carbon. We do not recommend the use of such estimates for monitoring for the following reasons:

- For calculations of changes in stocks of elements, a systematic bias might occur (for instance for organic carbon stock calculations, in which organic carbon content would be used both for C content and for bulk density estimation).

- If bulk density is to be used as an indicator for changes in soil compaction, then it is useless to estimate it by a pedotransfer function, because this function cannot give an estimate of soil response to stress loading.

4.7.4.1 Recommendation

Because bulk density is highly variable over very short distances in soil we recommend that bulk density should be measured on large volumes (equal or > 500 cm^3) and with at least three replicates. Soils with a large content of coarse fragments should be sampled with the excavation method for bulk density determination, preferably near, but outside, the monitoring area, as this method is too destructive for long term monitoring.

4.7.5 Particle-size fractions

The proportion of particle-size fractions is essential information for soil monitoring. Numerous soil parameters are strongly linked to soil particle-size distribution and cannot be interpreted without knowledge of this characteristic. In particular, baseline or threshold values for some indicators are known to be related to soil texture (for instance organic carbon, bulk density, cation exchange capacity, some total elements).

Monitoring changes in proportions of particle-size fractions may be useful when changes are suspected to occur (i.e. area subjected to erosion or deposition of particles). In areas where no change in particle-size distribution is expected, its determination can be useful to ensure that samples taken at different times are really comparable.

Several classifications of particle-size fractions are used in SMNs. The most widely used upper limit for clay is 2 µm which corresponds to the limit used by two major textural classifications used in the world; the International and the USDA/FAO system. Five upper limits are observed for silt fractions, 20 µm, 50 µm, 53 µm, 60 µm, or 63 µm. Empirical regression models can be used to convert one fraction to another one (see for example, Minasny and McBratney, 2001). However, this would require large databases storing both determinations on the same samples, and the results of such conversions are likely to be linked to regional characteristics (i.e. results for the loamy belt of northern Europe would certainly be different from results for the calcareous areas of southern Italy).

Table 19 lists the upper limits of particle–size grades used in SMNs.

Table 29. Upper limits of particle-size grades used in SMNs (in µm)

Country	Clay	Silt	Sand
Austria	2	63	2000
Belgium	2	50 then 63	2000
Bulgaria	1	50	1000
Denmark	2	63	2000
England & Wales	2	63	2000
Estonia	2	50	2000
Finland	2	50	*Unknown*
France	2	50	2000
Germany	2	63	2000
Greece	2	50	2000
Hungary	*unknown*	*unknown*	*Unknown*
Italy	2	50	2000
Latvia	*unknown*	63	*Unknown*
Lithuania	1	50	1000
Malta	*unknown*	53	*Unknown*
Northern Ireland	2	60	2000
Norway	2	60	2000
Poland	*unknown*	*unknown*	*Unknown*
Portugal	2	20	2000
Romania	2	50	2000
Scotland	2	50	2000
Slovac Republic	1	50	2000
Spain	2	20	2000
Sweden	2	60	2000
The Netherlands	2	63	2000

4.7.5.1 Recommendation

Ideally, the best option would be to have a continuous cumulative curve of particle-size so that all classes can be used and all results can be compared.

4.7.6 Cation exchange capacity and exchangeable cations

The extractant used for exchangeable cations and for cation exchange capacity determination varies amongst SMNs. About 40% of the SMNs use barium chloride ($BaCl_2$), nearly 30% use ammonium acetate (CH_3COONH_4) at pH 7, the others being equally distributed among cobalt hexamine trichloride method, and various versions of the Mehlich method.

4.7.6.1 Recommendation

Methods which do not tend to change the pH of the soil (i.e. ammonium acetate at pH 7) should be used.

4.7.7 Phosphorus content

Various forms of phosphorus are measured in the SMNs (Table). They were classified into four main categories by the ENVASSO partners : total, extractable, available or soluble P content.

Table 20. Forms of phosphorus measured in SMNs

Country	Total P	Extractable P	Available P	Soluble P
Austria	x		X	
Belgium	x			
Bulgaria	x			
England & Wales	x		X	
Estonia			X	
Finland	x			
France	x			x
Germany	x			
Greece		x	X	
Hungary	x		X	
P	x			
Ireland		x		
Latvia	x			
Lithuania	x		X	
Northern Ireland	x		X	
Poland	x		X	
Romania			X	
Scotland	x			
Slovakia			X	
The Netherlands	x	x		x

Most SMNs use at least two methods, total P content being measured by nearly all of them.

4.7.7.1 Recommendation

We recommend measuring at least total P content as it is the relevant parameter for linking changes in soil P to P balance estimates at regional levels.

4.7.8 Inter-laboratory control

Most SMNs use inter-laboratory quality control. However, except for the on-going project “Forest Focus Biosoil”, there is no central laboratory acting as a reference for European soil analyses.

4.7.8.1 Recommendation

A central laboratory could help to improve harmonisation at the EU level.

4.7.9 Partial conclusion on analytical techniques

Except for some parameters for which a consensus exists, the question of the harmonisation of analytical techniques remains a very difficult issue. For several parameters, combining several techniques, on all samples or on a subset of samples, would be the best option in order to be able to use previous campaigns to detect changes, and to establish pedotransfer functions linking results obtained using different methods. As the main cost in soil monitoring is due to sampling in the field, adding new determinations would not greatly affect the total cost, for the basic variables discussed.

Another proposal is that a central laboratory could make all the determinations on a subset of samples and could work on establishing transfer functions between results of various methods.

4.8 Archiving

Long-term storage of samples is not the norm for national SMNs, although 62% of the SMNs study already store soil samples (Figure 67). This storage is vital in order to allow the use of new analytical techniques, which might appear in the future and in order to be able to re-analyse samples when a new problem arises (e.g., Cs-137 was not measured in soils before the Chernobyl accident in 1986). There is also a need to maintain QA between sampling campaigns so as to minimise the risk of drift in the data (e.g. due to changes in methodology, instrumentation, analytical sensitivity, etc.).

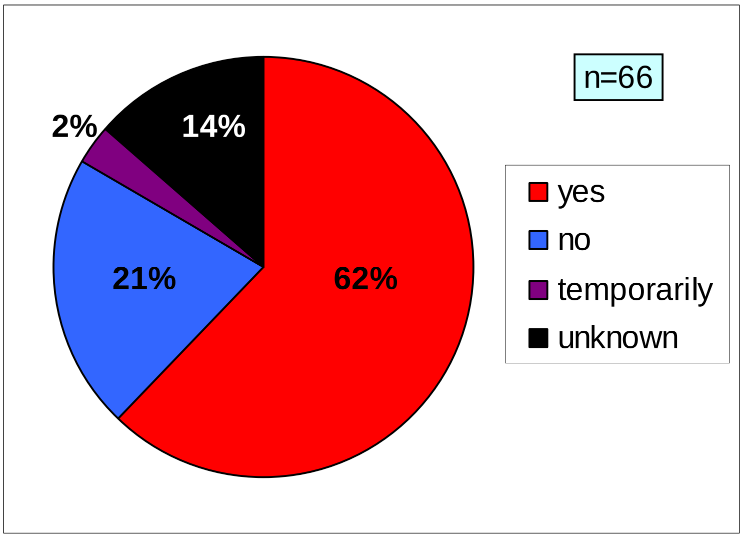


Figure 67. Archiving of samples in the SMNs

4.8.1 Recommendation

We recommend archiving samples in order to:

- Re-analyse samples of previous inventories to detect changes linked to analytical protocols
- Allow *a posteriori* analyses of new indicators
- Constitute a soil bank for research and inter-laboratory calibration

The sample material for storage should be kept in relatively large quantities (at least several kg), dried at 40°C, in closed containers free from potential pollutants, under normal room conditions, with minimal temperature and humidity fluctuations, and shielded from direct light.

We also recommend archiving the information related to samples, for example related data, history of samples, measurements made on samples, remaining stocks, etc.).

4.9 Conclusions

We reviewed sampling and testing protocols used in existing soil monitoring networks. Uniformity in methodology and coverage, albeit existing in some countries, is far from common even amongst national systems. This review highlights the large differences between existing networks.

The location of SMN sites may be selected on different criteria: grid-based site selection, representativeness (of landform, of soil types, of land use, of specific site-related situations); specific land uses or specific unusual conditions; to maintain documentation and control of land use and practices; integration of sites into other currently established ecological observation areas.

- A recommendation is that SMNs should be dense enough to capture all soil types and land-uses and to be able to detect diffuse gradients of change in soil properties. They could also be denser in parts of Europe where such gradients are suspected (for instance around urban and industrialised areas).

Apart from watersheds, most sites have areas ranging from 100 m^2 to a few ha and are selected to be homogeneous with regard to soil profile development. In most cases, sampling is based upon several subsamples (from 4 to 100) taken in this area.

- We recommend taking at least 4 subsamples and to adapt subsampling density by taking from 10 to 100 subsamples depending on the size of the site.
- It is recommended that the exact location of cores is known in order to avoid these locations in a further re-sampling procedure.
- Subsampling density could also be adapted to known spatial heterogeneity of soil type and/or pas land management and land use (if the data exists).

Fixed-depth increments are most often used for core sampling. This method of sampling ensures standardisation between sites. It is also the most relevant approach for assessing some anthropogenic characteristics (e.g. heavy metals, radionuclides, organo-chemicals), and for parameters with a strong gradient near the soil surface. It is very difficult to make recommendations on the depths to adopt. Indeed, changing of depth for a national SMN would in some cases make it difficult to use previous campaigns for the assessment of changes. One way to harmonise reporting at the EU level could be to report the results on the basis of an equivalent mineral mass. This would require considerable effort.

- We recommend that at least concentrations or stocks of elements could be calculated for depths ranging from 0-15 to 0-30 cm.

Although a broad range of time intervals is found between repeated samplings, depending on parameters and on networks, most SMNs use time steps of up to 10 years. Some SMNs recommend adopting shorter time steps at the beginning of monitoring and adapting the re-sampling to the rates of observed changes.

- Recommending a maximum time step of 10 years would enable incorporation of nearly all the SMNs into a common framework. For a large number of indicators, shorter time steps would not reliably demonstrate changes.

There is generally a minimum set of mandatory parameters which are measured systematically (at least once) or monitored (with different frequencies). This minimum set differs amongst countries (see Section 1). The use of international standards for analytical procedures (when existing) is far from common among the systems.

Except for some parameters for which a consensus exists, the question of the harmonisation of analytical techniques remains a very difficult issue.

- For some parameters, combining several techniques would be the best option in order to use previous campaigns to detect changes, and to establish pedotransfer functions linking the results obtained using one method to those obtained with another. As the main cost in soil monitoring is generated by sampling in the field, adding new determinations would not affect costs greatly.

Most SMNs use inter-laboratory quality control. However, except for the on-going project Forest Focus Biosoil, there is no central laboratory acting as a reference for European Soil analyses.

- A central laboratory could help to improve harmonisation at the EU level, by making determinations on a subset of samples, and working on pedotranfer functions to compare results of various methods.

Finally, we recommend archiving of samples in order to:

- Re-analyse samples of previous inventories to detect changes linked to analytical protocols
- Allow « *a posteriori* » analyses of new indicators
- Constitute a soil bank for research and inter-laboratory calibration

4.10 References

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5 MINIMUM DETECTABLE CHANGE

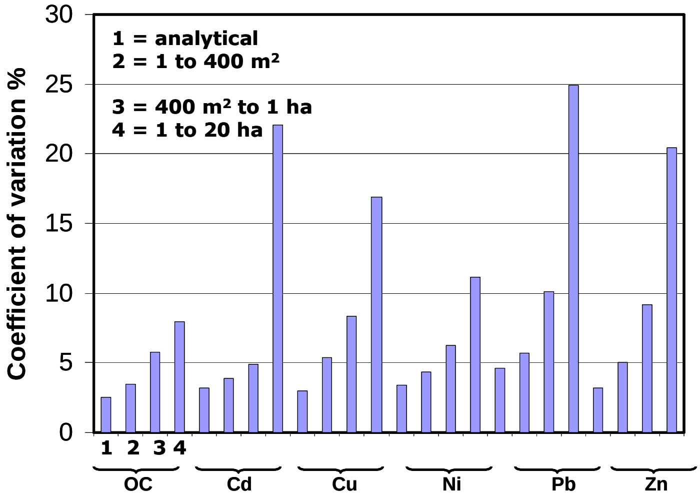
When planning sampling in a site where a soil indicator is expected to change, it is necessary to know how many samples will need to be taken to demonstrate a given change and after how long this change will be detectable. At the site level, numerous studies have adressed these issues (see for example, Hungate, *et al*., 1996; Zar, 1996; Garten and Wullscheleger, 1999; Conen, *et al*., 2003; Conen, *et al*., 2004; Saby and Arrouays, 2004; Smith, 2004). At a landscape or country level, or at the EU level, it is also necessary to assess what would be the effect of the number of sites and of inherent soil spatial variability on the detection of a global change in soil indicators (see for example Saby and Arrouays, 2004; Bellamy, *et al*., 2005).

In this section we make a synthesis of the within-site variability review. Then we assess the consequences of within-site variability and of broad scale national variability of soil parameters on the minimum changes that could be detected by existing monitoring schemes. We make a first attempt to calculate and map these minimum detectable level of changes (MDC), in section 5.3. We also examine the consequences of the time steps required to detect a given change and the effect of the number of sites on these MDC and time steps. To produce these estimates, we needed estimates of national variability and of projected changes. This information was only available for organic carbon, pH and some trace elements.

5.1 Review of within-site variability

The methodology to review within-site variability is described in section 2 of this report. One hundred and twenty references were collected, providing information of short-range variability of soil indicators, for sites having areas ranging from 1 m² to 20 ha. The data were used to derive quantitative estimates of the mean values of variances, standard deviations and coefficients of variation for all available parameters. We examined the possible relationships between within-site variability and site area and/or mean values.

We found a strong relationship between within-site variability of some parameters and site area. Other parameters did not exhibit such area-related variance.



(OC: organic carbon, and total contents of Cd, Cu, Zn, Ni, Pb, Zn)

Figure 68. Median coefficients of variations for 6 topsoil indicators.)

Figure 68 shows the relationship between the coefficients of variation of soil parameters and the area of sites, grouped by classes of area. The analytical value (1) corresponds to the coefficient of variation obtained when re-analysing the same sample several times.

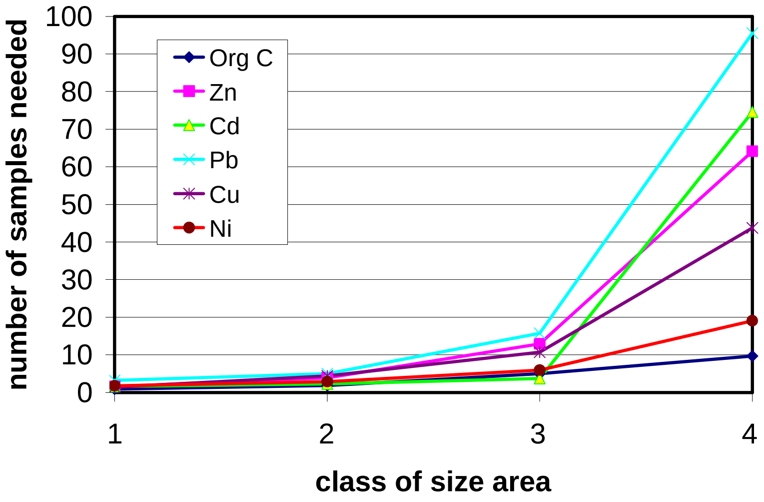
We observed a clear link between variability and the area of the sites for these six parameters. A marked relative increase is observed for sites having areas > 1 ha. This is particularly the case for some heavy metals which are known to exhibit large spatial variations over quite short distances (Pb, Cd, Zn, Cu).

Indeed, if we assume that within a given site-area class, measurements are spatially independent and normally distributed (which is obviously false in the present case) the number of samples, the coefficient of variation and the accuracy of a mean value are linked as follows :

$$n = t^2 \, CV^2/ER^2$$

where n is the number of samples, CV the coefficient of variation, ER the accuracy, and t the Student "t" value for the desired probability or confidence level (Snedecor and Cochran, 1967).

Figure 69 shows the number of samples needed to estimate a mean value (with a relative error of 5% and with 95% confidence) of the parameters studied above as related to the area of sites.



1: analytical; 2: 1 to 400 m^2; 3: 400 m^2 to 1 ha; 4: 1 ha to 20 ha

Figure 69. Number of samples needed to estimate a mean value with a relative error of 5%, depending on classes of size area.

For some highly variable parameters such as Pb, the number of samples to be taken becomes prohibitive when the sites exceed 1ha. Moreover, note that in numerous cases a relative error of 5% is not accurate enough with regard to the changes that we want to detect (see, requirements for indicators in WP1 report). For lead, the same calculations for a relative error of 2.5% would result in number of samples of 13, 20, 63 and 380 for the classes 1, 2, 3 and 4 respectively.

In view of the increase in variability with site area and the sample number calculations above, we recommend adoption of site areas not exceeding 1ha if we want to keep the number of sub-samples practically feasible.

5.2 Minimum detectable changes for a set of countries and indicators

5.2.1 National variability of indicators

ENVASSO partners were asked to provide summary statistics on the soil parameters measured in their SMNs, when available. We collected 13 tables giving national mean values and variances for soil parameters for the following countries: Austria, Bulgaria, Czech Republic, England & Wales, Greece, France, Ireland, Northern Ireland, Poland, Portugal, Scotland, Slovakia, The Netherlands.

Figure 70 and Figure 71 summarise the mean values of the coefficients of variation (CV) which were calculated at national levels for different land uses and for different indicators. For forest soils, the coefficients of variation were rather large, most of them ranging from 75 to 120%, except for pH. The largest CVs were observed for the metals Cd, Pb and Cu.

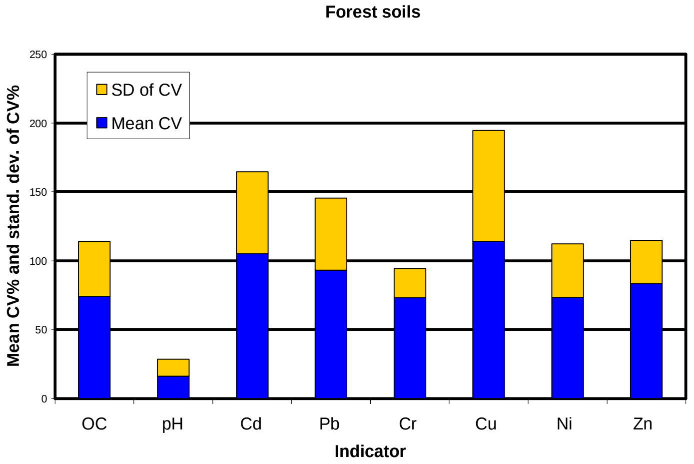


Figure 70. Mean national coefficients of variation (blue bar) and their standard deviation (yellow part only) for forest soils

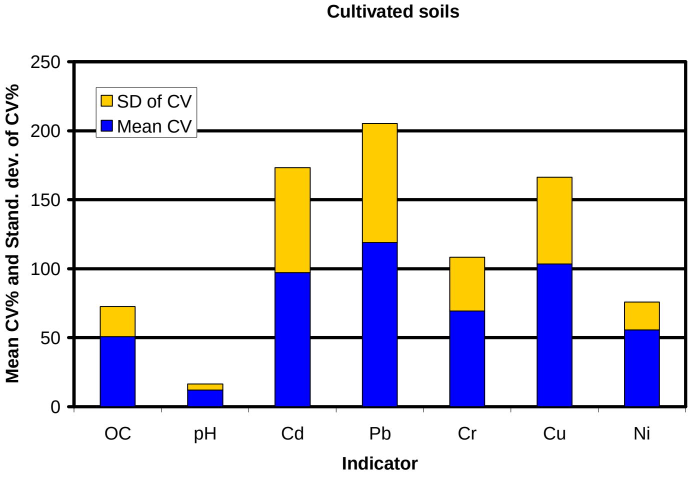


Figure 71. Mean national coefficients of variation (blue bar) and their standard deviation (yellow part only) for cultivated soils

For the cultivated soils, most of the coefficients of variation are similar to those observed under forest. However, they are less than those observed under forest for organic carbon and pH. This can be explained by the smaller values of organic carbon under cultivation, and by the effect of liming on agricultural soils, which tends to reduce in field variation of pH values for cultivated soils.

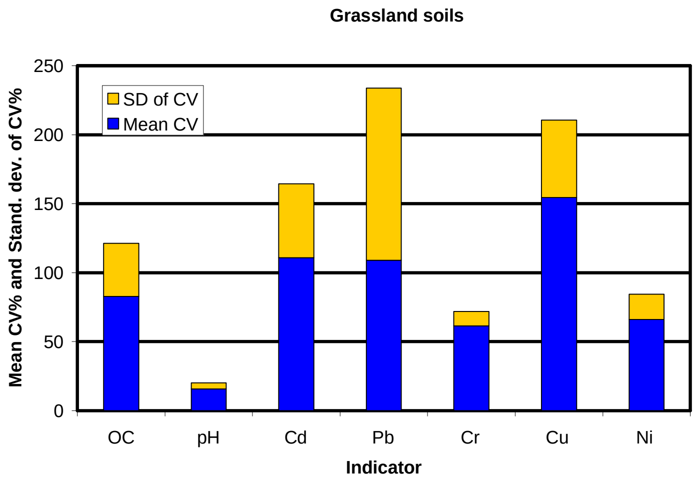


Figure 72. Mean national coefficients of variation (blue bar) and their standard deviation (yellow part only) for grassland soils

Values for grassland soils were also comparable to values for other land-uses, except for Cu which seems to have a higher coefficient of variation. This might be due to variable Cu inputs to soils by animals (Figure 72).

Some quite small countries exhibited large variability for some indicators : for instance small countries having mountainous areas showed very strong gradients in soil organic carbon.

5.2.2 Calculation of a national variance for indicators

As we did not get statistics for all the countries, it was necessary to get an estimate of national variances for indicators in order to calculate the minimum detectable level of changes. As explained in section 2, we chose to focus on pH, topsoil organic carbon content and on total Pb, Cu, Zn and Cd contents and we proceeded in two ways.

For organic carbon we estimated a national variance using national variances of values of organic carbon content predicted by the European map of Jones *et al*. (2005). Results show a marked effect of climate (Figure 73). The northern countries have very large standard deviations, which can be related to the existence of extreme values (peat soils). On the contrary, Mediterranean countries, which are generally characterised by smaller and more uniform values, show the smallest standard deviations.

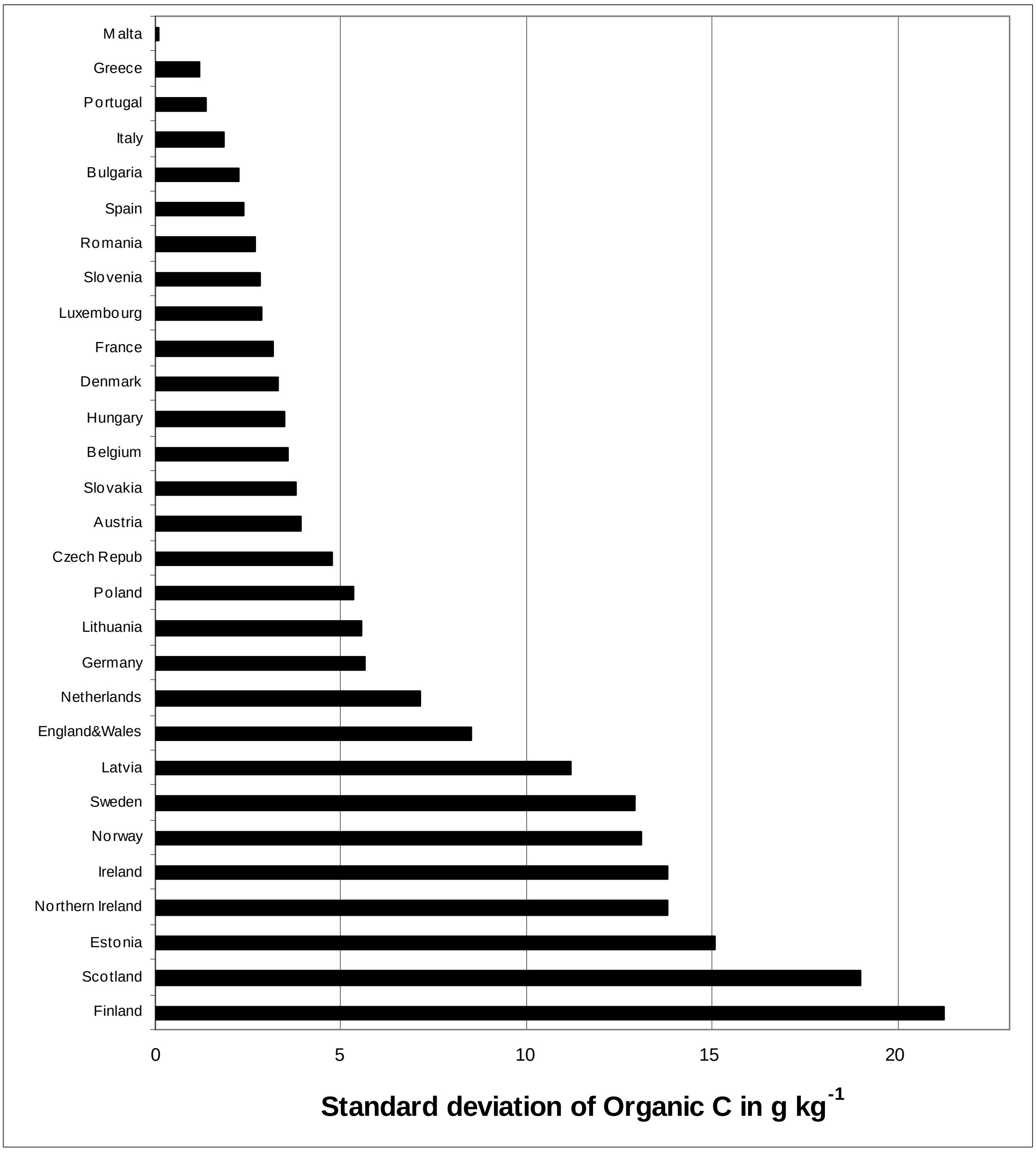


Figure 73. Calculated Standard deviation of Organic C content, using the organic carbon map from Jones et al. (2005) for the ENVASSO Countries

For the other parameters, using real data from the French soil monitoring network, we established a relationship between the area covered by a soil monitoring network and the variance of the parameter. All the standard deviations of the parameters increase with increasing area, following a logarithmic pattern (Figure 74). Note that even very small areas show large variances, reaching at least more than half of the variances calculated on 300,000 km^2. This illustrates the fact that all these parameters are very variable, even over small areas.

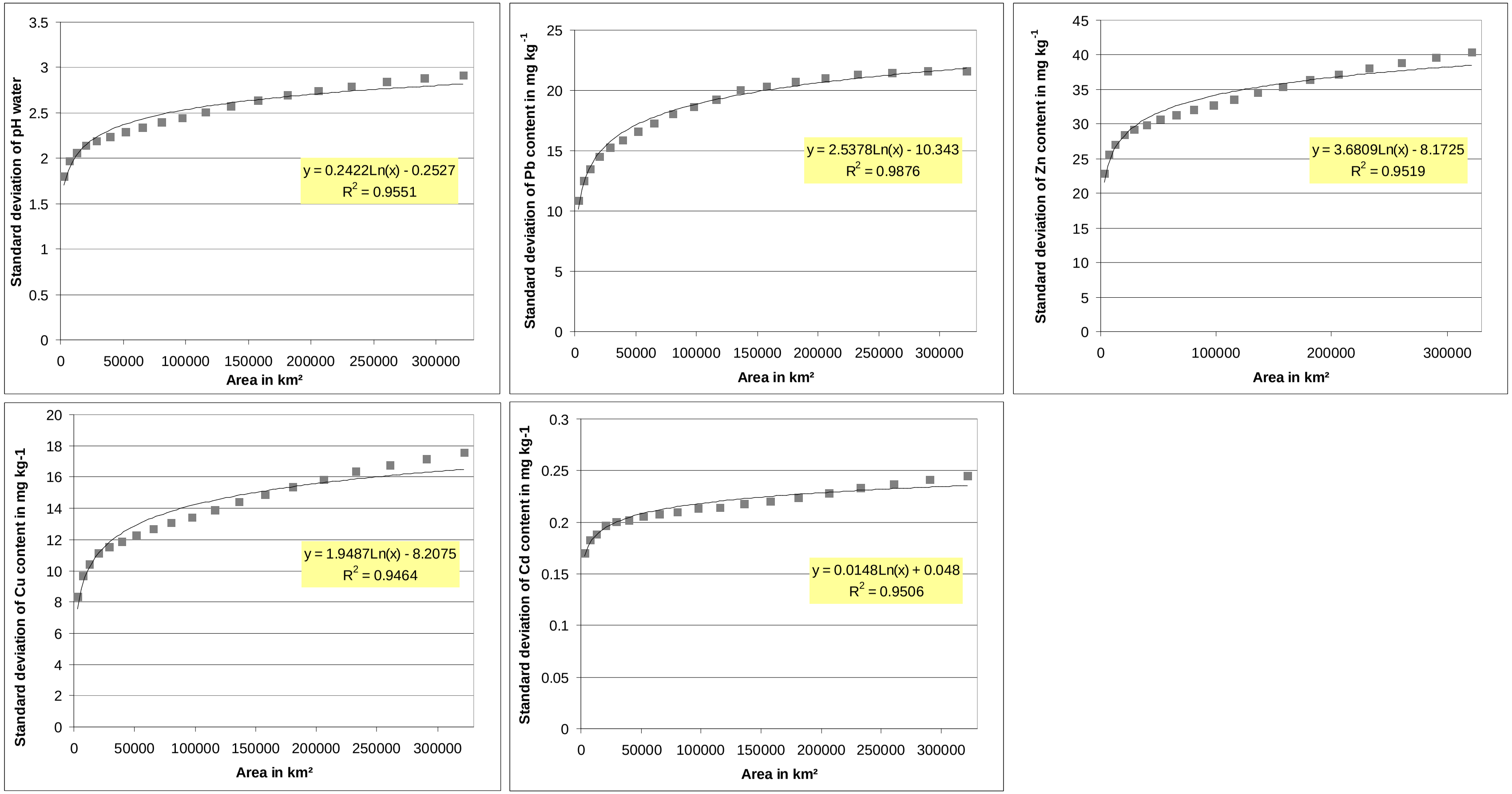


Figure 74. Standard deviation of parameters vs area.
The grey squares represent the observed standard deviation for the French soil monitoring network and the black line represents the fitted values by the equation which is given in the respective plot

We used these relationships to generate theoretical variances in EU countries. These variances may be underestimated for large countries: indeed the data we used to estimate them do not contain information on areas larger than the present coverage of the French SMN which is about 400,000 km², they might also be underestimated for SMNs in which highly contaminated sites might be included. Figure 75 shows the example of the standard deviation of Pb content.

