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Grant Proposal

The effects of global change on soil faunal communities: a meta-analytic approach

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Abstract

Human impacts are causing an unprecedented change of biodiversity across scales. To quantify the nature and degree of the biodiversity change, there have been a number of meta-analysis studies investigating the effects of global change drivers (land use, climate, etc.). However, these studies include few primary literature studies of soil biodiversity. Soil biodiversity is important for a variety of ecosystem services that are critical for human wellbeing. Yet, we know little about how soil organisms may respond to changing environmental conditions. Although studies have investigated the impact of global change drivers on soil biodiversity, they lack sufficient depth in the number of drivers and/or taxa included. Additionally, the previous focus on aboveground organisms has also resulted in a bias towards certain global change drivers in the primary literature. For example, climate change and land use change are more often studied, whilst pollution is typically understudied as a global change driver. Building on previous studies, we will conduct a meta-analysis to compare the effects of global change drivers (land use, habitat fragmentation/loss, fire, climate change, invasive species, pollution, and nutrient enrichment) on soil fauna (micro- to macro-invertebrates). This project aims to fill the current gaps in the literature, and actively participate in incorporating soil biodiversity into future global biodiversity assessments, by creating the first global open-acess dataset on the impacts of multiple global change drivers on soil fauna.

Keywords

Soil biodiversity; Global change drivers; Land use intensification; Climate change; Pollution; Nutrient enrichment; Invasive species

Lay Summary

Human activities are resulting in global change. These can be localised changes, such as destroying a forest, or more global ones, such as changing of the climate through increased atmospheric emissions. Most people are aware that our activities can negatively affect animals like elephants or bears, or that our actions are causing invasive species like Japanese knotweed to spread. However, soil harbours some of the highest diversity on the planet, and yet we know surprisingly little about how soil organisms might be impacted by our actions. In recent years, ecologists have been conducting a number of reviews to assess how humans impact biodiversity, typically the number of species, by amalgamating individual studies from different locations. The results of these reviews have allowed general conclusions to be made, which can be applied across the globe and ideally result in conservation actions. However, these reviews have generally looked at biodiversity of aboveground animals and plants, largely ignoring organisms in the soil, such as earthworms. Yet, soil, and the organisms within it, are critical for life on land and support many ecosystem services that are essential for human well-being. For example, earthworms have been to shown to increase crop production and help regulate water movement into the soil. Many organisms within the soil are also involved in the carbon cycle, by breaking down litter material from the soil surface and storing carbon in the soil. While a number of previous reviews have been conducted on the impacts of human activities on soil communities, most have focussed on a single species group, or identified only a couple of human impacts. However, as all organisms are subjected to multiple human impacts, and these are likely to affect organisms in a variety of ways, as well as influence the interactions among organisms, a comprehensive review which encompasses a multitude of organisms and human impacts is necessary.

In this study, we propose to systematically review the literature to determine how human activities impact soil organisms. For this review, we will use a meta-analytical approach - analysing the results of previously published studies to obtain an overall indication of the direction and the magnitude of the effect. The published literature we collate will not be restricted to a specific group of soil fauna, and we will attempt to include a wide variety of species. Similarly, we will use data from studies investigating a wide range of human impacts including land use change, habitat fragmentation, pollution, invasive species, and climate change. We expect to find that, on average, all soil organisms will be negatively affected by the human impacts, but with some human impacts, such as land use change and invasive species, having a greater effect. However, we anticipate that within each of the human impacts, such as among different land use types, the results might vary. The proposed meta-analysis will allow us to better understand and manage human impacts on soil biodiversity.

