CALL FOR COLLABORATION

A call for collaboration to create the European Atlas of Soil Fauna

Maria A. Tsiafouli[1]*, Jérôme Cortet[2] and David Russell[3]

[1] Department of Ecology, School of Biology, Aristotle University of Thessaloniki, University campus, 54124 Thessaloniki, Greece
[2] CEFE, Univ Paul Valéry Montpellier 3, Univ Montpellier, CNRS, EPHE, IRD, Route de Mende – 34199, Montpellier cedex 5, France
[3] Department Soil Zoology, Senckenberg Museum of Natural History, Am Museum 1, 02826 Görlitz, Germany
* Corresponding author, Email: tsiafoul@bio.auth.gr

Abstract

Soil biodiversity, and particularly soil fauna, drives essential soil functions leading to crucial ecosystem services. Many research activities over the last decades have produced data, which are however widely dispersed and not easily available, hence their re-usage is limited. Here, we aim to collect a maximum of already published or available data on soil fauna (micro-meso- and macro-fauna) from the European territory, by creating the first comprehensive 'European Atlas of Soil Fauna'. With this initiative, we envision a vibrant collaborative effort in which 'data owners' become 'co-creators' of the Atlas by contributing their (published) data to an overall soil fauna data set. The data set will be used to produce information and maps on soil fauna distribution and diversity across Europe, to support research, policy, education, conservation and monitoring activities.

Keywords Soil biodiversity | soil functions | ecosystem services | edaphobase data warehouse | soil maps

1.   Introduction

Soil biodiversity plays a crucial role in pedogenesis and soil functioning, including chemical and physical processes, creating conditions for providing crucial ecosystem services, such as nutrient cycling, biomass production, water or pest regulation (Brussaard et al. 1997, de Vries et al. 2013, Lavelle et al. 2016, Erktan et al. 2020). Soil animals are particularly abundant and comprise around 25 % of all animal species on earth (Decaëns et al. 2006). Several classifications of soil animals have been proposed, aiming to describe and understand their ecological relevance for soils (Hedde et al. 2022).

Over the last century, soils have been degraded by many factors linked to human activities, including land-use changes related to agricultural intensification and more recently urbanization, or introduction of exotic species, leading to soil biodiversity loss and weakening of soil functions, which has been documented by many publications during the last 30 years (e.g., Decaëns et al. 2006, Tsiafouli et al. 2015, Orgiazzi et al. 2016). In this context, soil animals have been proposed and used as indicators of soil quality and health throughout various land uses (Cortet et al. 1999, Joimel et al. 2017, Tsiafouli et al. 2017).

However, considering that new species are regularly described and the overall soil fauna biodiversity is underestimated, even in Europe, with strong endemism in some areas (Marchán et al. 2022), the conservation methods and status of soil animals have not progressed (Decaëns et al. 2008). This is likely due to several factors, including the deficit of public awareness beyond the dedicated scientific community, as already described for many groups of insects (Leandro et al. 2017), but also the lack of policy and legislative regulations regarding soils (Desrousseaux et al. 2019). Latest developments to improve this situation at the European level are the new EU Soil Strategy for 2030, the future Soil Health Law, which will be enforced in 2023 as well as several activities of the EU Soil Mission.

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It should be noted, that some European programmes have made progress to systematically collect information about soil biodiversity in some areas of Europe, for example in French Brittany (Cluzeau et al. 2012) or in the Netherland (Rutgers et al. 2009), while recently the LUCAS soil survey (Fernandez-Ugalde et al. 2022) also took soil biodiversity into consideration. Furthermore, a huge quantity of data regarding soil fauna has already been collected regarding soil fauna by soil-biodiversity experts across Europe over the last decades, and it is now crucial to summarize and present these data and information in a more user-friendly manner, especially to attract the attention of land users, policy makers and other stakeholders. This can be performed using data warehouses, such as Edaphobase (Burkhardt et al. 2014; https://www.eudaphobase.eu/), which can generate soil-biodiversity maps at various spatial, taxonomic and thematic levels.

