· Letter ·
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# A preliminary study of freshwater meiofaunal communities at Greenwich Island, South Shetland Islands, Antarctica

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**Abstract** Meiofaunal communities of three small, shallow freshwater habitats sampled during the austral summer of 2013 in Greenwich Island, South Shetland Islands, Antarctica, are reported. Communities are dominated by tardigrades (85%), nematodes (11%), and rotifers (3%). Collembola, Oligochaeta, crustacean larvae (nauplii) and unidentified organisms account for 0.3%. Total meiofaunal densities reach 11 770 ind·cm$^{-2}$, with mean densities (ind·cm$^{-2}$) of 1 365.83 ± 2 716.65 (Zone A), 523.67 ± 1 166.48 (Zone B) and 72.17 ± 110.78 (Zone C). Given the age of freshwater habitats, and the general lack of higher-trophic level predatory taxa, those species we report are likely early stage colonizers, and these communities are at an early stage of ecological succession. Non-parametrical analysis revealed the main variables influencing meiofaunal density and distribution are related to granulometric characteristics of sediments and microphytobenthic biomass. There were close relationships between meiofaunal abundance and microphytobenthic biomass, which indicates that benthic microalgae significantly influence meiofaunal distribution. A strong correlation between nematode abundance and the percentage of silt, clay and carbon in the sediment was also shown by canonical correspondence analysis and Spearman rank correlation.

**Keywords** **meiofauna, freshwater, Greenwich Island, Shetland Islands, Antarctica**

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## 1 Introduction

Although extreme meteorological conditions and continuous sub-zero temperatures render most of the Antarctic continent permanently ice-covered, the climate in the maritime region of the western side of the Antarctic Peninsula and nearby islands is less extreme, experiencing relatively higher mean temperatures and precipitation than elsewhere in Antarctica[1]. A variety of water bodies can be found here during the austral summer, ranging from large deep lakes to small, temporary, shallow depressions fed by snow and melting ice[2].

The invertebrate communities of shallow-water bodies can play important roles in nutrient cycling, energy flow, decomposition, herbivory, and parasitism[3-5]. Meiofauna, microscopic invertebrates that live within aquatic sediments, can stimulate microbial activity within sediments, provide food for higher trophic levels, and be a bioindicator of environmental impact; their production can even exceed that of macrofauna[6]. However, most research in the Antarctic has focused on aquatic benthic macrofauna instead[7], and marine meiofaunas[5,7-10].

Studies in ice-free areas across Antarctica have revealed seasonal, habitat and geographic variation in microfaunal composition. Higher soil moisture content during summer have been related to increased growth of photosynthetic autotrophs, microbial and microfaunal species[11]; abiotic factors have been recognized to influence nematode communities more so than biotic factors[12]; and soil microfaunal community structure has been related to soil geochemistry[13]. In continental Antarctica, nematodes have been identified as the most diverse and abundant invertebrate group from Victoria land[14], but results from Dronning

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Maud Land shows that rotifers, followed by tardigrades and nematodes are the most common taxa[15-16]. The Antarctic peninsula is the most rapidly warming region in the world[17]. Studies on limnology on King George Island, South Shetland islands started in the 1970's[18]. The diversity of freshwater fauna of King George Island is lower than that of the South Orkney Islands, but richer than that of the Antarctic Peninsula[19]. In Admiralty Bay, the density of Monogononta, Bdelloidea, Tardigrada and Nematoda was lower than in the Antarctic lakes, and greatest in the moss banks, in which the highest densities of nematodes and tardigrades were also encountered[20]. Otherwise research effort on Antarctic soil ecosystems has been limited, hampering attempts to ascertain or predict the possible effects of warming throughout this region.

Here we report freshwater meiofaunal community structure (main groups) and relate it to microphytobenthic biomass, water chemistry and soil geochemistry in three areas in Punta Fort Williams, Greenwich Island, in the South Shetland Islands. Our objective was to determine what, if any, relationship exists between community structure and a series of environmental variables. To the best of our knowledge no such investigation has been previously reported for this area.

