APPENDIX 4B

EXPERIMENTS TO ACCELERATE HEATHER RECOLONISATION

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INTRODUCTION

Upland moorland dominated by heather *Calluna vulgaris* (L. (Hull)) (hereafter *Calluna*) and related dwarf shrubs is recognized as a habitat of high conservation importance within the United Kingdom (The UK Biodiversity Steering Group, 1995; Thompson *et al.*, 1995; Usher & Thompson, 1993) and the European Union (EC Habitats Directive (92/43/EEC)). Its conservation value is rarely in the plant community itself but rather in the invertebrate and vertebrate assemblages it supports (Thompson *et al.*, 1995), and because of its recent decline in area and condition across much of Western Europe (Pakeman *et al.*, 2003). Furthermore, *Calluna*-dominated moorlands are important for tourism, game management and grazing in the UK (Thompson *et al.*, 1995; Usher & Thompson, 1993). Grazing has a major influence on vegetation condition. Overgrazing by sheep (*Ovis aries*) and deer is acknowledged as promoting the replacement of *Calluna*-dominated moorland by rough grassland in recent years (Anderson & Yalden, 1981; Hartley & Mitchell, 2005; Welch, 1984; Welch, 1986; Welch & Scott, 1995). Only 14% of moorland in England is assessed as in favourable condition (English Nature, 2001).

Experimental research underpinning the restoration of *Calluna*-dominated moorlands has concentrated principally in three areas: (1) reduction in grazing intensity (Anderson & Radford, 1994; Hulme *et al.*, 1999, 2002; Pakeman *et al.*, 2003), (2) the spraying out of dominant grasses (usually *Molinia caerulea*) (Marrs *et al.*, 2004; Milligan *et al.*, 2004) and (3) the restoration of vegetation on eroded land (Anderson *et al.*, 1997; Gilbert & Anderson, 1998). A reduction in grazing intensity alone can allow *Calluna* to spread (Anderson & Radford, 1994; Hill *et al.*, 1992), but this depends on its initial abundance, its condition and whether increased nutrient availability through atmospheric pollution affects its competitive ability (Hartley & Mitchell, 2005). Often a reduction in grazing only brings about small changes in community composition (Hope *et al.*, 1996; Hulme *et al.*, 1999, 2002; Pakeman *et al.*, 2003). Such changes are not sufficient to increase the *Calluna* cover on many degraded moorlands as there is little or no *Calluna* in the vegetation. Therefore, conditions must be created in which new *Calluna* plants can establish.

For the re-establishment of *Calluna* to occur there must be a sufficient seed supply and the conditions must be suitable for the germination of the seed and the establishment and survival of the plants. Seed limitation will occur when the seed-bank is depauperate and/or buried in the lower soil layers, and when seed input by existing or nearby plants is poor (i.e. the existing population is small). Experiments to study these processes must therefore consider three important factors: disturbance, competition and seeding. Disturbance may be required both to expose the viable seed-bank and to provide open conditions for germination and establishment. Methods of disturbance can include turf stripping, topsoil removal, burning or mowing. Turf stripping and topsoil removal are expensive and not practical in remote upland situations and risk large-scale soil erosion. Burning has traditionally been used to regenerate mature *Calluna* (Yallop *et al.*, 2006), but is not suitable for a grass-dominated sward (Marrs *et al.*, 2004), as the heat required to destroy the grass is too intense for any remaining *Calluna* seeds to survive. Moreover, these methods destroy most of the vegetation, making it impossible to continue grazing the site whilst *Calluna* recovers. Rotavation can create small patches of bare ground without destroying the entire vegetation community, and in lowland situations has been suggested to be a more cost effective and successful way of promoting re-establishment of *Calluna* than turf stripping or cutting (Britton & Marrs, 2000). However, in upland situations, access to remote hillsides with mechanical equipment can be difficult, and an alternative, not previously studied, may be to use livestock to disturb the ground.

To ensure successful establishment of *Calluna* in a grass-dominated sward, a window must be created in which the grass competition is reduced so that *Calluna* can become established and compete effectively with encroaching or re-establishing grasses before the grasses recovers (Gilbert & Anderson, 1998). This has been recognized as an issue in the restoration of *Calluna* in *Molinia*-dominated swards for many years (Anon, 1999), and Milligan *et al.* (2004) suggest that this window of reduced competition should be at least 18 months. A longer window of reduced competition provides more time for the *Calluna* plants to grow to a sufficient size to out-compete the grasses. If not over-grazed or damaged by pollution, *Calluna* is able to out-compete competitive grasses (Hartley & Mitchell, 2005). The disturbance technique used to create bare ground may control competitive species, such as moorland grasses, to a limited extent, but there are concerns that rapid regeneration of grasses (especially if mineralization rates are increased due to disturbance) may occur in the absence of further control. Herbicides can be used to control these competitive species (Milligan *et al.*, 1999), but many hill farms are in agri-environment schemes where the application of herbicides on a large scale is discouraged (Milligan *et al.*, 2004). Control of competitive species may be possible by grazing if the correct balance can be found between allowing *Calluna* to establish and containing its competitors. Seeding with *Calluna* seed may be required if the seed-bank does not contain sufficient viable *Calluna* seeds (Putwain & Rae, 1988).

