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Field methodological approaches to investigate the short-term responses of enchytraeids to climate change

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Abstract

Research investigations on the effects of climate change on soil organisms face several methodological and practical difficulties. Experimental approaches to simulate the predicted changes in the climatic factors are usually costly and difficult to maintain, but also require a fair amount of background information of the selected study site and their animal communities. Available literature shows that most published work on climate change responses have focussed on nematodes and microarthropods (mites and springtails) and very few attempts have been made on enchytraeids. However, enchytraeid worms constitute excellent model organisms for climate change research. Besides their ecological importance in decomposition processes they are very sensitive to temperature and moisture changes, hence they quickly respond by altering their abundance and vertical distribution. Therefore, as part of the project REN2002-03224/GLO ('Warming and Peatland soils: effects on the community structure and carbon fluxes'), funded by the Spanish Ministry of Education, we have investigated the soil community composition and its seasonal changes in diversity and abundance in a Galician peatland (NW Spain) from 2003 to 2006. The field sampling survey has allowed a better knowledge of the community structure of this ecosystem and the identification of the main dominant faunal groups. Furthermore, the seasonal changes in population densities and/or vertical distribution of the different enchytraeid species and other soil fauna groups (microarthropods) have provided further insights into their survival strategies and will allow better predictions of the possible implications of climate change on the ecosystem functioning.

Keywords: manipulation experiments, soil fauna, peatlands, temperature, moisture

1. Introduction

Field measurements of climate-induced changes in the diversity, abundance and habitat distribution of soil biota are usually investigated using manipulative experiments. These experimental approaches involve alterations to ambient and soil temperatures (e.g. by heating the soil or the air above the ground) and rainfall inputs (e.g. by protecting the experimental units with removable roofs). Difficulties are usually associated with undesirable side effects on solar radiation, plant damage, or soil disturbance. In addition, some of the available devices are costly and difficult to maintain, especially in remote locations or with harsh environmental conditions. Therefore, the experimental design should take into account the effort-cost ratio and minimise unwanted effects to be representative of field conditions.

Peatland soils are estimated to store a third of all terrestrial carbon stocks and are very sensitive to climate change (e.g. Parton et al. 1987). The environmental conditions in these systems (continuous high precipitation; more than 30 days per annum with risk of frost; frequent cloudiness) have a strong influence on the composition and activities of their communities (plants and animals). The plant communities are dominated by non-vascular plants and among them mosses, in particular, play an important role. Regarding the fauna, enchytraeid worms can constitute up to 70 % of the total faunal biomass (Cragg 1961). Importantly, previous studies have shown that temperature increases have marked effects on their reproduction rates (Briones et al. 1997), with important implications for nutrient cycling (Briones et al. 1998a, b, Cole et al. 2000, Carrera et al. 2009), and CO_2 emissions to the atmosphere (Briones et al. 2004, Carrera et al. 2009). Therefore, enchytraeids constitute excellent model organisms for climate-change research.

In this contribution we present a brief overview of the methodologies commonly employed to investigate the effects of climate change on soil fauna and provide some practical considerations to be taken into account when planning this type of research in the field. The preliminary results gained from the ongoing research in a Galician peatland, as part of the project REN2002-03224/GLO ('Warming and Peatland soils: effects on the community structure and carbon fluxes') funded by the Spanish Ministry of Education, will provide a case study of the applicability of some of these methodological aspects in order to ensure good representation of the information gathered and validation of the conclusions derived.

2. Overview of the methodologies and experimental considerations

Two experimental approaches are commonly used to investigate the ecological responses of soil faunal populations to climate change in the field: (i) microclimatic manipulations, and (ii) monitoring changes associated with the natural climate variations of the selected studied sites. The former option includes latitudinal and altitudinal gradients, and other costly devices to heat the air and/or the soil and to alter rainfall inputs (Tab. 1), whereas the second approach does not involve any alteration of the ecosystem. As it can be seen in Tab. 1, most studies have been performed on microarthropods (mites and collembolans) and nematodes.

Enchytraeids play an important role in ecosystem functioning and are very sensitive to climate change (e.g. Briones et al. 2007). However, there is still a lack of information regarding the future of these organisms in different biomes in response to global warming and with respect to potential consequences of any alterations in the structure of their populations to biogeochemical cycling. This is the result of difficulties in manipulating these organisms across large geographic gradients and the complexity of their taxonomy (Wall et al. 2008).

