Contributed Paper

Effects of Human Trampling on Populations of Soil Fauna in the McMurdo Dry Valleys, Antarctica

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Abstract: *Antarctic ecosystems are often considered nearly pristine because levels of anthropogenic disturbance are extremely low there. Nevertheless, over recent decades there has been a rapid increase in the number of people, researchers and tourists, visiting Antarctica. We evaluated, over 10 years, the direct impact of foot traffic on the abundance of soil animals and soil properties in Taylor Valley within the McMurdo Dry Valleys region of Antarctica. We compared soils from minimally disturbed areas with soils from nearby paths that received intermediate and high levels of human foot traffic (i.e., up to approximately 80 passes per year). The nematodes* Scottnema lindsayae *and* Eudorylaimus *sp. were the most commonly found animal species, whereas rotifers and tardigrades were found only occasionally. On the highly trampled footpaths, abundance of* S. lindsayae *and* Eudorylaimus *sp. was up to 52 and 76% lower, respectively, than in untrampled areas. Moreover, reduction in* S. lindsayae *abundance was more pronounced after 10 years than 2 years and in the surface soil than in the deeper soil, presumably because of the longer period of disturbance and the greater level of physical disturbance experienced by the surface soil. The ratio of living to dead* Eudorylaimus *sp. also declined with increased trampling intensity, which is indicative of increased mortality or reduced fecundity. At one site there was evidence that high levels of trampling reduced soil CO_2 fluxes, which is related to total biological activity in the soil. Our results show that even low levels of human traffic can significantly affect soil biota in this ecosystem and may alter ecosystem processes, such as carbon cycling. Consequently, management and conservation plans for Antarctic soils should consider the high sensitivity of soil fauna to physical disturbance as human presence in this ecosystem increases.*

Keywords: carbon cycling, disturbance, ecotourism, footpaths, nematodes, polar desert, rotifers, soil biodiversity, soil CO_2, tardigrades

Efectos del Pisoteo de Humanos sobre Poblaciones de Fauna del Suelo en los Valles Secos McMurdo, Antártida

Resumen: *Los ecosistemas de la Antártida a menudo son considerados casi prístinos porque los niveles de perturbación antropogénica son extremadamente bajos. Sin embargo, en las décadas recientes ha habido un rápido incremento en el número de personas, investigadores y turistas, que visitan la Antártida. Evaluamos, durante 10 años, el impacto directo del tráfico peatonal sobre la abundancia de animales del suelo y las*

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propiedades del suelo en el Valle Taylor dentro de la región de los Valles Secos McMurdy de la Antártida. Comparamos suelos de las áreas con mínima perturbación con suelos de veredas cercana que tenían niveles intermedios y altos de tráfico peatonal (i.e., hasta ~80 pases por año). Los nemátodos Scottnema lindsayae *y* Eudorylaimus *sp. fueron las especies animales más comunes, mientras que solo encontramos rotíferos y tardígrados ocasionalmente. En las veredas con tráfico peatonal intenso, la abundancia de* S. lindsayae *y de* Eudorylaimus *sp. fue hasta 52% y 76% menor, respectivamente, que en las áreas sin tráfico. Más aun, la reducción en la abundancia de* S. lindsayae *fue más pronunciada después de 10 años que dos años y en el suelo superficial que en el suelo profundo, presumiblemente debido a un período de perturbación más largo y al mayor nivel de perturbación física en el suelo superficial. La proporción vivos – muertos de* Eudorylaimus *sp. también declinó con el incremento de la intensidad del tráfico peatonal, lo cual es un indicador de incremento de la mortalidad o reducción de la fecundidad. En un sitio, hubo evidencia de que los niveles altos de tráfico peatonal reducían los flujos de CO_2 del suelo, que está relacionado con una actividad biológica total en el suelo. Nuestros resultados muestran que aun niveles bajos de tráfico humano pueden afectar significativamente a la biota en este ecosistema y pueden alterar procesos del ecosistema, como el ciclo del carbono. Consecuentemente, los planes de manejo y de conservación de los suelos de la Antártida deberían considerar la alta sensibilidad del la fauna del suelo a la perturbación física a medida que incrementa la presencia humana en este ecosistema.*

