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SHORT COMMUNICATION

The European Modern Pollen Database (EMPD) project

**Basil A. S. Davis · Marco Zanon · Pamella Collins · Achille Mauri ·
Johan Bakker · Doris Barboni · Alexandra Barthelmes · Celia Beaudouin ·
Anne E. Bjune · Elissaveta Bozilova · Richard H. W. Bradshaw ·
Barbara A. Brayshay · Simon Brewer · Elisabetta Brugiapaglia · Jane Bunting ·
Simon E. Connor · Jacques-Louis de Beaulieu · Kevin Edwards ·
Ana Ejarque · Patricia Fall · Assunta Florenzano · Ralph Fyfe · Didier Galop ·
Marco Giardini · Thomas Giesecke · Michael J. Grant · Jöel Guiot ·
Susanne Jahns · Vlasta Jankovská · Stephen Juggins · Marina Kahrmann ·
Monika Karpińska-Kołaczek · Piotr Kołaczek · Norbert Kühl · Petr Kuneš ·
Elena G. Lapteva · Suzanne A. G. Leroy · Michelle Leydet · José Guiot ·
Susanne Jahns · Vlasta Jankovská · Stephen Juggins · Marina Kahrmann ·
Monika Karpińska-Kołaczek · Piotr Kołaczek · Norbert Kühl · Petr Kuneš ·
Elena G. Lapteva · Suzanne A. G. Leroy · Michelle Leydet · José Antonio López Sáez ·
Alessia Masi · Isabelle Matthias · Florence Mazier · Vivika Meltsov ·
Anna Maria Mercuri · Yannick Miras · Fraser J. G. Mitchell · Jesse L. Morris ·
Filipa Naughton · Anne Birgitte Nielsen · Elena Novenko · Bent Odgaard ·
Elena Ortu · Mette Venås Overballe-Petersen · Heather S. Pardoe ·
Silvia M. Peglar · Irena A. Pidek · Laura Sadori · Heikki Seppä ·
Elena Severova · Helen Shaw · Joanna Święta-Musznicka · Martin Theuerkauf ·
Spassimir Tonkov · Siim Veski · W. O. van der Knaap · Jacqueline F. N. van Leeuwen ·
Jessie Woodbridge · Marcelina Zimny · Jed O. Kaplan**

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Abstract Modern pollen samples provide an invaluable research tool for helping to interpret the quaternary fossil pollen record, allowing investigation of the relationship between pollen as the proxy and the environmental parameters such as vegetation, land-use, and climate that the pollen proxy represents. The European Modern Pollen Database (EMPD) is a new initiative within the European Pollen Database (EPD) to establish a publicly accessible repository of modern (surface sample) pollen data. This new database will complement the EPD, which at present holds only fossil sedimentary pollen data. The EMPD is freely available online to the scientific community and currently has information on almost 5,000 pollen samples from throughout the Euro-Siberian and Mediterranean regions, contributed by over 40 individuals and research groups. Here we describe how the EMPD was constructed, the various tables and their fields, problems and errors, quality controls, and continuing efforts to improve the available data.

Keywords Pollen · Surface sample · Database · EPD · EMPD · Europe

The readers are requested to refer the ESM for complete list of author details.

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B. A. S. Davis (✉)
ARVE Group, School of Architecture, Civil & Environmental Engineering, Station 2, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland
e-mail: basil.davis@epfl.ch

Introduction

The development of publicly accessible databases of fossil pollen data during the last 20 years such as the European

Pollen Database (EPD) have provided scientists with an unrivalled source of information to study past changes in terrestrial vegetation, land-cover and climate at both large and small spatial scales over the quaternary period (Fyfe et al. 2009). Interpreting fossil pollen records however requires a clear understanding of the relationship between pollen as the proxy, and the environmental parameter (vegetation, land-use, climate) that it represents. Establishing these relationships has largely been achieved through the use of modern pollen surface samples, but unlike fossil pollen data, there has not been a public database of modern pollen data available for Europe until now. Surface sample datasets that have been used to date have either been smaller-scale compilations based on primary sample collection and analysis by individuals or laboratories for specific projects, or collections of such data gathered from many sources, most of which have been poorly documented and include problematic secondary data sources such as digitised published pollen diagrams.

