

The distribution of peatland in Europe

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SUMMARY

This paper derives the distribution of peatland in Europe as the extent of peat and peat-topped soils indicated by soil databases. The data sources were the 1:1,000,000 European Soil Database (v1.0) and a data set of organic carbon content (%) for the topsoils of Europe at 1km x 1km resolution that was recently published in map form. The strong influences of vegetation and land use on soil organic carbon (OC) content were taken into account in computing the 1km (OC) data set, as was the influence of temperature. The areas of peat and peat-topped soils estimated from the European Soil Database are generally in close agreement with those obtained using the *Map of OC in Topsoils of Europe*. The results reveal a strong northern bias in the distribution of organic soils across Europe. Almost one-third of the peatland resource of Europe is in Finland, and more than a quarter is in Sweden. The remainder is in Poland, the UK, Norway, Germany, Ireland, Estonia, Latvia, The Netherlands and France. Small areas of peat and peat-topped soils also occur in Lithuania, Hungary, Denmark and the Czech Republic. For most European countries, the distribution of peat and peat-topped soils is probably more accurately portrayed by the *Map of OC in Topsoils of Europe* than by the European Soil Map and Database. Such baseline data are important for the conservation of peat and for making much more precise estimates of carbon stocks in topsoil than have been possible hitherto. The results are also relevant to the planning of effective soil protection measures at European level.

KEY WORDS: Peat, peatland, distribution, organic carbon, Europe, soil databases

INTRODUCTION

Peat is the accumulated remains of plant material, and it forms in growing peatlands (mires) where the activity of decomposing organisms is suppressed by waterlogging. It ranges in character from moss peat in arctic, subarctic, and boreal regions; *via* reed/sedge peat and forest peat in temperate regions; to mangrove and swamp forest peat in the humid tropics (Driessen *et al.*, 2001). The rate of peat accumulation depends upon factors such as water regime and temperature, but modal rates are in the order 20–60cm per 1000 years (Walker, 1970).

Joosten & Clarke (2002) define peat as “sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material”, and a peatland as “an area, with or without vegetation, with a naturally accumulated peat layer at the surface”. Depending on country and scientific discipline, Joosten & Clarke (2002, p.30) found that peatlands have been defined as having a minimum thickness of 20, 30, 45, 50 or 70 cm of peat, but adopted a minimum peat depth of 30 cm for their inventories.

Peat is included in soil classification systems

under names such as ‘peat soils’, ‘muck soils’, ‘bog soils’, and ‘organic soils’. The name that is used most commonly at international level is **Histosol** (FAO-UNESCO, 1974; FAO-UNESCO-ISRIC, 1990; FAO, 1998), derived from the Greek *histos*, meaning ‘tissue’. Histosols are found at all latitudes, but the vast majority of them occur at low altitudes. A Histosol has a surface or shallow subsurface *histic* or *folic* horizon, which consists of partially decomposed plant remains with or without admixed sand, silt and/or clay. To comply with the World Reference Base (WRB) definition (FAO, 1998), this organic horizon must be at the soil surface and at least 10 cm thick; or its upper surface must be within 30 cm of the soil surface and it must then be at least 40 cm thick.

A *histic* horizon is saturated with water for at least one month in most years, and is thus poorly aerated. It generally contains >12% organic carbon (OC), equivalent to >20% organic matter (OM) by weight, but it must have at least 18% OC (30% OM) if there is a mineral fraction with >60% clay (FAO, 1998 p.35). The widely accepted ratio for OC:OM of 1:1.72 was adopted in this study. A *folic* horizon has similar characteristics, except that it is well aerated

and normally waterlogged for less than one month per year.

Burton & Hodgson (1987), on the other hand, define **peat** as >50% OM, measured as loss on ignition. **Sandy peat** has 35–50% OM, and its fine mineral fraction (<2mm) contains >50% sand; whilst **loamy peat** has the same OM content but the fine mineral fraction contains <50% sand. **Peaty loam** has <35% OM and, depending on clay content, >20–25% OM (<20>12–14.5% OC).

It has long been known that soil fertility, and thus the productivity of land under grazing or cropping, is associated with organic matter content as indicated by soil colour. Soil organic matter stores nutrients, buffers rapid changes in soil reaction (pH), and provides an energy source for soil micro-organisms. It also contributes to soil aeration; thereby reducing soil compaction, improving infiltration rates and increasing the storage capacity for water. Organic matter is thus important for soil structure and for the formation of stable aggregates (Waters & Oades, 1991; Beare *et al.*, 1994). Because soil organic matter is important in many soil processes, a reduction in organic matter content is usually accompanied by a lowering of fertility in most soils. Therefore, the maintenance of soil organic matter levels is vital to sustainable land management.