Background

Human impacts are causing an unprecedented change of biodiversity, at global and local scales. To quantify the nature and degree of the biodiversity change, there have been a number of meta-analysis studies investigating the effects of global change drivers, e.g., land use, climate and pollution (e.g., Murphy and Romanuk 2013, Mantyka-pringle et al. 2011). However, these studies include few primary literature studies of soil biodiversity. Soil biodiversity is exceptionally important for a variety of ecosystem services that are critical for human wellbeing (Wall et al. 2015, Bardgett and van der Putten 2014). Yet, we know surprisingly little about how soil organisms may respond to changing environmental conditions (Bardgett and van der Putten 2014). Although studies have investigated the impact of global change drivers on soil biodiversity, they lack sufficient depth in the number of drivers and/or taxa included (Blankinship et al. 2011, Mazor et al. 2018). Global change consists of a multitude of drivers, and the degree of the change is likely to vary across taxa or body size groups. Organisms in soil span a huge gradient of body size (Veresoglou et al. 2015), which is linked to their microhabitat requirements, dispersal capabilities and reproductive rates, all of which will influence their response to global change drivers similar to that seen in aboveground organisms (Brook et al. 2008). Additionally, the previous focus on aboveground organisms has resulted in a bias to certain global change drivers, as a result of the bias in the primary literature. For example, climate change and land use change is more often studied, whilst pollution is typically understudied as a global change driver (Bernhardt et al. 2017, Mazor et al. 2018).

Building on previous studies, we will conduct a meta-analysis to compare the effects of global change drivers (land use change and intensification, habitat fragmentation/loss, climate change, invasive species, pollution, and nutrient enrichment) on soil fauna (micro- to macro-invertebrates). An advantage of using a meta-analytical approach is that results from globally distributed, small-scale experiments and observations can be combined to create more generalisable results (Koricheva et al. 2013). In addition, the amalgamation of the individual studies eventually spans a variety of biomes, countries and gradients of global change drivers, and thus can answer questions that the individual studies by themselves can not. By creating such a dataset to conduct this meta-analysis, we will also be creating a resource that can be used to answer additional questions in the future; for example, identifying particularly sensitive regions, or an above-/belowground comparison. Increasing the ease of access to soil biodiversity data will likely result in these taxa being included in further analyses. For example, the TRY database, which collates functional traits of plants from across the globe, has now been used in over 150 further publications (https://www.try-db.org).

Research Questions

We will address three general questions with this meta-analysis (Fig. 1): What are the relative impacts of different drivers of global change on soil fauna? Is there variation in the response of different soil fauna groups? Does the classical grouping of soil fauna based on body size adequately represent their response to global change drivers?

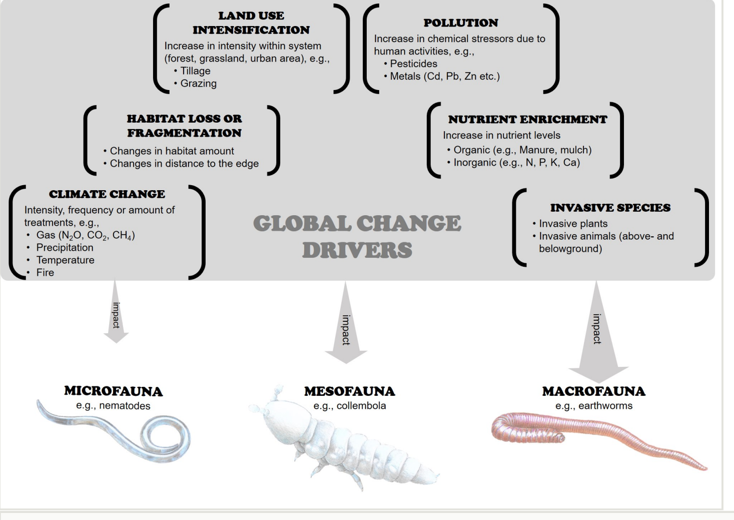

Figure 1. doi

Conceptual framework of the meta-analysis.

The project will address a hierarchy of hypotheses, looking at the overall impacts across and within global change drivers.

