SOIL ORGANISMS **96** (1) · April 2024 pp. 47–60

CALL FOR COLLABORATION

Soil BON Earthworm - A global initiative on earthworm distribution, traits, and spatiotemporal diversity patterns

Pierre Ganault[1,2,3,*], Christian Ristok[2,3], Helen R. P. Phillips[4,5,6], Mickaël Hedde[7], Yvan Capowiez[8], Nicolas Bottinelli[9,10], Thibaud Decaëns[11], Daniel Marchan[11,12], Sylvain Gérard[7,11], Jérôme Mathieu[9], Anton Potapov[13,2,14], Erin K. Cameron[5], George G. Brown[15], Marie Bartz[16,17], Romy Zeiss[2,3], Yacouba Zi[9], Maria Tsiafouli[18], David J. Russell[13], Carlos Guerra[3,19] and Nico Eisenhauer[2,3]

[1] Laboratoire ECODIV USC INRAE 1499, Université de Rouen Normandie, Place Emile Blondel, 76821 Mont Saint-Aignan, France
[2] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstraße 4, 04103 Leipzig, Germany
[3] Institute of Biology, Leipzig University, Talstraße 33, 04103 Leipzig, Germany
[4] Department of Terrestrial Ecology, Netherlands Institute of Ecology (NIOO-KNAW), Droevendaalsesteeg 10, 6708 PB Wageningen, The Netherlands
[5] Department of Environmental Science, Saint Mary's University, 923 Robie St, Halifax, NS B3H 3C3, Canada
[6] Organismal and Evolutionary Biology Research Programme, Faculty of Biological and Environmental Sciences, University of Helsinki, Yliopistonkatu 4, 00100 Helsinki, Finland
[7] Eco&Sols, INRAE, IRD, CIRAD, Institut Agro, Campus La Gaillarde, Batiment 12, 2 place Viala, 34060 Montpellier Cedex 2, France
[8] INRAE, UMR 1114 EMMAH, University of Avignon, Site Agroparc, 84914, Avignon, Cedex 09, France
[9] Institute of Ecology and Environmental Sciences (iEES Paris), Sorbonne Université, CNRS, UPEC, CNRS, IRD, INRAE, 4 Place Jussieu, 75005 Paris, France
[10] Soils and Fertilizers Research Institute (SFRI), Dong Ngac, Tu Liem, Hanoi, Viet Nam
[11] CEFE, Université de Montpellier, CNRS, EPHE, IRD, 1919, route de Mende, 34293 Montpellier, Cedex 5, France
[12] Biodiversity, Ecology and Evolution Department, Faculty of Biology, Universidad Complutense de Madrid, Avenida de Séneca, 2 Ciudad Univer, Spain
[13] Senckenberg Museum for Natural History Görlitz, Am Museum 1, 02826 Görlitz, Germany
[14] Institute of Zoology and Anthropology, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany
[15] Embrapa Forestry, Estrada da Ribeira Km. 111, Colombo, 83411-000, Brazil
[16] Centre for Organic and Regenerative Agriculture, Organic Farming - Agriculture and Organic Production Partnership, 6060 Idanha-a-Nova, Portugal
[17] Department of Life Sciences, Centre for Functional Ecology, University of Coimbra, 3041 Coimbra, Portugal
[18] School of Biology, Department of Ecology, Aristotle University of Thessaloniki, University Campus, 54124 Thessaloniki, Greece
[19] Universidade de Coimbra, Faculdade de Letras, Departamento de Geografia e Turismo, Coimbra, Portugal
* Corresponding author, Email: pierre.ganault@univ-rouen.fr

Received 10 January 2024 | Accepted 22 March 2024
Published online at www.soil-organisms.de 1 April 2024 | Printed version 15 April 2024
DOI 10.25674/362

Abstract

Recent research on earthworms has shed light on their global distribution, with high alpha richness in temperate zones and high beta diversity in tropical areas. Climate and agricultural practices, notably plowing and conservation methods, were shown to strongly influence earthworm communities. However, data gaps persist in regions like North Australia, Asia, Russia, and Africa, limiting our understanding of earthworm distribution and their responses to global changes. Understanding changes within earthworm communities is crucial given their profound influence on ecosystem functions such as soil structure, nutrient dynamics, and plant

ISSN 1864-6417 (print) · **ISSN** 2509-9523 (online)

growth. Classifying earthworms into functional groups remains complex, prompting the adoption of a trait-based approach for a more comprehensive classification, but there is no representative global data on earthworm traits. To address these knowledge gaps, the Soil BON Earthworm initiative aims at creating a global community of earthworm experts, standardizing sampling methods and databases, collecting time series data on earthworm communities, and modeling future earthworm distributions under different climate scenarios. The initiative aims to address key questions, such as the dynamic of earthworm communities over time and their response to environmental factors and anthropogenic influences, their impact on ecosystem functioning, and the redefinition of functional groups based on traits. The consortium invites researchers worldwide to contribute to this endeavor and encourages the resampling of study sites, to expand currently limited time series datasets. To facilitate data collection, standardized protocols and data templates are proposed, ensuring data quality and interoperability. Furthermore, the initiative intends to make use of citizen science in expanding observations and improving taxonomic coverage, highlighting platforms like iNaturalist for community engagement. Soil BON Earthworm seeks to unite global expertise and foster collaborative research to address critical gaps in understanding earthworm ecology and its implications for ecosystems at a global scale.

Keywords Community ecology | ecosystem functioning | functional traits | citizen science | temporal dynamics

1. Introduction

The last decades of research on earthworms (Oligochaeta, Crassiclitellata) have led to important breakthroughs in our understanding of their distribution and ecology (Fonte et al. 2023, Lang et al. 2023, Phillips et al. 2022, 2019). Recent global efforts to synthesize earthworm community data resulted in predictions of global distribution patterns, which showed high alpha richness (at the site level) in high latitudes (temperate zone), and high between-sites compositional dissimilarity (beta diversity) and regional species richness (gamma diversity) in tropical areas (Phillips et al. 2019). At this global scale, precipitation and temperature were the main drivers of earthworm richness, abundance, and biomass, suggesting potentially dramatic changes in community structure with ongoing climate change (Lavelle et al. 2022, Singh et al. 2019).

In recent meta-analyses, the importance of agricultural practices was also highlighted, showing an overall negative influence of plowing and pesticide use, variable influences of nitrogen fertilization, and a positive effect of conservation agriculture on abundances and biomass, especially of anecic and epigeic earthworms (Betancur-Corredor et al. 2023, Briones & Schmidt 2017, Gunstone et al. 2021). These results suggest that climate, land-use change and management will be important determinants of earthworm communities in the future (FAO 2020). However, our understanding of these processes remains limited by the data available to test ecological hypotheses. The current largest database on earthworm community data gathers data from 10,840 sites, with 184 species, from 60 countries, and all continents except Antarctica. The data were obtained from 182 articles published between 1973 and 2017, and 17 unpublished datasets. However, large areas still lack data, such as North Australia, Asia, Russia, and Africa, as often observed in soil ecology research (Cameron et al. 2018, Guerra et al. 2020), which limits our ability to predict earthworm responses to future global changes. Besides, there are limited time series data available (Phillips et al. 2022), further restricting our ability to predict dynamics of earthworm communities.

Changes in earthworm community composition and structure are also expected to have a profound impact on ecosystem functioning. The importance of earthworms for ecosystem functioning has long been acknowledged, and extensive evidence shows that their activity promotes soil structure, organic matter and nutrient dynamics, soil microbial activity, plant growth, and crop yields (Blouin et al. 2013, Fonte et al. 2023, Lang et al. 2023, Lubbers et al. 2013, Shipitalo & Le Bayon 2004, van Groenigen et al. 2015, Vidal et al. 2023). The role of earthworms and of the different species has been mainly studied through the lens of ecological categories (anecic, endogeic, and epigeic earthworms) as defined by Bouché (Bottinelli et al. 2020, Bouché 1972), highlighting mixed and variable trends among species of the same ecological earthworm group. However, such ecological categories poorly represent functional groups from only a limited geographical zone (France) as they were initially proposed to define the ecological optimum of species belonging to mostly the Lumbricidae family (Bottinelli & Capowiez 2021) limiting their applicability to the other 22 megadrile families and/or to different biogeographical contexts. Applying a trait-based approach, i.e. testing and quantifying the relationships between morphological, physiological, phenological, and behavioral features at the species level (Pey et al. 2014b) and soil functions, would provide a more adequate and comprehensive classification of earthworms (and other soil taxa) into functional groups (Capowiez et al. 2024, Hedde et al. 2022) and would facilitate their integration into biogeochemical models (Fry et al. 2019). Recent work successfully linked morpho-anatomical traits of 23 Vietnamese earthworm species to water infiltration rates (Pham Van et al. 2023), and the use of bioturbation behavior of 50 French species/subspecies allowed their grouping into six new functional groups, only partially overlapping with traditional ecological categories (Capowiez et al. 2024). These results show that although earthworms are one of the most frequently studied groups of soil organisms, our knowledge can still largely improve.