Following the unprecedented expansion and intensification of agriculture during the 20th century, there is now clear evidence of a general reduction in organic carbon (OC) levels in many soils (Sleutel *et al.*, 2003; Bellamy *et al.*, 2005). Even though peatlands are much richer in organic matter than mineral soils, peat exploitation over the past century, through cultivation and extraction, has caused a significant decline in their extent and organic matter status (cf. Hooghoudt *et al.*, 1961; Hutchinson, 1980). This is recognised in the European Official Communication *Towards a Thematic Strategy for Soil Protection* (EC, 2002), adopted in April 2002, which identifies declining organic matter as one of the most serious threats to soil. Thus, measures to counteract any further depletion of organic matter are urgently required if the benefits of organic matter for soils, crop production and survival of ecosystems are to be retained.

The starting point for any soil protection strategy must be adequate baseline information on current status. This applies as much to peatlands as to mineral soils, and is relevant whether the peatlands are still growing mires or have been converted to other uses. Good inventories of the extent, distribution and quality of peatland are needed to guide the wise planning of conservation, *in situ* use,

peat extraction and peatland restoration (Joosten & Clarke, 2002).

Most of the soil surveys carried out in Europe during the last four decades have mapped soil types, including organic soils (and thus mires and peatland), at national level. National inventories of peat deposits have also been made (*e.g.* Troels-Smith, 1955; Puustjärvi, 1977; Ratcliffe, 1977; Burton & Hodgson, 1987), and are currently in progress in other European countries, especially those where peat is extensive and so represents an important economic resource (*e.g.* the Geological Survey of Finland report series). However, these national data are seldom fully accessible. Different countries have adopted different techniques and scales of field survey, used different criteria to classify the soils, and adopted different sampling methods (*e.g.* grid versus random or selective sampling) and sampling densities (*e.g.* from <1 per 10 km² to 50 per km²), so that these data are too diverse and disparate to be amalgamated meaningfully (Bragg & Lindsay, 2003).

Although the peat resources of Europe are described in part by Lappalainen (1996) and for Central Europe also by Bragg & Lindsay (2003), there appears to be no exhaustive inventory of the distribution of peat, based on harmonised criteria for Europe as a whole, that could be used to support the ongoing development of a strategy for soil protection. One possibility for constructing a pan-European inventory would be to attribute an OC content to the polygons of the *European Soil Map* (CEC, 1985). An OC value for each soil type could be derived by making measurements at a small number of representative locations, then applying this value to all polygons with that soil type. This procedure was ruled out, however, because organic carbon content can vary significantly within the same soil type due to the influence of land use and vegetation. The potential for serious errors is confirmed by Batjes (1996, 1997), who calculated coefficients of variation ranging from 50% to 150% for the OC content of different topsoil samples belonging to the same pedological (FAO) group.

In an attempt to aid the policy-making process at European level, Jones *et al.* (2005) used a different approach to assessing organic carbon in topsoils from version 1.0 of the European Soil Database. The resulting 1km x 1km raster data set has recently been published in ISO B1 format as *The Map of OC Topsoils of Europe* (Jones *et al.*, 2004). Here, we use this map (Figure 1), and the associated 1km data set, in conjunction with the European Soil Database, to estimate the extent of peatland in Europe.

We include peat and soils that have a surface layer at least 30 cm thick with >35% OM (>20% OC) if the mineral fraction comprises 60% or more clay, or >20%OM (>12% OC) where the mineral fraction has no clay, and a lower limit of organic carbon between 20 and 35% where the clay

content is between 0 and 60%. We term the latter group ‘peat-topped soils’, and this category encompasses the ‘sandy peat’, ‘loamy peat’ and ‘peaty loam’ types of Burton & Hodgson (1987).

