BD5105 FINAL REPORT

APPENDIX 1

SYSTEM STUDY

INTRODUCTION

The study is sited on 71 ha of *Nardus stricta* dominated grassland at an elevation of 305-625 m above sea level, with annual rainfall *c.* 2000 mm, on the Cambrian Mountains in mid-Wales, UK (52˚22´N, 3˚46´W). Soils consisted of Stagnopodzols with peaty top soils of the Hiraethog and Hafren series, or shallow soils of the Powys series with bedrock at 30 cm. Following a long period of sheep grazing at 2.2-2.7 ewes ha^{-1} during the growing season, the site had been ungrazed from 1990 to 1994 and then grazed at a maximum stocking density of 1.0-1.5 ewes ha^{-1} until 2002. The site was formerly dwarf shrub heath, degraded by the past heavy grazing. The main objective was to reduce the abundance of *N. stricta,* to restore dwarf shrubs such as *Vaccinium myrtillus* and *Calluna vulgaris*, and maintain the diversity of other plant species. The vegetation most closely resembled the U5 *N. stricta – Galium saxatile* grassland, with vegetation similar to the U5a species-poor and U5b *Agrostis canina – Polytrichum commune* sub-communities represented (Rodwell, 1992).

In 2002, the area was divided into three blocks, each subdivided into four paddocks (12 paddocks in total). Four grazing treatments were applied from spring 2003 to autumn 2010, allocated randomly to paddocks and replicated over the three blocks. Treatments were low sheep (LS; 1.0 Welsh Mountain ewes per ha[a] for 10 months per year + lamb from May to August), high sheep (HS; 1.5 Welsh Mountain ewes per ha[b] for 10 months per year + lamb from May to August), cattle only (CO; 0.5 Welsh Black 2-year old heifers per ha[c] for 2 months in July and August) and mixed sheep plus cattle grazing (SC; low sheep + cattle). Only ewes with single lambs were returned to the paddocks after lambing. From 2010 to 2012 none of the paddocks were grazed, and the grazing regimes were then reintroduced for a further four years from 2013 to 2016. The regimes during the

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[a] *n* = 5-7 ewes per paddock
[b] *n* = 9-11 ewes per paddock
[c] *n* = 4 heifers per paddock

final four years were modified because they were applied by an independent grazier and it was not possible to exactly replicate the regimes applied when the site was occupied and managed by ADAS. During this period, ewes were taken off the paddocks for tupping as previously, but were not returned over winter. In 2016, attempts to turn out heifers on the paddock with SC treatment in Block 3 had to be abandoned because the heifers were behaving erratically and posed a safety risk. Data from this paddock in 2016 were therefore omitted from the analyses.

VEGETATION

Vegetation recording

For vegetation assessments, a grid of 1 x 1 m fixed quadrats at 75 m spacing was superimposed on the 12 paddocks. The original grid established in 2002 comprised 129 quadrats but this was reduced to 99 by 2010 due to loss of permanent markers. To compensate for this loss, a remarking exercise was carried out in 2012 to re-establish fixed markers at all quadrat locations. Data were available for analysis from 124 quadrats in this current phase of the project (2012 – 2016).

Vegetation recording in the paddocks was done during 5th to 23rd October in 2012 and 19th October to 3rd November in 2016. Each fixed 1 x 1 m quadrat was subdivided into 100 cells of 10 x 10 cm. Percentage top cover was estimated using a sighter with cross-wires in the centre of each cell and recording the plant species, plant litter and bare peat present at the cross-wire intersection. The presence of all plant species in each quadrat was also recorded. Some records were made at genus level if it was not possible to identify to species level in the field. The presence of four key species (*N. stricta*, *V. myrtillus*, *C. vulgaris*, *and Molinia caerulea*) in each 10 cm cell (local frequency) was recorded, along with the presence of any grazed shoots of these species in each cell. The maximum sward height at each of five locations within each quadrat was measured using a sward stick.

Data analysis

The analyses focussed on the effects of re-introducing the previous grazing regimes on the vegetation, and on any consequent changes in the vegetation during the period of grazing from 2012 to 2016. A more limited set of analyses was also carried out using the

99 quadrats available in both 2010 and 2012, to assess changes that had occurred during the period without grazing.

Treatment effects on the overall plant community were analysed by Partial Redundancy Analysis (pRDA) with 999 Monte Carlo permutations on log-transformed mean cover and paddock frequency (mean number of quadrats per paddock in which they were present) data, in which blocks were treated as covariables and the four grazing treatments as nominal variables. Analyses were carried out on 2012 and 2016 datasets separately. Preliminary Detrended Correspondence Analyses showed low species turnover (length of gradients <3 SD), indicating that linear models were suitable. Community analyses were done using Canoco v.4.5 software (ter Braak & Šmilauer, 2002).

Treatment and temporal effects on mean values per paddock for cover and local frequency (all subjected to arcsine $\sqrt{x}$ transformation), were assessed by repeated-measures Analysis of Variance using the General Linear Model procedure in Statistica v11 (Statsoft Inc, 2012). The same analyses were performed on paddock mean vegetation heights and coefficients of variation in height calculated at both paddock and local scales (the latter from the five measurements per quadrat). Treatment effects on grazing indices (percentage of shoots grazed) in 2016 were analysed using a mixed model Analysis of Variance using the General Linear Model procedure.

Results

In total, 58 species were recorded in 2012 and 61 in 2016. *Pleurozium schreberi*, *V. myrtillus*, *N. stricta*, *F. ovina*, and *Galium saxatile* were recorded most frequently (Annex 1).

In 2012 after the period without grazing, the LS treatment had a significant effect on species frequencies, and there was also a statistically significant effect of the four grazing treatments collectively (Table 1). The effect of SC was just outside the limits of statistical significance (P = 0.08). This trend was similar to 2010, at the end of the first period of grazing, when both treatments had an effect. Axis 1 separated LS from the other three treatments, while axis 2 separated SC (Figure 1). *G. saxatile* and *V. myrtillus* had high frequencies (present in more than 50% of quadrats) and tended to be more associated with LS, while less frequently occurring species associated with LS included *Festuca* *rubra* and the mosses *Dicranum* sp., *Aulacomnium palustre* and *Plagiothecium undulatum*. Species with high frequencies that tended to occur under the SC treatment were *Festuca ovina* and *Agrostis capillaris*, along with the sedges *Carex binervis*, *C. rostrata* and *C. echinata*.

In 2016 following re-introduction of grazing, LS still had a significant effect on the plant species frequencies, although the overall effect of the four treatments collectively was no longer significant (Table 1). The mosses *Hylocomium splendens*, *P. schreberi* and *Polytrichum* sp. tended to be associated with LS, as did the palatable grasses *A. capillaris* and *F. rubra*. In contrast, the mire vegetation was less associated with LS (as indicated by, for example, *Eriophorum vaginatum*, *E. angustifolium*, *Sphagnum* sp. and *Trichophorum germanicum*) (Figure 2).

There were no significant treatment effects on top cover of the overall plant community in either 2012 or 2016 (Table 1).

Table 1. pRDA results of 2012 and 2016 species frequency and cover. LS = low sheep only; HS = high sheep only; SC = sheep plus cattle; CO = cattle only. The fourth treatment in each analysis was the final nominal variable after forward selection and was not significant. $^{(*)}$ P<0.1, * P<0.05, ns not significant.

