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Rewilding the uplands: the effects of removing sheep grazing on soils and plants

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Summary

Rewilding the uplands almost inevitably involves the removal of grazing livestock. Whilst the concept of rewilding is gaining in popularity there is very little evidence about the likely outcomes or over the time-scales that any change might happen. Here, we report preliminary results from a recent study of eight long-term experiments at Moor House NNR in the north-Pennines, where permanent plots with- and without-sheep grazing were established between 1954–67 on a range of typical upland plant communities. Soils and vegetation were sampled and their chemical properties analysed were found. No significant differences in soil properties, above-ground biomass or the nutritional status of the vegetation. The above-ground biomass was correlated with altitude suggesting that climate was a more important driver than sheep grazing pressure. Assuming that the results scale-up from these small-scale experiments to the landscape scale, these results suggest that rewilding the uplands by reducing sheep densities to zero will have little impact in the short- to medium-term on soil or vegetation nutritional properties.

Key words: Soil nutrition, biomass, herbage, plant nutrition, sheep grazing, exclosures

Introduction

Much of the current debate about rewilding is focussed on reducing in stock grazing pressures, especially in upland areas (Monbiot, 2013). This reduction in grazing pressure could be brought about by managed reductions or by the introduction of apex predators. Unfortunately, we know relatively little about the long-term effects of reducing stock grazing pressures, especially to zero, and specifically how long it will take for any change in sheep-grazing reduction to take effect. One way of starting to gain an understanding of the processes involved is to measure change in long-term exclosure experiments set up to assess the impacts of removing stock grazing altogether. One good example of a series of experiments are those set up on Moor House NNR between 1954 and 1972. This suite of experiments, each with a sheep-grazed plot and ungrazed comparator were distributed across the reserve to assess the effects of grazing *vs* grazing removal on a series of community types that encompass a large variation of plant communities found across upland Britain. The plant communities also occur on a range of soil types from deep blanket peat through to brown-earth soils, and are subject to very different sheep grazing pressures (Eddy *et al.*, 1968; Rawes & Welch, 1969). It is of course accepted that not all community-types found in upland Britain (Averis *et al.*, 2004) were available to be included.

However, even such simple experiments are not without their complications. For example, in the early years, detailed studies by Rawes & Welch (1969) estimated that there were 15,400 sheep on the reserve in the summer months. Assuming a grazing area of 3500 ha, this averaged out at 4.4 sheep ha^{-1} across all vegetation types. In 1972, after the formalization of grazing rights under the Commons Registration Act (1965), grazing density was more than halved to 7000 sheep or 2 sheep ha^{-1}. Thereafter, in the early 2000s following the outbreak of Foot and Mouth disease in 2002 some common grazing rights were bought up by Natural England and grazing pressure has been reduced again to *c*. 3500 sheep or 1 sheep ha^{-1}. Hence, here we are comparing an "uplands business-as-usual" scenario, i.e. a reducing sheep grazing pressure against no sheep grazing. Moreover, it is well known that the sheep distribute themselves according to forage quality on this reserve (Rawes & Welch, 1969).

These experiments were set up to measure changes in species composition through time, and some preliminary studies have already been published (Rawes, 1981, 1983; Marrs *et al.*, 1988; Lee *et al*., 2013) and an holistic analysis of change up to the year 2001 (Milligan *et al.*, 2016). The latter study concluded that in the sheep-grazed plots there was a reduction in species diversity, in abundance of vascular plants, grasses, lichens, liverworts and mosses; whereas herbs, sedges and shrubs increased. Removal of sheep grazing had some positive benefits; with the herbs, mosses, sedges and shrubs increasing, but with reductions in grasses and liverworts compared to their grazed counterparts. However, these experiments also provide an opportunity to assess how the reduction in sheep grazing has changed other aspects of these grazed ecosystems and how they might be affected by the removal of sheep grazing, for example soil properties and herbage production. A study of this was carried out in the mid-1980s when few significant differences were found between the nutrient concentrations in the grazed and ungrazed plots within each experiment (Marrs *et al.*, 1989). With the current interest in rewilding this study was revisited in 2015 after a further 30 years. We hypothesised that with a reduced nutrient offtake, where there is no sheep grazing, we would expect the vegetation to become more nutritious and more palatable to grazers relative to the sheep-grazed situation and the soil fertility to increase. Accordingly, here we test this hypothesis by assessing the effects of sheep grazing *vs* no sheep grazing on selected soil properties and herbage biomass.