Our aim here is to call for collaboration in creating the first comprehensive 'European Atlas of Soil Fauna', which will include information and maps on soil fauna distribution and diversity across Europe, with a broader aim to support relevant research, policy, education, conservation and monitoring activities. The Atlas we aim to construct will focus specifically on soil fauna and will be based on spatial data and maps. Thus, the European Atlas of Soil fauna will differ from the Atlas of Soil Biodiversity, which is more an 'Encyclopedia of Soil Biodiversity' (Jeffery et al. 2010). Our initiative can support (at least for the European territory) ongoing activities aiming at the conservation and monitoring of soil and soil biodiversity, such as SoilBON (Guerra et al. 2021, Potapov et al. 2022), FAO-NETSOB and the EU Soil Observatory and in general the EU Soil Mission.

In the following chapters we briefly present ongoing activities within the EU Cost Action EUdaphobase (striving to collect, harmonize, store and publicly provide data in a domain-specific data warehouse), and provide guidelines for collaboration. While data mobilization can gladly occur from throughout the world with the same procedures presented here, in this call we specifically seek soil ecologist/zoologist to become co-creators of the Atlas by contributing their (published) data to an overall soil fauna data set for the European territory.

2. Methods

The work environment was created within the 'EUdaphobase' Cost Action CA18237 (https://www.cost.eu/actions/CA18237). Within this Cost Action, opportunities for meetings, interaction, and collaboration, as well as networking tools such as Short-Term Scientific Missions or Virtual Mobility Grants, enabled the shaping of the concept and the development of a work plan for creating the European Atlas of Soil Fauna, structuring the content, drafting chapter text and developing supporting tools or technical requirements. Several steps performed are described in the following paragraphs.

2.1 Locating possible data sources for creating maps of soil fauna distribution

With 'soil fauna' we aim to include data on the populations of taxa which spend all or part of their life cycle in soil or whose essential habitat is the soil surface (cf. Wallwork 1970, Lavelle & Spain 2001). Focus is on taxonomic groups for which data structures already exist and sufficient available data is expected (i.e. earthworms, Enchytraeidae, Nematoda, Collembola, Acari. Myriopoda, terrestrial Isopoda, Pseudoscorpions, Tardigrades etc.). While further groups can be easily included, groups such as Mammalia, Aranaea or Coleoptera will not be currently incorporated, despite their importance in soil food webs, since valuable data collections are available elsewhere.

In a literature review (Tsiafoul et al. in prep) we used data-base queries to search Scopus, Web of Science, and Zoological Records for articles on soil fauna from studies throughout Europe, using keywords of several soil fauna taxonomic groups (i.e. earthworm* or Lumbricid* , enchytraed*, nematode*, tartigrad*, collembol* or springtails, soil mite*, oribatid*, symphylan*, centipede* or chilopod*, isopod*, diplopod* or millipede*, pseudoscorpion* etc). The over 1200 articles found were reviewed and retained if they included sampling of one or more soil fauna groups from study sites in European countries. The high number of possible data sources triggered the idea of creating the European Atlas of Soil Fauna, where all such data could be visualized in thematic maps. The data on soil fauna and related metadata from the literature articles are the first considered data source for inclusion in the European Atlas of Soil Fauna, and will be referred in the following text as 'data to be collected'. The authors of the relevant articles containing those data are considered as the 'data owners'. In addition, appropriate data that are already publicly available as part of data repositories (e.g., Edaphobase), from meta-analyses, (unpublished) data of other projects or data from other relevant articles that were not found by the literature search etc. will also be included and are also considered as 'data to be collected'. As the 'data to be collected' must be accompanied by spatial information,

these data will be used to produce maps of soil fauna distribution (e.g. maps depicting the distribution of various taxa across ecoregions, land-use or soil types, soil-fauna diversity, etc.).