2012	**Frequency**			**Cover**	
Treatment	Lambda	F	Treatment	Lambda	F
LS	0.18	2.0*	LS	0.13	1.3 ns
SC	0.12	1.5$^{(*)}$	SC	0.10	1.0 ns
HS	0.07	0.7 ns	HS	0.08	0.8 ns
All treatments	Eigenvalue	F		Eigenvalue	F
Axis 1	0.18	1.4$^{(*)}$		0.14	1.0 ns
Overall	0.37	1.4*		0.31	1.0 ns

2016	**Frequency**			**Cover**	
Treatment	Lambda	F	Treatment	Lambda	F
LS	0.13	1.4*	CO	0.12	1.3 ns
SC	0.09	1.0 ns	HS	0.09	1.0 ns
HS	0.09	0.9 ns	LS	0.08	0.9 ns
All treatments	Eigenvalue	F		Eigenvalue	F
Axis 1	0.13	1.0 ns		0.14	1.1 ns
Overall	0.31	1.1 ns		0.29	1.0 ns

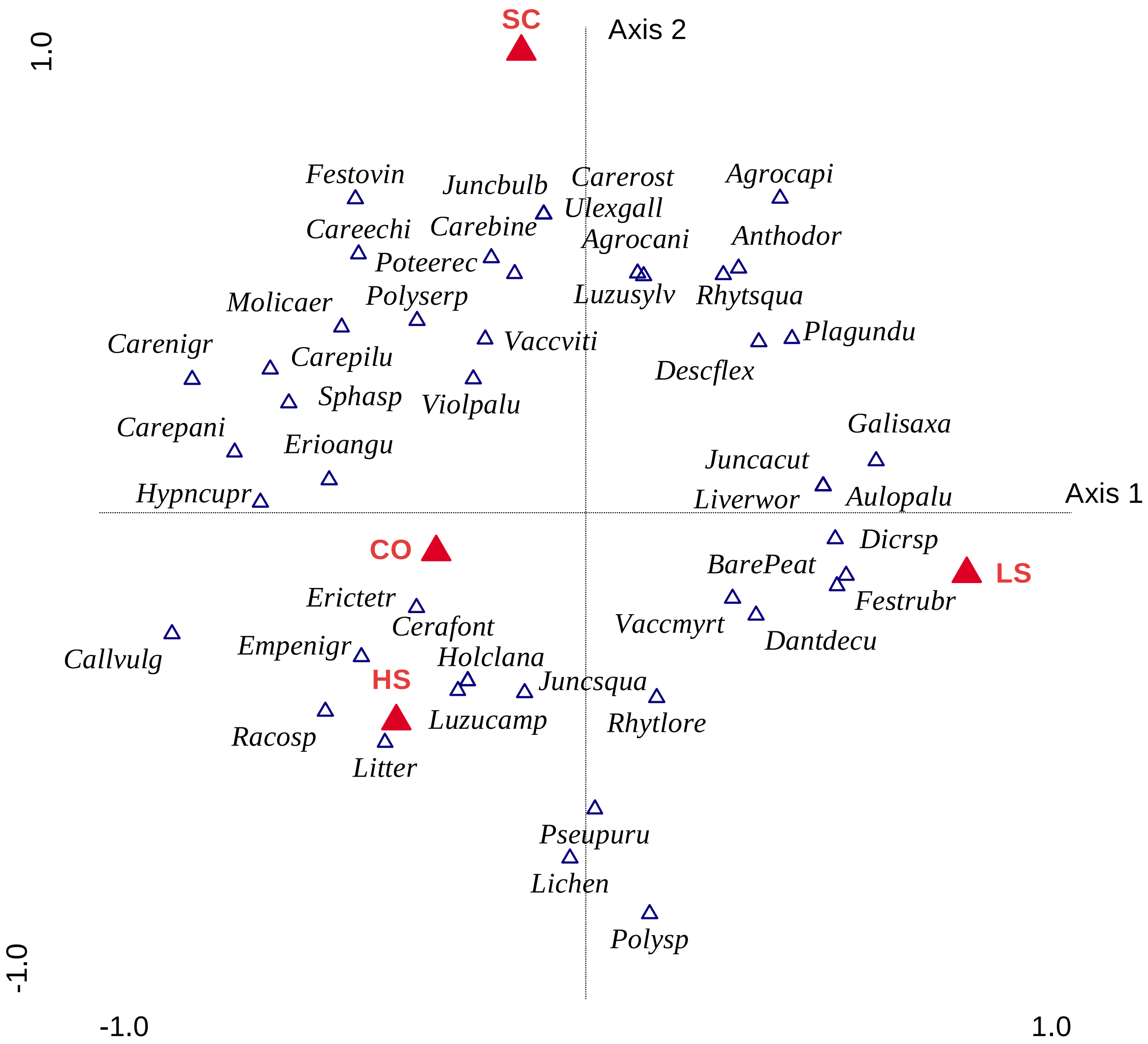

Figure 1. pRDA biplot of plant species frequencies and grazing treatments in 2012. Only species with fit >=10% shown for clarity. Treatment codes as Table 1. Species codes: Agrocani = Agrostis canina; Agrocapi = Agrostis capillaris; Anthodor = Anthoxanthum odoratum; Aulopalu = Aulacomnium palustre; Callvulg = Calluna vulgaris; Carebine = Carex binervis; Careechi = Carex echinata; Carenigr = Carex nigra; Carepani = Carex panicea; Carepilu = Carex pilulifera; Carerost = Carex rostrata; Cerafont = Cerastium fontanum; Descflex = Deschampsia flexuosa; Dicrsp = Dicranum sp.; Dantdecu = Danthonia decumbens; Empenigr = Empetrum nigrum; Erictetr = Erica tetralix; Erioangu = Eriophorum angustifolium; Festovin = Festuca ovina; Festrubr = Festuca rubra; Galisaxi = Galium saxatile; Holclana = Holcus lanatus; Hypncupr = Hypnum cupressiforme; Juncacut = Juncus acutiflorus; Juncbulb = Juncus bulbosus; Juncsqua = Juncus squarrosus; Liverwor = Liverwort; Luzucamp = Luzula campestris; Luzusylv = Luzula sylvatica; Molicaer = Molinia caerulea; Plagundu = Plagiothecium undulatum; Polyserp = Polygala serpyllifolia; Polysp = Polytrichum sp.; Poteerec = Potentilla erecta; Pseupuru = Pseudoscleropodium purum; Racosp = Racomitrium sp.; Ryhtlore = Rhytidiadelphus loreus; Rhytsqua = Rhytidiadelphus squarrosus; Sphasp = Sphagnum sp.; Ulexgall = Ulex gallii; Vaccmyrt = Vaccinium myrtillus; Vaccviti = Vaccinium vitis-idaea; Violpalu = Viola palustris.