First-level hypotheses

At the first level, we will consider the relative impacts of different categories of global change drivers and the relative sensitivity of different soil taxa. We hypothesize that global change drivers will differ in their impact on soil faunal diversity, with some drivers decreasing (land use intensification, invasive species, pollution, drought) and others increasing (CO_2, warming) soil biodiversity (Thakur et al. 2017). Recent syntheses have highlighted that land-use change and invasive species are the global change drivers that will impact biodiversity the most (Maxwell et al. 2016, Murphy and Romanuk 2013). In the case of soil fauna, we can also expect that land use intensification and invasive species will strongly affect soil fauna by combining changes in soil properties and in plant and or soil communities. Therefore, we hypothesize that among the different global change drivers, invasive species and land use intensification will have larger impacts on soil biodiversity compared to others e.g. pollution and climate change. If sufficient data are reported on the impact of simultaneous global change drivers in factorial experiments, we will be able to test for interacting effects between global change drivers on soil biodiversity (Côté et al. 2016, Frishkoff et al. 2016).

Soil fauna varies greatly in body size and shape and is generally classified into three main size groups: microfauna (< 100 µm), mesofauna (100 µm - 2 mm) and macrofauna (> 2 mm) (Decaëns 2010). In this project, we will test whether this categorization can be linked to the sensitivity of soil fauna to global change impacts. Larger organisms are often more sensitive to the impacts of global change, because they have longer generation times and require larger microhabitats (Birkhofer et al. 2017). This hypothesis has rarely been tested on a global scale for soil fauna. Thus, we will test the hypothesis that soil macrofauna is more sensitive to the impacts of global change compared to micro- and mesofauna.

Second-level hypotheses

At the second level of the meta-analysis, we will test hypotheses within global change drivers categories, taking into account the potential effect of covariates such as biome or experimental *versus* observational data that might determine the strength and direction of the hypothesized relationships on soil taxa.

Land-use: We expect that land use practices that directly disturb the soil, such as tillage, will impact soil fauna more negatively than drivers that indirectly modify soil properties and affect the soil biome in the longer term (e.g. forest plantations) (Briones and Schmidt 2017).

Invasives: We hypothesize that invasive plant species will have the largest impact among different invasive species by changing soil physico-chemical properties, resource availability and habitat structure (Vilà et al. 2011). We will further separate invasive species into belowground fauna and aboveground fauna and test their differential impacts. We expect that among invasive fauna, belowground invasive species, through direct competition or trophic interaction with soil organisms and direct habitat interference, will have a greater impact than indirect competitors (i.e. aboveground fauna).

Pollution: Despite the variety of pollutants (pesticides, pharmaceuticals, etc.), we expect that soil fauna will generally decrease in response to pollution regardless of the nature of the pollutant (e.g. Nahmani and Lavelle 2002, Birkhofer et al. 2008). We further hypothesize that the response of the soil fauna will increase with the intensity (concentration) of the pollution.

Nutrient enrichment: For nutrient enrichment, we assume the nature of the input will impact the direction of soil fauna’s response. While inorganic nutrient enrichment (nitrogen deposition, inorganic fertilizers) is expected to decrease soil fauna, organic amendments (manure, sludge) could have a positive effect by creating habitats for soil organisms (Bünemann et al. 2006).

Climate change: Soil fauna is particularly sensitive to soil water availability. Therefore, among climate change drivers, we expect that changes in the frequency and quantity of precipitation will affect soil organisms more than temperature changes which could be buffered by the soil (Blankinship et al. 2011). CO_2 represents a resource for microorganisms, and previous syntheses showed that microbial biomass increases in response to increase in atmospheric CO_2 (Blankinship et al. 2011). Because many soil organisms rely on microbial biomass, we can expect that soil fauna diversity will increase in response to CO_2 enrichment through indirect effects on microbial biomass. Fire will reduce soil populations, including offspring and dormant individuals. The intensity and frequency of the fire events will determine soil fauna response, with larger impacts expected in situations involving an increased number of fires (yearly) (Neary et al. 1999).

Habitat fragmentation/loss: Fragmentation can alter the microclimate, and soil properties (Riutta et al. 2012). The reduced dispersal abilities of most soil fauna means that communities directly affected by fragmentation effects (i.e. due to changes in the microclimate) will be negatively impacted. Thus, the scale of habitat fragmentation/loss will determine the effect of the response in soil taxa (Rantalainen et al. 2008).