Palabras Clave: biodiversidad del suelo, ciclo de carbono, CO_2 del suelo, desierto polar, ecoturismo, nemátodos, rotíferos, tardígrados, veredas

Introduction

Antarctica is the most pristine continent on Earth, primarily as a result of minimal human disturbance. Nevertheless, since the early expeditions of the 19th century, the number of research expeditions to Antarctica has increased annually, and the rate of visitation has accelerated over recent decades. Since the 1980s Antarctica has become an increasingly popular tourist destination (Frenot et al. 2005), with over 26,000 tourists landing on the continent in the austral summer of 2004–2005 (www.iaato.org/tourism_stats.html). Increased human presence in Antarctica could influence terrestrial and aquatic ecosystems indirectly (e.g., through introduction of exotic species [Frenot et al. 2005]) and directly (e.g., through physical disturbance of the ecosystem or pollution [Aislabie et al. 2004]). Moreover, the cold desert climate of Antarctica may make this area particularly sensitive to anthropogenic or natural changes because other arid or unproductive ecosystems often exhibit little resistance or resilience to disturbance (Schlesinger et al. 1990; Wall & Virginia 1999; Webb 2002). For example, desert biological crusts help stabilize the soil surface, and when they are lost arid soils erode and biological activity declines (Belnap 2006). The direct impact, however, of increased human activity from researchers and tourists in regions such as the McMurdo Dry Valleys, Antarctica, is poorly known.

The McMurdo Dry Valleys is the largest area of ice-free land on the continent and has one of the harshest environments on Earth (Campbell & Claridge 1987; Fountain et al. 1999). In addition, there is a relatively high human presence in this region because it is accessible to tourist cruise ships and several research stations via short helicopter flights. The terrestrial ecosystems host some of the simplest food webs described. There are no vascular plants, and moss and algae are typically limited to moist soils near ice-covered lakes and ephemeral streams, although microalgae and cyanobacteria occur in soils throughout the McMurdo Dry Valleys (Adams et al. 2006). The soils support a food web of microbes, protozoa, and typically up to 3 animal phyla (Rotifera, Tardigrada, and Nematoda). The nematode *Scottnema lindsayae* is the most abundant and widespread animal in this ecosystem (Freckman & Virginia 1997, 1998; Adams et al. 2006). Rates of soil CO_2 efflux, an indicator of total belowground biological activity, are lower in this ecosystem than almost anywhere in the world (Parsons et al. 2004; Barrett et al. 2006).

In the McMurdo Dry Valleys even paths that receive little foot traffic are easy to visually identify one or more years since they were last used, which indicates the potential for mid- to long-term effects of soil disturbance (Campbell & Claridge 1987). The physical effects of human foot traffic on soils in this ecosystem have received some attention. Campbell et al. (1994) report increased albedo (i.e., reflection of sunlight), due to exposure of the light-colored subsurface material and compaction as a consequence of human trampling of soil in the McMurdo Dry Valleys. The impact of trampling on the biotic community and biogeochemical cycling, however, has not been investigated in this ecosystem. Indeed, direct impacts of human disturbance on soils in arid and semiarid ecosystems worldwide have primarily been limited to physical properties, such as compaction and susceptibility to erosion (e.g., Kutiel et al. 2000; Webb 2002; Belnap et al. 2007). Only a few studies have focused on the effects of human trampling on biogeochemical properties or the biotic community, primarily in relation to crusts (Ros et al. 2004; Barger et al. 2006; Belnap 2006).

We assessed soil biotic properties and processes in areas that had experienced different levels of human trampling in the McMurdo Dry Valleys. We hypothesized that human disturbance increases mortality and decreases populations of the dominant organisms and alters ecosystem functioning. Specifically, we predicted that invertebrate abundances, the ratio of live to dead individuals, and soil CO_2 efflux would decrease with increased trampling intensity.