2.2 Paving the way for a collaborative effort and structuring the Atlas

To construct the European Atlas of Soil Fauna through a collaborative effort, online workshops were organized to discuss the form, the intended audience, the structure, and the content of the Atlas. Initially, most workshop participants were members of the EUdaphobase Cost Action. However, other soil-biodiversity researchers from outside the Action quickly joined the workshops and, where possible, became members of the Cost Action. In addition, members from other projects, such as 'EJP SOIL Minotaur' (https://ejpsoil.eu/soil-research/minotaur) expressed interest in combining activities and participating in the Atlas activities. Although we now live in an era of 'data sharing', it is still likely that this is not always the most obvious part of a researcher's work activities. Taking this into consideration, we envision the Atlas as a vibrant collaborative effort in which 'data owners' become 'co-creators' of the Atlas by contributing their (published) data to the overall European soil fauna data set. The data set collected from all data providers will be used to produce the map visualizations for the Atlas, but will also serve other data-analyses in research, monitoring, and decision-making as well in the future.

It is intended to publish the Atlas in open access (e.g., with a CC-BY license), with the option of an online version for future updates. At the same time, however, we are strongly committed to respecting and acknowledging the intellectual property rights of all data owners. The corresponding publications of literature data will of course be cited in the references. While the creators of the Atlas and any visualizations as well as leaders of the chapters will be main editors, it is proposed to list data and text providers as authors. Subject to the consent of data owners, data will be uploaded to the publicly available soil-biodiversity data warehouse Edaphobase (https://portal.edaphobase. org). Here, data owners have the opportunity to receive DOIs for specific data sets (Edaphobase data policy and data-sharing agreement, Senckenberg 2018; and future updates). Data is intended to be (potentially) open access and follow the FAIR principles (Wilkinson et al. 2016), but will intentionally not be made 'open data'.

In this manner, the Atlas intends to not only make soil biodiversity more accessible to the general public, but also to increase the viability of researchers and their specific investigations generating soil-biodiversity data. Furthermore, data made available in Edaphobase will not only be used to create the Atlas, but can also serve other, future data-analyses in research, monitoring, and decision-making. Current and future data re-usage include, e.g., elucidation of the drivers of soil-fauna distribution, effects of land use or soil management, development of indicators, and especially analyses of functional soil biodiversity via linkage to taxa's functional traits. As regulated in the data policy, data providers thereby have the opportunity of being included in such future studies or collaborations.

2.3 Approaching possible data owners and preparing the ground for data sharing

We created a questionnaire (link to access Atlas questionnaire: https://docs.google.com/forms/d/1Ki5LE aK9q8yCKBOs4yDaP634U6fM_SCKTsV6m4pikSU/ edit) to approach data owners and understand their potential interest in sharing their data, as well as to obtain information on which data are available. Considering the answers, when data owners are willing to share their data, this should proceed in a non-laborious, non-time-consuming manner. Simultaneously, data should be provided in a consistent manner, allowing them to be compiled and harmonized into a uniform database. For this purpose, we created a Standard Data Template (link to access Atlas Data Template: https://drive. google.com/drive/folders/1Om94lMTiZP_Uu-ob1xQfJY cslCxnbkR0) in Excel format. Finally, for approaching possible data owners we used the EUdaphobase website (https://eudapbhobase.eu), created a Twitter account (@ soilfaunaAtlas), presented the concept at conferences, and distributed information through our personal networks to disseminate information and news about the Atlas' creation and progress.

3. Results and discussion

3.1 Bringing biodiversity of soil fauna to maps

Our literature search resulted in the identification of over 2000 soil fauna study sites that have not yet been included in data repositories or meta-analysis studies (Tsiafouli et al. in prep.). As an example, Fig. 1 map depicts earthworm study sites, containing the data we aim to collect (data to be collected) to create detailed maps for

the Atlas. This map indicates where intensive sampling effort has been undertaken in Europe (e.g., in this case, France including Corsica), but also ecoregions where earthworms studies have been more scarce (e.g. Sicily). Another example (Fig. 2) shows data for two diplopod genera that are currently available in the data warehouse Edaphobase, indicating the disparate availability of their distributional data.

The collection of data for the Atlas will concentrate the dispersed knowledge into distribution and other thematic maps for an overall view.