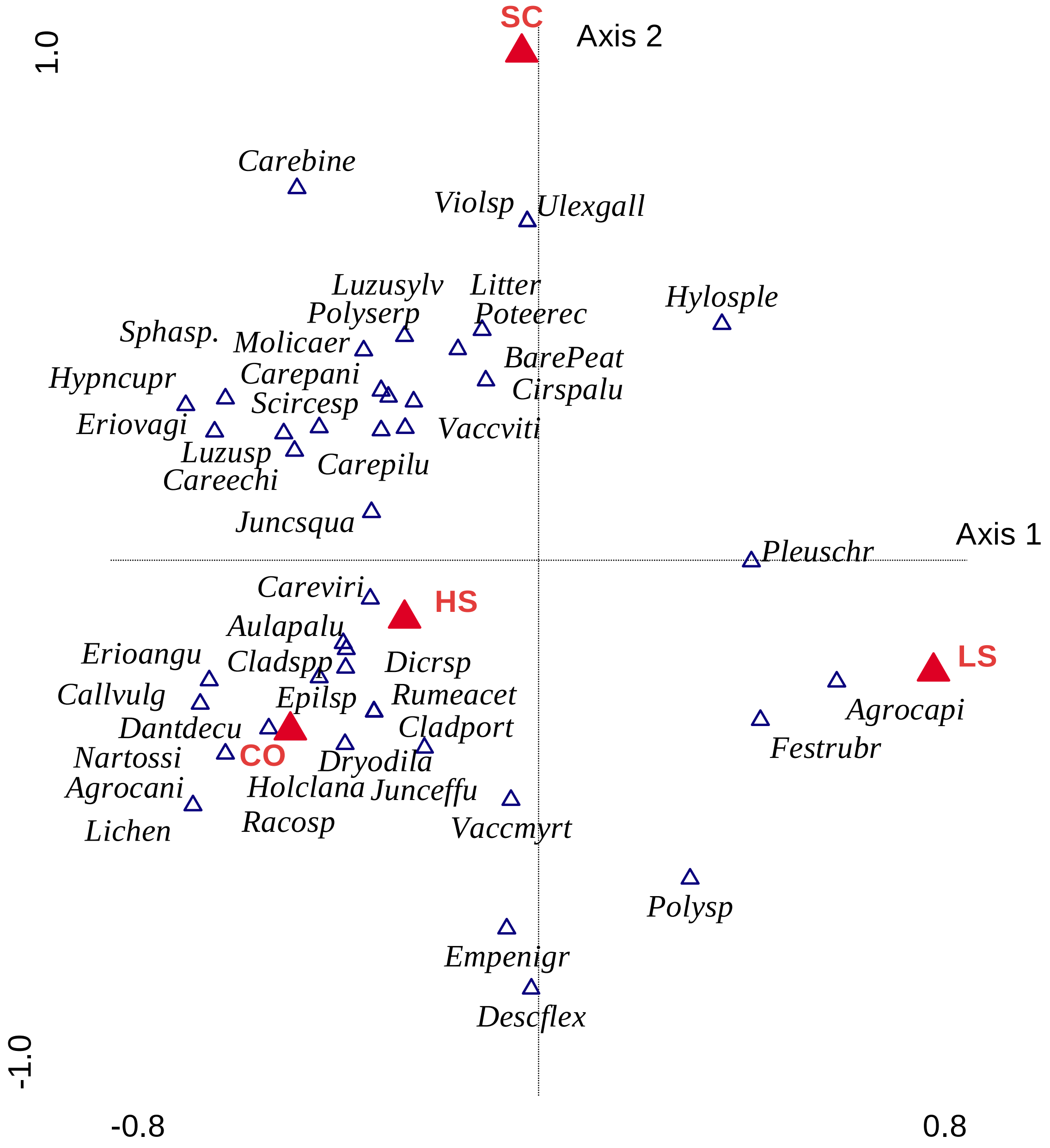

Figure 2. pRDA biplot of plant species frequencies and grazing treatments in 2016. Only species with fit >=10% shown for clarity. Treatment codes as Table 1. Species codes as Figure 1 plus: Careviri = Carex viridis; Cirspalu = Cirsium palustre; Cladport = Cladonia portentosa; Cladspp = Cladonia spp; Dryodila = Dryopteris dilatata; Epilsp = Epilobium sp.; Eriovagi = Eriophorum vaginatum; Hylosple = Hylocomium splendens; Junceffu = Juncus effusus; Luzusp = Luzula sp.; Nartossi = Narthecium ossifragum; Pleuschr = Pleurozium schreberi; Rumeacet = Rumex acetosa; Scircesp = Trichophorum germanicum ; Violsp = Viola sp.

During the period with no grazing, there was a non-significant declining trend in *N. stricta* frequency from 37.6% in 2010 to 30.8% in 2012 (*P*=0.06, Table 2). This apparent reduction occurred across all treatments, there being no significant year x treatment interaction. A significant decline had been recorded previously from 51.4% in 2003 to 36.8% in 2005, and this represented a further reduction. *M. caerulea* was only present at low frequencies but showed a significant increase from 4.4% to 6.7% across all treatments during the no-grazing period. Top covers of the species groups were closely similar in 2010 and 2012, indicating there had been no gross changes since grazing ceased. Mean vegetation height showed a non-significant increasing trend across all treatments during the period without grazing, but only by *c*. 2cm (from 15.5 cm in 2010 to 17.4 cm in 2012) (P=0.06). Height variability at the local scale also showed an overall declining trend (P=0.06). Height variability at the paddock scale appeared to increase in the SC treatment (significant year x treatment interaction) but also declined slightly in the HS and CO treatments.

Table 2. Mean (±SE) local frequency of key species, top cover of species groups and vegetation structure variables in 2010 and 2012, with F statistics from repeated-measures ANOVA. Untransformed data presented for clarity. $^{(*)}$ P<0.1, * P<0.05, ns = not significant.

Variable	**2010**		**2012**		**Year**	**Year x treatment**
					$F_{1,6}$	$F_{3,6}$
Key species frequency						
Calluna vulgaris	1.7	±0.88	2.2	±1.24	0.9 ns	0.3 ns
Molinia caerulea	4.4	±1.02	6.7	±1.38	11.5*	1.6 ns
Nardus stricta	37.6	±3.29	30.8	±3.16	5.5$^{(*)}$	0.1 ns
Vaccinium myrtillus	52.1	±3.34	57.0	±4.87	3.1 ns	0.2 ns
Top cover of species groups						
Dwarf shrubs	10.6	±0.92	9.5	±1.09	2.5 ns	0.2 ns
Graminoids	64.8	±1.30	67.1	±2.64	0.9 ns	0.5 ns
Bryophytes	18.3	±0.96	18.9	±1.91	0.0 ns	0.2 ns
Forbs	3.4	±0.41	3.4	±0.50	0.2 ns	1.9 ns
Vegetation structure						
Mean height	15.5	±0.86	17.4	±1.02	5.2 $^{(*)}$	1.8 ns
Paddock-scale CV	0.31	±0.030	0.31	±0.016	0.0 ns	8.2*
Local-scale CV	0.34	±0.020	0.29	±0.013	5.2 $^{(*)}$	1.6 ns

No changes were detected in the local frequencies of key species from 2012 to 2016, and this was consistent among treatments for all species, as indicated by the year x treatment interactions (Table 3). However, overall during this period there was a significant treatment effect on *Calluna vulgaris* frequency ($F_{3,5}$ = 7.5, $P < 0.05$), with greatest mean frequency in CO (10.5 ±0.36% SE) compared to means of 0.1% – 3.6% in the other treatments. Frequency of *Nardus stricta* was very similar in 2012 and 2016, which followed the overall decline in frequency in previous years of the study.