Methods

Study Site

The Taylor Valley (77°40′ S, 162°53′ E) is located between the Ross Sea and Polar Plateau in the McMurdo Dry Valleys and is the principal site of the U.S. McMurdo Long Term Ecological Research project. Mean annual temperatures in Taylor Valley range from −16 to −21 °C (Doran et al. 2002*a*) and annual precipitation (almost entirely as snow) is <10 cm water equivalent (Clow et al. 1988). The soils are poorly developed, predominantly sand (>95%) and rock fragments (Bockheim 1997; Campbell et al. 1997, 1998), highly saline (0.1–1 dS/m; Campbell & Claridge 1987), low in organic carbon (<1%; Burkins et al. 2000; Barrett et al. 2005), and have some of the lowest levels of biological activity in the world (Freckman & Virginia 1997; Parsons et al. 2004; Barrett et al. 2006). No vascular plants or vertebrates inhabit the McMurdo Dry Valleys. Soil nematodes are the most widespread and abundant animals in this ecosystem, and, except for the rare *Geomonhystera villosa*, there are only 3 nematode species: *S. lindsayae*, *Eudorylaimus* sp., and *Plectus* spp. (Adams et al. 2006). Rotifers, tardigrades, mites, and collembolans also occur in the McMurdo Dry Valleys, although the latter 2 are patchily distributed along stream channels and in intermittently saturated soils (Stevens & Hogg 2004; Adams et al. 2006). Only approximately 65% of soils in the dry valleys contain invertebrates, and half of those have only one invertebrate species, usually *S. lindsayae* (Freckman & Virginia 1997, 1998; Poage et al. 2008).

Soil Fauna

We collected soil samples from paths and adjacent untrampled areas at the south side of Lake Hoare to assess the impact of human trampling on soil fauna. The paths were associated with an experiment located at this site. The main access path to this area experienced relatively high levels of trampling, whereas other paths between experimental blocks received moderate levels of trampling, and some areas were not trampled at all. These classifications are relative terms, and even the traffic on the highly trampled path would be considered low in most ecosystems. For instance, people walked the highly trampled path approximately 50–80 times per year, and the path between the experimental blocks was walked only 10–15 times per year, with most of the traffic limited to December and January during the austral summer. The difference in the effect of human traffic on the soil was clearly visible among the 3 categories. The highly trampled path appeared very disturbed, whereas the untrampled areas looked much like the surrounding desert.

In the austral summers of 1995–1996 and 2003–2004, 2 and 10 years after the paths were established, respectively, soil was collected to a depth of 10 cm from areas that experienced each level of trampling (i.e., high, mid, and none). In 1995–1996 soil samples were collected at depths from 0 to 10 cm, whereas in 2003–2004 soil samples were collected in layers from 0 to 2.5 cm and from 2.5 to 10 cm. Fifteen samples were collected for each level of trampling on both sampling dates. Each sample consisted of approximately 500 g of soil collected with sterilized plastic scoops and was placed in previously unused plastic bags (Freckman & Virginia 1993).

Soil samples were placed in ice chests and transported to the Crary Laboratory at McMurdo Station, where they were processed within 48 h. Under a laminar flow hood, we removed pieces in each sample that were >4 mm. Subsamples of soil were dried at 105 °C for 48 h to determine gravimetric soil moisture content. We extracted soil invertebrates from fresh soil (100 g) with a modified sugar centrifugation technique (Freckman & Virginia 1993). Nematodes were identified to species and characterized by life stage (adult vs. juvenile) and whether they were dead or living on the basis of observation of movement. Because some samples contained no dead nematodes, the ratio of living versus dead was calculated as live:(dead+1). We also counted tardigrades and rotifers, but did not identify them further. Invertebrate abundance was expressed per kilogram of soil (oven dry-weight equivalent). The effects of trampling, year, and soil depth on the various soil parameters were assessed with analysis of variance (ANOVA) in JMP statistical software (SAS Institute, Cary, North Carolina). Because soil was only collected in 0- to 2.5-cm and 2.5- to 10-cm layers in 2003–2004, the effect of depth was nested within year. All data were $\log(n+1)$ transformed to meet assumptions of normality and homogeneity of variance.