However, improving our knowledge of the spatio-temporal structuring of earthworm communities, their impact on ecosystem functioning, and their response to different climatic and land-use/management scenarios, will require the construction of new, comprehensive datasets. To achieve this objective, we now need to harmonize and standardize our sampling, meta-data variable acquisition, and data analysis strategies. Here, we present a new data mobilization effort to address the goals and gaps described above by motivating the structuring of a global earthworm research community (Phillips et al. 2022). This initiative draws heavily on similar ones dedicated to soil food webs, soil biodiversity and functions, nematodes and springtails (Eisenhauer et al. 2023, Geisen et al. 2019, Guerra et al. 2021b, Mathieu et al. 2022, Potapov et al. 2022, Tsiafouli et al. 2022).

In this paper, we describe the Soil BON Earthworm initiative, an extension of the Soil Biodiversity Observation Network (Soil BON, https://www.globalsoilbiodiversity.org/soilbon), and its main objectives:

1. Building a community of research experts in earthworm ecology and taxonomy
2. Standardize sampling methods and trait measurements in the field and laboratory
3. Standardize community and trait data templates to facilitate data integration
4. Encourage re-sampling of study sites to provide larger time-series datasets and explore temporal trends of earthworm communities
5. Model future earthworm distribution under different climatic scenarios
6. Improve society‘s access to knowledge on earthworms and tools to contribute to research efforts

Soil BON Earthworm will work at improving our knowledge and tackle the following questions:

1. a. How have earthworm communities changed over the last decades, in terms of taxonomic, functional, and phylogenetic diversity?
   b. What is the relative importance of stochasticity, environment (climate, soil, vegetation, and land use) and biotic interaction (competition) in these changes?
   c. At which scales do global changes in contemporary earthworm communities occur, from local scale (alpha), to various nested beta diversity measures, up to global scale?
2. a. How will earthworm communities respond to future climate scenarios?
   b. Are there areas of specific concern where earthworm communities will strongly decline?
   c. How may changes in earthworm community composition alter ecosystem functioning?
3. a. Which earthworm traits can be used to position all known earthworm species in the ecological categories' triangle?
   b. Can we redefine functional groups based on a trait-based approach?
   c. Which traits can best explain earthworm species effects on ecosystem functions?

2. Soil BON Earthworm community

Soil BON Earthworm builds on a previous global synthesis effort on the global distribution of earthworms (Phillips et al. 2019) which gathered around 150 experts from all continents. Currently, most of the researchers are located in the northern hemisphere (especially Europe) and the goal is to now widen this consortium by increasing the number of participants and their geographic representation. This will allow for a better spatial, temporal, taxonomic, and habitat coverage as well as foster synergies between scientists to develop international projects, applying for funding, and ensuring the use of standardized methods and data sharing. New members can register using this link (https://docs.google.com/forms/d/e/1FAIpQLSfv6Vy0ZdVzEwfY_vtXTtn4vsCE1BDTWPp1za9hYYXVE0x04g/viewform?usp=sf_link) and will be asked to provide their name, institution, location, and email address to be added to the emailing list. New members must be able to provide data on earthworm trait or distribution, be willing to participate in funding calls and collaborative sampling or experiments, as well as share knowledge.

3. Standardizing earthworm communities' assessments

3.1 A common sampling protocol

The Soil BON Earthworm protocol is adjusted from the Soil BON (Guerra et al. 2021b, 2021a), Soil BON Foodweb

(Potapov et al. 2022), and TSBF (Anderson et al. 1993) protocols to ensure compatibility and interoperability, while ensuring a representative sampling of earthworm communities. To develop the protocol, two online webinars were conducted on December 5th and 6th 2022, gathering 60 earthworm experts that had to collectively decide the mandatory and optional steps detailed in supplementary information. Briefly, a site is defined as a 30 × 30 m area with homogeneous vegetation, soil type and land use, and earthworms are sampled in 5 points forming a north-south oriented cross (Fig. 1). Each point is a 25 × 25 cm block, sampled in three layers: litter, 0–10 cm, and 10–20 cm. The litter is defined here as in Soil BON Foodweb and comprises the layer of entire and fragmented leaves, ~100 % organic material (Potapov et al. 2022, Zanella et al. 2018). Earthworms must be cleaned from soil on their skin before being fixed in 70 % ethanol, or 99 % ethanol if barcoding is planned. Optional steps comprise pouring mustard solution into the soil pit to extract deep-burrowing earthworms in ecosystems where this method is suitable (mostly temperate grassland, forests, and croplands), sampling of microhabitats (rotten logs, under rocks, near water bodies like streams, ponds, lakes or marshes, rapid and deep digging around a midden), or sampling of other macrofauna at the same time, in a separate vial.

Further, identification is done according to local taxonomic keys, and taxonomic names must be checked against the recent global earthworm species checklist (Misirlioğlu et al. 2023) and the associated database (Brown et al. 2024). To facilitate the curation and data integration of taxonomic names, a community data template has been developed by Soil BON Earthworm and is detailed in a latter section of this article.

3.2 Community data template

The development and use of a standardized data template following the FAIR principles (Wilkinson et al. 2016) and DarwinCore standards (Darwin Core Maintenance Group 2023) is essential to ensure data quality, maintenance and integrity, and to facilitate data reuse and aggregation for syntheses. The Soil BON Earthworm consortium created proposes a data template to report the data, so that it can be collated in a straightforward way. The template is an updated version of the one developed for the EUdaphobase COST Action initiative 'European Atlas of Soil Fauna' (Tsiafouli et al. 2022).

It is composed of different spreadsheets:

1. 'Readme': this tab contains all column names from the next tab and provides the necessary information to complete the file.
2. 'Template to fill with data': this tab is composed of several columns where the data provider can enter the information on dataset, site, methodology and taxa sampled. This tab is to be filled with density data, and another file should be produced for biomass data at the finest resolution possible (species-level).
3. 'Drop down list': this tab is non-modifiable and contains the different lists from which values are taken for certain metadata variables, such as soil type following the WRB FAO classification (IUSS Working Group WRB 2015).

The data template is deposited on Zenodo (https://zenodo.org/records/10284283), where new versions will be uploaded as regularly as necessary. All new data contributions will pass through a quality control by the Soil BON Earthworm coordination team, before being collated and made available on the database repository. In the future, new data produced will be deposited by Edaphobase www.portal.edaphobase.org (Burkhardt et al. 2014), to ensure data visibility and access through the GBIF initiative (Edwards et al. 2000).

3.3 Taxonomic backbone

The number of extant earthworm species is estimated between 10,400 and 11,200, of which approximately

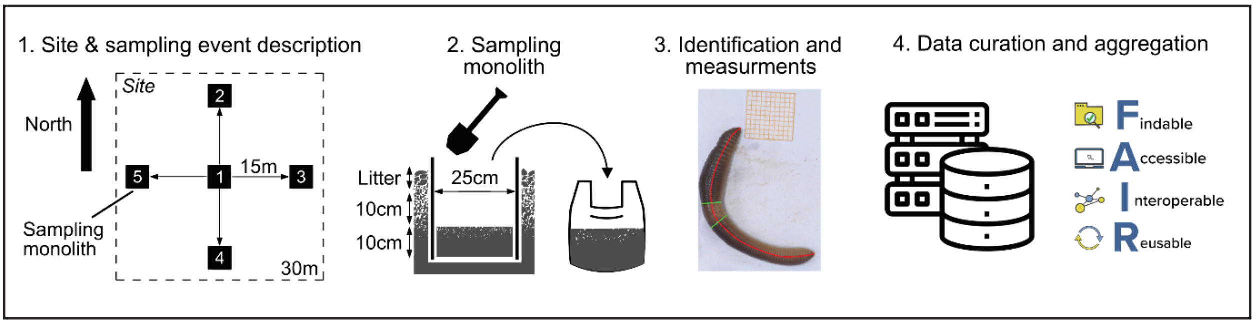

Figure 1. Summary of essential steps of the earthworm sampling protocol.