3.2 Atlas structure

The main concept of the Atlas is to provide clear and accessible information for non-specialists, including land-users, policy makers and the general public. The Atlas will be structured into two parts. The first will include text chapters providing general information about soil fauna, such as an historical overview of soil-faunal research and general facts about taxonomic/ecological/ life-form classification and sampling methods, as well as use of soil fauna as bio-indicators, in experiments, but also prospectively in citizen science. The second part will focus on distribution and ecological maps produced for each identified taxon (such as earthworms, Collembola, Oribatid mites, etc.), accompanied by graphs explaining and complementing the maps. We will focus on key

questions, such as land-use effects on soil-animal density or species richness, or the occurrence of specific taxa. We will also explore the impact of vegetation type, climate, soil type, conservation actions and soil threats.

3.3 Atlas Questionnaire and Atlas Data Template

A questionnaire has been developed, to invite researchers to provide data and participate on the Atlas. The Atlas questionnaire (here the link: : https://docs.google.com/ forms/d/1Ki5LEaK9q8yCKBOs4yDaP634U6fM_SCKT sV6m4pikSU/edit) takes no more than 10 minutes to complete and has 21 questions (17 of which are mandatory). The questionnaire's introduction provides a general overview of the Atlas and contact information for any questions, problems, or further suggestions.

The first questions ask the person filling out the questionnaire (potential 'data provider') for basic contact information, i.e. e-mail, institute, and country (it is confirmed in the introductory section that personal data will not be made public). The following questions inquire if the potential 'data provider' is familiar with the EUdaphobase COST Action and/or the Atlas Initiative. Further questions ask the potential 'data provider' if there is a willingness to contribute to the Atlas through data sharing, text authorship, photographs, graphics, or other contributions, and if not, what their conditions would be for doing so.
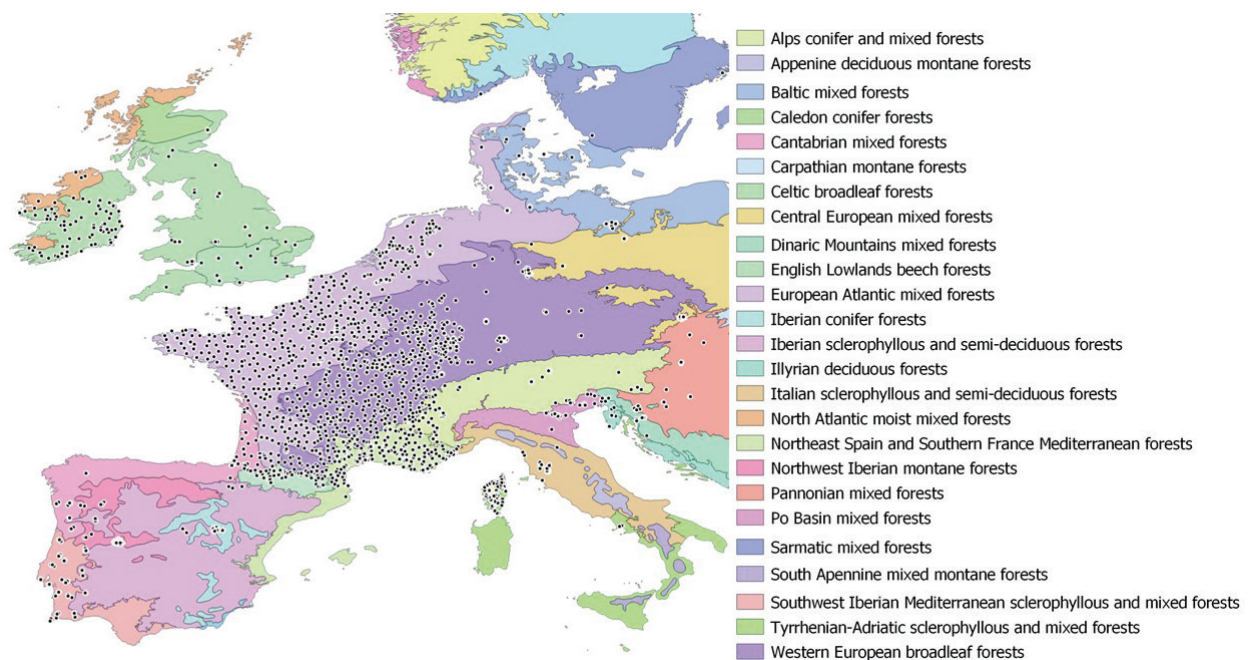