Soil Respiration

To assess the effect of trampling on an ecosystem function, we measured CO_2 efflux from soil in paths that received different levels of trampling intensity. We assessed the impact of trampling on soil CO_2 efflux in 3 distinct hydrologic basins (Fryxell, Hoare, and Bonney) within Taylor Valley so as to encompass some of the spatial variability within the McMurdo Dry Valleys (Barrett et al. 2004; Ayres et al. 2007). We measured soil CO_2 efflux from paths that were established during the 1999–2000 austral summer and experienced high, mid, or low

Table 1. The *F* values from analysis of variance of soil moisture, nematode abundances, and ratio of live to dead individuals.[a]

Independent variable[b]	*Soil moisture*	S. lindsayae *adults*	S. lindsayae *juveniles*	S. lindsayae *live:dead*	Eudorylaimus *sp. adults*	Eudorylaimus *sp. juveniles*	Eudorylaimus *sp. live:dead*
Disturb	0.6	5.5**	4.1*	4.2*	3.3*	2.7†	3.2*
Year	147.0***	15.1***	12.2***	10.7***	4.6*	2.6	10.0**
Depth [year]	170.8***	8.2**	7.4**	2.6	20.6***	9.4**	16.3***
Disturb x year	0.1	4.1*	4.4*	0.3	0.8	1.9	1.6
Disturb x depth [year]	2.7†	4.0*	3.0†	1.2	0.1	0.8	1.0

[a]*Significance:* †$p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
[b]*Depth was nested within year because soils were only sampled by depth in 2003–2004.*

levels of trampling. In each case the paths were associated with an experiment located on the south side of the lake in each hydrologic basin. The main access paths to each area experienced relatively high levels of trampling (high), whereas paths between experimental blocks received moderate levels trampling (mid), and some areas only experienced a few footsteps per year (low). The amount of foot traffic on the high- and mid-level paths was comparable to similarly classified paths of the soil-fauna study.

In the austral summer of 2006–2007 (i.e., 7 years after establishment of the paths), we measured soil respiration rates in paths that received high-, mid-, and low-level trampling in Fryxell, Hoare, and Bonney basins. We took respiration measurements at 10 locations for each level of trampling in each basin. Two sets of measurements were taken over the course of 1 day (between late morning and midafternoon). Respiration rates were measured with an infra-red gas analyzer with an SRC-1 chamber and STP-1 soil temperature probe (PP Systems, Amesbury, Massachusetts). Soil respiration rates and temperatures from the 2 points in time were averaged and data were analyzed with an ANOVA in JMP, which included basin, trampling intensity, and their interaction as independent variables.

Results

We recovered rotifers and tardigrades and 2 species of nematodes (*S. lindsayae* and *Eudorylaimus* sp.) from the soil samples. Rotifers and tardigrades, however, were rarely found, and their abundance could not be analyzed statistically. *S. lindsayae* were less abundant in 2003–2004 than in 1995–1996 and in the surface soil compared with deeper soil (Table 1; Fig. 1). The abundance of adult and juvenile *S. lindsayae* exhibited a similar pattern in response to 3 levels of trampling (Table 1; Fig. 1). The highest level of trampling reduced the abundance of adult and juvenile *S. lindsayae* by 54 and 51%, respectively, compared with untrampled soil. The effect of trampling was more pronounced in 2003–2004 and in the surface soil (i.e., there was a significant disturbance × year and disturbance × depth[year] interaction, although for juveniles the latter only approached significance; Table 1; Fig. 1).

Overall *Eudorylaimus* sp. adults were more abundant in 2003–2004 than 1995–1996, but juvenile abundance did not differ significantly between years (Table 1; Fig. 2). Similar to *S. lindsayae*, adult and juvenile *Eudorylaimus* sp. were more abundant in the deeper soil. The highest level of trampling reduced the abundance of adult and juvenile *Eudorylaimus* sp. by 67 and 86%, respectively, compared with untrampled soil, although the latter decline only approached significance ($p = 0.074$; Table 1; Fig. 2). Interactions between disturbance and year or depth were not significant.