Materials and Methods

Experimental design

Nine experiments were located across the Moor House reserve to cover the range of variation in moorland vegetation, from relatively productive *Agrostis-Festuca* grassland on brown-earth soils and a calcareous flush at the neutral end of the soil spectrum through grasslands dominated by *Festuca ovina* or *Nardus stricta*, to rush (*Juncus squarrosus*), sedge (*Eriophorum* spp.) and dwarf shrub *Calluna vulgaris, Erica tetralix* or *Empetrum nigrum*-dominated vegetation on blanket bog (least productive). Exact locations and plot details are shown in Table 1 and Supporting Information (Fig. S1). Species nomenclature follows Stace (2010), Atherton *et al*. (2010) and Dobson (2000) for vascular plants, bryophytes and lichens respectively.

Eight NVC plant community types (Table 2) were covered but the range of experiments ranging from blanket bog mire communities (M19, M20), upland grasslands (U5, U6), an upland heath community (H19), calcareous grassland (CG10) and a flushed community (M38). All of the communities showed a high goodness-of-fit for compositional satisfaction but a lower value for mean constancy, implying that a reasonable number of the constant species were present, but the vegetation is relatively species-poor (Hill, 2015). There was a discrepancy (Table 2) between the original description of Festucetum for Hard Hill and Little Dun Fell (Eddy *et al.*, 1968) which was classified as H19 (*Vaccinium myrtillus-Cladonia arbuscula* heath: *Festuca ovina-Galium saxatile* sub-community). The vegetation at both sites included all four of these species; *Festuca ovina*, *Galium saxatile* and *Cladonia arbuscula* are dominants; *Vaccinium myrtillus* is present, but less abundant.

At each location an experiment was set up of paired plots (between 10 m × 10 m and 30 m × 30 m) with one being fenced to exclude sheep and the other left open to allow free range grazing. Sheep grazing densities were estimated during the International Biological Program in the late 1960s (Table 1, Rawes & Welch, 1969). In this investigation the experiment at Moss Burn was not studied as its fences were removed in 2013 to encourage the rare *Saxifraga hirculus* which had disappeared as a result of the lack of sheep grazing (Milligan *et al.*, 2016). Detailed descriptions of vegetation change within these experiments have been published elsewhere (Rawes, 1981; Rawes, 1983; Marrs *et al.*, 1988; Milligan *et al.*, 2016).

Vegetation and soil sampling and processing

In late June 2015, four random positions were located in both the enclosed and grazed plots at each experimental location. At each position, the surface vegetation was harvested with secateurs to ground level within a 0.25 m^{-2} quadrat and two soil cores taken (1 cm diameter, 21 cm depth) and pooled. The harvested material was transported to the laboratory and weighed to determine fresh weight. A sub-sample was removed randomly for sorting to species level and the fresh weight of both the sample for sorting and the residue were determined. Both the residue and the sorted fractions were dried at 80°C for 3 days and dry weight measured. Dry mass was re-calculated as g m^{-2}.

The chemical properties of vegetation and soil samples were determined using methods described by Allen (1989). Vegetation was ground to pass a 1 mm sieve and the concentrations of C, N, P, K, Ca, Mg and Na measured using the dry-ashing method (Allen, 1989). For soils the following properties were measured: soil pH, soil available N nitrogen (NH_4-N and NO_3-N) and P and exchangeable K, Ca, Mg and Na. These were assessed on fresh soils using 2M KCL as the extractant for available N and 2.5% vol:vol acetic acid for both available P and the cations. Thereafter the soil was oven-dried and ground to pass a 1 mm mesh. Total N and C determinations were made using a Thermo Scientific Flash 2000 Organic Elemental Analyser; NH4-N and NO_3-N and P were analysed by colorimetry (P) on a Seal Analytical AA3 HR AutoAnalyser and cations by both absorption (Ca and Mg) and emission spectrophotometry (K and Na) on a Thermo Electron Corporation Solaar S4 AAS.

