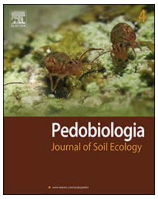
Pedobiologia - Journal of Soil Ecology 67 (2018) 1–9

Contents lists available at ScienceDirect

Pedobiologia - Journal of Soil Ecology

journal homepage: www.elsevier.com/locate/pedobi



Using data from schools to model variation in soil invertebrates across the UK: The importance of weather, climate, season and habitat

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ARTICLE INFO

Keywords:
Soil
Invertebrates
Earthworms
Climate
Citizen science
Rainfall

ABSTRACT

Soil invertebrates play important roles in nutrient cycling, the development of soil structure, food webs and even climate regulation. It is likely that climate change will have far-reaching impacts on soil invertebrates but a lack of information about how soil invertebrate populations vary with soil characteristics and climate make projections difficult. To address this gap, we present the results of a large-scale citizen science project that examined the abundance of soil macro-invertebrates across the UK.

The abundance and biomass of twelve invertebrate groups were recorded by school children using standardised protocols on six occasions over two years. Using these data, we examined the relative impact of local habitat and soil characteristics, and weather and climate, upon these taxa.

The abundance of many soil invertebrate groups varied with season and small-scale habitat factors. We found that the abundance and biomass of earthworms was strongly correlated with soil moisture. There was, however, little evidence that large-scale variation in soil invertebrate abundance could be explained by spatial variation in climate.

Given the importance of earthworms for soil processes, periods of dry weather may reduce their ability to undertake nutrient cycling and the provision of other services such as food for invertivorous species. Future analyses of the impacts of climate change on soil invertebrates may usefully consider variables such as frequency of rain, rather than monthly or seasonal averages more widely used.

Our results were generally in accord with patterns expected from previous literature, providing important quality assurance. This indicates that this could be an effective scheme for long-term monitoring of soil invertebrates and that it is possible to utilise educational establishments as a forum for large-scale environmental data collection. Not only can this deliver valuable environmental data, but also it can engage school children in the collection of scientifically valuable data.

1. Introduction

Soil invertebrates play important roles in the development of soil structure, nutrient cycling, flood and erosion control, and even climate regulation (Lavelle et al., 2006; Blouin et al., 2013). Earthworms contribute the largest component of the animal biomass in the majority of terrestrial ecosystems (Lavelle and Spain, 2001), and are regarded as major ecosystem engineers (Lavelle et al., 1997). A wider range of invertebrate groups, including collembola and myriopods also contribute to nutrient cycling as litter transformers (Lavelle et al., 1997). Other soil invertebrate taxa, such as Diptera, Lepidoptera, Gastropods and Coleoptera, can be agricultural pests with significant economic impacts (Rowson et al., 2014; Ellis et al., 2015). Many soil invertebrates are keystone species in ecological systems, due to their role in nutrient cycling, herbivorous impact on plants, or because they form an important part of the diets of many bird and mammal species, whose populations therefore rely upon them (e.g. Pearce-Higgins, 2010). Any changes in the abundance of soil invertebrates can have far-reaching consequences for the provision, regulating and cultural services provided by ecosystems.

Despite their importance, there remains much that is uncertain about how soil invertebrate populations, including even earthworms, vary with soil characteristics, vegetation type and climate (Blouin et al., 2013). Given projected future changes in the climate driven by anthropogenic climate change (IPCC, 2014), and the potential sensitivity of soils and soil processes to both variation in temperature (Davidson and Janssens, 2006) and moisture (Seneviratne et al., 2010), the potential impacts of climate change upon soils are likely to be significant.

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https://doi.org/10.1016/j.pedobi.2018.01.002
Received 5 September 2017; Received in revised form 24 January 2018; Accepted 24 January 2018

One of the key mechanisms by which climate change will affect soils and soil processes will be through the impact of temperature and rainfall patterns on soil invertebrates. The effects can be assessed and tested in a quantitative way using a number of approaches. Firstly, soil cores can be transplanted between different climates and the varying responses of different invertebrate groups monitored (Briones et al., 1997). Secondly, experimental manipulation of temperature and water availability can be undertaken and the impacts on soil invertebrates studied (Blankinship et al., 2011). Thirdly, large-scale variation in the distribution of abundance of soil invertebrates could be measured and modelled as a function of climate (Briones et al., 2007). Whilst many studies projecting impacts of climate change on biodiversity rely on large-scale information on the distribution of species (Pacifici et al., 2015) or abundance (e.g. Howard et al., 2014), there is relatively little data available on the large-scale distribution and abundance of soil invertebrates available to undertake such projections (Rutgers et al., 2016), even in well studied regions such as the UK (Carpenter et al., 2012).