Disturbance significantly affected the ratio of live to dead *S. lindsayae* and *Eudorylaimus* sp. (Table 1; Fig. 3). There was a greater proportion of living versus dead *Eudorlaimus* sp. in undisturbed soil than in highly trampled areas. The effect of trampling on this measure,

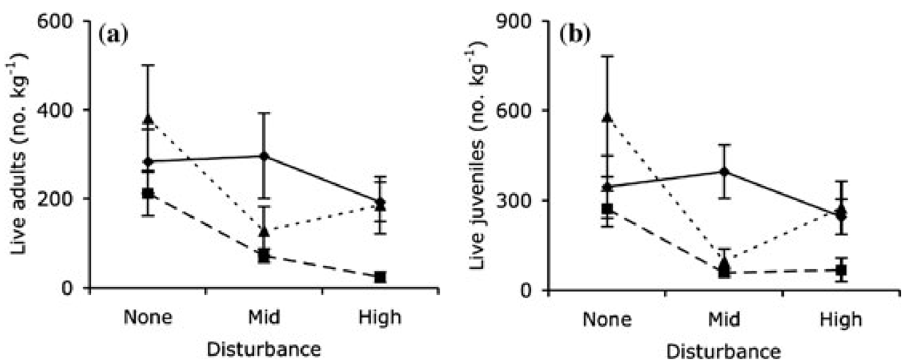

Figure 1. Abundance of (a) adult and (b) juvenile S. lindsayae *in the austral summer of 1995–1996 in soil samples taken at depths of 0–10 cm (solid line), of 2003–2004 in soil samples taken at depths of 0–2.5 cm (dashed line), and of 2003–2004 in soil samples taken depths of 2.5–10 cm (dotted line). Values are means with standard error.*

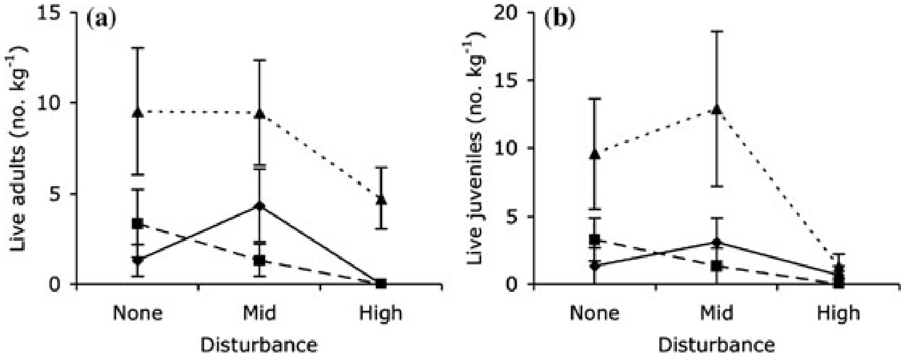

Figure 2. Abundance of (a) adult and (b) juvenile Eudorylaimus *sp. in the austral summer of 1995–1996 in soil samples taken at depths of 0–10 cm (solid line), of 2003–2004 in soil samples taken at depths of 0–2.5 cm (dashed line), and of 2003–2004 in soil samples taken depths of 2.5–10 cm (dotted line). Values are means with standard error.*

however, was inconsistent for *S. lindsayae* populations; the greatest live to dead ratio occurred in areas with mid-level trampling. Two samples at the mid level of disturbance that had relatively large numbers of live *S. lindsayae* individuals (>200/ kg of soil) and no dead individuals were the primary cause of this inconsistent response. The ratio of live versus dead individuals was greater in 2003–2004 than 1995–1996 for both *S. lindsayae* and *Eudorylaimus* sp. (Table 1; Fig. 3). Also, the live to dead ratio was greater in the deeper soil in 2003–2004 than in the surface soil for *Eudorylaimus* sp., but not *S. lindsayae*.

Similar to invertebrate populations, time was a significant source of variation in soil water content. Soil moisture was greater in 2003–2004 than 1995–1996 and in deeper soils (Table 1; Fig. 4). Nevertheless, human trampling intensity did not influence soil moisture, and none of the interactions between disturbance and year or depth within year were significant.

