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 European peatland resource 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: Histosol, organic carbon, peat distribution, 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”. These authors found that peatland has been variously defined, depending on country and scientific discipline, to have a minimum peat thickness of 20, 30, 45, 50 or 70 cm, and adopted a minimum peat thickness of 30 cm for their own inventories.

Peat is included in soil classification systems under names such as ‘peat soils’, ‘muck soils’, ‘bog soils’, and ‘organic soils’, but 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 a soil with >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 the 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 peatland as to mineral soils, and is relevant whether the peatland is still growing mire or has been converted to other uses, since 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 employed different sampling methods (e.g. grid *versus* random or selective sampling) and sampling densities (e.g. from <1 per 10 km^2 to 50 per km^2), 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 OC contents 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 has been 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 assess 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.

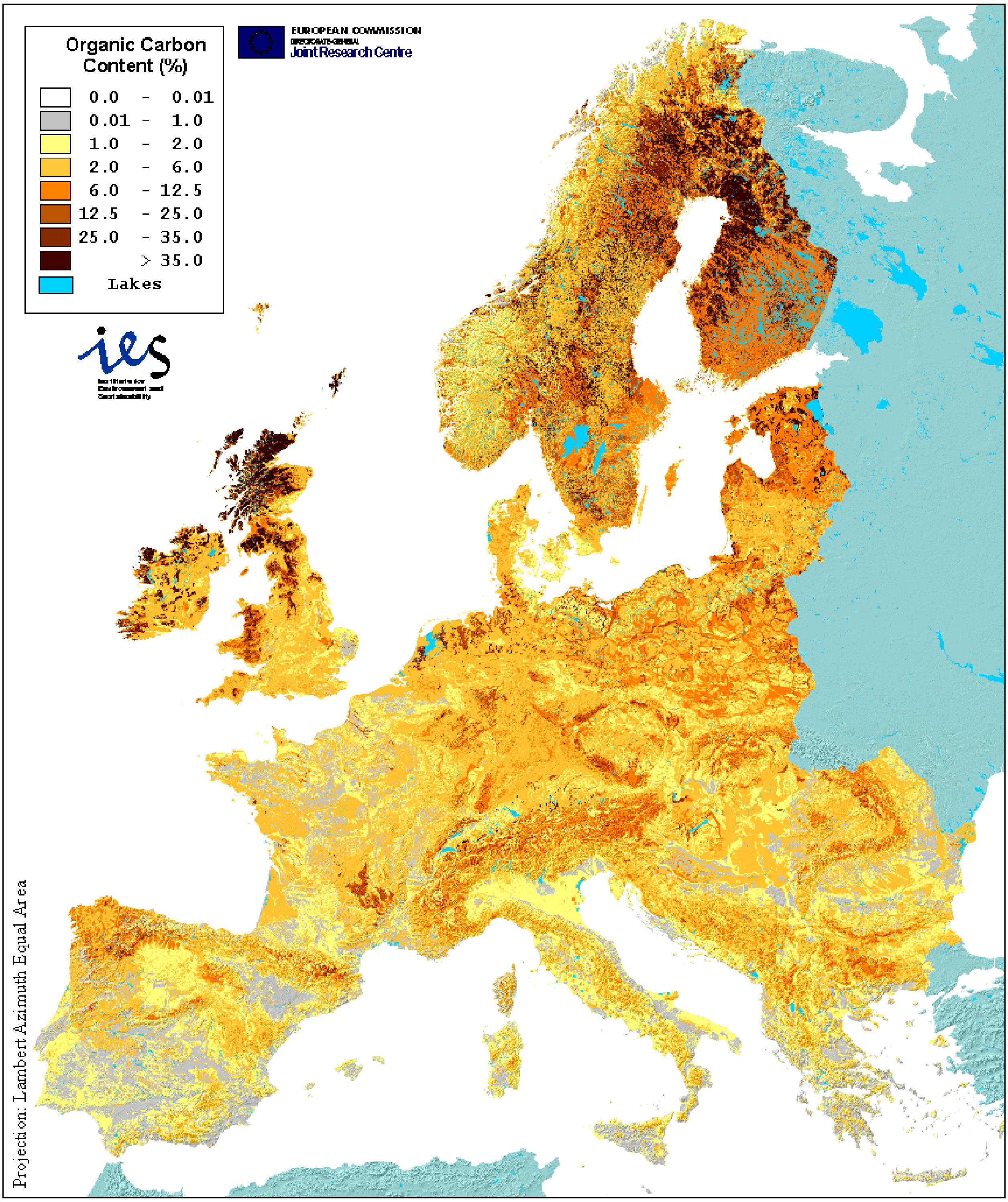

Figure 1. Organic carbon content (%) in topsoils (0–30cm) in Europe (adapted from Jones *et al.* 2004).