Therefore, choosing the appropriate methodology to investigate the responses of enchytraeid populations to climate change in the field requires the consideration of several aspects:

(1) The spatial heterogeneity of the study site(s), including slope aspects, soil type, soil patchiness and vegetation cover, could greatly affect the results due to differences in the climatic conditions (e.g. north-south orientation of the area), and the type of food available to soil organisms (quantity and quality of organic matter, root biomass and exudates). Replication should assure the representativeness of the samples collected by taking into account the natural variation and the spatial autocorrelation associated with field studies.

(2) The local meteorological conditions (i.e. inter-annual variations of rainfall and temperature regimes) determine the structure of the animal communities. It is often assumed that the superimposed treatments are the main influential factors explaining the observed results. However, soil animals are very responsive to moisture and temperature changes and therefore, sparse sampling collections could give misleading information. For example, an exceptionally dry or very wet year could alter densities of organisms and thus overestimate the effects of the treatments.

(3) Soil heating versus air heating: Both approaches could provide interesting results as long as other components of the ecosystem are not damaged and other environmental factors are not affected. For example, overhead radiators (Harte et al. 1996) can be useful in heating the air above the ground but could also result in undesired effects on the vegetation; furthermore, they are costly and difficult to maintain in remote places; closed chambers and cloches can greatly increase air temperatures inside and also lead to condensation problems; removable plastic covers (roofs and curtains) are useful in manipulating rainfall inputs but could affect solar radiation and litter fall inputs; buried heating cables also result in profound alterations of the soil profile.

(4) Short-term versus long-term responses: The duration of the investigation and the frequency of sampling have important implications for the validity of the results. Due to the high sensitivity of the soil animals, intensive samplings over a year or two give more valuable information than few sampling collections distributed over several years. However, in climate change studies long-term responses are preferred to build better model predictions and this can only be achieved with long monitoring studies or when the site under investigation has a long history of scientific research.

(5) Depth and habitat distribution: Although enchytraeid populations usually concentrate in the top soil layers, certain species are known to prefer deeper horizons, such as *Fridericia profundicola* Dózsa-Farkas, 1991. More importantly, they are able to move down the soil profile to avoid adverse conditions at the surface (Springett et al. 1970, Briones et al. 1997). This survival strategy should be taken into account when analysing their responses to climate manipulations and it should be included in the sampling design.

(6) Species responses versus population responses: Similar to vertical distribution soil animal responses to changes in temperature and moisture regimes are highly specific and both these environmental factors can have either positive or negative effects on the population sizes of the different species (e.g. Briones et al. 1997).

Tab. 1 Field climate change studies using soil mesofauna with notes of the employed methods and the investigated organisms.

Author/Year	Ecosystem type	Manipulation	Soil organisms
Sohlenius & Wasilewksa 1984	Boreal forest	Irrigation (sprinklers 50 cm above the ground)	Nematodes
Kennedy 1994	Tundra	Temperature (passive cloches)	Mites and collembolans
Coulson et al. 1996	Tundra and heathland	Temperature (polythene tents)	Oribatid mites and collembolans
Harte et al. 1996	Subalpine meadow	Air heating (IR radiators 2.6 m above the plots)	Macroarthropods, mites, collembolans and nematodes
Briones et al. 1997	Moorland	Altitudinal gradient and rainfall manipulations (rainwater collection and distribution with pipes)	Enchytraeids
Webb et al. 1998	Tundra	Temperature (polythene dome-shaped tents)	Oribatid mites
O'Lear & Blair 1999	Grassland	Irrigation transect and core transplanting	Mites
Todd et al. 1999	Grassland	Irrigation transect and core transplanting	Nematodes
Ruess et al. 1999a	Tundra	Temperature (passive greenhouses)	Nematodes
Ruess et al. 1999b	Tundra	Temperature (passive greenhouses)	Microorganisms and nematodes
Bakonyi & Nagy 2000	Semiarid grassland	Temperature (wooden walls painted black or white plus shading) and rainfall manipulations (northern-southern orientation plus transparent plastic plates coupled with a plastic pipe system)	Nematodes
Pflug & Wolters 2001	Coniferous forest	Rainfall (clear Perspex roofing)	Collembolans
Convey et al. 2002	Tundra	UV (UV filtering materials)	Diptera, mites and collembolans
Ferguson & Joly 2002	Deciduous forest	Moisture (250 ml of water added to each experimental unit (box))	Collembolans

Tab. 1 cont.

