Applicant: [redacted]

Funding Sought: **£16,054.94**
Funding Awarded: **£16,054.94**

LRB18/1013

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

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 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.

PRIMARY APPLICANT DETAILS

Name [redacted]
Surname [redacted]
Tel (Work) [redacted]
Email (Work) [redacted]

CONTACT DETAILS

Name [redacted]
Surname [redacted]
Email (Work) [redacted]

CONTACT DETAILS

Name [redacted]
Surname [redacted]
Email (Work) [redacted]

Section 1 - Your Part A Application

Employment History

Please note if you do not know the exact day, select the 1st day of the month e.g. March 2005: 01/03/2005

Start Date	End Date	Position	Organisation	Additional Info
[redacted]	[redacted]	Postdoctoral Researcher	[redacted]	*No Response*
[redacted]	[redacted]	Data-Analyst	[redacted]	*No Response*
[redacted]	[redacted]	Research Intern	University [redacted]	[redacted]
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*

Please specify:

No Response

Education History

Please note if you do not know the exact day, select the 1st day of the month e.g. March 2005: 01/03/2005

Start Date	End Date	Qualification	Organisation	Additional Info
[redacted]	[redacted]	PhD	[redacted]	[redacted]

[redacted]	[redacted]	Master's	[redacted]	Master's in Ecology, evolution and conservation
[redacted]	[redacted]	BSc Zoology (With Hons.)	University [redacted]	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*	*No Response*

Research Grants/Fellowships Awarded

Date	Details	Amount Awarded (£)	Additional Info
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*

Conference Participation

Conference Name	Details

BES/GfO Joint Annual Meeting 2017: Ecology across Borders	Talk title: [redacted]
Global Soil Biodiversity Conference 2017	Keynote talk title: [redacted]
EU Macro Meeting 2015 (a joint meeting of the German, BES and Denmark macroecology groups)	Talk title: [redacted]
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*

Other Awards/Achievements/Skills

No Response
No Response
No Response
No Response
No Response
No Response
No Response
No Response
No Response
No Response

Summary of Publication Record

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Professional Membership

BES Member since 2011

Additional Information

No Response

Summary Project Details

Total project cost: £	Amount requested from BES: £
16,054.94	0.00

Project title:

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

Project 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 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.

Project start date:	**Project end date:**
03 September 2018	31 March 2020

Project country:

Germany

We have chosen a selection of keywords, which cover the breadth of the ecological research we fund. These keywords link the ecological content of an application to the most appropriate member of the BES Review College.

As your selections will determine which reviewers are asked to assess your application, please select carefully.

Please choose three words from the following:

- ☑ Biodiversity
- ☑ Global change ecology
- ☑ Species distributions

Please provide a project description

This should include:

a) background and rationale
b) the question or hypothesis to be tested
c) an outline of the methods to be use
d) expected outputs
e) expected timescales

Please capitalise all headings

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 (GCDs), e.g., land use, climate and pollution (e.g., Murphy and Romanuk 2014, DOI:10.1002/ece3.909; Mantyka-Pringle et al., 2011, DOI:10.1111/j.1365-2486.2011.02593.x). 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, DOI:10.1038/nature15744; Bardgett et al., 2014, DOI:10.1038/nature13855). Previous studies investigating the impact on soil biodiversity of GCDs lack sufficient depth in the number of drivers and/or taxa included. As global change consists of a multitude of drivers and the degree of the change is likely to vary across taxa.

Building on previous studies we will conduct a meta-analysis to compare the effects of GCDs (land use, habitat fragmentation/loss, fire, climate change, invasive species, pollution, CO2 and nutrient enrichment) on soil fauna. We expect

the magnitude and direction of the effects to vary across drivers and taxa. We hypothesise that GCDs will generally decrease soil faunal diversity and, based on previous meta-analysis, for land use and species invasions to have the largest impacts.
Following a literature search, building upon previously successful search terms (from project team members), titles and abstracts will be screened and irrelevant papers removed. Suitability of the remaining papers will be assessed by screening the main text. Papers will be suitable if they investigated the effect of at least one GCD on at least one group of soil fauna and contain at least one reference/undisturbed site (i.e. control), and one site impacted by the GCD. The log-proportional change between the mean diversity of the control and the impacted sites (log-response ratio) will be calculated for each GCD 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 and biomass).