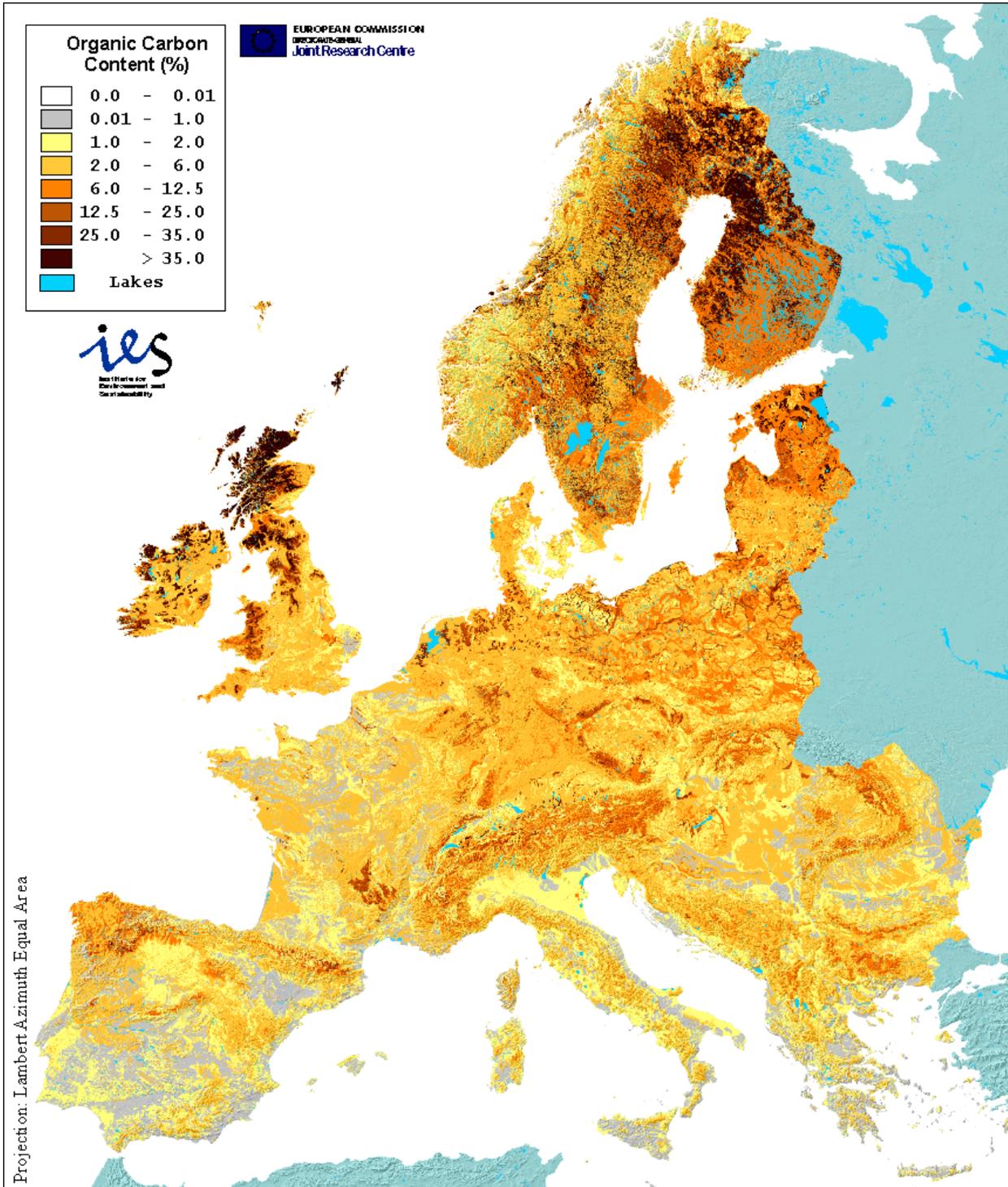


Figure 1. Organic carbon content (%) in topsoils (0–30cm) in Europe (adapted from Jones *et al.*, 2004).