Figure 1. Map depicting study sites of Earthworms found in Ecoregions of Central, and Central West Europe from the literature review by Tsiafouli et al. (in prep.). The data of these sites are those we aim to collect for constructing the maps of the Atlas. Please note that the list of Earthworm study sites located up to now is not exclusive.
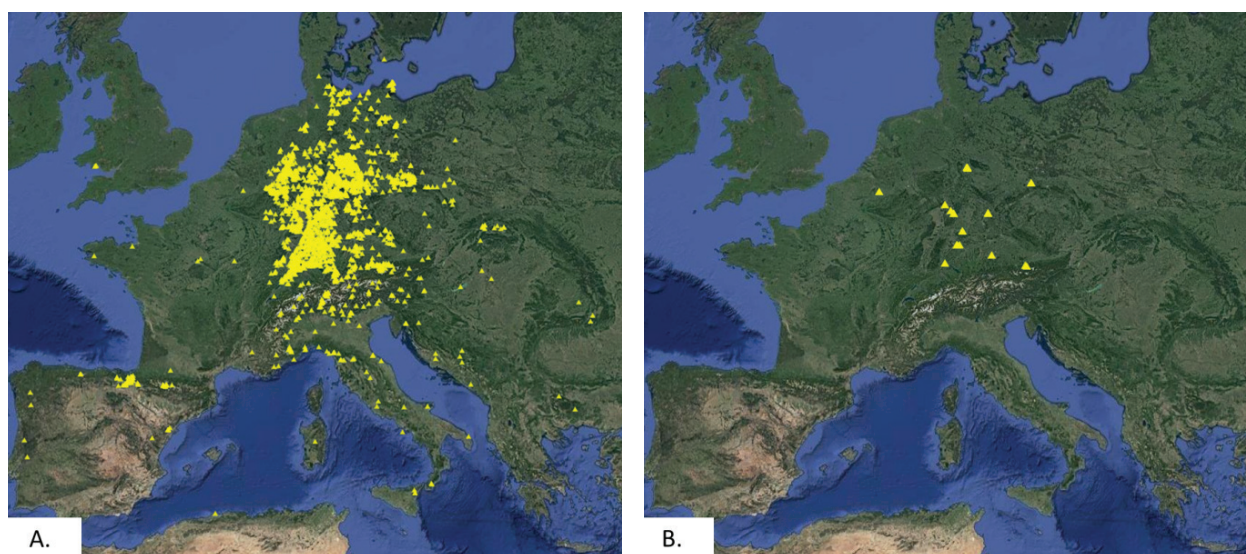
Figure 2. Example map created from the data stored in the Edaphobase data warehouse. The yellow triangles depict the distribution of the Diplopod genera *Glomeris* (**A**) and *Geoglomeris* (**B**). Please note that the absence of points does not necessarily mean that the genus is absent, but rather means that the genus has either not been recorded (yet) or it has been recorded but relevant data have not been included in the Edaphobase data warehouse.

Additional questions ask the potential 'data provider' what type of data are available and for which soil fauna groups (Earthworms, Isopods, Millipedes, Enchytraeids, Collembola, Mites [Mesostigmata, Oribatida], Nematodes, Protozoa, or other groups), what specific type of data is available (e.g. individual observations of species, community data, etc.), and what population/community parameters have been considered (biomass, density, etc.). Further questions enquire about the type of spatial information available, the Pedoclimatic region covered, the type of land-use studied (based on Corine Land Cover), the number of available datasets, and the years (decades) those data were collected. The final questions concern the potential availability of other data linked to soil-fauna data, such as data on microbes or physicochemical habitat parameters, as well as whether data have already been published.

