European Soil Data Centre: Response to European Policy Support and Public Data Requirements

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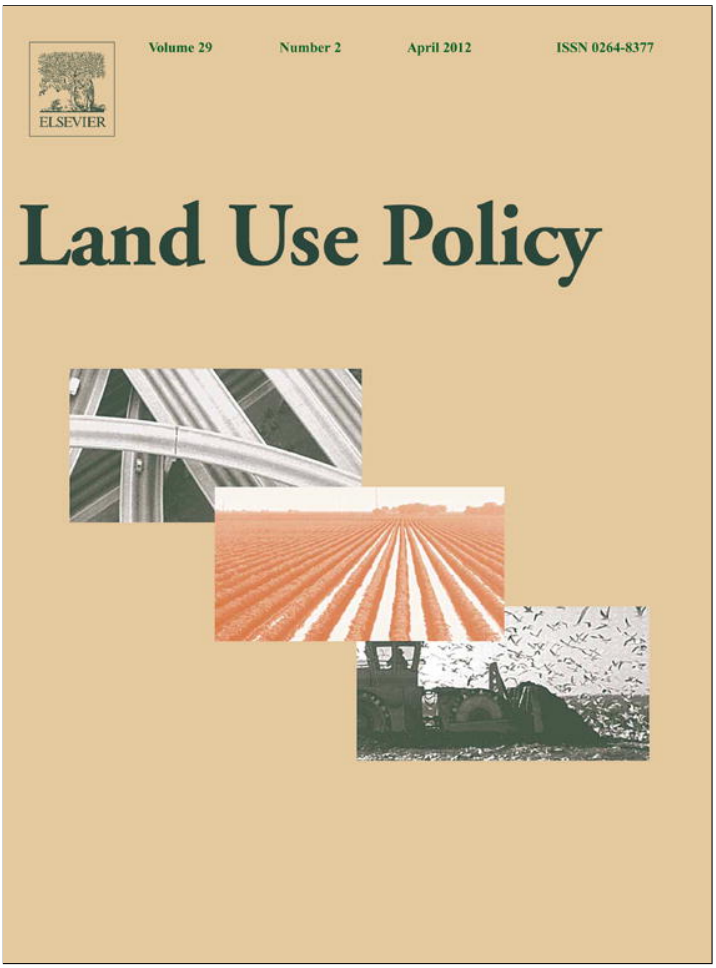

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European Soil Data Centre: Response to European policy support and public data requirements

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ABSTRACT

In the context of the European Union's Soil Thematic Strategy, policy makers require easy access to soil data and information of various types and scales to assess the state of soils at European level. To satisfy this need, the European Commission and the European Environment Agency (EEA) decided to establish the European Soil Data Centre (ESDAC), located at the European Commission's Joint Research Centre.

The ESDAC is one of ten environmental data centres that have been established during the last 4 years in support of policy development, implementation and monitoring by the European Commission's Directorate General for Environment. The ESDAC, located at http://esdac.jrc.ec.europa.eu, has become the focal point for soil data and information at European Union level by hosting a series of soil products and web-based tools that allow access to the data. The ESDAC acts as the primary data contact point for the Commission and EEA to fulfill their information needs. The establishment and the evaluation of harmonised databases should facilitate improved soil protection measures.

Introduction

The successful conception, development, implementation, monitoring and further improvement of environmental policies at European Union level depends on the availability of robust data on the pressures on and state of the environment, on their possible impacts and on responses that counteract any degradation of the environment.

In order to ensure the provision of such data at European scale to the relevant policy makers, the European Commission's Directorate General Environment (DG ENV), the Joint Research Centre (JRC) and Eurostat (the European Commission's Statistical Services), together with the European Environment Agency (EEA), have developed the concept of "Environmental Data Centres". These centres are seen as a common system for the provision of data in critical environmental domains. Specific areas where assigned to individual organizations and are illustrated in Fig. 1. The main objective of the data centres is to support policies and data requirements at DG ENV. The European Soil Data Centre (ESDAC) is the thematic centre for soil related data and information at pan European scale.

The ESDAC acts as the primary data contact point for DG ENV in order to fulfill DG ENV's soil information needs. The main objective is to ensure that soil data are collected, quality-checked and organized in an efficient way and that all data are accessible to various parties.

The general objective of this paper is to demonstrate how ESDAC contributes to the planning and implementation of soil related policies. More specifically, an attempt is made to:

- summarise the main soil data needs at European level and identify possible data contributors;
- propose a new way for dealing with soil data at European and national level, as compared to data management in the past;
- explain how decision making is supported through data availability;
- demonstrate the geographical coverage of data requests from ESDAC, to point out the scale at which the data are deployed and to indicate the main types of applications that use the ESDAC datasets.

User requirements and data collection

DG ENV, being the main customer of the ESDAC, expressed its overall requirements to ESDAC as follows:

(a) To receive scientific and technical support for the development of guidelines on data and for the development of European datasets,
(b) To receive support in relation to integrated assessment and
(c) To have access to all ESDAC hosted soil related data and information.

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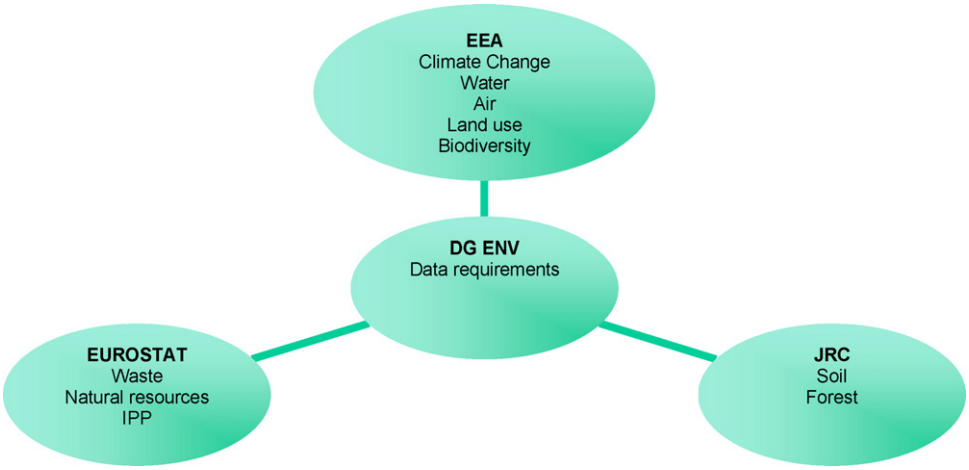

Fig. 1. Environmental Data Centres.

Specifically, ESDAC should provide DG ENV with quality-assured scientific and technical support on issues related to the proposed Soil Framework Directive (EC, 2006a), such as the development of guidelines on the identification of risk areas related to the major soil threats, and guidelines on data and metadata quality, utilization of historical data, methods, access and data-exchange formats related to the implementation of the Directive.

In terms of a practical implementation, the user requirements of the ESDAC require the development of:

(a) **A repository of data products and their metadata** (i.e., soil related datasets, derived maps and indicators, scientific reports/documents and services applications).
(b) **Appropriate user access to ESDAC products**. Most of the ESDAC products should be available on line for the public users while some databases could only be accessed after registration
(c) **A user help desk** that cares for assistance in the download of data, the notification of data-related news and the scientific/technical support for the use of the various products.