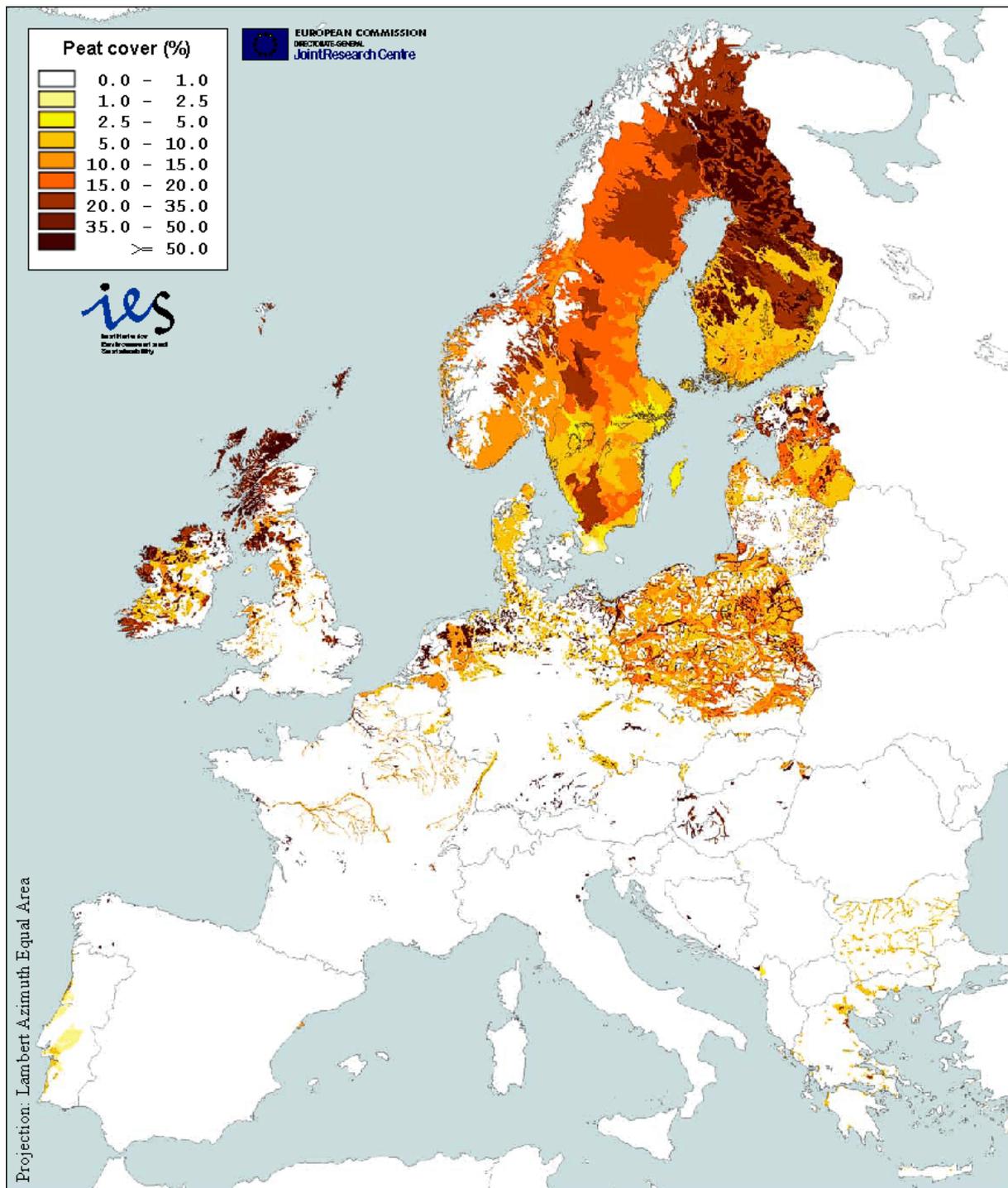


Figure 2. Relative cover (%) of peat and peat-topped soils in the SMUs of the European Soil Database.

METHODS

The European Soil Database v.1.0 (King *et al.*, 1994, 1995) covers the enlarged EU, former EFTA countries and Candidate Countries. The source data were first prepared and published at a scale of 1:1,000,000 (CEC, 1985). The data were then harmonised according to a standard international

classification (FAO-UNESCO, 1974; FAO-UNESCO-ISRIC, 1990) and combined with analytical data for standard profiles (Madsen & Jones, 1995). More recently, the data have been re-classified according to the World Reference Base (WRB) for Soil Resources (FAO, 1998).

The spatial component of the database consists of polygons, known as Soil Mapping Units (SMUs)

comprising one or more Soil Typological Units (STUs).

Each STU is unambiguously defined by a single set of parameters, a key attribute being the Reference Soil Group (RSG) of WRB (FAO, 1998). An SMU may contain up to eight STUs. The spatial location of STUs within each SMU is not known, but the proportion of each STU within the SMU is defined in the database. Thus the STU attribute data can be related to SMUs through a relational join.