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 locations of STUs within each SMU are not known, but the proportion of each STU within the SMU is defined in the database. Thus STU attribute data can be related to the 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 (PZhugl), 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 in Topsoils of Europe* is more useful for these 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 of the 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 (peatland) within Europe was derived by separating the continuous data into 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. In this case, the area of peatland was calculated for two thresholds, namely 20% OC (35% OM) and 25% OC (43% OM), for general compliance with those quoted for histic horizons (12–18% OC; 20–30% OM) by FAO (1998, p.35) and peat (20% OC; 35% OM) by Clayden & Hollis (1984, p.8), as well as those for sandy peat/loamy peat (20% OC; 35% OM) and peat (30% OC; 50% OM) by Burton & Hodgson (1987).

RESULTS

Figure 2 shows the distribution of SMUs considered to contain peat or peat-topped soils and the percentage of each 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 areas of peatland for each country, derived from the European Soil Database and from the *Map of OC in Topsoils of Europe* using the thresholds of 20% and 25% OC, are shown numerically in Table 1 and 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. Information is provided directly only on the proportions of the different RSGs, and not on the soil OC content of the area concerned. By contrast, the *Map of OC in Topsoils of Europe* contains estimates of OC, and areas of peat and 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 these areas.

Table 1 shows that the estimates from the European Soil Database agree closely 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%).