The ESDAC is populated with data coming from a significant number of data providers (Fig. 2):

- **In-house JRC projects**: Data which are already available at JRC, originating from in-house research or from collaboration with networks of soil experts. One example is the European Soil Database (Daroussin et al., 2006) which is the result of a collaboration within the European Soil Bureau Network (ESBN).
- **Soil sampling activities**: Soil data that are generated within other Commission services in various soil sampling campaigns; for example, the soil data collected during Eurostat's LUCAS Survey (Gallego and Bamps, 2008) or the JRC's Biosoil project (Lacarce et al., 2009).
- **Network of Soil Data Centres**: National soil survey and/or research organizations feed the ESDAC with national data to allow the development of pan-European products. The European Soil Bureau Network (Dusart, 2006) is such an example, consisting of a member institutes with excellent scientific background in the soil domain.
- **Collaborative research projects**: Results that stem from collaboration between JRC and important relevant organizations such as EuroGeoSurveys, ISRIC–World-Soil-Information and the Food and Agriculture Organization of the United Nations (FAO).
- **Other services**: Data originating from networks such as European Environment Information and Observation Network (EIONET).
- New data coming from **Member States:** In the context of a proposed Soil Framework Directive, EU Member States eventually will report their soil data to the European Commission and ESDAC should have a facilitating role in it.
- **European Commission**: Data and information that result from soil related projects at EU-level, for example, funded projects from the 6th and 7th Framework Programmes; examples are ENVASSO (Morvan et al., 2008), Ramsoil (Van Beek et al., 2010), SoilTrEC (Banwart, 2011), Digisoil (Lambot et al., 2009), iSoil (Van Egmond et al., 2009) and eSoter.

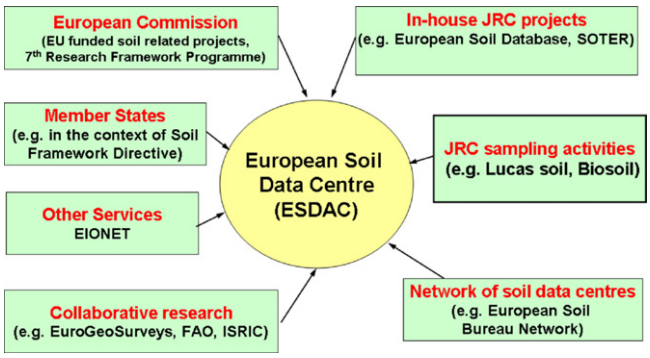

Fig. 2. ESDAC Data providers.

ESDAC technical specifications

ESDAC has become the single focal point for policy relevant soil data and information at EU level, hosting relevant **soil data** and providing web-based tools for the **access** and the **update** of information located at the ESDAC infrastructure.

In order to keep control over its data and information holdings, the ESDAC has been developed as a **centralized** system meaning that data and information resides physically on ESDAC servers located at the JRC. In order to be **interoperable** with other emerging services, **metadata** have been created according to international standards such as ISO19115 (Gebhardt et al., 2010) and **applications** (services) have been developed according to principles such as those set by the Open GIS Consortium (Best et al., 2007). The ESDAC service interoperability is achieved by utilizing open geospatial interfaces (Granell et al., 2010).

The ESDAC is as "**open**" as legally possible, meaning that if data and information resident in the ESDAC system can legally be published, the system does. Even when a product is protected for access by only privileged users, efforts are made in order to present its

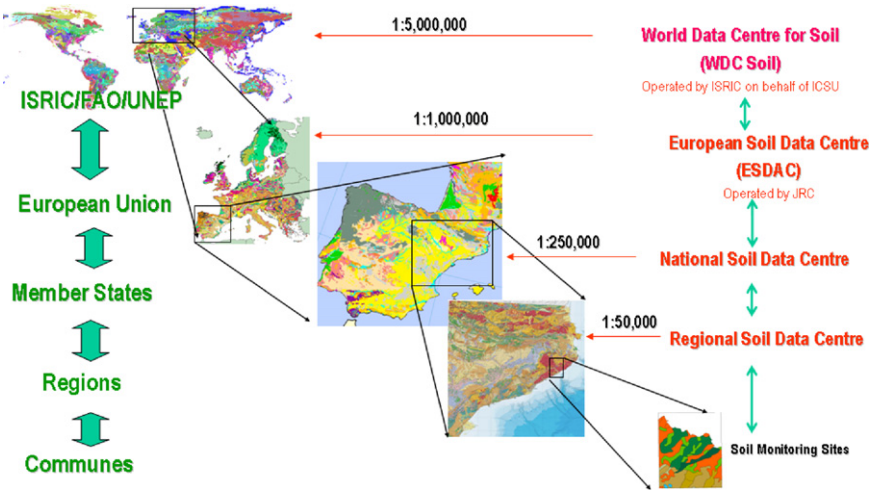

Fig. 3. ESDAC as one node in a constellation of Soil Data Centres.

metadata to the user. Whenever relevant soil data cannot be hosted physically on ESDAC infrastructure (for instance due to license restrictions), provisions have been made so that the product is visible in the ESDAC system through its metadata.

Quality control is crucial in ESDAC soil data management; two types of checks are foreseen. The data are checked by ESDAC data managers for conformity to data specifications. For example, updates (or extensions) of the European Soil Database (ESDB) should be according to data specifications (ESDB ver2, 2004; ESBN RR5, 2001). At a second level, expert members of the European Soil Bureau Network and the EIONET network are asked for data quality control from the contents point of view by cross-checking proposed ESDAC datasets with their available national/regional datasets. In the future, a new data-quality mechanism will be introduced through the submission of ESDAC data to independent teams of external soil experts (peer-review like procedures).

Compliant with principles from the INSPIRE directive (INSPIRE, 2007), the ESDAC follows the concept of a nested system of soil data centres (Panagos et al., 2011a). The ESDAC is one soil data centre in a constellation of soil data centres including the World Soil Data Centre (hosted in ISRIC), National Soil Data Centres (at Member State level) such as the French National Soil Data Centre (De Forges and Arrouays, 2010) and Regional Soil Data Centres (at EU Regional level), that are providing policy relevant soil information for different scales (Fig. 3).

ESDAC components

The ESDAC user interface consists of three main elements: a catalogue of available resources, a map viewer and the European Soil Portal.

The catalogue of soil resources is a light-weight metadata system that describes and points to various soil resource types: datasets, services/applications, documents, events, projects and external links. The catalogue of metadata for Datasets and Applications/Services has been constructed according to INSPIRE rules for spatial metadata. This is a first step to make the system interoperable with other catalogue services (e.g., catalogues of other environmental data centres).

The ESDAC Map Viewer (Fig. 4) allows the user to navigate key soil data for Europe. It provides access to the attributes of the European Soil Database and some additional data related to main soil threats as identified in the Soil Thematic Strategy (EC, 2006a,b,c,d,e). The ESDAC Map Viewer is developed according to standards so that they are interoperable with similar information allowing real-time integration of environmental data from around the world.