Table 3. Mean (±SE) local frequency of key species in 2012 and 2016, with *F* statistics from repeated-measures ANOVA. Untransformed data presented for clarity. ns = not significant.

Species	**2012**		**2016**		**Year**	**Year x treatment**
					$F_{1,6}$	$F_{3,6}$
Calluna vulgaris	3.2	±1.33	4.6	±1.92	2.2 ns	4.6 ns
Molinia caerulea	5.3	±1.21	4.0	±1.13	0.9 ns	2.7 ns
Nardus stricta	30.6	±3.19	33.1	±3.32	1.7 ns	0.8 ns
Vaccinium myrtillus	55.7	±4.24	53.4	±3.74	0.4 ns	0.6 ns

Background grazing levels on key species in 2012 were negligible in the absence of livestock. In 2016, overall grazing levels on *C. vulgaris*, *M. caerulea* and *N. stricta* were very low, but were higher on *V. myrtillus* (*c*. 10 – 14%, Table 4). However, no differences were detected among treatments in the levels of grazing on any of the key species.

Table 4. Mean (±SE) grazing indices of key species in 2016 by treatment, with *F* statistics from mixed model ANOVA. Untransformed data presented for clarity. ns = not significant.

Species	**LS**		**HS**		**SC**		**CO**		$F_{3,5}$
Calluna vulgaris	0.0		0.0		3.0	±3.03	0.5	±0.29	1.2 ns
Molinia caerulea	0.9	±0.73	1.8	±1.52	11.3	±5.29	5.0	±2.54	1.7 ns
Nardus stricta	0.8	±0.71	0.0		0.8	±0.32	0.1	±0.07	2.9 ns
Vaccinium myrtillus	12.6	±3.30	13.8	±4.08	10.7	±0.36	10.0	±1.40	0.2 ns

Graminoids had the highest top cover values of all species groups in both 2012 and 2016, and increased significantly from *c.* 67% to *c.* 80% following the re-introduction of grazing (Table 5). However, the palatable grasses subset showed no change, indicating that it was primarily the less palatable species that had increased. Conversely, covers of bryophytes, dwarf shrubs and forbs all decreased following re-introduction of grazing. The changes in covers of the species groups were consistent among treatments (none of the year x treatment interactions was significant).

The cover of several species analysed also changed between 2012 and 2016. Cover of *E. vaginatum* increased by a small amount, from *c.* 4% to 5.6%. In contrast, there were small but significant decreases in the covers of *V. myrtillus*, the mosses *P. schreberi* and *Rhytidiadelphus squarrosus* and the forb *G. saxatile*. Notably, there was a non-significant upward trend in the cover of *N. stricta* from *c.* 17% to *c.* 22% (*P* = 0.08). The year x treatment interactions indicated that all these changes occurred consistently among the four treatments, with the exception of *R. squarrosus*, which declined in all treatments apart from SC. *C. vulgaris* cover was higher in the CO treatment than the other treatments during 2012 and 2016 (treatment $F_{3,5}$ = 7.5, *P* <0.05) but no other treatment effects on other species or species groups were detected.

Table 5. Mean (±SE) top cover of species groups and key species in 2012 and 2016, with *F* statistics from repeated-measures ANOVA. Untransformed data presented for clarity. * *P*<0.05, ** *P*<0.01, *** *P*<0.001, ns = not significant.

Variable	**2012**		**2016**		**Year**	**Year x treatment**
					$F_{1,5}$	$F_{3,5}$
Dwarf shrubs	9.8	±1.20	7.25	±0.75	9.0*	0.7 ns
Graminoids	66.9	±2.72	80.1	±1.99	47.0**	0.4 ns
Bryophytes	19.2	±2.13	10.3	±1.78	70.7***	0.7 ns
Forbs	3.3	±0.45	1.3	±0.21	18.3**	0.7 ns
Palatable grasses	23.6	±1.90	26.7	±2.76	2.9 ns	0.6 ns
Calluna vulgaris	1.4	±0.74	2.0	±0.88	0.2 ns	2.3 ns
Deschampsia flexuosa	3.5	±0.99	5.1	±1.13	2.6 ns	0.3 ns
Eriophorum vaginatum	4.0	±0.94	5.6	±1.27	10.7*	2.0 ns
Festuca ovina	6.4	±0.58	5.5	±0.62	0.3 ns	0.2 ns
Galium saxatile	1.4	±0.14	0.8	±0.14	18.0**	0.3 ns
Juncus squarrosus	3.5	±0.86	4.4	±1.06	4.2 ns	1.3 ns
Molinia caerulea	2.5	±0.73	2.1	0.81±	0.3 ns	3.4 ns
Nardus stricta	17.3	±2.14	22.1	±2.22	4.8 ns	0.3 ns
Pleurozium schreberi	4.4	±0.81	0.72	±0.15	32.3**	0.5 ns
Rhytidiadelphus squarrosus	2.6	±0.45	1.5	±0.34	113.1***	15.8**
Vaccinium myrtillus	7.7	±1.06	4.5	±0.64	22.5**	0.2 ns

There was a significant decline in mean vegetation height across all paddocks of *c*. 4 cm during the 4-year period following re-introduced grazing in 2012 (Table 6). The decline was consistent across treatments (time x treatment interaction was not significant). This followed the increasing trend of *c.* 2 cm in mean height during the period without grazing earlier in the study. However, there were no changes in coefficients of variation in height at either spatial scale, nor did this vary among treatments.

Table 6. Vegetation height values (±SE) in 2012 and 2016, with *F* statistics from repeated-measures ANOVA. CV = coefficient of variation; ** *P*<0.01, ns = not significant

Variable	**2012**		**2016**		**Year**	**Year x treatment**
					$F_{1,5}$	$F_{3,5}$
Mean height	17.9	±1.08	14.0	±0.59	22.1**	1.9 ns
Paddock-scale CV	0.27	±0.011	0.31	±0.016	4.0 ns	1.7 ns
Local-scale CV	0.28	±0.013	0.30	±0.014	1.5 ns	1.3 ns

INVERTEBRATES

Methods

Pitfall traps had been used to obtain activity-density estimates of epigeal invertebrates at the soil surface in 2006 and in 2010. This was repeated in 2016 to obtain estimates at the end of the four-year period when grazing was re-introduced. At each of two randomly selected locations per paddock, five pitfall traps were sunk into the soil, with 1m between traps. Ethylene glycol was used as a preservative in the base of each trap and each trap was secured with coarse wire mesh to prevent interference from livestock. Traps were in place for two sessions from 4 July to 3 August and 7 September to 4 October 2016 and emptied at the end of each session. Individual adults and larvae (if present) were sorted and counted in major taxonomic groups, *viz.* Hymenoptera (excluding Apoidea, which were treated as a separate group), Diptera, Coleoptera, Lepidoptera, Hemiptera, Collembola, Thysanoptera, Araneae, Acarina, Chilopoda, Mollusca and Annelida.