Consideration should also be given to the impact of the restoration techniques used on the other species present in the community. Dwarf shrub species, other than *Calluna*, are rarely included in restoration work; at the very least the techniques should not destroy or significantly reduce the cover of desirable species such as *Vaccinium* sp. and *Erica* sp. Disturbance techniques to create bare ground may also encourage the establishment of invasive species such as *Juncus effusus* and this should be avoided.

Here we present the results of a five year replicated experiment conducted on two sites (an *Agrostis*/*Festuca/Nardus* site and a *Molinia*/*Calluna*-dominated site) which aimed to test intervention techniques to establish *Calluna* on grass-dominated moorlands alongside appropriate grazing regimes. Specifically we aimed to assess:

- if disturbance to create bare ground is required for successful *Calluna* establishment, and if so, whether mechanical disturbance or animal trampling is more successful
- if the addition of *Calluna* seed is required
- if grazing reduces competition from grasses and promotes *Calluna* establishment
- which of three grazing treatments is most successful in allowing *Calluna* establishment and how they affect *Calluna* morphology
- if the disturbance and grazing treatments were detrimental to the rest of the moorland plant community

- if the disturbance treatments reduced competition from grasses
- how quickly the vegetation recovered from the disturbance treatments
- if the disturbance treatments encouraged the spread of *Juncus effusus*
- which combination of restoration treatments (grazing, disturbance, seeding) developed a community most similar to target communities containing 30, 50, 70 or 90 % *Calluna*

METHODS

Sites and grazing treatments

The experiment was established on the ADAS farms at Pwllpeiran (52 ^{o} 22' N, 3^{o} 46' W) and Redesdale (55^{o} 14' N, 2 ^{o} 15' W). At Pwllpeiran, there were three blocks of land, each with three fields. Fields ranged in size from 5 to 7 ha. In each block the three fields were randomly assigned to one of three grazing treatments: "cattle only" (0.5 cow/ha for two months only (July and August)), "mixed" (0.5 cow/ha for 2 months only plus 1 ewe/ha all year) and "sheep only" (1.5 ewes/ha all year). In each field six 10 m x 10 m plots were established in areas with similar vegetation comprising a mixture of fine grasses (*Agrostis* sp./*Festuca ovina*/*Nardus stricta*) and *Vaccinium myrtillus*. At Redesdale, there were three fields with different grazing intensities: "mixed high" (1.5 ewe/ha all year plus 0.75 cows/ha for July and August), "sheep only" (1.5 ewes/ha all year) and "mixed low" (0.66 ewes/ha all year plus 0.75 cows/ha for July and August), which were not replicated. Fields ranged in size from 21 to 29 ha, and the vegetation was dominated by *Molinia caerulea* with small amounts of *Calluna*. In each field, eighteen 10 m x 10 m plots were established. Thus at each site there were 54 plots. At both sites, the grazing treatments started in spring 2002 and continued until autumn 2006.

Plot treatments

Within each field, the plots were randomly assigned to one of three disturbance treatments (undisturbed, rotavation and trampling). Each disturbance treatment therefore occurred twice per field at Pwllpeiran and six times per field at Redesdale.

At Pwllpeiran, rotavation was carried out using a 2 m Howard tractor-mounted rotavator with 6 rows of 10 tines each 2.5 cm diameter and 20 cm long. The rotavator was adjusted so that the tines dug into the ground about 5-7 cm. The plots were then harrowed twice using a 4.5 m hydraulic chain harrow in the same direction as the rotavation, in order to bundle up the litter created by the rotavation. At Redesdale, the rotavation was carried out by a Howard HR30 with bladed rotors, which created slots about 10 cm long. The plots were rotavated twice, the second time at 90 degrees to the first to create a grid of small pockets of bare ground c 10 cm x 10 cm. The trampling treatment was carried out by Welsh Black bulling heifers at Pwllpeiran and horses at Redesdale. At Pwllpeiran, interlocking gates were erected around the edge of the plot to form a pen and five heifers halter trained so that they could be walked to the plots. The heifers were encouraged to walk round the plot trampling the vegetation. As the corners of the plot tended to become trampled quickly, the gates were moved to prevent further trampling of these areas once the desired level of trampling had been achieved. The heifers were walked round the plot until about 25% of the plot had been trampled, which took between 25 and 45 minutes depending on the aspect, vegetation type and ground wetness. At Redesdale, a mountain pony, was ridden round the plots creating patches of bare ground. Each plot took about 40 minutes though this varied according to how tough the vegetation was. Frosty days were avoided. The pony was ridden round the plot until there were visible hoof-prints across the whole area of the plot. The disturbance treatments were carried out in September 2002.