The European Soil Portal (http://eusoils.jrc.ec.europa.eu) is considered as the virtual place where all ESDAC resources are located. The current **data and information service** makes available **four types of products**: data, documents, data-based applications and scanned maps. Most **data** are derived products from the European Soil Database while others result from projects at EU-level (e.g., SPADE). The adoption of the "Thematic Strategy for Soil Protection" (EC, 2006a,b,c,d,e) by European Commission and the identification of the eight main threats (erosion, loss of organic matter, compaction, salinization, contamination, decline of biodiversity, landslides and sealing) has driven the ESDAC to focus on the development of relevant datasets to describe these issues. The **documents section contains** reports written in the context of JRC activities, many in collaboration with partners of the ESBN. Other technical assessments and scientific reports are also included in this section. **Data-based applications** allows any user to browse the data and information for specific soil themes (such as erosion, organic carbon content) and for projects. The **maps** include an impressive archive of more than 6000 soil-related maps and incorporates access to the JRC Soil Atlas Series (Soil Atlas of Europe, Soil Atlas of the Northern Circumpolar Region and European Atlas of Soil Biodiversity). The latter are widely considered as major achievements in raising awareness on soil issues, an important factor in relation to soil policy making.

In addition, access is provided to information on a series of **soil projects** undertaken at European level and to documentation on the EU **soil threats.** An additional section in the portal is reserved for **Awareness Raising**, while the **Events-Presentations** section facilitates the distribution of material presented at meetings, conferences and workshops.

ESDAC use

The ESDAC supports an increasing number of customers from the European Commission and Member States. They range from policy makers, public organizations and local authorities, and public administrations to research institutes, technical institutions, universities and schools, modeling groups, research projects and citizens.

The ESDAC receives requests for data, documents, maps and information from users from different geographic locations and working in various disciplines. The volume and the type of requests are recorded and provide useful output that illustrates the

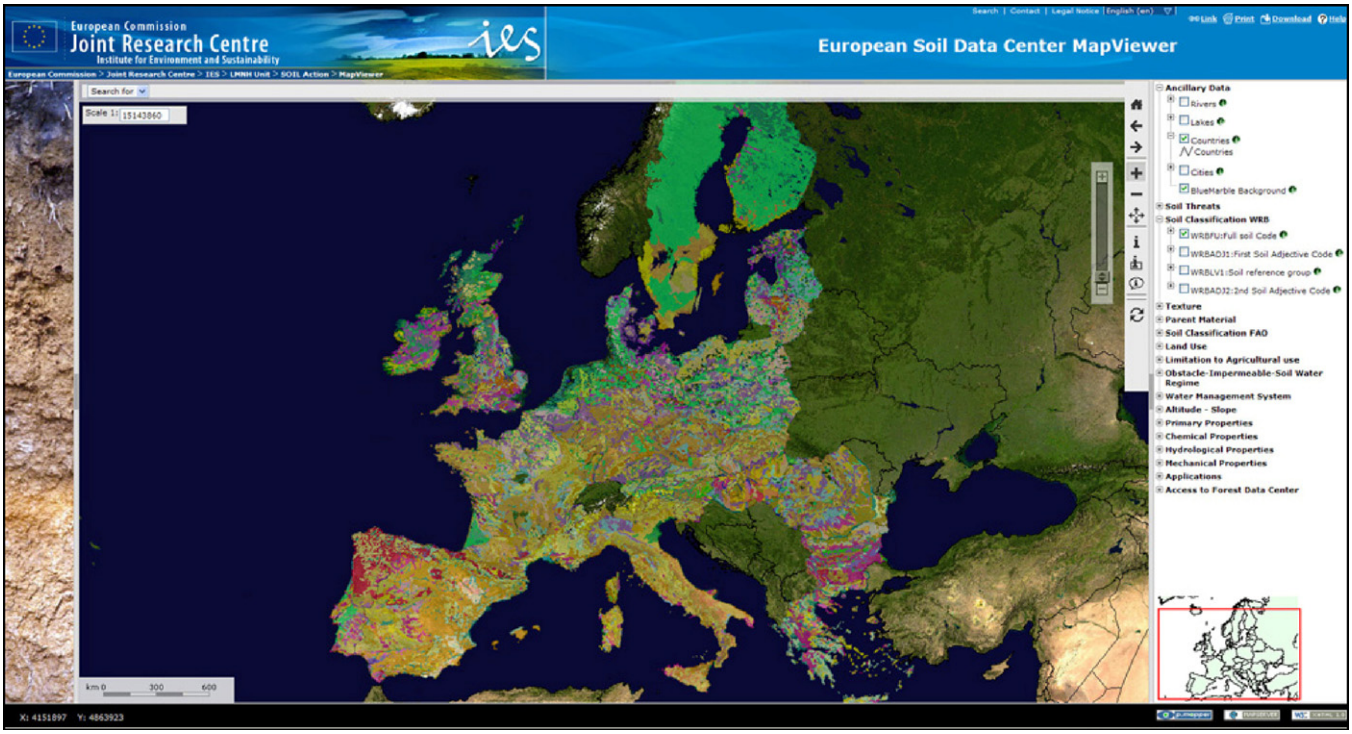

Fig. 4. ESDAC Map Viewer.

operation of ESDAC. Three types of indicators are presented: (i) Web log files; (ii) Data registration requests; (iii) Helpdesk requests. A future development will log, citations of the data in scientific journals.

Web access time series are available in web log files and derived web-usage metrics are useful indicators to evaluate the relation of ESDAC with the soil scientific community and with policy making. In-depth analysis of access to various sections of the portal, allow the development of usage maps that identify which issues match to the main user requirements (Butler, 2009). The number of visitors, data and document downloads performed and total numbers of pages viewed are important web usage indicators (Table 1) which contribute to the evaluation of the impact of ESDAC over time.

A typical soil user browses 6–7 pages on average and downloads 2–3 resources (i.e., reports, documents, datasets, maps, etc.) per visit. Analysis of the web statistics for 2010 show a significant increase in the use of ESDAC resources compared to 2009. Interestingly, the ESDAC Map Viewer (http://eusoils.jrc.ec.europa.eu/wrb/) recorded more than 26,000 user sessions in the first 11 months of operation.

The major datasets hosted by the ESDAC (Fig. 5) are available for downloading after prior registration. Other datasets such as the Soil Profile Analytical Database of Europe – Measured Parameters (SPADE/M) (Hiederer et al., 2006) or Heavy Metals in European Soils (Lado et al., 2008) can be downloaded without any registration.

Certain datasets are not publically available as they have explicit copyright restrictions or are undergoing quality control. In the first case, access is given only to colleagues from other European Union institutions while in the second case, the data can be made available once the necessary data quality checks and documentation have been completed.

Table 2 shows the download of datasets which require prior registration. Users are requested to provide their name, organization and e-mail; they are also required to enter the purpose for which the data will be used. This process, originally based on the email exchange of a license agreement document that is proof that the user agrees with the conditions of use of the data, has been replaced by a more automated registration application that handles the data access requests and registers them in a database.

The European Soil Database (ESDB), ESDAC's flagship product, provides EU-wide data for 73 soil attributes and is the most demanded dataset. It is available in two formats: 66.3% of the users request the vector format of the database while 33.7% prefer the raster version.