Depending on data availability, global change drivers categories could be merged to increase the power of the analysis. For example, nutrient enrichment could be grouped with pollution, CO_2 increase with climate change.

Methods

Following a literature search, using and expanding upon previously successful search terms (discussed below; Suppl. material 1), titles and abstracts will be screened and irrelevant papers removed. The Covidence software will be used for screening titles and entire papers, which will allow multiple team members to screen papers simultaneously, whilst also facilitating testing the repeatability and reliability of the screening process. Suitability of the remaining papers will then be assessed by screening the main text. Papers will be suitable if they

1. investigated the effect of at least one global change driver on at least one group of soil fauna and
2. contain at least one reference/undisturbed site (i.e. control), and one site impacted by the global change driver.

The log-proportional change between the mean diversity of the control and the impacted sites (log-response ratio) will be calculated for each global change driver and taxa group in the study. We will focus on species richness (the most commonly reported diversity measure) but will likely have sufficient data to investigate other measures that are often reported in the soil literature (e.g., abundance, biomass, Shannon diversity index).

To be able to answer the second-level hypotheses (i.e. changes within each of the global change drivers), each impacted site will have additional information extracted from the paper, which will also be used to inform the classification within the global change drivers. For example, for effect sizes from papers on land use, we will capture information on which land use the reference and impacted sites are (e.g., pastures, croplands) and other disturbances within the land use category that might impact soil fauna diversity (e.g., ploughing and tillage practices). For non-categorical global change drivers, such as pollutants or fire, we will capture rates, intensity or amounts of the global change driver.

As it is likely that factors unrelated to the global change drivers or the soil fauna will influence the magnitude of the response, we will also extract additional information that can be used as covariates in the meta-analysis. For example, we will test whether the effect sizes differ between observational or experimental (but non-manipulated communities) designs, and between biomes or regions in which the original study was conducted. Where possible, we will also capture geographic coordinates of the study sites. This will enable us to match the effect sizes to external data layers, such as those relating to soil parameters (using SoilGrids, with a resolution of 250 m). There are many covariates that may influence the response of soil fauna to global change drivers. These will be discussed in the initial workshop organised as part of this project. Following discussions, the structure of the database with be finalised, to ensure all potentially important variables are captured.

Analyses will first focus on the entire dataset, using the global change drivers as predictors for the soil taxa diversity measures (species richness, Shannon index, abundance and biomass). In subsequent models, detailed analyses will be performed using hierarchical categories within each global change driver (e.g., to examine the effects of different types of land use on soil fauna), as effects may vary within a driver. Mixed effects models (using the R package ‘metafor’), with random effects to account for non-independence of observations, will be used throughout.

Preliminary data

All members of the project team have previously been or are currently involved in similar meta-analysis projects, and thus have preliminary work that can be used in this project. HRPP, EKC, and VJB have previously compiled search terms that identify soil organisms within the literature. This will be modified for this project in order to successfully capture all soil fauna. HRPP, LB, OF, NE and VJB have search terms that identify some of the global change drivers. These search terms will be modified and added to ensuring adequate representation of the global change drivers that will be studied in this project. Finally, HRPP, LB, EKC and OF have bibliographic information on datasets that encompass aspects of the soil fauna and global change drivers that this meta-analysis will deal with. For example, HRPP has bibliography data for papers that measured earthworm diversity in different land uses. This bibliographic information can be used to ensure that we are capturing the literature we expect to with our search terms.

HRPP, LB, EKC, OF and NE have previously done meta-analytical analyses, and thus have knowledge, information and R code for such analyses. In particular, we will modify previously used R code to increase efficiency. All code used in this project will be made publically available via GitHub (www.github.com).

Data management and sharing of the products of research

All code will be made publically available via GitHub (https://github.com). Data will be made publically available on the iDiv portal (https://idata.idiv.de), but could also be made available on other platforms, such as the Natural History Museums' data portal (http://data.nhm.ac.uk).