A distribution map of peat and peat-topped soils was generated directly from the database. The corresponding values in the original database were generated using a pedotransfer rule (Van Ranst *et al.*, 1995; Daroussin & King, 1997) to identify all polygons that contained soils belonging to RSG classes Histosols (HS*), Humi-gley Podzols (PZhu1), Humic Gleysols (GLhu) and Histic Gleysols (GLhi).

The European Soil Database provides relatively efficient data storage. However, its structure is not particularly well suited to analyses that involve applying mathematical functions rather than rule-based systems, to combining external information with the soils data, or to spatial analysis in raster format. The *Map of OC Topsoils of Europe* is more useful for operations because it is a single spatial (raster) layer with continuous values of topsoil OC. It was derived from an area-weighted distribution of SMU attributes.

Spatial representation was improved by performing a multi-criteria analysis within each SMU on the basis of the characteristics for those STUs comprising the SMU. Vegetation and land cover data from the CORINE database and climate data from the Global Historical Climatology Network (GHCN) (Easterling *et al.*, 1996) were combined with soil attributes in order to take account of the influences of vegetation, land cover and temperature on soil organic carbon content. The process for generating the OC values is fully explained by Jones *et al.* (2005). The resulting values fell within the expected range, none of them exceeding 63% (equivalent to 100% OM) and they have been further verified by comparison with measured data from more than 12,000 sampling sites in the UK (England and Wales) and Italy.

The distribution of peat and peat-topped soils within Europe was derived by separating the continuous data into seven discrete classes of OC (%). According to the definitions adopted here, peat has >30% OC (>50% OM) and peat-topped soils have >20<30% OC (>35<50% OM). The data were also used to derive areas of peat and peat-topped soils for each country, as a percentage of the total area of the country.

Furthermore, the calculations were performed for two other thresholds, namely 20% and 25% OC (35% and 43% OM), to comply with the definitions quoted for histic horizons (12–18% OC; 20–30% OM) (FAO, 1998, p.35) and peat (20% OC; 35% OM) (Clayden & Hollis, 1984, p.8).

RESULTS

Figure 2 shows the distribution of SMUs considered to contain peat or peat-topped soils and the percentage of the SMU occupied by these soils. Figure 3 shows the relative cover of peat-topped soils (0–30cm) in Europe by country, as derived from the European Soil Database.

The area of peatland for each country is shown in Table 1, based on the European Soil database and derived from the *Map of OC in Topsoils of Europe* using the thresholds of 20% and 25% OC, for comparison purposes. The distributions of soils classified as peat and/or having peat-topped soils are shown graphically in Figure 4.

On an area basis, almost one-third of the peat and peat-topped soils in Europe are found in Finland, and more than a quarter in Sweden. The remainder occur in Poland, the UK, Norway, Germany, Ireland, Estonia, Latvia, the Netherlands and France. Small areas of peat and peat-topped soils also occur in Lithuania, Hungary, Denmark and the Czech Republic

DISCUSSION

While the two data sets used in this study have some sources in common, they focus and integrate data from other sources to different degrees. The European Soil Database contains the percentage of peat and peat-topped soils within a spatial unit, the SMU. No information is provided directly on the OC content of the area concerned, only the proportion of the different Reference Soil Groups.

By contrast, the *Map of OC in Topsoils of Europe* contains estimates of OC, and areas of peat-topped soils can be identified from the OC content. The two data sets are thus complementary, in that one indicates the locations of peat-topped land and the other gives the quantity of OC in those areas.

Table 1 shows that the estimates from the European Soil Database are generally in close agreement with those obtained using the *Map of OC in Topsoils of Europe* (with the two thresholds of 20 and 25% OC) for many countries; *e.g.* Finland (29.5%, 33.3%, and 32.6%) and Ireland (16.5%, 18.9%, and 18.5%).