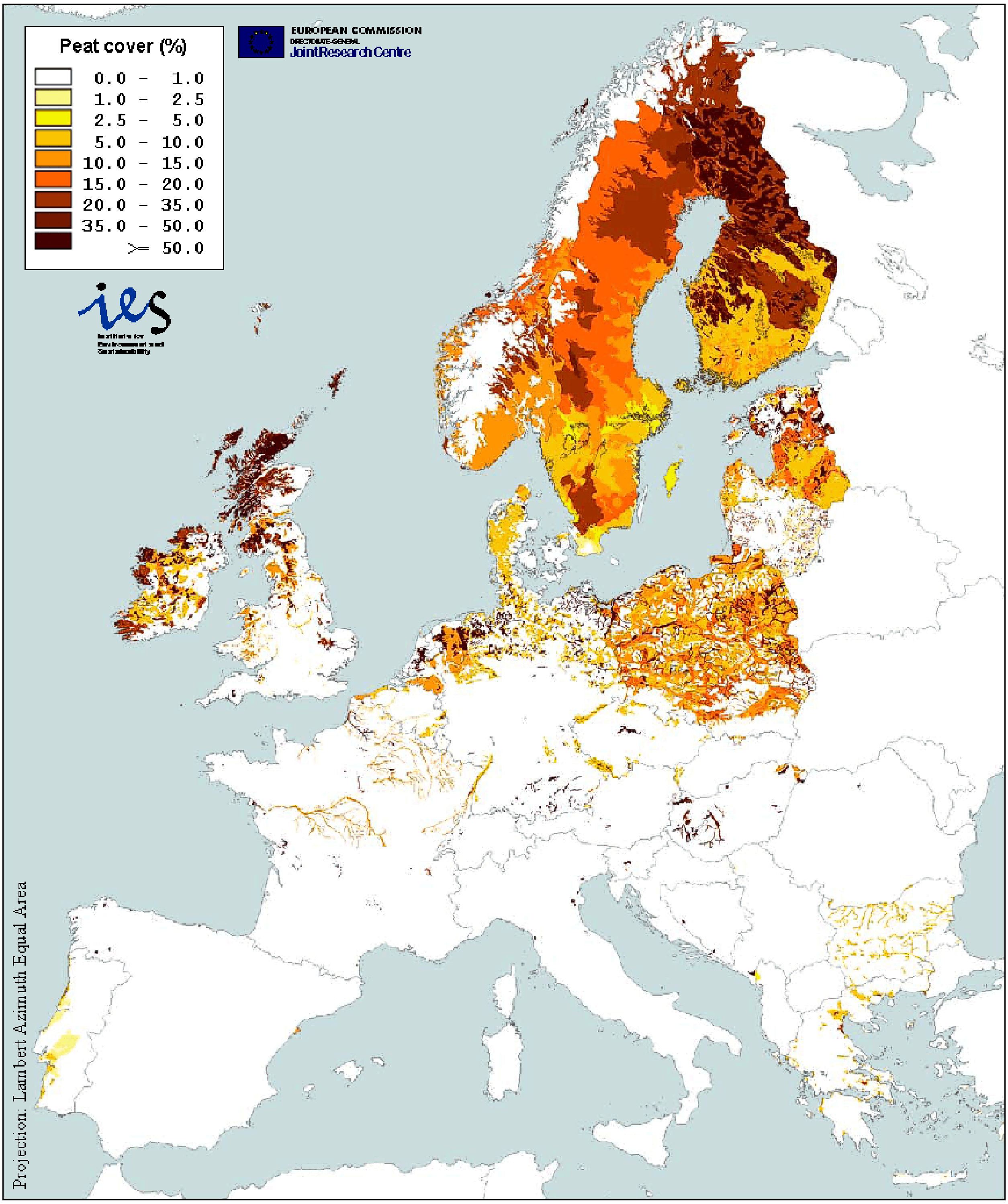

Figure 2. Relative cover (%) of peat and peat-topped soils in the SMUs of the European Soil Database.

However, the 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%).

For Latvia and Poland, the discrepancies 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, and it may be that the rasterisation process was confounded by the complexity of the SMUs. Further efforts will be directed towards clarifying this issue. In The Netherlands, the differences 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