Geographical criteria are used for a more in depth analysis of the registered data requests. To date, the ESDAC has served user data requests from 57 countries. Fig. 6 shows the percentage of requests for each of the 20 most registered countries. The remaining 37 countries represent around 10% of all data requests. Other European Commission services account for 2.5% (39 registrations) of the total requests. It is remarkable that around 12% of requests come from outside of the European Union.

Table 1
Usage of the European Soil Portal (January–November 2010).

	Current 30/11/2010	Estimation 31/12/2010	Comments
Visitors	806,884	880,200	Increase of 14% since 2009
Downloads	1,824,027	1,990,000	Increase of 25% since 2009
Page viewed	5,263,022	5,741,000	Increase of 22% since 2009

Table 2
Data registration requests from November 2004 to November 2010.

Dataset	Number of requests	Average monthly requested rate	Available since
European soil database	1164	24.25	November 06
Soil organic carbon	192	2.67	November 04
Soil erosion (Pesera)	193	2.68	November 04
Soil compaction	18	1.50	October 09
Salinization	19	1.58	October 09
pH	18	1.80	January 10
Total	1604		

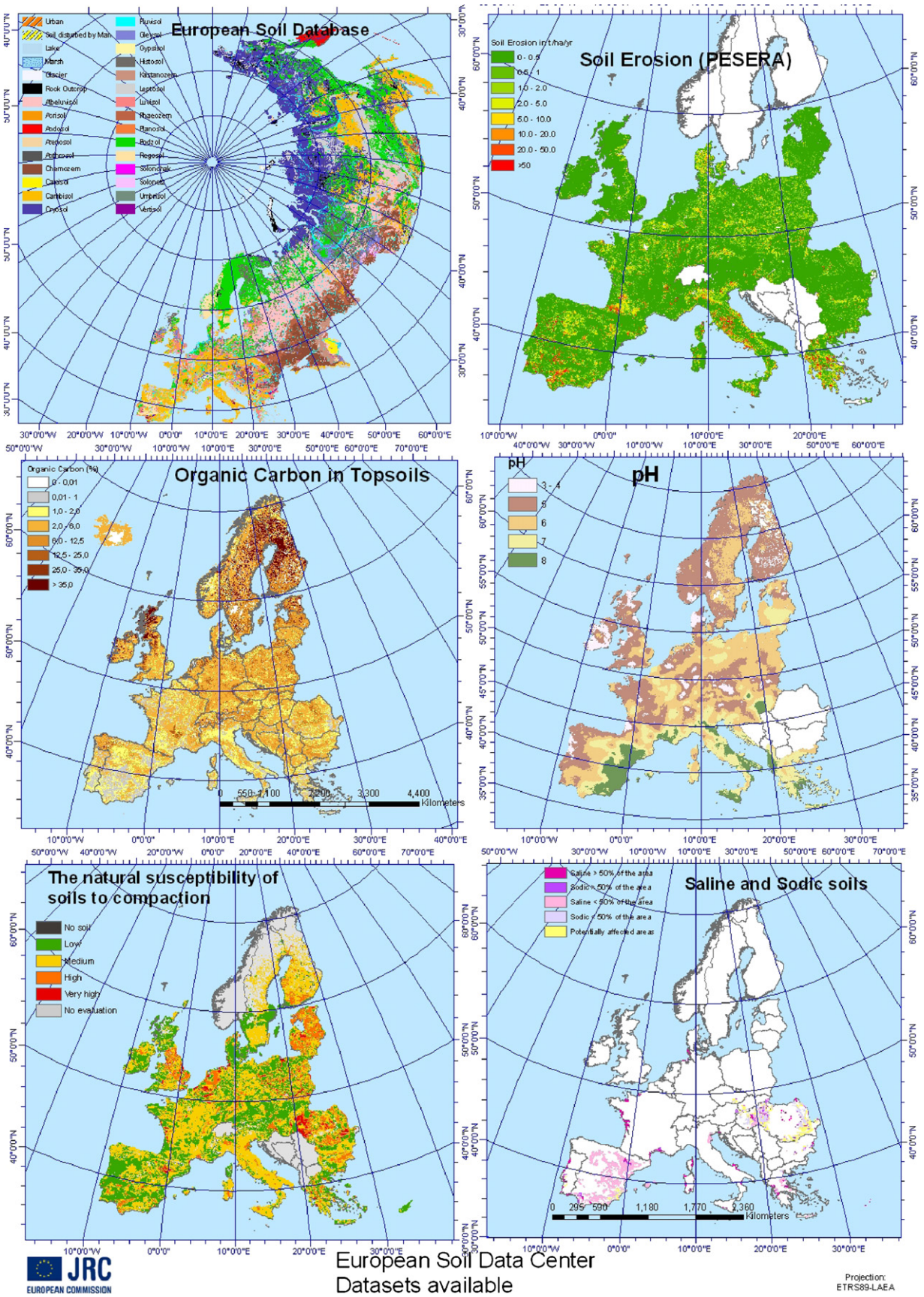

Fig. 5. Major datasets in ESDAC.

Table 3
Scale of dataset use (November 2004–November 2010).

Dataset	European/global scale	National/regional scale	Not defined	Total requests
European soil database	357	373	434	1164
Organic carbon	73	56	63	192
Soil erosion (Pesera)	67	72	54	193
Compaction	3	7	8	18
Salinization	1	8	10	19
pH	5	3	10	18
Total	506	519	579	1604
%	31.55	32.36	36.10	100.00

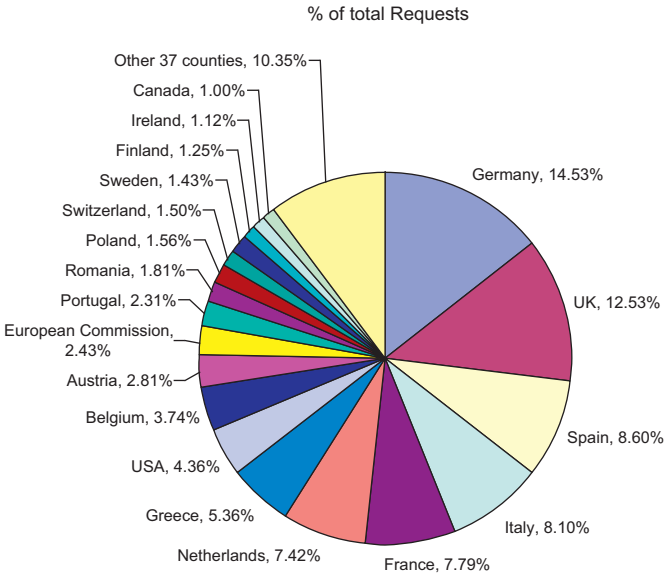

Fig. 6. Geographical coverage of data requests (% per Country).

To access the data, users are asked to provide the purpose for which the information is to be used. This useful feedback allows the requests to be categorized according to different variables. One such variable is the scale (or extent) of intended data use. The second and third column of Table 3 indicate respectively if the data are going to be used at global, European or trans-boundary scale, or if they will serve at national, regional, local or catchment scale. The "not defined" column groups the requests in which there is no mentioning of the scale.