Statistical analysis

All analyses were performed in the R statistical environment (R Core Team, 2017). The main problem in analyzing data from these individual experiments is that they are unreplicated with only one sheep-grazed plot and an equivalent ungrazed exclosure in each experimental location (Marrs *et al.*, 1988; Milligan *et al.,* 2016). Here, we have analyzed the eight experiments together as a randomized block experiments with the sites as blocks and the grazed/ungrazed plots as treatments; the analysis was performed on the mean data per plot to avoid pseudoreplication issues. A secondary issue is that experiments have been run for different periods of time, but any temporal effect will be site-specific and will be included within the site effect. Here, analysis of variance and its interpretation was performed using the 'aov' function in R. Model reduction *sensu* Crawley (2013) was performed using the 'anova' function and differences between sites and grazing treatments were assessed using the 'TukeyHSD' function. QQ-plots were inspected to assess normality and transformations used as necessary ($\log_e x$ and arcsin for percentages). Rank correlation coefficients (Kendall's tau) were calculated between herbage and soil chemical variables using the 'cor.test' function.

Results

Changes in soil properties

There were no differences in any of the soil properties measured between the grazed and ungrazed treatments, but highly significant differences for all soil variables between experiments (Soil pH, $F_{7,8}$ = 59.88, *P*<0.0001; Total C, $F_{7,8}$ = 46.09, *P*<0.0001; Total N, $F_{7,8}$ = 8.156, *P*=0.0041; C:N, $F_{7,8}$ =

33.96, $P<0.0001$; Available NO_3-N, $F_{7,8} = 12.1$ $P=0.0011$; Available NO_3-N $F_{7,8} = 7.292$ $P=0.0059$; available P, $F_{7,8} = 20.33$, $P=0.0002$; exchangeable K, $F_{7,8} = 8.737$, $P=0.0033$; exchangeable Na, $F_{7,8} = 6.374$, $P=0.0091$; exchangeable Ca, $F_{7,8} = 4.167$, $P=0.0315$; exchangeable Mg, $F_{7,8} = 5.492$, $P=0.0143$).

The soil chemical properties reflected a change across the bog-grassland transition (Fig. 1). Soil pH was low (mean <4.0) in all sites except the Knock Fell *Agrostis-Festuca* grassland (mean±SE, 5.3±0.3). Total soil C was greatest in the Bog sites and Cottage Hill (*Juncus squarrosus* grassland), intermediate in the *Nardus*- and *Festuca*-dominated grassland (means all > 20%) and lowest in the *Agrostis*-Festuca grasslands at Knock Fell (5.0±0.2%). Total soil N showed a similar pattern. The C:N ratio showed a clear transition from the bog sites (mean > 30%), the *Juncus*-, *Nardus*- and *Festuca*-dominated grasslands between 19–24% and Knock Fell the lowest at 11.4±2.8%.