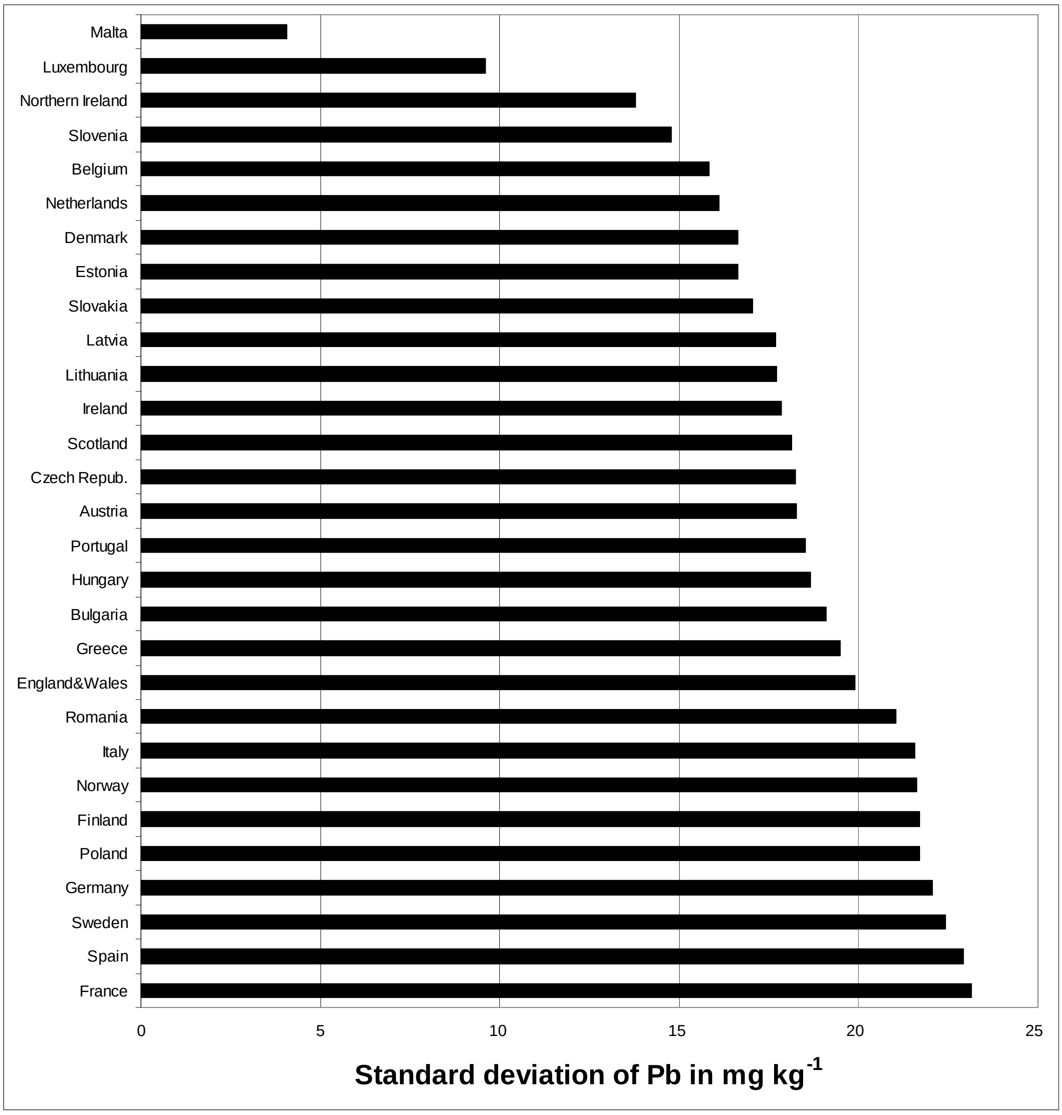


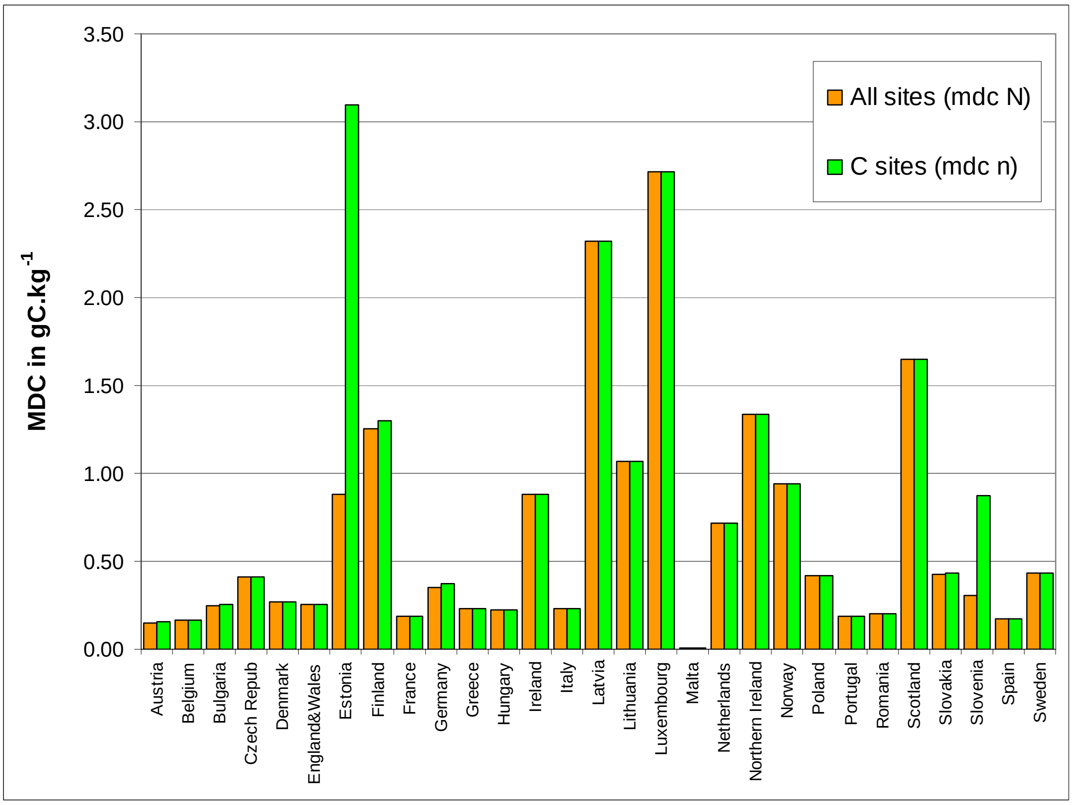
Figure 75. Estimated Standard deviation of total Pb content in mg kg-1 for the ENVASSO Countries

5.2.3 Minimum detectable change (MDC)

The minimum detectable change (MDC) has been calculated using information about the number of monitoring sites given by the partners: the total number of monitoring sites (N) and secondly, the number of sites (n_i) where a given indicator (i) is measured. N is always greater than n_i. MDC_n calculated with n_i represents an actual MDC for a given indicator i whereas a MDC_N calculated with N represents a relatively easy to reach MDC without having to sample new sites. To reach MDC_N, it is necessary to have measurements at all existing monitoring sites.

5.2.3.1 Detailed results for organic carbon and Pb content

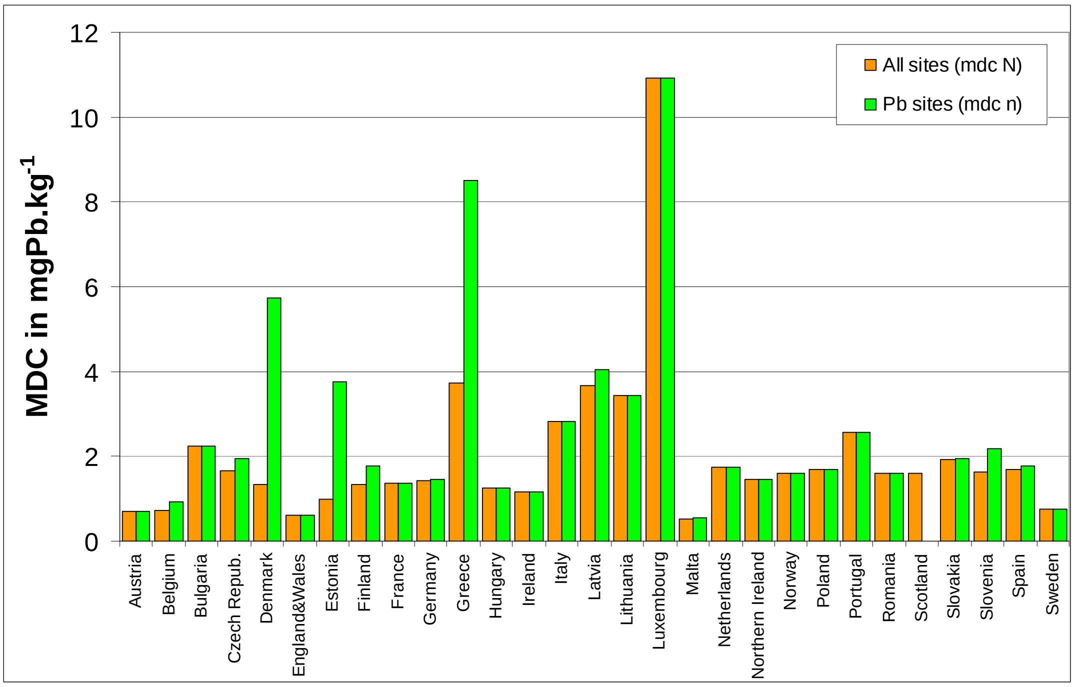
The MDC was highly variable amongst SMNs. As expected, the largest MDC values for organic carbon were observed in countries having very organic soils and/or in countries having very few sites measuring this indicator (Figure 76). Large MDC_n observed in Estonia or Slovenia could be considerably decreased by measuring C content in all the existing monitoring sites.



(orange: all sites; green: sites where organic C content is measured)

Figure 76. Minimum detectable level of change for Organic C content according the national statistics of the variance and depending on the number of sites taken into account

The MDC for total Pb content was also very variable. The main factor controlling this variability is the number of sites in the SMN (Figure 77). The largest values were observed in countries having very few sites measuring this parameter. Again, large MDCs for Denmark, Estonia and Greece could be reduced if all the monitoring sites were analysed for Pb.



Zero value for Scotland indicates no site where Pb is currently measured
(orange: all sites; green: sites where Pb content is measured)

Figure 77. Minimum detectable change for Pb content according the national estimates of the variance and depending on the number of sites taken into account.

According to results from the previous section (5.1), it is possible to make an attempt to map the minimum detectable changes at national level.

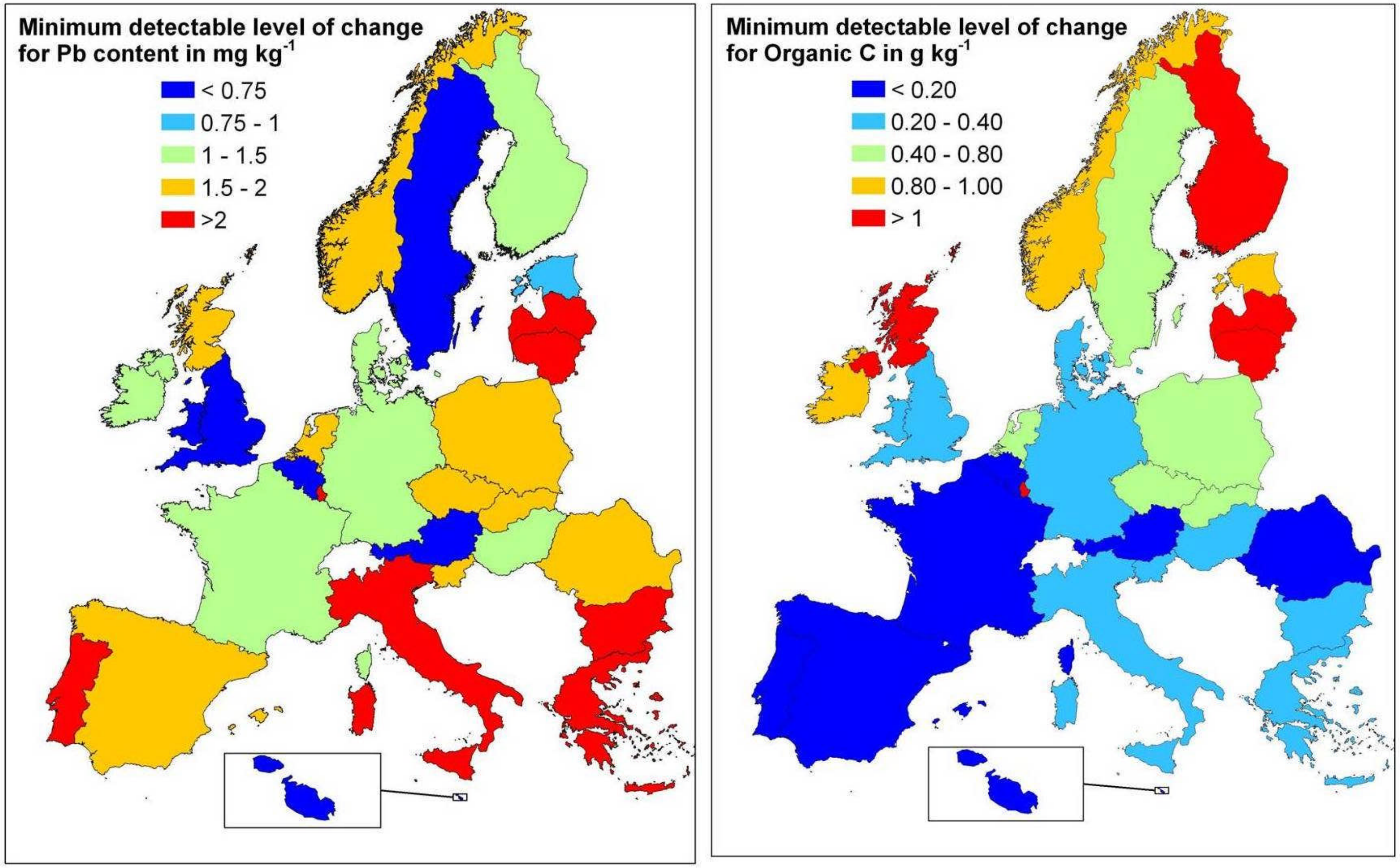


Figure 78. Maps of minimum detectable level of change for topsoil total Pb content (left) and topsoil organic carbon (right) according to the national statistics of the variance and to the total numbers of SMN N within each country

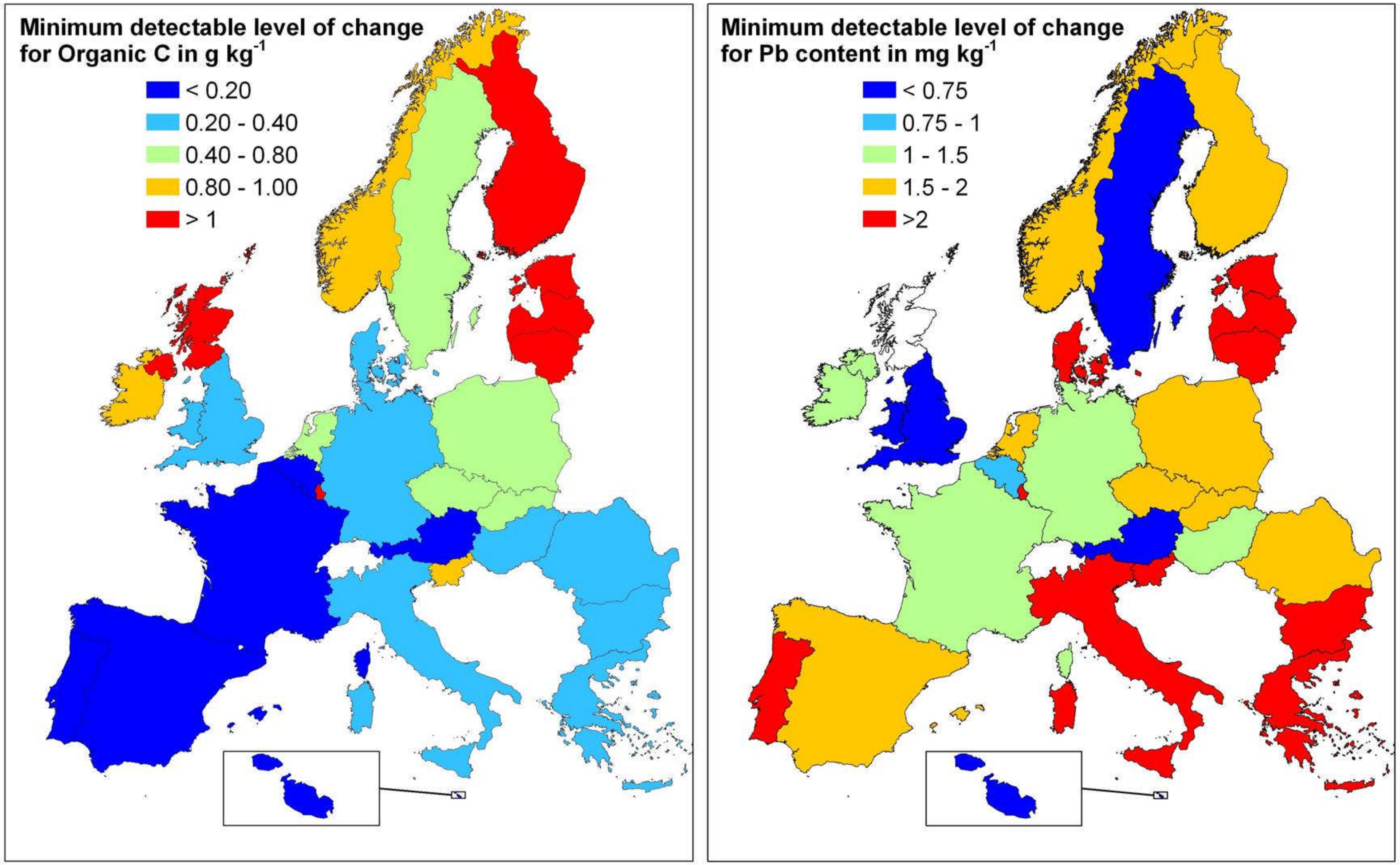


Figure 79. Maps of minimum detectable level of change for topsoil organic carbon (left) and topsoil total Pb content (right) according to the national statistics of the variance and to the numbers of sites n where indicator is measured at present.

5.2.3.2 Other parameters

In this section, we provide estimates of MDC per country for selected parameters (pH, Cd, Cr, Cu, Zn) (Table 21).

Table 31. Minimum detectable change for selected parameters – pH and Cd content

		pH			**Cd (MDCs are in mg kg^{-1})**		
Country	**N**	**mdc$_N$**	**n**	**mdc$_n$**	**mdc$_N$**	**n**	**mdc$_n$**
Austria	3829	0.10	3531	0.10	0.005	1110	0.01
Belgium	2546	0.11	-	-	0.005	432	0.02
Bulgaria	436	0.29	432	0.29	0.018	738	0.01
Czech Repub	738	0.22	-	-	0.013	47	0.05
Denmark	848	0.19	-	-	0.009	6018	0.00
England&Wales	6018	0.08	-	-	0.004	107	0.03
Estonia	1588	0.14	-	-	0.007	1563	0.01
Finland	1563	0.17	1446	0.17	0.010	1532	0.01
France	1532	0.18	-	-	0.009	1374	0.01
Germany	1380	0.18	1317	0.19	0.011	29	0.06
Greece	150	0.50	141	0.52	0.024	1328	0.01
Hungary	1328	0.16	-	-	0.010	22	0.08
Ireland	1317	0.16	-	-	0.008	341	0.02
Italy	341	0.36	-	-	0.021	107	0.03
Latvia	127	0.51	-	-	0.024	146	0.02
Lithuania	146	0.48	-	-	0.023	6	0.11
Luxembourg	6	1.64	-	-	0.113	0	-
Malta	388	0.15	271	0.17	0.005	531	0.01
Netherlands	531	0.24	-	-	0.015	582	0.01
Northern Ireland	582	0.20	-	-	0.013	1057	0.01
Norway	1057	0.20	-	-	0.012	894	0.01
Poland	895	0.22	894	0.22	0.011	290	0.02
Portugal	291	0.35	290	0.35	0.017	948	0.01
Romania	952	0.21	948	0.21	0.010	0	-
Scotland	721	0.22	-	-	0.010	424	0.01
Slovakia	432	0.27	428	0.27	0.013	56	0.03
Slovenia	468	0.24	56	0.69	0.011	928	0.01
Spain	1009	0.22	-	-	0.011	0	-
Sweden	4885	0.10	-	-	0.005	0	-

Based on national estimates of the variance and:

(mdcN) the total number (N) of monitoring sites
(mdcn) number (n) of monitoring sites where a parameter is measured
Where there is no difference between N and n, or if n is null, mdcn is not calculated

Table 4. Minimum detectable change for the Cr, Cu and Zn content

		Cr (MDCs are in mg kg^{-1})			Cu (MDCs are in mg kg^{-1})			Zn (MDCs are in mg kg^{-1})		
Country	**N**	**mdc$_N$**	**n**	**mdc$_n$**	**mdc$_N$**	**n**	**mdc$_n$**	**mdc$_N$**	**n**	**mdc$_n$**
Austria	3829	0.52	1552	0.72	0.52	2024	0.62	1.26	2024	1.58
Belgium	2546	0.56	432	1.63	0.56	432	1.66	1.41	432	4.18
Bulgaria	436	1.62	0	-	1.65	738	1.21	4.16	738	3.10
Czech Repub	738	1.19	0	-	1.21	47	4.29	3.10	47	10.77
Denmark	848	1.02	6018	0.46	1.01	6018	0.45	2.53	6018	1.08
England & Wales	6018	0.46	0	-	0.45	128	2.59	1.08	107	7.04
Estonia	1588	0.74	817	1.35	0.74	1563	0.99	1.83	1563	2.40
Finland	1563	0.97	909	1.36	0.99	1532	1.04	2.40	1532	2.42
France	1532	1.05	697	1.48	1.04	1318	1.09	2.42	1318	2.65
Germany	1380	1.05	0	-	1.07	26	6.76	2.59	47	12.14
Greece	150	2.83	1234	0.94	2.81	1328	0.92	6.79	1328	2.34
Hungary	1328	0.91	1295	0.88	0.92	1317	0.87	2.34	1317	2.12
Ireland	1317	0.87	0	-	0.87	341	2.10	2.12	341	5.12
Italy	341	2.07	0	-	2.10	105	3.04	5.12	105	7.45
Latvia	127	2.79	63	3.96	2.77	146	2.58	6.78	146	6.33
Lithuania	146	2.60	0	-	2.58	6	7.53	6.33	6	23.88
Luxembourg	6	7.11	345	0.45	7.53	345	0.40	23.88	345	1.70
Malta	388	0.43	531	1.24	0.38	531	1.27	1.60	531	3.37
Netherlands	531	1.24	582	1.02	1.27	582	1.05	3.37	582	2.92
Northern Ireland	582	1.02	0	-	1.05	1057	1.20	2.92	1057	2.92
Norway	1057	1.18	216	2.63	1.20	894	1.29	2.92	894	3.03
Poland	895	1.29	290	1.94	1.28	290	1.92	3.03	290	4.70
Portugal	291	1.94	0	-	1.92	948	1.20	4.69	948	2.84
Romania	952	1.21	0	-	1.20	0	-	2.84	0	-
Scotland	721	1.20	309	1.72	1.19	420	1.46	2.93	420	3.62
Slovakia	432	1.46	203	1.86	1.44	259	1.63	3.57	259	4.21
Slovenia	468	1.22	195	2.92	1.21	928	1.33	3.13	928	3.11
Spain	1009	1.28	4885	0.57	1.28	4885	0.57	2.98	4885	1.32
Sweden	4885	0.57	0	-	0.57	0	-	1.32	0	-

Based on national estimates of the variance and:
(mdcN) the total number (N) of monitoring sites
(mdcn) number (n) of monitoring sites where a parameter is measured
Where there is no difference between N and n, or if n is null, mdcn is not calculated

5.3 Effect of the number of sites on minimum detectable level of change

Minimum detectable changes are strongly influenced by the number of sites. In this section we calculate the number of monitoring sites which would be required to achieve a given MDC. A comparison between the numbers of sites N and n allows us to advise the EU Member states about the number of additional sites they would need to sample if a specific MDC is to be achieved.

5.3.1 Organic carbon

The number of sites necessary to detect a relative decrease of 5% of the national mean of topsoil organic carbon contents mainly depends on country area and on C contents variability within the country (Table 23). If we compare this theoretical number of sites to the number of sites n where measurements of organic carbon content are undertaken currently, or to the total number of sites N, we can deduce an estimate of the number of sites which would have to be added in each country to reach this level of detection of changes. Except for some countries where quite dense SMNs already exist, most Member States would have to make considerable efforts to detect a 5% relative change in soil organic carbon.

The theoretical number (n1) of sites needed to detect a relative decrease of 5% of the national mean of topsoil organic carbon contents can also be used to calculate a theoretical density of sites per country. This calculation shows that the lowest required density is ca 1 site per 320 km^2 (for Sweden). This result is consistent with the recommendation that all national SMNs should have at least such a density.

Using the data we have, it is possible to repeat this calculation for any relative change that we would wish to detect. Figure 80 shows that except for Malta, the number of sites needed to detect a 1% relative change would be extremely large, exceeding 20,000 in all cases, and more than 170,000 in Norway. At the EU level, the number of sites needed would be close to 1,000,000.

Table 5. Number of monitoring sites for organic carbon

Country	N	n	n1	n2	n3 :
Austria	3829	3313	1073	0	0
Belgium	2546	2546	2105	0	0
Bulgaria	436	432	866	434	430
Czech Repubic	738	738	1933	1195	1195
Denmark	848	848	1323	475	475
England & Wales	6018	6018	3853	0	0
Estonia	1588	128	2314	2186	726
Finland	1563	1446	2153	707	590
France	1532	1532	2182	650	650
Germany	1380	1254	2079	825	699
Greece	150	146	1230	1084	1080
Hungary	1328	1328	1680	352	352
Ireland	1317	1317	3121	1804	1804
Italy	341	341	1331	990	990
Latvia	127	127	2513	2386	2386
Lithuania	146	146	2849	2703	2703
Luxembourg	6	6	850	844	844
Malta	388	271	34	0	0
Netherlands	531	531	2086	1555	1555
Northern Ireland	582	582	3116	2534	2534
Norway	1057	1057	6988	5931	5931
Poland	895	894	1580	686	685
Portugal	291	290	1540	1250	1249
Romania	952	948	1286	338	334
Scotland	721	721	1255	534	534
Slovakia	432	424	1374	950	942
Slovenia	468	56	850	794	382
Spain	1009	1009	2304	1295	1295
Sweden	4885	4885	1764	0	0
Total	**36104**	**33334**	**57628**	**32498**	**30361**

(N) Total number of actual monitoring sites
(n) number of sites where carbon content is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of topsoil organic carbon contents according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

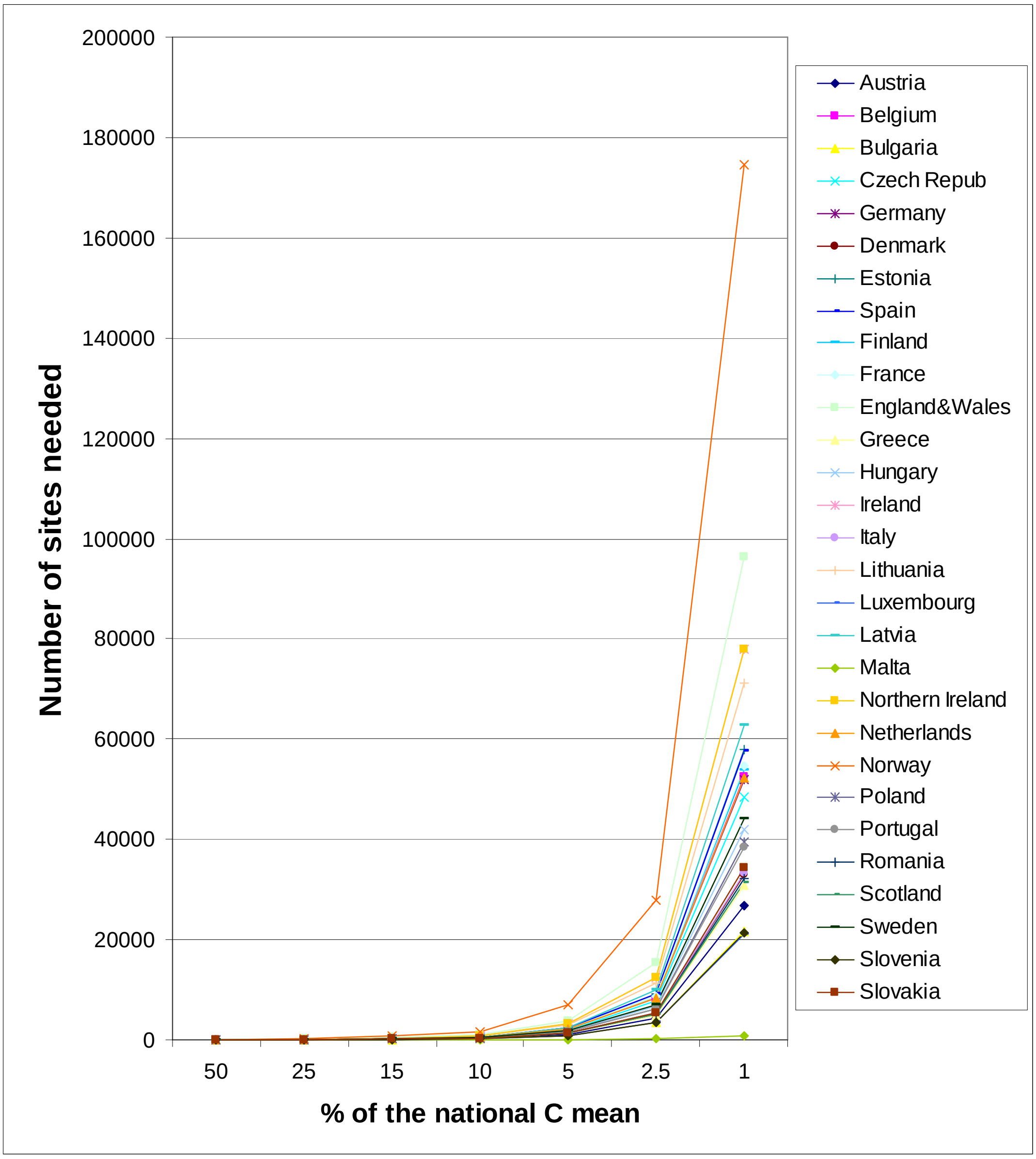


Figure 80. Number of sites needed for a level of detectable change corresponding to decreasing percentages of the national means (topsoil organic carbon content).

5.3.2 Lead

For lead contents the number of sites necessary to detect a relative change of 5% of the national mean ranges from 69 to 1874, depending on country area (Table 24). If we compare this theoretical number of sites to the number n of sites where measurements of Pb content are undertaken currently or to the total number of sites N, we can deduce an estimate of the number of sites which would have to be added in each country to reach this level of detection of change. Except for some countries where quite dense SMNs already exist (Austria, Belgium, England & Wales, Hungary, Ireland, Malta, Sweden), most of the countries would have to make considerable efforts to be able to detect a 5% relative change in Pb content.

Table 6. Number monitoring sites for lead (Pb) contents

Country	N	n	N1	n2	n3
Austria	3829	3313	1172	0	0
Belgium	2546	2546	900	0	0
Bulgaria	436	432	1408	976	972
Czech Repub.	738	738	1297	559	559
Denmark	848	848	989	141	141
England & Wales	6018	6018	1388	0	0
Estonia	1588	128	975	847	0
Finland	1563	1446	1775	329	212
France	1532	1532	1874	342	342
Germany	1380	1254	1831	577	451
Greece	150	146	1346	1200	1196
Hungary	1328	1328	1348	20	20
Ireland	1317	1317	1121	0	0
Italy	341	341	1758	1417	1417
Latvia	127	127	1101	974	974
Lithuania	146	146	1103	957	957
Luxembourg	6	6	460	454	454
Malta	388	271	69	0	0
Netherlands	531	531	1043	512	512
Northern Ireland	582	582	799	217	217
Norway	1057	1057	1766	709	709
Poland	895	894	1667	773	772
Portugal	291	290	1220	930	929
Romania	952	948	1550	602	598
Scotland	721	721	1170	449	449
Slovakia	432	424	1021	597	589
Slovenia	468	56	787	731	319
Spain	1009	1009	1853	844	844
Sweden	4885	4885	1759	0	0
Total	**36104**	**33334**	**36552**	**15158**	**13634**

(N) Total number of actual monitoring sites
(n) number of sites where Pb content is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of topsoil Pb contents according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

Note that a relative increase of 5% of Pb content is a highly improbable hypothesis. For instance, increasing a Pb content of a 0-30 cm topsoil containing 20 mg.kg^{-1} by 5% would mean an increase of 1 mg.kg^{-1}. If this happened in 10 years, and taking soil a bulk density of 1, it would mean that the soil received approximately 30 kg km^2 yr^{-1} of Pb. Therefore, in situations where there is no local contamination, the time necessary to detect changes will be very long. This is the point we assess in the Section 0.

5.3.3 Other parameters

In this section we provide tables which show for each Member State and for selected parameters, the number of existing monitoring sites, the number of sites where a given parameter is measured, and the calculated number of additional sites required.