## 2 Methods

Samples were collected from Punta Fort William at the northeastern tip of Greenwich Island, one of the southernmost islands in the South Shetland complex of islands in Antarctica (Figure 1). Punta Fort Williams is a headland (~1.6 km$^2$) neighboring Quito Glacier, and although usually devoid of snow during summer[21], during our sampling in January of 2013 it was blanketed in snow, so sampling locations were distributed in the ice-free areas in the vicinity of the Ecuadorian station "Pedro Vicente Maldonado".

Three sites were selected (Zone A, B, C), within which sampling occurred two weeks following ice melt. In total 27 samples were collected from shallow water ponds and streams; nine samples from each site. Zone A, characterized by visible vegetation (moss, cyanobacteria or algae), zone B, near shore streams with visible dead macroalgae on bottom, and zone C, pond situated on glacial lateral moraines.

At each site, water samples were collected to measure physicochemical parameters using a multiparameter sonde HORIBA UX22 (HORIBA Instruments Incorporated, Texas, USA), Additional samples were collected and filtered using membrane syringe filters of 25 mm inner diameter and 0.22 µm, for total organic carbon (TOC) and major ion determination. At each site, nine replicate meiofaunal samples were collected by PVC core of 3 cm inner diameter (surface area 10 cm$^2$). Cores were carefully pushed into the sediment and brought to the surface as undisturbed as possible, with the upper 1 cm of each core removed, bagged and fixed in 4% formaldehyde until further analysis. Additional surface sediment samples were collected in the same place for microphytobenthic biomass analysis (Chlorophyll *α*), and elemental and granulometric analysis; these samples were kept frozen (−20°C) in the dark until processing. Analysis of

