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Mapping earthworm communities in Europe

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ABSTRACT

Existing data sets on earthworm communities in Europe were collected, harmonized, collated, modelled and depicted on a soil biodiversity map. Digital Soil Mapping was applied using multiple regressions relating relatively low density earthworm community data to soil characteristics, land use, vegetation and climate factors (covariables) with a greater spatial resolution. Statistically significant relationships were used to build habitat–response models for maps depicting earthworm abundance and species diversity. While a good number of environmental predictors were significant in multiple regressions, geographical factors alone seem to be less relevant than climatic factors. Despite differing sampling protocols across the investigated European countries, land use and geological history were the most relevant factors determining the demography and diversity of the earthworms. Case studies from country-specific data sets (France, Germany, Ireland and The Netherlands) demonstrated the importance and efficiency of large databases for the detection of large spatial patterns that could be subsequently applied at smaller (local) scales.

1. Introduction

Monitoring soil biodiversity has been addressed by recent EU research programs (e.g. Bispo et al., 2009; Lemanceau, 2011) and national initiatives (e.g. RMQS and BiSQ: Gardi et al., 2009; Pulleman et al., 2012; Edaphobase: Burkhardt et al., 2014; and the UK Soil Indicators Consortium: Ritz et al., 2009). For instance, in the EU project EcoFINDERS a suite of indicators on soil biodiversity attributes, including microbia (bacteria and fungi), microfauna (protozoans and nematodes) and mesofauna (enchytraeids and microarthropods), was tested at 85 sites along a European transect (Stone et al., 2016). The aim was to demonstrate the feasibility of such an endeavour at a continental scale, and to collate the first set

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of harmonized earthworm data and maps and hence, allowing soil biodiversity to be upgraded from a theoretical to a practical issue on the environmental policy agenda at European and national levels.

A synthesis of existing data is not only timely, but also a more efficient use of limited resources for land management and decision making, than filling data gaps with additional costly surveys and monitoring. Such a database could also become a valuable source of information for awareness raising and environmental policy making, and possibly for some academic objectives, despite the fact that data were obtained from different countries, generated by different researchers using different sampling and identification methods, and with different project objectives.

Earthworms (Lumbricidae) are surprisingly under-recorded taxa (Carpenter et al., 2012) and were excluded from the aforementioned EcoFINDERS transect for practical and logistic reasons (Stone et al., 2016; B.S. Griffiths et al., *in progress*). However, macrofaunal groups are known to strongly reflect their habitats according to the niche modelling principles of Hutchinson (1957) and therefore, their geographical distribution can potentially be predicted from environmental data. For this reason, we collected and harmonized existing earthworm community data from several European countries and validated this information with environmental and climatic variables, generating the first continuous biodiversity map of earthworms.

The production of this first earthworm map faced a number of challenges:

1. The first challenge was to track and to source earthworm data, because there is no single public facility where such data can be accessed. Some progress has been achieved recently for different national data sets on soil biodiversity via the Global Biodiversity Information Facility (www.GBIF.org), the DRYAD Digital Repository (e.g., datadryad.org/resource/doi:10.5061/dryad.g7046), the Drilobase and Macrofauna database (earthworms.info and macrofauna.org) and the NBN Gateway (data.nbn.org.uk/Datasets). In addition, much of the earthworm data are often published in grey literature, such as project reports (e.g. Römbke et al., 2000, 2002; Schmidt et al., 2011; Rutgers and Dirven-Van Breemen, 2012 and references therein). Frequently, data are presented in appendices or dissertations and can only be accessed by contacting the source holders directly. We received data from earthworm inventories through personal contacts with professionals and researchers in different European countries, under the restriction to use the resulting database solely for producing these maps.
2. The second challenge was to compile sufficient relevant and reliable environmental information to enable meaningful analyses. We sought to link earthworm data to environmental variables in order to produce models for predicting their habitat–response relationships and hence, the distribution of earthworms according to independent niche modelling (*sensu* Hutchinson, 1957).
3. The third challenge was to harmonize the earthworm and environment variables as the collected information differed in relation to site selection, sampling design, collection, extraction, storage, the use of identification keys, and methods for soil analysis.