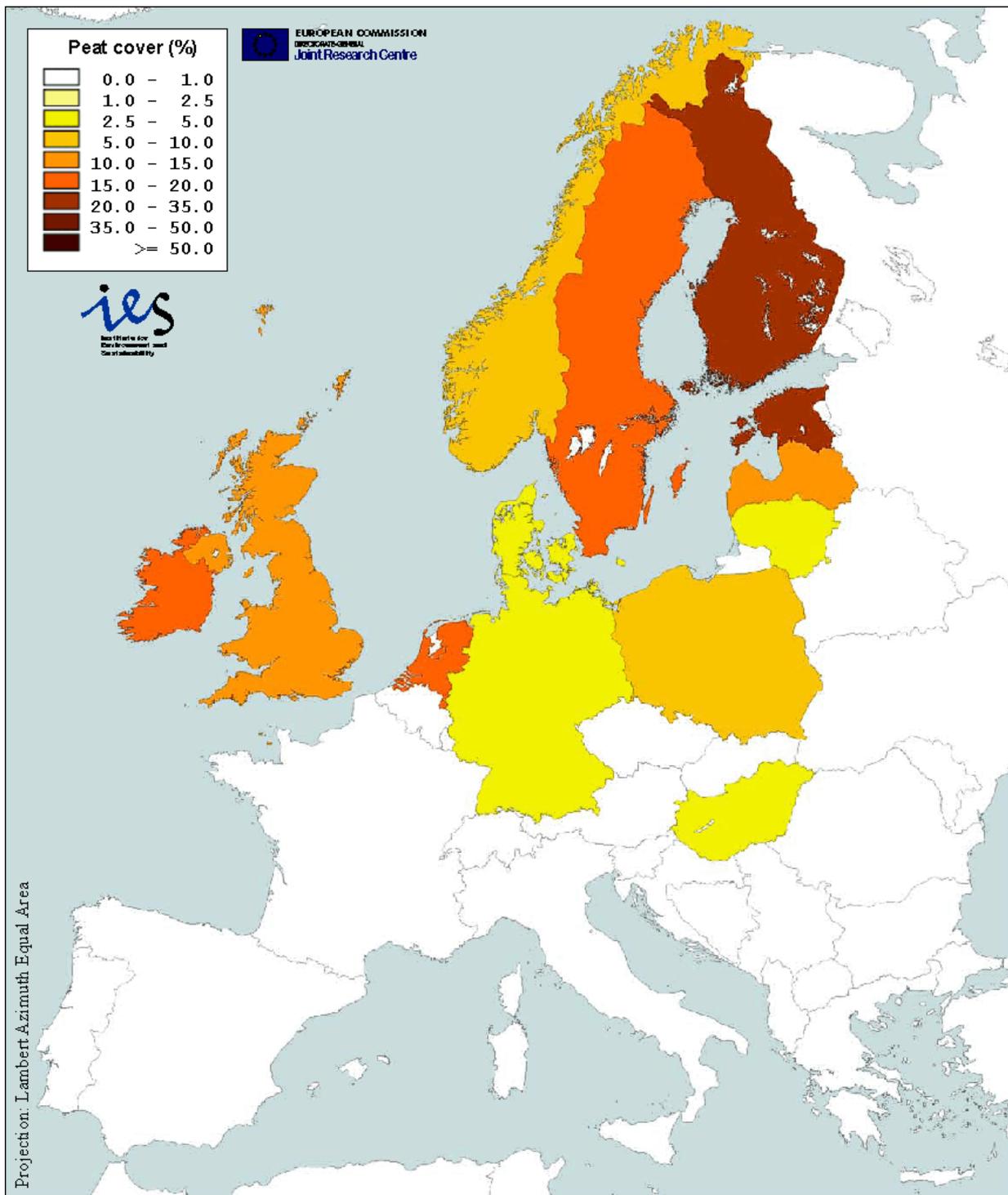


Figure 3. Relative cover (%) of peat and peat-topped soils (0–30cm), per country, based on the European Soil Database in Table 1.

However, these estimates diverge noticeably for a few countries, *e.g.* Latvia (11.7%, 6.3% and 5.3%), Poland (9.7%, 4.9% and 1.5%), The Netherlands (15.6%, 9.3%, and 5.9%) and the UK (10.9%, 22.6%, and 18.3%).

In the case of Latvia and Poland, the differences in these estimates are difficult to explain. In both

countries, the peat and peat-topped soils occur in complex glacial deposits where soil characteristics change significantly over short distances. It may be that the rasterisation process was confounded by the complexity of the SMUs resulting in these discrepancies. Further efforts will be directed towards finding an explanation.

Table 1. Area of peat and peat-topped soils, country-by-country, estimated from (a) The European Soil Database and (b) the *Map of Organic Carbon in the Topsoils of Europe* (and the associated 1km data set), using thresholds of 20% and 25% OC.