Table 7. Number of monitoring sites for pH

Country	N	n	n1	n2	n3
Austria	3829	3531	338	0	0
Belgium	2546	2546	280	0	0
Bulgaria	436	432	359	0	0
Czech Repub.	738	738	337	0	0
Denmark	848	848	298	0	0
England & Wales	6018	6018	379	0	0
Estonia	1588	1588	298	0	0
Finland	1563	1446	428	0	0
France	1532	1532	470	0	0
Germany	1380	1317	439	0	0
Greece	150	141	368	227	218
Hungary	1328	1328	347	0	0
Ireland	1317	1317	327	0	0
Italy	341	341	425	84	84
Latvia	127	127	324	197	197
Lithuania	146	146	324	178	178
Luxembourg	6	6	158	152	152
Malta	388	271	80	0	0
Netherlands	531	531	286	0	0
Northern Ireland	582	582	235	0	0
Norway	1057	1057	427	0	0
Poland	895	894	429	0	0
Portugal	291	290	344	54	53
Romania	952	948	410	0	0
Scotland	721	721	334	0	0
Slovakia	432	428	308	0	0
Slovenia	468	56	257	201	0
Spain	1009	1009	464	0	0
Sweden	4885	4885	449	0	0
Total	**36104**	**35074**	**9922**	**1092**	**882**

(N) Total number of actual monitoring sites
(n) number of sites where pH is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of topsoil pH according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

Table 8. Number of monitoring sites for Cadmium (Cd) contents

Country	N :	n :	n1 :	n2 :	n3
Austria	3829	3815	167	0	0
Belgium	2546	1110	133	0	0
Bulgaria	436	432	282	0	0
Czech Repub.	738	738	268	0	0
Denmark	848	47	244	197	0
England & Wales	6018	6018	196	0	0
Estonia	1588	107	142	35	0
Finland	1563	1563	228	0	0
France	1532	1532	355	0	0
Germany	1380	1374	233	0	0
Greece	150	29	187	158	37
Hungary	1328	1328	175	0	0
Ireland	1317	22	262	240	0
Italy	341	341	224	0	0
Latvia	127	107	260	153	133
Lithuania	146	146	158	12	12
Luxembourg	6	6	161	155	155
Malta	388	0	20	20	0
Netherlands	531	531	135	0	0
Northern Ireland	582	582	205	0	0
Norway	1057	1057	327	0	0
Poland	895	894	328	0	0
Portugal	291	290	173	0	0
Romania	952	948	216	0	0
Scotland	721	0	165	165	0
Slovakia	432	424	150	0	0
Slovenia	468	56	116	60	0
Spain	1009	928	251	0	0
Sweden	4885	0	239	239	0
Total	**36104**	**24425**	**6002**	**1436**	**337**

(N) Total number of actual monitoring sites
(n) number of sites where Cd content is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of Cd contents according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

Table 9. Number of monitoring sites for Cadmium (Cd) contents

Country	N :	n :	n1 :	n2 :	n3 :
Austria	3829	3256	459	0	0
Belgium	2546	1552	350	0	0
Bulgaria	436	432	503	71	67
Czech Repub.	738	0	459	459	0
Denmark	848	0	385	385	0
England & Wales	6018	6018	544	0	0
Estonia	1588	0	382	382	0
Finland	1563	817	647	0	0
France	1532	909	736	0	0
Germany	1380	697	669	0	0
Greece	150	0	526	526	376
Hungary	1328	1234	479	0	0
Ireland	1317	1295	439	0	0
Italy	341	0	641	641	300
Latvia	127	0	431	431	304
Lithuania	146	63	432	369	286
Luxembourg	6	0	132	132	126
Malta	388	345	31	0	0
Netherlands	531	531	359	0	0
Northern Ireland	582	582	264	0	0
Norway	1057	0	644	644	0
Poland	895	216	652	436	0
Portugal	291	290	476	186	185
Romania	952	0	608	608	0
Scotland	721	0	456	456	0
Slovakia	432	309	400	91	0
Slovenia	468	203	306	103	0
Spain	1009	195	725	530	0
Sweden	4885	4885	690	0	0
Total	**36104**	**23829**	**13826**	**6449**	**1643**

(N) Total number of actual monitoring sites
(n) number of sites where Cr content is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of Cr contents according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

Table 28. Number of monitoring sites for Copper (Cu) contents

Country	N :	n :	n1 :	n2	n3
Austria	3829	3816	1039	0	0
Belgium	2546	2024	789	0	0
Bulgaria	436	432	1192	760	756
Czech Repub.	738	738	1092	354	354
Denmark	848	47	869	822	21
England & Wales	6018	6018	1234	0	0
Estonia	1588	128	861	733	0
Finland	1563	1563	1525	0	0
France	1532	1532	1674	142	142
Germany	1380	1318	1575	257	195
Greece	150	26	1191	1165	1041
Hungary	1328	1328	1138	0	0
Ireland	1317	1317	993	0	0
Italy	341	341	1509	1168	1168
Latvia	127	105	975	870	848
Lithuania	146	146	977	831	831
Luxembourg	6	6	341	335	335
Malta	388	345	55	0	0
Netherlands	531	531	863	332	332
Northern Ireland	582	582	644	62	62
Norway	1057	1057	1516	459	459
Poland	895	894	1481	587	586
Portugal	291	290	1077	787	786
Romania	952	948	1380	432	428
Scotland	721	0	1032	1032	311
Slovakia	432	420	903	483	471
Slovenia	468	259	687	428	219
Spain	1009	928	1650	722	641
Sweden	4885	4885	1570	0	0
Total	**36104**	**32024**	**31831**	**12760**	**9986**

(N) Total number of actual monitoring sites
(n) number of sites where Cu content is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of Cu contents according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

Table 10. Number of monitoring sites for Zinc (Zn)

Country	N :	n :	n1	n2 :	n3 :
Austria	3829	3816	536	0	0
Belgium	2546	2024	443	0	0
Bulgaria	436	432	659	227	223
Czech Repub.	738	738	620	0	0
Denmark	848	47	476	429	0
England & Wales	6018	6018	613	0	0
Estonia	1588	107	464	357	0
Finland	1563	1563	789	0	0
France	1532	1532	782	0	0
Germany	1380	1318	808	0	0
Greece	150	47	605	558	455
Hungary	1328	1328	638	0	0
Ireland	1317	1317	517	0	0
Italy	341	341	783	442	442
Latvia	127	105	510	405	383
Lithuania	146	146	511	365	365
Luxembourg	6	6	299	293	293
Malta	388	345	87	0	0
Netherlands	531	531	527	0	0
Northern Ireland	582	582	435	0	0
Norway	1057	1057	786	0	0
Poland	895	894	718	0	0
Portugal	291	290	560	270	269
Romania	952	948	670	0	0
Scotland	721	0	542	542	0
Slovakia	432	420	481	61	49
Slovenia	468	259	401	142	0
Spain	1009	928	783	0	0
Sweden	4885	4885	743	0	0
Total	**36104**	**32024**	**16786**	**4092**	**2480**

(N) Total number of actual monitoring sites
(n) number of sites where Cu content is measured
(n1) theoretical number of sites needed to detect a relative decrease of 5% of the national mean of Cu contents according to national statistics on variances
(n2) number of additional sites needed by comparison with n
(n3) number of additional sites needed ny comparison with N

5.4 Time intervals for monitoring

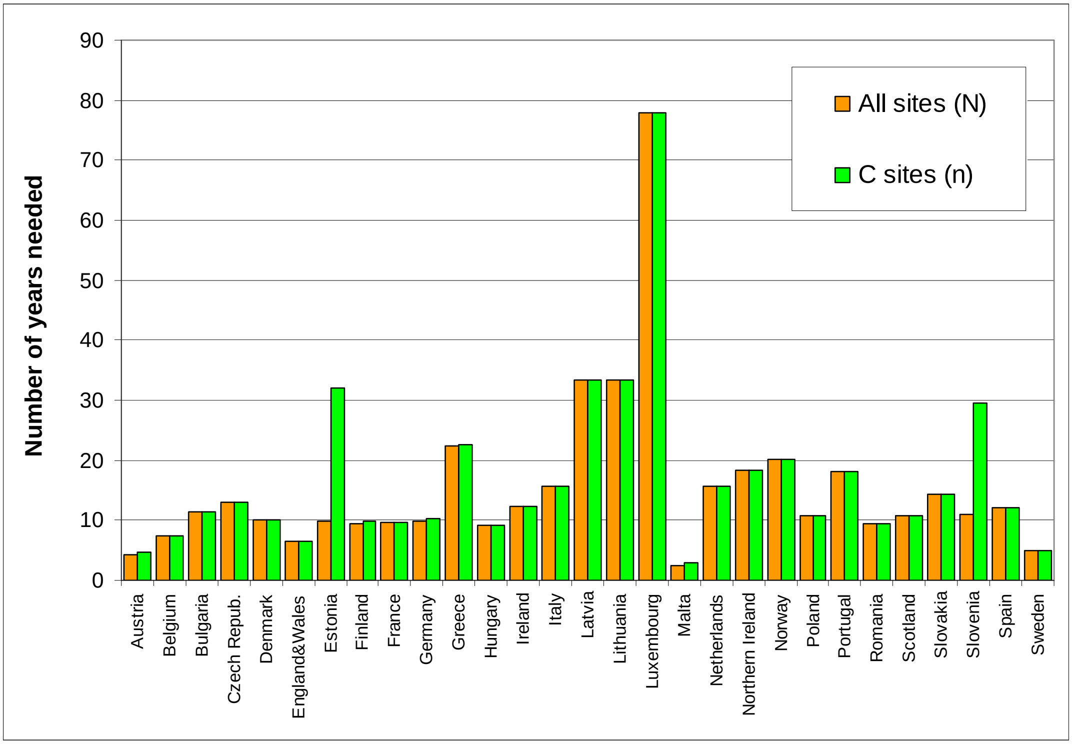
With the assumption that a variable is changing at an estimated rate of change k and that this is constant over the whole time interval between samplings and over the whole of Europe, and if we assume a given number of sites, then we can calculate the time necessary to detect a given change. For this exercise we will take two examples.

The first example is based on a study from Bellamy *et al*., (2005) who showed very large changes in soil organic carbon across England and Wales, from 1978 to 2003. They used data from the National Soil Inventory of England and Wales obtained between 1978 and 2003 to show that carbon was lost from soils across England and Wales over the survey period at a mean rate of 0.6% yr^{-1} (relative to the existing soil carbon content). They found that the relationship between rate of carbon loss and carbon content was irrespective of land use, suggesting a link to climate change.

If we suppose that such a change might have happened all over Europe, we can calculate the time interval that will be necessary to detect it, either by using existing SMNs, or by simulating the existence of additional sites as we did in Section 5.3.

For most countries having quite dense SMNs, the time necessary to detect such a change is below or close to 10 yr (Figure 81). This result supports the idea that, at least for quite dense SMNs and for this parameter, a time interval of 10 yr would be efficient. The cases of Estonia and Slovenia give a good example of the importance of archiving samples. Analysing organic C on archived samples for all sites would reduce the number of years needed from ca 30 yr to ca 10 yr.

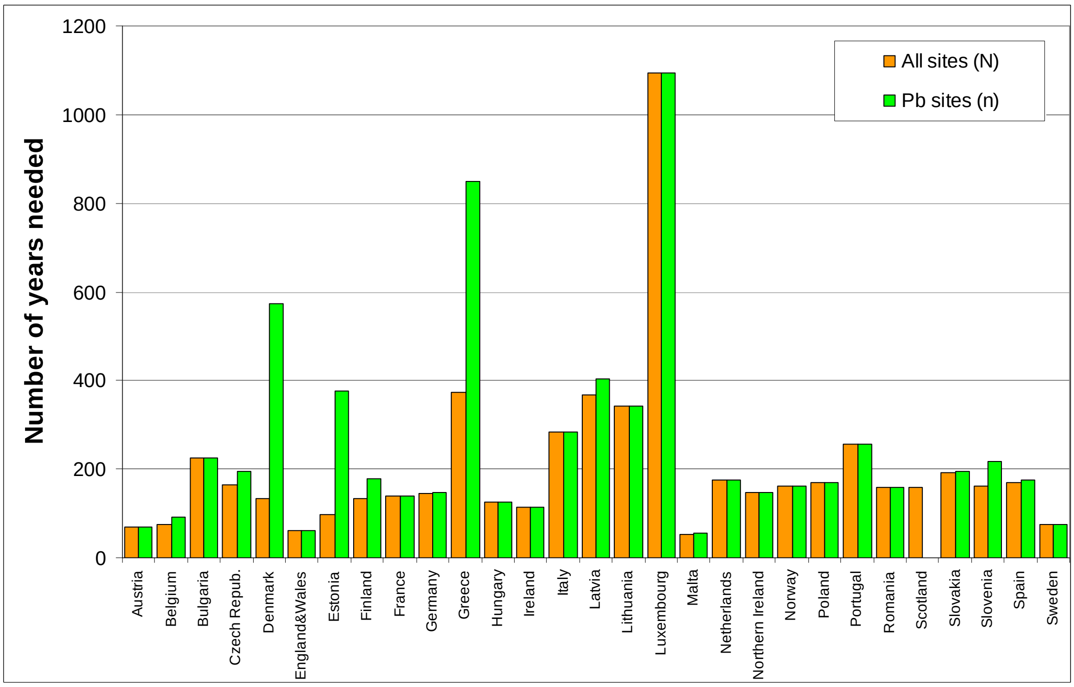
If we require that all EU countries have a dense enough SMN to detect this change in a 10yr period, then almost all the countries should have a density of site greater than 1 site per 300 km^2, except for Sweden, France, Italy and Spain (densities ranging 1 site per 320 to 380 km^2).



Orange: all monitoring sites; Green: sites where organic carbon is already measured

Figure 81. Number of years needed to detect a change in organic carbon at a mean rate of 0.6% yr^{-1} (relative to the existing soil carbon content).

For the simulation concerning lead, we used estimates of deposition to soil in France, provided by the EMEP programme. We took a hypothesis of a deposition of 3 kg km² yr^{-1} which, if we consider that all Pb is retained in topsoil, and that samples are taken in a topsoil layer of 0-30 cm having a bulk density of 1, would induce an increase of 0.01 mg Pb kg^{-1}yr^{-1}.



Orange: all monitoring sites; Green: sites where Pb content is already measured

Figure 82. Number of years needed to detect a increase of 0.01 mgPb kg^{-1} year^{-1} according the national statistics of the variance.

According to our estimates, the time necessary to detect such a change would be very long, in most cases longer than 100 years (Figure 82). In the case where the soil remains undisturbed (for instance under no-till, or under forest), and if we accept the hypothesis that lead is strongly retained at the surface, this time could be reduced by reducing the depth of sampling. Whatever is done, for these rates of changes, most of the SMNs would not be able to detect changes in 10 yr periods, and if such a change were detected with this time interval, it would imply that considerable contamination had occurred.

As for organic carbon, the situation in Denmark, Estonia, and Greece provide a good example of the importance of sample archiving.

5.5 Conclusion on detectable changes

Our results suggest that minimum detectable changes (MDC) differ considerably amongst soil monitoring networks and amongst indicators. Whatever the indicator, considerable effort would be necessary for some countries to reach acceptable densities of sites to achieve realistic levels of minimum detectable changes. For some indicators such as topsoil organic carbon, a time interval of ca 10 years would enable the detection of some simulated changes. Note that the density of sites required for such detection is denser than 1 site per 300 km^2 for most of the countries. This result is consistent with the recommendation that all SMNs should have at least this density. For some other indicators, such as heavy metals, detecting changes occurring during such a time interval would be impossible, except in the case of considerable and sudden contamination.

5.6 References

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6 CONCLUSION

This report constitutes the most exhaustive review of European soil monitoring networks to date. Official frameworks for comprehensive soil monitoring exist in most countries, but uniformity in methodology and coverage, albeit existing in some Member States, is far from standard even within national systems. This study highlights the differences between existing networks.

The present coverage is very heterogeneous amongst countries. National and regional networks are much denser in northern and eastern parts of Europe than in southern countries. The median density of sites in 50km x 50km cells applied all over Europe is 1 site per 300 km². Such a density is close to the density of the ICP Forest grid. This density is, in practice, already reached for half of the European territory. However, the situation differs when considering various indicators, as the minimum set of parameters measured differs amongst countries.

If we take into account the existing sites, achieving at least a median density of 1 site per 300 km² in all 50km x 50km cells would require 4,100 addition sites mainly located in southern countries (Italy, Spain, Greece), and parts of Poland, Germany, Baltic countries, Norway, Finland and France. This figure might be a slight overestimate, because some metadata are missing for Italy and Spain, and some SMNs are currently being implemented (e.g. France). This whole study illustrates the large differences between monitoring activities in Member States, and the considerable effort that would be needed to reach a common acceptable site density.

The locations for the installation of new SMN sites might be selected on different criteria: grid-based site selection, representativeness (of landform, soil types, land use, specific site-related situations); specific land uses or unusual conditions; documentation and control of land use and practices; and integration of sites into other currently established ecological observation areas. Whatever the selection criteria eventually chosen, we recommend that 1 monitoring site per 300 km^2 should be the absolute minimum density of sites to be setup over all-Europe as this would represent most of the important soil type and land use combinations in the European Union.

Apart from watersheds monitored for erosion, we recommend selection of rather small areas for sampling, ranging from 100 m^2 to 1 ha and being homogeneous with regard to soil profile development. We recommend taking at least 4 subsamples, and preferably to adapt sub-sampling density by taking from 10 to 100 subsamples depending on the size of the site. It is recommended that the exact location of cores is known in order to avoid these locations in future re-sampling campaigns.

Fixed-depth increments are most often used for core sampling. This sampling method ensures standardisation between sites. It is also the most relevant for some anthropogenic characters (e.g. heavy metals, radionuclides, organo-chemicals), and for parameters showing a strong concentration gradient near the soil surface. For this purpose, smaller increments are often adopted near the soil surface. Pedogenetic horizons are often collected in soil pits, outside the monitoring area, but close to it. This method of sampling is relevant for some parameters (e.g. particle size, water retention properties, mineralogy). It is also the most relevant unit to link SMN observations to geographical soil information systems derived from soil mapping activities.

It is very difficult to recommend exact sampling depths and changing depth of sampling for an existing national SMN might would make it very difficult to compare future results with previous campaigns to assess changes. One way to harmonise reporting at the EU level could be to report the results on the basis of a same equivalent mineral mass. We recommend that at least topsoil concentrations or stocks of elements could be calculated for depths ranging from 0-15 to 0-30 cm.

Although a broad range of time intervals is observed between sampling campaigns, depending on parameters and on networks, most SMNs use time steps ≤ 10 years. Some SMNs adopt shorter time steps at the beginning of monitoring, and then adapt the re-sampling rate to observed changes. Recommending a maximum time step of 10 years would enable incorporation of nearly all the SMNs. For a large number of indicators, shorter time steps would not enable demonstration of changes.

Our results suggest that the minimum detectable change differs considerably amongst soil monitoring networks and amongst indicators. Whatever the indicator, considerable efforts will be needed in some countries to reach acceptable levels of monitoring to identify robustly minimum detectable changes. For some indicators, such as topsoil organic carbon, a time interval of *ca.* 10 years would enable detection of some simulated changes. This requires that most SMNs achieve a sampling design denser than 1 site per 300 km^2. For some other indicators, such as heavy metals, detecting changes over a 10-year time interval is impossible, unless there has been a considerable and sudden contamination.

Except for some parameters, for which a large consensus exists, the question of the harmonisation of analytical techniques remains a very difficult issue. For several parameters, combining several techniques, on all samples or on a subset of samples, would be the best option in order to use previous campaigns to detect changes, and to establish pedotransfer functions linking the results obtained using different methods. As the main cost in soil monitoring is due to sampling in the field, adding new determinations would not greatly affect total costs. Another proposal could be that a Central Laboratory makes all the determinations on a subset of samples, and works on establishing transfer between results of various methods.

Among the top three indicators identified in Volume I, the density of the coverage is very heterogeneous. Soil organic carbon and pH are most often measured parameters, whereas some other parameters have a very weak coverage, even if this evaluation is restricted to risk areas. In particular, indicators related to soil biodiversity and to soil erosion are very seldom. Some trace elements are measured in almost all the countries (e.g. Pb), whereas others are not so in numerous ones (e.g. Hg). Indicators for soil compaction such as bulk density and packing density are not measured in about half of the countries.

A large number of periurban areas are not monitored for contaminants, especially in southern countries. Areas identified as having the greatest heavy metal deposition rates appear not to be sampled densely enough, especially concerning Hg. Areas with great livestock pressures are unequally covered by related indicator measurements. About 7% of the area covered by the soil mapping units do not have any monitoring site and should be sampled if an exhaustive monitoring of soils is desired in Europe.

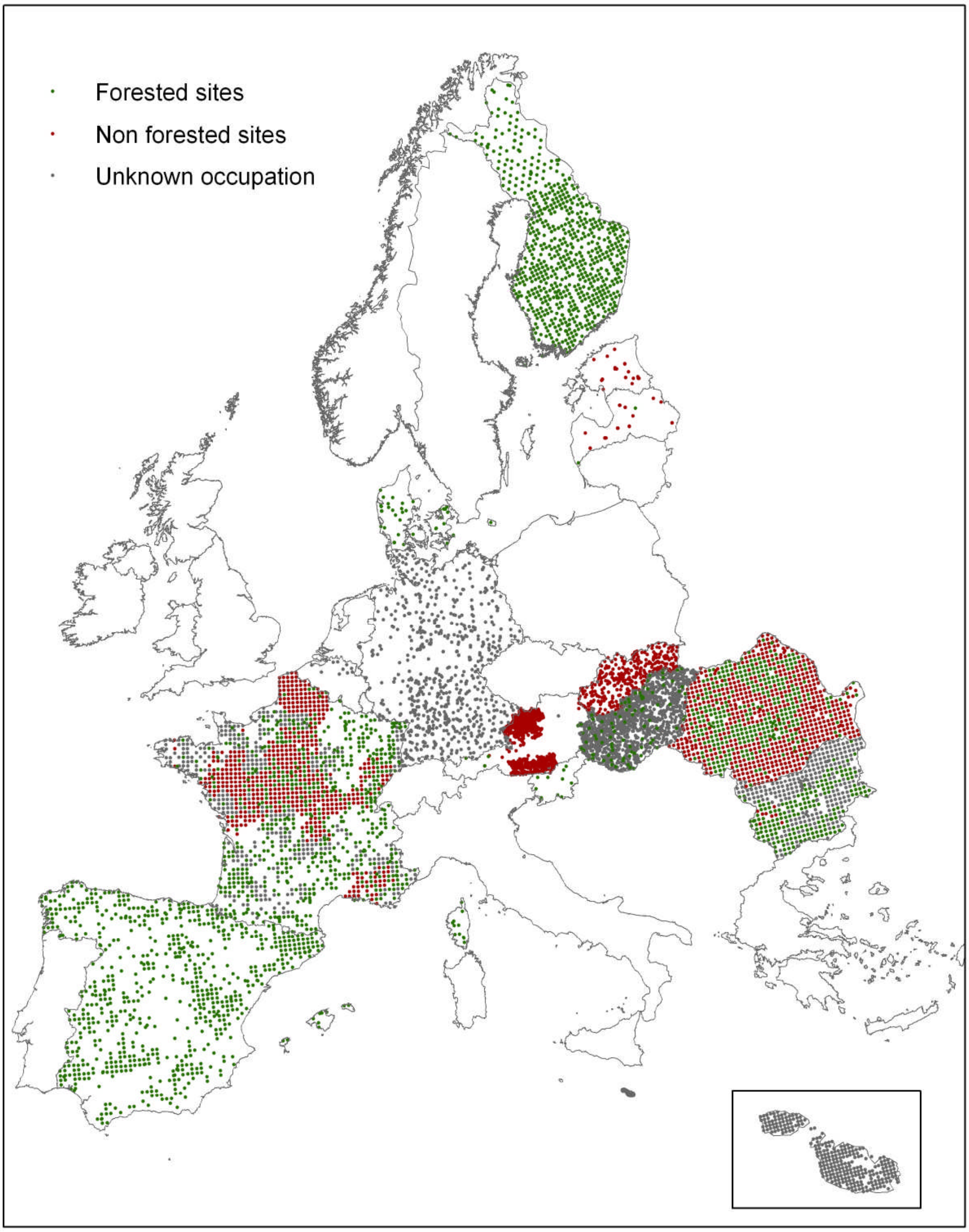
In view of this situation, it is clear that harmonisation and co-ordination are necessary. When SMNs are dense enough, this harmonisation could be done by adding measurements for the missing indicators, otherwise, it would also require addition of new sites. Indeed, considerable efforts are still needed to reach a common acceptable level of soil monitoring in Europe.

Yet, it is necessary to provide a framework for a harmonised system which will enable comparison of the data provided by monitoring networks and geographical databases. One way to enhance comparability is to develop a European SMN manual, acting as a reference for national networks, and to test its suitability on test areas. To create a minimum coverage of one site per 300 km^2 is the least that should be accepted, together with an intensive programme of cross-method validation to permit valid spatial and temporal comparisons both within and between countries.

Environmental Assessment of Soil for Monitoring Volume II: Inventory & Monitoring

Annex I Distribution of Soil Monitoring Sites and Indicators measured

List of Figures (Annex I)



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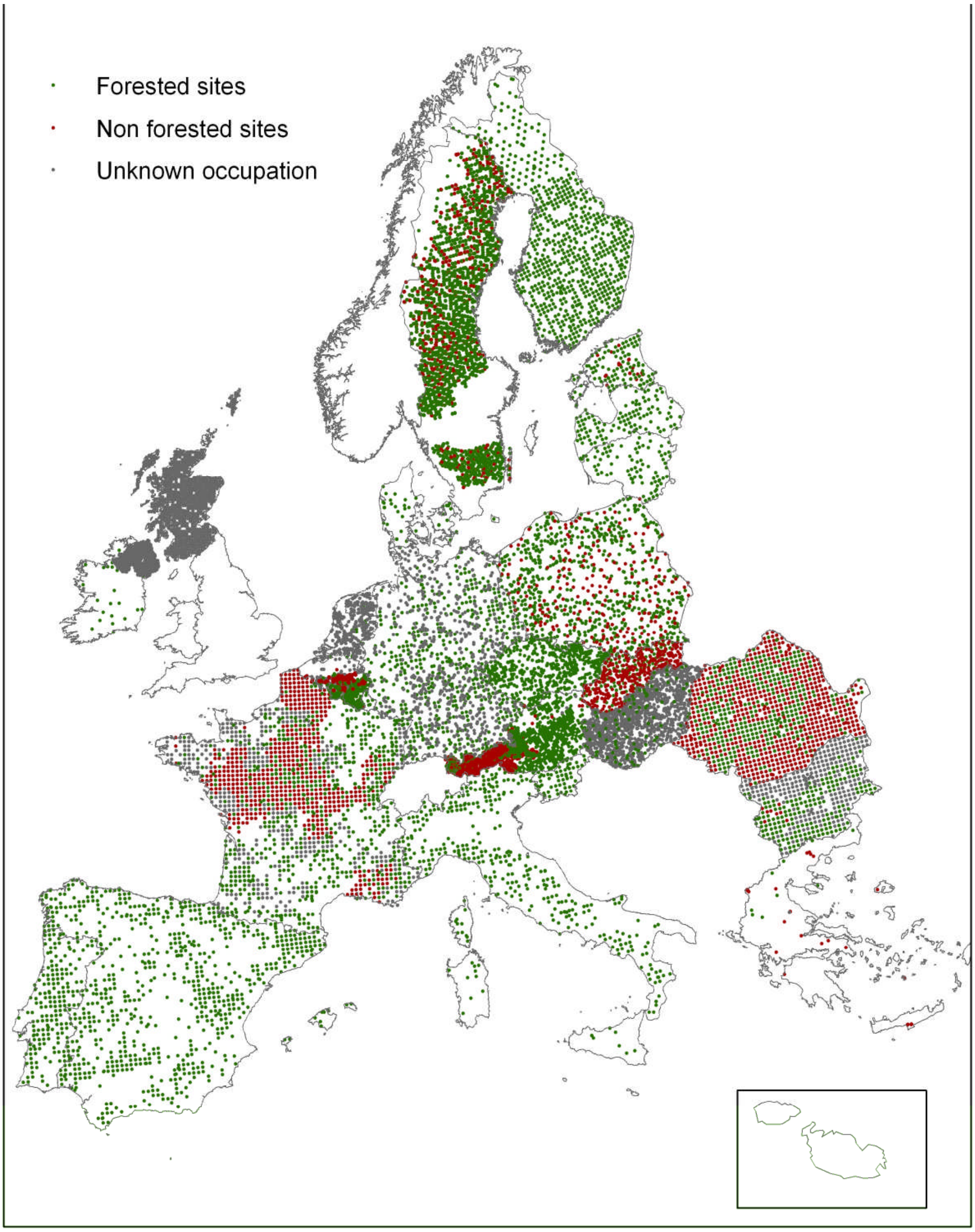

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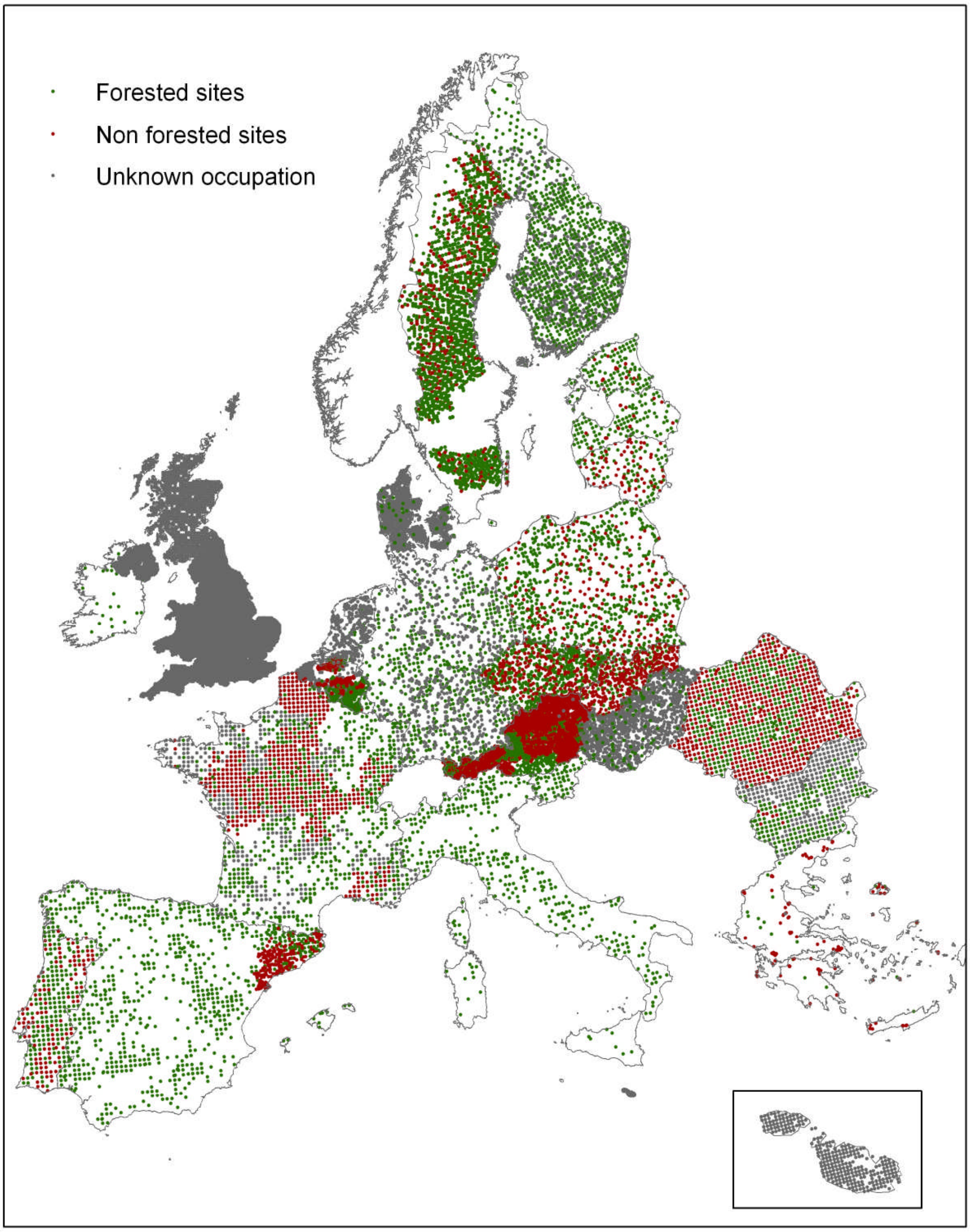

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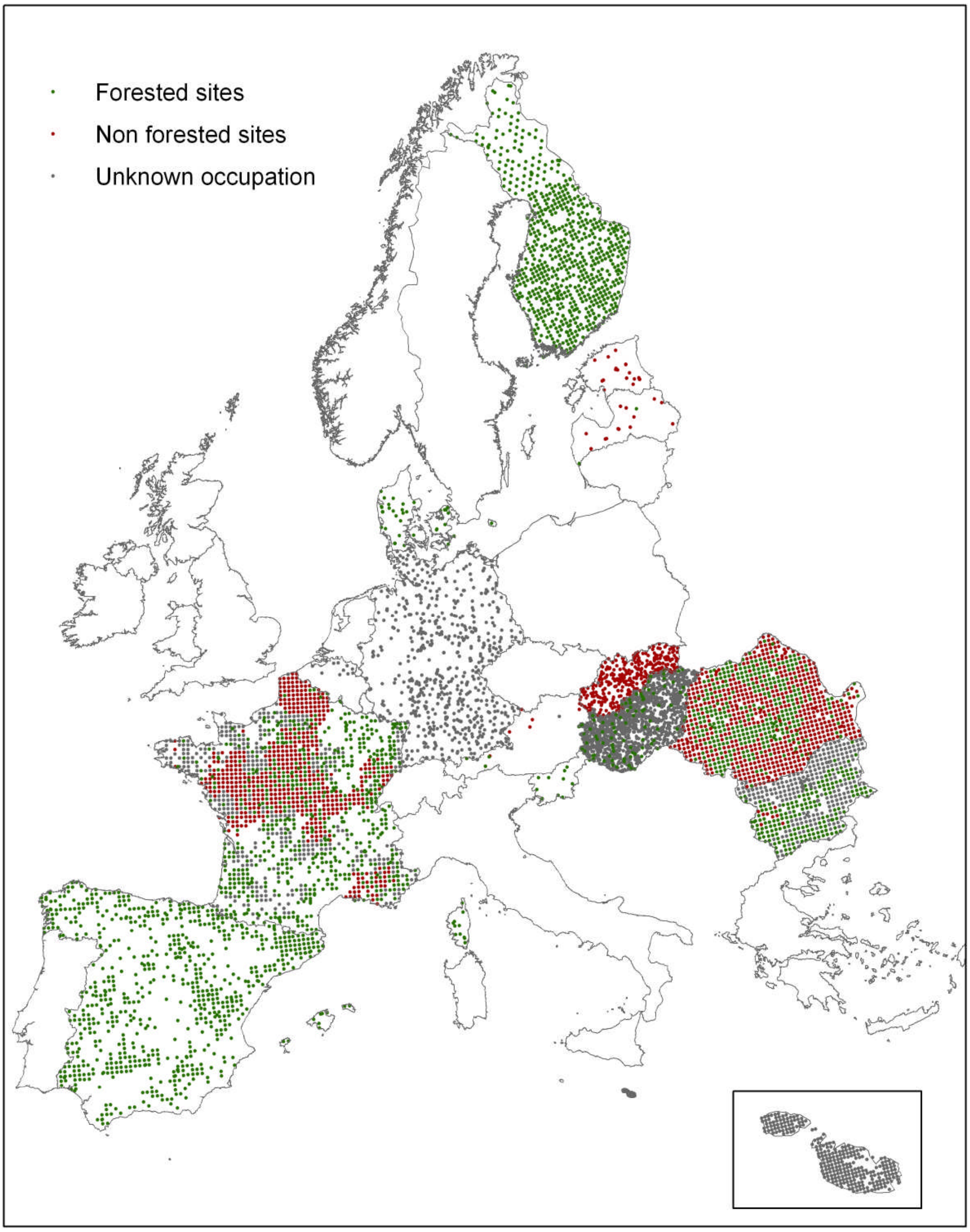