Belonging to the macrofauna, earthworms are among the few soil-dwelling organisms which are large enough to be seen by the naked eye. Earthworms are an important food source for small mammals (e.g. the mole: *Talpa europaea*) and birds (e.g. the black-tailed godwit *Limosa limosa)*. Importantly, fertile soils in temperate regions are greatly dependent on the dwelling/burrowing action of earthworms and for this reason they are considered important ecosystem engineers and used as valuable indicators for soil quality (Lavelle et al., 1997; Didden, 2003; Cluzeau et al., 2012; Van Groenigen et al., 2014). Although some earthworms are invasive species in northern America (e.g. Bohlen et al., 2004), in Europe Lumbricidae are native and charismatic for the general public, farmers and academics (Darwin, 1881).

Earthworms have been traditionally classified into three functional groups, representing different traits in the soil system (Bouché, 1977; Edwards and Bohlen, 1996), i.e. dwellers in the mineral layer (endogeics), dwellers in the litter layer (epigeics) and vertical burrowers (anecics). The abundance of earthworms is strongly affected by land use (Spurgeon et al., 2013). For example, the total abundance of earthworms in nutrient-rich grasslands under a temperate climate can easily differ one order of magnitude, as it has been reported to be as low as 138 individual m^{-2} (Sechi et al., 2015) and as high as 1333 individuals m^{-2} (Cluzeau et al., 2012). When taking into account all sites with recorded earthworms, the coefficient of variation of theirs abundance (individuals m^{-2}) at European level is high (134%) and, as expected, climate-related (a possible soil moisture deficit is known to reduce earthworm populations).

At a local scale, steep changes in the numerical abundance and diversity of earthworms can be expected at the interface between natural and agricultural land and at the edges between pastures and arable fields (Rutgers et al., 2009; Sechi et al., 2015). Consequently, digital soil mapping (DSM; McBratney et al., 2003) was utilized in the present study, building upon earlier efforts to map soil biodiversity in The Netherlands (Van Wijnen et al., 2012; Rutgers and Dirven-Van Breemen, 2012; Rutgers et al., 2012). DSM statistically correlates soil attributes with a low spatial resolution to attributes with a higher spatial resolution, such as the soil organic matter content and the land use type. In this study, earthworm community attributes (i.e. total abundance, abundance per taxon, Shannon diversity and richness) were used in a multiple regression analysis with data on soil characteristics, land use, vegetation and climate.

European maps of earthworm abundance (total and single species), richness and Shannon index were produced for areas where earthworm data were collected and subsequently harmonized, i.e. The Netherlands, Germany, Ireland, Northern Ireland, Scotland, France, Slovenia, Denmark, together with parts of Spain. The maps were created primarily to raise awareness, to advocate soil biodiversity as an environmental policy issue, and as a plea for enhancing long-term environmental monitoring, but not for analyzing earthworm community distributions in Europe. These maps and their associated raw data may enhance the recently launched *Global Soil Biodiversity Atlas* (www.globalsoilbiodiversity.org), a follow-up to the *European Atlas of Soil Biodiversity* (Jeffrey et al., 2010), and are open for future enrichment. To our knowledge no other continental scale soil biodiversity map has been generated using a DSM approach.

2. Materials and methods

2.1. Data collection and standardisation

Total abundance of earthworms and number of species or genera, adults and juveniles, together with selected biodiversity indices, were the targeted level of resolution for mapping. Thus, all potential contributors were asked to collect and assemble earthworm data on abundance (and/or biomass) per taxon (at species level, where possible), with an indication of the collection and identification method. The primary data providers, organized per country, are the authors of this article. The final database comprised earthworm records from 3838 sites in 8 countries