The statistics appear to show a good balance between the use of ESDAC datasets at both a European/global scale and national/regional scale. Users are encouraged to use the European datasets primarily for projects at European or trans-boundary scale as these applications reflect the scope of the original data specification.

The data requests have also been categorized according to broad categories of '**intended use**': Education (only), Education and Research, Policy, Research (only), Assessment – Study, Other (Table 4). The "Education" category includes the use for mainly university courses along with teaching material in secondary schools and awareness raising activities. The category "Research" specifies use of datasets for research in its broadest sense. The category "Education and Research" indicates that data are used for both Education and Research in general. The "Assessment – Study" option includes data analysis, comparison of ESDAC datasets with national ones and validation of third party data. The "Policy" option covers those intentions that specifically mention legislation or decision-making areas. The "Other" category includes mainly mapping purposes, software development (web application/services, demonstrations) and private/business use of data.

Further analysis of the Research requests (Fig. 7) show that users deploy ESDAC data mainly (but not exclusively) for modeling purposes (35%), Projects (26%), PhD work (12%) and Master theses (4%).

Data from the ESDAC are used as inputs for various models in the areas of hydrology, carbon sequestration, land use, climate, biodiversity, species, habitat, ozone and nutrient management. Significantly, data support a variety of EU funded projects in both the European 6th and 7th Framework Programmes for Research (FP6 and FP7). Examples are: CarboEurope, FOOTPRINT, ForstINNO TRACE, ALARM, REFUEL, NitroEurope, WASSERMed.

The majority of requests to the ESDAC Helpdesk come via e-mail. Over 350 requests were registered during the period January–November 2010. There is a high variability to the type of requests; most are related to data availability, documentation and questions about specific data fields.

The **ESDAC user base** is defined as the group of persons who actively show an interest in the ESDAC contents through registration to an on-line interest group (e-mail list). The ESDAC user base, which includes soil-related networks such as European Soil Bureau and the EIONET National Focal Points and National Reference Centres of Soil, receive news on ESDAC updates and the soil-related announcements (e.g., policy developments, meetings, calls for proposals) via a monthly newsletter. Currently, the ESDAC user base includes 1150 members and increased by more than 400 new registrations during 2010.

ESDAC and policy making

The ESDAC can support European Union (EU) policies related to soil as many key data sources are held by it and readily accessible

Table 4
The application of ESDAC data.

Dataset	Education	Education and research	Policy	Research	Assessment – study	Other
European soil database	38	28	74	812	161	51
Soil organic carbon	5	4	20	138	8	17
Soil erosion (Pesera)	7	2	36	98	37	13
Compaction		2	1	12	2	1
Salinization	1	2	2	13	1	
pH	2	1		12	3	
Total	53	39	133	1085	212	82
%	3.30	2.43	8.29	67.64	13.22	5.11

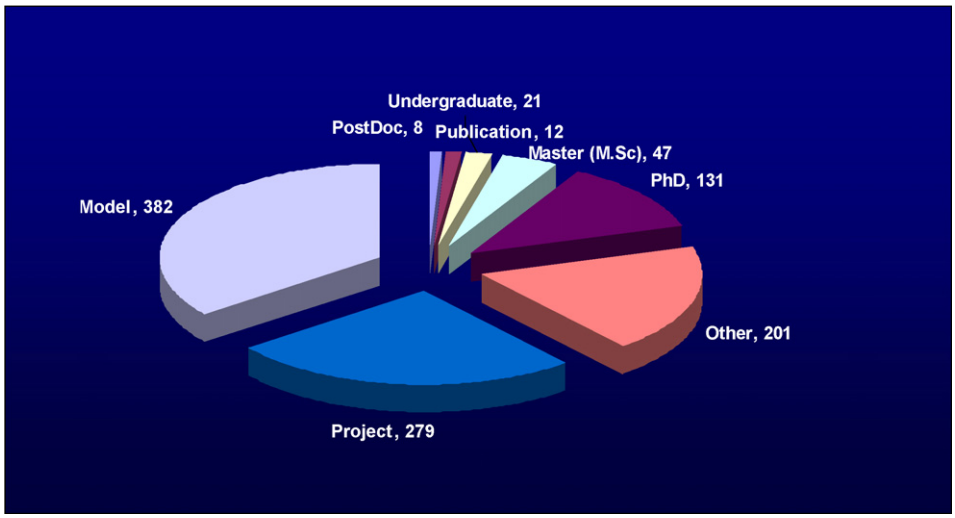

Fig. 7. Applications of ESDAC data for research.

to policy makers, the scientific community and to the public at large. Data collection organized by ESDAC has been conducted efficiently thanks to the possibilities of having access to a pool of expert knowledge and of being able to rely on networking capabilities. Moreover, a key aspect of the ESDAC is the ability to produce synthesis or develop value-added datasets from information contained in the data centre.

ESDAC data and information are highly relevant for the development, implementation and assessment of a number of EU policy areas: agriculture, soil protection, bio-energy, water protection, nature protection, development policy, health and sustainable development. Specific examples include:

- **Common Agricultural Policy (CAP)**: Agro-environmental policies and regulations have requested data from ESDAC in the framework of the SoCo (Sustainable Agriculture and Soil Conservation) project (Louwagie et al., 2009). Soil compaction data, diffuse contamination from eight heavy metals (Lado et al., 2008) and soil erosion rates (Kirkby et al., 2008) were used to define areas where good agricultural practices should be followed for pollution decrease and remediation. ESDAC is providing an assessment of soil quality problems in risk areas, to make realistic estimates of food production and to monitor changes in sustainability and environmental quality as related to agricultural management. The soil quality assessment assists in the formulation of realistic agricultural and land use policies (Doran, 2002). Moreover, ESDAC data contribute to the assessment of biophysical criteria for defining areas which are less favourable for agriculture in Europe (LFA) (EC, 2005; Eliasson et al., 2010).
- **EU Forest Action Plan** (EC, 2006d): Data from the 2005 Biosoil forest soil monitoring programme (Lacarce et al., 2009) are being compared to the results from previous pan-European forest surveys provide new information on trends in soil organic carbon levels in European forests (JRC, 2010a).
- **Climate Change policies**: Soil organic data are requested for models relating to climate change. The role of soil in this debate, in particular peat, as a store of carbon and its role in managing terrestrial fluxes of carbon dioxide (CO_2), has become prominent. Soil contains about twice as much organic carbon as above-ground vegetation. Soil organic carbon stocks in the EU-27 are estimated to be around 75 billion tonnes of carbon (Jones et al., 2005). The benefits of soil conservation for mitigating climate change (increased carbon sequestration) should not be underestimated (Kuhlman et al., 2010).
- **Land use and land use changes**: Degradation of soil functions and increased soil threats lead to changes in land use. Data from the ESDAC on soil organic carbon, pH, compaction, soil erosion and salinization are used to identify land use changes. Moreover, soil properties such as texture allow the identification of sandy soils where drainage is easier but crops grown on these soils can suffer during periods of drought. Another example is the MARS (Monitoring Agriculture with Remote Sensing) Project (MARS, 2010) which uses soil data as part of an agro-meteorological model for pan-European crop yield forecasting (Sommer et al., 1998).
- **Renewable Energies (Biofuel)**: There are many concerns that increasing biofuel production will lead to inappropriate land management and increased land degradation. Soil types classified according to the World Reference Base (WRB) (IUSS Working Group WRB, 2006) of the European Soil Database are among the available thematic data layers for the calculation guidelines of land carbon stocks in Annex V to Directive 2009/28/EC (EC, 2009).
- The **INSPIRE Directive** aims at making relevant geographic information available and structurally interoperable for the purpose of formulation, implementation, monitoring and evaluation of Community policy-making related to the environment. To that end, data specifications for various themes are to be developed. The Soil theme is listed in Annex III of the INSPIRE Directive. A team of experts around ESDAC and ESBN is participating in the official INSPIRE working group responsible for the soil data specifications. ESDAC data inventories have been used as input for the compilation of preparatory reference material for the working group.
- **Protection of EU consumers and food security**: ESDAC provides support to the European Food Agency (EFSA) for the scenario selection and for the parameterization of models estimating exposure of pesticides to soil organisms (Gardi et al., 2011). Dry bulk density, pH, soil organic matter, soil profile analytical data (SPADE) and soil texture have been used as inputs. Moreover, the annual impact of soil losses due to urbanisation on the production capability of agriculture in the EU-25 has been estimated to be equivalent to the loss of more than 4.4 million of tonnes of wheat.
- **Spatial planning and urban development:** Analysis of data reporting the extent of soil sealing in Europe (EEA, 2010) together with the land cover data for 1990 and 2000, show that an estimated 970,000 ha of agricultural land has been lost in 20 EU Member States in this ten year period due to urbanisation. The rate of change is not the same across all countries. The sealed area