Previous studies have suggested that soil invertebrates may be sensitive to climate change, although with variation between taxa. UK climate change projections have indicated that key changes will be increasing temperatures, particularly in summer, an increased frequency of summer drought and increases in winter rainfall (Jenkins et al., 2009). Studies of Lumbricidae (which includes most European earthworms) and Tipulidae, two important components of soil macro-invertebrate communities, have suggested their abundance may be reduced by climate change, if associated with summer warming and increased frequency of summer drought (Staley et al., 2007; Pearce-Higgins, 2010, Pearce-Higgins et al., 2010; Carroll et al., 2011). Lepidoptera, some of which whose larvae dwell in the soil, may also be negatively impacted by climate change if that results in warmer, wetter winters (Martay et al., 2016; McDermott Long et al., 2017). Conversely, other invertebrate groups such as Hymenoptera, including soil-dwelling ants, tend to be positively associated with temperature (Pearce-Higgins, 2010; Pearce-Higgins et al., 2017). These assessments, particularly of Lumbricidae and Tipulidae, are based largely upon the results of small scale studies focussed on a limited number of species. There is a lack of large-scale data on the abundance and distribution of soil invertebrates and their relationships with climate and habitat in order to assess their potential sensitivity to climate change. This is starting to be addressed: a map of earthworm abundance and diversity across north-west Europe has identified a largely positive relationship between earthworm abundance and temperature, and a positive relationship with average annual rainfall (Rutgers et al., 2016). However, much more data and information is required, such as how earthworms are affected by the interaction between temperature and rainfall and other changing land-use, before climate change impacts can be predicted confidently.

To address this gap, and to understand the extent to which spatial variation in the abundance of key soil invertebrate groups may be driven by climate, weather and small-scale habitat features, we present the results of a large-scale project to describe soil macro-invertebrate abundance across the UK. As soil invertebrate abundance varies with land-use (Rutgers et al., 2016), to maximise our ability to identify relationships with climate variables, we focussed largely on a single habitat-type with common management, that of school playing fields, which can often be an important green space within urban environments. Importantly, by focusing data collection on schools, we were able to take advantage of the opportunity to align our requirements for data collection with the educational curriculum, facilitating a large number of schools from across the country to take part. As it would not have been possible to cost-effectively achieve the national-scale coverage using professional scientists, given our reliance upon non-professional scientists, we regard this as citizen science (Silvertown, 2009). The occurrence, abundance and biomass of different soil invertebrate groups were recorded by school children using standardised protocols under supervision from their teachers on six occasions over two years. Using these data, we examined the relative impact of local habitat and soil characteristics, and weather and climate, upon these species groups, as a precursor to understanding the potential future impacts of climate change. Importantly, we discuss the extent to which the results from the first two years of sampling indicate the potential for a citizens-science scheme such as this, to effectively provide long-term monitoring of soil invertebrates.

2. Materials and methods

2.1. Soil invertebrate data

Pupils surveyed soil macro-invertebrates during six sampling months over two years: October, March and June in the academic years 2015–16 and 2016–17. These months were chose to give three well-spaced sampling periods, avoiding colder months when sampling may have been difficult due to rain or frozen ground, and summer months when pupils are on holiday. Up to five soil samples were taken within each recording month during biology or science lessons under supervision from their teachers following standard protocols. Samples were of randomly located 30 × 30 cm squares of turf and soil, dug to 5 cm depth (Appendix S1 for pupil instructions). Within each sample, all macro-invertebrates ($>$ 3 mm) were sorted, counted and separated into 12 taxonomic groups using a simple key (Appendix S1) as follows: Annelida (earthworms), Gastropoda (slugs), Gastropoda (snails), Isopoda (woodlice), Chilopoda (centipedes), Arachnida (spiders and harvest spiders), Demapterida (earwigs), Lepidoptera larvae (caterpillars), Diptera larvae (fly larvae, primarily Tipulidae), Hymenoptera (ants), Coleoptera (beetles) and Coleoptera larvae (beetle larvae). The length of individual earthworms was measured, and the numbers within 2 cm size-classes to $>$ 10 cm, counted. This sampling method may be less- effective for sampling fast-moving earthworm species (Singh et al., 2016) and highly mobile taxa such as Arachnida and Coleoptera, and so the densities presented may represent under-estimates. However, it does provide a repeatable method that can be consistently applied by supervised school children to provide data across a wide range of invertebrate groups.

Optionally, classes were encouraged to record the wet weight of each taxonomic group. Although only 82 schools did this, there were sufficient data to model earthworm biomass as the most frequently recorded taxon. Earthworm weight was modelled as a function of earthworm abundance in each of six size-classes as six different variables, using a generalised linear model (GLM) with a normal error structure. This model was then used to estimate earthworm biomass across all samples based on the size distribution.

2.2. Habitat and soil characteristics

The habitat-type that samples were taken from was recorded as playing field, garden, flower bed, public park, other grassy area or other habitats. Based upon sample size, we combined the ‘garden’ and ‘flowerbed’ categories into a single category and we combined ‘public parks’, ‘other grassy areas’ and ‘other habitats’ into a single category, ‘other’, of which 74% were from ‘other grassy areas’. Pupils also recorded whether shrubs or trees were present within 3 m of their sample. Participants were also encouraged to classify soil texture and pH (Appendix S2), but as this was optional, only 53% and 15% of schools recorded these data. These variables were therefore not included in the analysis. Instead, variation in soil composition and texture were estimated from maps of soil organic carbon content (SOCC) (Jones et al., 2005), and clay, silt and sand content (Hiederer, 2013a,b), all published at 1 km resolutions. Across our samples there was a strong correlation between% sand and both% silt ($r = 0.80$) and% clay ($r = 0.85$) content, but not between% clay and% silt ($r = 0.39$). Therefore only clay and silt content were used for further analysis.