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Evaluation of mesofauna communities as soil quality indicators in a national-level monitoring programme

Paul B.L. George [a, b, *], Aidan M. Keith [c], Simon Creer [d], Gaynor L. Barrett [b], Inma Lebron [b], Bridget A. Emmett [b], David A. Robinson [b], David L. Jones [a]

[a] School of Environment, Natural Resources & Geography, Bangor University, Deiniol Road, Bangor, Gwynedd, LL57 2UW, United Kingdom
[b] Centre for Ecology & Hydrology, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW, United Kingdom
[c] Centre for Ecology & Hydrology, Lancaster Environment Centre, Library Avenue, Bailrigg, Lancaster, LA1 4AP, United Kingdom
[d] School of Biological Sciences, Bangor University, Deiniol Road, Bangor, Gwynedd, LL57 2UW, United Kingdom

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ABSTRACT

Mesofauna underpin many ecosystem functions in soils. However, mesofauna communities are often overlooked when discussing these functions on large scales. They have been proposed as bioindicators of soil quality and ecosystem health. This study aimed to evaluate differences amongst mesofauna communities, particularly Acari and Collembola, across multiple habitat and soil types, as well as organic matter levels, and their relationships with soil characteristics, on a national-scale. Soil cores were collected from 685 locations as part of a nationwide soil monitoring programme of Wales. Plant community composition, soil type, as well as physical and chemical variables, including pH, total C and N, were measured at these locations. Mesofauna were extracted from soil cores and identified using a Tullgren funnel technique. Acari were sorted to Order; Collembola were sorted according to Super-family. Abundances of mesofauna were consistently lowest in arable sites and highest in lowland woodlands, except for Mesostigmata. Differences between similar habitat types (e.g. Fertile and Infertile grasslands) were not detected using the national-level dataset and differences in mesofauna communities amongst soil types were unclear. Relationships between mesofauna groups and soil organic matter class, however, were much more informative. Oribatid abundances were lowest in mineral soils and correlated with all soil properties except moisture content. Collembola and Mesostigmata abundances were likely negatively influenced by increased moisture levels in upland peat habitats where their abundances were lowest. These groups also had low abundances in heathlands and this was reflected in low diversity values. Together, these findings show that this national-level soil survey can effectively identify differences in mesofauna community structure and correlations with soil properties. Identification of mesofauna at high taxonomic levels in national-level soil monitoring is encouraged to better understand the ecological context of changes in soil properties.

1. Introduction

Mesofauna represent a major component of soil biological communities and play a critical role in maintaining soil quality and a range of ecosystem functions (Barrios, 2007). Soil invertebrates support decomposition, nutrient cycling, and soil formation, which facilitates water supply and regulates local erosion and climate (Lavelle et al., 2006: Barrios, 2007). Such functions are key components soil health (Doran and Zeiss, 2000). Acari (Gulvik, 2007) and Collembola (Rusek, 1998) are the most abundant groups of mesofauna. Collembola in soils are important consumers of microbial films and fungal hyphae or larger plant detritus, and can influence soil structure in some systems (Rusek, 1998). Important Acari sub-orders include Oribatida and Mesostigmata. Oribatids are the most numerous and diverse group in most undisturbed soils. They are slow moving, heavily armoured, with comparatively low fecundity and relatively long lifespans to other mesofauna (Gulvik, 2007) and consume organic matter as well as fungi (Schneider et al., 2005). Mesostigmatids are commonly important predators within soils, consuming a wide range of

* Corresponding author. School of Environment, Natural Resources & Geography, Bangor University, Deiniol Road, Bangor, Gwynedd, LL57 2UW, United Kingdom.
E-mail address: afp67e@bangor.ac.uk (P.B.L. George).

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invertebrate fauna (Gulvik, 2007).

With such life-history characteristics as well as their small size, varied ecological preferences, relatively high fecundity, and ease of sampling, mesofauna may serve as bioindicators of soil quality and ecosystem health (Gerlach et al., 2013). At the broad level, abundances of Acari and Collembola are useful for understanding how biota respond to the impacts and intensity of land-use on ecosystems (Black et al., 2003; Rutgers et al., 2009; Nielsen et al., 2010a; Arroyo et al., 2013), as well as the effects of anthropogenic disturbance (Tsiafouli et al., 2015). While mesofauna are often overlooked, studies of mesofauna as bioindicators have been implemented in a number of large-scale soil assessment and ecosystem monitoring programmes across Europe.

In the Netherlands, abundances of mesofauna, specifically in agricultural and horticultural sites, declined in areas with high disturbance and increased in areas where disturbance was minimal (Rutgers et al., 2009). Cluzeau et al. (2012) suggested that greater abundances of Collembola indicated the use of organic fertilisers and high-level of agricultural management. Ireland's Crébeo soil biodiversity assessment found indicator species that differentiated agricultural land uses (Keith et al., 2012). Soil invertebrate measures were added as bioindicator metrics to the UK Countryside Survey in 1998. Black et al. (2003) found Acari, especially oribatids, preferred highly organic, moist soils as well as undisturbed upland habitats including moors, heaths, bogs, and woods, whereas Collembola made up a greater proportion of mesofauna communities in grasslands and deciduous woodlands.

