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Vulnerability of soil invertebrate communities to the influences of livestock in three grasslands

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ABSTRACT

Soil invertebrates are coming under increasing pressure as pastoral agriculture is intensified. Grazing livestock affects the soil invertebrate community by impacting on the physical habitat through treading, and on nutrient cycling through dung and urine return. In this study the sensitivity of soil invertebrates to livestock was examined by quantifying the abundance and diversity of invertebrates in the grazed pasture and comparing it with those under adjacent permanent fence lines on three different soil types at three locations. Resilience of the invertebrate communities was also explored by sampling mown, fertilised and irrigated plots within grazed pastures, where livestock had been excluded for the previous three years.

Of the soil invertebrates the predatory and omnivorous nematodes, Oribatida and predatory macrofauna were the most sensitive to grazing livestock. In comparison, earthworms with their higher mobility and ability to burrow were more resistant to livestock. The combined effect of removing treading pressure and moisture stress in the fenced plots appeared to be the major factors influencing invertebrate recovery, rather than the quantity and quality of food entering the soil food-web as influenced by fertiliser application. Earthworms, exhibited the greatest resilience, doubling in abundance in the mown and irrigated plots. Nematodes were more resilient than the larger and longer-lived Oribatida. The oribatid community in the irrigated and mown plots were limited in both diversity and abundance in comparison to the community under the fence line. That the vulnerability of soil invertebrates to livestock treading was consistent at all three sites would suggest that organism characteristics (i.e., life-history and ability to move through the soil) and trophic interactions are important in structuring the biological community.

1. Introduction

Soils are coming under increasing pressure as pastoral agriculture is intensified. Soil communities are variable through time, and respond to stresses and disturbances. Since soil biology plays a central role in soil services, the vulnerability of communities to human-induced disturbances needs to be understood. Vulnerability is a combination of sensitivity and/or resistance of a system to disturbance, which includes the ability to respond to or withstand pressure, and resilience following disturbance, which includes the ability to recover (Bardgett et al., 2005; Grimm et al., 1992; Odum, 1985; Pimm, 1984; Wall, 2004; Wardle, 2002). Livestock grazing impacts on the physical properties of the soil (through treading) and on nutrient cycling (through defecation and urine), both are examples of sources of disturbance for the invertebrate community.

Increased live-weight loading on the soil by grazing animals impacts on soil structure causing a decline in macroporosity, restricting air and water movement through the soil and reducing pasture growth (Greenwood and McKenzie, 2001; Mackay, 2008). Soil compaction may also have a negative effect on invertebrate populations (Clapperton et al., 2002; Cole et al., 2008; Hassink et al., 1993; Schon et al., 2008; Yeates et al., 2002). The resistance of soil invertebrate communities to stock treading depends on a number of factors including livestock type and density, soil type and its susceptibility to compaction, as well as attributes of the soil community itself (Greenwood and McKenzie, 2001; Hewitt and Shepherd, 1997; Odum, 1985; Wardle, 2002). For example, earthworms are ecosystem engineers (Jones et al., 1994) with ability to restore their habitats. They may, therefore, be more resistant to livestock treading than invertebrates such as Oribatida, which are not ecosystem engineers, but depend on existing habitable pores (Elliott et al., 1980).

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Associated with increased pasture production from nitrogen (N) and phosphorus (P) fertiliser in grazed pastures, are higher livestock loadings on soils. Further, with more organic matter cycled through animal defecation, nutrients are cycled more quickly through the soil-plant system (Ruess and Seagle, 1994). This can stimulate components of soil invertebrate communities by providing greater food resources (Cole et al., 2005; Curry et al., 2008; Oliver et al., 2005; Yeates, 1976). In pastures where food availability is not limiting, invertebrates may be more resilient following the removal of treading pressures (Bardgett et al., 2005; Wardle, 2002). The resilience of an invertebrate community is influenced by the dominant species and trophic interactions, with short-lived species, typical of disturbed systems, being more resilient than longer-lived organisms (Wardle, 2002).

This study examined the vulnerability of soil invertebrate community to livestock in grazed pastures on three different soils. The sensitivity of invertebrates to livestock was examined by comparing each grazed pasture with adjacent permanent fence lines, where livestock could not tread and where dung and urine were not returned. The resilience of the invertebrate community in each grazed pasture was also examined with reference to mown and irrigated plots located within each field, where moisture and nutrients had been non-limiting for the previous three years, providing optimal conditions for invertebrate recovery. It was expected that different invertebrates would behave differently in response to livestock, but that effect of livestock would be consistent across all three sites, despite differences in soils and climate. Further, it was expected that different combinations of N and P fertiliser would impact on the soil invertebrates.

2. Materials and methods

2.1. Study sites

Samples were collected during winter and early spring of 2007 from three long-term (>50 years) pastures located in three separate regions throughout New Zealand. The sites spanned a distance of approximately 1000 km North to South. The northern-most site was located in the Waikato region on an Andosol (FAO) or Allophanic soil (NZSC). Further south, the site in the Manawatu region was located on a Luvisol (FAO) or Pallic soil (NZSC). The southern-most site was located in Southland on a Cambisol (FAO) or Brown soil (NZSC). All sites were located on lowland and had mixed ryegrass (*Lolium perenne*) and clover (*Trifolium repens*) pastures. For further details of the sites see Table 1.