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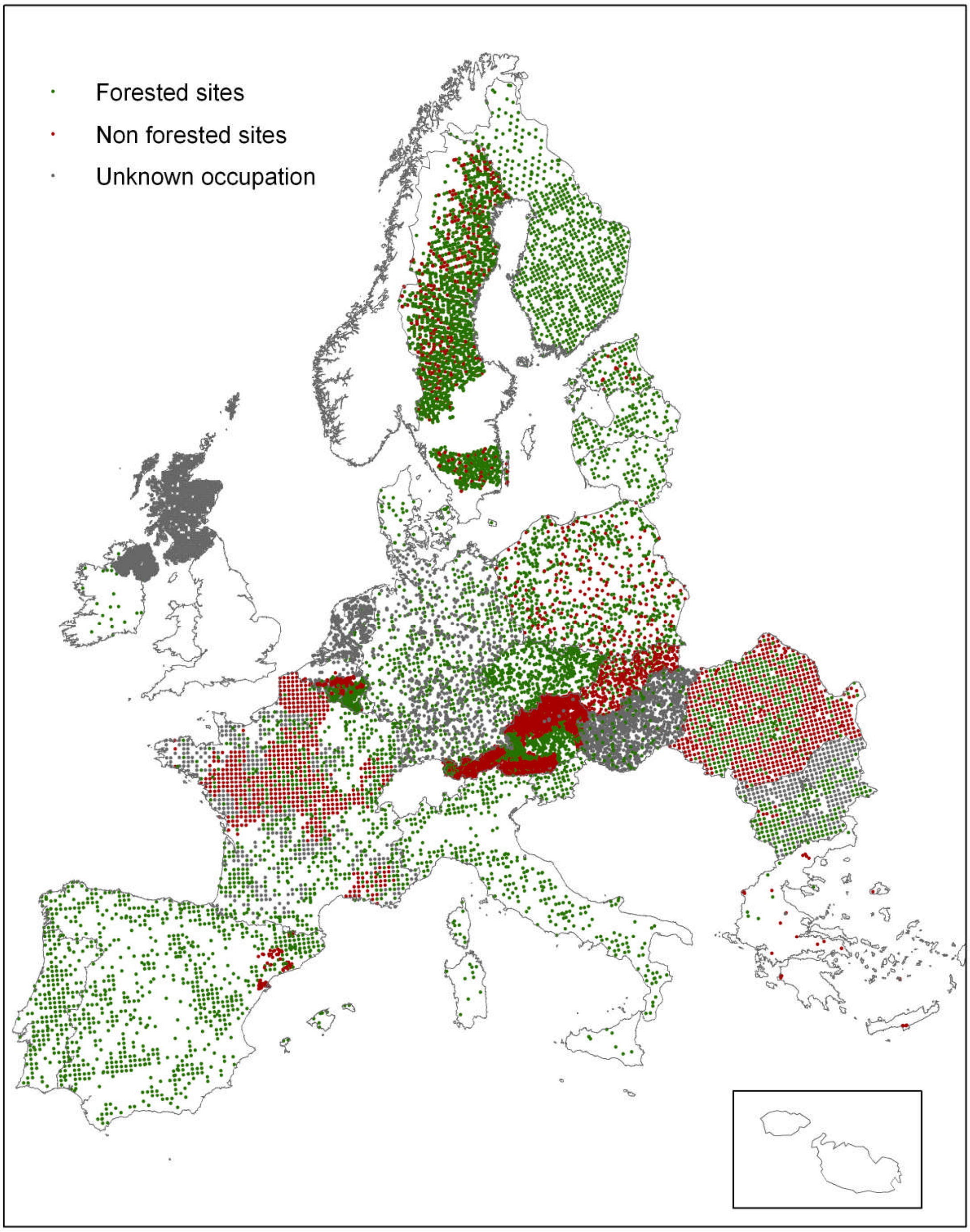

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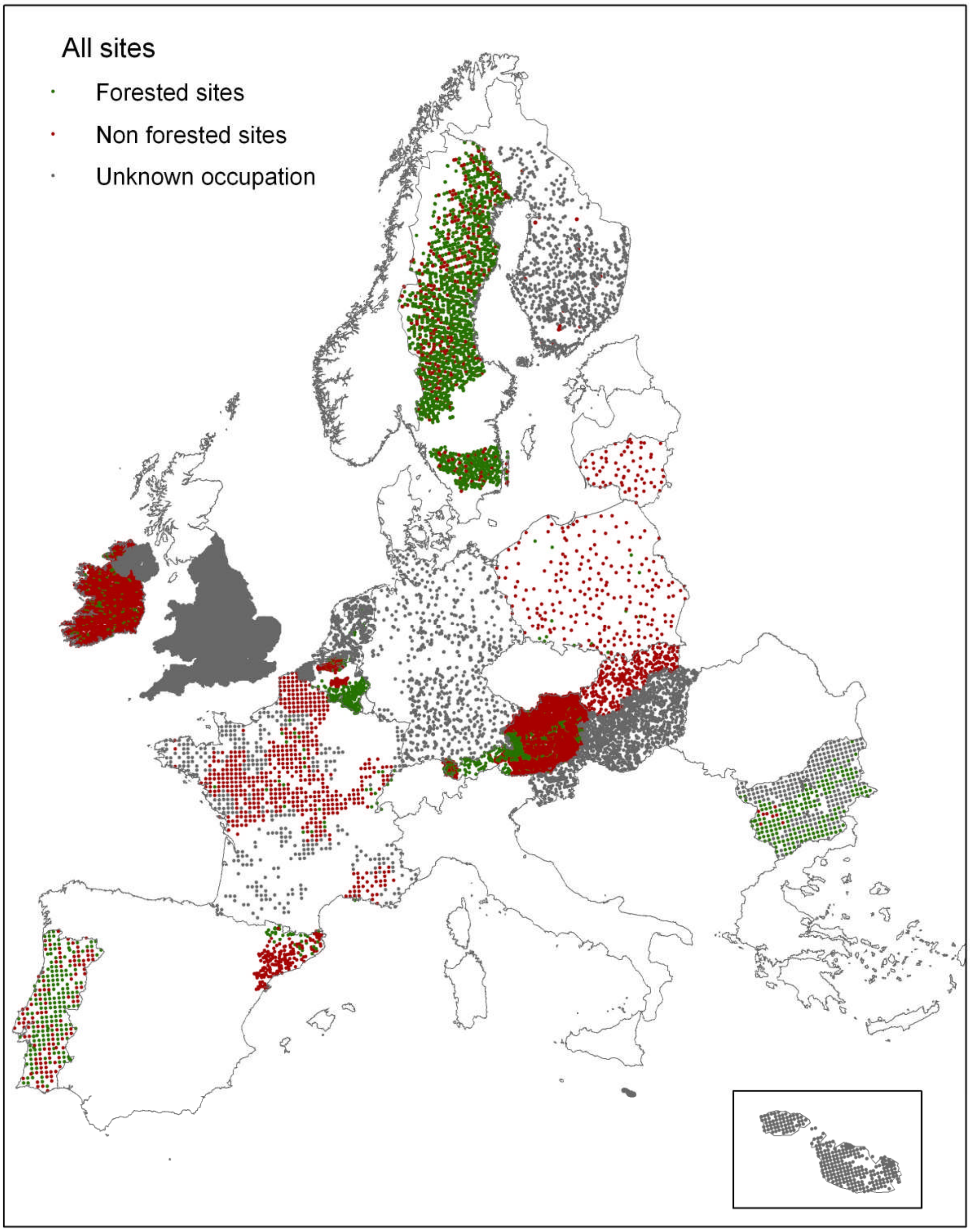

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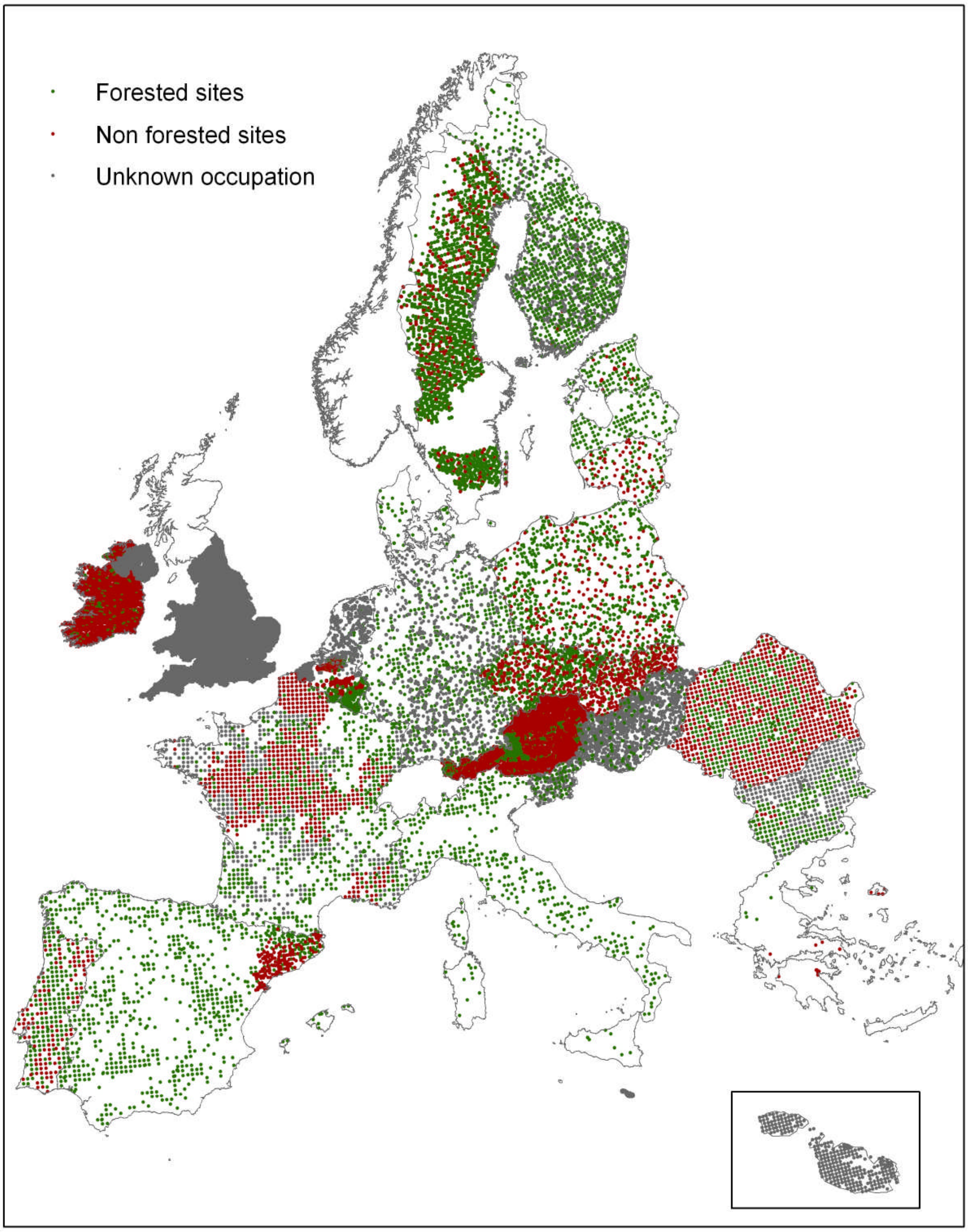

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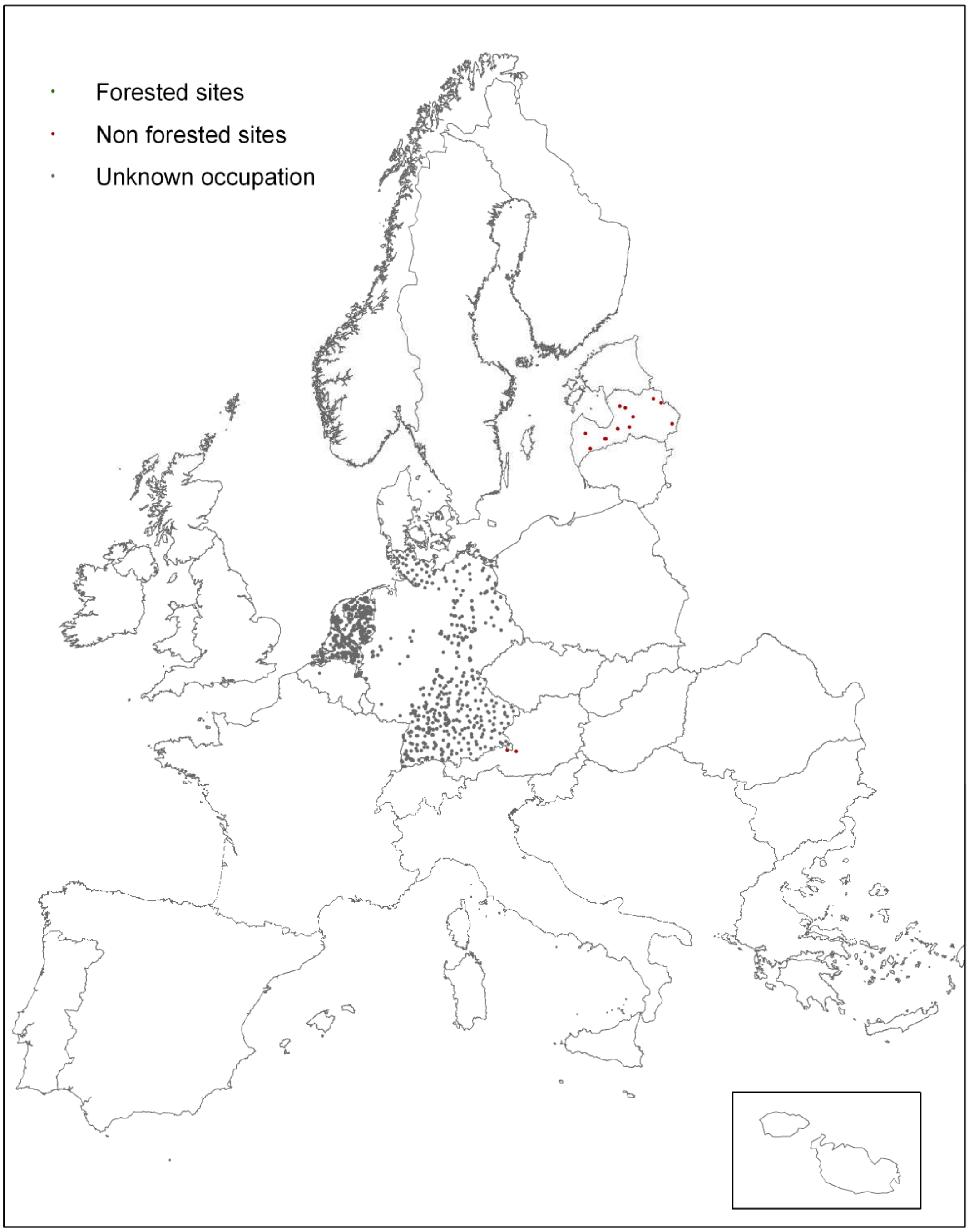

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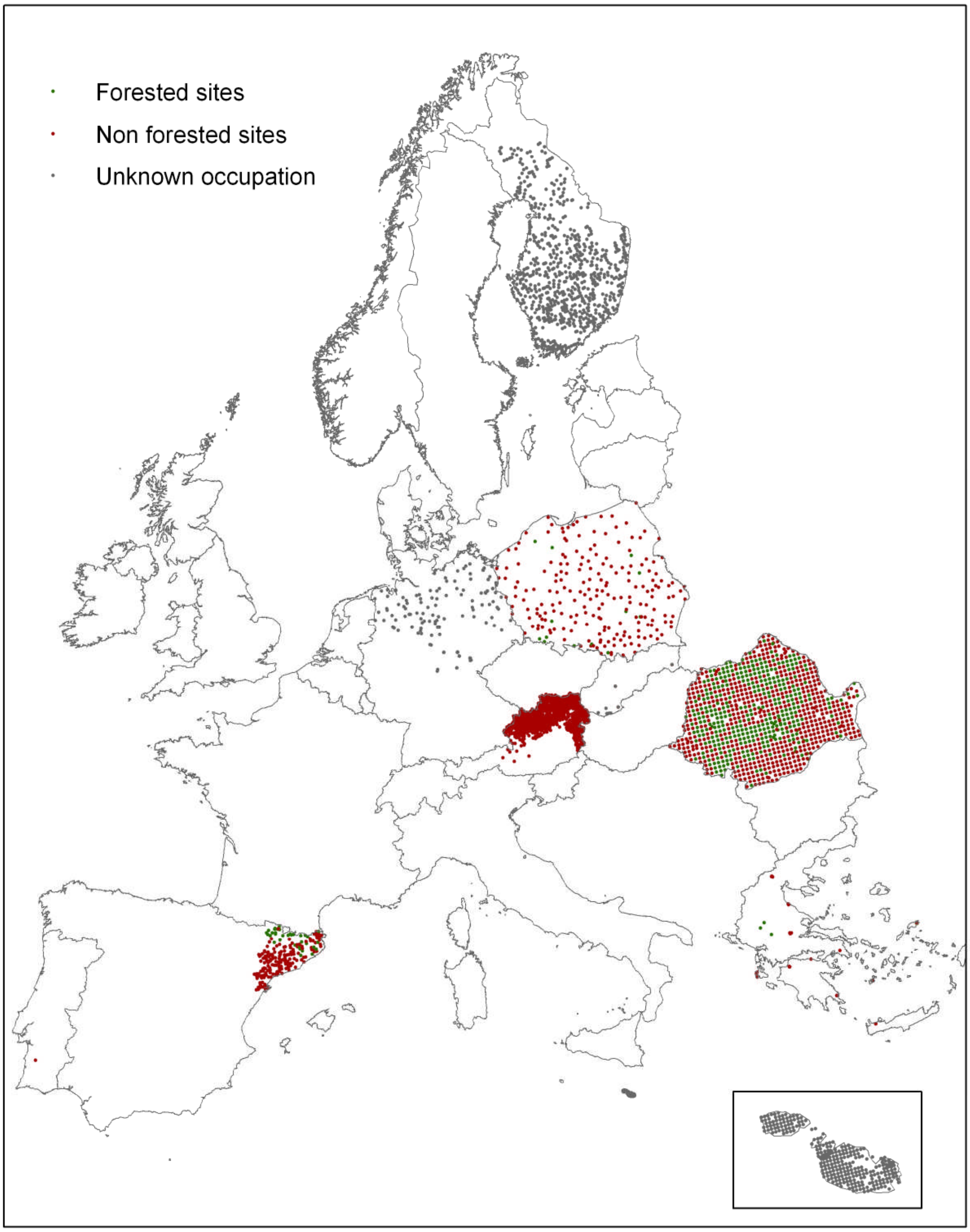

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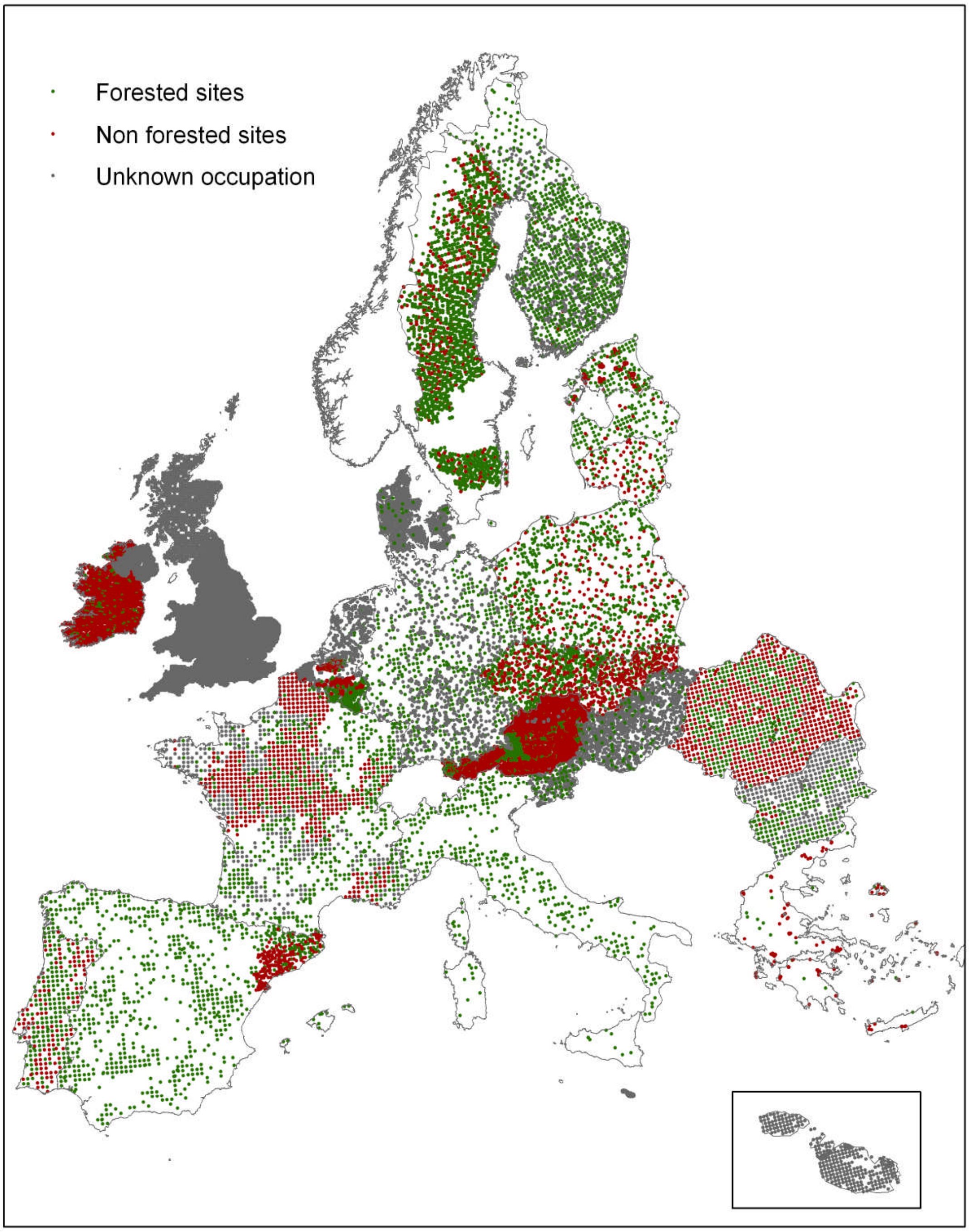

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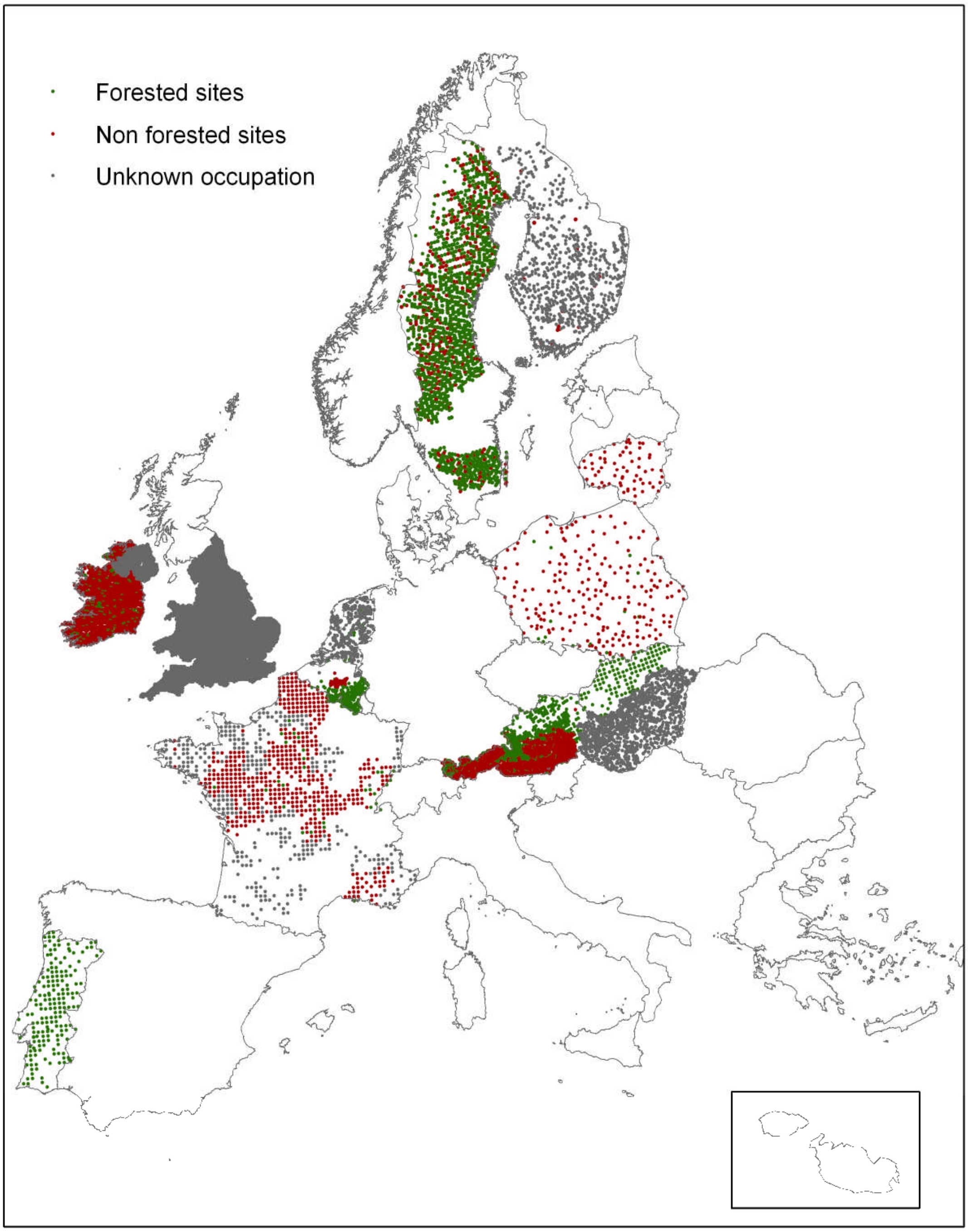

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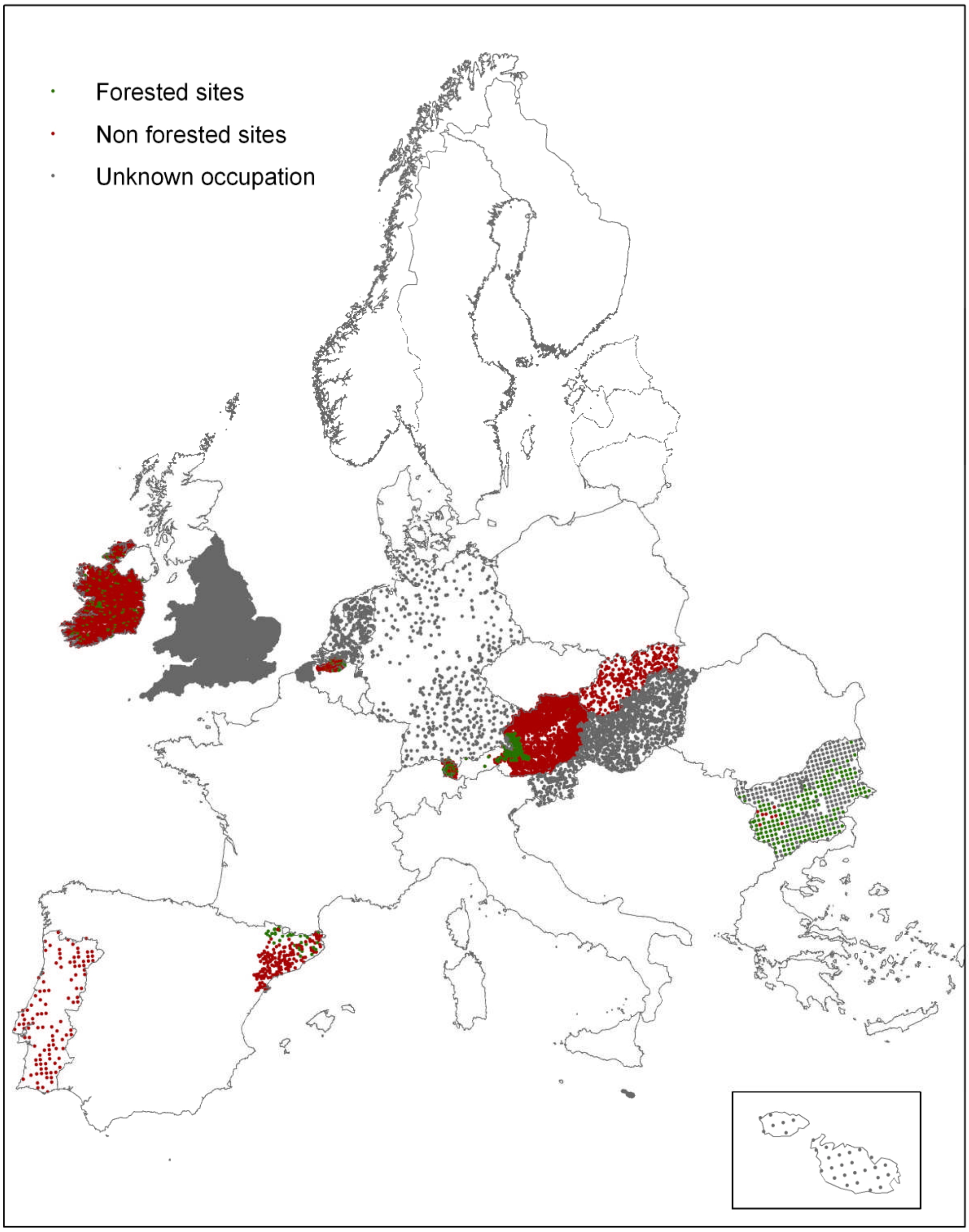