Discussions at conferences and workshops amongst palynologists and other researchers with an interest in pollen proxy records, including the EPD workshop in Aix-en-Provence in 2007[1] and the International Palynological Congress (IPC XII) in Bonn in 2008, identified a pressing need for an open, accessible, standardised, fully documented and quality controlled dataset of modern pollen samples. The EPD provides an existing organisational and physical structure for such a database, and it seemed a logical step to develop a European Modern Pollen Database (EMPD) as part of the EPD. The new database would be designed to hold data on samples comparable to fossil samples currently held in the EPD, and therefore would also be different from the pollen monitoring program (Giesecke et al. 2010) which is mainly concerned with annual to sub-annual sampling of pollen rain. This paper outlines the establishment of the database, the process of collecting and assimilating data, the database structure and its planned development in future. It is hoped that this new database will form an important new resource for pollen-based palaeo-environmental inquiry, predicated upon the same principles of open community ownership and participation that have made the EPD so successful.

Why are pollen surface samples useful?

Modern pollen samples have been used in a wide variety of different scientific applications:

Interpretation of the fossil pollen record

Investigating past vegetation, land-use and ecosystem change using fossil pollen data requires an understanding of how vegetation is represented in the pollen record. Surface samples have long formed the basis for developing this understanding since the introduction of modern pollen analysis by von Post (cf. Erdtman 1943). This approach has been widely applied in Europe to understand the qualitative relationship between pollen composition and vegetation, for example in alpine environments (Court-Picon et al. 2006), boreal forest (Pisaric et al. 2001), western and southeastern European mountains (Tonkov et al. 2001; Ejarque et al. 2011), Middle East desert (Elmoslimany 1990), *Olea* silviculture (Vermoere et al. 2003), fen carr woodland (Waller et al. 2005; Binney et al. 2005), Mediterranean woodlands (López-Sáez et al. 2010) and wetlands (Amami et al. 2010), *Hedera* vegetation (Bottema 2001), temperate open-woodlands (Bunting 2002; Waller et al. 2012), wetlands (Zhao et al. 2006), off-shore islands (Fossitt 1994; Brayshay et al. 2000), archaeological contexts (Fernández Freire et al. 2012), as well as areas of anthropogenic land-use (Behre 1981; Hjelle 1998; Court-Picon et al. 2006; Mazier et al. 2006, 2009; Miras 2009; Cugny et al. 2010). Surface samples have also formed the basis for the quantitative analysis of pollen-vegetation relationships (Andersen 1970; Bradshaw 1981) and the recent development of detailed quantitative models describing the dispersal and deposition of pollen (Gaillard et al. 2008b).

Quantitative estimates of past (anthropogenic) land-cover

Reconstructing the absolute quantity of different types of vegetation land-cover from pollen data is complicated by differences in pollen productivity between taxa, and differences in the size of source area between different pollen sites. Surface samples have played an important role in investigating this problem in conjunction with numerical modelling, such as in the early work by Prentice (1983, 1985) that was later developed by Sugita (1993). This methodology has since been expanded and refined through the POLLANDCAL project (Gaillard et al. 2008a), and the ongoing LANDCLIM project (Gaillard et al. 2010), and many studies in Europe have used surface samples to estimate relative pollen productivity of different plant species for quantitative reconstructions (Broström et al. 2008). Other less spatially and ecologically discrete approaches have also used surface samples, either statistically interpolated (Guiot et al. 1996), or calibrated using satellite-derived estimates of woodland vegetation cover to quantify past changes in woodland cover from fossil pollen data (Tarasov et al. 2007).

[1] The workshop participants were Marco Zanon, Pamella Collins, Achille Mauri, Anne E. Bjune, Simon E. Connor, Ralph Fyfe, Thomas Giesecke, Petr Kuneš, Jesse L. Morris, Filipa Naughton, Martin Theuerkauf, Pim (W. O.) van der Knaap, Jacqueline F. N. van Leeuwen, and Jed O. Kaplan.