6,000 have been described worldwide (Decaëns 2010, Decaëns et al. 2006, Orgiazzi et al. 2016). Several initiatives have gathered, cleaned, and updated the global earthworm species list, including: the 'Earthworm species. A searchable database' (http://earthworm.uw.hu, Csuzdi 2012), DriloBase (http://taxo.drilobase.org), the Integrated Taxonomic Information System (https://www.itis.gov), and Nomenclatura Oligochaetologica (Reynolds & Wetzel 2022). Building on these initiatives, a recent global checklist of 5,453 valid earthworm species names has been curated and validated by an international consortium (Misirlioğlu et al. 2023, Brown et al 2024). The species list is accessible on Zenodo (https://doi.org/10.5281/zenodo.7301847) and should be used to harmonize taxa names in the community data template. However, the largest database of earthworm community distribution (Phillips et al. 2021) currently includes data on less than 4 % of the already described species. Taxonomy resolution is hampered by the scarcity of earthworm taxonomic expertise, and particularly in tropical regions where classical morpho-anatomical features used for identification are often insufficient, thus requiring the additional use of DNA sequencing information (Decaëns et al. 2016, Marchán et al. 2022). This taxonomic backbone will serve as a reference to list species for which data is especially needed. Future taxonomic updates will also be quickly shared with the community by working closely with taxonomy experts.

The use of a standardized sampling method, community data and meta-data templates, and species names checklist will greatly improve dataset aggregation and hence promote collaborative efforts, data re-use, and research syntheses at different scales. Those resources will be updated depending on user feedbacks and future evolution of earthworm taxonomy, stressing the importance of regular communication among the consortium.

4. Collecting and using trait data

4.1 Updated thesaurus

Functional traits are defined as 'any morphological, physiological, phenological or behavioral (MPPB) feature measurable at the individual level, from the cell to the whole-organism level, without reference to any other level of organization' (Pey et al. 2014b, Violle et al. 2007). Functional traits can be classified into non-exclusive categories of (i) performance traits linked to the organism's fitness, (ii) response traits that are sensitive to an environmental abiotic gradient, and (iii) effect traits linked to the organism's effects on ecosystem processes. For soil invertebrates and notably for earthworms, the first trait thesaurus (T-SITA, https://opentheso.huma-num.fr/opentheso/?idt=th558; Pey et al. 2014a) defined several traits of interest and is associated with an open database (Joimel et al. 2021) following standards for ecological trait definition and data management (Keller et al. 2023, Schneider et al. 2019), constituting a major resource for West-European earthworm species.

To foster applications of the trait-based approach for earthworms at the global scale, there is a need to improve the thesaurus, define new traits, and harmonize data entry into a common database. Additionally, certain trait modalities and measurements must still be defined and standardized, and links to functions tested. International efforts such as the COST Action EUdaphobase (www.eudaphobase.eu) initiated the harmonization work of the existing community and trait databases and is a strong basis for future global collaboration. In this context, with earthworm taxonomists and trait experts, we initiated an updated list of (mostly effect) traits with a clear definition, currently available only as a excel data file tab (see below). The list encompasses morpho-anatomical traits (size, weight, internal digestive organ shape and size, epithelium and muscle type and thickness), physiological (metabolic, consumption and casting rates, mucus production), as well as extended phenotypic traits such as burrow system characteristics, which could be considered as behavioral traits (burrow length, diameter, continuity), and cast properties compared to bulk soil, particularly pH, C, selected nutrient (specify here which ones), and organic matter contents.

4.2 Trait database

Building on this updated thesaurus, trait data was gathered from descriptions of European species, gathering ~10.000 trait values on 358 species from 8 families. Morphological traits are the most documented with at least one value of body length, diameter, color, and volume for 97 %, 85 %, 82 %, and 76 % of the species respectively. Information on anatomy is less complete, with data on typhlosole type, gizzard extension, and musculature type for 68 %, 62 %, and 57 % of the species, respectively. Surprisingly, pigmentation is also poorly covered with data on only 37 % of the species. A global effort of gathering species descriptions, as performed by Reynolds & Wetzel (2022) or Drilobase (REF here please), and encoding them in a structured format would be extremely valuable to increase the taxonomic and trait coverage of a trait database.

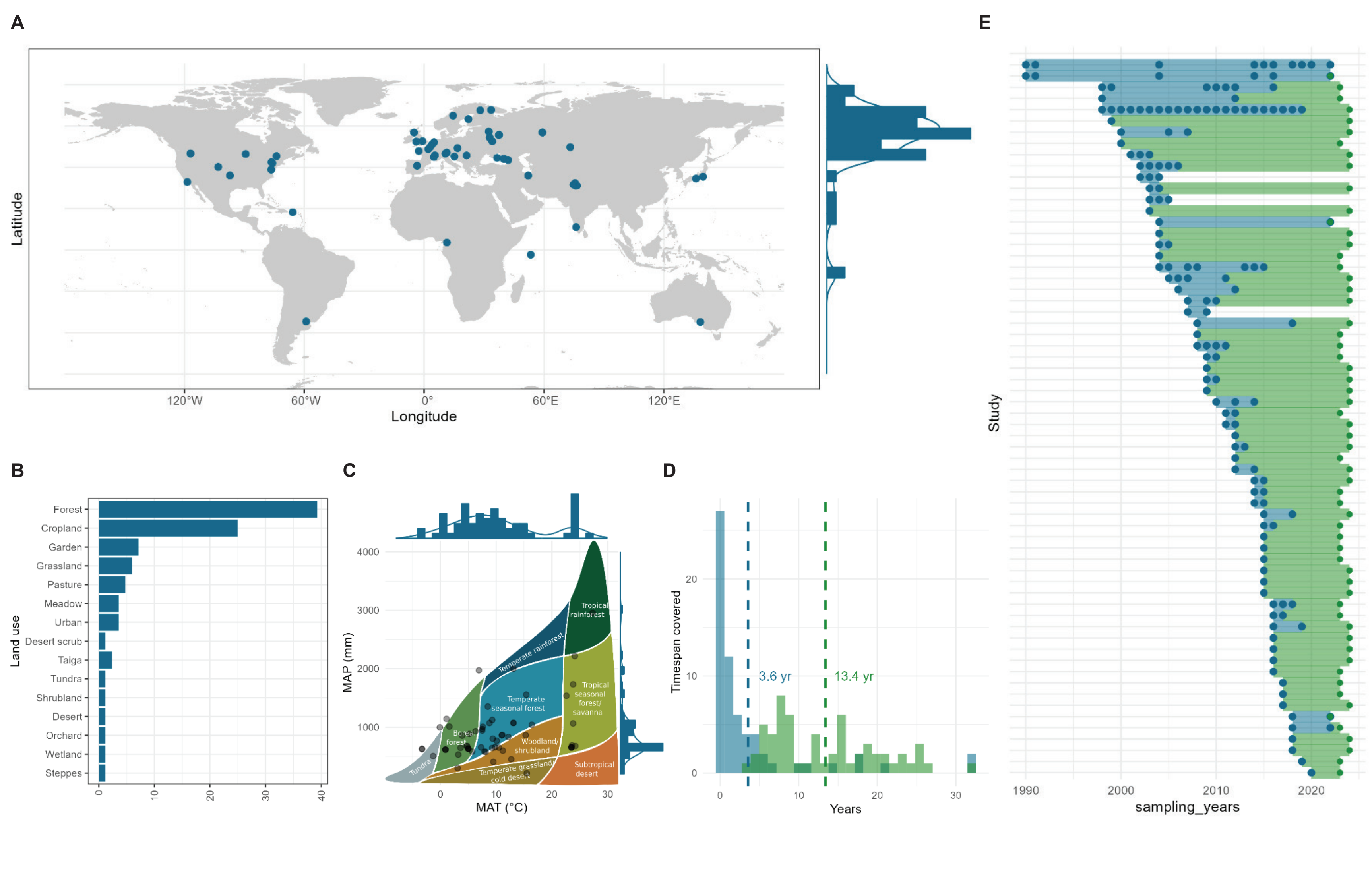

Figure 2. Information on studies that will be resampled globally by the Soil BON Earthworm consortium. (**A**) Global distribution of studies, with the distribution of sites along longitude and latitude, (**B**) distribution of ecosystem types among studies, (**C**) localization of sites among terrestrial biomes defined by Mean Annual Temperature (MAT, °C) and Mean Annual Precipitation (MAP, mm), with the distribution of MAT and MAP values, (**D**) distribution of time span with blue and green colors representing the variable distribution before and after resampling, respectively, (**E**) Temporal coverage of individual studies.

