Diversity and distribution of tardigrades in soils of Edmonson Point (Northern Victoria Land, continental Antarctica)

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Abstract

This work contributes to the knowledge on distribution, diversity and ecology of the Antarctic soil biota. Different soil habitats from several ice-free coastal sites were sampled along the Victoria Land across 7° of latitude from 71° to 78°S during five austral summer seasons between 2003/04 and 2011/12. In this paper we report preliminary data on soil tardigrades (water bears) from Edmondson Point, Northern Victoria Land. Tardigrades were found to be present in 23 of the 41 examined soil samples (56%). Their presence was associated exclusively with soil samples collected from bryophytes communities and under cyanobacterial mats, whereas they were completely absent in fellfield and ornithogenic soils. Tardigrades were least numerous among all soil micrometazoans, their abundance in the positive samples was very variable and ranged from 3 to 1824 individuals per 100 g of soil DW. High water content seemed to be the major factor determining occurrence of tardigrades in the soils investigated. On the other hand low water content and toxic compounds from penguin guano seemed to act as a strong constraint on their existence in the Antarctic soils. Taxonomic evaluation of the extracted tardigrades revealed presence of only two species belonging to class Eutardigrada: *Acutuncus antarcticus* (Richters, 1904) and *Milnesium antarcticum* Tumanov, 2006. While *A. antarcticus* has already been reported previously as the most widespread and abundant tardigrade across the Victoria Land, the information on *M. antarcticum* is novel, both for Victoria Land and the continental Antarctica.

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Key words: Tardigrada, Metazoa, biodiversity, soil biota, soil properties, Antarctic soils

Introduction

In the continental Antarctic, soil habitats belong to the most physically and chemically demanding environments on Earth and were once considered to be adverse to all life. Despite being exposed to severe environmental stresses, particularly freezing and desiccation, they provide conditions supporting the existence of numerous biota. With no vascular plants, biotic communities are dominated by bryophytes, lichens and microbiota such as algae, cyanobacteria, bacteria and microfungi, and microfaunal taxa consisting of mites, springtails, rotifers, nematodes, tardigrades and protozoans (Adams et al. 2006, Smykla et al. 2010). Compared with soil habitats in other parts of the world, the diversity of the Antarctic soil biotic communities is very low. Being taxonomically and functionally simple, they are regarded as bioindicators of environmental change. Increased recognition that climate change and human induced perturbations have substantial impact and will profoundly modify the Antarctic soil habitats makes the need of investigations on their biodiversity especially critical (Wall 2005).

Tardigrades, commonly known as water bears, are microscopic metazoans (typically 50-1200 µm in size) closely related to arthropods and onychophorans. They are distributed across all continents, oceans and seas, inhabiting virtually all terrestrial, freshwater and marine ecosystems. In fact, they are probably the most widely distributed and least known invertebrates (Guidetti et al., in press). In extreme environments, such as those in the continental Antarctica, tardigrades usually occur with rotifers, nematodes and protozoans and constitute a major component of biotic communities in all aquatic, moss and soil habitats (Porazinska et al. 2004, Adams et al. 2006, Sohlenius et Boström 2008), in some cases, they may even constitute the only metoazoan element present in an ecosystem (Convey et McInnes 2005). Although widely distributed and being an important element of extreme ecosystems, tardigrades are little known and for a long time were mostly neglected. Only in recent years has there been an increasing interest in assessment of their diversity and the factors determining their distribution (*see* Tradigrada Newsletter – References, Web sources).

The presence of tardigrades in the Victoria Land and elsewhere in the Ross Sea sector of continental Antarctica was noted during the earliest scientific explorations of this area conducted by the British Antarctic Expeditions at the beginning of 20th century (*e.g.* Richters 1909, Murray 1910). Since then, a few opportunistic collections, predominantly in Southern Victoria Land have been made, but until recently there were only very few published reports that included data on the tardigrade fauna of this Antarctic region (Adams et al. 2006). It was not until the 1990s that Victoria Land tardigrades received more attention, and their taxonomic evaluation was conducted by Italian researchers who described several new tardigrade species found in various limnoterrestrial environments (*e.g.* Pilato et Binda 1999, Binda et Pilato 2000). However, until now the area of the Victoria Land has not been investigated uniformly, as the majority of the investigations have focused on the areas of McMurdo Dry Valleys and the Ross Island in Southern Victoria Land with little information available from Northern Victoria Land. Moreover, most reports did not identify tardigrade specimens beyond genus or identifications were done by non-specialist and have not been subjected to critical taxonomic re-evaluation. Thus, reliable knowledge on diversity of Victoria Land tardigrades is extremely limited and distribution data are restricted to very few specific collection localities (Adams et al. 2006).