Delimitation of forest boundaries

Altitudinal and latitudinal changes in forest boundaries have often been interpreted from the fossil pollen record as a proxy for climate change. The free dispersal of pollen either side of these boundaries makes defining this limit from the pollen record difficult (Binney et al. 2011). Pollen surface samples, often together with macrofossils, have been used to investigate this problem in areas such as the forest-steppe boundary (Tarasov et al. 1998b; Djamali et al. 2009), forest-tundra boundary (Gervais and MacDonald 2001; Salonen et al. 2011), steppe–forest–tundra boundaries (Pelanková and Chytry 2009; Pelanková et al. 2008) and the mountain timberline (Connor et al. 2004).

Reconstructions of past climate

Climate has a strong influence on vegetation and fossil pollen data have been widely used as a basis for reconstructing past climate change (Brewer et al. 2007). Pollen surface samples have been used to calibrate and/or evaluate almost all pollen-based climate reconstruction techniques including: taxon-based modern analogues (Guiot et al. 1989; Cheddadi et al. 1998), plant functional type (pft) based modern analogues (Davis et al. 2003), response surfaces (Huntley 1993), partial least squares regression (Seppä et al. 2004; Finsinger et al. 2007; Bjune et al. 2010), neural networks (Peyron et al. 1998), Bayesian approaches (Haslett et al. 2006), as well as inverse modelling methods using vegetation models such as BIOME4 (Wu et al. 2007), and LPJGUESS (Garreta et al. 2010). Surface samples have also been used to evaluate pollen-climate reconstructions of altitudinal temperature gradients (Ortu et al. 2010), reconstructions from marine sediments (Combourieu Nebout et al. 2009) and the climatic tolerances of specific taxa (Ninyerola et al. 2007).

Integration with vegetation models

A growing realisation of the link between the climate system and the terrestrial biosphere has seen the development of vegetation models and their integration with the pollen record of past vegetation change. This has been based on the concept of compatible units based on biomes and pfts (or traits) developed within projects such as BIOME6000 (Prentice and Jolly 2000), that have been evaluated using surface pollen samples over the European region (Prentice et al. 1996; Collins et al. 2012) and former USSR (Tarasov et al. 1998b; Mokhova et al. 2009). Surface samples have also been used to develop and refine these techniques in a number of other European studies, including the relationship between plant traits and climate (Barboni et al. 2004), and the probabilistic assignment of plant attributes and biomes (Gachet et al. 2003; Gritti et al. 2004). A different but related application of surface samples has also been to evaluate the ability of niche-models to reconstruct past changes in the distribution of individual plant taxa in response to climate change (Pearman et al. 2008).

Investigation of taphonomic problems

Pollen surface samples have also been used to investigate the process of pollen deposition in different sedimentary environments in Europe, including marine sediments (Cundill et al. 2006; Naughton et al. 2007; Beaudouin et al. 2007), coprolites (Carrión 2002), cave sediments (Carrión et al. 2006) and comparisons of Tauber trap sampling versus moss polsters (Pardoe et al. 2010; Lisitsyna et al. 2011). Modern pollen samples have also been exploited to define the percentage levels of pollen that may indicate the regional presence or absence of major European trees (Lisitsyna et al. 2012), as well helping to determine sediment provenance in earthquake limnology (Leroy et al. 2009).

A short history of surface-sample datasets from the Euro-Siberian and Mediterranean area

The creation of large continental-scale datasets of modern pollen data was initially motivated by the development of pollen-climate transfer functions in the 1980's. The resulting datasets were almost all based on a mix of primary raw-count data and secondary percentage data digitised from published pollen diagrams. In Europe, this dates specifically to the pioneering work of Joel Guiot (JG) (Guiot 1985, 1987; Guiot et al. 1989) and Brian Huntley and Colin Prentice (HP) (Huntley and Prentice 1988).