First the entire dataset will be analysed using the GCDs as predictors. In subsequent models, detailed analyses will be performed using hierarchical categories within each GCD (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.

We expect at least one high-impact paper in a peer-reviewed and international journal. As a large dataset will have been collated, there is the potential for additional papers, focussing on specific aspects (i.e., most sensitive taxa, regions most at risk). The collated dataset will also be made open-access. We will also highlight the work outside of academia (details below).

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 manuscript submission at the end of the project (March 2020).

What are the risks to the health and safety of those involved in the project and how are these risks to be minimised?

We foresee minimal health and safety risks. As this is a desk-based project, we will ensure that everyone involved has a suitable desk setup, minimising the risk of RSI and other issues associated with long periods at a computer.

Please provide details of agreed collaborations and project partners that will facilitate the proposed project:

[redacted]

Please provide details of the suitability of the institution where the work will be carried out and the availability of equipment and facilities required for the work:

The work will be conducted at [redacted] There are further researchers within the institute that have a great deal of experience conducting meta-analysis [redacted] A number of lab groups have a focus on soil and soil organisms [redacted] 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.

Please provide details of necessary permits/licences obtained, if applicable:

A licence for 'Covidence' software (https://www.covidence.org/), for screening papers and data extraction, will be bought.

Please indicate how you will assess the scientific impact of the project and the benefits for non-academic audiences:

At least one high impact paper will result from this project. [redacted] 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.

How do you intend to make your research data publically available?

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/).

Please provide details of any published papers relevant to this project:

[redacted]

Have you previously applied for a grant from the BES?

No

Equipment/Consumables

Item	Quantity	Description	Total Cost
Covidence software	1	Software for paper screening and data extraction; one review license; https://www.covidence.org	£180.00
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*

No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
		Overall Equipment Cost:	**£** 180.00

Personal Travel/Accommodation/Subsistence

Description	Total Cost
Expenses for 2-day workshop of research consortium at iDiv in Leipzig, Germany: Flights for 2 members (2 x 300GBP)	£600.00
Expenses for 2-day workshop: Accommodation for two members (70euros x 3 nights x 2)	£370.00
Expenses for 2-day workshop: Lunch and Coffee for 6 members	£212.88
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
	Overall Personal Travel Cost: **£** 1,182.88

Field Travel/Accommodation/Subsistence

Description	Total Cost
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*
No Response	*No Response*

No Response			*No Response*
No Response			*No Response*
No Response			*No Response*
No Response			*No Response*
No Response			*No Response*
		Overall Field Travel Cost:	**£** 0.00

Employment
(note only casual, short term assistance will be considered)

Position	Description of role	Rate & Duration of employment	Total Cost
Student assistant (part-time, with an MSc)	Paper screening and selection, data extraction	£ 16.17/hour x 82.6 hours/month x 12 months	£14,692.06
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
No Response	*No Response*	*No Response*	*No Response*
		Overall Employment Costs:	**£** 14,692.06

If the total cost of the event is greater than the amount sought from the BES, please state how the balance will be met:

No Response

Other

Item	Description	Total Cost
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*

No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
No Response	*No Response*	*No Response*
	Overall Other Costs:	**£** 0.00

Total project cost:
£

16,054.94

Amount Requested from BES

£16,054.94

Section 2 - Contact Details

PRIMARY APPLICANT DETAILS

Name [redacted]
Surname [redacted]
Tel (Work) [redacted]
Email (Work) [redacted]

CONTACT DETAILS

Name [redacted]
Surname [redacted]
Email (Work) [redacted]

CONTACT DETAILS

Name [redacted]
Surname [redacted]
Email (Work) [redacted]

GMS ORGANISATION

Type	Organisation
Name	[redacted]
	[redacted]
Phone (Mobile)	[redacted]
Email (Work)	[redacted]
Address	[redacted]
	[redacted]
	[redacted]
	[redacted]
	[redacted]
	[redacted]