Impact

At least one high impact paper will result from this project. Leipzig University and iDiv will pay for all papers to be fully open-access. Press releases will accompany all papers, assisted by media teams at our institutes. All team members will present results in talks at conferences and seminars.

We will showcase the project at outreach events at iDiv (e.g., 'Science Notes', 'Long Night of Science') and the Natural History Museum, London (e.g., 'Lates'). Blogs of team members will also communicate information about the project and results to scientific and non-scientific audiences.

Timeline

The project will start in September 2018 (after the student assistant position has been filled). The literature search will be performed immediately. From personal experience (previous meta-analyses) and a preliminary literature search, we estimate that obtaining data will take 12 months (Screening of titles and abstracts: 10-15 days; Screening of main text: 30-60 days; Data extraction: 28 weeks), with the student assistant helping for 11 months (part-time, in accordance with German student employment law). Analysis will begin in July 2019 (before all data extraction is complete), and the first manuscript will be submitted at the end of the project (March 2020).

Funding program

British Ecological Society - Large Research Grant (2018)

Grant title

The effects of global change on soil faunal communities: a meta-analytic approach

Hosting institution

The work will be conducted at the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig. There are further researchers within the institute that have a great deal of experience conducting meta-analysis (e.g., Dr. Dylan Craven, Dr. Simone Cesarz). A number of lab groups have a focus on soil and soil organisms (e.g., led by Prof. Dr. Nico Eisenhauer, Prof. Dr. Francois Buscot, Prof. Dr. Kirsten Küsel, and Prof. Dr. Nicole van Dam). We are in contact with researchers all over the world who have large datasets on soil faunal communities. iDiv also runs a synthesis centre (sDiv), where many high-profile researchers visit for working groups. iDiv has a High Performance Computer cluster (HPC), that are available if the models require more processing power. iDiv has a media and communications team, to assist with publicity of publications or events.

Conflicts of interest

No conflicts of interest

References

- Bardgett R, van der Putten W (2014) Belowground biodiversity and ecosystem functioning. Nature 515 (7528): 505-511. https://doi.org/10.1038/nature13855
- Bernhardt ES, Rosi EJ, Gessner MO (2017) Synthetic chemicals as agents of global change. Frontiers in Ecology and the Environment 15 (2): 84-90. https://doi.org/10.1002/fee.1450
- Birkhofer K, Bezemer TM, Bloem J, Bonkowski M, Christensen S, Dubois D, Ekelund F, Fließbach A, Gunst L, Hedlund K, Mäder P, Mikola J, Robin C, Setälä H, Tatin-Froux F, Van der Putten W, Scheu S (2008) Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. Soil Biology and Biochemistry 40 (9): 2297-2308. https://doi.org/10.1016/j.soilbio.2008.05.007
- Birkhofer K, Gossner M, Diekötter T, Drees C, Ferlian O, Maraun M, Scheu S, Weisser W, Wolters V, Wurst S, Zaitsev A, Smith H (2017) Land-use type and intensity differentially filter traits in above- and below-ground arthropod communities. Journal of Animal Ecology 86 (3): 511-520. https://doi.org/10.1111/1365-2656.12641
- Blankinship JC, Niklaus PA, Hungate BA (2011) A meta-analysis of responses of soil biota to global change. Oecologia 165 (3): 553-565. https://doi.org/10.1007/s00442-011-1909-0
- Briones M, Schmidt O (2017) Conventional tillage decreases the abundance and biomass of earthworms and alters their community structure in a global meta-analysis. Global Change Biology 23 (10): 4396-4419. https://doi.org/10.1111/gcb.13744
- Brook B, Sodhi N, Bradshaw C (2008) Synergies among extinction drivers under global change. Trends in Ecology & Evolution 23 (8): 453-460. https://doi.org/10.1016/j.tree.2008.03.011
- Bünemann EK, Schwenke GD, Van Zwieten L (2006) Impact of agricultural inputs on soil organisms—a review. Soil Research 44 (4). https://doi.org/10.1071/sr05125