Rates of soil CO_2 efflux across the 3 hydrologic basins varied from -0.02 to 0.07 g $CO_2 \cdot m^{-2} \cdot h^{-1}$. Respiration rates were highest in Fryxell and Bonney basins and lowest in Hoare basin (Fig. 5a; $p < 0.001$). There was a significant interaction between basin and trampling intensity ($p = 0.001$), with reduced respiration rates at high levels of trampling at Fryxell (Fig. 5a). Soil CO_2 efflux was not significantly affected by trampling intensity in the other basins. Patterns of soil temperature among the hydrologic basins were different than patterns of soil respiration, with the highest temperatures at Fryxell and Hoare basins (Fig. 5b; $p < 0.001$). Soil temperature was not affected by trampling intensity.

Discussion

Foot traffic can have multiple effects on soils that are related to compaction, loss of soil structure, and killing of soil organisms. The intensity of human disturbance consistently reduced the abundance of *S. lindsayae* and *Eudorylaimus* sp. The overall decline of live *S. lindsayae* (52%) and *Eudorylaimus* sp. (76%) in heavily trampled areas relative to untrampled soil indicates that even the relatively low levels of human trampling that occur across the terrestrial landscape in this ecosystem can dramatically affect nematode populations. The effect of disturbance on *S. lindsayae* was more pronounced in 2003–2004 and in the surface soil, presumably because of the longer period of disturbance (i.e., 10 years in 2003–2004 vs. 2 years in 1995–1996) and the greater level of physical disturbance to the surface soil. In addition, the unusually long life cycle of *S. lindsayae*, which is thought to encompass multiple austral summers (Overhoff et al. 1993), may have resulted in a time lag in their response to trampling consistent with the larger declines observed in 2003–2004. The interaction between disturbance and year or depth did not influence the abundance of *Eudorylaimus* sp. This might have been caused by the larger body size of *Eudorylaimus* sp. (1.5–2 times longer than *S. lindsayae*;

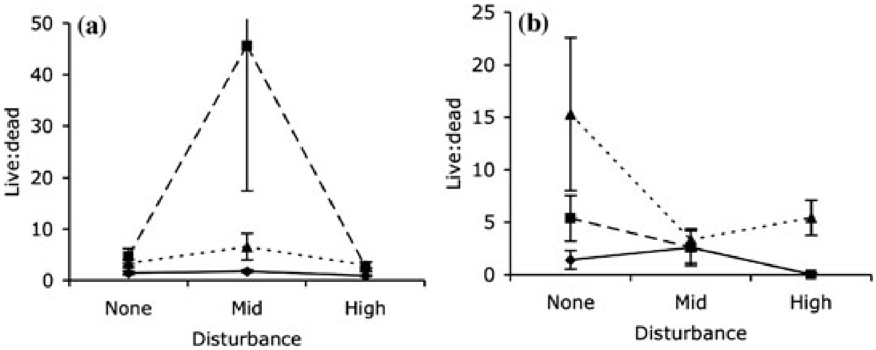

Figure 3. Ratio of live versus dead (a) S. lindsayae *and (b)* Eudorylaimus *sp. individuals in the austral summer of 1995–1996 in soil samples taken at depths of 0–10 cm (solid line), of 2003–2004 in soil samples taken at depths of 0–2.5 cm (dashed line), and of 2003–2004 in soil samples taken at depths of 2.5–10 cm (dotted line). Values are means with standard error.*