All plots then had two sub-treatments applied to them in March 2003. *Calluna* seed was mixed with silver sand and hand sown at a rate of 0.8 g seed/m^2 on half of each plot. A no-grazing treatment was applied by fencing half the plot perpendicular to the seeding treatment, thus creating a 2 x 2 factorial structure: (a) grazed, not seeded; (b) not grazed, not seeded; (c) not grazed, seeded, (d) grazed and seeded. Within each quarter plot, one 4 m x 4 m sub-plot was established within which all recording was carried out, leaving 2 m buffer zones between treatments across the centre of the plot. Each sub-plot was divided into four 4 m^2 quadrats and further into sixteen 1 m^2 quadrats depending on the response being recorded.

Soil chemistry

Twenty five soil cores (diameter 5 cm, depth 15 cm) were randomly taken from each plot before the disturbance treatments were applied. The samples were bulked at the plot level and analysed for pH, loss on ignition, soil moisture and extractable nitrate, phosphorus, potassium and magnesium by Direct Laboratories, Wergs Road, Wolverhampton.

Seed-bank

In September 2002, 16 soil cores (diameter 2.4 cm, depth 5 cm) were taken randomly from each plot and bulked at the plot level. The soil was dried, sieved and spread thinly over sterile sand in seed trays. The trays were placed in a glasshouse and watered regularly to enable seedling germination. As seedlings emerged they were identified and counted.

***Calluna* establishment**

There was some *Calluna* present at both sites before the experiment started, but all plants were very old. It was therefore straightforward to identify newly established *Calluna* plants, and it was those which were recorded as *Calluna* presence within the nine 1 m^2 quadrats closest to the centre of the plot in each sub-plot in May 2004, 2005 and 2006. Each 1 m^2 quadrat was divided into twenty-five 20 cm x 20 cm cells. The number of newly-established *Calluna* plants in the centre 20 cm x 20 cm cell was recorded. By May 2006, some of the newly-established *Calluna* plants had grown such that distinguishing individual plants was difficult. Instead, the percentage cover of the newly-established *Calluna* plants in the central cell was estimated by eye to the nearest 5%.

***Calluna* morphology**

In spring 2006, up to three young *Calluna* plants were collected at random from otherwise unrecorded parts of the grazed and ungrazed seeded sub-plots of each plot. The plants were cut at ground level, and the height, number of shoots greater than 2 cm long, distance up stem to the first shoot and the total dry weight, following drying at 60 ºC for three days, were recorded.

Change in *Calluna* , bare ground and *Juncus effusus* cover

Prior to the disturbance treatments being applied and at the end of the experiment, the total cover of *Calluna* was estimated in the four 4 m^2 quadrats in each sub-plot to provide a measure of overall change of *Calluna*. The cover of bare ground was recorded in May 2003 and in September 2004 and 2005 in the nine 1 m^2 quadrats used for *Calluna* establishment. *Juncus effusus* presence and cover was recorded in all sixteen 1 m^2 quadrats in each sub-plot in May 2003 (6 months after the disturbance treatments), in September 2004 and in September 2005.

Vegetation heights

In each of the sixteen 1 m^2 quadrats in each sub-plot, the vegetation height was measured using a drop disc (30 cm diameter, weight 180 g). Vegetation heights were recorded every autumn and spring from September 2002 to September 2006. From September 2003 onwards, the height of the vegetation in the field surrounding each plot was also recorded in order to assess whether the animals were preferentially grazing the plots rather than the rest of the field. Six measurements were taken at 5 m from the fenced side and six at 5 m from the unfenced side of each plot.

Plant community composition

Within each sub-plot, the plant community composition was recorded in one of the 4 m^2 quadrats in September 2002 prior to treatment, in 2003 one year after treatment and in 2006 four years after treatment. The cover of all plant species was estimated by eye to the nearest 5%. The change in species cover in the 4 m^2 quadrat in each sub-plot from baseline data to one and four years after the start of the experiment was calculated. The impact of the grazing, disturbance and fencing treatments on the change in species cover was assessed on the dominant species at each site

(*Agrostis* sp., *Carex pilulifera*, *Deschampsia flexuosa*, *Nardus stricta*, *Festuca ovina* and litter at Pwllpeiran; *Molinia caerulea, Agrostis* sp., *Festuca ovina*, *Nardus stricta* and litter at Redesdale).
In addition, at each site in September 2005, thirty two 4 m^2 quadrats were recorded outside the study area, on a neighbouring hillside, in vegetation similar to that which we hoped to establish inside the plots. These quadrats were used as target communities in the analysis to assess the success of the treatments. Target communities were in four classes based on the percentage cover of *Calluna*: T30 = 30-40%; T50 = 50-65%; T75 = 75-80% and T90 = 90% or more.