Effects of grazing treatments and vegetation composition and structure on the invertebrate groups were analysed by Partial Redundancy Analysis (pRDA) with 999 Monte Carlo permutations on 2016 log-transformed counts from each sampling location. Mean vegetation height, height CV (quadrat scale) and sample scores from the first two axes of a Principle Components Analysis of 2016 plant species cover at each invertebrate sampling location were included as environmental variables along with grazing treatments (the latter as nominal variables). Blocks were treated as covariables. A preliminary Detrended Correspondence Analysis showed a linear model was suitable.

Effects of treatments on log-transformed numbers of individual taxonomic groups were determined by a mixed model analysis of variance by general linear modelling, using Statistica v.11 software (Statsoft Inc., 2012). Groups with few captures were not analysed if data could not be normalised by transformation.

Results

In July, the groups with highest activity-density indices were Hymenoptera, Araneae and Coleoptera. Activity-density indices were lower in September, but the groups with highest indices then were Araneae, Coleoptera and Diptera.

None of the environmental variables had a significant effect on the invertebrate groups in July, nor did they have a significant effect collectively (Table 7). However, in September the vegetation PCA axis 1 and the SC treatment both had a significant effect on invertebrate groups. There was also a weak non-significant effect ($P<0.1$) of CO and mean vegetation height, and of LS (the latter being significant only after adding the previous variables to the model). Vegetation PCA axis 1 represented a gradient from mire or wet vegetation at the positive end (including *Eriophorum* spp, *M. caerulea*, *Sphagnum* sp., *C. vulgaris*, *Erica tetralix*, *Narthecium ossifragum* and *Trichophorum germanicum*), to acid grassland vegetation at the negative end (including *A. capillaris*, *N. stricta*, *Carex pilulifera*, *Potentilla erecta*, *Hypnum cupressiforme*, and *F. ovina*). All invertebrate groups tended to be more associated with the grassland rather than the mire vegetation, the strongest effect being on Acarina, Mollusca, Coleoptera, Hemiptera and Collembola (Figure 3). In addition, most groups tended to be less associated with SC compared to all the other treatments; the strongest effect was on Collembola, Diptera larvae and Hemiptera. Mean vegetation height was correlated with the third pRDA axis (not shown); Chiloptera, Coleoptera larvae and Mollusca tended to be associated with shorter rather than taller vegetation. All treatments collectively also had a significant effect on invertebrate captures in September.

Table 7. pRDA results of invertebrate pitfall captures in July and September 2016. LS = low sheep only; HS = high sheep only; SC = sheep plus cattle; CO = cattle only; Veg1 = vegetation PCA axis 1 score; Veg2 = vegetation PCA axis 2 score. In both cases HS was the final nominal variable after forward selection and was not significant. $^{(*)}$ *P*<0.1, * *P*<0.05, ** *P*<0.01, ns not significant.

	July		**September**	
Variable	Lambda	F	Lambda	F
Veg1	0.03	0.84 ns	0.09	2.02*
SC	0.05	1.07 ns	0.10	2.21*
CO	0.04	0.89 ns	0.07	$1.7^{(*)}$
Mean height	0.03	0.66 ns	0.06	$1.6^{(*)}$
LS	0.02	0.48 ns	0.08	1.9*
Veg2	0.06	1.31 ns	0.05	1.57 ns
Height CV	0.04	0.64 ns	0.04	1.11 ns
HS	-	-	-	-
All treatments	Eigenvalue	F	Eigenvalue	F
Axis 1	0.094	1.47 ns	0.142	2.18 ns
Overall	0.269	0.78 ns	0.492	1.95**

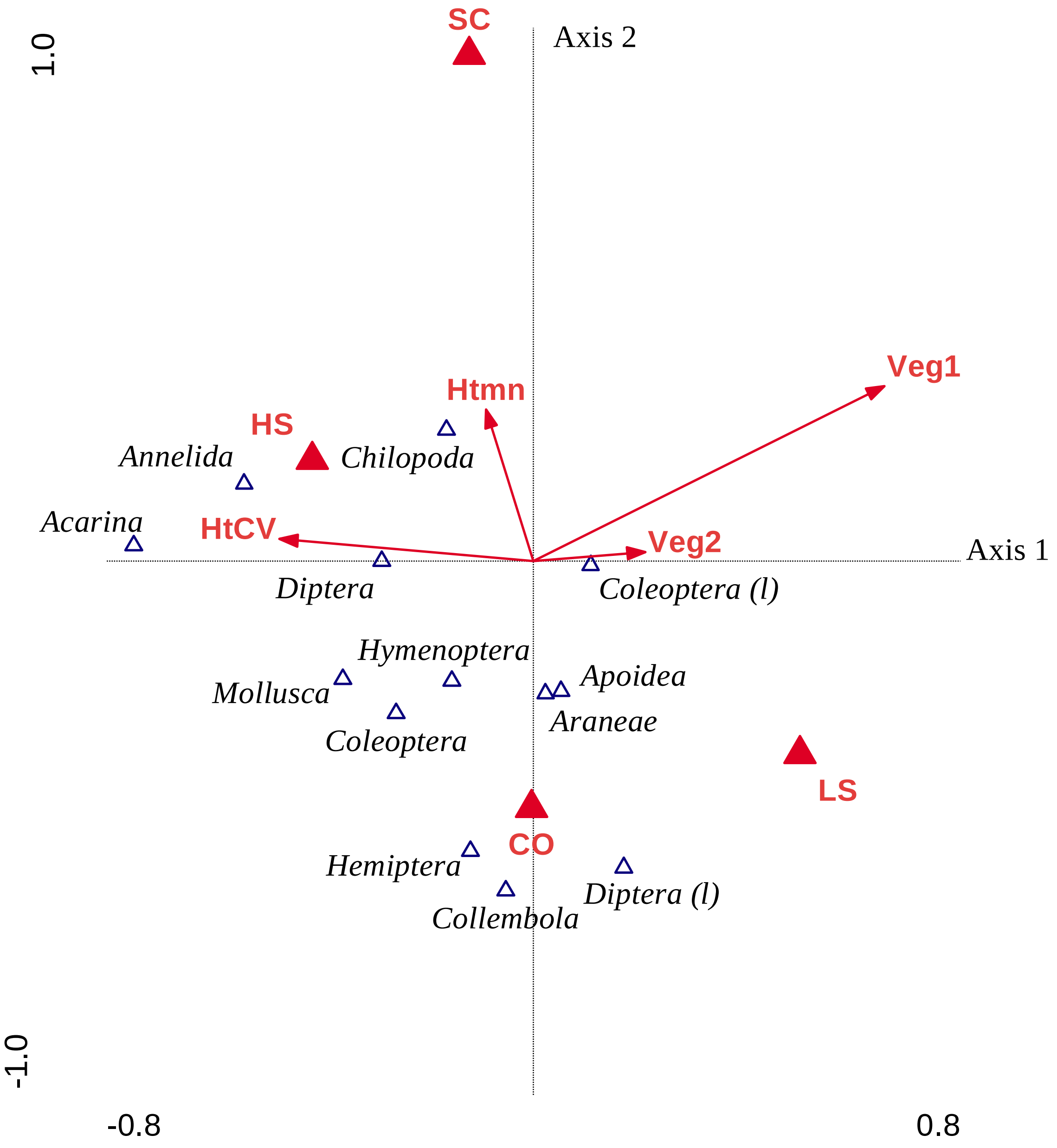

Figure 3. pRDA biplot of invertebrate captures (l = larvae, otherwise adults) and grazing treatments and vegetation variables in September 2016. Environmental variable codes as Table 7, plus Htmn = mean vegetation height, HtCV = vegetation height coefficient of variation.