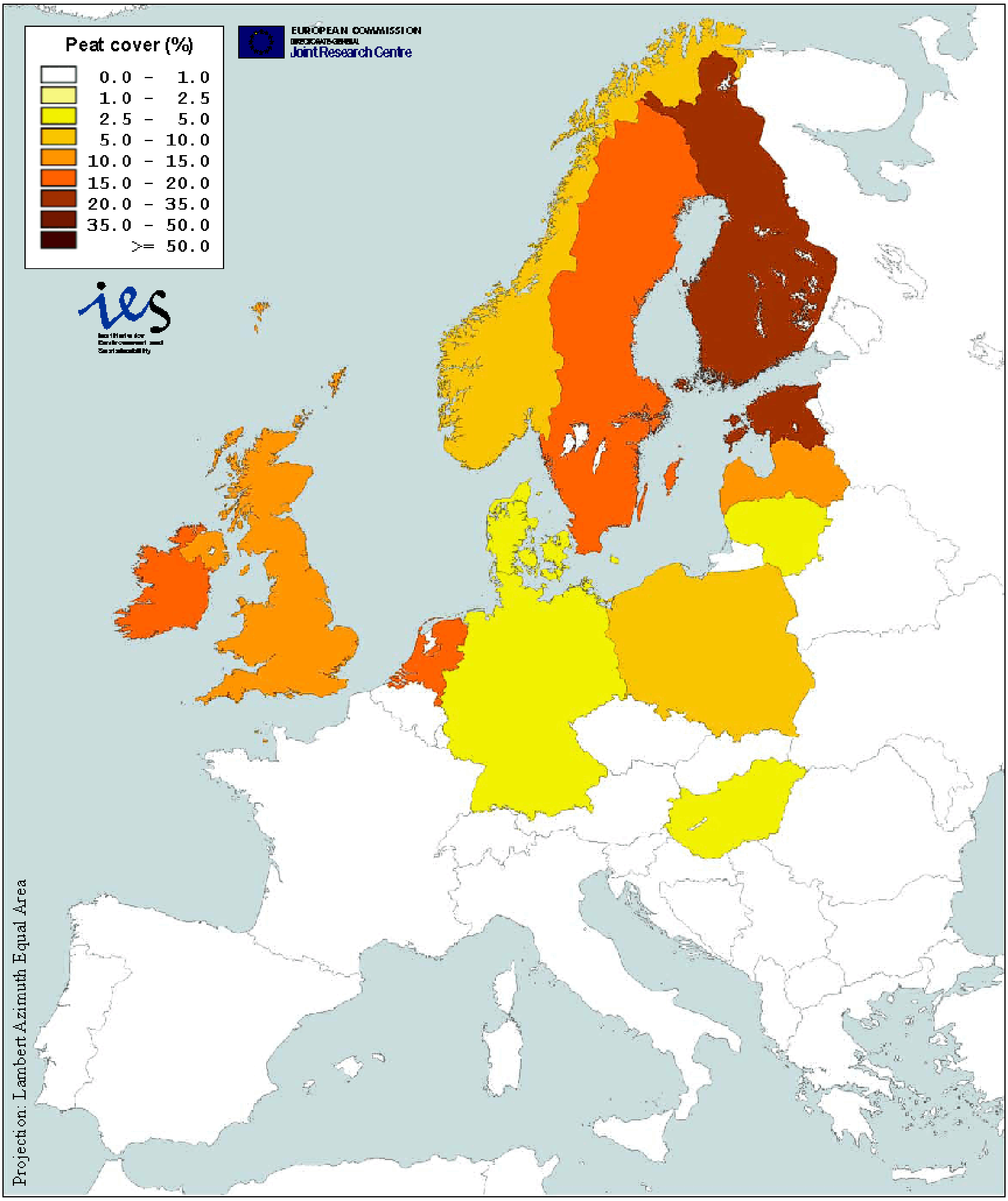

Figure 3. Relative cover (%) of peat and peat-topped soils (0–30cm), per country, based on the European Soil Database and Table 1.

from soil information compiled between 1950 and 1975, whereas 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). Therefore, the differences may reflect a real decline in OC resulting from the oxidation of organic matter during the 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 has reduced the OC content sufficiently for some soils that would previously have been called 'peat-topped' to fall out of the category.

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

Country	(a) Area of peat[1] in SMUs of European Soil Database		(b) Area of peat and peat-topped soils from *Map of OC in Topsoils of Europe*[2] OC ≥20%		OC ≥25%	
	km²	%	km²	%	km²	%
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.