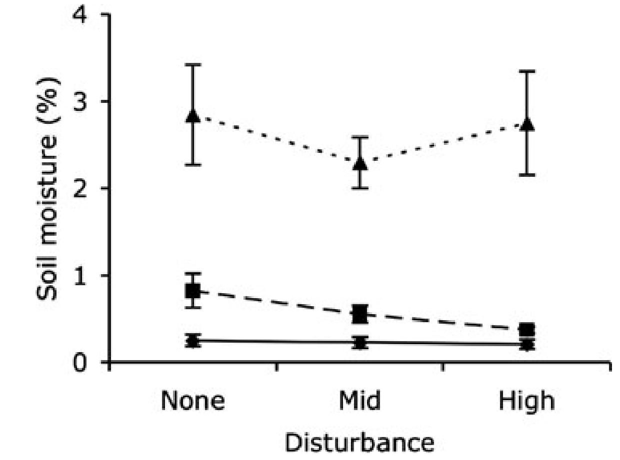

Figure 4. Soil moisture content in the austral summer of 1995–1996 in samples taken at depths of 0–10 cm (solid line), of 2003–2004 in samples taken at depths of 0–2.5 cm (dashed line), and of 2003–2004 in samples taken at depths of 2.5–10 cm (dotted line). Values are means with standard error.

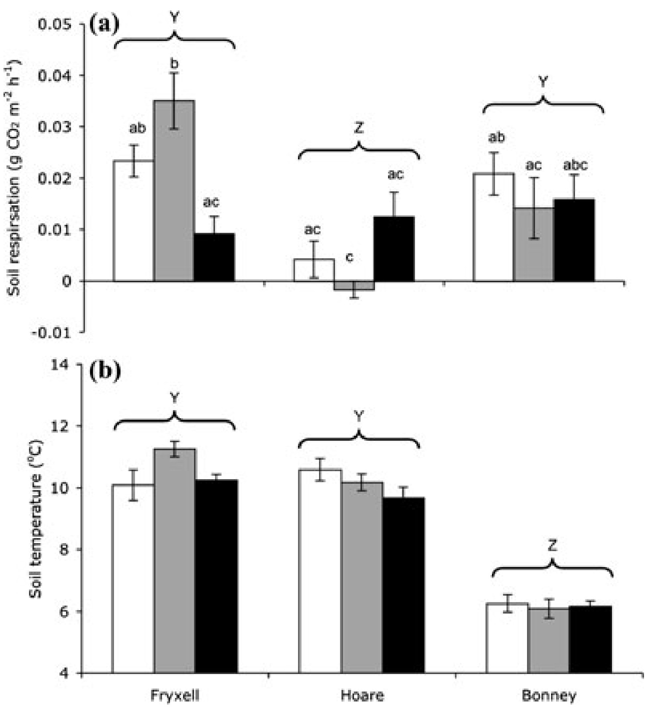

*Figure 5. Soil (a) respiration rates and (b) temperature in 3 hydrologic basins in Tayler Valley. Low-, mid-, and high-trampling intensities are represented by white, gray, and black bars, respectively. Different letters denote significant differences (*p* < 0.05) among hydrologic basins (capital letters) and among trampling intensities × basin (lowercase letters). Values are means with standard error.*

Andrássy 1998), which might raise the chances of their being crushed and result in a faster equilibration at a new population size for a given level of disturbance.

In addition to the declines in total abundance of nematodes, disturbance influenced the ratio of living versus dead individuals. Although the effect on this ratio for *S. lindsayae* was idiosyncratic, disturbance decreased the live to dead ratio of *Eudorylaimus* sp. by 75%, which is consistent with increased mortality or decreased fecundity as a result of human trampling.

Temporal trends in nematode abundances coincided with differences in soil moisture. Soil moisture was greater in 2003–2004 than in 1995–1996. It is not clear whether this reflects short-term patterns of moisture variability or a sustained increase in moisture. Soil moisture was greater in the deeper soil, presumably as a result of greater evaporation or sublimation rates from surface soil. Disturbance did not significantly alter soil moisture, although there was a tendency for decreased moisture with increasing disturbance in the 0- to 2.5-cm soil in 2003–2004 ($p = 0.071$). Results from previous studies of soil moisture in the McMurdo Dry Valleys (Campbell et al. 1994), the sub-Antarctic (Gremmen et al. 2003), and coastal dunes in Israel (Kutiel et al. 2000) show no difference in soil moisture between trampled and untrampled sites.