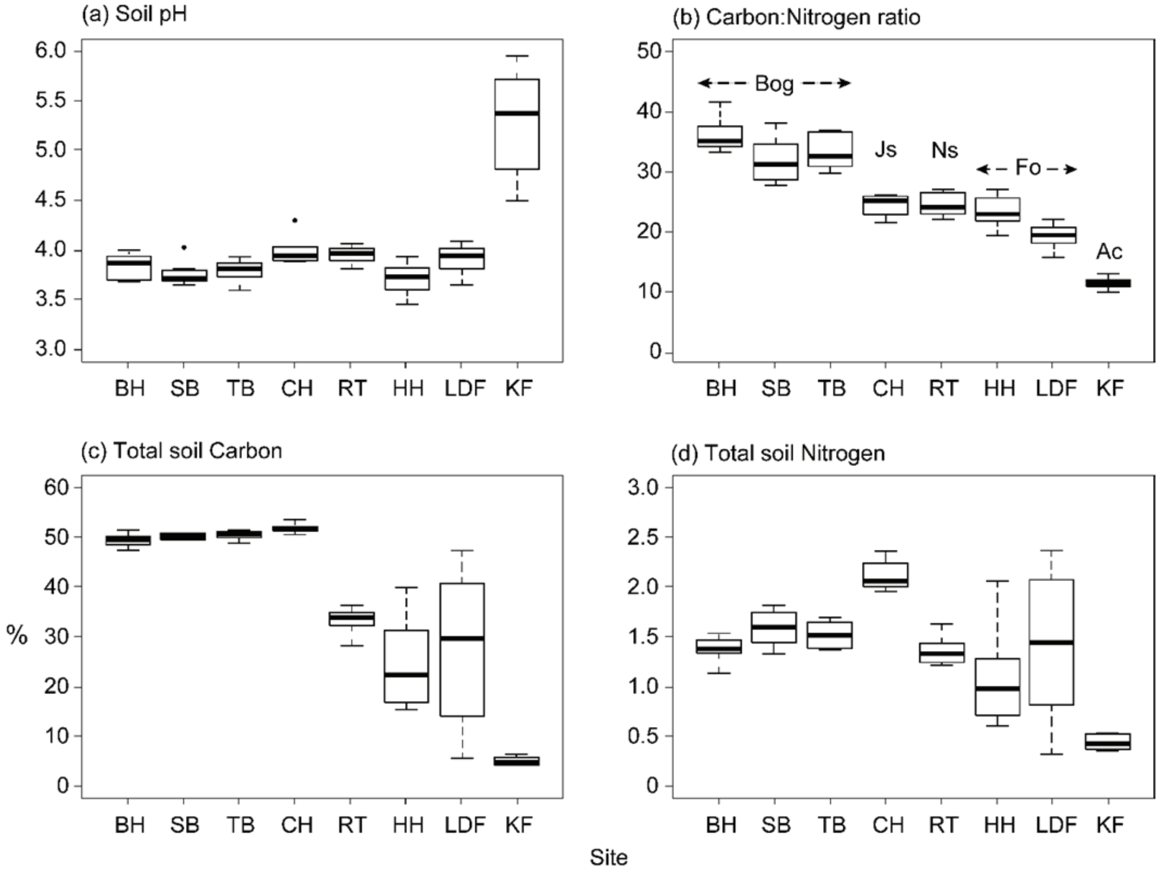

Fig. 1. Chemical properties of soils in the long-term sheep-exclosure experiments at Moor House NNR: (a) soil pH, (b) total soil carbon, (c) total soil nitrogen, (d) soil C:N ratio. Site codes: BH = Bog Hill, SB =- Silverband, TH = Troutbeckhead, CH = Cottage Hill, RT = River Tees, HH = Hard Hill, LDF = Little Dun Fell and KF – Knock Fell. Main vegetation types are denoted: Bog *Calluna/Eriophorum*, Js = *Juncus squarrosus*, NS = *Nardus stricta*, Fo = *Festuca ovina* and Ac = *Agrostis capillaris*.

Changes in above-ground vegetation

Like the soils, there were no differences in either the herbage biomass or the chemical variables measured between the grazed and ungrazed treatments. The herbage biomass showed marginally significant differences between sites ($P<0.03$); highly significant between-site differences for C, C:N, P and K ($P<0.01$), marginal differences for N ($P=0.02$) and no significant differences Ca, Mg and Na ($P>0.05$).

The herbage biomass showed no consistent trend with respect to community with low values in Silverband (recovering bog) and the *Festuca*- and *Agrostis*-dominated grasslands at Little Dun Fell and Knock Fell respectively (Fig. 2a). There was, however, a significant negative relationship with elevation (Fig. 2b, regression equation: Herbage yield (g m^{-2}) = 6113.396 - 6.526 × Elevation (m); $F_{1,6} = 20.88$, $R^2_{adj} = 0.7396$, $P=0.0038$. The herbage biomass at the lowest elevations was *c*. 3000 g m^{-2} reducing to *c*. 1000 g m^{-2} at the higher elevations.