Country	(a)		(b)			
	Area of peat ¹ in SMUs of European Soil Database		Area of peat and peat-topped soils from <i>Map of OC in Topsoils of Europe</i> ²			
			OC>20%		OC>25%	
	km ²	%	km ²	%	km ²	%
Albania	44	0.2	41	0.1	0	0.0
Austria	276	0.3	1262	1.5	134	0.2
Belgium	240	0.8	96	0.3	95	0.3
Bosnia Herzegov	170	0.3	86	0.2	32	0.1
Bulgaria	53	0.5	1	0.0	0	0.0
Croatia	41	0.1	0	0.0	0	0.0
Czech Republic	687	0.9	1449	1.9	251	0.3
Denmark	1091	2.6	249	0.6	66	0.2
Estonia	9353	21.7	8196	19.0	6889	16.0
Faeroe Islands	201	15.0	111	8.3	92	6.9
Finland	88908	29.5	100440	33.3	98353	32.6
France	3157	0.6	5417	1.0	775	0.1
FYROM ³	0	0.0	18	0.1	0	0.0
Germany	15276	4.3	17846	5.0	6279	1.8
Greece	554	0.4	0	0.0	0	0.0
Hungary	2738	3.0	1018	1.1	401	0.4
Ireland	11392	16.5	13014	18.9	12725	18.5
Italy	292	0.1	3	0.0	1	0.0
Latvia	7385	11.7	4017	6.3	3382	5.3
Lichtenstein	0	0.0	0	0.0	0	0.0
Lithuania	2433	3.8	1850	2.9	1489	2.3
Luxembourg	3	0.1	0	0.0	0	0.0
Malta	0	0.0	0	0.0	0	0.0
Monaco	0	0.0	0	0.0	0	0.0
Netherlands	5392	15.6	3209	9.3	2022	5.9
Norway	18685	6.0	28380	9.2	18798	6.1
Poland	29720	9.7	15043	4.9	4677	1.5
Portugal	271	0.3	0	0.0	0	0.0
Romania	95	0.0	585	0.2	39	0.0
Slovakia	35	0.1	555	1.1	1	0.0
Slovenia	78	0.4	180	0.9	0	0.0
Spain	360	0.1	196	0.0	184	0.0
Sweden	65859	15.6	105025	24.9	90785	21.5
Switzerland	183	0.5	4762	11.9	836	2.1
United Kingdom	26519	10.9	54957	22.6	44411	18.3
Yugoslavia ⁴	110	0.1	3	0.0	0	0.0

¹ Peat as defined by the pedotransfer rule; ² S.P.I.04.72, Jones *et al.*(2004); ³ FYROM – Former Yugoslav Republic of Macedonia; ⁴ Yugoslavia – Serbia and Kosovo.