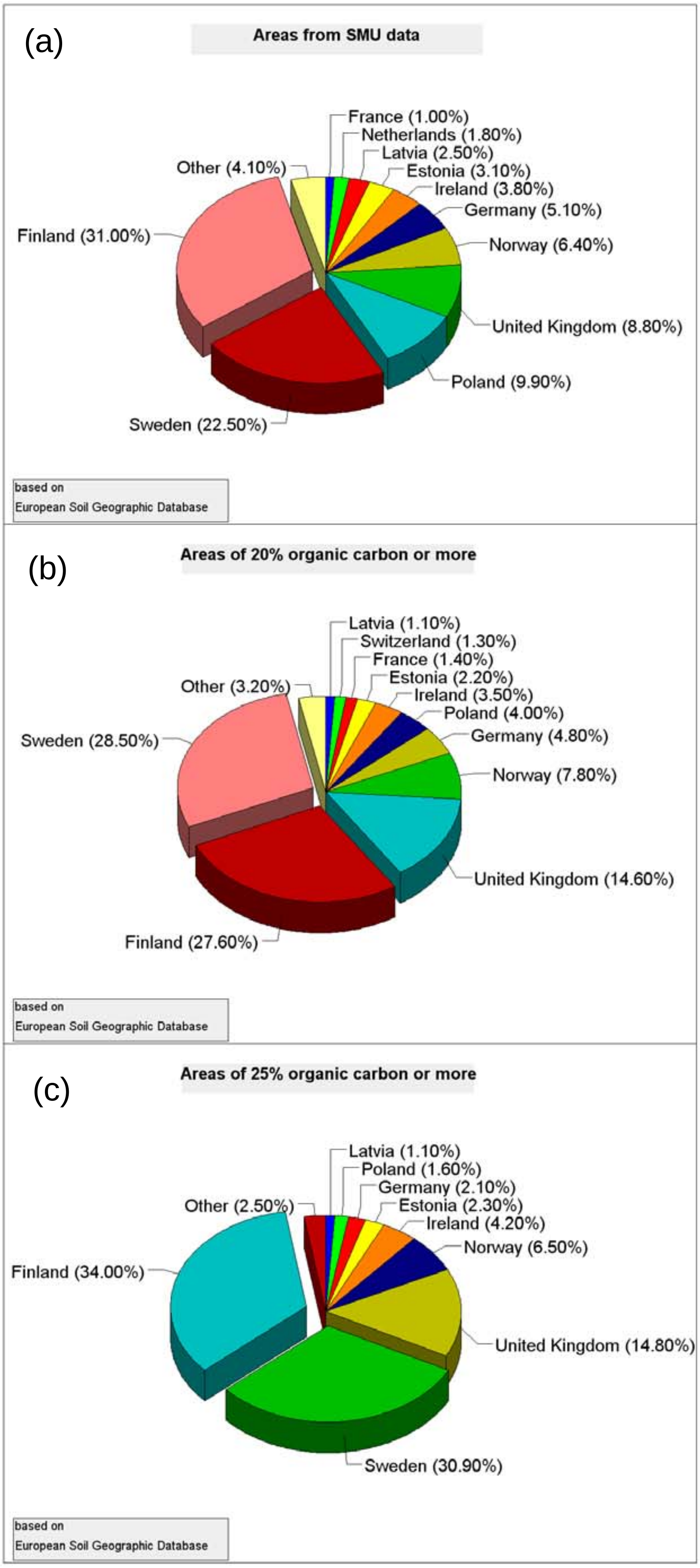

Figure 4. The distribution of peat and peat-topped soils (0–30cm) in Europe, based on: (a) European Soil Database v 1.0; (b) *Map of OC in Topsoils of Europe* with OC ≥20%; and (c) *Map of OC in Topsoils of Europe* with OC ≥25%.

The area under peat and peat-topped soils has recently been estimated at 48,714 km^2 for Great Britain (Burton 1996) and 1,713 km^2 for Northern Ireland (Shier 1996). These estimates give a total of 50,427 km^2 of peatland for the UK, compared with the 54,957 km^2 and 44,411 km^2 indicated by the *Map of OC in Topsoils of Europe* with thresholds of 20% OC and 25% OC respectively, and the 26,519 km^2 derived from the European Soil Database. Moreover, Shier (1996) has estimated the peatland area in Ireland to be 11,757 km^2, compared with our estimates of 13,014 km^2 and 12,725 km^2 based on the *Map of OC in Topsoils of Europe* with thresholds of 20% OC and 25% OC respectively, and 11,392 km^2 based on the European Soil Database. 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. Moreover, on balance, the *Map of OC in Topsoils of Europe* with a threshold of 25% OC gives more accurate estimates of the area of peatland (peat and peat-topped soils) in Europe than a threshold of 20% OC 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 derived from standard databases, these estimates can be used with more confidence than previous data, for example to support the soil protection policy initiatives that are active in Europe today. Future revision of the estimated extent of peatland in Europe will be supported by a new land cover map for Europe (CORINE 2000); a new version of the European Soil Database extended to include Belarus, Ukraine and Russia; and updated climate data.

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REFERENCES

Batjes, N.H. (1996) Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, 47, 151-163.

Batjes, N.H. (1997) A world data set of derived soil properties by FAO-UNESCO soil unit for global modelling. *Soil Use and Management*, 13, 9-16.

Beare, M.H., Hendrix, P.H. & Coleman, D.C. (1994) Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. *Soil Science Society of America Journal*, 58, 777-786.

Bellamy, P.H., Loveland, P.J., Bradley, R.I., Lark, R.M. & Kirk, G.J.D. (2005) Carbon losses from all soils across England and Wales 1978-2003. *Nature,* 437/8, 245-248.

Bragg, O. & Lindsay, R. (eds.) (2003) *Strategy and Action Plan for Mire and Peatland Conservation in Central Europe*. Wetlands International, Wageningen, The Netherlands, vi + 94 pp.

Burton, R.G.O. & Hodgson, J.M. (1987) *Lowland Peat in England and Wales*. Soil Survey Technical Monograph No.15, Harpenden, UK, 146 pp.

Burton, R.G.O. (1996) The peat resources of Great Britain (Scotland, England and Wales and Isle of Man). In: Lappalainen, E. (ed.) *Global Peat Resources.* International Peat Society, Jyskä, Finland, pp. 79-86.

CEC (1985) *Soil Map of the European Communities, 1:1,000,000*. CEC, Luxembourg, 124 pp., 7 maps.

Clayden, B. & Hollis, J.M. (1984) Criteria for differentiating soil series. *Soil Survey Technical Monograph* No.17, Harpenden, UK, 159 pp.

Daroussin, J. & King, D. (1997) A pedotransfer rules database to interpret the Soil Geographical Database of Europe for environmental purposes. In: Bruand, A., Duval, O., Wosten, H. & Lilly A. (eds). *The Use Of Pedotransfer In Soil Hydrology Research In Europe*. European Soil Bureau Research Report No.3, EUR 17307 EN, INRA, Orleans, France, pp. 25-40.

Driessen, P., Deckers, J., Spaargaren, O. & Nachtergaele, F. (2001) *Lecture notes on the major soils of the world.* World Soil Resources Reports No. 94, FAO, Rome, 344 pp.

Easterling, D.R., Peterson, T.C. & Karl, T.R. (1996) On the development and use of homogenized climate data sets. *Journal of Climate*, 9, 1429-1434.