- Côté IM, Darling ES, Brown CJ (2016) Interactions among ecosystem stressors and their importance in conservation. Proceedings of the Royal Society B: Biological Sciences 283 (1824). https://doi.org/10.1098/rspb.2015.2592
- Decaëns T (2010) Macroecological patterns in soil communities. Global Ecology and Biogeography 19 (3): 287-302. https://doi.org/10.1111/j.1466-8238.2009.00517.x
- Frishkoff L, Karp D, Flanders J, Zook J, Hadly E, Daily G, M'Gonigle L (2016) Climate change and habitat conversion favour the same species. Ecology Letters 19 (9): 1081-1090. https://doi.org/10.1111/ele.12645
- Koricheva J, Gurevitch J, Mengersen K (2013) Handbook of eta-analysis in Ecology and Evolution. Princeton University Press https://doi.org/10.1515/9781400846184
- Mantyka-pringle C, Martin T, Rhodes J (2011) Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. Global Change Biology 18 (4): 1239-1252. https://doi.org/10.1111/j.1365-2486.2011.02593.x
- Maxwell S, Fuller R, Brooks T, Watson JM (2016) Biodiversity: The ravages of guns, nets and bulldozers. Nature 536 (7615): 143-145. https://doi.org/10.1038/536143a
- Mazor T, Doropoulos C, Schwarzmueller F, Gladish D, Kumaran N, Merkel K, Di Marco M, Gagic V (2018) Global mismatch of policy and research on drivers of biodiversity loss. Nature Ecology & Evolution 2 (7): 1071-1074. https://doi.org/10.1038/s41559-018-0563-x
- Murphy GP, Romanuk T (2013) A meta-analysis of declines in local species richness from human disturbances. Ecology and Evolution 4 (1): 91-103. https://doi.org/10.1002/ece3.909
- Nahmani J, Lavelle P (2002) Effects of heavy metal pollution on soil macrofauna in a grassland of Northern France. European Journal of Soil Biology 38: 297-300. https://doi.org/10.1016/s1164-5563(02)01169-x
- Neary DG, Klopatek CC, DeBano LF, Ffolliott PF (1999) Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 122: 51-71. https://doi.org/10.1016/s0378-1127(99)00032-8
- Rantalainen M, Haimi J, Fritze H, Pennanen T, Setala H (2008) Soil decomposer community as a model system in studying the effects of habitat fragmentation and habitat corridors. Soil Biology and Biochemistry 40 (4): 853-863. https://doi.org/10.1016/j.soilbio.2007.11.008
- Riutta T, Slade E, Bebber D, Taylor M, Malhi Y, Riordan P, Macdonald D, Morecroft M (2012) Experimental evidence for the interacting effects of forest edge, moisture and soil macrofauna on leaf litter decomposition. Soil Biology and Biochemistry 49: 124-131. https://doi.org/10.1016/j.soilbio.2012.02.028
- Thakur M, Tilman D, Purschke O, Ciobanu M, Cowles J, Isbell F, Wragg P, Eisenhauer N (2017) Climate warming promotes species diversity, but with greater taxonomic redundancy, in complex environments. Science Advances 3 (7): e1700866. https://doi.org/10.1126/sciadv.1700866
- Veresoglou SD, Halley JM, Rillig MC (2015) Extinction risk of soil biota. Nature Communications 6: 8862. https://doi.org/10.1038/ncomms9862
- Vilà M, Espinar JL, Hejda M, Hulme PE, Jarošík V, Maron JL, Pergl J, Schaffner U, Sun Y, Pyšek P (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters 14 (7): 702-708. https://doi.org/10.1111/j.1461-0248.2011.01628.x
- Wall DH, Nielsen UN, Six J (2015) Soil biodiversity and human health. Nature 528: 69-76. https://doi.org/10.1038/nature15744

Supplementary material

Suppl. material 1: Supplementary methods doi

Authors: HRPP, LB
Data type: description of methodology
Brief description: The supplementary methods describes with further details the data collection and extraction initial steps of the meta-analysis. It contains the search terms for the literature search.
Download file (10.51 kb)