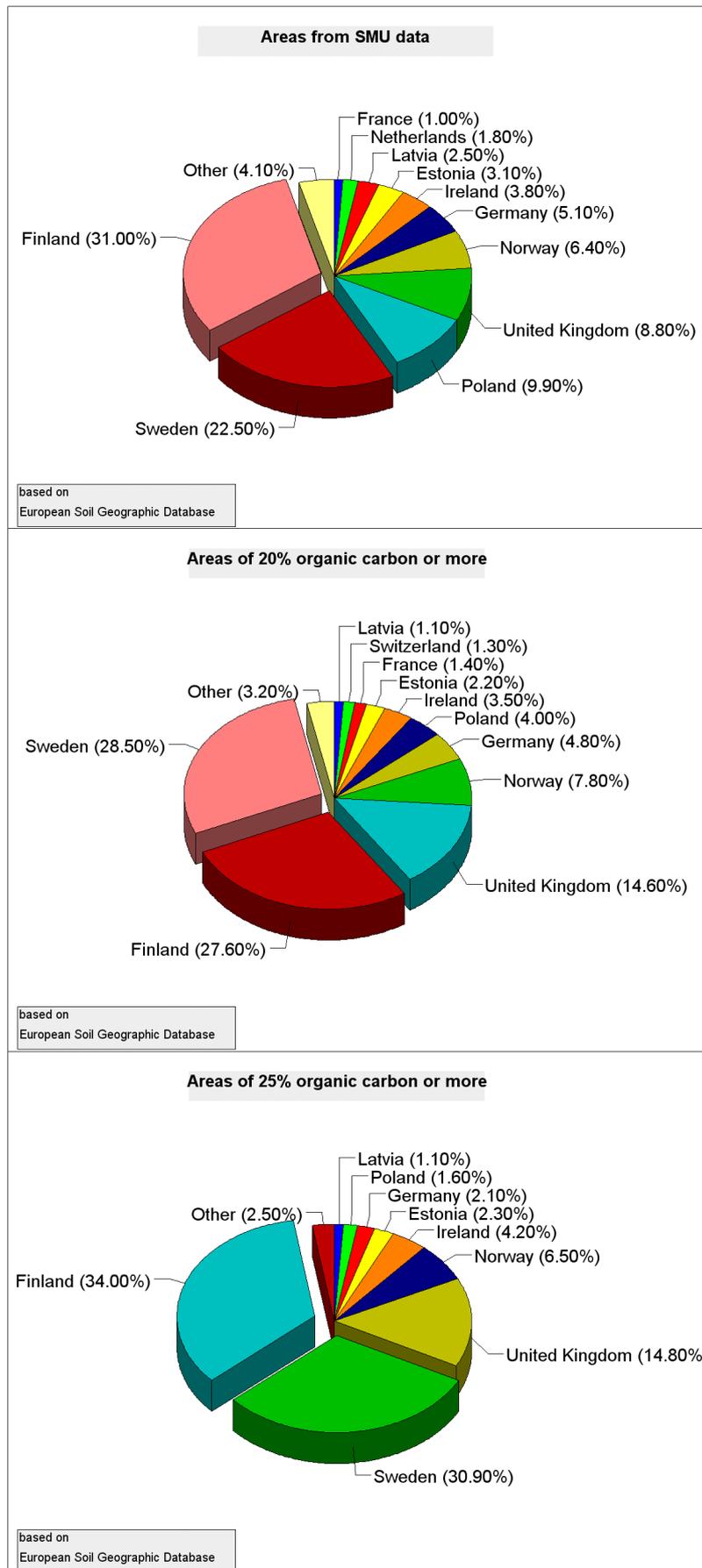


Figure 4: Distribution of peat and peat topped soils (0–30cm) in Europe, based on: (a) European Soil Database v 1.0; (b) *Map of OC in Topsoils of Europe*, with threshold of OC \geq 20%; and (c) *Map of OC in Topsoils of Europe*, with threshold of OC \geq 25%.

In The Netherlands, the difference between the estimates can be explained by the fact that the value from the European Soil Database (15.6% of the land area) is derived mainly from soil information compiled between 1950 and 1975. The area values of 9.3% (where OC>20%) and 5.9% (where OC>25%) from the *Map of OC in Topsoils of Europe* probably reflect the effects of more recent land use (1990) and climate (1980–89) on reducing OC content.

Therefore, the differences may reflect a real decline in OC resulting from the oxidation of organic matter during 30 years of intensive cultivation of peatland, since the soil data for The Netherlands were supplied to the European Soil Database. It is likely that this level of exploitation could have reduced the OC content sufficiently for some soils that would previously have been called 'peat-topped' to fall out of this category.

We conclude that for most European countries, the distribution of peat and peat-topped soils is probably more accurately portrayed by the *Map of OC in Topsoils of Europe* than by the European Soil Map. For example, recently the area under peat and peat-topped soils has been estimated to be 48,714 km² in Great Britain (Burton, 1996,) and 1,713 km² in Northern Ireland (Shier, 1996). These estimates give a total of 50,427 km² for the UK compared with 54,957 km² and 44,411 km², based on the *Map of OC in Topsoils of Europe*, with thresholds of OC>20% and OC>25% respectively, but only 26,519 km² based on the European Soil Database. Shier (1996) has also estimated the peatland area in Ireland to be 11,757 km² compared with our estimates of 13,014 km² and 12725 km², based on the *Map of OC in Topsoils of Europe*, with thresholds of OC>20% and OC>25% respectively, and 11,392 km², based on the European Soil Database.

Thus, we think that on balance the *Map of OC in Topsoils of Europe* with a threshold of OC>25% gives more accurate estimates of the area of peat and peat-topped soils – peatland – in Europe than a threshold of OC>20% (with the same spatial data) or the European Soil Database. The results of this study provide harmonised estimates of the extent of peatland in Europe at the beginning of the 1990s. Because they are based on standard databases, these estimates can be used, with more confidence than previous data, to support soil protection policy initiatives currently active in Europe today. A new land cover map for Europe – CORINE 2000, a new version of the European Soil Database – extended to include Belarus, Ukraine & Russia – and updated climatic data will support future revision of the estimated extent of peatlands in Europe.

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