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Short communication

Grazing exclusion affects soil and plant communities, but has no impact on soil carbon storage in an upland grassland

Eduardo Medina-Roldán[a,*], Jorge Paz-Ferreiro[a,b], Richard D. Bardgett[a]

[a] Soil and Ecosystem Ecology Laboratory, Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, United Kingdom
[b] Departament of Edaphology, Escuela Técnica Superior de Agrónomos, Universidad Politécnica de Madrid, Madrid 28043, Spain

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ABSTRACT

We evaluated the impact of 7 years of grazing exclusion on vegetation and belowground properties related to soil carbon (C) and nitrogen (N) cycling in grazed, upland grassland in northern England. For this, we compared a landscape-level, moorland restoration project (grazing exclusion) with adjacent continuously grazed acidic grasslands to test whether changes in vegetation composition after restoration impacted on soil properties including soil C storage. Grazing exclusion significantly increased the proportion of dwarf-shrubs at the expense of graminoids. Despite high seasonal variability, this change in vegetation was associated with increased plant litter mass, soil moisture content and the ratio of dissolved organic to inorganic N, and reductions in rates of ammonium mineralisation, soil microbial activity, and microbial biomass N. Our observations suggest that grazing-exclusion as a restoration tool for upland habitats results in a slowing down of rates of C and N cycling. However, as yet, this has had no detectable impact on total C and N stocks in surface soil. Whereas increases in soil C and N stocks might be expected in the longer term, our results suggest that a certain level of grazing is compatible with the provision of ecosystem services such as soil C storage under traditional upland farming practices.

1. Introduction

Despite their limited agricultural value, British upland ecosystems show a long history of land use (Simmons, 2003), particularly grazing management (Anderson and Yalden, 1981; Done and Muir, 2001). Effects of grazing on upland ecosystems include the replacement of vegetation dominated by *Calluna vulgaris* and other dwarf-shrubs (moorlands) by acidic, low productivity grasslands of a lower conservation value (Bardgett et al., 1995; Thompson et al., 1995). Herbivore exclusion is a common practice to restore moorlands, but its effects on ecosystem services related to soil carbon (C) and nutrient cycling has been poorly studied in upland habitats. Such lack of knowledge occurs despite the recognition that upland habitats represent one of the UK's largest stores of soil C (Milne and Brown, 1997), and their status as sensitive habitats (Thompson et al., 1995).

Here, we assessed 7 years of grazing exclusion on vegetation biomass (aboveground and belowground), plant functional group composition, and soil properties, including biomass and activity of soil microbes, rates of soil N mineralisation, concentration of soluble C and N forms, and total contents of C and N. Our sampling included seasonal variability in order to determine grazing-exclusion effects against seasonal variation. We tested the hypothesis that grazing-exclusion is associated with a slowing-down in soil N and C cycling, characterised by reductions in rates of N mineralisation and microbial activity, and an increase in soil C and N content.

2. Materials and methods

2.1. Site description and experimental design

In 2007, we selected 2 adjacent areas with similar topography and altitude, but with contrasting recent grazing management in the Ingleborough National Nature Reserve in the Yorkshire Dales northern England (54.18°N, 2.36°E, Fig. 1, climate is temperate maritime, mean annual precipitation is 1840 mm). One area (hereafter grazed area) is a 58 ha acidic grassland dominated by *Nardus stricta* L., *Festuca ovina* L., *Agrostis capillaris* L., with a minor presence of *Eriophorum vaginatum* L. The grazed area was grazed at

* Corresponding author. Tel.: +44 01524592935.
E-mail address: e.medina@lancaster.ac.uk (E. Medina-Roldán).