Nomenclature follows Stace (1995) for vascular plants, Paton (1999) for liverworts and Smith (2004) for mosses.

Data analysis

Univariate analysis

Separate analyses were carried out for each site. All analyses were conducted at the sub-plot level, except for analysis of *Calluna* morphology, which was conducted at the individual plant level. Where there was more than one measurement within a sub-plot, the data were treated as follows. Presence/absence of *Calluna* and *Juncus effusus* were analysed as the probability of a plant being present in a 1 m^2 quadrat, i.e. the number of successes out of nine (*Calluna*) or sixteen (*J. effusus*) trials (the nine or sixteen quadrats recorded within each sub-plot). Count data (number of *Calluna* plants) were summed at the sub-plot level. Cover data and vegetation height data were analysed as the mean value for the sub-plot.

Presence/absence data were analysed by fitting generalized linear mixed models (GLMM; SAS v. 9.1 macro GLIMMIX, SAS 2005) with a binomial error term and a logit link function; count data were fitted to a GLMM with a Poisson error term and a log link function. Disturbance, fencing, seeding, visit and their interactions were included as fixed effects. For Pwllpeiran, block and grazing treatment were also included as fixed effects, and for Redesdale field only. Plot and, where appropriate, sub-plot were included as random effects and repeated measures were modelled using an autoregressive residual covariance structure. Differences between individual pairs of treatments were tested using least squared means and adjusted using the Tukey-Kramer correction for multiple tests.

Continuous variables (vegetation height, species cover/change and *Calluna* morphology) were analysed by fitting linear mixed models (MIXED procedure in SAS v. 9.1, SAS 2005) with fixed and random terms as described above. Response variables were log-transformed prior to analysis if necessary to meet assumptions of normally-distributed residuals. As the vegetation height data showed a seasonal cyclic pattern, autumn and spring data were analysed separately.

Multivariate analysis

Changes in plant species community composition between autumn 2002 and autumn 2006 were analysed using Detrended Correspondence Analysis (DCA) (CANOCO 4.5; Ter Braak & Smilauer, 2002). Cover (%) data were transformed as (log X + 0.1) and rare species were down-weighted using the down weighting option in CANOCO. The data from the four target communities were included in the analysis. The Euclidean distance in multivariate space between the quadrats in 2006 and the mean position of each of the target communities was calculated in four dimensions (Manly 1986), to provide a measure of how similar the plots were to the target community after treatment. The effect of the grazing, disturbance, fencing and seeding treatments on this measure of vegetation community change was then analysed using linear mixed models as described above.

RESULTS

Soil chemistry

The soil chemistry at both sites was typical of moorland soil (Table 1). Soils from Pwllpeiran were less acidic and had lower organic matter content, nitrate and extractable phosphorus than those from Redesdale.

Table 1 Soil properties at the start of the experiment at Pwllpeiran and Redesdale

(mean ± 1 SE; n = 6 for each field at Pwllpeiran and 18 at Redesdale) (DM = data missing.)

Site	Block	Field	Moisture (%)	pH	Extractable phosphorus (mg/l)	Potassium (mg/l)	Extractable magnesium (mg/l)	Loss on ignition (% organic matter) (mg/l)	Nitrate (mg/l)
Pwllpeiran	A	Cattle only	61.9 ± 1.0	4.28 ± 0.04	6.2 ± 0.5	99.0 ± 5.4	74.5 ± 6.7	18.4 ± 4.3	2.7 ± 0.5
		Sheep only	66.9 ± 3.0	4.41 ± 0.04	7.0 ± 0.9	76.2 ± 8.0	107.0 ± 17.6	28.8 ± 6.4	2.7 ± 0.3
		Mixed	59.1 ± 1.6	4.41 ± 0.06	6.7 ± 0.6	158.3 ± 62.5	85.2 ± 6.4	13.9 ± 3.2	1.8 ± 0.2
	B	Cattle only	65.7 ± 2.5	4.18 ± 0.01	7.0 ± 0.6	84.7 ± 4.1	76.2 ± 4.7	30.6 ± 10.1	1.8 ± 0.2
		Sheep only	66.3 ± 3.0	4.2 ±0. 068	6.7 ± 0.3	98.8 ± 5.4	89.3 ± 11.9	31.2 ± 8.5	2.2 ± 0.7
		Mixed	61.8 ± 1.9	4.16 ± 0.04	5.7 ± 0.6	88.8 ± 9.5	71.5 ± 10.8	22.2 ± 1.8	2.2 ± 0.2
	C	Cattle only	DM	4.16 ± 0.03	6.7 ± 0.8	62.8 ± 6.4	61.8 ± 5.0	42.5 ± 6.8	2.3 ± 0.2
		Sheep only	DM	4.21 ± 0.03	5.3 ± 0.6	67.3 ± 7.4	61.2 ± 4.7	32.5 ± 4.1	2.3 ± 0.2
		Mixed	DM	4.16 ± 0.03	5.5 ± 0.6	75.3 ± 9.4	60.8 ± 2.2	29.0 ± 3.4	2.2 ± 0.5
Redesdale		High mixed	72.7 ± 1.8	3.96 ± 0.01	9.1 ± 0.7	100.3 ± 6.3	83.7 ± 3.2	46.7 ± 4.7	<5
		Sheep only	81.0 ± 0.7	3.78 ± 0.02	8.5 ± 0.6	73.7 ± 5.5	53.1 ± 3.0	78.2 ± 2.0	<5
		Low mixed	74.3 ± 1.0	3.74 ± 0.01	10.1 ± 0.8	100.7 ± 6.2	78.7 ± 5.8	57.7 ± 4.2	<5