4.3 Trait data template

A template was developed like that of the community data, building largely on the one created by the BETSI database for Biological and Ecological Traits of Soil Invertebrates (Joimel et al. 2021) and following recommendation of trait-data standards (Keller et al. 2023, Schneider et al. 2019). The template includes data at the individual level, and is composed of several excel file tabs:

1. 'Readme': this tab contains all column names from the tab 'template to fill with data' and provide the necessary information to properly complete the file.
2. 'Template to fill with data': this tab is a long-format table in which each line is a trait value from a specific reference, allowing multiple trait values of the same trait for the same species to account for intraspecific trait variability due to inter-population variability, geography or ontogeny (Bonfanti et al. 2018, Violle et al. 2012).
3. 'Trait definition': this tab is non-modifiable and contains the different traits with their definition, modalities, and units.

The trait data template is available on Zenodo (https://zenodo.org/records/10302872) where new versions will be uploaded as regularly as necessary. All new data contributions will pass through a quality control by the Soil BON Earthworm coordination team, before being collated and made available on the database repository, i.e., the BETSI database (https://portail.betsi.cnrs.fr). One can contribute by extracting morpho-anatomical trait information from species descriptions (especially for non-European species) or physiological and behavioral traits from experimental studies. A future version of the template will include a sheet for metadata about the experiment or the environment of the individual specimens on which traits were measured, to account for environmental effects on trait expression and intra-specific variability. To ensure standard measurements of traits, we recommend using the handbook written by Moretti et al. (2017), that includes details on morphological and physiological traits in the supplementary materials. Protocols for cast trait measurements can be found in Coq et al. (2022), Joly et al. (2020) and Le Mer et al. (2022). Measurements for behavioral traits, e.g. burrows characteristics, are described in Capowiez et al. (2024).

4.4 Trait-based analyses and classification

Depending on the growth of the trait database, several analyses can be considered, similar to those performed using plant trait ecology which started with Grime's CSR strategy grouping of European herb species (Grime 1974), progressed with the trait-based assignment of CSR categories to plants across biomes worldwide (Pierce et al. 2017), and the definition of a Leaf and Root Economic Spectrum (Roumet et al. 2016, Wright et al. 2004). Trait information available from species' descriptions can be used to assign earthworm species a percentage of affinity to the three main ecological categories, following the explicit procedure described by Bottinelli et al. (2020), which has not yet been applied globally. To do so, information is needed on 13 traits as listed in Bottinelli et al. (2020): length, diameter, weight, pigmentation, skin coloration, antero-posterior and dorso-ventral pigmentation gradient, flattening index (of body?), epithelium rigidity, muscle structure, longitudinal furrow on segments, transversal furrow, typhlosole type. Among these, three are most relevant for ecological category assignment: body length and width, pigmentation, and color. A first goal of the SoilBON Earthworm initiative is to gather trait values for the 3 (or 13) more simple traits for all known species/subspecies from taxonomic descriptions and develop an equation to assign as many described species as possible to ecological categories based on their traits. For species with more complete trait descriptions, other classifications can be explored and compared to ecological categories (Capowiez et al. 2024, Hedde et al. 2022), and trait-functions relationships can be tested (Pham Van et al. 2023).

5. Exploring temporal trends of earthworm communities

5.1 Time-series analysis

Recent interest in temporal trends in biodiversity has led to several important discoveries, such as the decline of terrestrial insect abundance and richness (Hallmann et al. 2017, Seibold et al. 2019, van Klink et al. 2020). Such declines may have major impacts on ecosystem functioning that are worth further attention (Eisenhauer et al. 2023). However, some studies have detected no temporal trends or positive ones on various invertebrate taxa (Basset et al. 2023, Greenop et al. 2021, van Klink et al. 2020), and shown the importance of spatial scale, number of sampling sites, and distinction of local, regional, and global changes (Blowes et al. 2019, Dornelas et al. 2014, Valdez et al. 2023). Observed changes in invertebrate populations were attributed to agricultural practices and climate change (Müller et al. 2023, Outhwaite et al. 2022), which are also known to be strong drivers of earthworm communities. Hence, we expect changes in earthworm communities that are yet to be quantified.

To date, available data is still too scarce to explore any change in community at a large spatial scale, as it covers only a limited time span in only a subset of bioclimatic zones (Phillips et al. 2022). One goal of Soil BON Earthworm is therefore to encourage the resampling of sites worldwide to increase the spatio-temporal coverage of a global time series dataset. Members of the consortium already agreed to resample 55 studies, increasing temporal coverage of the available data, switching the average timespan covered from 3.6 to 13.4 years and the average number of sampling events from 2.4 to 3.4 (Fig. 2). Forests and croplands represent 39 % and 25 % of the covered ecosystems, respectively, dominating over gardens (7 %), grasslands (6 %), pastures (5 %), meadows (4 %), and others (14 %) (Fig. 3). However, those studies mostly cover Europe, leading to an over-representation of temperate and boreal climates. Therefore, with this call paper we invite researchers from under-represented areas to contribute to this data collection. Any motivated researcher can propose resampling a study site previously sampled in their region before 2020 by filling the Soil BON Earthworm form (https://docs.google.com/forms/d/e/1FAIpQLSfv6Vy0ZdVzEwfY_vtXTtn4vsCE1BDTWPp1za9hYYXVE0x04g/viewform?usp=sf_link), and engaging to voluntarily perform the re-sampling and identification following original methods from the study. New data will be accepted until June 2025 and all contributors whose data will meet standards of the quality control will be invited as co-authors of the outcoming publications. We also invite participants to consider the establishment of longer-term monitoring of the sites and to explore the feasibility of planning regular resampling in the future.

5.2. Projection under different future scenarios

The planned time-series data collection (see previous section) will improve our knowledge on earthworm taxonomic and functional response to multiple drivers, across various spatial and temporal scales. For example, extreme climate events like droughts were previously shown to have detrimental effects on earthworm communities (Singh et al. 2019). This knowledge will open the path to predict earthworm responses to future global changes under different scenarios that account for change in environmental drivers, also due to anthropogenic impacts (Pereira et al. 2010). Using a space for time substitution approach (De Palma et al. 2018), species-distribution (Zeiss et al. 2023) and agent-based modeling, we will explore different scenarios of land-use and climate change (e.g. RCPs, SSPs, Hurtt et al. 2011, Riahi et al. 2017), and associated future patterns of earthworm taxonomic and functional diversity, abundance, and biomass. This will allow for the identification of population dynamics and current range sizes, which can inform conservationists and land managers about potentially threatened earthworm species and habitats. For example, species that show limited ranges (e.g. endemics) or have sensitive dynamics are expected to be more prone to extinction (Urban 2015) and therefore require extensive local sampling and frequent monitoring to track changes in population status. Predictions of earthworm patterns will also enable detecting future areas of major changes in earthworm diversity and in earthworm-driven ecosystem services that may require a specific scientific and management effort. Measures of change in earthworm diversity need to consider invasiveness of species, as exotic species tend to contribute to alpha but not beta diversity. Because data availability is low in Eastern Europe and Asia (Cameron et al. 2018), we do not know when species were introduced and how invasions will advance. Loss of native species can lead to unforeseen changes in ecosystem services that are not visible from earthworm richness measures alone. Research and conservation efforts therefore require targeted approaches appropriate for the focal ecosystem and species.