If you do not have a current organisation (i.e. you are an independent researcher/retired), please provide your preferred contact address above and select the checkbox to the right	Unchecked

Section 3 - Grant Specific Questions

Please provide any responses to the reviewer comments received for Part A of your application form. If these comments have resulted in any changes to your project proposal, please ensure you outline these changes here:

Reviewer: Excellent publication record in some of the highest impact journals such as Nature Ecology & Evolution, Nature and Science. Has given a keynote talk at the Global Soil Biodiversity conference in 2017. References are excellent. This project uses a meta-analysis approach to investigate how global change drivers affect soil fauna, with a well defined hypothesis for testing. Since this is desk-based, the project is low-risk, and the majority of costs are to support a part-time student assistant. Meta-analysis projects remain firmly in the 'big picture' and can have great resource value – was pleased to see that the dataset will be made publicly available.
We thank the reviewer for all of their kind comments. We are very pleased that they believe the project proposal has strong potential.

Response: The reviewer highlighted many positive points of this project, such as meta-analyses being a useful tool and the creation of the open access dataset. Given the increase in the word limit of the research plan, we have further highlighted these points within the background of the project.

Reviewer: The proposal is for a meta-analysis with a focus on human impacts on soil ecology - tackling an important and understudied area. The impacts considered will be a broad range: Land use change, habitat fragmentation, pollution, fire, climate change, invasive species) and the impacts on a range of soil organisms will be considered.

Response: We fully agree that soil biodiversity is understudied, despite its importance for many ecosystem functions. We have expanded the background information describing this project to highlight this further.

Reviewer: The applicant makes certain broad predictions, but the data set should be sufficiently detailed to drill down into many different aspects.

Response: Based on this comment, we felt that we could provide more precise hypotheses and predictions for the effect of different global change drivers on soil taxa. These hypotheses and predictions have been added to the research plan. We now present hypotheses using a two-tiered approach. The first tier has overarching hypotheses on the effects of the global change drivers on soil taxa, and whether the impact varies depending on body size. The second tier of hypotheses considers the effect within each global change driver, as effects are likely to vary depending on the intensity or the exact nature of the driver.

We have also added additional detail about what information will be extracted from the papers, in terms of the global

change drivers, and covariates that may be used within the model to explain additional variation. An initial workshop will build upon the presented hypotheses and required data/covariates for modelling, ensuring that the dataset created by this project will have a high level of detail, not only suitable for this analysis, but also hopefully suitable for further analyses once shared with the scientific community.

Reviewer: The timetable proposed is feasible - experience enables her to be realistic about the time required for each step. I am pretty certain that a high impact publication would result.

Response: Thank you, we agree that exciting results should emerge from this project.

Amount sought from the BES:

If this has been altered in response to reviewer comments, please update.

£16,054.94

If relevant, please briefly summarise any amendments made to the budget:

NA

Please describe the objectives of the project:

This project will undertake a meta-analysis to research the effects of multiple global change drivers on a broad range of soil fauna (micro- to macro-invertebrates), a previously understudied group of organisms in this respect. Global change drivers will explicitly include ones that are often neglected in terrestrial systems (e.g., pollutants). If the dataset permits, interacting effects between the global change drivers will also be investigated. It is advantageous to study a variety of soil fauna in the meta-analysis, as it is likely that some taxa will show stronger changes than others, potentially in opposing directions, although these changes may be consistent within body-size groups. By the end of the project, we will have created a large dataset, which could be used for further analyses, and will be made open access.

Please provide details of the Research Plan:

This should include the background to the project, preliminary data, research questions, experimental approach and timetable for delivery.

Please capitalize all headings.

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 (GCDs), e.g., land use, climate and pollution (e.g., Murphy and Romanuk 2014, DOI:10.1002/ece3.909; Mantyka-Pringle et al., 2011, DOI:10.1111/j.1365-2486.2011.02593.x). 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, DOI:10.1038/nature15744; Bardgett et al., 2014, DOI:10.1038/nature13855). Yet, we know surprisingly little about how soil organisms may respond to changing environmental conditions (Bardgett et al., 2014). Although studies have investigated the impact of GCDs on soil biodiversity, they lack sufficient depth in the number of drivers and/or taxa included (Blankinship et al. 2011, DOI:10.1007/s00442-011-1909-0; Mazor et al., 2018, DOI:10.1038/
s41559-018-0563-x.). 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, DOI: 10.1038/ncomms9862), 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, DOI:10.1016/j.tree.2008.03.011). Additionally, the previous focus on aboveground organisms has resulted in a bias to certain GCDs, 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 GCD (Bernhardt et al., 2017, DOI:10.1002/fee.1450; Mazor et al., 2018).