Table 2 Seedbank composition in the nine fields at Pwllpeiran

(mean number of seeds $m^{-2} \pm$ 1SE, n = 6)

The detection limit was 23 seeds m^{-2} for a group of 6 plots. Means in parenthesis are based on a species only occurring in one of the 18 plots, thus it is not meaningful to calculate a SE.

	Block A			**Block B**			**Block C**		
	Cattle only	**Sheep only**	**Mixed**	**Cattle only**	**Sheep only**	**Mixed**	**Cattle only**	**Sheep only**	**Mixed**
Agrostis sp.	(184)	944 ± 480	1888 ± 385	530 ± 268	760 ± 374	(161)	< 23	184 ± 117	806 ± 293
Carex binervis	< 23	< 23	92 ± 92	< 23	< 23	< 23	< 23	< 23	92
Carex demissa	990 ± 180	719 ± 193	875 ± 452	806 ± 173	253 ± 121	875 ± 423	161 ± 103	299 ± 135	967 ± 402
Festuca ovina	207 ± 132	253 ± 183	207 ± 132	(92)	345 ± 236	(345)	461 ± 342	< 23	230 ± 146
Galium saxatile	< 23	< 23	(115)	262 ± 124	(138)	276 ± 178	< 23	(92)	161 ± 103
Juncus effusus	< 23	1013 ± 400	2326 ± 833	181 ± 117	(138)	< 23	< 23	< 23	< 23
Juncus squarrosus	1612 ± 363	368 ± 201	(230)	967 ± 307	783 ± 442	1704 ± 744	806 ± 337	1980 ± 483	3329 ± 674

Table 3 **Seedbank composition in the three fields at Redesdale**
(mean number of seeds $m^{-2} \pm$ 1SE, n = 18)

The detection limit was 8 seeds m^{-2} for a group of 18 plots. Means in parenthesis are based on a species only occurring in one of the 18 plots, thus it is not meaningful to calculate a SE.

	Mixed high	**Sheep only**	**Mixed low**
Agrostis sp.	130 ±79	<8	499 ± 204
Calluna vulgaris	606 ± 217	3784 ± 680	2587 ± 432
Carex nigra	721 ± 213	599 ± 173	1167 ± 257
Erica tetralix	<8	445 ± 238	<8
Festuca ovina	998 ± 217	706 ± 255	1243 ± 396
Galium saxatile	84 ± 46	<8	107 ± 59
Juncus effusus	345 ± 117	(130)	307 ± 239
Juncus squarrous	1911 ± 350	721 ± 240	1673 ± 531
Luzula sp.	384 ± 162	(69)	69 ± 48

Seed-bank composition

The seed-bank at Pwllpeiran was species poor, and only seven species germinated (Table 2). *Calluna* was below the limits of detection (23 seeds m^{-2}) and thus was for restoration purposes absent from the seed-bank, which was dominated by graminoids.

The seed-bank at Redesdale yielded 9 species (Table 3). *Calluna* was present in the seed-bank at low densities in the mixed high grazing field (606 seed m^{-2}) and at higher densities in the sheep only and low mixed grazing fields (3784 and 2587 seeds m^{-2} respectively). *Festuca ovina* and *Juncus squarrosus* were the most frequent graminoids present.