6. Integration of citizen science

According to the European Citizen Science (CS) Association, ‘Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding. Citizens may act as contributors, collaborators, or as project leaders and have a meaningful role in the project’ (Gold 2022). The number of citizen science projects is increasing exponentially since the last two decades (Pocock et al. 2017), and they have greatly contributed to our scientific understanding of biodiversity patterns (Chandler et al. 2017, Pereira & Cooper 2006). As in academic ecological research, the vast majority of citizen science-based biodiversity monitoring is focused on aboveground diversity and non-invertebrate, non-soil-related taxa (Donaldson et al. 2017, Theobald et al. 2015). Earthworms are among the most represented soil taxa in citizen science-based programs with great examples of earthworm monitoring by farmers in north-west France (OPVT, https://ecobiosoil.univ-rennes1.fr/OPVT_accueil.php) or in Great Britain (60minworms, Stroud 2019, Stroud et al. 2022). Spatial and taxonomic coverage is however still very limited. On iNaturalist (inaturalist.org), one of the most popular citizen science-based biodiversity monitoring platforms with over 166 million multi-taxa observations worldwide in 2023, we found 102,600 observations of terrestrial Oligochaetes (assessed on 6th of December 2023; Fig. 3) among which only 5,817 (approximately 6 %), are at a research grade level, i.e., with a coordinate, date, and identification at the species or genus level supported by at least ? of the community. Taxonomic coverage is limited to 102 of the 5,406 described species, 99 % of the observations being only assigned to the subclass Oligochaeta. Additionally, species identification quality needs to be improved. For instance, most of Lumbricus terrestris observations are falsely identified because the low number of pictures with correct identification in the iNaturalist database led to a poorly trained AI-based image identification software. Hence, there is high potential for improving the quality of observations and taxonomic assignment by encouraging soil taxonomists to join the iNaturalist project 'curated collection of earthworm ID' dedicated to earthworm taxonomy, [https://www.inaturalist.org/projects/curated-collection-of-earthworms-id (Mathieu et al. 2023)]. This project is gathering verified pictures of earthworm species around the world to build a reference image gallery of species that can be used for identification. Soil BON Earthworm will promote projects, protocols, and tools that will foster citizen science and improve society awareness on earthworm ecology and threats.

7. Conclusion

By fostering international collaboration, integrating new data through standardized sampling protocols and data templates, Soil BON Earthworm paves the way for a deeper comprehension of earthworm diversity status and changes, and their critical role in ecosystems. By mobilizing experts, broadening geographical studies, and encouraging citizen participation, this initiative strives to bridge current gaps to better predict earthworm responses to future climate changes and to manage their habitats more effectively for conservation purposes. This initiative draws inspiration from similar efforts on other soil taxa that are rapidly developing (Eisenhauer et al. 2023) and directs its effort to one of the most emblematic and famous soil taxa. The study of earthworms may serve as a common ground, bringing together scientists, citizens, and practitioners in a joint effort toward a more sustainable world, showcasing how collective engagement can positively impact both our environment and society.

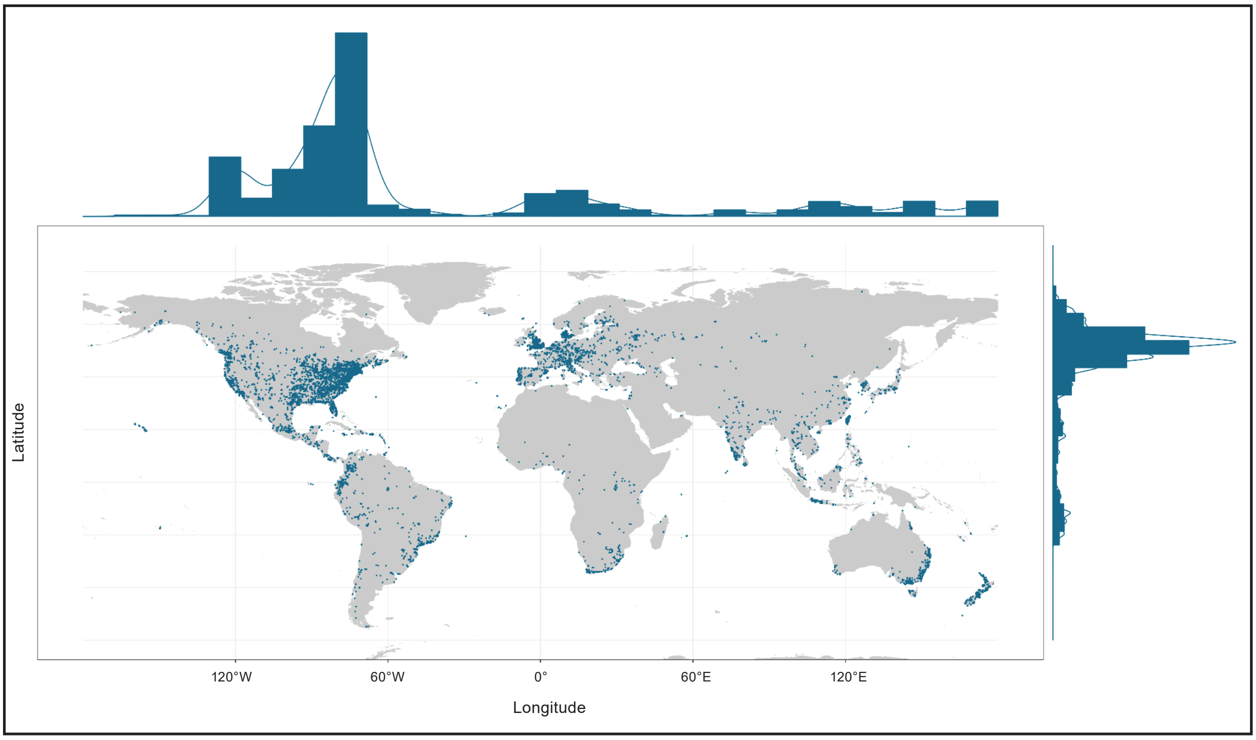

Figure 3. Global distribution of Oligochaeta observations on iNaturalist (assessed on the 16th of November 2023) and longitudinal and latitudinal distribution.

8. Acknowledgments

PG, NE, AP and RZ gratefully acknowledge the support of iDiv, funded by the German Research Foundation (DFG – FZT 118, 202548816). PG and NE acknowledge the support by the DFG (Ei 862/29-1; Ei 862/31-1). PG, MH, TD, YC acknowledge the fruitful discussion within the TEBIS community. PG acknowledges the financial support by EUdaphobase through the STSM grant E-COST-GRANT-CA18237-020c4de5 for the establishment of the trait thesaurus, template, and database. HRPP received funding from European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 101033214 (GloSoilBio). RZ was funded by the German Federal Environmental Foundation (DBU, 20021/752). AP was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Projektnummer 493345801. GGB acknowledges support of the Brazilian National Council for Scientific and Technological Development (CNPq Process nos. 312824/2022-0, 441930/2020-4, 404191/2019-3, and 310690/2017-0).

9. References

Anderson, J. M., J. S. I. Ingram, International Union of Biological Sciences & International Society of Soil Science (eds) (1993): Tropical soil biology and fertility: a handbook of methods, 2. ed. – CAB International, Wallingford.

Basset, Y., P. T. Butterill, D. A. Donoso, G. P. A. Lamarre, D. Souto-Vilarós, F. Perez, R. Bobadilla, Y. Lopez, J. Alejandro Ramírez Silva & H. Barrios (2023): Abundance, occurrence and time series: long-term monitoring of social insects in a tropical rainforest. – Ecological Indicators **150**: 110243 [https://doi.org/10.1016/j.ecolind.2023.110243]

Betancur-Corredor, B., B. Lang & D. J. Russell (2023): Organic nitrogen fertilization benefits selected soil fauna in global agroecosystems. – Biology and Fertility of Soils **59**: 1–16 [https://doi.org/10.1007/s00374-022-01677-2]

Blouin, M., M. E. Hodson, E. A. Delgado, G. Baker, L. Brussaard, K. R. Butt, J. Dai, L. Dendooven, G. Peres, J. E. Tondoh, D. Cluzeau & J.-J. Brun (2013): A review of earthworm impact on soil function and ecosystem services: Earthworm impact on ecosystem services. – European Journal of Soil Science **64**, 161–182 [https://doi.org/10.1111/ejss.12025].

Blowes, S. A., S. R. Supp, L. H. Antão, A. Bates, H. Bruelheide, J. M. Chase, F. Moyes, A. Magurran, B. McGill, I. H. Myers-Smith & et al. (2019): The geography of biodiversity change in marine and terrestrial assemblages. – Science **366**: 339–345 [https://doi.org/10.1126/science.aaw1620].

Bonfanti, J., M. Hedde, S. Joimel, P. H. Krogh, C. Violle, J. Nahmani & J. Cortet (2018): Intraspecific body size variability in soil organisms at a European scale: Implications for functional biogeography. – Functional Ecology **32**: 2562–2570 [https://doi.org/10.1111/1365-2435.13194].