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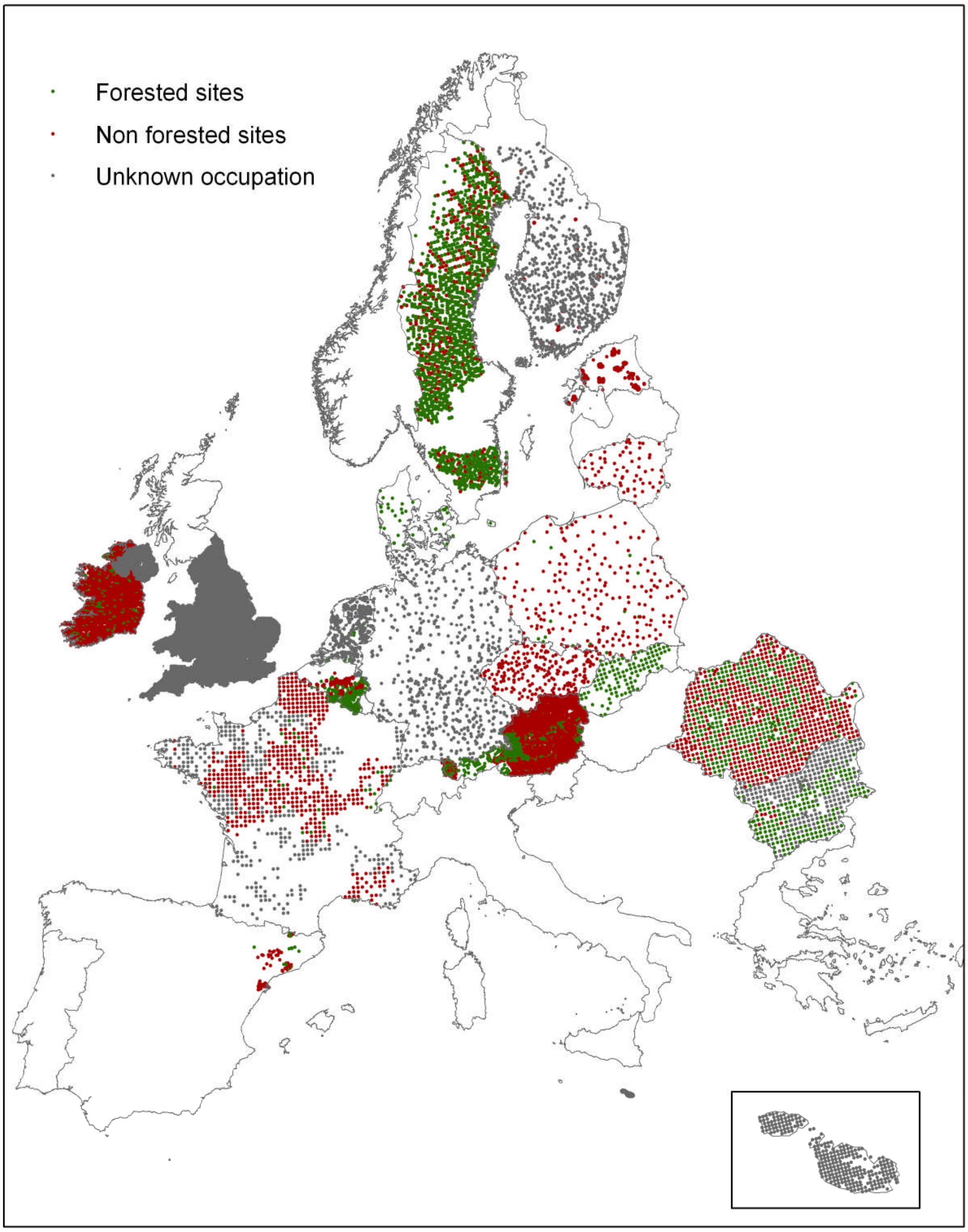

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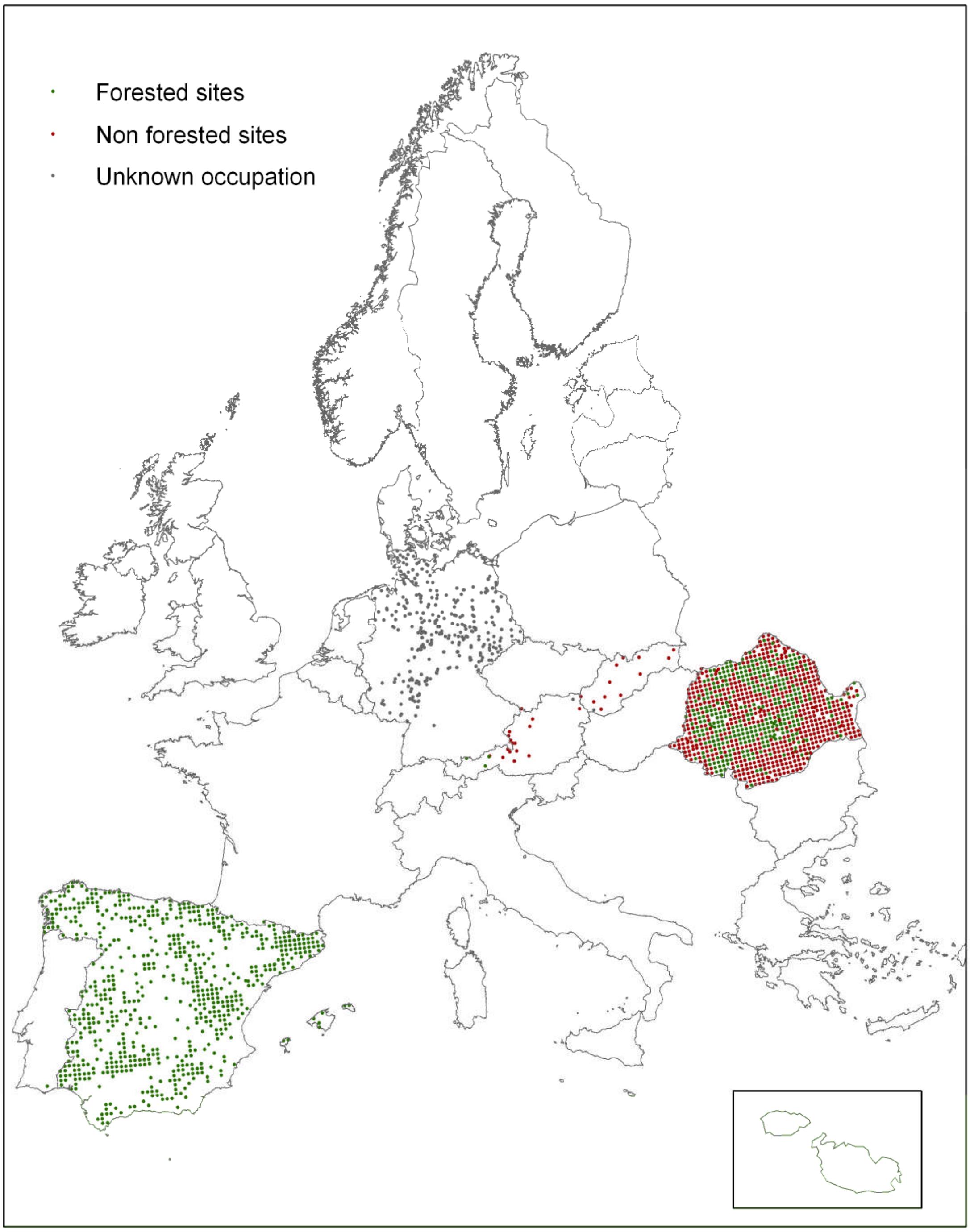

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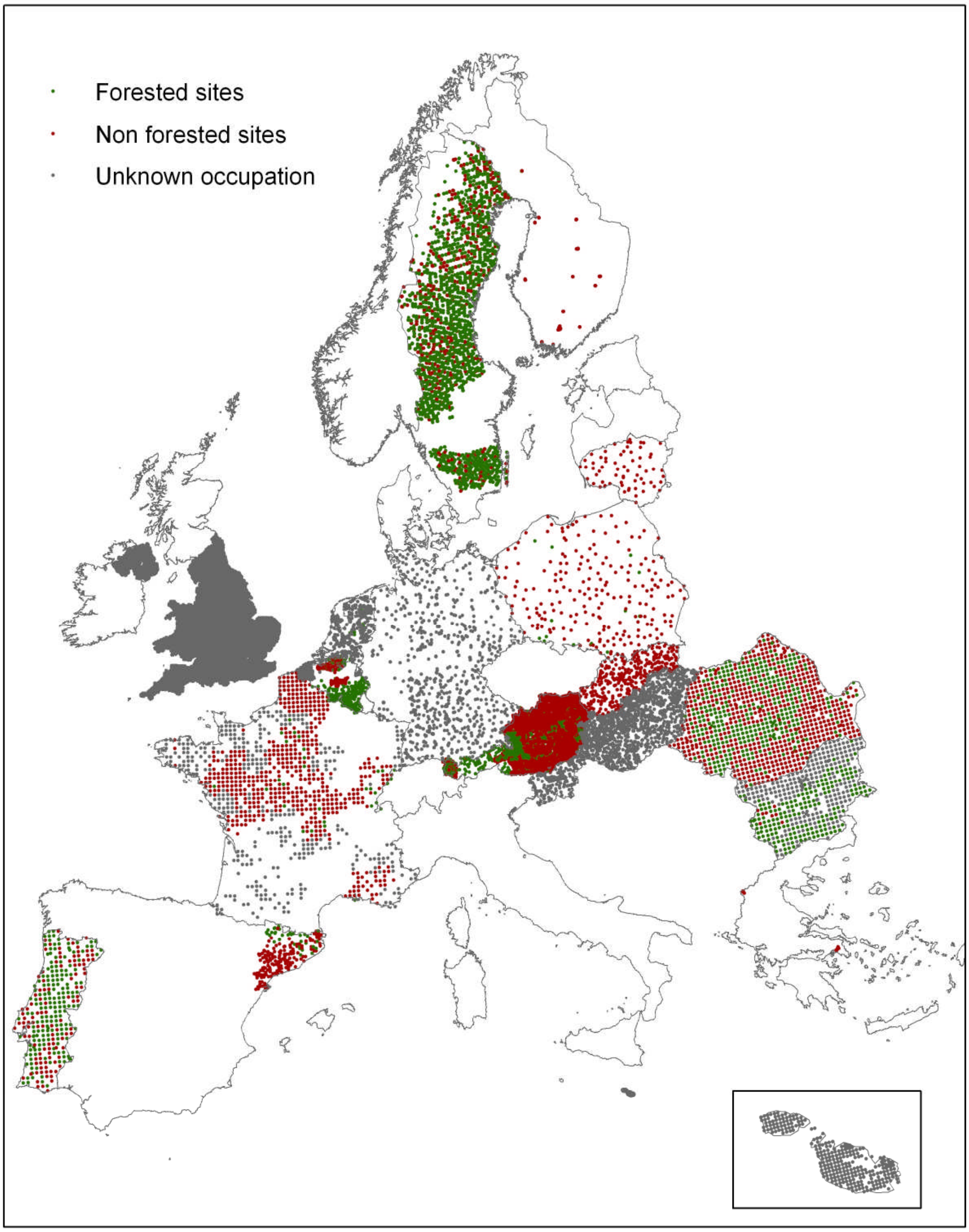

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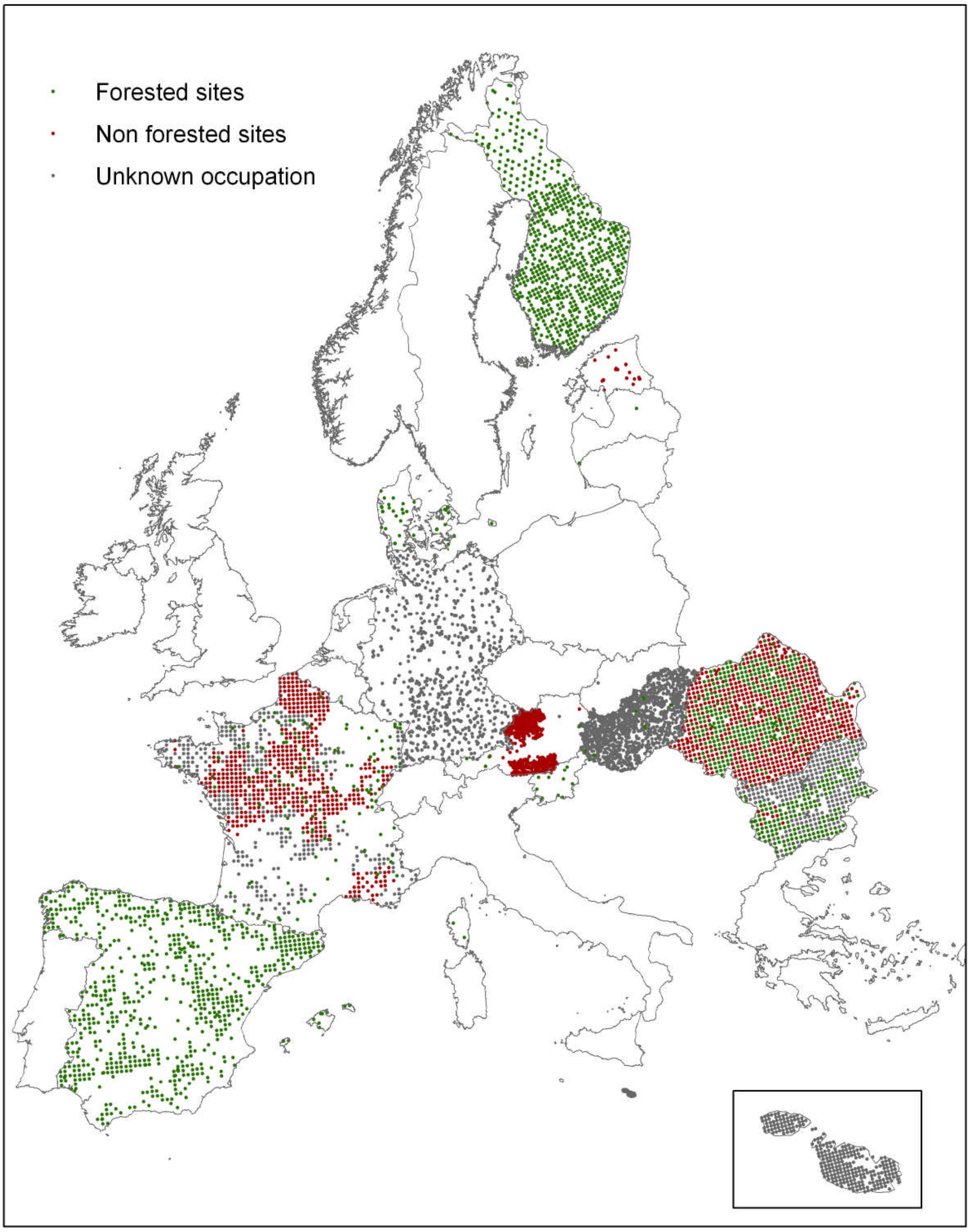

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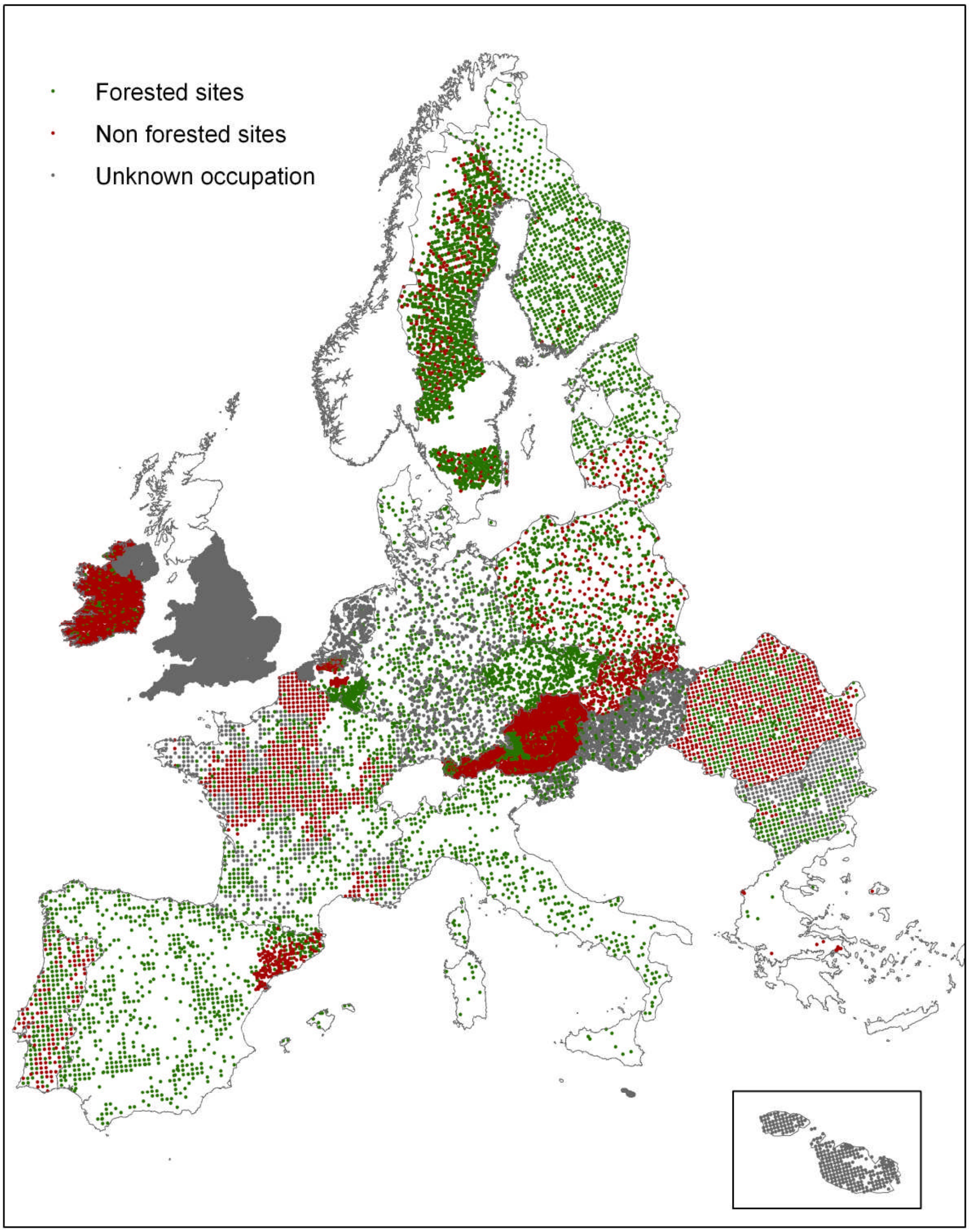

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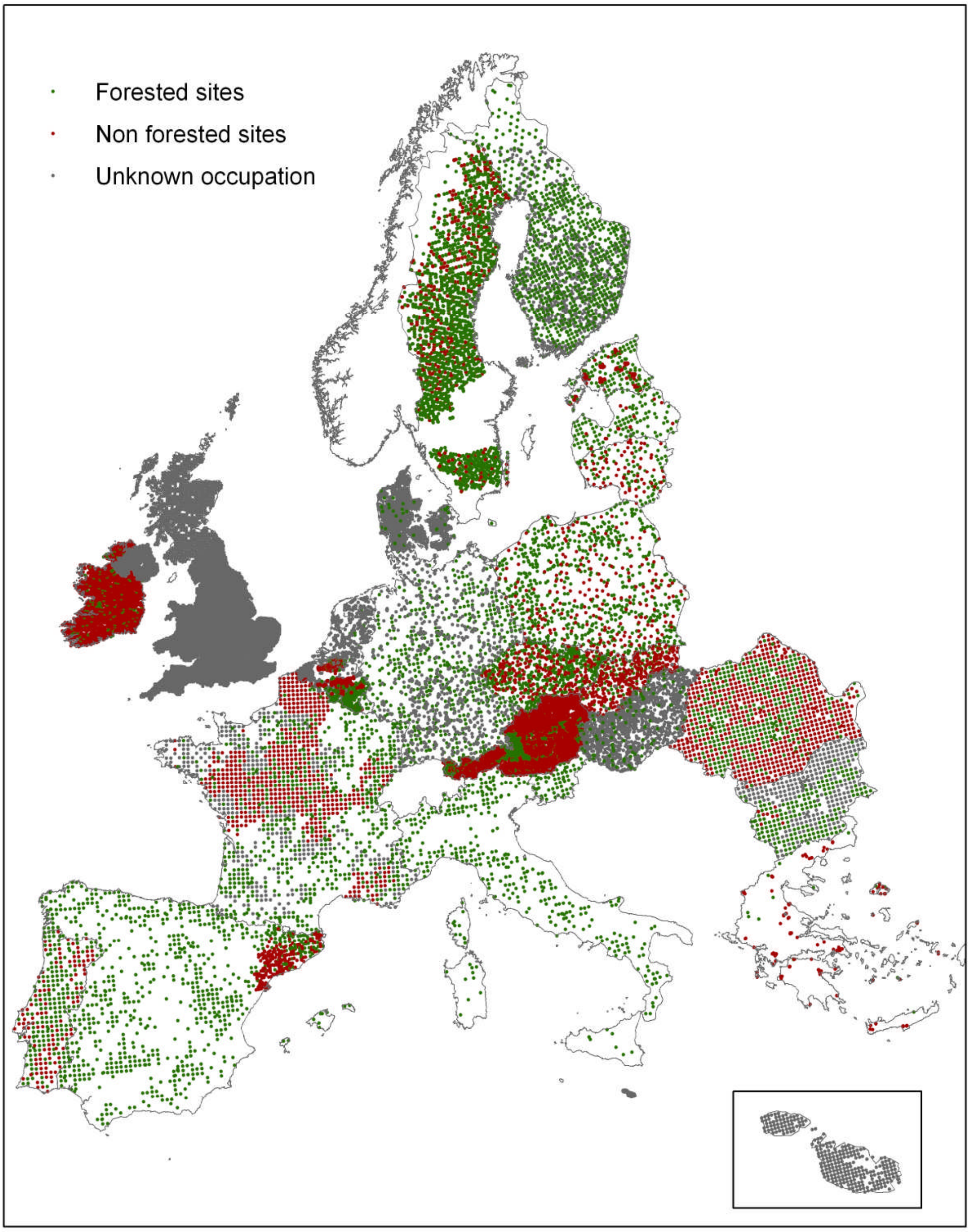

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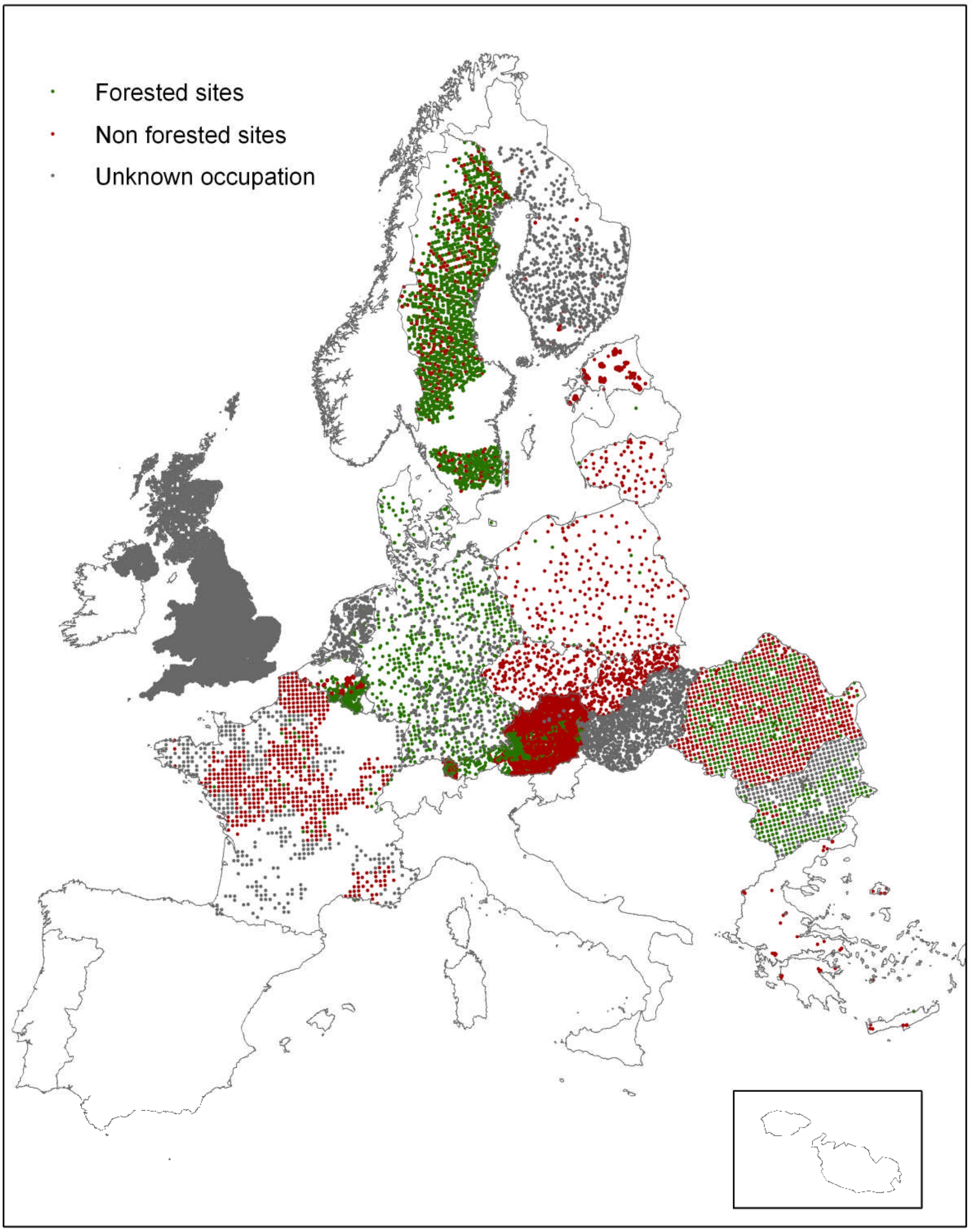

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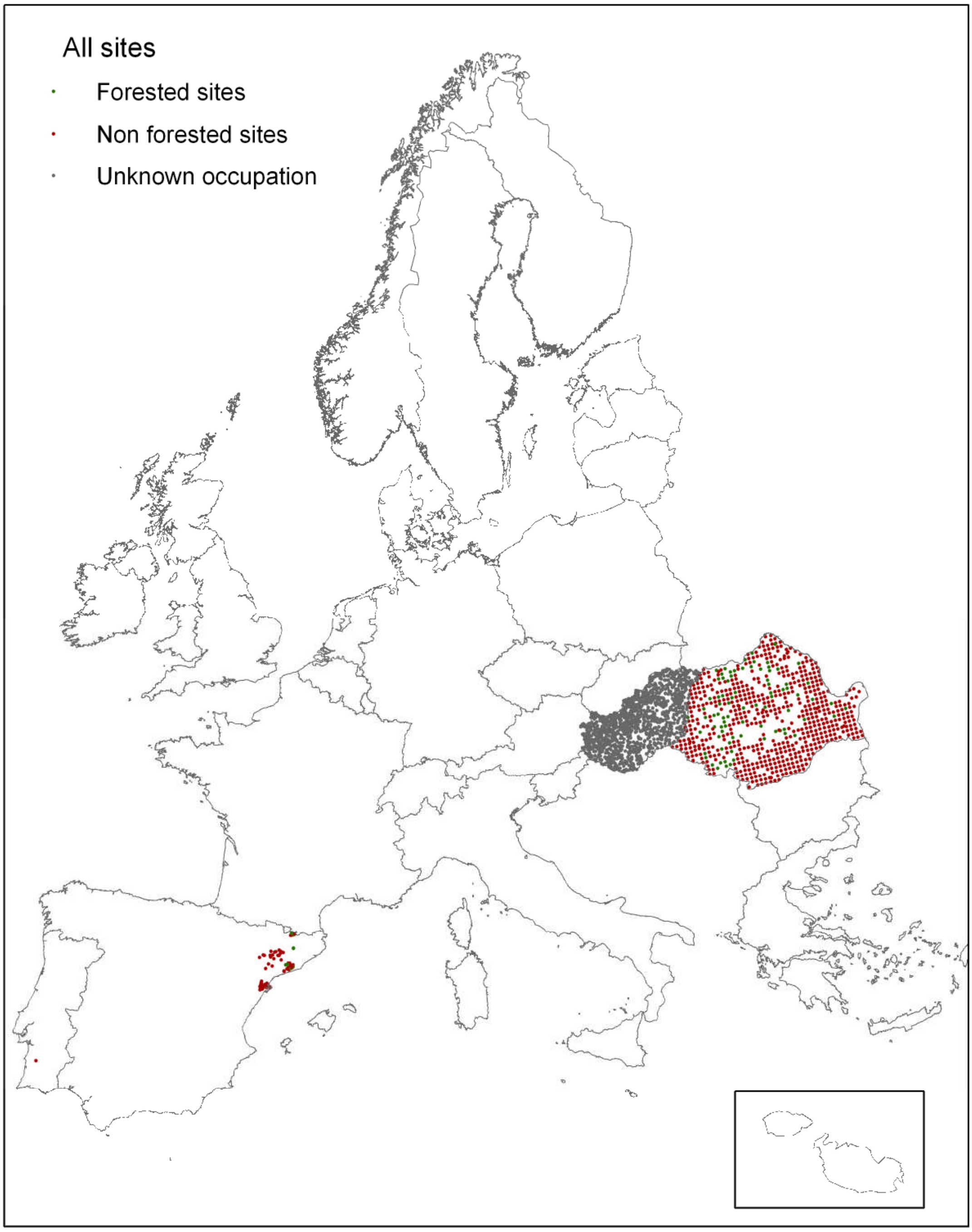

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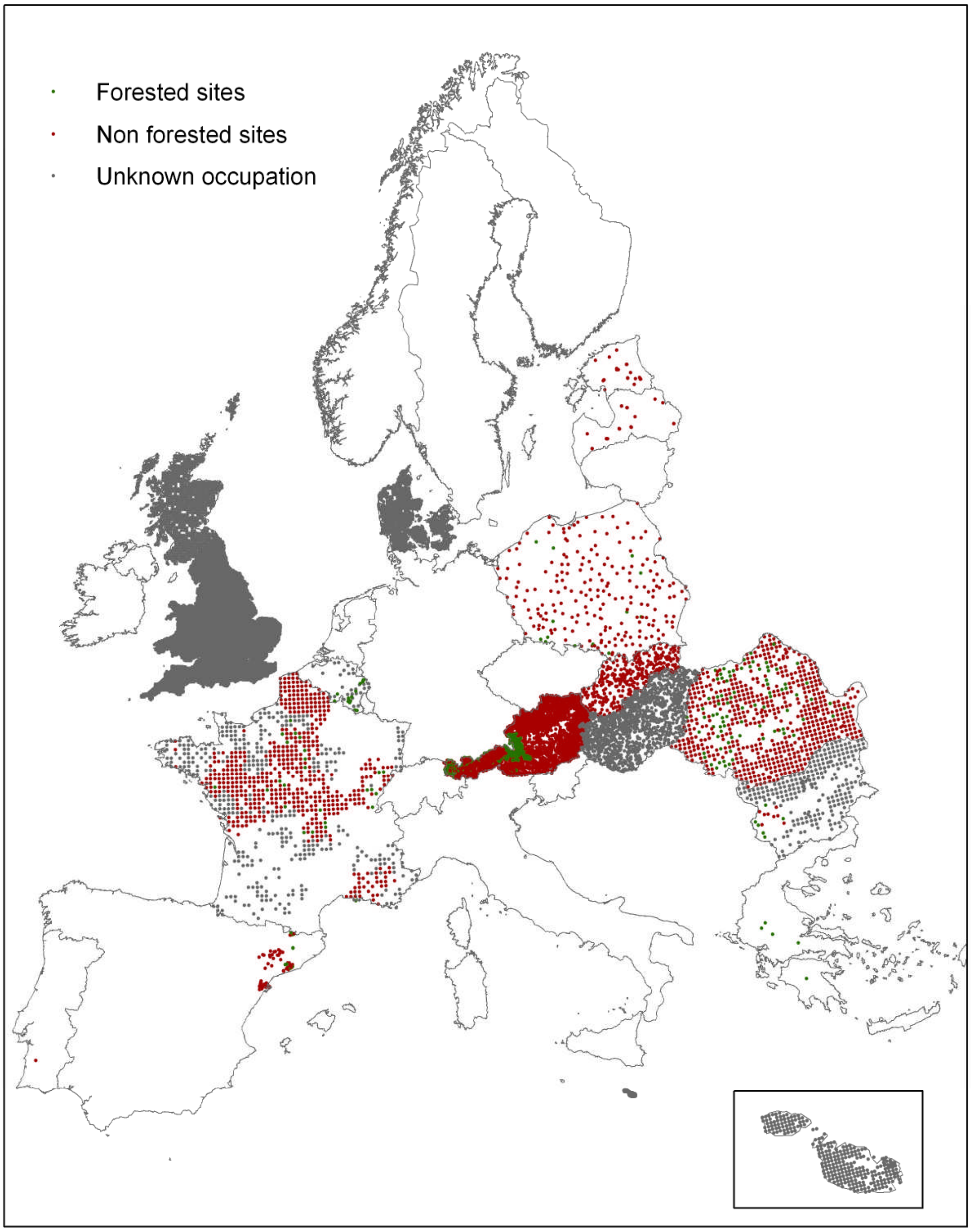

