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Geochemical and biotic factors influencing the diversity and distribution of soil microfauna across ice-free coastal habitats in Victoria Land, Antarctica

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ABSTRACT

Soils in Antarctica support simple but unique biological assemblages in one of the most extreme terrestrial habitats on Earth. Among terrestrial fauna, microscopic invertebrates (nematodes, rotifers and tardigrades) are the most abundant and diverse, but the paucity of surveys still limits a more thorough understanding of their diversity and distribution patterns. To address this gap in knowledge, we conducted a survey across soil environments with differing biogeochemical characteristics (i.e., fellfields, moss communities, wetlands, and ornithogenic soils) at Edmonson Point. Our primary objective was to identify local diversity and drivers of distribution patterns of soil microfauna assemblages at the species level for all phyla. Presence of a broad range of soil habitats supported abundant and diverse microfauna of 24 species, including 18 rotifers, 4 nematodes, and 2 tardigrades. While nematode and tardigrade fauna were generally consistent with previous reports in the region, rotifers consisted mostly of bdelloids, newly-recorded and likely endemic species. Bdelloid rotifers were generally the most abundant followed by nematodes and tardigrades in similar numbers, with very patchy distributions and only nematodes found across all soil habitats. The type of soil environment was the most significant predictor of species distributions, with the richest and most abundant microfauna found in moist soils associated with cryptogamic vegetation and the poorest in dry fellfields and ornithogenic soils. Species distributions were also highly variable within particular environments and were related primarily to moisture, nutrients and organic matter, but availability and quality of food resources was the major underlying driver. Given the exceptionally wide range of terrestrial environments, Edmonson Point represents one of the most important biodiversity hot-spots for microfauna in the Ross Sea region, emphasizing its outstanding ecological importance and conservation value.

1. Introduction

The Antarctic, as a predominantly ice-covered polar region, provides exceptionally few habitats for terrestrial organisms. Of the continent's 14 million km^2 surface area less than 0.35% remains seasonally ice and snow free (Bockheim, 2015) and is highly fragmented. Because the continent is centred around the southern pole and surrounded by the vastness of the Southern Ocean, it remains isolated from the influence of other landmasses. Soils of the ice-free areas are one of the most extreme environments on Earth – they are thus very poorly developed, lack cohesion and structural development and experience year-round low temperatures, low moisture, seasonal day-length

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variation, and daily freeze-thaw cycles (Bockheim, 2015; Campbell and Claridge, 1987). Despite the harshness, these soils have been increasingly recognized as habitat for simple but unique biological assemblages with flora limited to cryptogams and fauna to micro-invertebrates (Adams et al., 2006; Convey et al., 2014; Wall, 2005).

Among terrestrial microfauna, nematodes, rotifers and tardigrades are the most abundant, diverse and widely distributed (Adams et al., 2006; Velasco-Castrillón et al., 2014a). The past few decades of research have produced an impressive assessment of the origin and ecology (including relation to environmental properties, diversity, and distribution patterns) of their assemblages (Adams et al., 2006, 2014; Barrett et al., 2006b; Iakovenko et al., 2015; Wall, 2007; Velasco-Castrillón et al., 2014a, 2014c). For instance, it is well established that they occur in all types of terrestrial habitats along the coastline, but also on isolated inland nunataks and even on peaks of major mountain ranges (Adams et al., 2014; Convey and McInnes, 2005; Sohlenius et al., 2004), and display highly heterogeneous spatial distributional patterns (Freckman and Virginia, 1997; Sohlenius and Boström, 2008; Wall, 2007). Another important finding is the uniqueness of the microfauna as being comprised mainly of endemic rather than cosmopolitan species (Convey et al., 2008; Pugh and Convey, 2008), suggesting their impressive ability to survive multiple glaciations in potentially isolated ice-free refugia. This phenomenon appears to apply to all the microfaunal phyla, including nematodes (Andrássy, 1998, 2008; Maslen and Convey, 2006; Velasco-Castrillón and Stevens, 2014), rotifers (Iakovenko et al., 2015; Velasco-Castrillón et al., 2014b) and tardigrades (Convey and McInnes, 2005; Czechowski et al., 2012).

Among the ice-free areas, the McMurdo Dry Valleys in southern Victoria Land have received the most scientific attention, especially nematodes (Adams et al., 2006, 2014). Rotifers and tardigrades, while acknowledged, rarely have been addressed beyond a phylum level (but see Guidetti et al., 2014; Iakovenko et al., 2015; Smykla et al., 2010, 2012) leaving a significant gap in knowledge of microfaunal species diversity, distribution and role in respective habitats. Although the McMurdo Dry Valleys provide for exceptionally unique extreme habitats, they are not representative of coastal ice-free areas (Raymond et al., 2013; Sinclair, 2001). In comparison with the Dry Valleys, the coastal areas experience warmer temperatures and higher availability of water resulting in more productive and hospitable habitats. In addition, they are prone to inputs from marine vertebrates (i.e., seals, penguins and flying birds) that likely provide for more active soil processes and richer biogeochemistry (Barrett et al., 2006a; Cannone et al., 2008; Smykla et al., 2015). Overall, it is reasonable to expect that species composition, diversity and distribution patterns of soil microfauna, and underlying environmental drivers are different from those of the Dry Valleys.