For data collation, an Atlas Data Template has been created in Excel (link to access Atlas Data Template: https://drive.google.com/drive/folders/1Om94lMTiZP_Uu-ob1xQfJYcslCxnbkR0), a format that is familiar to the majority of researchers. The template (one sheet per dataset) has formatted data fields (columns) that represent standardized vocabularies and are accompanied with instructions. There are further data fields for collecting metadata, such as the name of the dataholder/s, the source of the data, the coordinates of the sampled areas as well as fields to include data on the taxon studied (e.g. name of species or genus and abundance or biomass in the sample). There are mandatory fields (e.g. data owner and name of the dataset, names and geo-coordinates

of the sites of occurrence, names of taxa included in the data, etc.), while additional data fields (columns) are optional (e.g., data on soil properties of the study sites). The categorization and names of the data fields have been developed according to the standardized vocabularies and structures of the Edaphobase data warehouse, to facilitate subsequent data collation.

3.4 Simple steps to collaborate and become a co-creator of the Atlas initiative

Fig. 3 provides an overview of the steps involved to become a co-creator of the Atlas initiative. The first step (step 01) is to complete the questionnaire described in section 3.3. The Atlas questionnaire can be found through this link: https://docs.google.com/forms/d/1Ki5LEaK9q8yCKBOs4yDaP634U6fM_SCK TsV6m4pikSU/edit, as well as via Twitter (@soilfaunaAtlas) and in the EUdaphobase website (https://eudaphobase.eu). Once the interest of data owners to provide data for the Atlas has been established (from positive responses to the relevant sections of the questionnaire), the data providers will receive via e-mail data templates and instructions. They will be asked to organize their data to the template (see templates with this link: : https://drive.google.com/drive/folders/1Om94lMTiZP_Uu-ob1xQfJYcslCxnbkR0) and send it back by e-mail within two months (Step 02). Approval from individual data providers for the use and

potential collation in the database will be secured for each dataset via a data-sharing agreement (see Section 2.2.). Data collected will be reviewed and become part of the overall data set (Step 03). Upon consent from the data provider, the data will then be uploaded to the Edaphobase data warehouse. The collected heterogeneous data will be standardized to follow specific rules of nomenclatural and methodological uniformity in order to maintain data comparability (e.g. similar extraction method, quantity unit etc.). Standardized vocabularies are provided with the data template. Uniform datasets will be analyzed together and used for the creation of maps for the Atlas, by a core group of scientist (e.g. editors, editorial board) (Step 04). It should be noted that everyone contributing at least one dataset will be considers as co-creator (see Section 2.2.). As one dataset, we consider the data deriving from one study (e.g. used for a published article) for one taxonomic group.

Figure 3. Overview of the steps involved for becoming a co-creator of the Atlas initiative as well as the handling of data and mapping of soil fauna distribution. Links: google questionnaire: https://docs.google.com/forms/d/1Ki5LEaK9q8yCKBOs4yDaP634U6fM_SCKTsV6m4pikSU/edit, Atlas data template: https://drive.google.com/drive/folders/1Om94lMTiZP_Uu-ob1xQfJYcslCxnbkR0, EUdaphobase website, Twitter account: @soilfaunaAtlas. For further information, please contact Maria Tsiafouli (tsiafoul@bio.auth.gr) and Jérôme Cortet (jerome.cortet@univ-montp3.fr).

We believe that the creation and public availability of the European Atlas of Soil Fauna will highly increase public, policy and general awareness of the vastness, richness and importance of soil biodiversity. The analysis of collected data and the maps will provide support for current research activities searching for appropriate management practices for soil biodiversity conservation and broader targets of Soil Mission 2030 and the new EU soil health law. We hereby call for all researchers studying soil biodiversity in Europe to collaborate in this effort and share their data. For further information, please contact Maria Tsiafouli (tsiafoul@bio.auth.gr) and Jérôme Cortet (jerome.cortet@univ-montp3.fr).

4.   Acknowledgements

5.   References

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