Bottinelli, N., M. Hedde, P. Jouquet & Y. Capowiez (2020): An explicit definition of earthworm ecological categories – Marcel Bouché's triangle revisited. – Geoderma **372**: 114361 [https://doi.org/10.1016/j.geoderma.2020.114361].

Bottinelli, N. & Y. Capowiez (2021): Earthworm ecological categories are not functional groups. – Biology and Fertility of Soils **57**: 329–331 [https://doi.org/10.1007/s00374-020-01517-1].

Bouché, M. (1972): Lombriciens de France. – Ecologie et systématique. – INRA, Paris.

Briones, M. J. I. & O. Schmidt (2017): Conventional tillage decreases the abundance and biomass of earthworms and alters their community structure in a global meta-analysis. – Global Change Biology **23**: 4396–4419. [https://doi.org/10.1111/gcb.13744].

Brown, G. G., S. W. James, C. Csuzdi, E. Lapied, T. Decaëns, J.W. Reynolds, M. Misirlioğlu, M. Stovanić, T. Trakić, J. Sekulić, H. R. P. Phillips & E. Cameron (2024): A checklist of megadrile earthworm (Annelida: Clitellata) species and subspecies of the world [https://doi.org/10.5281/ZENODO.8348860].

Burkhardt, U., D. J. Russell, P. Decker, M. Döhler, H. Höfer, S. Lesch, S. Rick, J. Römbke, C. Trog, J. Vorwald, E. Wurst & W.E.R. Xylander, (2014): The Edaphobase project of GBIF-Germany—A new online soil-zoological data warehouse. – Applied Soil Ecology **83**: 3–12 [https://doi.org/10.1016/j.apsoil.2014.03.021].

Cameron, E. K., I. S. Martins, P. Lavelle, J. Mathieu, L. Tedersoo, F. Gottschall, C. A. Guerra, J. Hines, G. Patoine, J. Siebert & et al. (2018): Global gaps in soil biodiversity data. – Nature Ecology & Evolution **2**: 1042–1043 [https://doi.org/10.1038/s41559-018-0573-8].

Capowiez, Y., D. Marchán, T. Decaëns, M. Hedde & N. Bottinelli (2024): Let earthworms be functional - Definition of new functional groups based on their bioturbation behavior. – Soil Biology and Biochemistry **188**: 109209 [https://doi.org/10.1016/j.soilbio.2023.109209].

Chandler, M., L. See, C. D. Buesching, J. A. Cousins, C. Gillies, R. W. Kays, C. Newman, H. M. Pereira & P. Tiago (2017): Involving Citizen Scientists in Biodiversity Observation. – In: M. Walters & R. J. Scholes (eds): – The GEO Handbook on Biodiversity Observation Networks. – Springer International Publishing, Cham: 211–237 [https://doi.org/10.1007/978-3-319-27288-7_9].

Coq, S., P. Ganault, G. Le Mer, J. Nahmani, Y. Capowiez, M.-F. Dignac, C. Rumpel & F.-X. Joly (2022): Faeces traits as unifying predictors of detritivore effects on organic matter turnover. – Geoderma **422**: 115940 [https://doi.org/10.1016/j.geoderma.2022.115940].

Csuzdi, C. (2012): Earthworm species, a searchable database. – Opuscula Zoologica **43**: 97–99 [https://doi.org/10.5281/zenodo.1045525].

Darwin Core Maintenance Group (2023): Simple Darwin Core. – Biodiversity Information Standards (TDWG) [http://rs.tdwg.org/dwc/terms/simple/2023-09-13 (accessed 12.8.23)].

De Palma, A., K. Sanchez-Ortiz, P. A. Martin, A. Chadwick, G. Gilbert, A. E. Bates, L. Börger, S. Contu, S. L. L. Hill & A. Purvis (2018): Challenges With Inferring How Land-Use Affects Terrestrial Biodiversity: Study Design, Time, Space and Synthesis, in: Advances in Ecological Research. – Elsevier **58**: 163–199 [https://doi.org/10.1016/bs.aecr.2017.12.004].

Decaëns, T., J. J. Jiménez, C. Gioia, G. J. Measey, P. Lavelle (2006): The values of soil animals for conservation biology. – European Journal of Soil Biology **42**: S23–S38 [https://doi.org/10.1016/j.ejsobi.2006.07.001].

Decaëns, T. (2010): Macroecological patterns in soil communities: Soil community macroecology. – Global Ecology and Biogeography **19**: 287–302 [https://doi.org/10.1111/j.1466-8238.2009.00517.x].

Decaëns, T., D. Porco, S. W. James, G. G. Brown, V. Chassany, F. Dubs, L. Dupont, E. Lapied, R. Rougerie, J.-P. Rossi & V. Roy (2016): DNA barcoding reveals diversity patterns of earthworm communities in remote tropical forests of French Guiana. – Soil Biology and Biochemistry **92**: 171–183 [https://doi.org/10.1016/j.soilbio.2015.10.009].

Donaldson, M. R., N. J. Burnett, D. C. Braun, C. D. Suski, S. G. Hinch, S. J. Cooke & J. T. Kerr (2017): Taxonomic bias and international biodiversity conservation research. – FACETS **1**: 105–113 [https://doi.org/10.1139/facets-2016-0011].

Dornelas, M., N. J. Gotelli, B. McGill, H. Shimadzu, F. Moyes, C. Sievers & A. E. Magurran (2014): Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss. – Science **344**: 296–299 [https://doi.org/10.1126/science.1248484].

Edwards, J. L., M. A. Lane & E. S. Nielsen (2000): Interoperability of Biodiversity Databases: Biodiversity Information on Every Desktop. – Science **289**: 2312–2314 [https://doi.org/10.1126/science.289.5488.2312].

Eisenhauer, N., W. E. R. Xylander & A. Potapov (2023): Spotlight on the unseen majority - the way to open community-driven publishing for global soil biodiversity. – Soil Organisms **95**: 173–177 [https://doi.org/10.25674/so95iss3id358].

FAO, I. (2020): State of knowledge of soil biodiversity – Status, challenges and potentialities. Summary for policy makers. – FAO, Rome, Italy [https://doi.org/10.4060/cb1929en].

Fonte, S. J., M. Hsieh & N. D. Mueller (2023): Earthworms contribute significantly to global food production. – Nature Communications **14**: 5713 [https://doi.org/10.1038/s41467-023-41286-7].

Fry, E. L., J. R. De Long, L. Álvarez Garrido, N. Alvarez, Y. Carrillo, L. Castañeda?Gómez, M. Chomel, M. Dondini, J. E. Drake, S. Hasegawa & et al. (2019): Using plant, microbe, and soil fauna traits to improve the predictive power of biogeochemical models. – Methods in Ecology and Evolution **10**: 146–157 [https://doi.org/10.1111/2041-210X.13092].

Geisen, S., D. H. Wall & W. H. Van Der Putten (2019): Challenges and Opportunities for Soil Biodiversity in the Anthropocene. – Current Biology **29**: R1036–R1044 [https://doi.org/10.1016/j.cub.2019.08.007].

Gold, M. (2022): ECSA 10 Principles of Citizen Science [https://doi.org/10.17605/OSF.IO/XPR2N].

Greenop, A., B. A. Woodcock, C. L. Outhwaite, C. Carvell, R. F. Pywell, F. K. Edwards, A. C. Johnson & N. J. B. Isaac (2021): Patterns of invertebrate functional diversity highlight the vulnerability of ecosystem services over a 45-year period. – Current Biology **31**: 4627-4634.e3 [https://doi.org/10.1016/j.cub.2021.07.080].

Grime, J. P. (1974): Vegetation classification by reference to strategies. Nature **250**: 26–31 [https://doi.org/10.1038/250026a0].

Guerra, C. A., A. Heintz-Buschart, J. Sikorski, A. Chatzinotas, N. Guerrero-Ramírez, S. Cesarz, L. Beaumelle, M. C. Rillig, F. T. Maestre, M. Delgado-Baquerizo & et al. (2020): Blind spots in global soil biodiversity and ecosystem function research. – Nature Communications **11**: 3870 [https://doi.org/10.1038/s41467-020-17688-2].

Guerra, C.A., R. D. Bardgett, L. Caon, T. W. Crowther, M. Delgado-Baquerizo, L. Montanarella, L. M. Navarro, A. Orgiazzi, B. K. Singh, L. Tedersoo & et al. (2021a): Tracking, targeting, and conserving soil biodiversity. – Science 371, 239–241. [https://doi.org/10.1126/science.abd7926].