***Calluna* establishment**

Disturbance had a significant effect on *Calluna* presence at Pwllpeiran ($F_{2,46}$ = 25.1; p<0.001) and Redesdale ($F_{2,40}$ = 44.4; p<0.001) (Fig. 1a & b). *Calluna* presence was greater in disturbed than undisturbed plots ($p<0.001$ for both sites). At Pwllpeiran there was no difference between the two forms of disturbance, rotavation and trampled. At Redesdale rotavated plots had significantly greater *Calluna* presence than trampled plots ($p<0.001$). *Calluna* presence was greater in seeded than unseeded sub-plots at both sites (Pwllpeiran: $F_{1,203} = 432$; $p<0.001$; Redesdale: $F_{1,217} = 63.8$; $p<0.001$) (Fig. 1a & b). At Pwllpeiran there was no effect of fencing on *Calluna* presence but at Redesdale there was greater *Calluna* presence in the grazed than the fenced sub-plots ($F_{1,215} = 7.7$; $p<0.001$) (Fig. 1d). There was a weak grazing by fencing interaction ($F_{2,199} = 2.6$; $p<0.1$) at Pwllpeiran. *Calluna* presence was greater on the cattle only grazed sub-plots than the ungrazed sub-plots or sub-plots with other grazing treatments (Fig. 1c). While these differences were only marginally significant, they may indicate a trend towards greater *Calluna* presence in the cattle only grazing treatment than the other grazing treatments. There was a significant disturbance by fencing interaction at Pwllpeiran ($F_{2,212} = 4.1$; $p<0.05$) and Redesdale ($F_{2,243} = 5.7$; $p<0.01$). At Pwllpeiran, fencing was significant only in the rotavated plots, where *Calluna* presence was greater in the ungrazed than the grazed sub-plots. At Redesdale, there was higher *Calluna* presence in grazed trampled sub-plots than in ungrazed trampled sub-plots, but no difference between grazed and ungrazed sub-plots under the rotavated and undisturbed treatments. *Calluna* presence increased with time (Pwllpeiran: $F_{2,405} = 28.3$; $p<0.001$; Redesdale: $F_{2,403} = 26.0$; $p<0.001$), there being significantly greater Calluna presence in 2006 than 2004. At Pwllpeiran, there was a visit by fencing interaction ($F_{2,397} = 3.5$; $p<0.01$). In 2004, *Calluna* presence was similar in ungrazed and grazed sub-plots; in 2005 *Calluna* presence was greater in the ungrazed sub-plots than the grazed sub-plots, whereas in 2006 *Calluna* presence was greater in the grazed than the ungrazed sub-plots. At Redesdale, the field by seeding interaction ($F_{2,245} = 9.7$; $p<0.001$) showed that in all fields the seeded sub-plots had a higher *Calluna* presence than unseeded sub-plots, but this difference was greatest in the sheep only field, despite this field having the highest seed-bank. Analysis of only fenced sub-plots showed the same pattern of a significant field by seeding interaction ($F_{2,85} = 6.5$; $p<0.01$). Thus this seeding by field interaction was not caused by grazing but by some other factor.