Here, we present analysis of soil microfauna from Edmonson Point, Wood Bay, Northern Victoria Land (74°20′S, 165°08′E; Fig. S1). We selected this specific site because it is one of the best examples of coastal ice-free ecosystems in northern Victoria Land. Moreover, it is characterized by a wide range of terrestrial environments, abundance of water, and influx of marine- and bird-derived organic matter. Thus, it is a useful model site for understanding of environmental processes and changes of coastal ice-free ecosystems in Antarctica (Harris and Grant, 2003; Smykla et al., 2015). The outstanding nature of the Edmonson Point terrestrial ecosystems has already resulted in studies on soil properties and geochemistry (e.g., Bargagli et al., 1999; Cannone et al., 2008; Malandrino et al., 2009; Smykla et al., 2015), diversity and distribution patterns of bryophytes and lichens (Cannone, 2006; Castello, 2003; Lewis Smith, 1999; Smykla et al., 2011), algae and cyanobacteria (Cavacini and Fumanti, 2005), bacteria (Gesheva, 2009), microfungi (Onofri et al., 2000; Tosi et al., 2005) and arthropods (Caruso and Bargagli, 2007; Caruso et al., 2007; Smykla et al., 2010), and impacts of climate change on ecosystem processes (Bargagli et al., 1997; Tosi et al., 2005), but not on terrestrial microfauna.

To address the general lack of information about terrestrial microfaunal assemblages in Antarctic coastal habitats, we investigated and sampled several different localities across the Ross Sea area, including Edmonson Point (see Iakovenko et al., 2015; Smykla et al., 2011, 2015). Our objective was to characterize the spatial variability in soil characteristics and biodiversity across multiple habitats (i.e., bare fellfields, moss-dominated, wetlands, and influenced by penguin guano). We also quantified co-variation among soil development, biogeochemistry, and biotic assemblages to identify suitable or unsuitable habitats (*sensu* Freckman and Virginia, 1998) and existence of local and regional biodiversity and endemism hot-spots that might be important for soil biota conservation. Our goal was to characterize microfaunal assemblages at the species level for all phyla (nematodes, rotifers and tardigrades) in soil habitats to determine their local diversity and distribution patterns. We expected that the presence of a broad range of soil habitats would support abundant assemblages with high species richness across all phyla. We also hypothesized that assemblages would differ among habitats with differences driven predominantly by abiotic factors (e.g., soil hydrology and marine/bird-derived organic influx), but because of the expected high species abundance and richness, the biotic interactions would be equally important.

2. Materials and methods

2.1. Study area

Edmonson Point (74°20′S, 165°08′E) is a coastal ice-free area located on the west coast of the Ross Sea, northern Victoria Land, continental Antarctica (Fig. S1). The area encompasses ~6 km^2 and is one of the largest non-mountainous, coastal ice-free areas in Victoria Land. As in most of the Antarctic ice-free terrestrial ecosystems, low temperatures and aridity are the main limiting factors for life. However, owing to a relatively mild climate, abundance of melt-water and bird-derived nutrients, Edmonson Point has an exceptionally wide range of limno-terrestrial environments and a relatively rich biota and thus, well suited for studies on development and diversity of coastal ice-free ecosystems in Antarctica. Detailed descriptions of these ecosystems, and factors affecting their development and diversity of their biotic assemblages have been published (e.g., Bargagli et al., 1997; Harris and Grant, 2003; Malandrino et al., 2009; Smykla et al., 2015; Tosi et al., 2005).

2.2. Field survey and sampling

The field survey and soil sampling follows the methods of Smykla et al. (2015). Briefly, during the Antarctic summers of 2003/04 and 2004/05, we collected 42 soil samples from a range of representative terrestrial environments, including bare fellfields (dry and unvegetated areas), moss communities, wetlands (wet depressions covered with algal and cyanobacterial mats, supplied with water draining from the melting permafrost and/or snowmelt) and ornithogenic soils from penguin colonies (Fig. 2, Smykla et al., 2015). Soil samples were collected from the upper soil layer (0–10 cm deep) (Barrett et al., 2004, 2006a; Courtright et al., 2001; Porazinska et al., 2002a) using a sterile scoop, then placed into sterile polyethylene bags (Whirl-Pak®). Sampled quantities were guided by a compromise between avoiding disturbance of the soil surface and obtaining enough material for parallel analyses of soil biota and biogeochemistry. To obtain homogeneous material for different analyses, each sample was gently mixed and split into separate bags at the time of collection. Gravel larger than ~5 mm diameter was removed from the samples in the field. In moss communities, the samples were collected directly at and/or among moss cushions, and to limit their disturbance, they were not removed from sampling sites.

Within a few hours after collection, all samples were transported to the Italian Station Mario Zucchelli at Terra Nova Bay and gradually cooled/frozen (from 3° to −20 °C) within 48 h. The samples were then shipped and stored in a frozen state for processing and analyses.