in the EU-15 increased by 6%, and productive soil continues to be lost to urban sprawl and transport infrastructures. Landslides inventories and added value technical reports (Hervás, 2007) offer new guidelines for the development of new infrastructures (roads, railways, buildings, etc.).

- **Rural development policies** take into account the current soil conservation practices and policies addressed in SoCo project (Gay et al., 2009). In addition, soil erosion data have been used for the rural development programmes in the region of Emilia-Romagna, Madrid and Scotland.
- **Water management and water protection policies**: Soil texture data, soil permeability and organic carbon data are used as inputs for pan-European flood alert models. Moreover, soil erosion data are being used to assess the pollution of water bodies related to this threat (Barth et al., 2007). ESDAC data assisted in the characterization of water bodies in the Water Framework Directive (WFD, 2000) and in the validation of a maximum capacity of soil water storage.
- **Research and development (RTD) policies**: Most research projects related to soil in FP6 and FP7 (ENVASSO, RamSoil, SoilTrEC, Digisoil, iSoil, eSoter, etc.) are presented in the European Soil Portal. Since ESDAC is providing dissemination capabilities and has a long-term mandate beyond the lifecycle of those projects, the outputs and results are transferred to ESDAC as no other party can guarantee that data will be kept available. Moreover, a significant number of EU research projects in other domains have requested the available datasets of ESDAC (Fig. 5) as inputs for their modeling.
- **European Shared Environmental Information System (SEIS)**: The Shared Environmental Information System (SEIS) is a collaborative initiative of the European Commission and the EEA to establish, together with the Member States, an integrated and shared EU-wide environmental information system. This system would link existing data gathering and information flows related to EU environmental policies and legislation. ESDAC as one of the 10 environmental data centres contributes to the implementation of SEIS.
- **Support to EUROSTAT**: Within the European Union, the IRENA initiative is a Commission-wide project to develop a set of thirty five agri-environmental indicators (EC, 2001). ESDAC data are the input for the formulation of the Soil Erosion indicator and the Soil Quality indicator. Additionally, the ESDAC will store the results of the 2009 LUCAS soil sampling campaign which collected and analysed more than 22,000 soil samples from across Europe.
- **Development policies of the European Union**: Data from the ESDAC were used in the development of the Harmonized World Soil Database v 1.1 (HWSD, 2009) and as legacy data for the Eurasia node of the GlobalSoilMap.net project (Sanchez et al., 2009). Additionally, data are being used to develop the Soil Atlas of Africa and Soil Atlas of Latin America. Together with the European Digital Map Archive (Panagos et al., 2011b), ESDAC data are significant building blocks of the JRC's Africa Caribbean Pacific Observatory (ACP, 2010).
- **Education/media policies**: The Soil Atlas of Europe (European Soil Bureau Network, 2005), the Soil Atlas of the Northern Circumpolar Region (Jones et al., 2010) and the European Atlas of Soil Biodiversity (Jeffery et al., 2010) are important contributions to public awareness of soil and support the need for soil protection in Europe.
- **Biodiversity**: Safeguarding soil biodiversity as presented in the European Atlas of Soil Biodiversity is a key goal of the EU. The atlas is a first push in the development of more complete databases of species and organisms living under the ground. ESDAC data are employed in analyses of the distribution and diversity patterns of European plant species.
- **Global Monitoring for Environment and Security (GMES)**: New approaches for the estimation of soil erosion have been applied in the international Geoland 2 (Geoland 2, 2009) project through the use of remote sensed satellite images. Detailed data on soil erosion are available for agri-environmental monitoring contributing to European Earth observation programme of GMES (Aschbacher et al., 2010).
- **Global Earth Observation System of Systems (GEOSS)**: ESDAC applications and services are contributing to the development of GEOSS (Lefevre et al., 2010), in particular to studies of ecosystems classification and mapping. The ultimate goal is the development of a Global Soil Information System (GLOSIS), as a "system of systems of soil data and information" as part of the GEOSS.
- **Bio-waste treatment**: Biochar is the charcoal residue from the pyrolysis of organic matter during biofuel production. There is currently a debate on the potential benefits of biochar for soil fertility and carbon sequestration (Verheijen et al., 2009).
- **Desertification**: ESDAC data have been used by national authorities in Italy and Portugal in the development of policy to combat drought and desertification.
- **State of Environment Report 2010** (SOER – Soil Assessment in Europe, 2010). Several datasets from the ESDAC have been used to illustrate the state of soil in Europe as part of the Thematic Assessment on Soil in the recently published (SOER, 2010).

Conclusion and outlook

The paper has shown that the European Soil Data Centre currently provides users with access to relevant, accurate, updated and reliable information on soil at European level. In addition to EU policy makers, the ESDAC serves the soil science community with data, documents, maps and applications while contributing to raising awareness of soil issues to the general public. The ESDAC has responded to emerging policy priorities such as climate change, renewable energies, biodiversity and food security where soil is a critical element.

The ESDAC access statistics are an indication of the development of national soil data centres. Requests for core datasets from France, Germany, Italy, The Netherlands and UK are relatively low as national institutes in these countries (INRA in France, BGR in Germany, Cranfield University in United Kingdom, Alterra in Netherlands and ISPRA in Italy) are fulfilling most of the requests at national level. However, in other countries where a national soil focal point is lacking, the ESDAC takes over the role of national soil data centre. For example, the French National Soil Data Centre (De Forges and Arrouays, 2010) is fulfilling most of the requests at national level and the number of data requests to ESDAC coming from France (7.79%) is relatively low according to the population. Instead, in Greece the lack of such an organization or soil data centre results to in a relative high number of data requests to ESDAC (5.36%).