Author/Year	**Ecosystem type**	**Manipulation**	**Soil organisms**
Lindberg et al. 2002	Boreal forest	Rainfall (transparent plastic roofs placed 1–1.5 m above ground) and irrigation (sprinklers placed 20 cm above the ground)	Mites, collembolans, enchytraeids
Sinclair 2002	Tundra	Temperature (passive cloches)	Mites and collembolans
Lindberg & Persson 2004	Boreal forest	Irrigation	Mites and collembolans
Hoschitz & Kauffmann 2004	Tundra	Altitudinal gradient	Nematodes
Taylor et al. 2004	Coniferous forest	Rainfall (transparent plastic roofs placed at 80 cm above the ground) and Irrigation (rainwater collection and distribution with pipes)	Mites, collembolans, enchytraeids and nematodes
Sjursen et al. 2005	Tundra	Temperature (Altitudinal gradient and Open Top Chambers)	Mites and collembolans
Taylor & Wolters 2005	Coniferous and deciduous forest	Rainfall (transparent plastic roofs placed at 80 cm above the ground)	Oribatid mites
Tsiafouli et al. 2005	Coniferous forest	Rainfall (transparent plastic roofs placed at 80 cm above the ground)	Mites and collembolans
Haimi et al. 2005	Boreal forest	Closed chambers to manipulate CO_2 and temperature levels	Mites, collembolans and enchytraeids
Dollery et al. 2006	Heathland	Temperature (Open Top Chambers and snowmelt transect)	Mites, collembolans, enchytraeids, aphids, hymenoptera, coleopteran and spiders

Tab. 1 cont.

Author/Year	**Ecosystem type**	**Manipulation**	**Soil organisms**
McGeoch et al. 2006	*Azorella selago*	Temperature and rainfall (cloches) and light (green shade cloth covering the whole plant)	Mites and collembolans
Bakonyi et al. 2007	Deciduous forest	Temperature (IR-reflective curtain) and rainfall (polyethylene plastic which automatically covered the plots when any rain was detected)	Nematodes
Cassagne et al. 2008	Coniferous forest	Altitudinal gradient	Mites, collembolans, enchytraeids, earthworms, nematodes, gasteropods and macroarthropods
Maraldo et al. 2008	Heathland	Temperature (night warming using a IR-reflective curtain) and rainfall (transparent waterproof covers which automatically covered the plots during rainy events)	Enchytraeids
Bokhorst et al. 2008	Tundra	Temperature and moisture (Open Top Chambers)	Mites and collembolans
Briones et al. 2009	Grassland	Soil artificial heating (metal mesh)	Earthworms, enchytraeids, mites and collembolans

3. Case study: a Galician peatland (NW Spain)

Galicia can be defined as a transitional biogeographical region and contains exceptional habitats such as the upland peatlands and, in particular, blanket bogs. Bogs are common ecosystems in Galicia and represent the most important natural wetland reserves of the Iberian Peninsula. Unlike other European countries, these ecosystems have a limited presence in Spain and they survive in mountain areas where cold temperatures and continuous moisture supply allow their presence (Martinez Cortizas & García-Rodeja 2001).

In the 'Natura 2000 network' the Natural Habitat Sierra of Xistral (within the province of Lugo, NW Spain) is listed among the large habitats (A-type). This region has been intensively mapped which has resulted in the elaboration of a biogeographical synopsis of the Sierra together with an inventory and an evaluation of the habitats present (Izco & Ramil-Rego 2001). Among the bogs present in the Sierra of Xistral the 'upland active blanket bogs' are of particular importance as they are considered to be 'Prioritary Natural Habitats' (Code 7130), due to their relict nature and for being the highest in Europe (Ramil-Rego et al. 1996). The term 'active' refers to the presence of an important percentage of peat-forming vegetation.

There is very little information on the soil faunal communities of the area. The only available unpublished report (Izco et al. 1996) is incomplete but shows that invertebrates are well represented, both in abundance and number of endemic species. This taxonomic survey included flatworms (3 families), molluscs (5 families), annelids (5 families) and a very detailed description of the arthropod diversity. A better characterisation of the soil fauna communities is evidently needed, not only to improve the management of this protected area and to develop future conservation policies, but also to plan and perform climate research investigations.