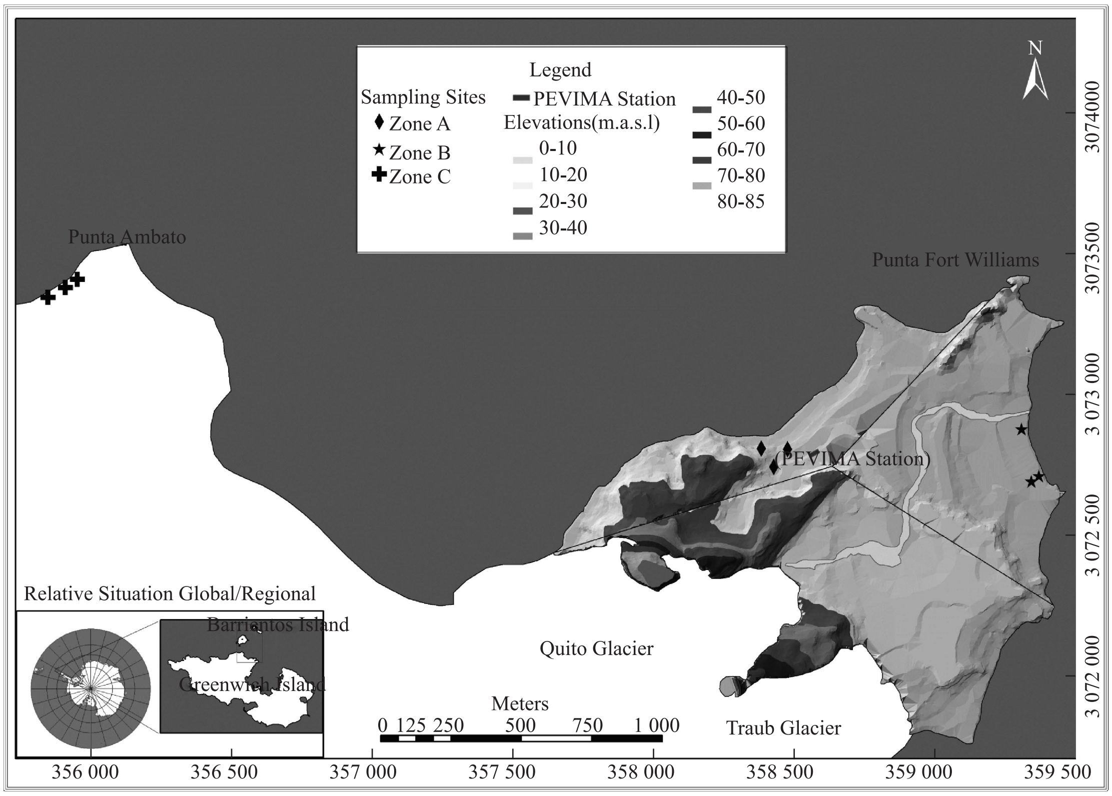

**Figure 1** Study area and sampling sites, Punta Fort Williams, Greenwich Island.

TOC was performed using a Teledyne Tekmar-Apollo 9000 TOC Analyzer. Major cations in water were analyzed using an Atomic Absorption Spectrometer Perkin Elmer AAnalyst 200, and anions were analyzed using an Ionic Chromatographer Dionex ICS-2100.

Fixed meiofaunal samples were washed over a 63 μm mesh using distilled water. Meiofauna and organic material were extracted from the remaining sand particles by density gradient treatment using a colloidal silica polymer (Ludox TM) as flotation medium[22]. Treated samples then were Rose Bengal stained, sorted using conventional light microscopy, and identified and counted [23-25].

Microphytobenthic biomass or chlorophyll $\alpha$ (Chl $\alpha$) concentration was determined from three replicate samples from each site. Sediment was lyophilized and homogenized, then extracted with 100% Acetone grade HPLC, and pigments separated using reverse phase high-performance liquid chromatography[26]. Samples for sediment grain-size analysis were first freeze dried, sieved through a 2.0 mm sieve, then processed using a granulometric analyzer Malvern Mastersizer 2000 with the dispersion unit Hydro 2000 G. Organic matter and moisture were determined using the ‘loss on ignition (LOI)’ procedure, using a combination of equations[27-29]. For elemental analysis (C, N, H and S), dried samples were analyzed using an Eager Analyzer 200 Stripchart.

One-way ANOVA was performed to determine whether significant differences existed between sites; Spearman rank correlation was used to assess relationships among variables; and Canonical Correspondence Analysis (CCA) was performed on log($x$+1)-transformed data (because of high variation in values between samples). All statistical analyses were conducted using PAST software, version 2.7.

## 3 Results

Water and sediment characteristics and microphytobenthic biomass for each site are presented in Table 1. Environmental variables differed significantly between sites ( $p<0.001$). Zone A had the greatest temperature, dissolved oxygen, oxygen reduction potential, organic matter, TOC and chlorophyll $\alpha$, with high silt, clay and sand contents in sediments, and high levels of N. However, the content of major ions within the water was the lowest of the three surveyed sites. Nitrate was below detection limits in all water samples.

The meiofaunal community was dominated by tardigrades (85%), nematodes (11%) and bdelloid rotifers (3%), with the rest 1% comprising Oligochaeta, Collembola, crustacean larvae (nauplii) and other unidentified taxa. Tardigrades numerically dominated all three sites, being most abundant at Zone A (6 851 ind·cm$^{-2}$) and least at Zone C (282 ind·cm$^{-2}$), followed by nematodes and bdelloid rotifers, both of which were similarly more abundant at Zone A (1 036 ind·cm$^{-2}$ and 290 ind·cm$^{-2}$ respectively), and least abundant at Zone C (110 ind·cm$^{-2}$ and 29 ind·cm$^{-2}$ respectively) (Figure 2). Most nematodes have been referred to *Plectus*, and most tardigrades to *Hypsibius*. Only one unidentified Oligochaete and three Collembola were found.