No significant treatment effects were detected on taxonomic groups individually apart from Collembola in September, when activity-density was highest in LS and lowest in SC (Table 8). A similar non-significant trend was also present for Coleoptera in September (*P*=0.054). Mean values for most other groups tended to be higher in the sheep only (especially LS) than CO or SC, albeit with high variability around the means. Exceptions to this general pattern were Mollusca and Annelida in both months. An analysis of total captures across all groups showed no significant treatment effect in either July ($F_{3,11}$ = 0.7, P = 0.59) or September ($F_{3,11}$ = 2.5, P = 0.18).

Table 8. Mean (±SE) counts of invertebrate taxonomic groups by treatment, with F statistics from mixed model analysis of variance. Untransformed data presented for clarity. (*) P<0.1, * P<0.05, ns = not significant.

July	**Group**	**LS**		**HS**		**SC**		**CO**		$F_{3,11}$
	Hymenoptera	55.8	±17.28	67.7	±19.47	19.8	±3.30	28.3	±4.89	1.8 ns
	Diptera	19.2	±6.35	27.5	±6.55	8.5	±1.32	10.5	±2.00	0.6 ns
	Coleoptera	31.5	±8.41	25.8	±5.68	11.5	±3.75	17.5	±4.06	1.0 ns
	Hemiptera	2.8	±1.11	3.8	±1.22	1.8	±0.63	4.8	±1.35	0.7 ns
	Collembola	9.3	±4.20	6.3	±2.40	5.5	±2.40	7.2	±2.37	0.1 ns
	Araneae	35.0	±8.52	41.8	±6.47	28.5	±4.66	33.0	±7.94	0.5 ns
	Acarina	19.7	±8.21	15.8	±4.85	7.5	±3.18	13.8	±6.30	0.0 ns
	Mollusca	20.8	±7.34	13.3	±5.32	20.3	±7.19	9.5	±2.26	0.7 ns
	Annelida	3.3	±0.99	3.7	±1.63	4.0	±1.78	0.7	±0.21	1.9 ns

Sept	**Group**	**LS**		**HS**		**SC**		**CO**		$F_{3,11}$
	Hymenoptera	20.7	±9.43	10.7	±2.29	5.8	±1.80	11.3	±2.96	2.1 ns
	Diptera	17.7	±5.67	15.8	±2.27	8.8	±1.38	10.8	±1.85	3.1 ns
	Coleoptera	30.3	±10.06	20.8	±3.61	12.5	±3.86	15.0	±4.66	5.1 (*)
	Hemiptera	2.0	±0.93	2.8	±1.08	1.5	±0.96	5.7	±2.80	0.9 ns
	Collembola	12.5	±3.50	7.7	±2.44	1.8	±0.85	4.3	±0.92	8.0*
	Araneae	30.7	±6.96	26.3	±3.36	22.5	±3.97	33.2	±4.38	1.2 ns
	Acarina	4.7	±3.13	4.5	±1.06	3.5	±1.32	2.7	±0.84	0.6 ns
	Mollusca	3.7	±1.20	1.7	±0.61	5.5	±2.60	3.0	±1.24	0.5 ns
	Annelida	1.8	±1.05	3.8	±1.62	3.5	±1.32	1.3	±0.49	2.0 ns

LIVESTOCK PERFORMANCE

Methods

Livestock data were recorded each year from 2013 to 2016. The methods used were the same as in the previous years of the study when livestock were on the paddocks, from 2003 to 2010. Liveweight and body condition scores were recorded for all heifers when turned onto and removed from the paddocks. Liveweights and body condition scores were recorded for ewes when turned out after lambing and at weaning in early September. Lambs were also weighed when turned out, at shearing in late June and at weaning.

Changes in livestock weights and condition scores each year were analysed using repeated measures analysis of variance by general linear modelling, in Statistica v.11 software (Statsoft Inc., 2012).

Results

Cattle liveweights increased significantly during the period of grazing on the paddocks in each of the three years 2013, 2014 and 2015 (Table 9). In 2016, there was also a non-significant increasing trend ($P = 0.052$) (although note there was reduced statistical power in 2016 due to missing data). No significant effect of treatment on weight change was detected in 2014, 2015 or 2016. In 2013, the significant change x treatment interaction showed that although weights increased in both treatments, the increase was slightly greater in the CO treatment than SC.

Table 9. Mean (±SE) cattle liveweights (kg) on and off the paddocks each year from 2013 to 2016. * $P<0.05$, ** $P<0.01$. *** $P<0.001$, ns = not significant.

	2013	**2014**	**2015**	**2016**
Weight on	334 ±6.7	390 ±5.0	360 ±8.6	365 ±6.2
Weight off	380 ±8.2	401 ±5.1	378 ±6.6	371 ±5.6
Weight change $F_{1,20}$	120.3***	31.1***	13.4**	4.4 ns[1]
Change x Treatment $F_{1,20}$	5.4*	0.2 ns	0.1 ns	0.0 ns[1]

[1] df $_{1,16}$ due to missing data in SC treatment, Block 3

Cattle condition scores also improved each year between turning out and removal from the paddocks ($P<0.05$). There was no overall effect of treatment on condition scores at the end of the grazing period each year. In 2014 only, condition scores increased in the SC treatment but not in CO (change x treatment $F_{1,20} = 4.8$, $P<0.05$). However, scores tended to be lower in SC than CO at the start and were similar in the two treatments by the end of the grazing period.

A comparison of cattle daily liveweight gains since the start of the extended study in 2003 showed considerable annual variation (Table 10). For example, the lowest gains were in 2016 whereas liveweight gains in 2013 were exceptionally good, and followed the two-year period when the site was not grazed. Differences between the two treatments also varied from year to year.

Table 10. Cattle mean daily liveweight changes (kg day^{-1}) throughout the extended study.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2013**	**2014**	**2015**	**2016**
CO	0.45	0.41	0.76	0.50	0.59	0.77	0.75	0.25	0.87	0.18	0.28	0.09
SC	0.59	0.31	0.69	0.36	0.63	0.56	0.63	0.04	0.57	0.21	0.32	0.08
Mean	0.52	0.36	0.73	0.43	0.61	0.67	0.69	0.15	0.72	0.19	0.30	0.09

Change in ewe liveweights, from onset of grazing after lambing until weaning, was variable from year to year. In 2013, immediately following the two-year period with no grazing, ewe liveweights increased significantly (Change in ewe condition scores also varied from year to year. In 2013 and 2016, condition scores increased significantly from the start of grazing after lambing until weaning ($P<0.05$), but there was no significant change in 2014 or 2015. The improvement in condition in 2016 occurred despite an overall decline in liveweights.

Table 11). In contrast, liveweights declined in both 2014 and 2016, whereas there was no significant change in 2015. There was no treatment effect on ewe weight change in any year from 2013 to 2016.