The HP dataset consisted of 973 samples based on a combination of core-top samples from the European fossil pollen core compilation by Huntley and Birks (1983), together with data from Petersen (1983) for the western USSR and Prentice (1983) for Sweden. This dataset also formed the basis for subsequent pollen-climate analysis by Huntley (1992) and Kelly and Huntley (1991), as well the study of the differences between present and past vegetation of Europe (Huntley 1990). The JG dataset began with 36 surface samples from sites in southeast France (Guiot 1985), later expanded to 182 samples covering most of Central Europe (Guiot 1987) and then 227 samples following additions from Southern Europe and North Africa (Guiot et al. 1989). This was later increased to 1,200 samples by merging the JG and HP datasets (Guiot 1990).

The BIOME6000 project (Prentice et al. 1996) developed a methodology for reconstructing vegetation biomes for Europe using pollen data. This technique was evaluated using modern pollen samples, and then applied to reconstruct biomes for the mid-Holocene. This study used a still larger dataset of 2,289 modern pollen samples based on a combination of data from Huntley and Birks (1983), Guiot et al. (1993) and Huntley (1994). Cheddadi et al. (1997) also examined the mid-Holocene, but focused on reconstructing the climate of Europe using a modern-analogue transfer-function approach that used a modern pollen dataset of 1,331 samples. This effort represented a combination of the HP dataset, plus Guiot (1990) and a further 148 samples of tundra and cool steppe vegetation from North America. Further work in differentiating warm and cold steppe biomes in Eurasia by Tarasov et al. (1998a) was based on a set of 878 modern samples from steppe environments that expanded on previous data from the Mediterranean (Prentice et al. 1996; Cheddadi et al. 1997) to include 90 samples from Kazakhstan.

The expansion of European datasets to include data from North America and other regions was developed further by Huntley (1993), and this approach was incorporated into subsequent studies by this author such as Allen et al. (2000) using a data set of 7,816 samples from the temperate and boreal regions of the Northern Hemisphere.

These large datasets often contained large amounts of secondary digitised data, whereas other authors sought to compile datasets based only on primary raw counts, albeit initially from smaller regional areas. Cheddadi et al. (1998) reconstructed Holocene climate at the site of Tigalmamine in Morocco using 636 raw count surface samples from Morocco and south-west Europe that were also used by Prentice et al. (1996). At the same time, the development of the EPD provided an additional source of primary raw-count data in the form of core-top samples. The study by Peyron et al. (1998) expanded the dataset of Cheddadi et al. (1998) by including 77 samples from the EPD, together with raw count data from other regions of Europe, Kazakhstan and Siberia to create a dataset of 1,328 samples. The growing amount of data in the EPD allowed Davis et al. (2003) to create a dataset of 2,363 samples for Europe and the Mediterranean, based on a combination of EPD core-top data, existing datasets (Guiot et al. 1993) and additional data from the PANGAEA data archive and individual contributors. Similar data were also used by Barboni et al. (2004) in a study that focused on the Mediterranean region. These authors undertook quality-control checks on existing datasets (e.g. Davis et al. 2003) and added additional data from individual contributors to create a 602 sample dataset for the circum-Mediterranean area.

More recently Peyron et al. (2005) used a dataset of 868 samples from an earlier study (Peyron et al. 1998), together with samples from Tibet (118), the Scandes Mountains (37) and Spain (17). This dataset was later expanded by Bordon et al. (2009) to a total of 2,748 samples by adding 763 samples from previous compilations plus a further 1,319 samples from individual contributors. A similarly large dataset of 2,653 samples was also used by Klotz et al. (2003) and Feurdean et al. (2008) based largely on data from Guiot (1990) and Peyron et al. (1998), but also including a large amount of secondary data from Huntley and Birks (1983).