Table 1. *Description of the eight monitored sheep-grazing experiments at Moor House NNR in north-west England*

Site Name	Site code	British National Grid reference	Elevation (m)	Year established	Vegetation type according to (Eddy *et al*., 1968)	NVC type according to Milligan *et al.* (2016). (Mean Goodness of fit)	NVC description	Total area of pure stands of the vegetation types on the Moor House reserve (ha)	**Sheep Grazing Density (sheep ha^{-1})
Bog Hill	BH	NY 76789 32869	550	1953	*Calluna-Eriophorum*	M19 (68%)	*Calluna vulgaris-Eriophorum vaginatum* blanket mire	1169	nd
Silverband	SB	NY 71059 30975	690	1966	Eriophoretum (eroding)	M20b (71%)	*Eriophorum vaginatum* blanket and raised mire: *Calluna vulgaris-Cladonia* spp. sub-community	323	0.25
Troutbeck Head	TB	NY 72236 31760	690	1966	Eriophoretum	M20b (73%)	As above	419	0.5
Cottage Hill	CH	NY 75801 33641	550	1967	*Juncus squarrosus* grassland	U6b (61%)	*Juncus squarrosus-Festuca ovina* grassland: *Carex nigra-Calypogeia trichomanis* sub-community	373	1.4
River Tees	RT	NY 74796 34485	550	1967	*Nardus stricta* grassland	U5 (73%)	*Nardus stricta-Galium saxatile* grassland	416	2.8
Hard Hill	HH	NY 72576 33034	690	1954	*Festucetum*	H19a (61%)	*Vaccinium myrtillus-Cladonia arbuscula* heath: *Festuca ovina-Galium saxatile* sub-community	180	2.6
Little Dun Fell	LDF	NY 70475 33104	830	1954	*Festucetum*	H19a (63%)	As above	-	5.8
Knock Fell	KF	NY 71794 31267	750	1955	Limestone Agrosto-Festucetum	CG10 (55%)	*Festuca ovina-Agrostis capillaris-Thymus praecox* grassland	125	5.8

*The total area of these communities makes up 3019 ha, i.e. 79% of the reserve area of 3842 ha, the remaining vegetation comprised predominantly re-colonising peatland, sandstone scree and mosaics of the above vegetation classes (Eddy *et al.*, 1968).

**Sheep grazing density was determined by dropping volume measurement (Rawes & Welch, 1969); data were not available for one site (nd).