Change in ewe condition scores also varied from year to year. In 2013 and 2016, condition scores increased significantly from the start of grazing after lambing until weaning ($P<0.05$), but there was no significant change in 2014 or 2015. The improvement in condition in 2016 occurred despite an overall decline in liveweights.

Table 11. Mean (±SE) ewe liveweights (kg) on the paddocks and at weaning each year from 2013 to 2016. * *P*<0.05, ** *P*<0.01. *** *P*<0.001, ns = not significant.

	2013	**2014**	**2015**	**2016**
Weight on	38.6 ±0.43	45.9 ±0.51	42.7 ±0.63	39.2 ±0.47
Weaning weight	39.8 ±0.45	43.6 ±0.53	42.2 ±0.73	38.1 ±0.46
Weight change *F*	6.1*	42.2***	0.8 ns	8.0**
df	1,59	1,66	1,66	1,57
Change x Treatment *F*	1.4 ns	0.0 ns	1.1 ns	0.6 ns
df	2,59	2,66	2,66	2,57

A comparison of ewe weaning weights since the start of the study shows a notable degree of annual variation, most likely attributable to weather conditions and availability and quality of forage (Table 12). There were no significant treatment effects on weaning weight in any single year from 2013 to 2016 (*P*>0.05), nor had there been any treatment effect during the earlier period of the study.

Table 12. Ewe mean weaning weights (kg) throughout the extended study.

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2013**	**2014**	**2015**	**2016**
LS	37.4	43.7	40.6	43.3	40.4	43.4	46.8	41.3	45.3	43.9	37.6
HS	36.7	43.0	38.7	42.4	41.5	40.8	46.8	39.4	42.6	42.4	38.3
SC	36.9	42.3	40.0	43.3	40.6	42.0	46.2	38.8	43.5	40.7	38.4
Mean	37.0	43.9	39.6	42.9	40.9	41.9	46.6	39.8	43.6	42.2	38.1

Lamb liveweight gains, between turning out to the paddocks and weaning, were affected by treatment in 2013 and 2016 (Table 13). In both years, liveweight gains were least in HS. In 2013 only, gains in SC were greater than in the other treatments (unequal N HSD *P*<0.05). However, there was no significant difference in weight gain among treatments in either 2014 or 2015.

Table 13. Mean (±SE) lamb liveweights (kg) on the paddocks and at shearing and weaning each year from 2013 to 2016. * $P<0.05$, ** $P<0.01$. *** $P<0.001$, ns = not significant, nd = no data.

	2013	**2014**	**2015**	**2016**
Weight on	14.6 ±0.33	15.7 ±0.31	15.7 ±0.37	12.9 ±0.25
Shearing weight	21.4 ±0.47	25.5 ±0.41	27.4 ±0.42	nd
Weaning weight	25.7 ±0.51	29.5 ±0.45	29.2 ±0.46	24.3 ±0.34
Change x Treatment *F*	4.3**	1.4 ns	0.8 ns	4.5*
df	4,114	4,130	4,132	2,57

Over the course of the extended study, lamb mean weaning weights varied from 23.8 kg in 2004 to 31.9 kg in 2007 (Table 14). There was no significant treatment effect on weaning of weights of lambs in any of the four years from 2013 to 2016, nor had there been in the previous years of the extended study.

Table 14. Lamb mean weaning weights (kg) throughout the extended study.

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2013**	**2014**	**2015**	**2016**
LS	25.0	25.6	27.3	31.8	29.9	30.0	30.4	25.4	30.5	29.3	24.2
HS	23.2	25.3	26.6	31.4	29.6	28.7	30.6	25.2	29.1	28.6	23.9
SC	23.7	25.0	27.8	32.5	28.6	29.1	30.4	26.7	29.3	29.9	25.3
Mean	23.8	25.3	27.2	31.9	29.3	29.2	30.4	25.7	29.5	29.2	24.3

DISCUSSION

Vegetation

The main aim of this phase of the experiment was to assess the effects of re-introducing grazing following a 2-year period when none of the paddocks was grazed. During the first period of grazing, there had been a decline in *N. stricta* frequency across all grazing treatments, and this trend continued during the two years without grazing. However, after re-introduction of grazing no further decline in *N. stricta* was detected, suggesting that it might have reached a stable level. Nonetheless, the overall decline from *c.* 51% local frequency at the beginning of the study to *c.* 33% some 13 years later does represent a positive change in the vegetation under relatively moderate levels of grazing intensity. Grazing levels on *N. stricta* were very low under all grazing treatments, so its decline was likely to be attributable to competition from other grasses as a result of the general reduction in grazing intensity compared to historic grazing levels on the site. However, the decline in frequency of *N. stricta* was not accompanied by a decline in its top cover. This suggests that *N. stricta* might be declining primarily in patches of vegetation where it is dispersed amongst other species but not where it is dominant, an effect consistent with model predictions from previous projects BD1211 and BD1228 (ADAS, 2002; Gardner et al., 2009).

During the first phase of the experiment, no treatment effects had been detected on the frequencies of key species. However, both *C. vulgaris* and *M. caerulea* had been grazed more when cattle were present than in the sheep-only regimes. When grazing stopped, *M. caerulea* frequency increased although it was still relatively scarce and patchily distributed in the sward. Following re-introduction of grazing, *C. vulgaris* frequency and cover were greatest in the CO treatment. This effect had been apparent in the plot-scale experiment since the start of the study (Mitchell et al., 2008; Critchley et al., 2013) but was also now manifest at the paddock scale, despite the greater spatial variability in vegetation at this scale. *V. myrtillus* declined in cover following re-introduction of grazing, and had relatively high grazing indices, suggesting that it might be vulnerable to grazing at the intensities applied in this study.

The changes in top covers demonstrated the short-term effects of grazing. During the no-grazing period, there was a surprising lack of change in covers of the species groups analysed, although small changes were apparent for some individual species. In contrast however, there were notable effects when grazing was re-introduced. The decline in dwarf shrub and forb covers was probably attributable directly to defoliation, while the decline in bryophytes was more likely to be the result of trampling by livestock. The increase in graminoids, which was restricted to less palatable species that would tend to be avoided by livestock, is undesirable for both conservation and economic objectives. This suggests that the overall vegetation objectives will be difficult, or take longer, to achieve if grazing is applied even at these relatively moderate intensities.

The changes in mean vegetation height and height variability in response to both cessation and re-introduction of grazing were relatively small in magnitude. This reflects the low productivity of the vegetation and slow growth rates of the component species (Morecroft et al., 2016).

Overall, the results indicate that the re-introduction of grazing *per se* had a greater effect on the vegetation than any differences among the four grazing treatments. However, during the earlier phase of the experiment when the paddocks had been grazed, the LS and SC grazing regimes had a significant effect on the overall plant species composition. In 2012 at the end of the no-grazing period, the LS treatment still had a detectable effect. This was also apparent in 2016 at the end of the second period of grazing, although the overall effects of the grazing treatments were weaker than in 2012. Collectively, these results might indicate inertia in the system, whereby the effects of applying or withdrawing grazing take a few years to manifest. The treatment effects were detected in species frequencies but not top cover (which is more of a short-term effect), which supports this premise.