This brief history is not exhaustive, but includes mention of most of the main datasets used over the past 27 years. Whilst in most cases these datasets have been sufficient for the purpose to which they have been applied, they have routinely been poorly documented and therefore difficult to audit. The Huntley and Birks (1983) data are included in many datasets despite being limited to only 43 selected taxa. This dataset is also known to contain large amounts of percentage data digitised by hand from published pollen diagrams with non-standardised pollen sums. More generally, the criteria for the inclusion of core-top data in most datasets are not well documented, and samples have been included with poor knowledge whether they were of modern age. Even where age-control is comparatively good, the definition of at what age a sample should be considered modern has varied, with one of the most common definitions being 0–500 B.P. (e.g. Prentice et al. 1996) leading to a mixture of core-top samples of quite different ages. Many surface samples have also often been poorly geo-referenced because many early surface samples were collected for vegetation studies and the recording of the exact location was neither seen as important nor easily achievable before the widespread use of GPS. Where geo-referencing has been provided, various conversion problems have been noted between UTM and national map co-ordinate systems to conventional latitude/longitude, and thence to decimal degree co-ordinates. In many cases these geo-referencing errors have gone un-noticed in continental-scale compilations, but are now easily detected using Google Earth. Other general problems with many datasets include a lack of metadata for each sample, such as the sampling method, depositional environment, data source(s) and authorship.

Justified criticism of these poorly documented and poorly quality-controlled datasets have led others to apply more stringent quality-control measures based on more uniform criteria (Seppä et al. 2004; Finsinger et al. 2007; Bjune et al. 2010). Although some of these represent relatively large datasets, they remain regional in extent because of resource limitations or sampling design. Differences also exist in the optimal design of datasets which varies depending on the research question being addressed, for instance between pollen-climate studies which favour samples from medium-sized lakes (Bjune et al. 2010), and land-use studies where emphasis has been placed on soil samples or moss polsters (Gaillard et al. 2008a). The creation of the EMPD is designed to provide a shared repository for this type of high quality and fully documented surface sample data, allowing users access to large datasets that can also be sub-selected according to the research question being addressed. But perhaps most importantly, the EMPD is to be a public database, whereas previously access to most of the datasets mentioned has been restricted.

Database launch

The EMPD project was started with the establishment of an EPD support group and an initial request for support directed at over 200 palynologists working in the Euro-Siberian region. This appeal resulted in pledges of over 3,000 surface samples and provided the basis for a successful application for funding from the Swiss National Science Fund for a small workshop that took place in September 2011 at the Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. By the time of the workshop, data from over 4,300 pollen samples were received from over 40 individuals and research groups, almost all of which was raw count data gathered by the individuals and groups concerned. This was supplemented by a further ~2,500 samples from a database developed by Doris Barboni (Barboni et al. 2004) and herein called the 'DB' dataset. These data were based on earlier datasets developed by other researchers including Rachid Cheddadi, Odile Peyron, Pavel Tarasov, Basil Davis, Joel Guiot and Brian Huntley. The DB dataset included a large amount of 'heritage' data from a mixture of sources including EPD 'core-top' and percentage data, where the pollen sum, selection criteria and original source had not always been clearly documented. Of this dataset, around 280 samples from Morocco were flagged for exclusion because of unresolvable geo-referencing errors, 800 samples from the former Soviet Union were excluded because they comprised mainly percentage data and lacked appropriate metadata including the basis for the pollen sum, and around 300 EPD core-top samples were excluded because they did not meet the more stringent chronological controls required to identify 'modern' samples (see the following section, note 5).

Data integration and quality control

The main task of the workshop at EPFL was to integrate all of the submitted data into a single database with a harmonised taxonomy and comprehensive metadata documentation. This involved the following tasks:

(1) *Data entry*. Data were submitted in various file formats (excel, Tilia, psimpoll etc.) and therefore needed to be converted and placed into a single data file.
(2) *Taxonomy harmonisation*. Different pollen analysts often adopt their own taxonomic naming conventions. All the taxa names submitted to the EMPD were retained, but needed to be placed within a standardized EPD taxonomy.
(3) *Metadata*. As well as the sample location and the pollen counts, the database also included for each sample information on: the type of sample and sampling method (core-top, moss polster, soil, Tauber-trap, single sample, merged samples etc.), site attributes (lake, bog, surface area, surrounding vegetation etc.), authorship, contact details and relevant publications. Where this information could not be obtained directly from the original authors it was gathered from the relevant literature.
(4) *Geo-referencing*. The location of each surface sample in the database was entered in decimal degrees. Where different co-ordinates were provided, such as UTM or analogue latitude/longitude, these were converted accordingly. Locations were checked using Google Earth and cross-checked against site altitude using a high resolution Digital Elevation Model (DEM). Semi-automatic routines were used in this task so that sites whose altitude was not close to the DEM altitude for the cited location were flagged. In a small number of cases where no altitude data were provided, elevations were assigned using Google Earth.
(5) *Core tops*. Core-top samples from existing fossil pollen records in the EPD were also included as surface samples where appropriate. The selection of core-top samples for the EMPD was undertaken based on a conservative approach to core-top dating using a recent comprehensive review of EPD chronologies. Only samples that could be confidently dated to younger than 200 cal. years B.P. were included, compared to 500 ^{14}C years B.P. used in most previous studies (e.g. Prentice et al. 1996).
(6) *Percentage data*. Only raw counts were included in the EMPD, in keeping with the established data protocol of the EPD. This precondition meant excluding ~1,200 samples in the DB dataset that were percentage data, most of which were from the former USSR region (Petersen 1983; Tarasov et al. 1998b). The main problem with these particular percentage data was that in many cases there was no proper documentation, and the basis for the pollen sum could not be established. Even where the basis

for the sum was known, the same criteria have often not been uniformly applied to all datasets or even all parts of the same dataset. The storage of raw count data in the EPD means that the user can define the sum according to their own scientific requirements, allowing for greater flexibility, and uniform criteria to be applied to all samples. It is also recognised that percentage data have been used in many previous studies and it is intended that the percentage data submitted to the EMPD will still be made available, though in a separate database.

(7) *Other*. Further quality-control checks were made on the data to identify and where appropriate, to remove samples that were duplicates or contained errant and/or unusual values.

Database design

The EMPD database is designed to be as accessible and easy to maintain as possible, and therefore follows a simple spreadsheet format. It is intended that the EMPD will be available in this format until the EPD and EMPD become part of the NEOTOMA relational database system (Blois et al. 2011), which should provide for much easier database access and maintenance. Once both databases become part of the NEOTOMA they will also become fully integrated with each other. In the meantime the EMPD will be compatible with but not identical to the EPD structure. It is expected that integration into NEOTOMA will occur early in 2013 (Eric Grimm, pers. comm.).

The EMPD database is currently available for download as a Microsoft Excel spreadsheet containing the metadata, and a text file containing the raw-count pollen data. The field columns provided in the metadata file are shown in ESM Table 1, together with the field descriptions in the look-up tables in ESM Table 2.

Two further working tables for the database will be available shortly. These will provide (1) climatic variables for each site for use in pollen-climate transfer functions, and (2) pre-classified and standardized land-cover classes surrounding each site derived from remote-sensing data. The derivation of these tables requires accurate geo-referencing of surface-sample sites and will be made available when the geo-referencing checks have been completed.

Accessing and submitting data

The EMPD is available to download in ‘beta’ form by following the surface-sample link on the EPD wiki (http://www.europeanpollendatabase.net/wiki/doku.php). Figure 1 depicts the spatial coverage of the data, while Fig. 2 shows the number of samples per country. Anyone wishing to submit data should follow the instructions on the same pages. Contributions of any data from the Euro-Siberian and Mediterranean region, including marine pollen data, would be very welcome.