**Table 1** Physicochemical parameters of water, sediment characteristics and microphytobenthic biomass in sampling sites (DO = dissolved oxygen, TDS = total dissolved solids, ORP = oxygen reduction potential, Chl $\alpha$ = Chlorophyll $\alpha$, OM = organic matter, TOC = total organic carbon)

| Parameter | Zone | | |
|---|---|---|---|
| | A | B | C |
| pH | 5.19 ± 0.00 | 5.31 ± 0.78 | 5.57 ± 0.12 |
| Conductivity/ (μS·cm$^{-1}$) | 47.00 ± 0.00 | 173.57 ± 10.21 | 159.77 ± 45.83 |
| DO/(mg·L$^{-1}$) | 7.97 ± 0.00 | 5.32 ± 0.23 | 8.03 ± 0.12 |
| Temperature/°C | 7.59 ± 0.00 | 5.37 ± 0.76 | 4.58 ± 1.10 |
| TDS/(g·L$^{-1}$) | 0.01 ± 0.00 | 0.11 ± 0.01 | 0.10 ± 0.03 |
| ORP (mV) | 308.00 ± 0.00 | 209.33 ± 45.51 | 242.56 ± 4.86 |
| Chl *a* /(μg·g$^{-1}$) | 10.43 ± 14.78 | 8.49 ± 14.55 | 0.17 ± 0.18 |
| Clay/% | 0.93 ± 0.556 | 0.26 ± 0.453 | 0 |
| Silt/% | 9.11 ± 3.342 | 3.04 ± 5.260 | 0 |
| Sand/% | 30.82 ± 7.979 | 8.24 ± 12.416 | 13.60 ± 2.746 |
| Gravel/% | 59.11 ± 11.853 | 88.46 ± 18.154 | 86.40 ± 2.746 |
| Moisture/% | 69.62 ± 6.02 | 68.91 ± 12.49 | 80.70 ± 1.55 |
| OM/% | 8.42 ± 2.10 | 7.06 ± 2.01 | 3.19 ± 0.67 |
| TOC/(mg·L$^{-1}$) | 1.10 ± 0.00 | 0.30 ± 0.17 | 0.40 ± 0.39 |
| $Ca^{2+}$/(mg·L$^{-1}$) | 0.11 ± 0.00 | 0.85 ± 0.50 | 1.04 ± 0.09 |
| $Mg^{2+}$/(mg·L$^{-1}$) | 0.29 ± 0.00 | 3.04 ± 0.05 | 0.92 ± 0.11 |
| $Na^{+}$/(mg·L$^{-1}$) | 8.55 ± 0.00 | 15.02 ± 9.74 | 16.67 ± 1.02 |
| $K^{+}$/(mg·L$^{-1}$) | 0.66 ± 0.00 | 0.67 ± 0.42 | 0.75 ± 0.08 |
| $Cl^{-}$/(mg·L$^{-1}$) | 9.63 ± 0.00 | 44.07 ± 50.35 | 23.87 ± 2.23 |
| $SO_4^{2-}$/(mg·L$^{-1}$) | 1.26 ± 0.00 | 3.38 ± 2.14 | 4.07 ± 0.34 |
| Carbonate/% | 14.48 ± 3.22 | 11.44 ± 2.86 | 6.01 ± 0.90 |
| Nitrogen/% | 0.31 ± 0.33 | 0.11 ± 0.08 | 0.07 ± 0.02 |
| Carbon/% | 0.86 ± 0.64 | 0.49 ± 0.55 | 0.07 ± 0.05 |
| Hydrogen/% | 0.93 ± 0.42 | 0.56 ± 0.18 | 0.33 ± 0.29 |

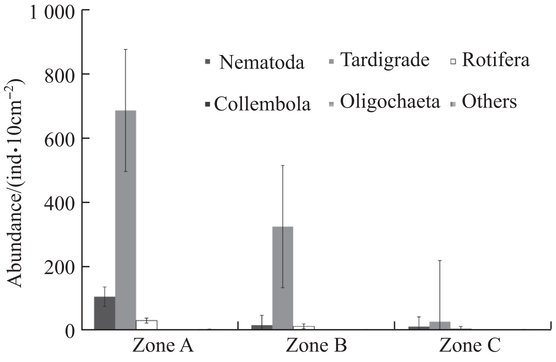

**Figure 2** Meiofauna abundance (ind·10cm$^{-2}$ ± SD) by site.

The Spearman rank correlation (Table 2) revealed significant and positive correlations between meiofaunal abundance with microphytobenthic biomass (Chl *α*) and silt, clay and sand content, and a negative correlation with gravel. Additionally, a significant and positive correlation was detected between all meiofaunal phyla and TOC, and the N, C and H content of sediments.