To address the lack of faunistic and ecological work on the Antarctic tardigrades, we examined tardigrade specimens extracted from soil and vegetation samples collected from several localities along the Victoria Land coast during five austral summer seasons between 2003/04 and 2011/12. The examined samples originated from the interdisciplinary research project, conducted by the senior author specify. The aim of this project was to understand the ecological role of current and relict penguin colonies in the Antarctic terrestrial ecosystems, in particular their influence on vegetation and soil biota diversity and distribution patterns, which is our contribution to the Scientific Committee on Antarctic Research (SCAR) program: Evolution and Biodiversity in the Antarctic (EBA). Exploring variety of terrestrial ecosystems across a wide range of latitudes along the Victoria Land coast also significantly contributes to the SCAR program: Latitudinal Gradient Project (LGP).

In previous papers we have provided data on occurrence, diversity and distribution of the Victoria Land lichens (Smykla et al. 2011) and preliminary data on Edmondson Point soil rotifers (Smykla et al. 2010). Here, we further utilize soil micrometazoan samples and provide baseline data on the taxonomic composition and abundance of soil dwelling tardigrades from the Edmondson Point area (the Northern Victoria Land). More detailed information on species composition and distribution of tardigrades as well as other soil invertebrates in relation to local environmental gradients (soil properties) and the latitudinal gradient along the Victoria Land will be given in forthcoming papers.

Material and Methods

Study area

Edmonson Point (74°20'S, 165°08'E) is located in Wood Bay on the western coast of the Ross Sea (Northern Victoria Land, continental Antarctica) (Fig. 1). Being 1.79 km^2 in area, it is one of the most extensive non-mountainous, coastal ice-free sites in Northern Victoria Land. The landscape of Edmonson Point was considerably modified by glacial and periglacial activity, resulting in a mosaic of hills (up to 300 m high), knolls and moraines, separated by small valleys with several ephemeral small melt-water streams, ponds and a few larger lakes. Such a range of freshwater habitats is unusual and the stream network is the most extensive in the Victoria Land. Most of the area, however, is extremely dry with the ground covered by salt encrustations. The ground is dark-colored and consists of volcanic materials (scoria, pumice, tuff, lavas) which originated from past volcanic activity of the Mount Melbourne. The soil is coarse-textured (fine gravel or coarse sand) with a very low proportion of silt and clay. It is generally poor in nutrients, however due to the presence of breeding birds and abandoned penguin colonies, concentrations of nitrogen and phosphate can reach relatively high levels. The climate is typical of coastal areas in continental Antarctic, with low temperatures (average monthly ranging from −5°/−2°C in January to −30°/−26°C in

August), low humidity and low precipitation (100–200 mm). However, Edmonson Point is well sheltered from local katabatic winds and its climate is milder than that of neighboring areas where the temperature during summer ranges between −15° and +5°C (Harris et Grant 2003).

As a result of the relatively mild climate, the abundance of melt water and bird-derived nutrients, Edmonson Point is characterized by a wide range of terrestrial habitats and relatively diverse biota. Flora of this area is entirely cryptogamic, consisting mainly of bryophytes (six mosses and one liverwort species) and lichens (*ca.* 30 species). A wide range of freshwater habitats account for the highest diversity of algae in Victoria Land, with over 120 species recorded there. The terrestrial fauna is limited to soil protozoans, rotifers, nematodes, tardigrades, springtails and mites (Harris et Grant 2003, Smykla et al. 2010). Because of all these outstanding ecological features, Edmonson Point provides an exceptional site for research on biotic communities and therefore has been designated as an Antarctic Specially Protected Area (ASPA) No. 165.

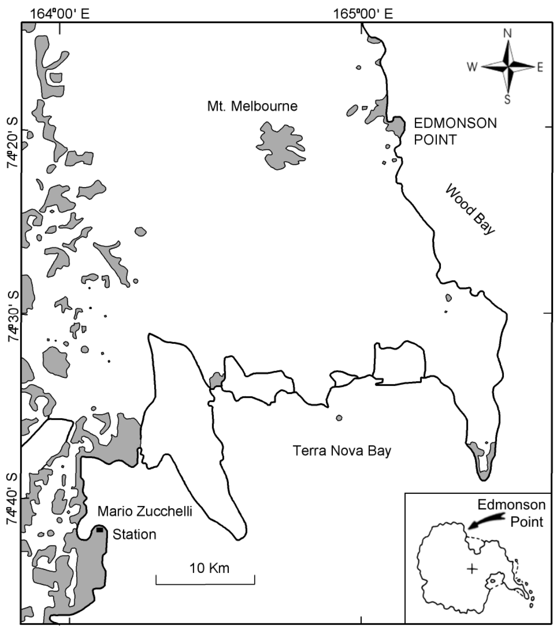

Fig. 1. Map showing the location of the Edmonson Point in the Northern Victoria Land. Insets shows the position of the Edmonson Point in the Antarctic. Gray color indicates ice-free areas.