Other investigators note associations between soil moisture and invertebrate distribution and abundances (Freckman & Virginia 1997; Treonis et al. 1999; Virginia & Wall 1999; Wall & Virginia 1999). We found that the abundance of *S. lindsayae*, the dominant soil animal in this ecosystem, was significantly lower in 2003–2004 than 1995–1996, whereas *Eudorylaimus* sp. exhibited the opposite response. This observed shift in community structure may have been driven by increased soil moisture in 2003–2004. *S. lindsayae* are generally associated with drier soils, whereas *Eudorylaimus* sp. are typically most abundant in wetter habitats (Treonis et al. 1999; Ayres et al. 2007). Doran et al. (2002*b*) reported reductions in nematode abundance (principally *S. lindsayae*) at this site over a 5-year period (1993–1998), and our results corroborate this finding of continued decline. Both *S. lindsayae* and *Eudorylaimus* sp. were more abundant in the deeper soil than the surface soil, which was in agreement with the results of previous studies of nematode distribution in this ecosystem, and this difference may result from greater stability of environmental conditions in the deeper soil (Powers et al. 1994, 1995).

In some cases we detected negative soil CO_2 fluxes (i.e. uptake of CO_2 from the atmosphere). This occurs because respiration rates are so low that physical processes that adsorb CO_2 can overwhelm respiration rates (Parsons et al. 2004). Soil CO_2 fluxes in Fryxell basin were influenced by the intensity of disturbance, with a 50% increase in CO_2 fluxes at areas subjected to mid-level trampling and a 61% decrease in CO_2 fluxes in highly trampled areas.

Microbes typically account for the majority of heterotrophic respiration in soils; however, soil fauna can have a large indirect effect on respiration rates because they influence the abundance, activity, and community structure of soil microbes (e.g., Seastedt 1984; Hedlund & Öhrn 2000). The impact of trampling on the microbial community in this ecosystem remains unknown, although it seems at least possible that mid-level trampling could have increased the availability of previously protected soil C to microbes as a result of the physical disturbance of the soil, thus stimulating their activity. Nevertheless, given the poorly developed sandy nature of the soil in the McMurdo Dry Valleys (Campbell & Claridge 1987), the level of physical protection of C may be small. High levels of trampling may have directly killed a large proportion of the microbial community, which would directly reduce soil respiration rates. In addition, the decrease in nematode abundance with increased trampling intensity observed in the faunal study may have directly and indirectly, via impacts on the microbial community, contributed to the reduction in respiration rates. Ros et al. (2004) observed reductions in soil respiration with increased human trampling intensity (none, 75, and 200 passes per day) in a semiarid Mediterranean ecosystem. Other disturbances, such as management practices in agroecosystems, can initially stimulate and then reduce soil respiration with increasing intensity (Zhang et al. 2004).

Unlike in the Fryxell basin, trampling intensity had no effect on soil CO_2 efflux at either Hoare or Bonney basins. It is possible that the effect of trampling intensity is site-specific. Alternatively, we may have been unable to detect differences in CO_2 effluxes at the rates measured at Hoare and Bonney basins, which were at or near the detection limit of our infra-red gas analyzer. In addition, the heavily trampled path in Fryxell basin led to several different experiments, and, as a result, this path probably experienced more foot traffic than the paths classified as highly trampled in Hoare and Bonney basins. Perhaps the greater intensity of human trampling in Fryxell reduced soil respiration rates, whereas trampling elsewhere was not sufficiently intense to reduce respiration rates. Regardless of the differences between basins, trampling affected soil respiration rates in this ecosystem, but the effect may be site-specific.

Human foot traffic had a significant negative effect on soils in this ecosystem. The highest trampling intensity caused large declines in the dominant and subdominant animal species and a reduction in soil CO_2 efflux at Fryxell. In most ecosystems, the levels of trampling intensity we studied would be considered mild; however, in this sensitive ecosystem, these levels constitute a significant disturbance. Human activity in this area, both scientific and recreational, is likely to continue to increase in the future, particularly in response to initiatives such as the International Polar Year (2007–2008) and the growing demand for tourism in the region. In light of these pressures, management and conservation options for Antarctic soils, such as limiting foot traffic to established paths, should consider the high sensitivity of soil fauna to physical disturbance.

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