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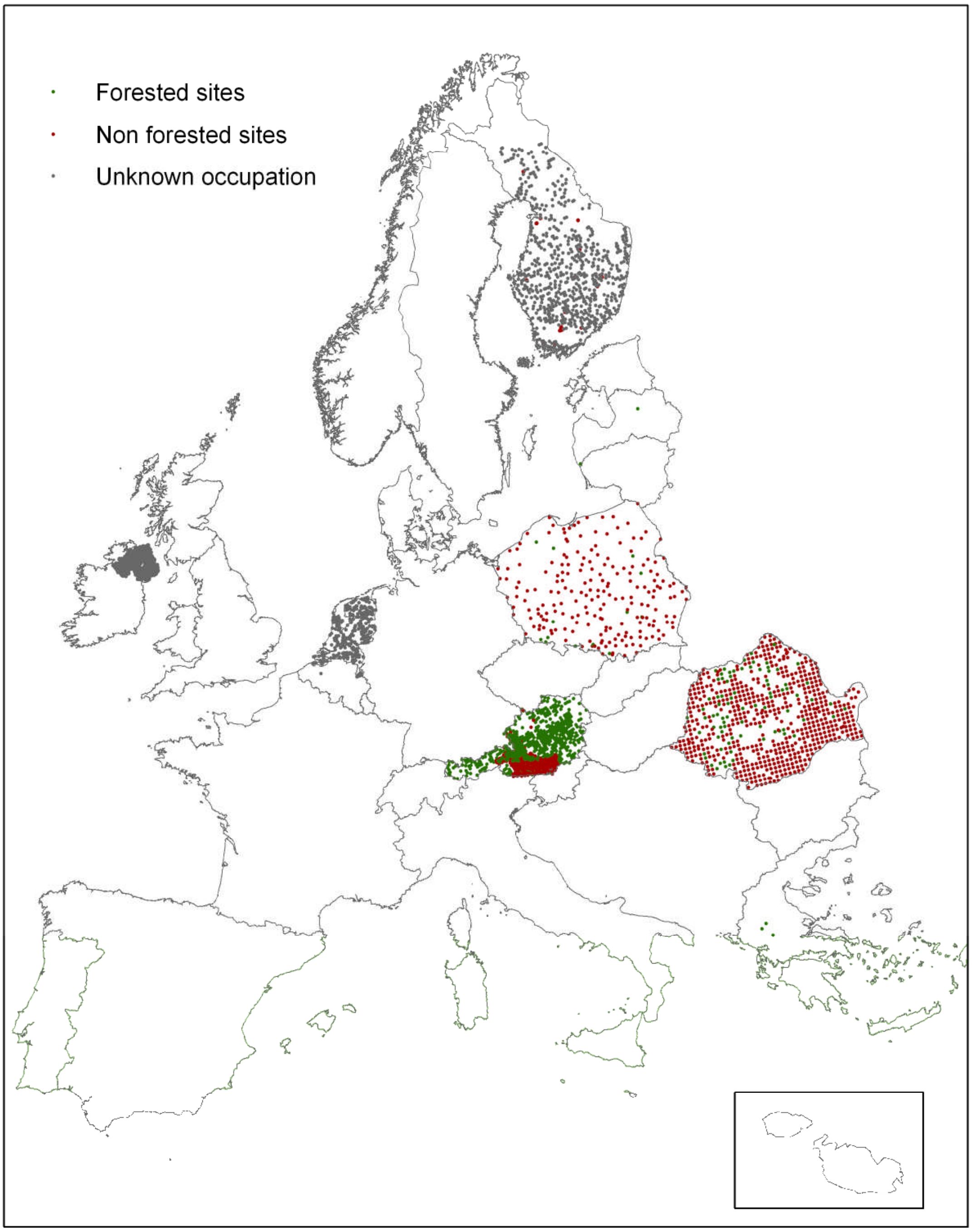

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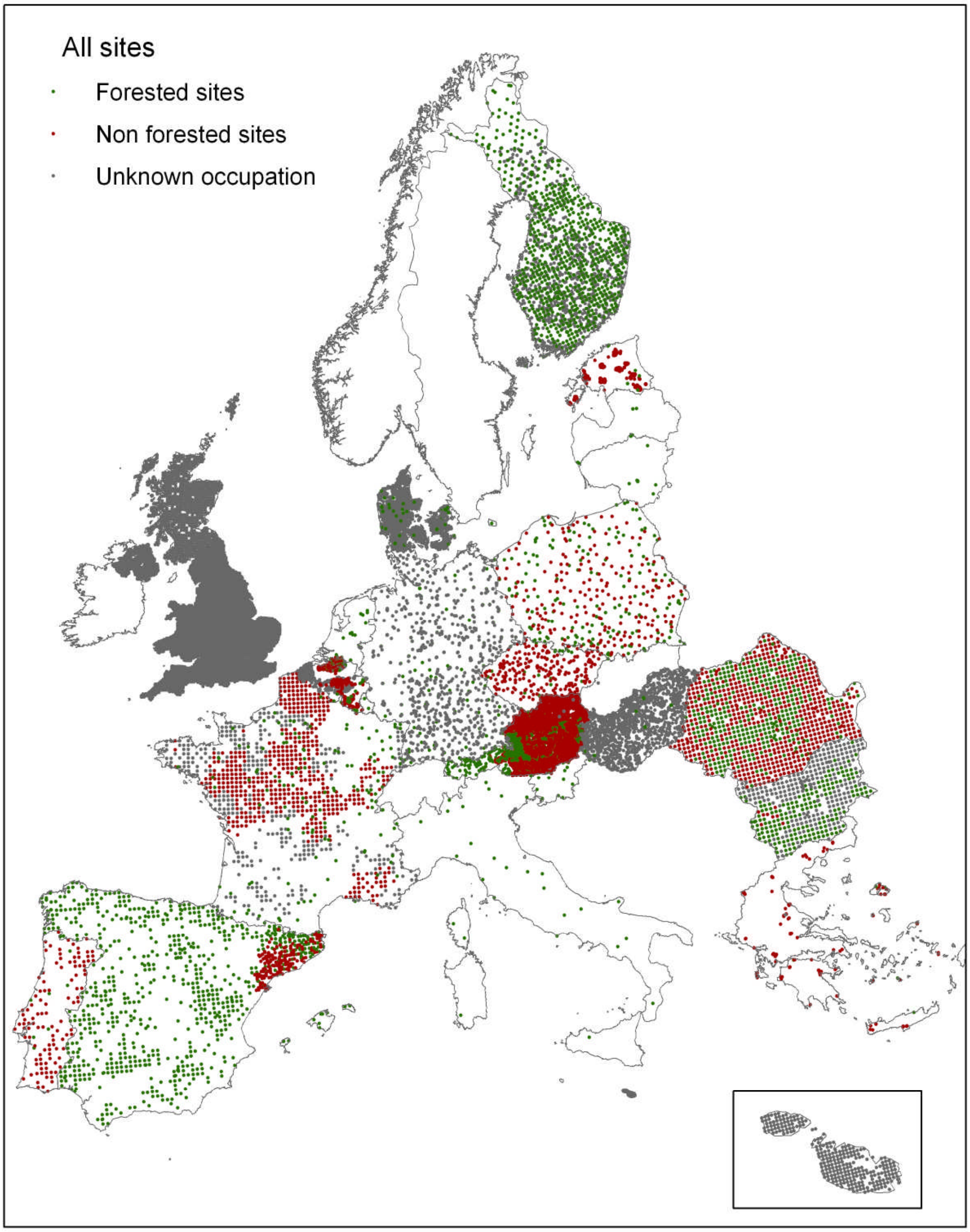

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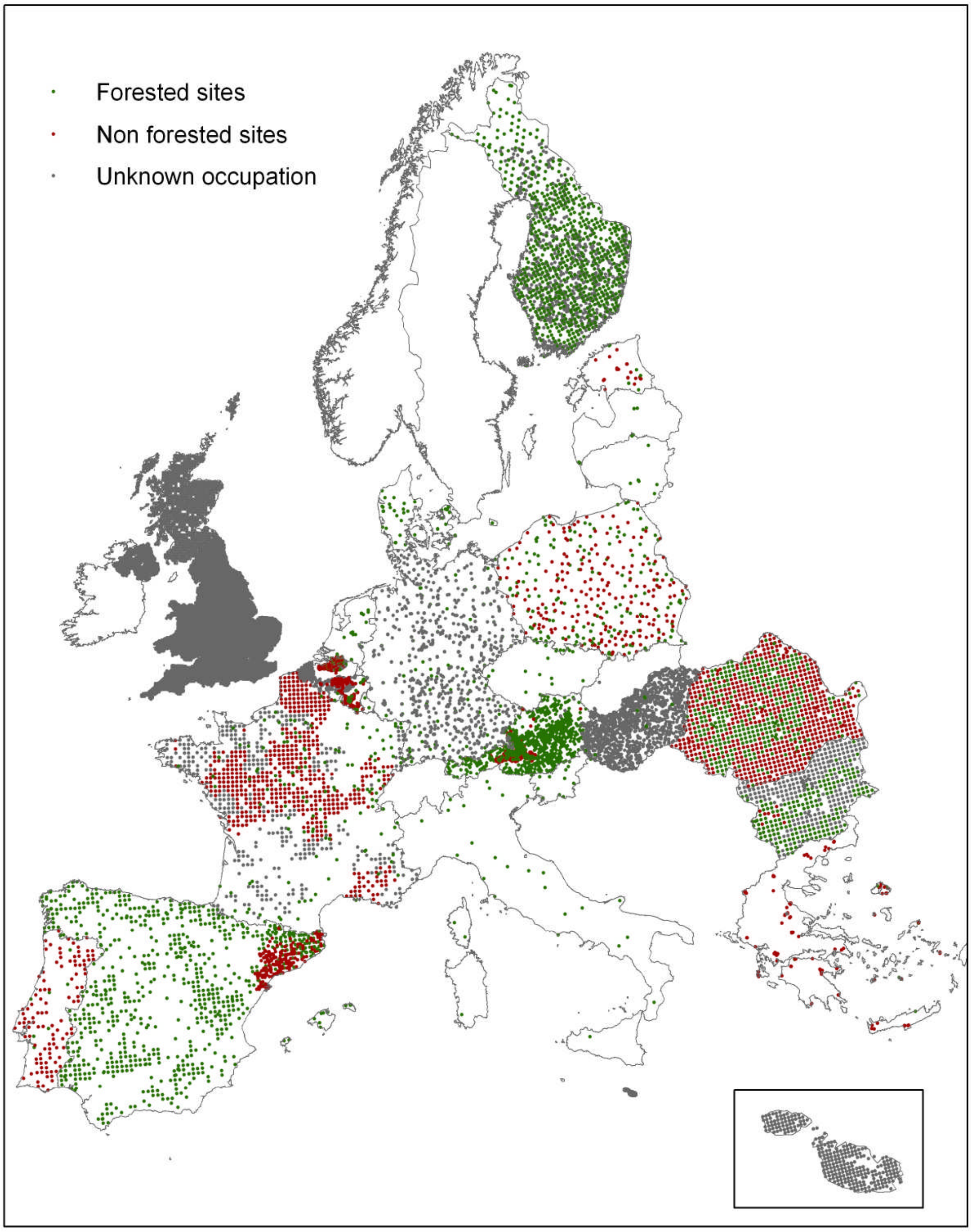

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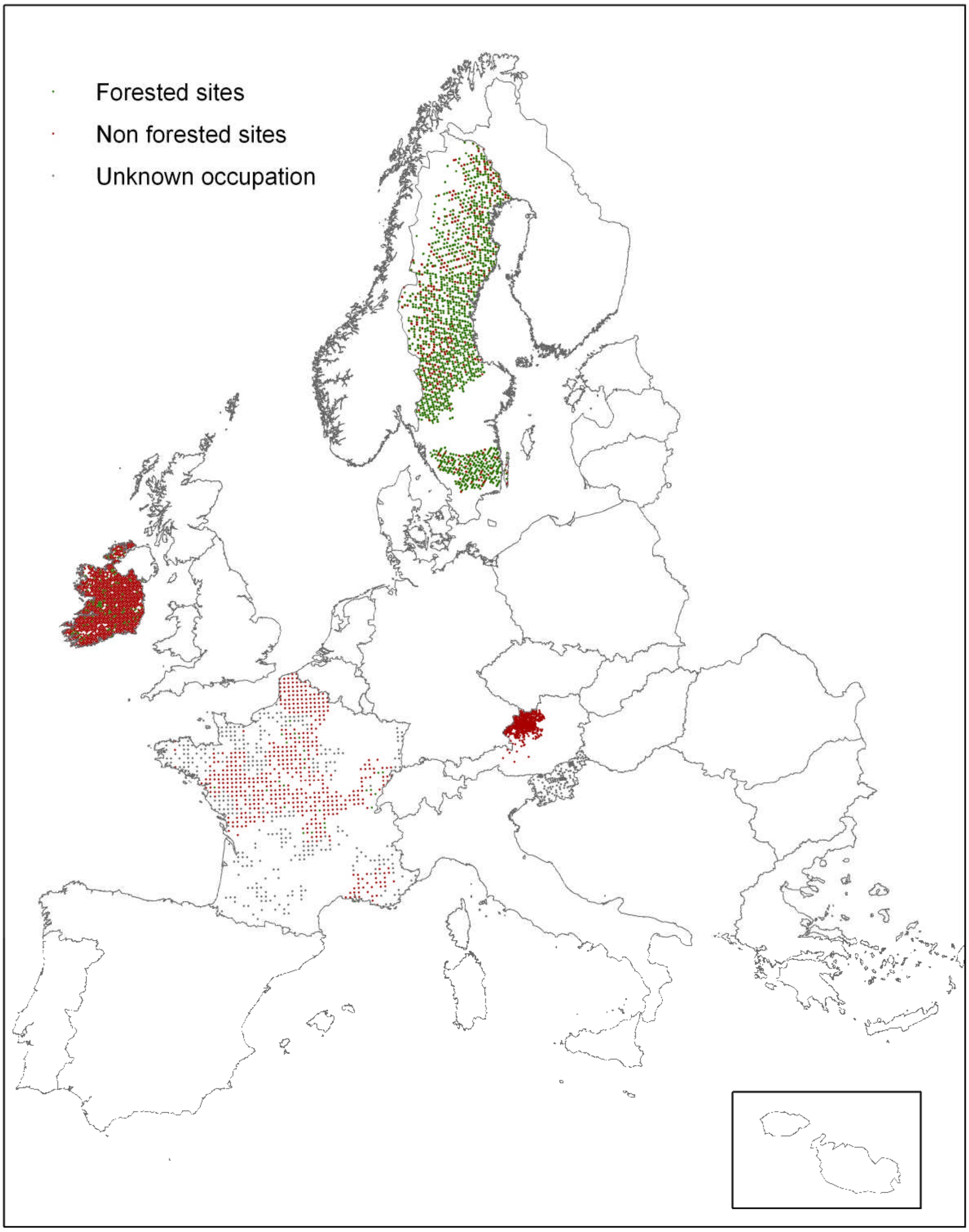

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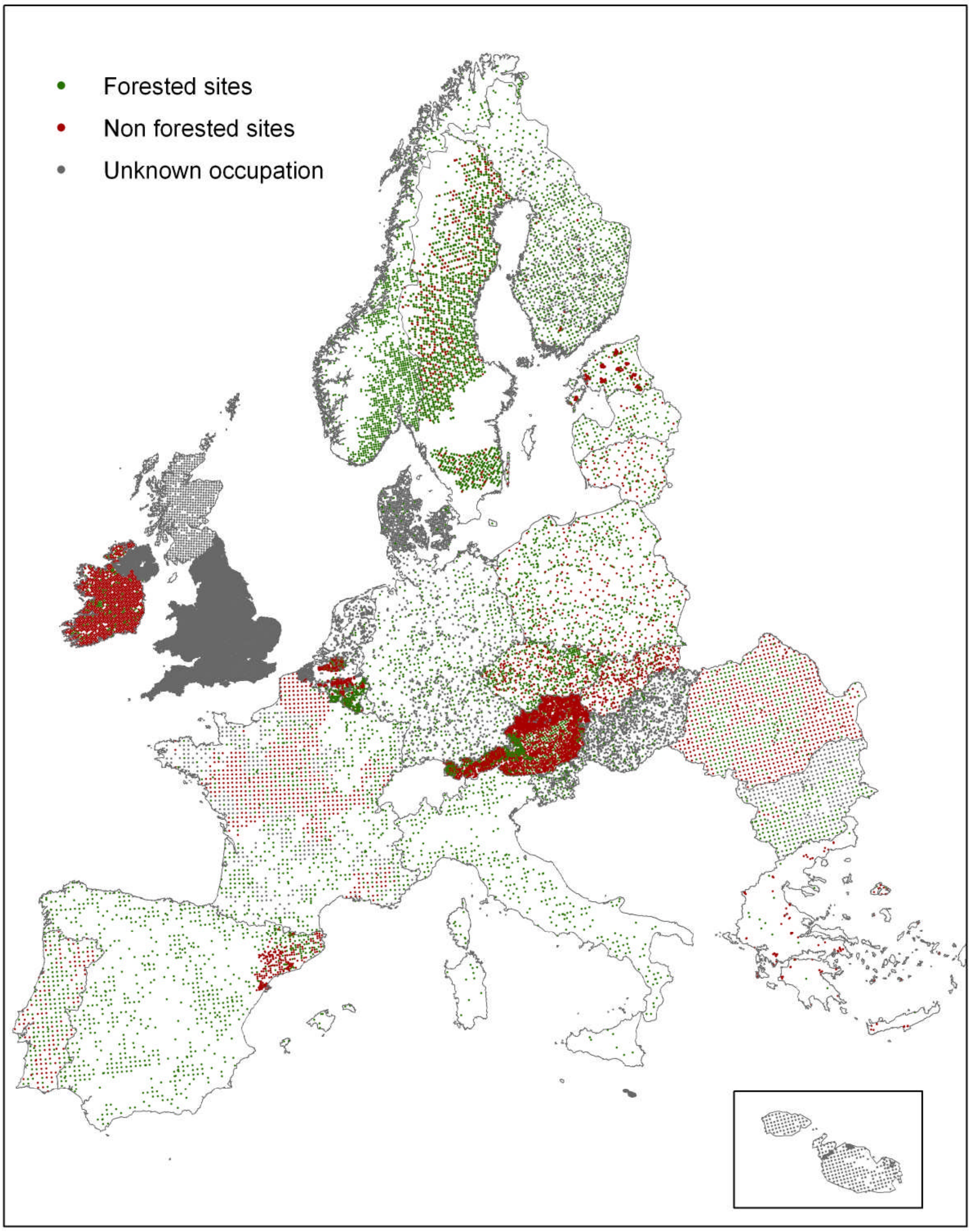

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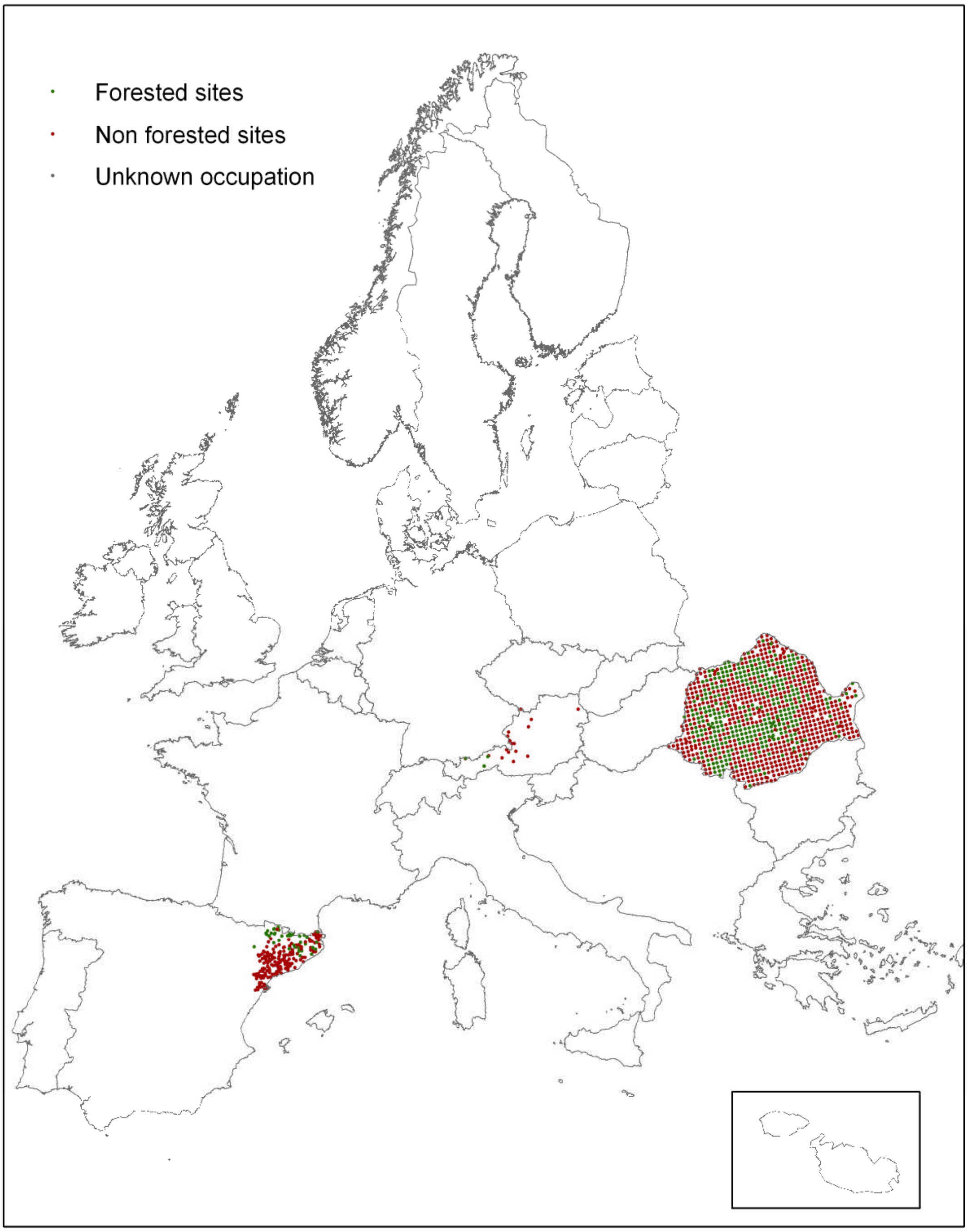

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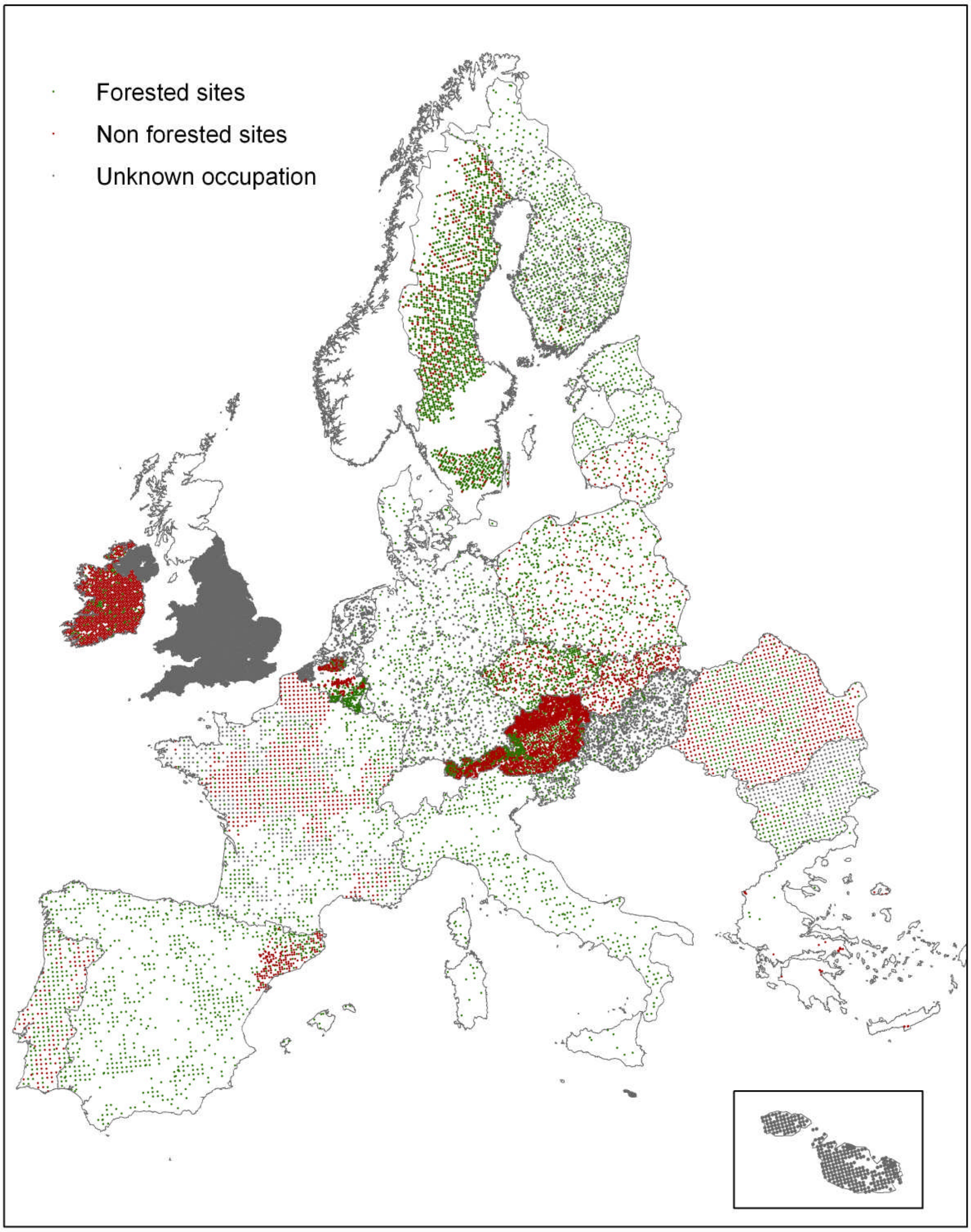

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Density of Soil Monitoring Sites and Indicator Measurements in European Soil Mapping Units

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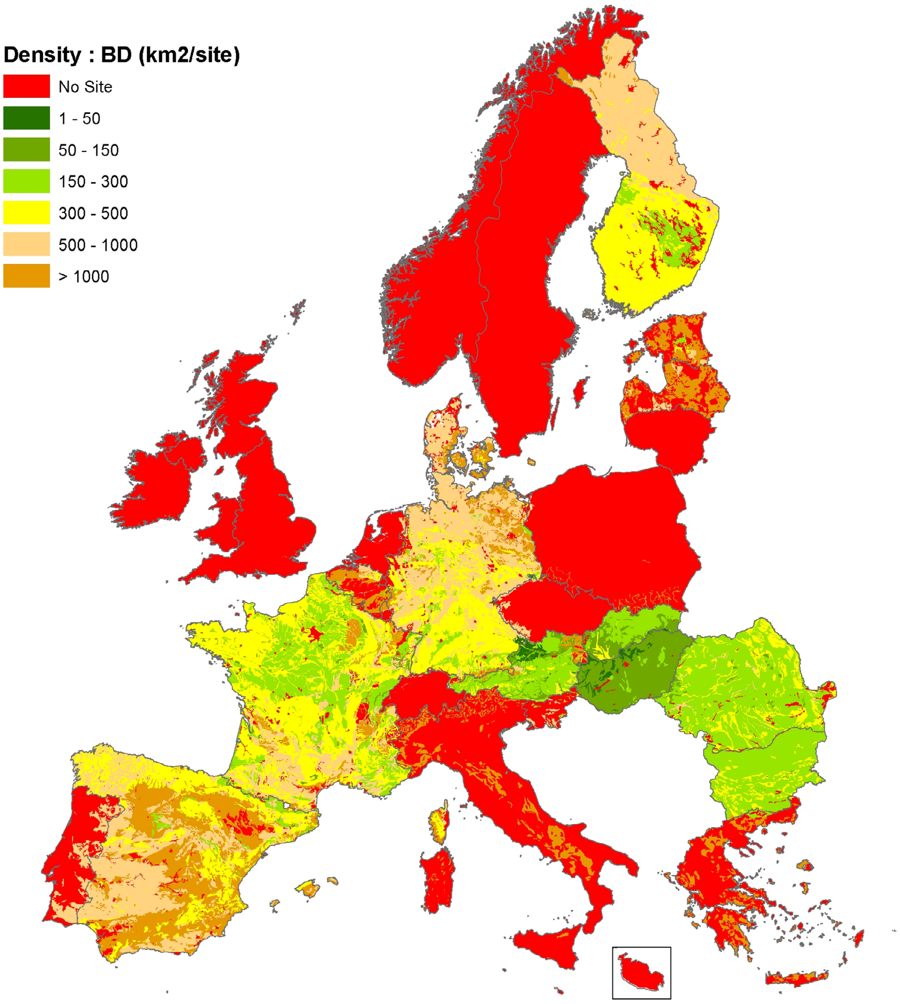

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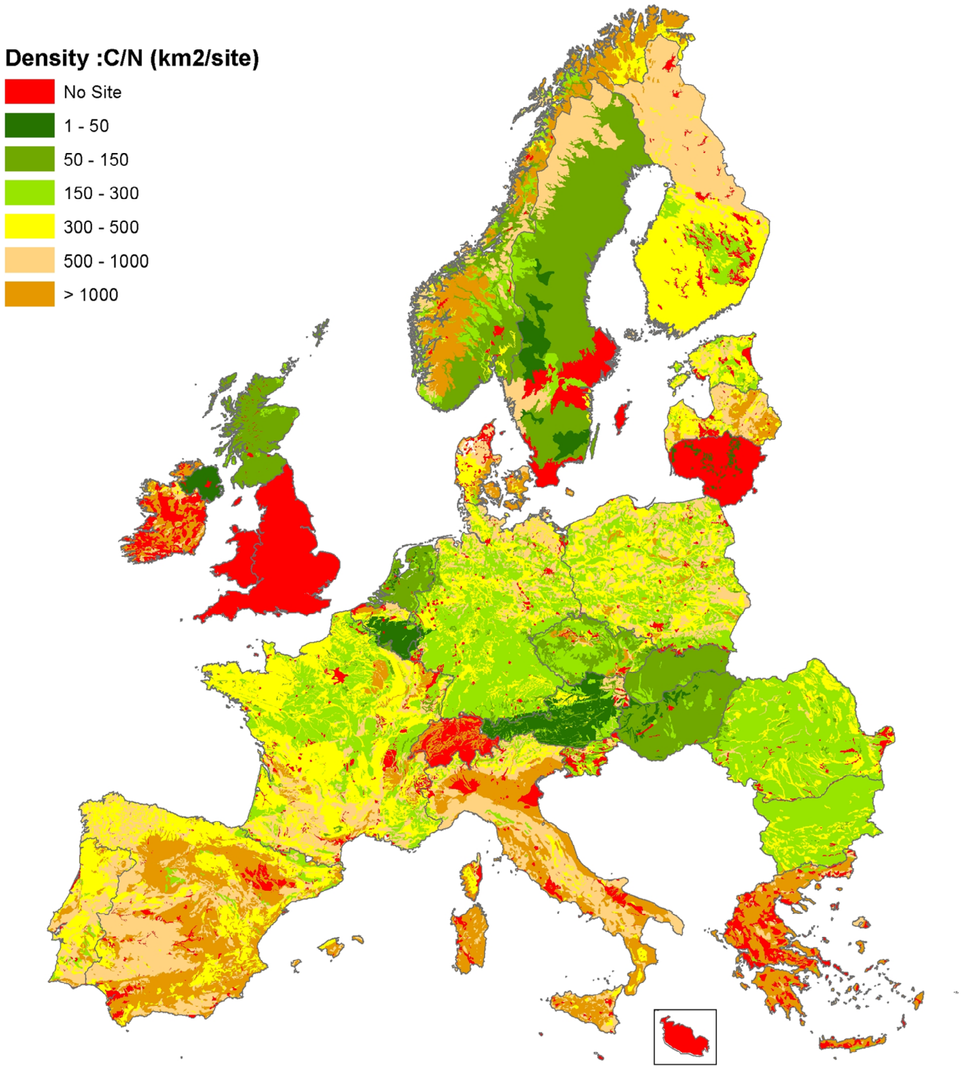

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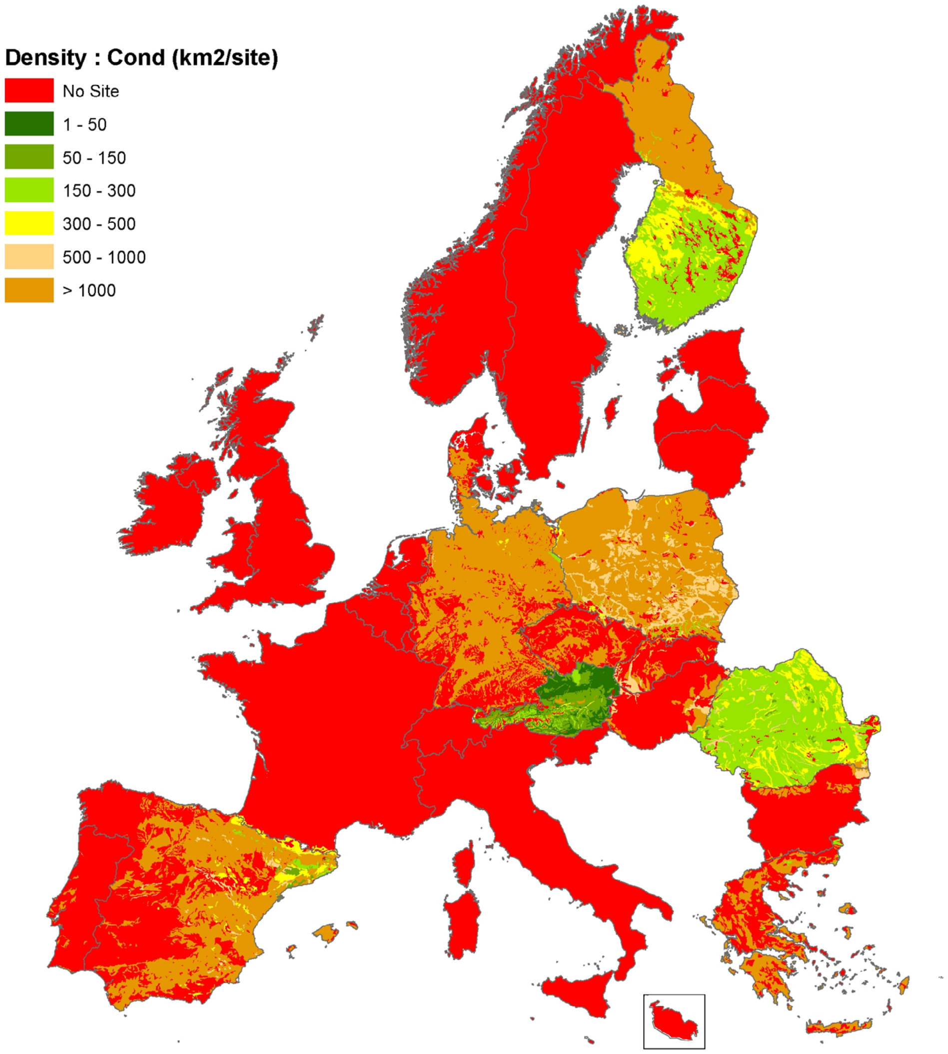