Guerra, C. A., D. H. Wall & N. Eisenhauer (2021b): Unearthing soil ecological observations. – Soil Organisms **93**: 79–81 [https://doi.org/10.25674/so93iss2id164].

Gunstone, T., T. Cornelisse, K. Klein, A. Dubey, N. Donley (2021): Pesticides and Soil Invertebrates: A Hazard Assessment. – Frontiers in Environmental Science **9**: 643847 [https://doi.org/10.3389/fenvs.2021.643847].

Hallmann, C. A., M. Sorg, E. Jongejans, H. Siepel, N. Hofland, H. Schwan, W. Stenmans, A. Müller, H. Sumser, T. Hörren, D. Goulson & H. de Kroon (2017): More than 75 percent decline over 27 years in total flying insect biomass in protected areas. – PLOS ONE **12**: e0185809 [https://doi.org/10.1371/journal.pone.0185809].

Hedde, M., O. Blight, M. J. I. Briones, J. Bonfanti, A. Brauman, M. Brondani, I. Calderón Sanou, J. Clause, E. Conti, J. Cortet& et al. (2022): A common framework for developing robust soil fauna classifications. – Geoderma **426**: 116073. [https://doi.org/10.1016/j.geoderma.2022.116073].

Hurtt, G. C., L. P. Chini, S. Frolking, R. A. Betts, J. Feddema, G. Fischer, J. P. Fisk, K. Hibbard, R. A. Houghton, A. Janetos & et al. (2011): Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. – Climate Change **109**: 117–161 [https://doi.org/10.1007/s10584-011-0153-2].

Joimel, S., J. Nahmani, M. Hedde, A. Auclerc, B. Léa, J. Bonfanti, J. Cortet, G. Pierre, F. Maunoury-Danger, P. Benjamin (2021): A large database on functional traits for soil ecologists: BETSI. Presented at the Global Symposium on Soil Biodiversity: 523.

Joly, F.-X., S. Coq, M. Coulis, J.-F. David, S. Hättenschwiler, C.W. Mueller, I. Prater & J.-A. Subke (2020): Detritivore conversion of litter into faeces accelerates organic matter turnover. – Communications Biology **3**: 660 [https://doi.org/10.1038/s42003-020-01392-4].

Keller, A., M. J. Ankenbrand, H. Bruelheide, S. Dekeyzer, B.J. Enquist, M. B. Erfanian, D. S. Falster, R.V. Gallagher, J. Hammock, J. Kattge & et al. (2023): Ten (mostly) simple rules to future-proof trait data in ecological and evolutionary sciences. – Methods in Ecology and Evolution **14**: 444–458 [https://doi.org/10.1111/2041-210X.14033].

Lang, B., B. Betancur-Corredor & D. J. Russell (2023): Earthworms increase soil mineral nitrogen content – a meta-analysis. – Soil Organisms 95: 1–16 [https://doi.org/10.25674/SO95ISS1ID308].

Lavelle, P., J. Mathieu, A. Spain, G. Brown, C. Fragoso, E. Lapied, A. De Aquino, I. Barois, E. Barrios, M. E. Barros, & et al. (2022): Soil macroinvertebrate communities: A world?wide assessment. – Global Ecology and Biogeography **31**: 1261–1276 [https://doi.org/10.1111/geb.13492].

Le Mer, G., N. Bottinelli, M.-F. Dignac, Y. Capowiez, P. Jouquet, A. Mazurier, F. Baudin, L. Caner & C. Rumpel (2022): Exploring the control of earthworm cast macro- and micro-scale features on soil organic carbon mineralization across species and ecological categories. – Geoderma **427**: 116151 [https://doi.org/10.1016/j.geoderma.2022.116151].

Lubbers, I. M., K. J. van Groenigen, S. J. Fonte, J. Six, L. Brussaard & J. W. van Groenigen (2013): Greenhouse-gas emissions from soils increased by earthworms. – Nature Climate Change **3**: 187–194. [https://doi.org/10.1038/nclimate1692].

Marchán, D. F., T. Decaëns, J. Domínguez & M. Novo (2022): Perspectives in Earthworm Molecular Phylogeny: Recent Advances in Lumbricoidea and Standing Questions. – Diversity **14**: 30 [https://doi.org/10.3390/d14010030].

Mathieu, J., A. C. Antunes, S. Barot, A. E. Bonato Asato, M. L. C. Bartz, G. G. Brown, I. Calderon-Sanou, E. Conti, J. Cortet, S. J. Decaëns & et al. (2022): sOilFauna - a global synthesis effort on the drivers of soil macrofauna communities and functioning: WORKSHOP REPORT. – Soil Organisms **94**: 111–126 [https://doi.org/10.25674/SO94ISS2ID282].

Mathieu, J., M. Bartz, G. G. Brown, E. Cameron, T. Decaëns, L. Dupont, D. F. Marchan, C. Fragoso, P. Ganault, A. Geraskina & et al. (2023): Collaboration call: Building an image collection for computer vision identification of worldwide earthworm species in iNaturalist [https://doi.org/10.13140/RG.2.2.22162.53447].

Misirlioğlu, M., J. W. Reynolds, M. Stojanović, T. Trakić, J. Sekulić, S. W. James, C. Csuzdi, T. Decaëns, E. Lapied, H. R. P. Phillips, E. K. Cameron & G. G. Brown (2023): Earthworms (Clitellata, Megadrili) of the world: an updated checklist of valid species and families, with notes on their distribution. – Zootaxa **5255**: 417–438 [https://doi.org/10.11646/zootaxa.5255.1.33].

Moretti, M., A. T. C. Dias, F. Bello, F. Altermatt, S. L. Chown, F. M. Azcárate, J. R. Bell, B. Fournier, M. Hedde, J. Hortal, S. Ibanez & et al. (2017): Handbook of protocols for standardized measurement of terrestrial invertebrate functional traits. – Functional Ecology **31**: 558–567 [https://doi.org/10.1111/1365-2435.12776].

Müller, J., T. Hothorn, Y. Yuan, S. Seibold, O. Mitesser, J. Rothacher, J. Freund, C. Wild, M. Wolz & A. Menzel (2023): Weather explains the decline and rise of insect biomass over 34 years. – Nature [https://doi.org/10.1038/s41586-023-06402-z].

Orgiazzi, A., R. D. Bardgett, E. Barrios, V. Behan-Pelletier, M. J. I. Briones, J. L. Chotte, G. B. De Beyn, P. Eggleton, N. Fierer, T. Fraser & et al. (2016): Global soil diversity atlas, European Union, Luxembourg.

Outhwaite, C. L., P. McCann & T. Newbold (2022): Agriculture and climate change are reshaping insect biodiversity worldwide. – Nature **605**: 97–102.

Pereira, H. & D. H. Cooper (2006): Towards the global monitoring of biodiversity change. – Trends in Ecology & Evolution **21**: 123–129.

Pereira, H. M., P. W. Leadley, V. Proença, R. Alkemade, J. P. W. Scharlemann, J. F. Fernandez-Manjarrés, M. B. Araújo, P. Balvanera, R. Biggs, W. W. L. Cheung & et al. (2010): Scenarios for Global Biodiversity in the 21st Century. – Science **330**: 1496–1501.

Pey, B., M.-A. Laporte, J. Nahmani, A. Auclerc, Y. Capowiez, G. Caro, D. Cluzeau, J. Cortet, T. Decaëns, F. Dubs & et al. (2014a): A thesaurus for soil invertebrate trait-based approaches. – PLoS ONE **9**: e108985.

Pey, B., J. Nahmani, A. Auclerc, Y. Capowiez, D. Cluzeau, J. Cortet, T. Decaëns, L. Deharveng, F. Dubs, S. Joimel et al. (2014b): Current use of and future needs for soil invertebrate functional traits in community ecology. – Basic and Applied Ecology **15**: 194–206.

Pham Van, Q., T. Nguyen, D. Lam, Y. Capowiez, D.A. Nguyen, P. Jouquet, T. Minh & N. Bottinelli (2023): Using morpho-anatomical traits to predict the effect of earthworms on soil water infiltration. – Geoderma **429**: 116245.