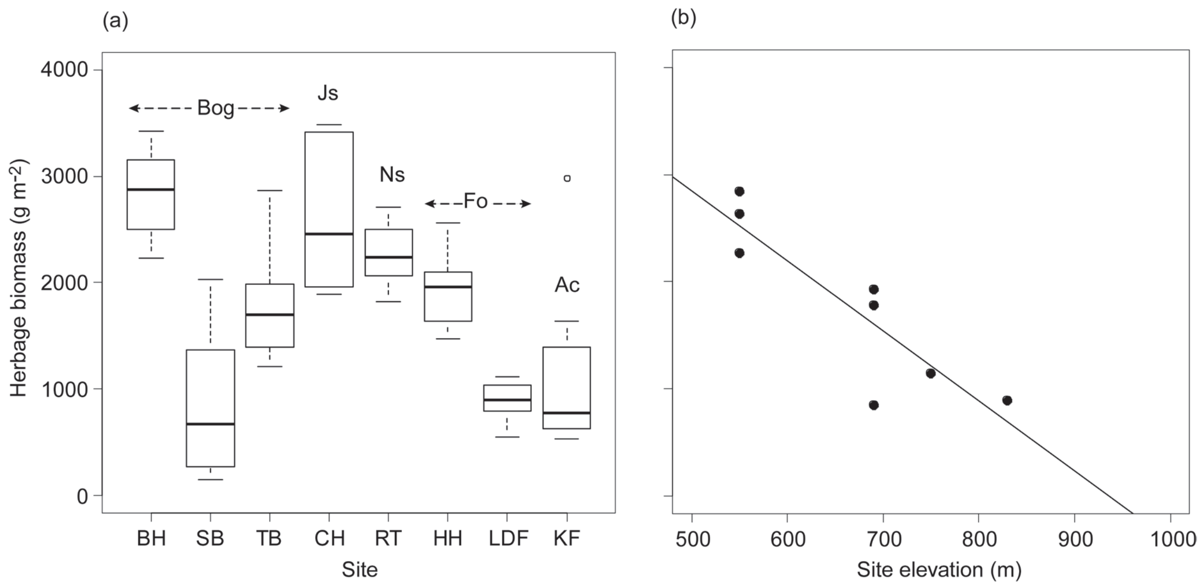

Fig. 2. Herbage biomass in each of the long-term sheep-exclosure experiments at Moor House NNR: (a) by site, and (b) with respect to elevation. Site codes: BH = Bog Hill, SB =- Silverband, TH = Troutbeckhead, CH = Cottage Hill, RT = River Tees, HH = Hard Hill, LDF = Little Dun Fell and KF – Knock Fell. Main vegetation types are denoted: Bog *Calluna/Eriophorum*, Js = *Juncus squarrosus*, NS = *Nardus stricta*, Fo = *Festuca ovina* and Ac = *Agrostis capillaris.*

Correlations between soil and herbage plant nutrient concentrations

There were significant positive rank correlations (P<0.0003) between herbage chemical properties and some soil variables total C, C:N ratio, exchangeable K and available as NO_3-N, NH_4-N and the summed total of available N; no significant correlation was detected with soil total N, available P and exchangeable Ca, Mg or Na.

Discussion

In the previous study of soil and plant chemical composition attention was drawn to a series of limitations, viz. lack of within-habitat replication, no baseline data and the fact that elemental data are expressed on a concentration basis. These criticisms remain but the results from these experiments do provide an unique assessment of potential changes in the nutritional status of soils and plants when sheep grazing is removed from upland landscapes, as has been proposed in rewilding policies (Monbiot, 2013). Such policies are intended to reverse the perceived current depauperate status of many upland plant communities, which has been ascribed to past and current (over)-grazing policies.

The previous analysis of the soil chemical variables (Marrs *et al*., 1989) showed large site differences but few and inconsistent differences between sheep-grazed and ungrazed sites. This result was confirmed here with no significant differences detected between the two treatments for any soil variable.

For herbage, there was a different outcome between the two surveys. Marrs *et al*. (1989) showed differences between the above-ground biomass in five of the eight experiments. These differences were not detected in this investigation. The only significant differences were between experiments and this appeared to be correlated with elevation rather than grazing treatment. This suggests that climatic conditions, i.e. comparatively warmer and drier conditions at the lowland sites and cooler and wetter conditions at the higher elevations, are the factors that control plant production. Data for the elemental concentrations were not available for the above-ground vegetation from the 1980s, because in that study the vegetation was sorted into individual species and each was analysed separately. Nevertheless, in this study there were no significant differences in elemental concentrations between grazed and ungrazed plots.

Taken together, the results for soils, plant production and plant nutritional state all indicate that there is a great inertia in soil-plant relationships when sheep grazing is removed. Whilst various components of the plant community have been shown to change in the ungrazed plots in these experiments relative to the "business-as-usual" sheep-grazing scenario, viz. reductions in species diversity, abundance of vascular plants, grasses, lichens, liverworts and mosses but increases in herbs, sedges and shrubs (Milligan *et al*., 2016, but these changes in species and species groups are not sufficient as yet to change the above-ground biomass, soil fertility or the nutritional state of the vegetation.

Essentially, even complete removal of sheep grazing in many plant communities in upland Britain suggested under some rewilding schemes (Monbiot, 2013) will have little material effect on soils in periods of up to the 60 years sampled here. It is possible of course that some changes might be detectable using more subtle approaches, i.e. using microbiological or molecular methodologies (e.g. De Vries *et al*., 2015; Fry *et al*., 2017) rather than the more traditional methods used here. It is also possible that the results of sheep removal from these relatively small-scale experiments will not scale up to the landscape scale, and to assess this long-term, landscape-scale experiments are needed.

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