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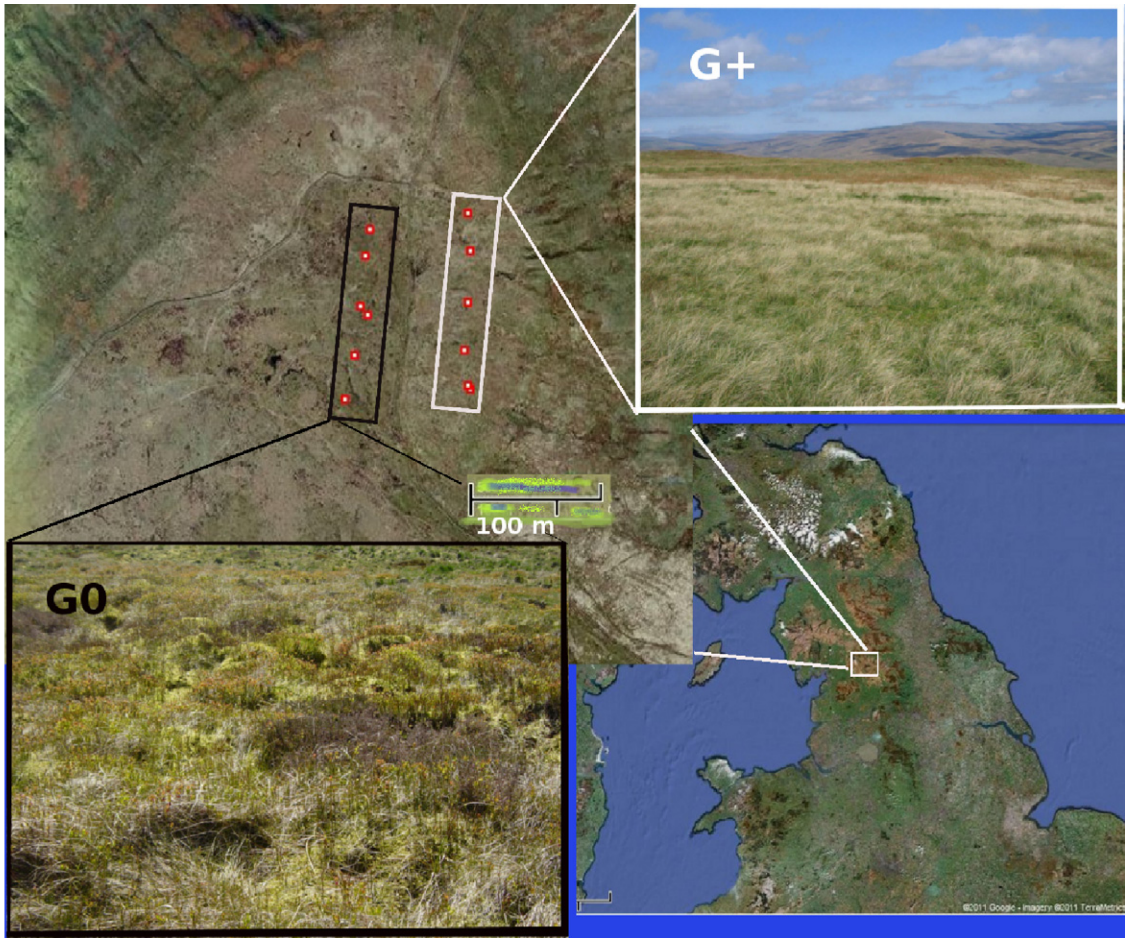

Fig. 1. The field site at Ingleborough National Nature Reserve, northern England, showing the approximate location of the experimental plots as determined by geographical positioning (red squares), and the main vegetation characteristics of an area where domestic herbivores have been excluded over 7 years (G0) and an adjacent grazed acidic grassland (G+). Images obtained from http://maps.google.com/(© Google 2011) and authors' own collection.

1–3 ewes ha^{-1} before 1996, but at 4 ewes ha^{-1} since then, with some cattle grazing for 10 weeks since mid-July onwards (Colin Newlands, Natural England, *pers. comm.*). Winter grazing stocking rate is 1.5 ewes ha^{-1} from early November until mid-March. The other area (hereafter grazing exclusion) is an adjacent 170 ha field fenced off in 2000 to exclude livestock to re-establish moorland vegetation. Soils in both areas are derived from carboniferous sandstones in the Yoredale group (Waltham, 2008), pH of 4.5 (triplicate measure in 1:2.5 soil to water suspensions), and have an organic horizon of 20–30 cm. Neither area has received artificial fertilisers or manures.

Since the restoration project was done at the landscape level, pseudo-replication was unavoidable. We randomly set up, 6 plots (4 m × 4 m) along a NW-SE transect within each area. Plots selected had representative vegetation, similar soil depth (40 cm on average), and were located at similar topographical positions in both areas (Fig. 1). Each replicated plot was split into 16 1 m × 1 m sub-plots wherein all soil and vegetation samples were randomly taken.

2.2. Soil and vegetation sampling

On each of 5 dates from mid spring 2007 until early summer 2008, we excavated a turf including vegetation and the organic peat horizon (20 cm × 20 cm area, 20 cm depth) from each sub-plot with a shovel. Samples were kept within coolers, transported, and stored at 4 °C, then analysed within 5 days after collection. Root biomass was measured from two soil cores (10 cm depth within the organic horizon since high moisture made recovery of intact soil cores from higher depths infeasible) adjacent to sub-plots. We inserted perforated PVC pipes (21 mm diameter × 1000 mm length) on each plot to record two-weekly water table depth (Oechel et al., 1998) from mid July until mid November 2007.

2.3. Aboveground and belowground biomass, and size of litter horizons

After being oven-dried at 70 °C for 48 h and weighed, dry mass pools of sampled turves were divided into 4 components following Ward et al. (2007): (1) aboveground plant biomass; (2) litter (L) horizon underlying vegetation; (3) a horizon (F + H not recorded on the second date) with unidentifiable plant residues and humified material; and (4) the organic horizon (O). Aboveground plant biomass was sorted into plant functional groups (Ward et al., 2009), namely graminoids, dwarf-shrubs, forbs and non-flowering plants including mosses and clubmosses (*Lycopodium* sp.). Roots were recovered by washing and sieving (minimum mesh size 0.5 mm) soil cores, then oven-dried and weighed to determine root biomass.