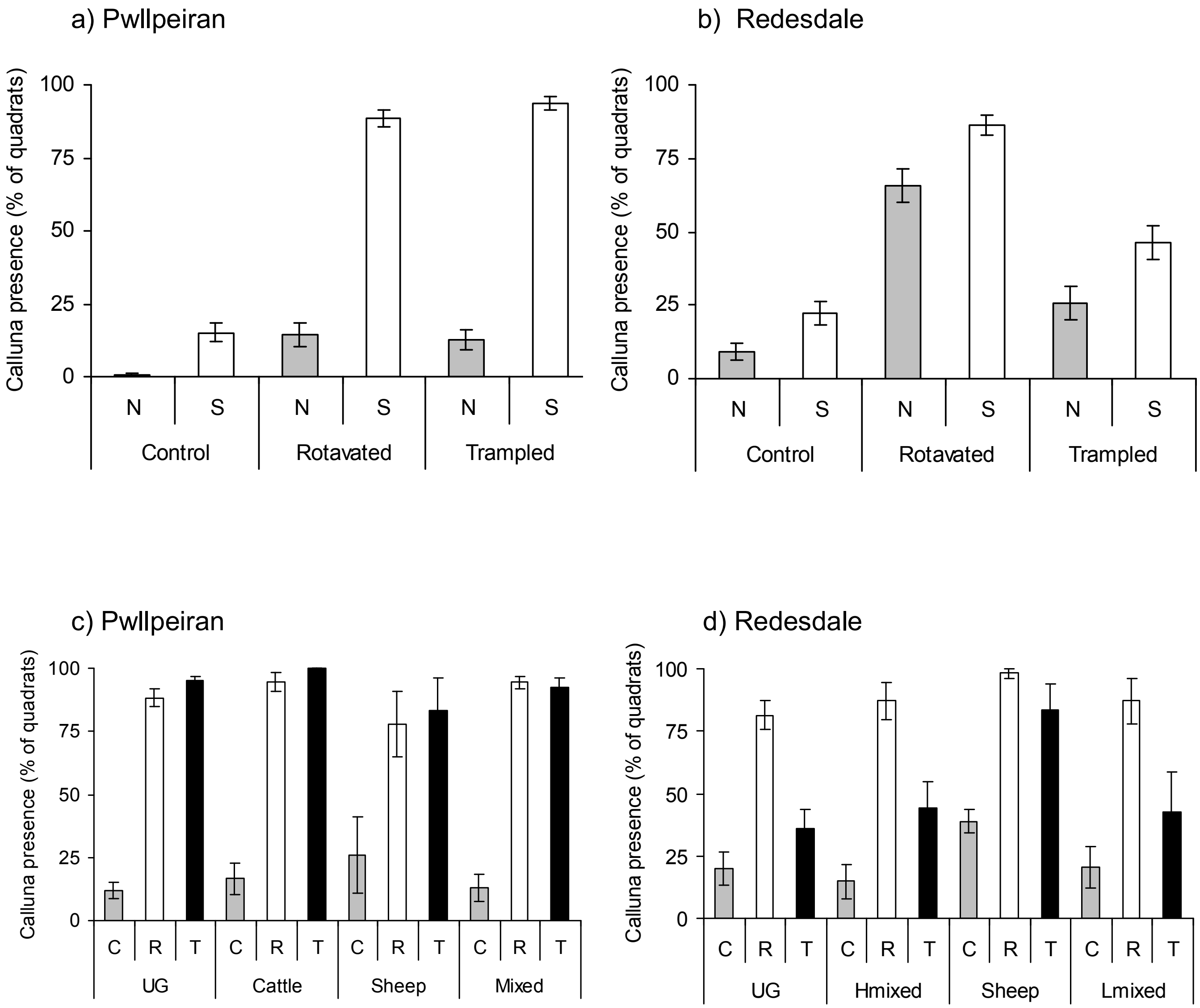


Figure 1 **The impact of (a, b) disturbance and seeding and (c, d) disturbance and grazing treatment on the mean proportion of 1 m^2 quadrats having new *Calluna* plants present at Pwllpeiran and Redesdale 3.5 years after the start of the experiment**

S = seeded; N = unseeded; C = undisturbed; R = rotavated; T = trampled; UG = ungrazed (fenced); Mixed = sheep and cattle; Hmixed = high sheep and cattle; Lmixed = low sheep and cattle. Error bars show ± 1 SE.

As it was established above that the plots needed to be disturbed and seeded for *Calluna* to establish at Pwllpeiran, a further analysis of only the seeded rotavated and trampled plots was conducted in which the cover of bare ground recorded at the 1 m^2 level in May 2003 was included as the initial explanatory term. The cover of bare ground had a significant positive effect on *Calluna* presence ($F_{1,69}$ = 11.7; p<0.01), but did not explain all the variation caused by the disturbance treatments which remained significant ($F_{1,30}$ = 7.5; p = 0.01), as did visit ($F_{2,131}$ = 11.0; p <0.001) and grazing by fencing ($F_{2,47}$ = 4.06; p <0.05). The probability of a *Calluna* plant occurring varied between grazing treatments even when the same amount of bare-ground was present (Fig. 2). The cattle only grazing treatment consistently had a greater *Calluna* presence than the other grazing treatments when there was only a small cover of bare ground created (<10%) (Fig. 2).