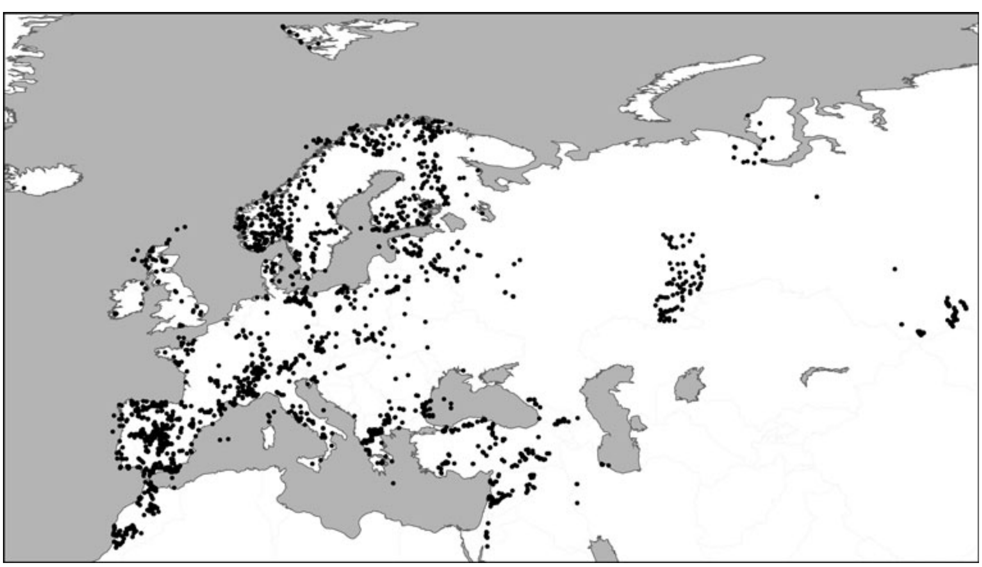

Fig. 1 EMPD surface sample locations

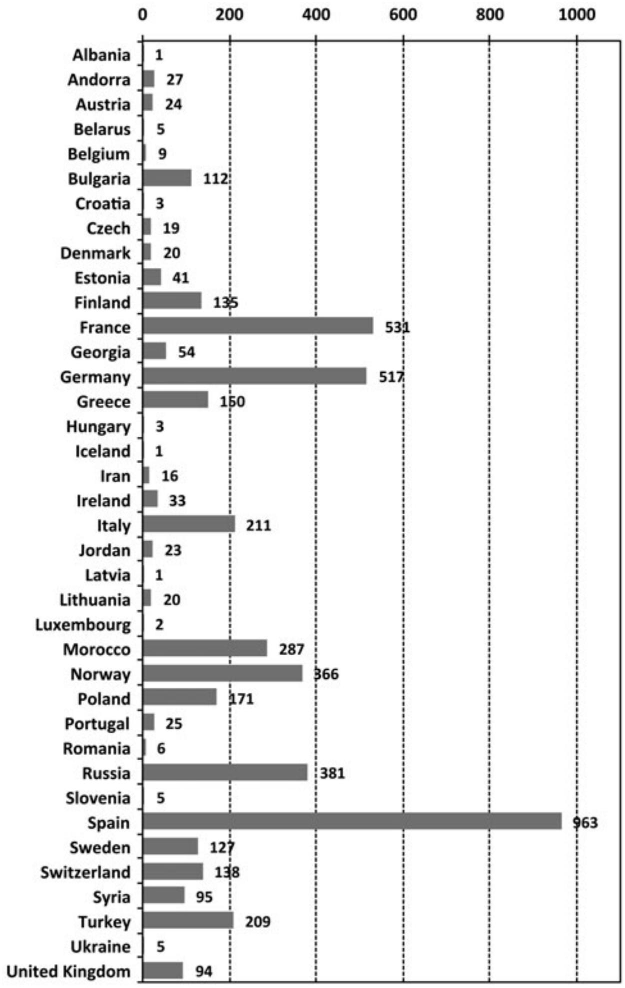

Fig. 2 Number of EMPD samples by country

Conclusions

The EMPD represents the first community-based public repository for modern surface-sample pollen data for the Euro-Siberian and Mediterranean region. The database currently holds raw count data (no percentage data are included) for nearly 5,000 samples, together with metadata that provide information on each sample's location, type, context or depositional environment, age, relevant publications and data source/authorship. The database has been rigorously quality controlled, and age and location uncertainty have been catalogued where appropriate. The database currently consists of two spreadsheets for metadata and pollen data and a Google Earth file of site locations. Two further spreadsheets consisting of working tables of climate and land-cover classifications at each sample site will be added shortly. It is envisioned that the establishment of the EMPD will encourage data sharing and facilitate community-based quality-control oversight. Additionally this dataset is intended to provide a basis for the standardisation of datasets and transfer-functions used in the study of land-cover and pollen-climate relationships, as well as to support the development of new studies and methodologies utilising pollen data. Participation and feedback about the database from all areas of the scientific community is welcome.

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