Invertebrates

In this study, invertebrates were counted in major taxonomic groups to provide an indication of the overall numbers of individuals associated with the grazing treatments and vegetation parameters. Pitfall trapping provides an activity-density index of epigeal invertebrates but does not sample foliar or soil-dwelling invertebrates efficiently. However, some clear relationships were detected in 2016 at the end of the second grazing period as well as in the earlier period of grazing up to 2010.

In 2016, all the invertebrate groups were more associated with acid grassland vegetation than with wetter, mire vegetation. This effect had not been detected after the first period of grazing but it is consistent with other studies that have shown relationships between upland invertebrate assemblages and plant species composition (Sanderson et al., 1995; Dennis et al., 1997; Littlewood et al., 2006). The relationships detected here might reflect differences in productivity in the vegetation types, with grassland tending to produce more biomass in terms of both living material and litter than the mire vegetation growing on a less fertile peat substrate. However, this study did not allow comparison of the habitat preferences of functional groups or individual species, which might have revealed more subtle preferences of certain groups or species with the mire vegetation. There was also a tendency for fewer captures in shorter vegetation. This could have been due to higher numbers or rates of activity at the soil surface or simply superior trapping efficiency in shorter vegetation.

There was also an effect of grazing treatment on the invertebrate assemblages, most groups being associated less with SC than the other treatments (despite the reduced statistical power from omitting one of the SC paddocks from the analyses). The overall stocking rate was greatest in SC, so the differences in invertebrate activity-density might have been attributable to higher levels of disturbance in this grazing regime. Previously in 2010, there had been a strong treatment effect on the invertebrates, with lower numbers of all groups caught where cattle were present. Similarly, this might have reflected higher levels of disturbance from the cattle compared to sheep. It was notable that most Collembola were caught in the LS treatment and least in SC. As detritivores, Collembola probably indicate a higher density of dead plant material in LS, which would result from lower levels of defoliation and disturbance.

In 2016, the treatment effects on invertebrate captures were only evident in September, which was at the end of the summer period of grazing. Similarly, in 2010 the treatment effects had been stronger in September than in July. This indicates that invertebrates respond relatively rapidly to changes in the environment and are indicative of recent management as well as variation in vegetation composition that has developed over much longer timescales.

Livestock

As in the previous grazing period up to 2010, cattle and sheep performance varied from year to year and was probably attributable to the amount and quality of forage available each year, and would reflect variation in weather conditions. The initial weight and condition of the animals would also affect performance each year. In 2013, the first year after the no-grazing period, cattle performance was exceptionally good, and followed the two-year period when the site was not grazed, which had allowed the biomass of available forage to build up. This was also the only year when weight gains differed between the two treatments, being slightly greater in CO than SC. This suggests the presence of sheep might have slightly reduced the forage that was available to cattle. In contrast, the lowest gains were in 2016 when there was generally poor growth in the region following a dull summer period. Annual variation in growth rates of cattle might also depend on how well they adapt to being enclosed within a small group. Cattle used to running in a large group sometimes do not settle well and this could adversely affect their performance.

Ewes also performed very well in 2013, which could be at least partly attributable to the lack of grazing in the previous two years. Lamb performance as measured by weaning weights showed no difference among treatments in any single year. However, liveweight gains were inferior in the HS treatment in some years, suggesting an effect of sheep stocking rate on lamb performance, which has been highlighted in other studies (Merrell et al., 2001). Overall, there was little evidence that cattle impaired sheep performance or vice versa, nor that there was any improvement in performance in the mixed grazing regime. The one exception to this was the superior lamb liveweight gains in the SC treatment in one year of the study, consistent with the findings of Fraser et al. (2013).

Together with the cattle results, this suggests that the improved performance after a period of no grazing could partly compensate graziers for the lack of returns during the no-grazing period of a pulsed grazing system. This would however be dependent on other grazing being available during the no-grazing period on the land in question. An alternative might be to subdivide larger moors into paddocks and rotate livestock among the paddocks each year, although this would only be possible on sites where fencing was not an issue.

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ANNEX 1

PLANT TAXA[1] RECORDED IN 2012 AND 2016

Data are mean percentages of quadrats across all paddocks in which each species was recorded, in descending order from 2012. [1]lichens also included

Taxon	**2012**	**2016**
Pleurozium schreberi	85.7	69.1
Vaccinium myrtillus	85.2	82.6
Nardus stricta	84.7	84.5
Festuca ovina	81.3	77.6
Galium saxatile	79.1	78.0
Agrostis capillaris	76.0	69.7
Hylocomium splendens	68.7	73.2
Rhytidiadelphus squarrosus	65.1	75.5
Carex pilulifera	58.4	52.2
Agrostis canina	57.5	73.5
Deschampsia flexuosa	53.6	73.2
Polytrichum sp.	53.2	53.3
Potentilla erecta	52.4	46.2
Rhytidiadelphus loreus	52.3	52.0
Juncus squarrosus	41.1	45.2
Carex binervis	38.5	42.4
Anthoxanthum odoratum	34.5	42.0
Hypnum cupressiforme	26.2	38.2
Carex panacea	23.1	28.1
Eriophorum vaginatum	16.7	22.1
Molinia caerulea	15.8	17.3
Carex nigra	15.4	18.6

Taxon	**2012**	**2016**
Racomitrium sp.	14.9	16.9
Eriophorum angustifolium	14.2	12.3
Lichen	12.4	3.5
Pseudoscleropodium purum	12.2	6.9
Juncus effusus	10.6	11.9
Dicranium sp.	10.5	11.0
Calluna vulgaris	9.7	9.9
Sphagnum sp.	8.9	10.3
Luzula campestris	8.4	16.6
Empetrum nigrum	7.9	11.7
Polygala serpyllifolia	7.7	3.3
Carex echinata	6.1	5.7
Plagiothecium undulatum	5.7	4.1
Trichophorum germanicum	3.8	6.2
Festuca rubra	3.6	7.7
Danthonia decumbens	3.1	2.1
Viola palustris	3.0	0.8
Luzula sylvatica	2.5	1.7
Erica tetralix	2.2	0.8
Vaccinium vitis-idaea	1.7	1.7
Vaccinium oxycoccos	1.7	0.0
Juncus bulbosus	1.5	0.0
Cerastium fontanum	1.2	1.2
Dryopteris dilatata	0.9	0.9
Narthecium ossifragum	0.9	2.3
Aulacomnium palustre	0.8	1.9

Taxon	**2012**	**2016**
Carex demissa	0.8	0.0
Carex rostrate	0.8	0.0
Juncus acutiflorus	0.8	0.0
Liverwort	0.8	1.5
Rumex sp.	0.8	0.5
Deschampsia cespitosa	0.8	0.8
Holcus lanatus	0.8	0.5
Ulex gallii	0.8	0.8
Carex viridula agg.	0.5	0.8
Epilobium palustre	0.5	0.0
Agrostis stolonifera	0.0	1.2
Cirsium palustre	0.0	1.4
Cladonia portentosa	0.0	0.5
Cladonia spp	0.0	2.4
Epilobium sp.	0.0	0.5
Kindbergia praelonga	0.0	0.8
Luzula sp.	0.0	11.1
Polytrichum strictum	0.0	1.7