Building on previous studies, we will conduct a meta-analysis to compare the effects of GCDs (land use, habitat fragmentation/loss, fire, climate change, invasive species, pollution, CO_2 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,

Princeton University Press). In addition, the amalgamation of the individual studies eventually spans a variety of biomes, countries and gradients of GCDs, 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: 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 GCDs?

HYPOTHESES
The project will address a hierarchy of hypotheses. At the first level, we will consider the relative impacts of different categories of GCDs and the relative sensitivity of different soil taxa. We hypothesize that GCDs will differ in their impact on soil faunal diversity, with some drivers decreasing (land use intensification, invasive species, pollution, drought) and others increasing (CO2, warming) soil biodiversity (Thakur et al. 2017, DOI: 10.1126/sciadv.1700866). Recent syntheses have highlighted that land use intensification and invasive species are the global change drivers that will impact biodiversity the most (Maxwell et al., 2016, DOI:10.1038/536143a, Murphy and Romanuk 2014). 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 GCDs on soil biodiversity (Cote et al. 2016, DOI:10.1098/rspb.2015.2592; Frishkoff et al., 2016, DOI:10.1111/ele.12645).

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, DOI: 10.1111/j.1466-8238.2009.00517.x). 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, DOI:10.1111/1365-2656.12641). 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.

2ND LEVEL HYPOTHESES
The dataset will further allow us to test hypotheses within GCD 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 agricultural practices (e.g. 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 et al., 2017, DOI:10.1111/gcb.13744).

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 (Vila et al., 2011, DOI:10.1111/j.1461-0248.2011.01628.x). 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 et al. 2002, DOI: 10.1016/S1164-5563(02)01169-X, Birkhofer et al. 2008, DOI: 10.1016/j.soilbio.2008.05.007). 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 (Büneman et al. 2006, DOI: 10.1071/SR05125).

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, DOI:10.1007/s00442-011-1909-0)

CO2: CO2 represents a resource for microorganisms, and previous syntheses showed that microbial biomass increases in response to increase in atmospheric CO2 (Blankinship et al., 2011). Because many soil organisms rely on microbial biomass, we can expect that soil fauna diversity will increase in response to CO2 enrichment through indirect effects on microbial biomass.

Habitat fragmentation/loss: Fragmentation can alter the microclimate, and soil properties (Riutta et al., 2012, DOI:10.1016/j.soilbio.2012.02.028). 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, DOI:10.1016/j.soilbio.2007.11.008).

Fire: Heat 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, DOI:10.1016/S0378-1127(99)00032-8).

Depending on data availability, GCD categories could be merged to increase the power of the analysis. For example, nutrient enrichment could be grouped with pollution, CO2 increase with climate change.

METHODS

Following a literature search, using and expanding upon previously successful search terms (discussed below), 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 GCD 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 GCD. The log-proportional change between the mean diversity of the control and the impacted sites (log-response ratio) will be calculated for each GCD 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 GCDs), each impacted site will have additional information extracted from the paper, which will also be used to inform the classification within the GCDs. 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 GCDs, such as pollutants or fire, we will capture rates, intensity or amounts of the GCD.

As it is likely that factors unrelated to the GCDs 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 GCDs. 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 GCDs 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 GCD (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. [redacted] 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. [redacted] have search terms that identify some of the GCDs. These search terms will be modified and added to ensuring adequate representation of the GCDs that will be studied in this project. Finally, [redacted] have bibliographic information on datasets that encompass aspects of the soil fauna and GCDs that this meta-analysis will deal with. For example, [redacted] 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.

[redacted] 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).

TIMETABLE

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).

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No Response

[redacted]