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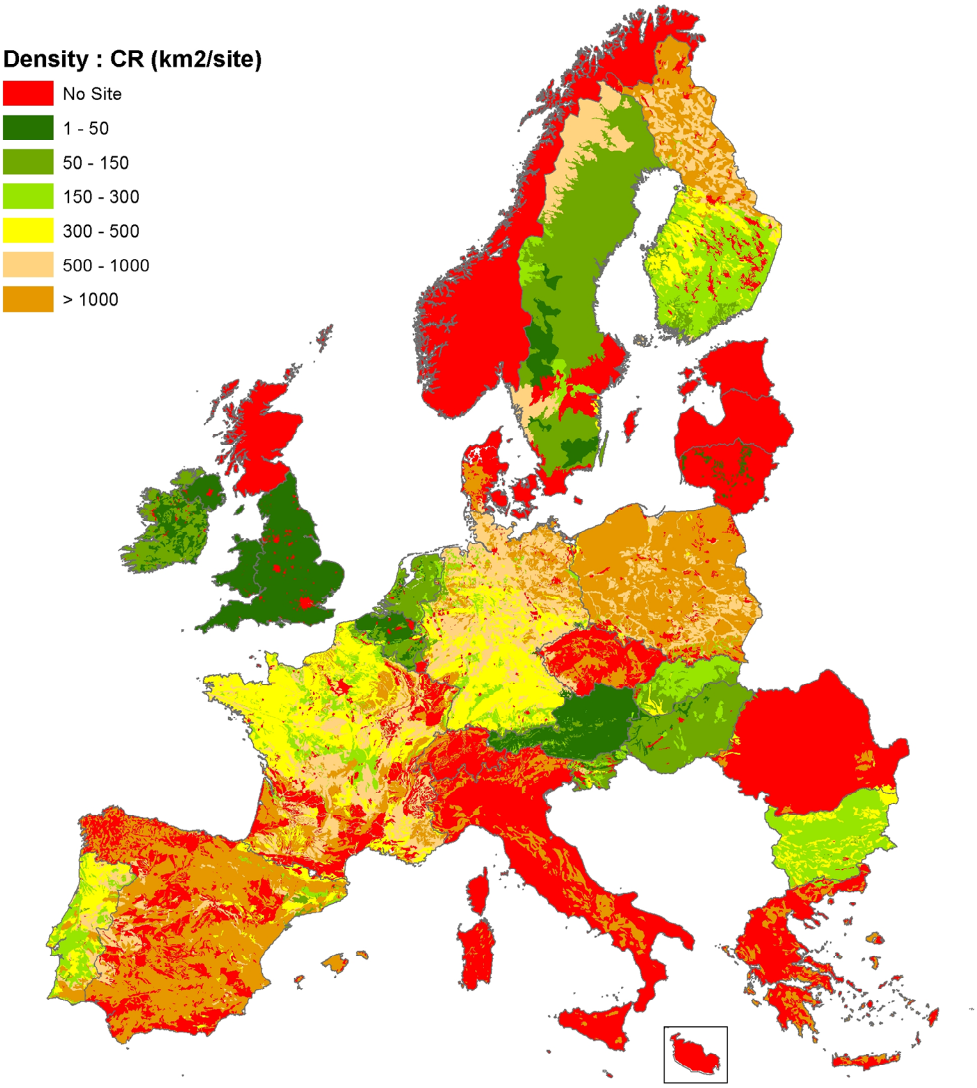

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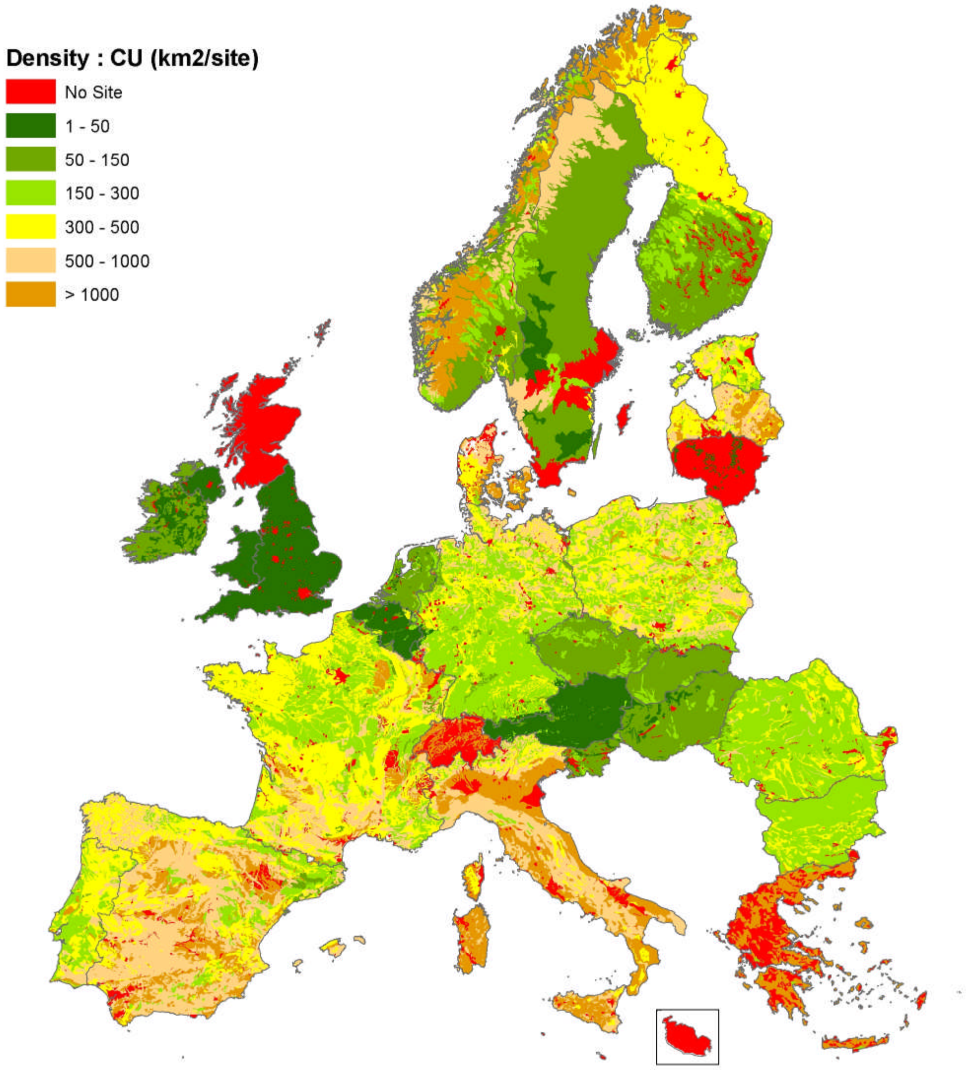

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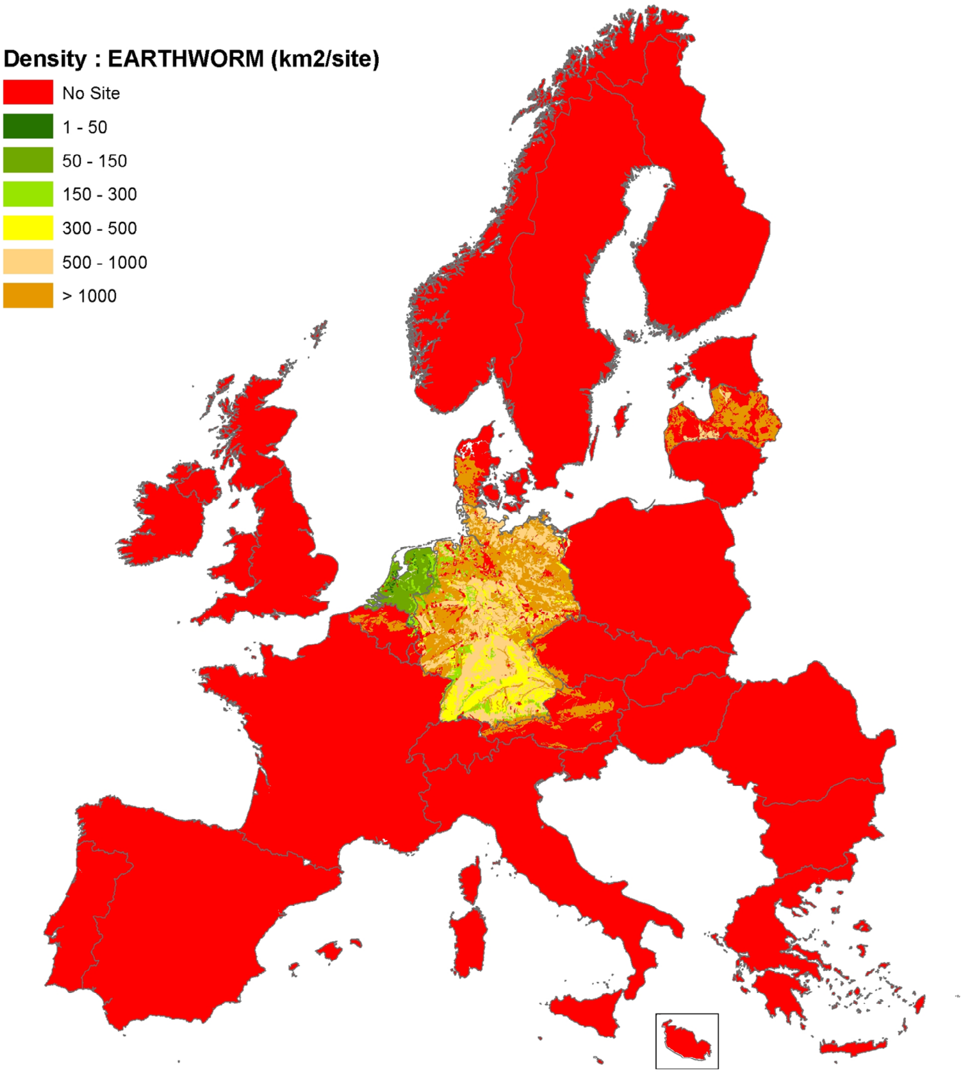

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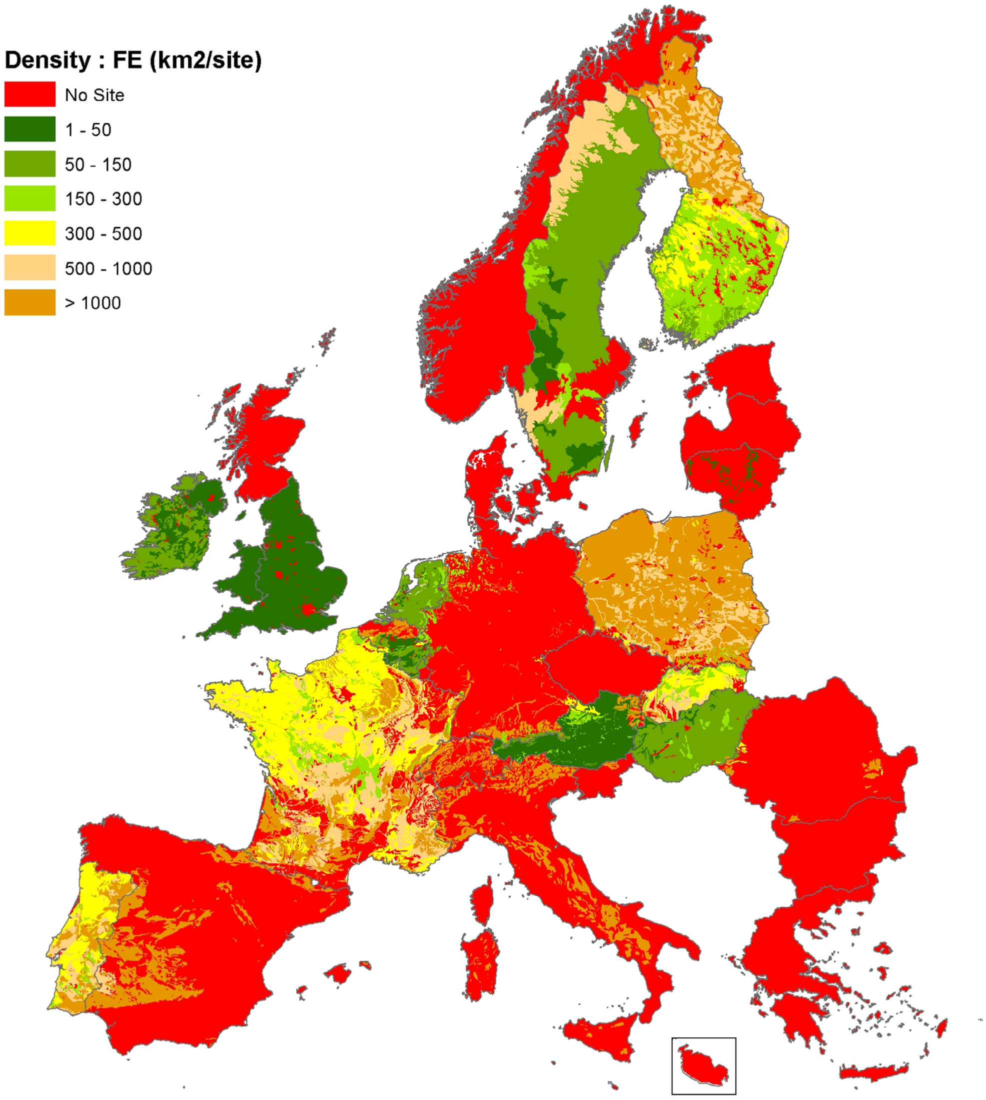

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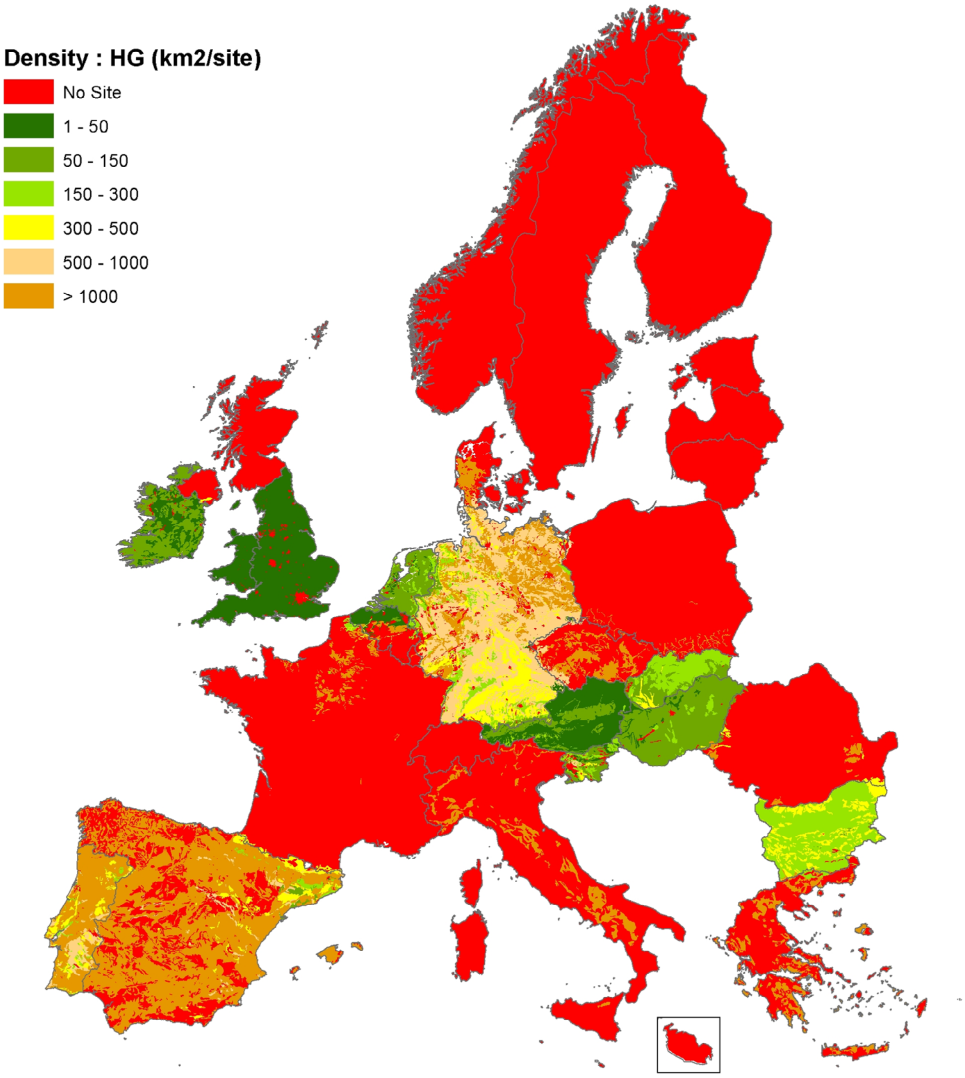

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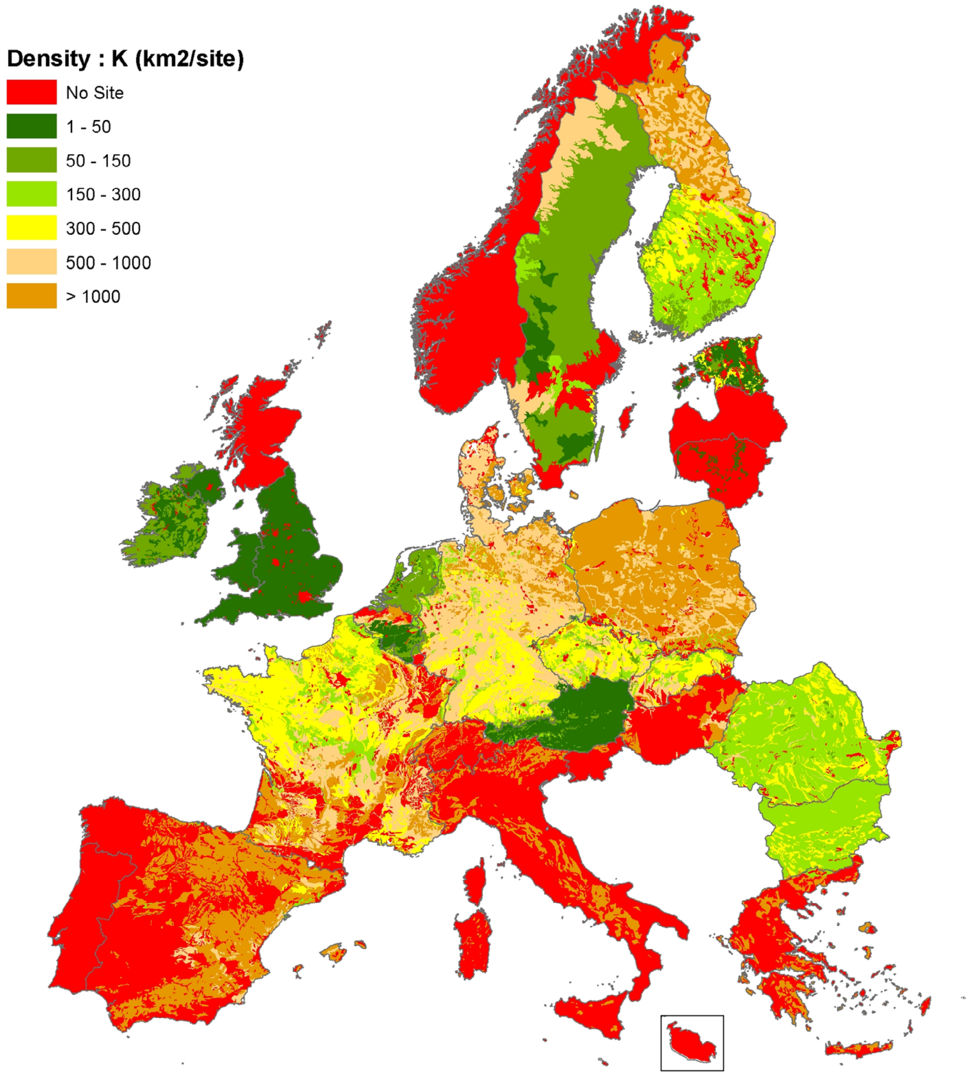

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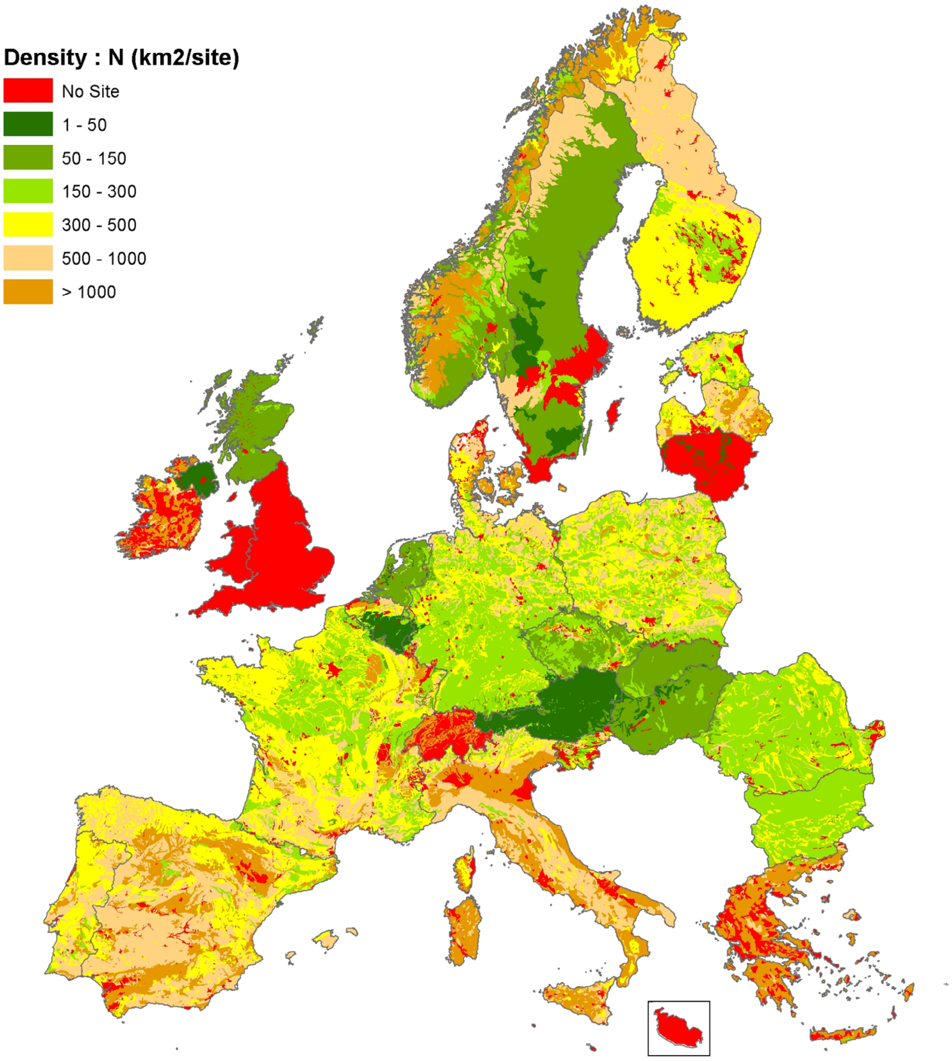

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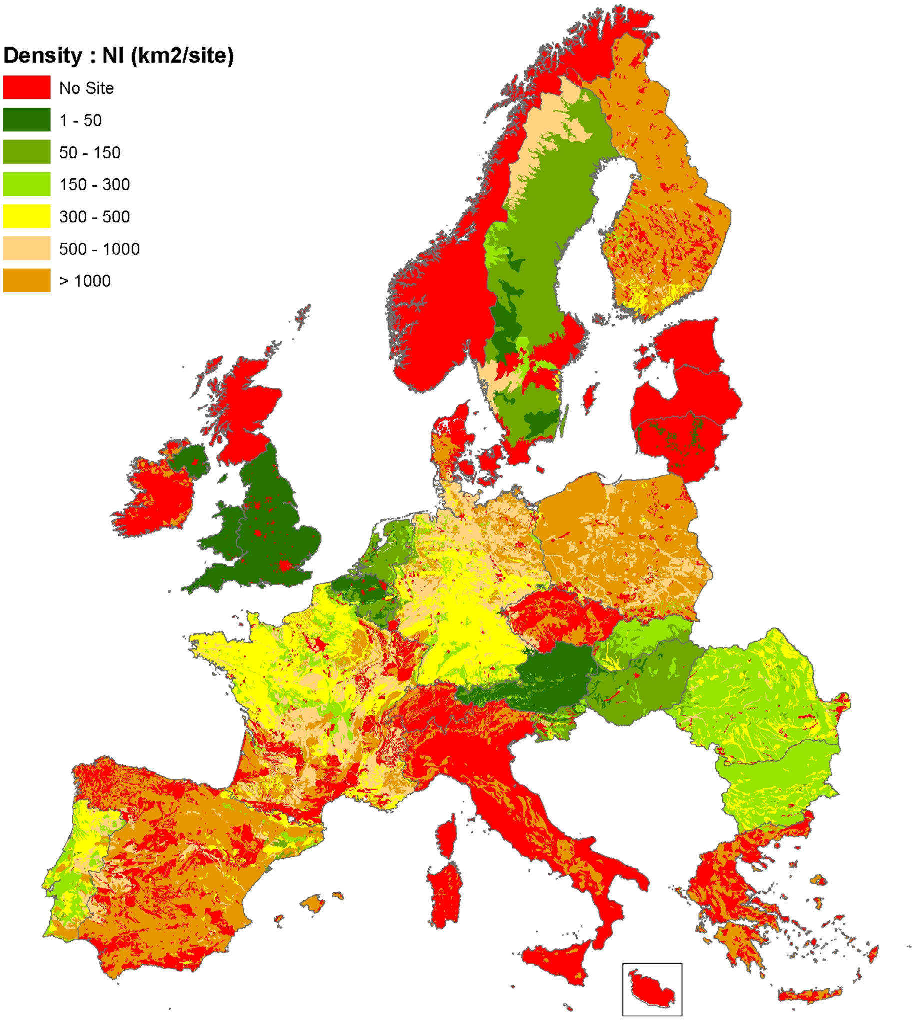

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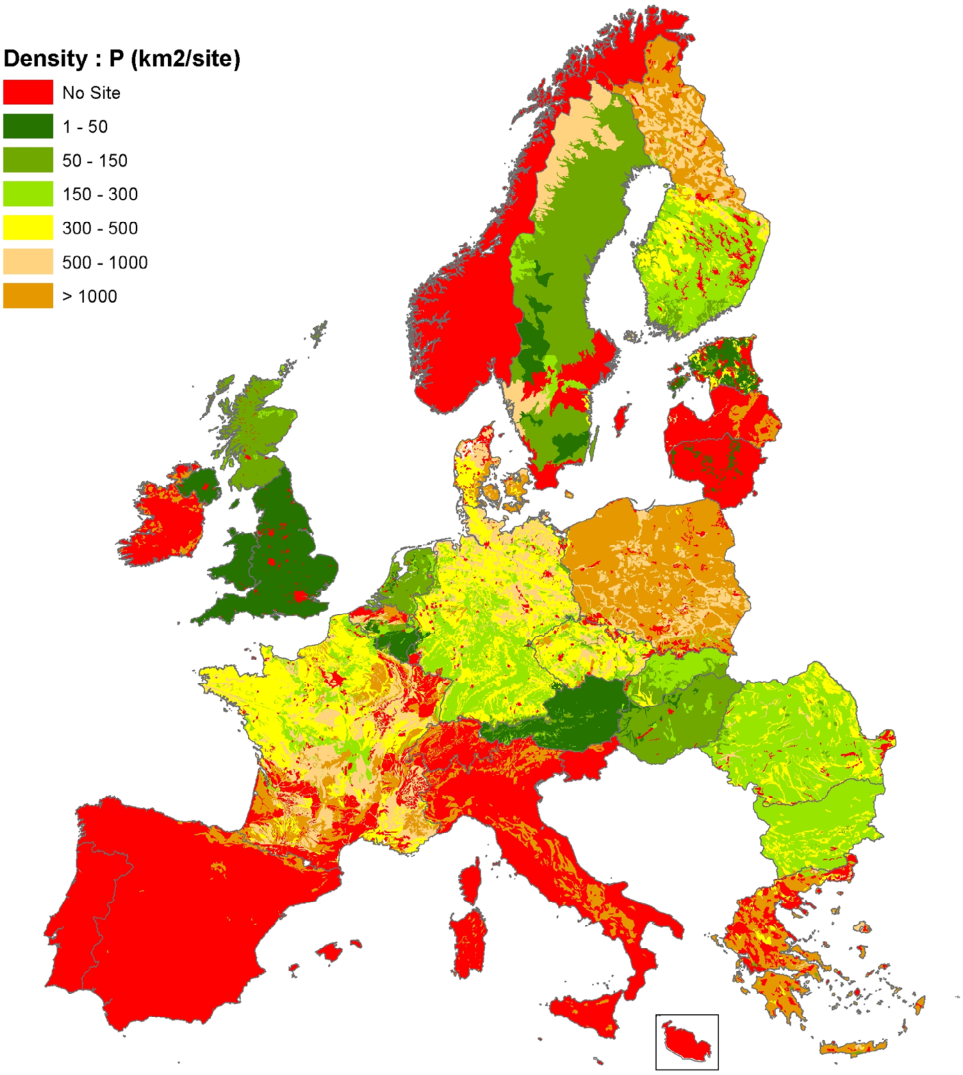

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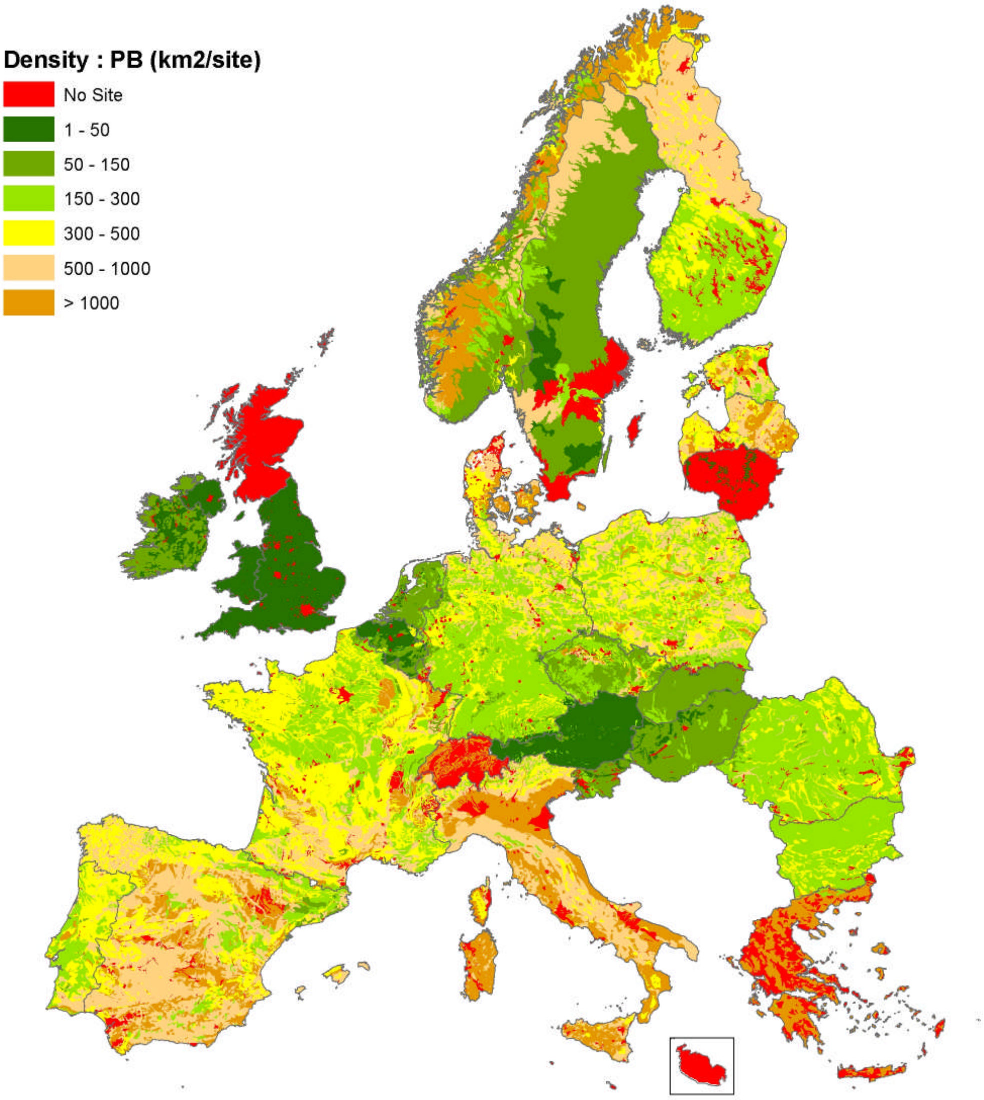