The fact that such monitoring programmes are undertaken at a national-scale means that trends can be observed for wide geographic areas, offering a range of benefits for ecological synthesis. Firstly, broad, intensive sampling contributes to a national taxonomic inventory for soil biota including information of diversity and distribution. Secondly, large-scale soil monitoring programmes provide a spatially varied dataset, ideal for linking biological indicators to ecosystem health/functions. Thirdly, such datasets also offer an opportunity to develop and test large-scale hypotheses on, agricultural practices, land remediation, and soil pollution in relation to ecosystem services and health. Finally, soils have been described as a critical resource for sustaining human life, similar to air and water (Havlicek, 2012). The importance of soil is slowly becoming recognised through policy, with, the government of Wales adopting soil carbon (C) as a national status indicator of progress under the Well-being of Future Generations (Wales) Act 2015 (Welsh Government, 2016).

The effectiveness of mesofauna as indicators of soil health at a national-scale is unclear, since contemporary surveys to date lack extensive detail on mesofauna trends. Of particular concern is whether differences amongst mesofauna communities are indicative of functional processes at the level of habitat or soil type. However, identifying mesofauna to species-level can present a significant impediment to researchers. Understanding if higher-level taxonomic groups of mesofauna can show consistent nationwide trends or highlight important environmental characteristics is needed to realise their application as effective bioindicators of soil quality.

Here, we present findings of mesofauna community metrics collected over a 2-year period as part of a nation-wide soil monitoring programme. Specifically, we aim to evaluate how mesofauna communities, including abundances of various groups of Acari and Collembola, differ amongst habitats and soils with diverse physicochemical properties across an intensively sampled national landscape including many diverging habitats. We hypothesise that mesofauna will be more abundant and diverse with decreasing disturbance and specifically, that biodiversity will be lowest in frequently disturbed agricultural soils and highest in less-disturbed sites like woodland soils. We also explore relationships between various mesofaunal groups and several, pre-selected soil physical and chemical parameters. We expect organic matter (positive), pH, (positive) and moisture content (negative) to be most strongly correlated with mesofauna abundances. The ultimate aim of the work was to establish whether important mesofauna groups effectively delineate habitat and environmental differences amongst sites for a national-scale assessment of soil quality.

2. Materials and methods

2.1. Study design

In Wales, UK, Glastir is a national-level agri-environment scheme, involving 4911 landowners with an area of 3263 km^2. It is the main way that the Welsh Government and the European Union (EU) pays for environmental goods and services. The Glastir Monitoring and Evaluation Programme (GMEP) was established to evaluate the scheme's effectiveness. GMEP collected evidence for six intended outcomes from the Glastir scheme; climate change mitigation, improvement to soil and water quality, a halt in the decline of biodiversity, improved woodland management and greater access to the welsh landscape and condition of historic features (Emmett and the GMEP Team, 2015). From 2013 to 2016, GMEP was the largest and most in-depth active soil monitoring programme measuring environmental state and change in the EU (Emmett and the GMEP Team, 2014). For a detailed description of GMEP see Supplementary Material.

As part of GMEP, survey teams travelled across Wales taking soil samples. The methodology used was established previously in the Countryside Survey (Emmett et al., 2010). Briefly, randomly allocated 1 km^2 squares, each containing 5 plot locations, were monitored across Wales. The habitat of each plot was classified using an Aggregate Vegetation Class (AVC) based on a high-level aggregation of vegetation types derived from plant species data in each plot. There are eight categories of AVC: Crops/weeds, Tall grassland/herb, Fertile grassland, Infertile grassland, Lowland wood, Upland wood, Moorland-grass mosaic, and Heath/bog (Bunce et al., 1999; for detailed description see Table S1). Soil type was categorised following the Main Group classifications of the National Soil Map (Avery, 1990; for detailed description see Table S2). In addition, an organic matter classification was used based on three loss-on-ignition (LOI) categories: mineral (0–8% LOI), humus-mineral (8–30% LOI), organo-mineral (30–60% LOI), and organic (60–100% LOI) as used in the Countryside Survey (Emmett et al., 2010).

Soils were sampled from late spring until early autumn in 2013 and 2014, with cores taken at each plot (8 cm depth, 4 cm diameter) for subsequent mesofauna extraction, co-located with cores for soil chemical and physical parameters. These were taken from 60×1 km^2 squares in 2013 and 90×1 km^2 in 2014 (Fig. 1), with 684 samples included in analyses. Cores were kept in cool boxes or fridges at 4 °C and then posted overnight to the Centre for Ecology and Hydrology, Lancaster for mesofauna extraction.

Soil physical and chemical characteristics were assessed on the additional soil cores from each site. We chose standard soil quality indicators including bulk density (g/cm^3), pH (measured in 0.01 M $CaCl_2$), volumetric water content (m^3/m^3), total phosphorus (P) (mg/kg), total C (%), total nitrogen (N) (%), and soil water repellency (as water drop penetration time in seconds). Mean values of each variable are presented in the Supplementary Material for each AVC (Table S3). These analyses were conducted following Countryside Survey protocols (Emmett et al., 2010).

2.2. Mesofauna extraction and identification

Mesofauna were extracted from soil cores using a Tullgren