Soil sampling and processing

Several ice-free coastal sites were surveyed and sampled along the Victoria Land across 7° of latitude from 71° to 78°S during five austral summer seasons between 2003/04 and 2011/12. For the purpose of this work, we utilize soil samples collected from Edmondson Point (Fig. 1). The Edmondson Point area was surveyed and sampled during two consecutive austral summers: 2003/04 and

2004/05. Sampling locations represented a range of soil habitats with a diversity of soil physical and chemical characteristics, including soils of dry and bare fellfields, bryophyte communities, seepage areas with cyanobacterial mats and active and relict penguin colonies (Smykla et al. 2010). The samples were collected from the upper layer of soil (0-10 cm deep) using a sterile scoop, then placed in a sterile polyethylene bag (Whirl-Pack®) and mixed thoroughly. Within several hours of collecting, all samples were transported to the laboratories of the Italian Station "*Mario Zucchelli*" at the Terra Nova Bay. Then, they were frozen by reducing temperature over a 48-h period from 1 to -20°C. The frozen samples were then shipped to Poland for processing.

In the laboratory, forty-one soil samples were analyzed to determine their physical and chemical properties, as well as soil invertebrate species composition. The invertebrates were extracted from sub-samples of *ca*. 100 g of soil by wet-sieving followed by centrifugation (Freckman et Virginia 1993). Extracted invertebrates were counted and identified to species based on morphological features. Prior to identification, tardigrades were fixed in ethanol and then mounted on microscopic slides in Hoyer's medium. Species were identified using the key to the World Tardigrada (Ramazzotti et Maucci 1983), and the original descriptions and re-descriptions from the current literature (Dastych 1991, Pilato et Binda 1997, Tumanov 2006). Tardigrade microslides were stored in the collection of the last author, at the Department of Animal Taxonomy and Ecology, A. Mickiewicz University, Poznań, Poland.

Results and Discussion

Overall, the investigated soil biotic communities were very abundant and relatively complex. They consisted of bacteria, cyanobacteria, algae, diatoms, microfungi, protozoans, nematodes, rotifers, tardigrades, mites and springtails. In our preliminary account (Smykla et al. 2010), we reported from the Edmondson Point soils the occurrence of 19 invertebrate taxa, including nine rotifers, four nematodes, five oribatid mites and one springtail. However, the presented list of taxa was incomplete as it was based only on examination of a limited number of samples. Furthermore, tardigrades, protozoans and some species of rotifers and mites were still under study for their identification. Rotifers and mites not corresponding to any of the known descriptions were recorded as genera and are considered potentially new for science. Their detailed morphological descriptions and critical taxonomical evaluations will be published elsewhere.

Tardigrades were found in 23 of the 41 examined soil samples (56%) collected from Edmondson Point. They were present exclusively in soil samples collected from bryophyte communities and under cyanobacterial mats, but were completely absent in soils from barren fellfields and from active and relic penguin colonies (Fig. 2). The Edmondson Point fellfield and ornithogenic soils, compared to the soils collected under cyanobacterial mats and from bryophyte communities, had very low water content (Smykla et al. 2010). Exposed and dry felfiled soils from McMurdo Dry Valleys also contained very low or no densities of tardigrades (Courtright et al. 2001, Gooseff et al. 2003). Tardigrades occurred exclusively in more favorable habitats with higher soil moisture and lower salinity (Courtright et al. 2001, Simmons et al. 2009). Because soil tardigrades inhabit soil particle water films, it is not surprising that soil moisture appears to be one of the most important factors determining their distribution in the Antarctic soils.

Absence of tardigrades in ornithogenic soils, regardless of their low water content, is most likely also related to strong inhibition effects of toxic substances form penguin excrements. Similarly to our results, previous studies (Porazinska et al. 2002, Sohlenius et Bostrom 2008) have also reported absence or only very low numbers of tardigrades in ornithogenic soils although the investigated soils had relatively high water content. It is well known that within penguin colonies, high concentrations of ammonium and other ornithogenic compounds act as a constraint on the existence of biota (Mataloni et Tell 2002, Smykla et al. 2007). Thus, life in nutrient-rich and saline soils of penguin colonies requires special adaptations that only a few invertebrate species have developed (Porazinska et al. 2002). Although tardigrades are known as one of the most hardy micrometazoans inhabiting even the most extreme environments (Bertolani et al. 2004, Guidetti et al. 2011), it seems that in the Antarctic soils, both low water content and toxic compounds from penguin guano act as a strong constraint on their existence.