Phillips, H. R. P., C. A. Guerra, M. L. C. Bartz, M. J. I. Briones, G. Brown, T. W. Crowther, O. Ferlian, O., K. B. Gongalsky, J. van den Hoogen, J. Krebs & et al. (2019): Global distribution of earthworm diversity. – Science **366**: 480–485 [https://doi.org/10.1126/science.aax4851].

Phillips, H. R. P., E. M. Bach, M. L. C. Bartz, J. M. Bennett, R. Beugnon, M. J. I. Briones, G. G. Brown, O. Ferlian, K. B. Gongalsky, C. A. Guerra & et al. (2021): Global data on earthworm abundance, biomass, diversity and corresponding environmental properties. – Scientific Data **8**: 136 [https://doi.org/10.1038/s41597-021-00912-z].

Phillips, H., E. Cameron & N. Eisenhauer (2022): Illuminating biodiversity changes in the 'Black Box'. – Research Ideas and Outcomes **8**: e87143.

Pierce, S., D. Negreiros, B. E. L. Cerabolini, J. Kattge, S. Díaz, M. Kleyer, B. Shipley, S. J. Wright, N. A. Soudzilovskaia, V. G. Onipchenko & et al. (2017): A global method for calculating plant CSR ecological strategies applied across biomes worldwide. – Functional Ecology **31**: 444–457 [https://doi.org/10.1111/1365-2435.12722].

Pocock, M. J. O., J. C. Tweddle, J. Savage, L. D. Robinson & H. E. Roy (2017): The diversity and evolution of ecological and environmental citizen science. – PLOS ONE **12**: e0172579 [https://doi.org/10.1371/journal.pone.0172579].

Potapov, A. M., X. Sun, A. D. Barnes, M. J. I. Briones, G. G. Brown, E. K. Cameron, C.-H. Chang, J. Cortet, N. Eisenhauer, A. L. C. Franco & et al. (2022): Global monitoring of soil animal communities using a common methodology. – Soil Organims **94**: 55–68 [https://doi.org/10.25674/SO94ISS1ID178].

Reynolds, J. W. & M. J. Wetzel (2022): Nomenclatura Oligochaetologica – A catalogue of names, descriptions and type specimens. – Editio Secunda.

Riahi, K., D. P. Van Vuuren, E. Kriegler, J. Edmonds, B. C. O'Neill, S. Fujimori, N. Bauer, K. Calvin, R. Dellink, O. Fricko & et al. (2017): The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. – Global Environmental Change **42**: 153–168 [https://doi.org/10.1016/j.gloenvcha.2016.05.009].

Roumet, C., M. Birouste, C. Picon-Cochard, M. Ghestem, N. Osman, S. Vrignon-Brenas, K. Cao & A. Stokes(2016): Root structure–function relationships in 74 species: evidence of a root economics spectrum related to carbon economy. – New Phytologist **210**: 815–826 [https://doi.org/10.1111/nph.13828].

Schneider, F. D., D. Fichtmueller, M. M. Gossner, A. Güntsch, M. Jochum, B. König-Ries, G. Le Provost, P. Manning, A. Ostrowski, C. Penone & N. K. Simons (2019): Towards an ecological trait-data standard. – Methods in Ecology and Evolution **10**: 2006–2019 [https://doi.org/10.1111/2041-210X.13288].

Seibold, S., M. M. Gossner, N. K. Simons, N. Blüthgen, J. Müller, D. Ambarlı, C. Ammer, J. Bauhus, M. Fischer, J. C. Habel & et al. (2019): Arthropod decline in grasslands and forests is associated with landscape-level drivers. – Nature **574**: 671–674 [https://doi.org/10.1038/s41586-019-1684-3].

Shipitalo, M. & R.-C. Le Bayon (2004): Quantifying the effects of earthworms on soil aggregation and porosity. – In: Edwards, C. (ed.): Earthworm Ecology. – CRC Press: 183–200 [https://doi.org/10.1201/9781420039719.pt5].

Singh, J., M. Schädler, W. Demetrio, G. G. Brown & N. Eisenhauer (2019): Climate change effects on earthworms - a review. – Soil Organisms **91**: 113–137 [https://doi.org/10.25674/so91iss3pp114].

Stroud, J. L.(2019): Soil health pilot study in England: Outcomes from an on-farm earthworm survey. – PLOS ONE **14** (2019): e0203909 [https://doi.org/10.1371/journal.pone.0203909]

Stroud, J. L., I. Dummett, S. J. Kemp & C. J. Sturrock (2022): Working with farmers to investigate anecic earthworm middens and soil biophysical properties. – Annals of Applied Biology **182**: 92–100 [https://doi.org/10.1111/aab.12795].

Theobald, E. J., A. K. Ettinger, H. K., Burgess, L. B. DeBey, N. R. Schmidt, H. E. Froehlich, C. Wagner, J. HilleRisLambers, J. Tewksbury, M. A. Harsch & J. K. Parrish (2015): Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. Biological Conservation **181**: 236–244 [https://doi.org/10.1016/j.biocon.2014.10.021].

Tsiafouli, M. A., J. Cortet & D. Russell (2022): A call for collaboration to create the European Atlas of Soil Fauna. – Soil Organisms **94**: 175–181 [https://doi.org/10.25674/SO94ISS3ID307].

Urban, M. C. (2015): Climate change. Accelerating extinction risk from climate change. – Science **348**: 571–573 [https://doi.org/10.1126/science.aaa4984].

Valdez, J. W., C. T. Callaghan, J. Junker, A. Purvis, S. L. L. Hill, H. M. Pereira (2023): The undetectability of global biodiversity trends using local species richness. – Ecography **2023**: e06604 [https://doi.org/10.1111/ecog.06604].

van Groenigen, J. W., I. M. Lubbers, H. M. J. Vos, G. G. Brown, G. B. De Deyn & K. J. van Groenigen (2015): Earthworms increase plant production: a meta-analysis. – Scientific Reports **4**: 6365 [https://doi.org/10.1038/srep06365].

van Klink, R., D. E. Bowler, K. B. Gongalsky, A. B. Swengel, A. Gentile & J. M. Chase (2020): Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. – Science **368**: 417–420 [https://doi.org/10.1126/science.aax9931].

Vidal, A., M. Blouin, I. Lubbers, Y. Capowiez, J. C. Sanchez-Hernandez, T. Calogiuri, J. W. Van Groenigen (2023): The role of earthworms in agronomy: Consensus, novel insights and remaining challenges. – In: Advances in Agronomy. – Elsevier: 1–78 [https://doi.org/10.1016/bs.agron.2023.05.001].

Violle, C., M.-L. Navas, D. Vile, E. Kazakou, C. Fortunel, I. Hummel & E. Garnier (2007): Let the concept of trait be functional! – Oikos **116**: 882–892 [https://doi.org/10.1111/j.0030-1299.2007.15559.x].

Violle, C., B. J. Enquist, B. J. McGill, L. Jiang, C. H. Albert, C. Hulshof, V. Jung & J. Messier (2012): The return of the variance: intraspecific variability in community ecology. – Trends in Ecology & Evolution **27**: 244–252 [https://doi.org/10.1016/j.tree.2011.11.014].

Wilkinson, M. D., M. Dumontier, Ij. J. Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J.-W. Boiten, L. B. da Silva Santos & et al. (2016): The FAIR Guiding Principles for scientific data management and stewardship. – Scientific Data **3** (2016): 160018 [https://doi.org/10.1038/sdata.2016.18].

Wright, I. J., P. B. Reich, M. Westoby, D. D. Ackerly, Z. Baruch, F. Bongers, J. Cavender-Bares, T. Chapin, J. H. C. Cornelissen, M. Diemer & et al. (2004): The worldwide leaf economics spectrum. – Nature **428**: 821–827 [https://doi.org/10.1038/nature02403].

Zanella, A., R. De Waal, B. Van Delft, J.-F. Ponge, B. Jabiol, M. De Nobili, C. Ferronato, J.-M. Gobat & A. Vacca (2018): Humusica 2, Article 9: Histic humus systems and forms—Specific terms, diagnostic horizons and overview. – Applied Soil Ecology **122**: 148–153 [https://doi.org/10.1016/j.apsoil.2017.05.026].

Zeiss, R., M. J. I. Briones, J. Mathieu, A. Lomba, J. Dahlke, L. Heptner, G. Salako, N. Eisenhauer & C. A. Guerra (2023): Climate effects on the distribution and conservation of commonly observed European earthworms. – Conservation Biology: e14187 [https://doi.org/10.1111/cobi.14187].