EC (2002) *Towards a Thematic Strategy for Soil Protection*. Communication of 16 April 2002 from the European Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions, 179 final 35 pp. [COM (2002), not published in the Official Journal, available at: http://europa.eu.int/scadplus/printversion/en//lvb/l28122.htm].

FAO (1998) *World Reference Base for Soil Resources.* World Soil Resources Report No. 84, FAO, Rome, 88 pp.

FAO-UNESCO (1974) *FAO-UNESCO Soil Map of the World: Vol. 1, Legend.* UNESCO, Paris.

FAO-UNESCO-ISRIC (1990) *FAO-UNESCO Soil Map of the World: Revised Legend.* World Soil Resources Report 60, Rome, 119 pp.

Hooghoudt, S.B., Woerdt, D. van der, Bennema, J. & Dijk, H. van (1961) Verdrogende veengronden in west-Nederland (Irreversible drying of peat soils in the west of the Netherlands). *Versl. Landbouwk. Onderz.,* 66, 23, 308 pp.

Hutchinson, J.N. (1980) The record of peat wastage in the East Anglian fenlands at Holme Post, 1848-1978 A.D. *Journal of Ecology*, 68, 229-249.

Jones, R.J.A., Hiederer, R., Rusco, E., Loveland, P.J. & Montanarella, L. (2004) *The map of organic carbon in topsoils in Europe, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.72 (S.P.I.04.72).* European Soil Bureau Research Report No.17, EUR 21209 EN, Office for Official Publications of the European Communities, Luxembourg, 26 pp. and 1 map in ISO B1 format.

Jones, R.J.A, Hiederer, R., Rusco, E., & Montanarella, L. (2005) Estimating organic carbon in the soils of Europe for policy support. *European Journal of Soil Science,* 56, 655-671.

Joosten, H. & Clarke, D. (2002) *Wise Use of Mires and Peatlands*. International Mire Conservation Group / International Peat Society, 304 pp.

King, D., Daroussin, J. & Tavernier, R. (1994) Development of a soil geographical database from the soil map of the European Communities. *Catena,* 21, 37-26.

King, D., Jones, R.J.A. & Thomasson, A.J. (1995) *European Land Information Systems for Agro-environmental Monitoring.* EUR 16232 EN, Office for Official Publications of the European Communities, Luxembourg, 285 pp.

Lappalainen, E. (1996) *Global Peat Resources.* International Peat Society, Jyskä, Finland, 161 pp.

Madsen, H. Breuning & Jones, R.J.A. (1995) Soil Profile Analytical Database for the European Union. *Danish Journal of Geography*, 95, 49-57.

Puustjärvi, V. (1977) *Peat and Its Use In Horticulture*. Publ. No. 3, Turveteollissuuslitto, Finland, 160 pp.

Ratcliffe, D.A. (1977) *A Nature Conservation Review*: *The Selection of Biological Sites of National Importance to Nature Conservation in Britai*n. Cambridge University Press, UK.

Shier, C. (1996) The peat resources of Ireland. In: Lappalainen, E. (ed.) *Global Peat Resources.* International Peat Society, Jyskä, Finland, pp. 95-96.

Sleutel, S., De Neve, S. & Hofman, G. (2003) Estimates of carbon stock changes in Belgian cropland. *Soil Use and Management,* 19, 166-171.

Troels-Smith, J. (1955) *Karakterisering of løse jordarter.* Geological Survey of Denmark, Copenhagen.

Walker, D. (1970) Direction and rate in some British post-glacial hydroseres. In: Walker, D. & West, R.G. (eds.) *Studies of the Vegetational History of the British Isles.* Cambridge University Press, UK, 117-139.

Waters, A.G., & Oades, J.M. (1991) Organic matter in water stable aggregates. In: Wilson, W.S. (ed.) *Advances in Soil Organic Matter Research. The Impact on Agriculture and the Environment*. R. Soc. Chem., Cambridge, 163-174.

Van Ranst, E., Thomasson, A.J., Daroussin, J., Hollis, J.M., Jones, R.J.A., Jamagne, M., King, D. & Vanmechelen, L. (1995) Elaboration of an extended knowledge database to interpret the 1:1,000,000 EU Soil Map for environmental purposes. In: King, D., Jones, R.J.A. & Thomasson, A.J. (eds.) *European Land Information Systems for Agro-environmental Monitoring.* EUR 16232 EN, Office for Official Publications of the European Communities, Luxembourg, pp. 71-84.

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