The relatively high number of requests for data use at national/regional scale (Table 3) implies that national/regional soil datasets do not exist or, if they exist, that it is difficult or impossible to access. This suggestion is confirmed by analyzing the responses of some countries. For instance, Greece that does not make available national soil data is using ESDAC datasets at national/regional scale 3 times more than at European/global scale. Instead in France where soil data at national/regional level are managed by the National Soil Data Centre, users require ESDAC datasets for both scales equally.

The contribution of ESDAC to research is significant since the majority of the data requests (67.6%) are for research application. ESDAC data are important inputs for research projects (European and national), modeling activities and university research (PhD thesis, Master dissertations, PostDocs, etc.).

In order to deal with heterogeneous types of data and user requests, ESDAC is following a **pragmatic approach** focusing mostly on user needs articulated by its main customers and less on pure technological developments. However, attention to the development of more Geospatial Web Services (Percivall, 2010) will continue. In a next step the development of Web Feature Services (WFSs) are envisaged, these would allow internet users to retrieve (and optionally update) soil data that reside at ESDAC.

A major INSPIRE-pushed technical development will be the integration of the ESDAC catalogue of resources with external relevant soil data catalogues. On the one hand, the ESDAC catalogue will be set-up as a service for automated consultation by external applications (e.g., through harvesting); on the other hand, part of the ESDAC catalogue will be populated in an automated way by entries from national and regional soil data catalogues.

References

ACP, 2010. Africa Caribbean and Pacific Observatory. http://acpobservatory.jrc.ec.europa.eu/;1 (accessed 14.12.10.).

Aschbacher, J., Beer, T., Ciccolella, A., Pilar Milagro, M., Paliouras, E., 2010. Observing earth, for a safer planet GMES space component: status and challenges. European Space Agency Bulletin 2010 (142), 22–31.

Banwart, S., 2011. Save our soils. Nature 474 (7350), 151–152.

Barth, J.A.C., Steidle, D., Kuntz, D., Gocht, T., Mouvet, C., von Tumpling, W., Lobe, I., Grathwohl, P., 2007. Deposition, persistence and turnover of pollutants: first results from the EU project AquaTerra for selected river basins and aquifers. Science of the Total Environment 376 (1-3), 40–50.

Best, B.D., Halpin, P.N., Fujioka, E., Read, A.J., Qian, S.S., Hazen, L.J., Schick, R.S., 2007. Geospatial web services within a scientific workflow: predicting marine mammal habitats in a dynamic environment. Ecological Informatics 2 (3 SPEC ISS.), 210–223.

Butler, D., 2009. Web usage data outline map of knowledge. Nature 458 (7235), 135.

Daroussin, J., King, D., Le Bas, C., Vrščaj, B., Dobos, E., Montanarella, L., 2006. The Soil Geographical Database of Eurasia at Scale 1:1,000,000: history and perspective in digital soil mapping. Developments in Soil Science 31, 55–65.

De Forges, A.C.R., Arrouays, D., 2010. Analysis of requests for information and data from a national soil data centre in France. Soil Use and Management 26, 374–378, doi:10.1111/j.1475-2743.2010.00267.x.

Dusart, J., 2006. Adapting Soil Data Bases Practices to the Proposed EU Inspire Directive. Developments in Soil Science 31 (C), 77–85.

Doran, J.W., 2002. Soil health and global sustainability: translating science into practice agriculture. Ecosystems and Environment 88 (2), 119–127.

EC, 2001. Communication from the Commission to the Council and the European Parliament Statistical Information needed for Indicators to monitor the Integration of Environmental concerns into the Common Agricultural Policy. COM/2001/0144 final.

EC, 2005. Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD).

EC, 2006. European Commission, 2006. Thematic Strategy for Soil Protection (Communication). Brussels, 22-9-2006. COM (2006) 231 final.

EC, 2006. European Commission, 2006. Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC. Brussels, 22-9-2006. COM (2006)232 final.

EC, 2006. European Commission, 2006. Impact Assessment of the Thematic Strategy on Soil Protection. Brussels, 22-9-2006. SEC (2006) 620.

EC, 2006d. European Commission, Soil Protection: The Story Behind the Strategy. European Communities, Brussels.

EC, 2006. Communication from the Commission to the Council and the European Parliament, on an EU Forest Action Plan. COM (2006) 302 final.

EC, 2009. Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

EEA, 2010. Soil sealing data in aggregated spatial resolution (100 × 100 m). http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m (accessed 15.12.10.).

Eliasson, A., Jones, R.J.A., Nachtergaele, F., Rossiter, D.G., Terres, J.-M., Van Orshoven, J., van Velthuizen, H., Le Bas, C., 2010. Common criteria for the redefinition of intermediate less favoured areas in the European Union. Environmental Science and Policy 13 (8), 766–777.

ESBN RR5, 2001. European Soil Bureau Network, Research Report No. 5. Georeferenced Soil Database for Europe: Manual of Procedures Version 1.1. European Soil Bureau, Scientific Committee. EUR 18092 EN 184 pp. (2001). Office for Official Publications of the European Communities, Luxembourg.

ESDB ver2, 2004. The European Soil Database distribution version 2.0, European Commission and the European Soil Bureau Network, CD-ROM, EUR 19945 EN, 2004 Office for Official Publications of the European Communities, Luxembourg.

European Soil Bureau Network, 2005. Soil Atlas of Europe. Office for Official Publications of the European Communities, L-2995, Luxembourg, pp. 128.

Gay, S.H., Louwagie, G., Sammeth, F., Ratinger, T., Maréchal, B., Prosperi, P., Rusco, E., Terres, J., van der Velde, M., Baldock, D., Bowyer, C., Cooper, T., Fenn, I., Hagemann, N., Prager, K., Heyn, N., Schuler, J., 2009. Final Report on the Project 'Sustainable Agriculture and Soil Conservation (SoCo)'. Office for Official Publications of the European Communities, Luxembourg, http://soco.jrc.ec.europa.eu/ (30.08.09.).

Gardi, C., Panagos, P., Hiederer, R., Montanarella, L.,Micale, F., 2011. Activities realized within the Service Level Agreement between JRC and EFSA, as a support of the FATE Working Group of EFSA PPR in support of the revision of the guidance document Persistence in Soil. EUR 24744 EN – Joint Research Centre – Institute for Environment and Sustainability. EUR – Scientific and Technical Research series.

Gallego, J., Bamps, C., 2008. Using CORINE land cover and the point survey LUCAS for area estimation. International Journal of Applied Earth Observation and Geoinformation 10 (4), 467–475.

Gebhardt, S., Wehrmann, T., Klinger, V., Schettler, I., Huth, J., Kunzer, C., Dech, S., 2010. Improving data management and dissemination in web based information systems by semantic enrichment of descriptive data aspects. Computers and Geosciences 36 (10), 1362–1373.

Geoland 2, 2009. Supporting the monitoring, protection and sustainable management of our environment. http://www.gmes-geoland.info/ (accessed 14.12.10.).