At each site a grazed paddock, a permanent fence line, and an adjacent irrigated mowing trial were sampled (Fig. 1). The permanent fence line was a paddock boundary fence which was in place well before the trials were established in 2004. The fence lines were not affected by livestock treading, irrigation, or nutrient return in dung or urine, but received fertiliser through drift. The area under the fence line was approximately 30 cm wide and hundreds of metres long; while it would have been preferable to have a wider field margin, in these systems this is the best long-term area where there is grazing but no livestock treading or nutrient return in dung and urine. Ruminants defoliated pasture under the permanent fence when grazing in the paddock at the Waikato and Manawatu sites, but could graze under the permanent fence line from one side only (rather than from paddocks on both sides) at the Southland site. The grazed pastures were all approximately 1 ha in size, received annual maintenance fertiliser, but were not irrigated. Pastures had been grazed uniformly year round with ruminants for over 50 years.

The mown, fertilised and irrigated plots (0.17 ha) had been established on existing grazed pastures in 2004. The plots were fenced to exclude livestock, and had four fertilizer treatments: high P/high N, high P/low N, low P/high N, low P/low N. Phosphorus fertiliser was applied as superphosphate to achieve target low and high soil Olsen P levels, and N fertiliser applied as urea at 0 and 400 kg N ha^{-1}. There were four replicates of each of the four treatments. The plots were irrigated during summer months to prevent limitations due to moisture stress, mown 10–14 times throughout the year with a domestic rotary mower, and received potassium fertiliser every three months and a basal fertiliser every six months.

2.2. Soil biological sampling

Four cores for macrofauna (Ø 15.5 cm, 0–15.5 cm deep) were collected from under the fence line and in the grazed paddock. Eight cores were collected from the mown area adjacent to two out of four fertiliser replicates. Macrofauna cores were hand-sorted, and specimens identified in the laboratory.

Four soil cores for mesofauna (Ø 5 cm, 0–7.5 cm deep) were collected from under the fence line and in the grazed paddock, and two cores were collected from each fertiliser replicate. Mesofauna were extracted using a modified Berlese–Tullgren apparatus, for details see Schon et al. (2008). Four composite soil samples for microfauna (nematodes) (each comprising 5 cores Ø 2.5 cm, 0–7.5 cm deep) were collected from the fence line and grazed paddock, and one composite sample was collected from each fertiliser replicate. Nematodes were extracted by the modified tray method described by Yeates (1978).

The Shannon–Wiener diversity index (H′), Margalef's richness (SR) and Pielou's evenness (J′) were calculated to describe the diversity of soil fauna (Ludwig and Reynolds, 1988; Yeates, 1984).

Soil microbial biomass was measured using a substrate induced respiration method. Four composite samples (10 cores pooled, each core Ø 2.5 cm, 0–7.5 cm deep) were collected from under the fence line and in the grazed paddock, one composite sample was collected from each fertiliser replicate. Samples were sieved to <2 mm and the amount of CO_2 respired in two hours was estimated by collecting 25 ml gas in a syringe and empty it into a pre-evacuated Exetainer® for analysis in a Shimadzu-20190 gas chromatograph (Shimadzu Scientific Instruments, Columbia, USA), for detailed methodology refer to Schon et al. (2010).

2.3. Soil and pasture sampling

Soil temperature (Checktemp, Hanna Instruments, England) and moisture (TDR 300 Soil Moisture Probe, Spectrum Technologies, Inc., USA) at 0–10 cm depth were recorded in the field at the time of sampling. After extraction the mesofauna cores were analysed for soil pH (1:2.5 soil:water), Olsen P (Olsen et al., 1954), total N and total carbon (C) (dry combustion using LECO-2000, LECO Equipment Corp., St. Joseph, USA). Bulk density was determined by collecting three intact soil cores from the fence line, grazed paddock and mown area (Ø 10 cm, 0–7.5 cm depth), drying (105 °C) and weighing.

Pore size distribution for pores Ø <60 μm was determined using tension plates (Schon et al., 2010). Tensions of 10, 50, and 1500 kPa equated to pore sizes of 30, 6, and Ø 0.2 μm, respectively. Larger pores (Ø >50 μm) were characterised in the Manawatu soil using fluorescent resin. Three Ø 15 cm cores were collected from each area (fence line, grazed paddock and mown area) in 2009 when soil moisture was <40%. The cores were impregnated with a fluorescent resin, and images of horizontal soil sections at 2.5 and 5 cm depths were analysed using Solicon© analysis software (The University of Sydney, Cotton Research and Development Corporation) (Vervoort and Cattle, 2003). Nematode body widths tend to be <100 μm (Swift et al., 1979). Acari and Collembola body widths tend to be <2000 μm (Swift et al., 1979), with small, short-lived oribatids regarded as