CCA revealed axis 1 explained 54.75% of variance and axis 2 explained 25.11% of variance (Figure 3). Strong evidence of a relationship between nematode and tardigrade abundance with the content of C, silt and clay percentage in sediment, and chlorophyll *α* from the microphytobenthos exists.

**Table 2** Spearman rank correlation for meiofauna groups with water physicochemical parameters, sediment features and microphytobenthic biomass (DO=dissolved oxygen; TDS=total dissolved solids; ORP= oxygen reduction potential; Chl *α* = Chlorophyll *α*; OM=organic matter; TOC=total organic carbon; -, non-significant; $^{*}p<0.05$; $^{**}p<0.01$)

| Parameter | Nematoda | Tardigrada | Rotifera | Collembola | Oligochaeta | Others |
|---|---|---|---|---|---|---|
| pH | - | - | - | - | - | - |
| Conductivity/($\mu S \cdot cm^{-1}$) | - | - | - | - | - | - |
| DO/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| Temperature/ ºC | - | - | - | - | - | - |
| TDS/ ($g \cdot L^{-1}$) | - | - | - | - | - | - |
| ORP/ (mV) | - | - | - | - | - | - |
| Chl *a*/ ($\mu g \cdot g^{-1}$) | $0.82^{**}$ | $0.84^{**}$ | $0.90^{**}$ | - | - | $0.86^{*}$ |
| Clay/% | $0.92^{**}$ | $0.86^{*}$ | $0.84^{*}$ | - | - | - |
| Silt/% | $0.90^{**}$ | $0.84^{*}$ | $0.87^{*}$ | - | - | - |
| Sand/% | $0.82^{**}$ | $0.77^{*}$ | $0.80^{*}$ | - |  | - |
| Gravel/% | $-0.82^{**}$ | $-0.77^{*}$ | $-0.80^{*}$ | - | - | - |
| Moisture/% | - | $-0.72^{*}$ | - | - | - | - |
| OM/% | - | - | - | - | - | - |
| Carbonate/% | - | - | - | - | - | - |
| Nitrogen/% | $0.81^{*}$ | $0.81^{*}$ | $0.88^{**}$ | - | - | $0.73^{*}$ |
| Carbon/% | $0.74^{*}$ | $0.76^{*}$ | $0.78^{*}$ | - | - | $0.74^{*}$ |
| Hydrogen/% | $0.63^{*}$ | - | - | - | - | - |
| $Ca^{2+}$/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| $Mg^{2+}$/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| $Na^{+}$/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| $K^{+}$/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| $Cl^{-}$/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| $SO_4^{2-}$/($mg \cdot L^{-1}$) | - | - | - | - | - | - |
| TOC/($mg \cdot L^{-1}$) | $0.87^{**}$ | $0.77^{*}$ | $0.78^{*}$ | - | - | - |

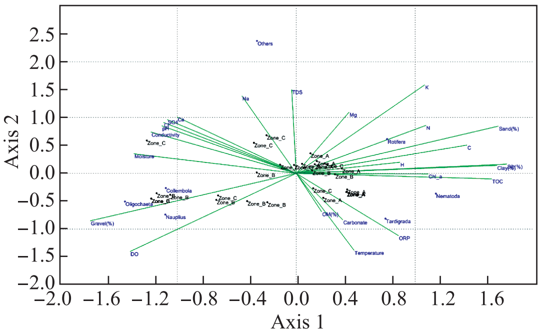

**Figure 3** Canonical correspondence analysis (CCA) of meiofauna abundance, chlorophyll *α*, and abiotic characteristics of water and sediment from each location (data log*x*+1 transformed)

## 4 Discussion

Climatic conditions in the maritime Antarctic are less extreme than those on the Antarctic continent. In Punta Fort William, terrestrial aquatic ecosystems such as ponds, lakes, and other water bodies usually contain liquid water and become ice-free in summer, allowing colonization by aquatic organisms[1,30-31]. The communities we describe likely comprise early stage colonizing taxa, therefore at an early stage of the ecological succession. The surveyed habitat was no more than 2 weeks old, and predatory taxa had yet to become established. Despite this, these communities were similar to that reported elsewhere in similar habitat throughout Antarctica[32].