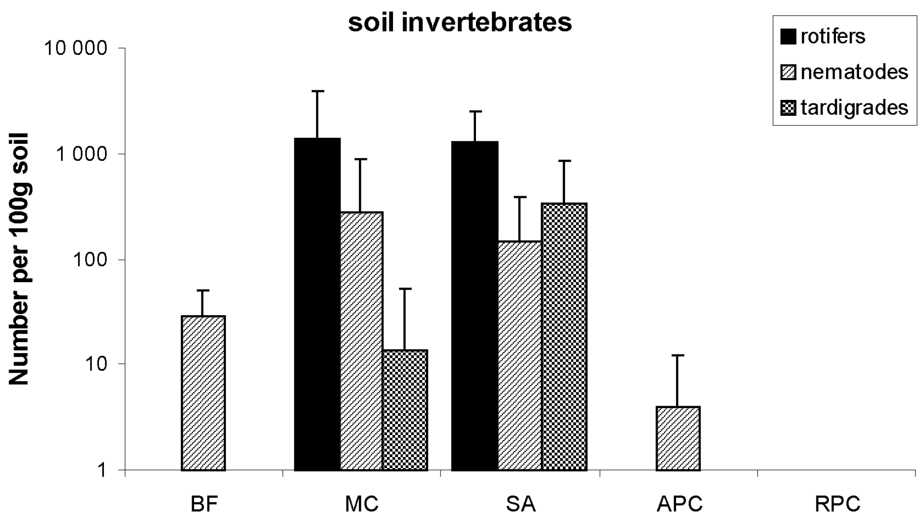

Fig. 2. Average number ± SD of invertebrates of particular taxa from soil habitats per 100 g of soil (after Smykla et al. 2010). Data presented in the logarithmic scale. Abbreviations indicate: BF – barren fellfields, MC – moss communities, SA – seepage areas, APC –active penguin colonies, RPC – relict penguin colonies.

In the investigated soils, tardigrades were least numerous among all soil micrometazoans (Fig. 2). Their abundance in the positive samples (*i.e.* samples collected from bryophyte communities and under cyanobacterial mats) was very variable and ranged from 3 to 1824 individuals per 100 g of soil. Several studies have reported the presence and number of tardigrades (albeit typically not identified to species) across Victoria Land and nearby islands (Adams et al. 2006). Similarly to our data, the results of these studies indicate that tardigrades are usually the least frequent and least numerous soil micrometazoans. Nevertheless, their abundance is usually very variable and in some Antarctic soils, tardigrades may be the dominant or even the only metazoans present (Convey et McInnes 2005). The highest abundance of over 4,600 tardigrades per 100 g of dry sediment was recorded in cryoconite holes (Porazinska et al. 2004). However, despite the apparent similarities between cryoconite sediment and soil, water in cryoconite holes is not a limiting factor and their biotic communities consisted of species typical of lake and stream sediment (Adams et al. 2006). In soils, tardigrade abundance is usually much lower, *e.g.* 0-49.8 (Porazinska et al. 2002), 0-7.2 (Gooseff et al. 2003) or 0-0.08 (Courtright et al. 2001) individuals per 100 g of dry soil. Compared with these results, the numbers of tardigrades recorded in our study are relatively high. Their high abundance can probably be explained by relatively high water availability in the Edmondson Point soils (Smykla et al. 2010). However, it is known that other environmental factors such as pH, nutrient availability, elevation (Porazinska et al. 2004) and soil organic matter (Sinclair et Sjursen 2001) may also affect tardigrade abundance.

The taxonomic evaluation of tardigrade specimens extracted from the Edmondson Point soils revealed the presence of only two species, both belonging to the class Eutardigrada: *Acutuncus antarcticus* (Richters, 1904) and *Milnesium antarcticum* Tumanov, 2006 (*see* Fig. 3). The occurrence of *Acutuncus antarcticus* has been reported previously from the Victoria Land since the earliest scientific expeditions (Richters 1909, Murray 1910) and later in several other reports (Dougherty et Harris 1963, Janetschek 1967, Cathey et al. 1981, Binda et Pilato 2000, Porazińska et al. 2004). In fact, this is the most widespread and the only tardigrade species reported both from the Northern and Southern Victoria Land (Adams et al. 2006). It is also often the only or the most numerous species found in various limno-terrestrial environments, including soils, cryptogamic vegetation, freshwater and cryoconite holes. On the other hand, the occurrence of *Milnesium antarcticum* is novel, both for the Victoria Land and continental Antarctica. To date this species was known only from its type locality on the King George Island in the maritime Antarctica (Tumanov 2006).