A research project funded by the Spanish Ministry of Education (Ref. REN2002-03224/GLO) has allowed the collection of soil samples to determine the structure of the soil communities and the effect of projected increased temperatures on the soil populations and carbon fluxes. The field survey consisted of two samplings per year (winter and summer) from 2003 to 2006. We chose these two sampling dates because they represent two extremes in the weather conditions which also determine the vegetation growth periods in the area. Although the Natural Habitat lacks automatic weather stations (AWS), some climate information can be obtained from the work by Carballeira et al. (1983). Accordingly, the mean annual temperature values range from 10.2 °C at Fraga Vella (710 m altitude) and 14 °C at Outeiro de Rei (414 m altitude), the two closest AWS stations. Climate in this area is characterised by mild temperatures, so that for an average altitude of 700 m annual values are around 9.4 °C, ranging from 5.8 °C in winter to 13.9 °C in summer.

On each sampling occasion fifteen soil cores (10 cm diameter x 22 cm deep) were collected and the top 10 cm sliced horizontally into five 2 cm layers (0–2, 2–4, 4–6, 6–8 and 8–10 cm) to account for seasonal differences in the vertical distribution of the soil organisms. From each layer three subsamples were taken, one for enchytraeid extraction (20 cm^2 approximately), one for microarthropods (40 cm^2 approximately) and one for chemical analyses of the soil (%moisture, %C and %N). In total there were 150 replicate samples for animal extractions and 75 for determining soil characteristics.

Preliminary results from the taxonomical identifications show that among the annelids Lumbricidae are poorly represented. In contrast, higher enchytraeid diversity than anticipated was observed, and up to 11 species have been identified, with *Cognettia sphagnetorum* (Vejdovsky, 1878) as the dominant species (Carrera et al. unpublished data). Population densities and vertical distribution of the different species mimicked the seasonal variability of the climatic conditions and corroborate the strong sensitivity of enchytraeids to temperature and moisture regimes. In agreement with previous studies (Briones et al. 1997) the response was species-dependent: whereas some species were able to migrate downwards when the surface layers became drier (e.g. *Cognettia sphagnetorum*), others were not able to withstand the adverse conditions and their populations were dramatically reduced (e.g. *Cernosvitoviella atrata*). Consequently, this resulted in alterations of the community structure in response to changing environmental conditions.

Microarthropod diversity was also extremely high in the study area, and although their populations also showed seasonal variations, they did not seem to alter their vertical distribution in response to changes in the environmental conditions. Recent studies have shown that warmer temperatures lead not only to considerable decreases in the abundance of these organisms but also to diversity increases and to changes in their trophic structure (Briones et al. 2009).

Interestingly, %C and %N decreased gradually and significantly during the first three years of investigation from initial values of 44 % and 2 %, respectively. The minimum values were recorded in June 2005 (C =18.5 %; N = 0.82 %) when the ambient temperatures reached 30 ºC at the time of the sampling. This hot summer also resulted in a severe soil drought, with moisture values being less than 60 % in the top 4 cm. Previous research has shown that increasing photosynthetic activity under warmer conditions could lead to greater plant growth and nutrient uptake (e.g. Ineson et al. 1998) and consequently, may lead to changes in soil chemistry.

4. Conclusions

Previous knowledge of the proposed studied area is needed prior to carry out any investigation or experimental work. This background information should take into consideration not only the diversity and seasonal changes of the soil faunal communities, but also the meteorological conditions at the time of sampling; the geographical characteristics of the area (slope, northern-southern orientation) and of the soil profile (depth of the rooting system, and incorporation of the soil organic matter); chemical characteristics (%C, %N, pH, metals, cations, etc.); and the vegetation cycles, which could have a strong influence on the composition and structure of the soil communities.

Enchytraeids are suitable organisms for climate change research, especially in acidic organic soils where they constitute the dominant faunal group in terms of biomass. Their burrowing and feeding activities play an important role in soil organic matter decomposition and nutrient cycling, which can be considered equivalent to that of earthworms in more neutral-alkaline soils. Their proved sensitivity to temperature and moisture conditions makes them suitable as potential biological indicators of climate change and consequently, the enchytraeids should be routinely monitored in selected vulnerable systems such as peatlands (Briones et al. 2007). Long term monitoring of their abundances, species composition and vertical distribution in response to changes in soil moisture, ambient and soil temperature and vegetation could provide scientifically reliable evidence of their status (conservation and deterioration). This information would be very valuable for understanding the ecological implications of these changes under future climate scenarios.

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