Granell, C., Díaz, L., Gould, M., 2010. Service-oriented applications for environmental models: reusable geospatial services. Environmental Modelling and Software 25 (2), 182–198.

In: Hervás, J. (Ed.), 2007. Guidelines for Mapping Areas at Risk of Landslides in Europe. Proc. Experts Meeting, JRC, Ispra, Italy, 23-24 October 2007. JRC Report EUR 23093 EN, Office for Official Publications of the European Communities, Luxembourg, 53 pp.

Hiederer, R., Jones, R.J.A., Daroussin, J., 2006. Soil Profile Analytical Database for Europe (SPADE): reconstruction and validation of the measured data (SPADE/M). Geografisk Tidsskrift 106 (1), 71–85.

HWSD, 2009. Harmonized World Soil Database v 1.1 http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/ (accessed 15.12.10.).

Jones, A., Stolbovoy, V., Tarnocai, C., Broll, G., Spaargaren, O., Montanarella, L. (Eds.), 2010. Soil Atlas of the Northern Circumpolar Region. European Commission, Office for Official Publications of the European Communities, Luxembourg, pp. 142.

JRC, 2010. In: Hiederer, R., Durrant, T. (Eds.), Evaluation of BioSoil Demonstration Project—Preliminary Data Analysis. Office for Official Publications of the European Union, EUR 24258 EN, Luxembourg, p. 126.

Jones, R.J.A., Hiederer, B., Rusco, F., Montanarella, L., 2005. Estimating organic carbon in the soils of Europe for policy support. European Journal of Soil Science 56, 655–671.

INSPIRE, 2007. INSPIRE EU Directive, Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), Official Journal of the European Union, L 108/1 50 (25 April 2007).

IUSS Working Group WRB, 2006. IUSS Working Group WRB, World reference base for soil resources 2006. World Soil Resources Report No. 103, FAO, Rome (2006) (see also 2007 electronic update at FAO web site http://www.fao.org/landandwater/agll/wrb/).

Kirkby, M.J., Irvine, B.J., Jones, R.J.A., Govers, G., Boer, M., Cerdan, O., Daroussin, J., Van Lynden, G., 2008. The PESERA coarse scale erosion model for Europe. I. – Model rationale and implementation. European Journal of Soil Science 59 (6), 1293–1306.

Kuhlman, T., Reinhard, S., Gaaff, A., 2010. Estimating the costs and benefits of soil conservation in Europe. Land Use Policy 27 (1), 22–32.

Lacarce, E., Le Bas, C., Cousin, J.-L., Pesty, B., Toutain, B., Houston Durrant, T., Montanarella, L., 2009. Data management for monitoring forest soils in Europe for the Biosoil project. Soil Use and Management 25, 57–65.

Lado, L., Hengl, T., Reuter, H., 2008. Heavy metals in European soils: a geostatistical analysis of the FOREGS geochemical database. Geoderma 148 (2), 189–199.

Lambot, S., Slob, E., Rhebergen, J., Lopera, O., Jadoon, K.Z., Vereecken, H., 2009. Remote estimation of the hydraulic properties of a sandy soil using full-waveform integrated hydrogeophysical inversion of time-lapse, off-ground GPR data. Vadose Zone Journal 8 (3), 743–754, doi:10.2136/vzj2008.0058.

Lefevre, R.J., Pearlman, J., Wiener, T.F., 2010. The role of science and technology in GEOSS. In: IEEE Aerospace Conference Proceedings, art. no. 5447002.

Louwagie, G., Gay, S.H., Burrell, A., 2009. Addressing soil degradation in EU agriculture: relevant processes, practices and policies. In: Report on the project 'Sustainable Agriculture and Soil Conservation (SoCo)'. JRC Scientific and Technical Reports, pp. 209.

MARS, 2010. The Monitoring Agricultural Resources. http://mars.jrc.ec.europa.eu/ (accessed 14.12.10).

Morvan, X., Saby, N.P.A., Arrouays, D., Le Bas, C., Jones, R.J.A., Verheijen, F.G.A., Bellamy, P.H., Kibblewhite, M.G., 2008. Soil monitoring in Europe: a review of existing systems and requirements for harmonisation. Science of the Total Environment 391 (1), 1–12.

Panagos, P., Van Liedekerke, M., Montanarella, L., 2011a. Multi-scale European Soil Information System (MEUSIS): a multi-scale method to derive soil indicators. Computational Geosciences 15 (3), 463–475, doi:10.1007/s10596-010-9216-0.

Panagos, P., Jones, A., Bosco, C., Senthil Kumar P.S., 2011b. European digital archive on soil maps (EuDASM): preserving important soil data for public free access.

International Journal of Digital Earth, in press, doi:10.1080/17538947.2011.596580.

Percivall, G., 2010. Progress in OGC Web Services Interoperability Development. Pages 37–61, Chapter 4 in book Standard-Based Data and Information Systems for Earth Observation, Lecture Notes in Geoinformation and Cartography, In: Di, L., Ramapriyan, H.K. (Eds.). doi:101007/978-3-540-88264-0_4, Springer-Verlag, Berlin Heidelberg.

Sanchez, P., Ahamed, S., Carré, F., Hartemink, A., Hempel, J., Huising, J., Lagacherie, P., McBratney, A., McKenzie, N., Mendonça-Santos, M., Minasny, B., Montanarella, L., Okoth, P., Palm, C., Sachs, J., Shepherd, K., Vågen, T., Vanlauwe, B., Walsh, M., Winowiecki, L., Zhang, G., 2009. Digital soil map of the world. Science 325 (5941), 680–681.

Jeffery, S., Gardi, C., Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Peres, G., Römbke, J., van der Putten, W.H. (Eds.), 2010. European Atlas of Soil Biodiversity. European Commission, Publications Office of the European Union, Luxembourg.

SOER – Soil Assessment in Europe, 2010. IES Contribution to SOER, 2010, Jones et al., The European Environment – State and Outlook 2010. Soil, 2010, Publications Office of the European Union, Luxembourg.

Sommer, S., Hill, J., Megier, J., 1998. The potential of remote sensing for monitoring rural land use changes and their effects on soil conditions. Agriculture, Ecosystems and Environment 67 (2–3), 197–209.

Van Beek, C.L., Tóth, T., Hagyó, A., Tóth, G., Recatalá Boix, L., Añó Vidal, C., Malet, J.P., Maquaire, O., Van den Akker, J.J.H., Van der Zee, S.E.A.T.M., Verzandvoort, S., Simota, C., Kuikman, P.J., Oenema, O., 2010. The need for harmonizing methodologies for assessing soil threats in Europe. Soil Use and Management 2010 (26 (September)), 299–309.

Van Egmond, Fenny, M., Dietrich, Peter, Werban, Ulrike, Uta, Sauer, 2009. Quality Assurance and Safety of Crops & Foods (QAS) 01 (2), 117–120, doi:10.1111/j.1757-837X.2009.00019.x.

Verheijen, F., Jeffery,S., Bastos, A.C., van der Velde, M., Diafas I. Biochar application to soils – a critical scientific review of effects on soil properties, processes and functions (2009). EUR 24099 – EN – Joint Research Centre – Institute for Environment and Sustainability.

WFD, 2000. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.