Various studies report different taxa to dominate different environment types: from nematodes in Antarctic soils and sediments[33], rotifers in freshwater environments (King George island)[19], to tardigrades in our small pond habitat from Greenwich Island. Although the feeding habits of tardigrades are not well established[14], we recognize their abundance to correlate with microphytobenthic biomass, and secondarily, with low numbers of nematodes (*Plectus* sp.). Competition for food would be expected in environments with high microfaunal population densities[19]. Tardigrades are linked to soils with high levels of carbon and microphytobenthic biomass, which agrees with results obtained by Velasco-Castrillón et al [12]. It is possible that tardigrades were more abundant than nematodes in our samples as predation pressure was low, perennial food abundance and highly developed cryptobiotic survival strategies, characteristics that have allowed them to reach very high population densities[33].

High abundances of tardigrades, nematodes and rotifers generally appeared to be associated with samples with a presence of mosses, which could be related to resource availability (Zone A), as it has been showed in other Antarctic sites, where meiofauna populations could be high because of abundant food and low competition[14]. Microphytobenthos is an essential component of the benthic food web, and its significance for meiofauna as a potential food source has been often demonstrated[5]. Food availability is likely the most important factor determining the distribution of the meiofauna in Antarctica[34]. Our results show a very close relationship in meiofaunal abundance and microphytobenthic biomass, implying microphytobenthos can significantly affect meiofaunal distribution. CCA and Spearman rank correlation also revealed a high correlation between nematode abundance and the % of silt, clay and carbon in the sediment. The relationship of nematode distribution in soil is affected by carbon content and moisture even though the environmental requirements vary depending on the species. Courtright et al observed that soils with high content of carbon were inhabited predominantly by *Plectus*[35], as in this study. *Plectus* sp. was the most abundant nematode, a bacterivorous that can also feed on microalgae[36], which potentially increase the range of habitats where it can be found. Zone A with presence of moss and microbial mats, favored the tardigrades. The climate inside the moss isolates the microfauna from very microclimatic changes, high organic material also favored nematodes, and the substrate is also energy rich with high content of Nitrogen and possibly high bacterial activity. Moss was absent in Zone B and C. At Zone B, organic material from dead macroalgae at the bottom of the stream could have favored the presence of nematodes and tardigrades, besides the microphytobenthic biomass. The Antarctic Peninsula is the most rapidly warming region in the world [16], with longer growing seasons and extended plant distributions predicted across the region. Although climatic conditions in maritime Antarctica are less severe than those of continental Antarctica, temperature and limited precipitation remain major constraints for meiofaunal communities. It has been found that increasing soil temperatures (combined with less temperature variability) and lower UV radiation have a strong positive influence on nematode abundance and caused a shift in the composition of nematode communities in Mars Oasis[36]. Considering our meiofaunal community was likely to be at an early stage of colonization, it is likely that abiotic factors have played a greater role in shaping it than biotic interactions, which will probably increase in importance later in community development and succession.

We would expect changes in soil geochemistry to occur in warmer periods, where nutrients and carbon accumulate in lower-altitude sites. We would similarly expect seasonal variation in biotic-abiotic interactions [12]. Further research is required to better understand the biotic (competition and predation) and abiotic interactions in this Antarctic ecosystems and how these affect community structure.

Although this was a preliminary study, our results contribute to a growing body of information on a largely neglected group of invertebrates from this region and are providing the baseline information about freshwater meiofauna in Punta Fort Williams, Greenwich Island. Accordingly, monitoring of meiofaunal taxa might facilitate rapid detection of anticipated environmental changes brought about as a consequence of global warming.

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