According to Adams et al. (2006), 14 tardigrade species were previously reported from the Victoria Land. However, Adams et al. (2006) quoting Binda et Pilato (1992), also listed the occurrence of *Minibiotus furcatus* Ehrenberg, 1859, but this information is erroneous since occurrence of this species was reported only from Europe and North America (*see* Binda et Pilato 1992). Adams et al. (2006) omitted *Macrobiotus meridionalis* Richters, 1909 described from Victoria Land Richters, 1909. Thus, including our current record of *Milnesium antarcticum*, the list of limno-terrestrial Tardigrada reported to date from Victoria Land consists of 15 species. Of these, only one species was recorded both in the Northern and Southern Victoria Land, eight species were found exclusively in northern and six exclusively in southern Victoria Land. Although the majority of the species seem to have very restricted distributions, this reflects the location of investigations rather than the real distribution of these animals. Most of the available information on their distribution is based only on studies documenting and/or describing new taxa (*e.g.* Murray 1910, Pilato et Binda 1999, Binda et Pilato 2000). Thus, the limited survey of available ice-free areas and potential habitats is a major factor that needs to be addressed in future work to allow analyses of the Victoria Land tardigrade distribution and biogeographical patterns.

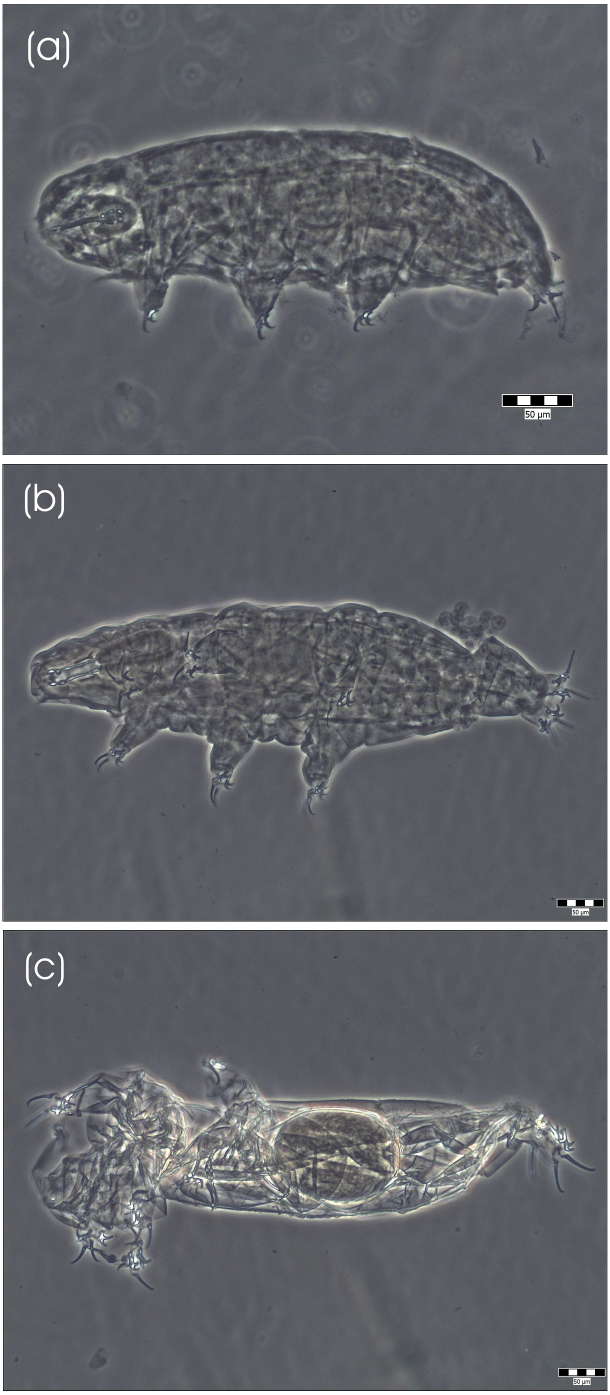

Fig. 3. Species of tardigrades recorded in the Edmondson Point soils: (a) *Acutuncus antarcticus* (Richters, 1904), (b) *Milnesium antarcticum* Tumanov, 2006, (c) *M. antarcticum* exuvia with an egg.

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