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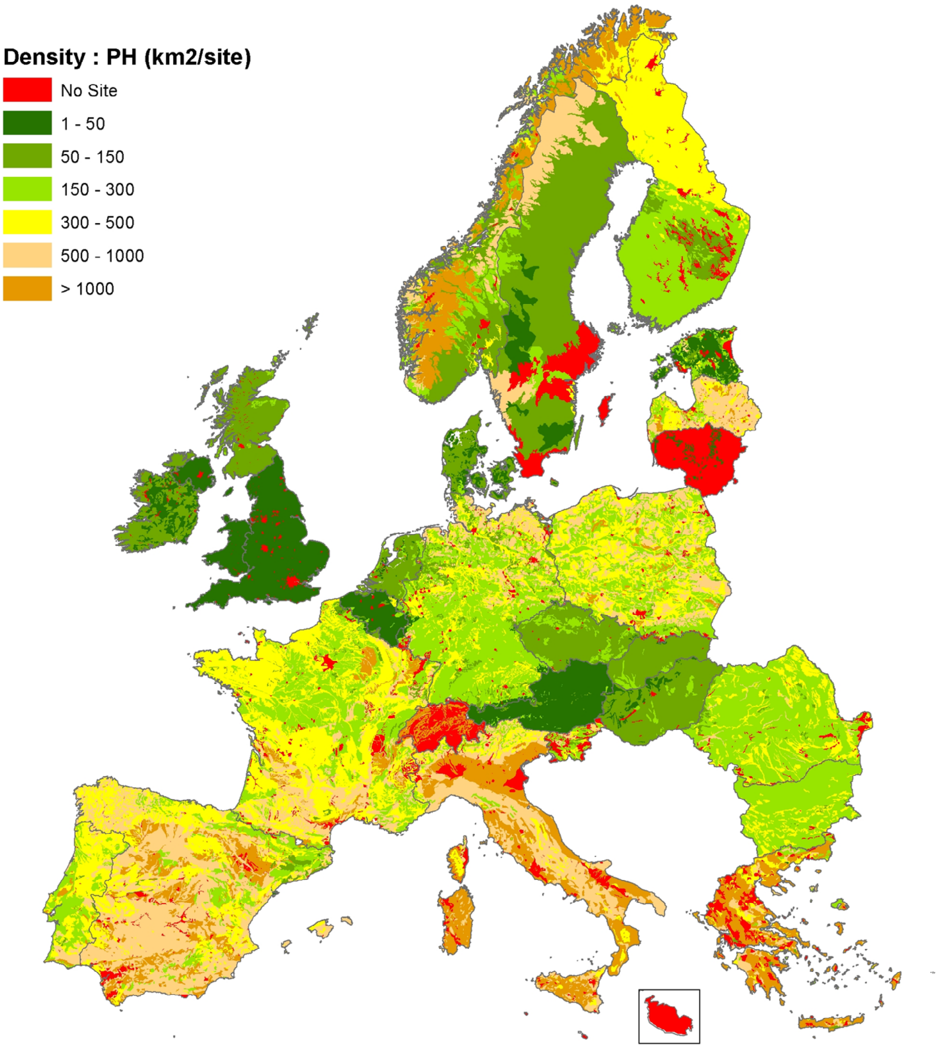

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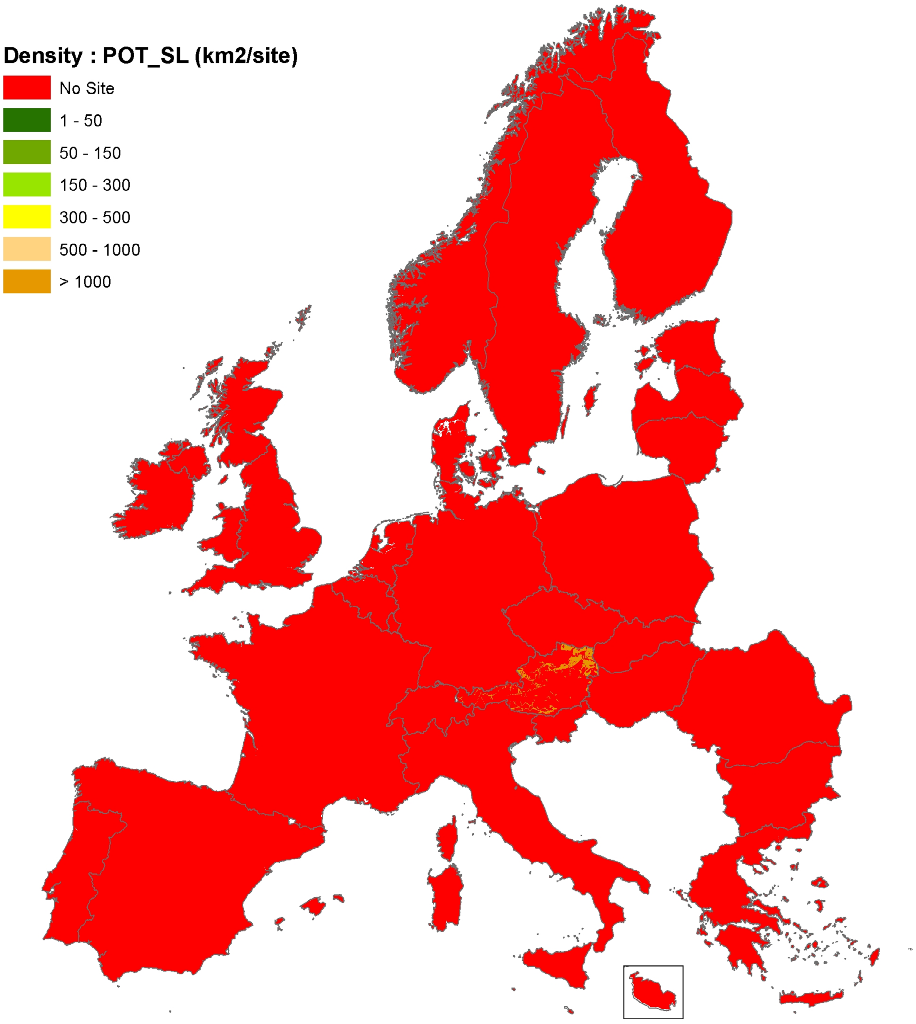

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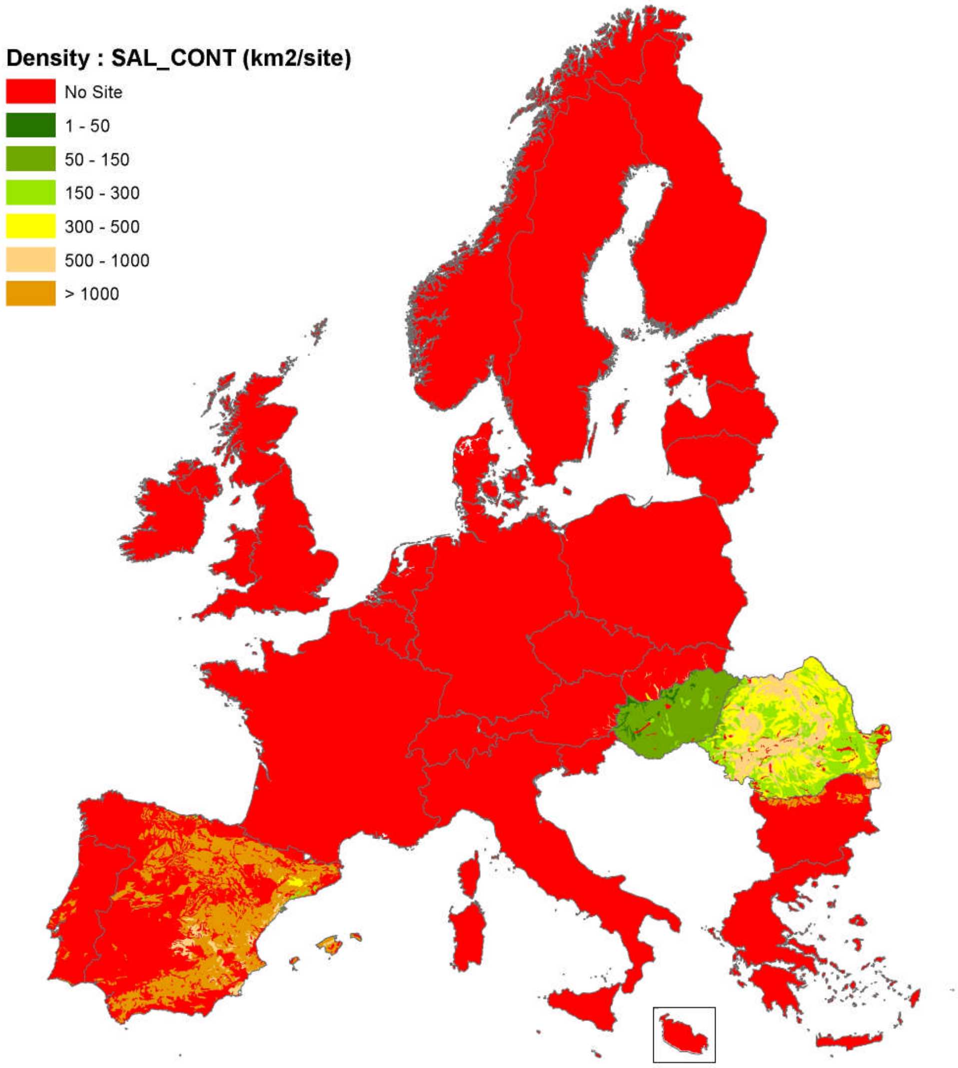

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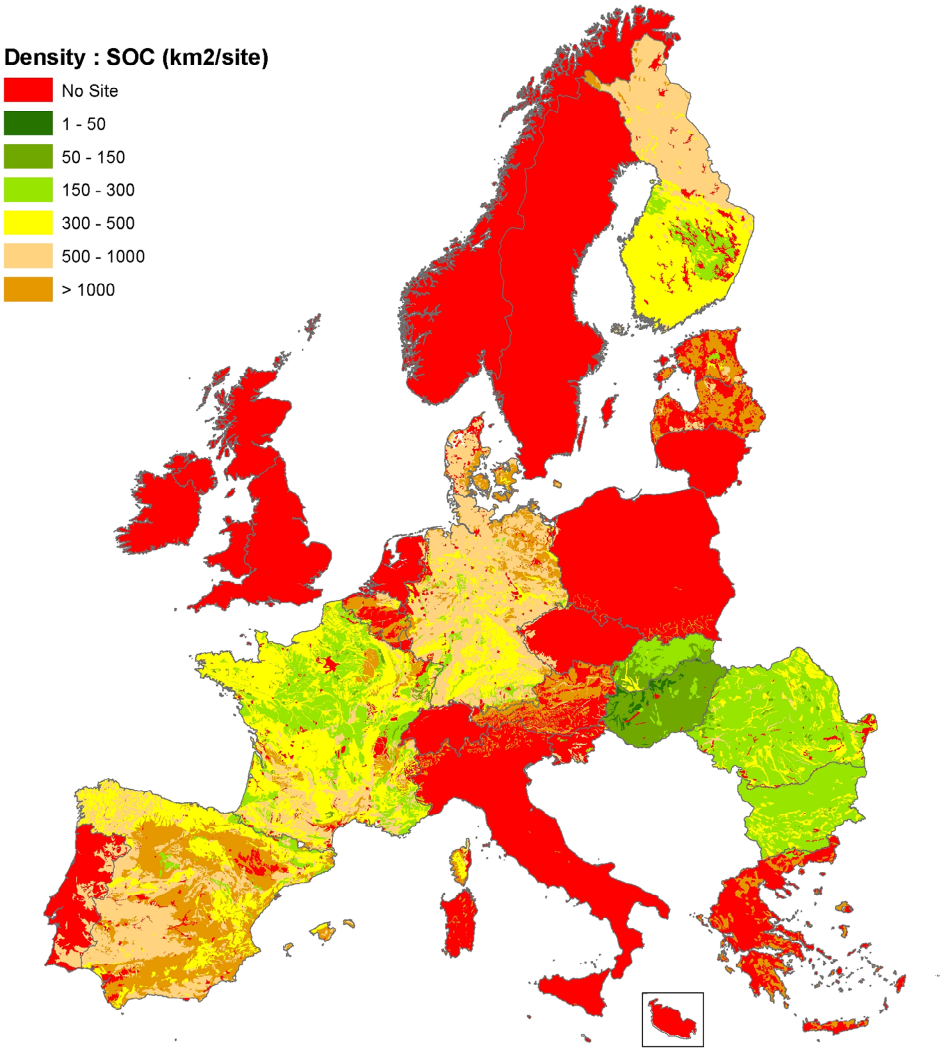

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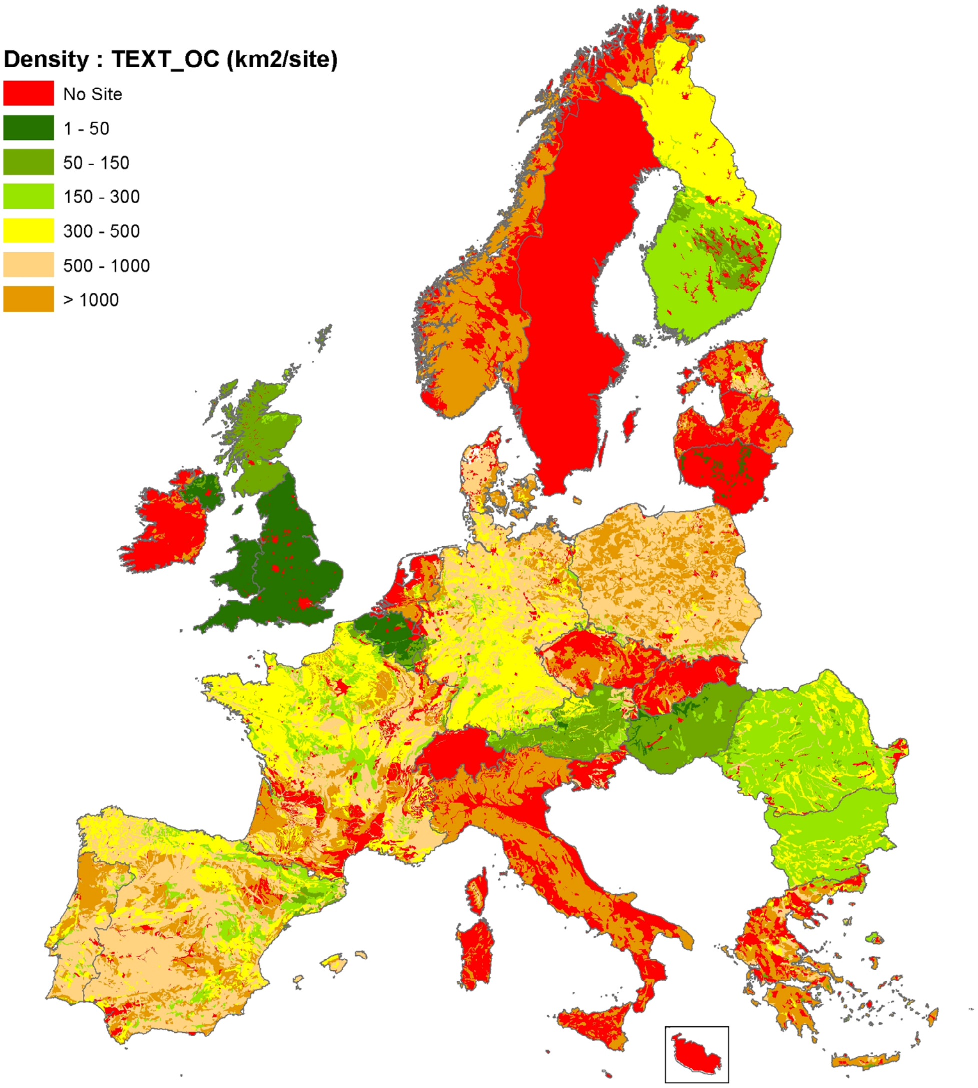

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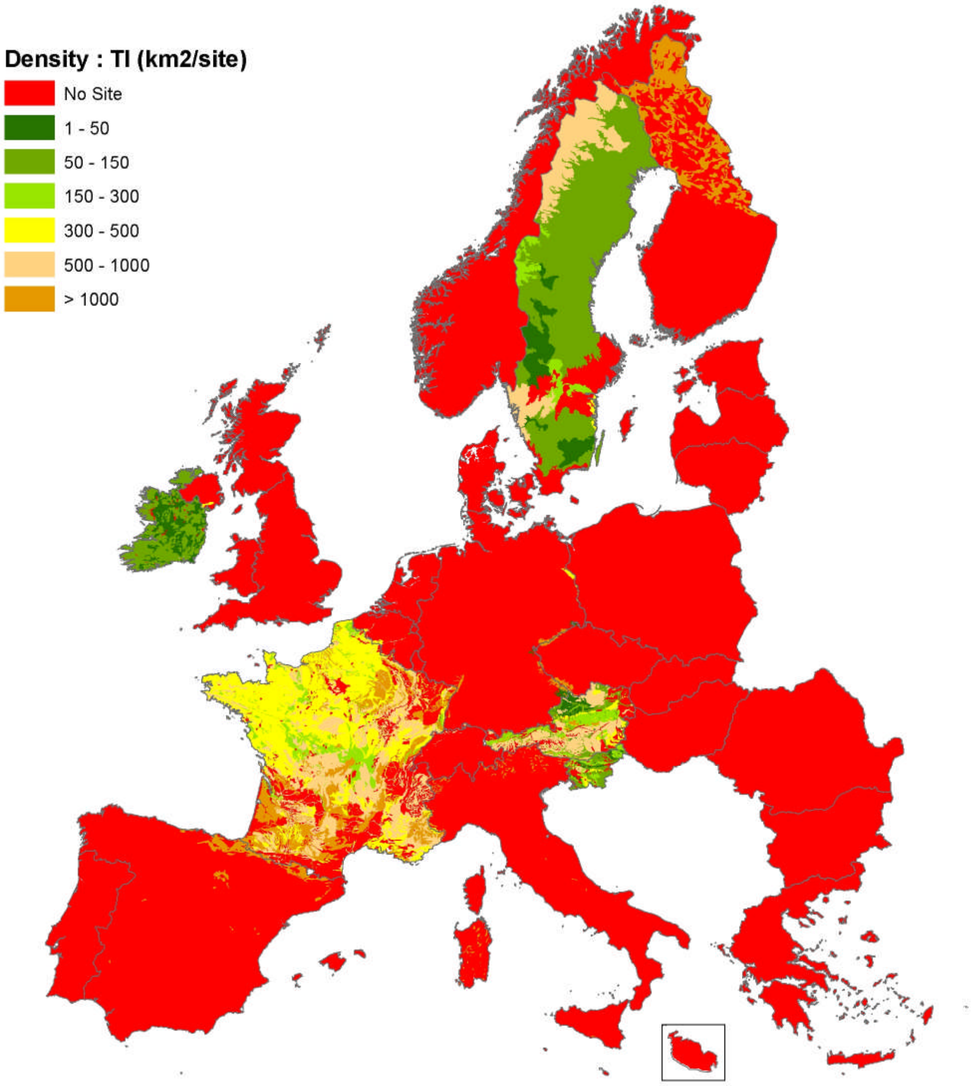

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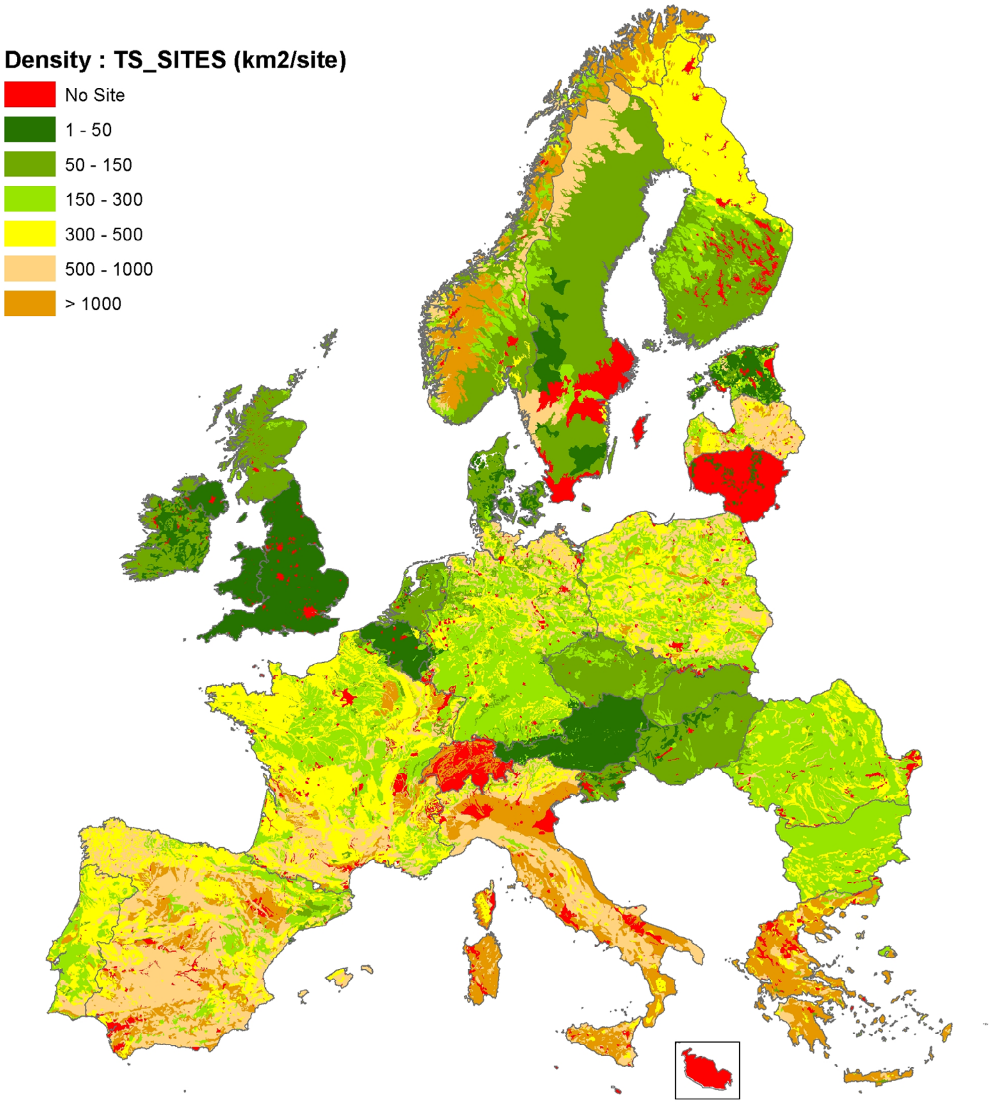

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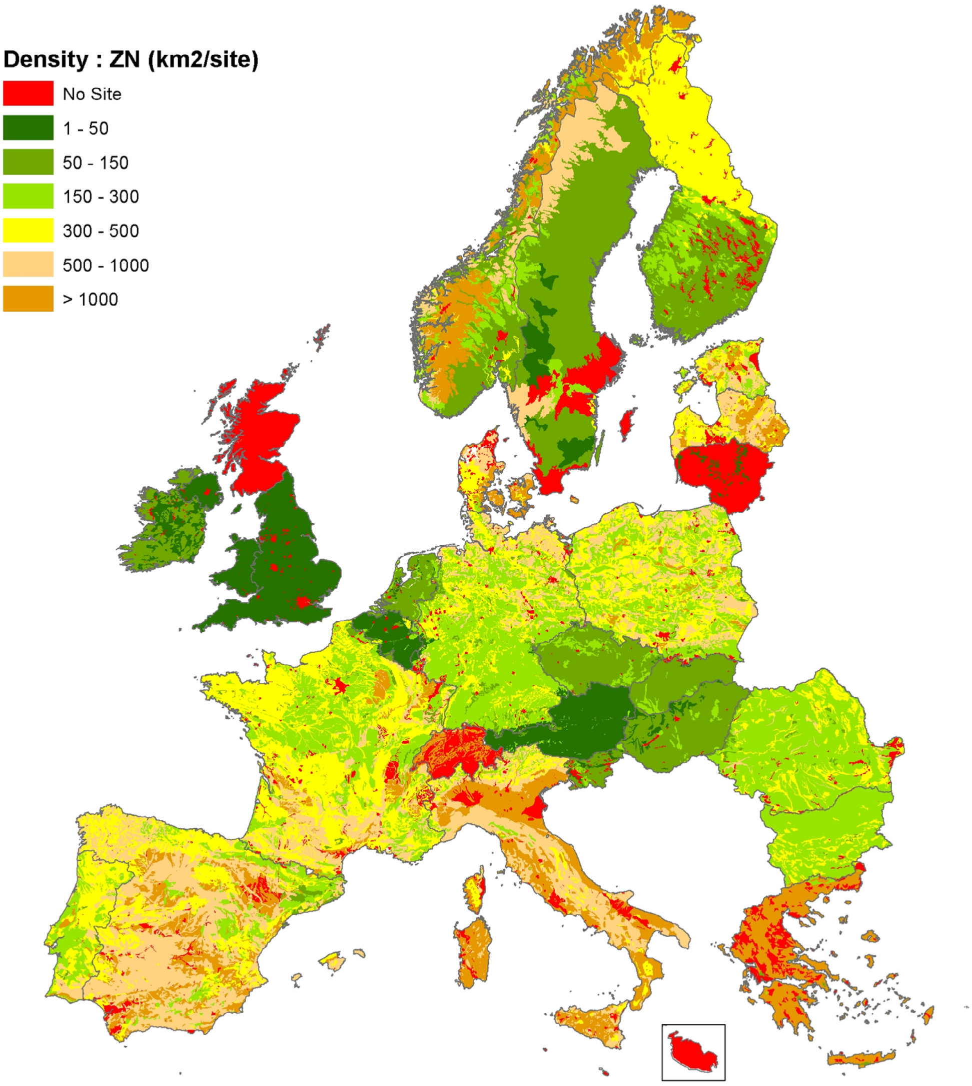

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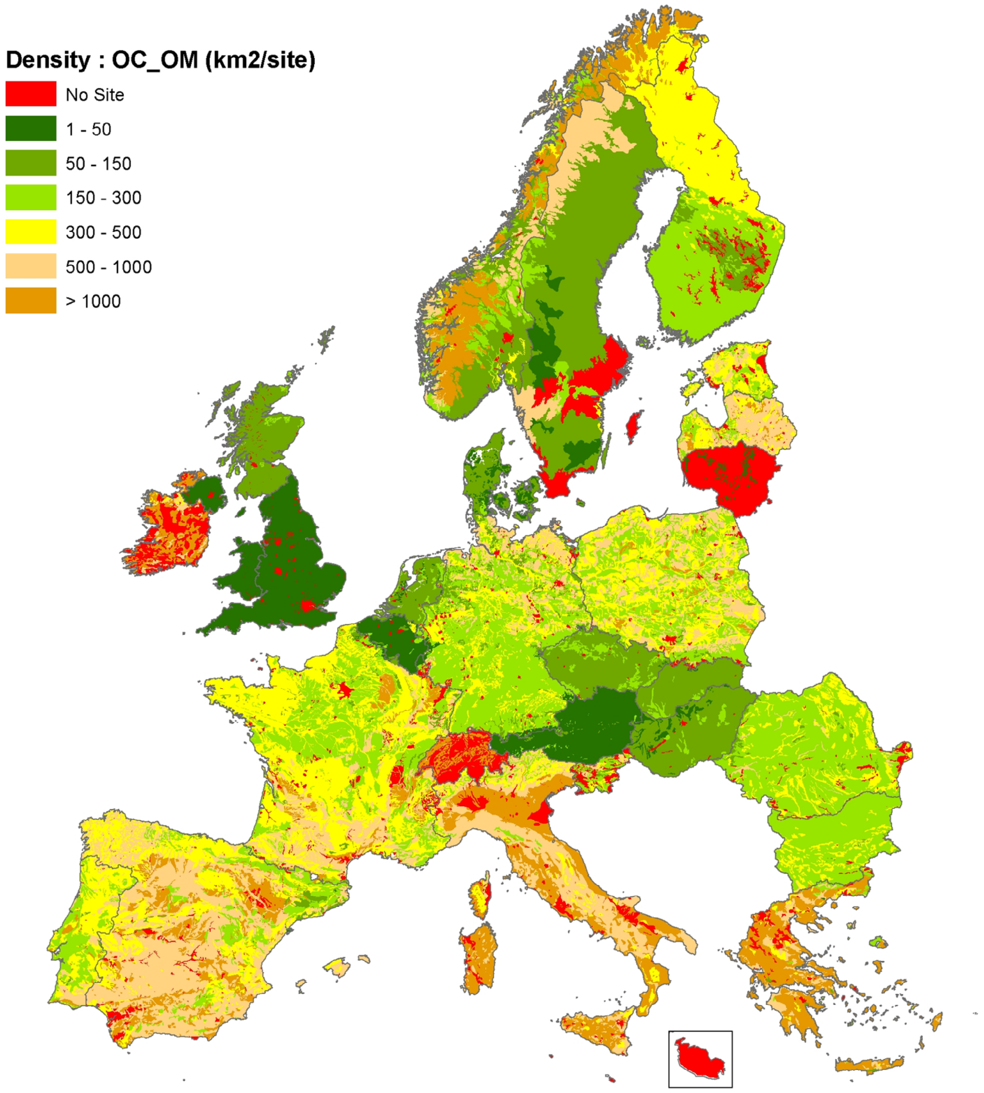

Figure 135: density of sites per soil mapping unit for topsoil organic carbon or organic matter content

Partner Number	Partner Name	Country
1	Cranfield University (CU)	United Kingdom
2	Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)	Germany
3	Umweltbundesamt (UBA-A)	Austria
4	Institut National de la Recherche Agronomique (INRA)	France
5	Szent István University (SIU)	Hungary
7	Österreichische Agentur für Gesundheit und Ernährungssicherheit (AGES)	Austria
8	Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW)	Austria
9	Bundesamt für Wasserwirtschaft (BAW)	Austria
11	Universiteit Gent (UGENT)	Belgium
12	Nikola Poushkarov Insitute of Soil Science (ISSNP)	Bulgaria
13	Česká Zemědělská Univerzita (CUA)	Czech Republic
14	Københavns Universitet (IGUC)	Denmark
15	Danmarks Miljøundersøgelser (NERI)	Denmark
16	Põllumajandusuuringute Keskus (ARC)	Estonia
17	Maa-ja Elintarviketalouden Tutkimus Keskus (MTT)	Finland
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Abstract

The ENVASSO Project (Contract 022713) was funded 2006-8, under the European Commission 6th Framework Programme of Research, with the objective of defining and documenting a soil monitoring system appropriate for soil protection at continental level. The ENVASSO Consortium, comprising 37 partners drawn from 25 EU Member States, reviewed almost 300 soil indicators, identified existing soil inventories and monitoring programmes in the Member States, designed and programmed a database system to capture, store and supply soil profile data, and drafted procedures and protocols appropriate for inclusion in a European soil monitoring network of sites that are geo-referenced and at which a qualified sampling process is or could be conducted. Volume IIa is the first of two parts that together constitute the most comprehensive study to date of the soil inventory and monitoring activities in the European Union. Volume IIa evaluates the extent to which existing soil monitoring networks adequately represent European soil typological units, land use/cover, specific soil criteria – such as soil organic carbon, bulk density, heavy metal contents – and existing spatial assessments of threats to soil such as soil erosion, compaction and desertification. The second part, Volume IIb, reports the results of a Survey of National Soil Monitoring Networks, which include comprehensive fact sheets that list for each national network, its purpose, the sampling strategy adopted, the analytical methods used and the number of operational monitoring sites.

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