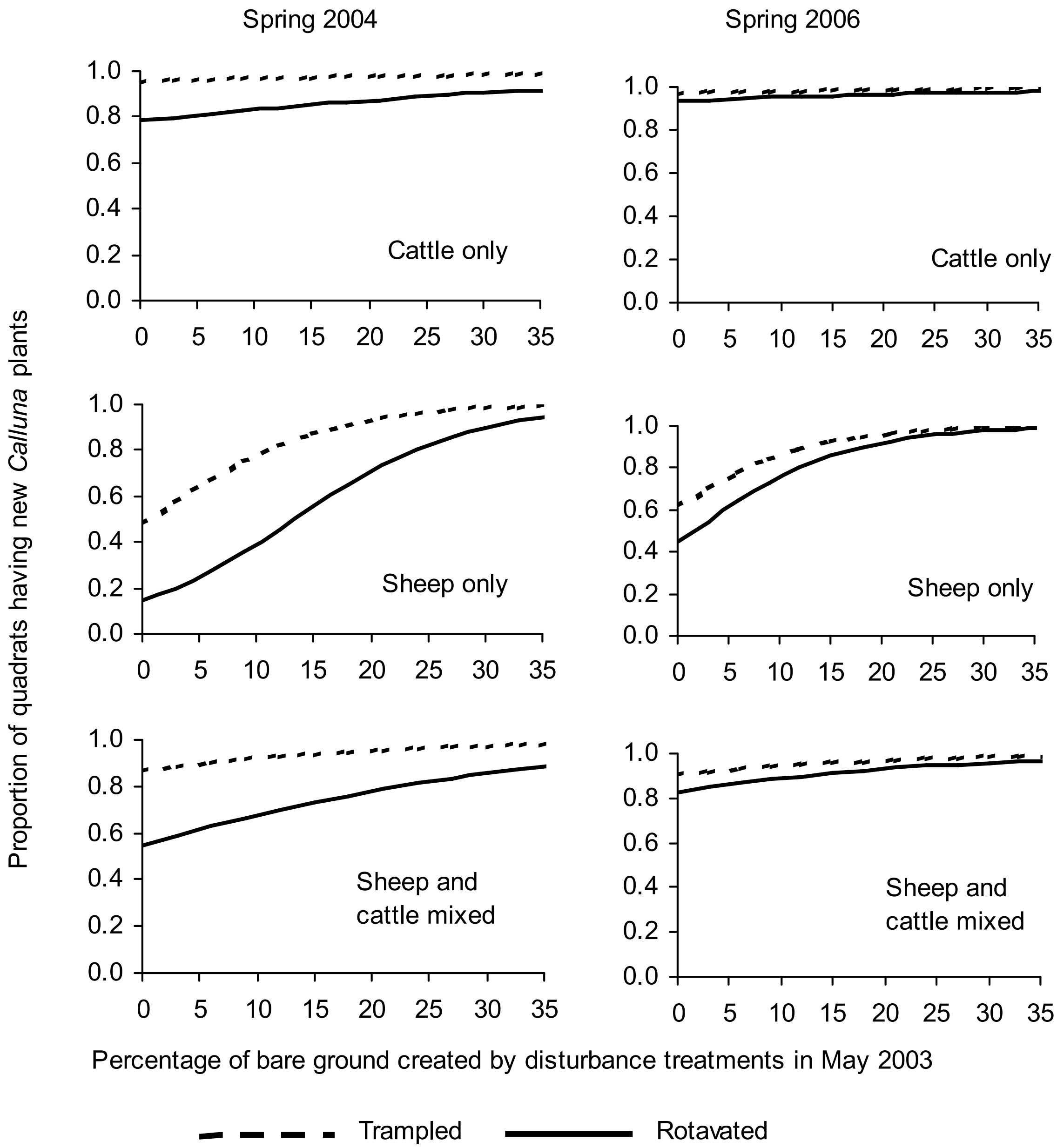


Figure 2 **Modelled relationship between *Calluna* presence and the amount of bare ground created by rotavating or trampling in three grazing treatments (cattle only, sheep only and mixed cattle and sheep) at Pwllpeiran in spring 2004 and 2006**

(Only data for seeded grazed sub-plots shown)

The Redesdale data were analysed in an similar way, including the cover of bare ground in May 2003, but total *Calluna* seed availability (as calculated from the seed-bank plus seed added in the seeded half of plots) was also included in the analysis to assess if the effect of disturbance and seeding could be explained by the amount of bare ground created and the available seed. The effect of disturbance was partly explained by the cover of bare ground ($F_{1,167}$ = 42.7; p<0.001), but there remained an effect of disturbance treatment over and above that of bare ground ($F_{2,40}$ = 34.7; p<0.001). In contrast, the effect of seeding was wholly explained by the total seed-bank ($F_{1,208}$ = 54.0; p<0.001). The effect of fencing was also reduced by the cover of bare ground, but remained significant ($F_{1,199}$ = 4.7; p<0.05). The field by seeding interaction of the initial model was wholly explained by the total seed-bank and was no longer significant, but the disturbance by fencing and disturbance by visit interactions remained significant ($F_{2,323}$ = 5.8; p<0.01 and $F_{4,401}$ = 7.3; p<0.001 respectively).

Number and cover of *Calluna* plants

Analysis of seeded and disturbed sub-plots at Pwllpeiran showed that there was no difference between the grazing treatments or between rotavated and trampled plots in the number of *Calluna* plants present in the central 20 cm x 20 cm cell of the quadrats in 2004 and 2005 (undisturbed and unseeded sub-plots omitted owing to insufficient presence). However, there were more plants in the fenced than unfenced sub-plots ($F_{1,38}$ = 12.0; p<0.001) (Fig. 3). In 2006, fencing ($F_{1,30}$ = 11.9; p<0.01) and grazing by fencing ($F_{2,30}$ = 6.1; p<0.01) were significant in explaining *Calluna* cover in the central 20 cm x 20 cm cell of seeded disturbed sub-plots (Fig. 3). The cattle only grazed plots had significantly higher cover than the sheep only plots (p<0.05), but were not significantly different from the mixed grazing regime. There was no difference in the cover of *Calluna* between grazed and ungrazed sub-plots in the cattle only and mixed grazing treatments, but there was in the sheep only grazing treatment (p<0.01).

In contrast to Pwllpeiran, there were sufficient *Calluna* plants on the unseeded sub-plots to include them in the analyses of the number and cover of plants on rotavated and trampled plots at Redesdale. The number of *Calluna* plants was affected by the type of disturbance ($F_{1,14}$ = 39.7; p<0.001), fencing ($F_{1,107}$ = 18.6; p<0.001), seeding ($F_{1,107}$ = 26.6; p<0.001) and visit ($F_{1,141}$ = 18.9; p<0.001); there was also a significant disturbance by fencing interaction ($F_{1,107}$ = 13.5; p<0.001). There were more *Calluna* plants in the rotavated than the trampled plots, in the grazed than the ungrazed sub-plots and in the seeded than the unseeded sub-plots (Fig. 3). The number of *Calluna* plants declined between 2004 and 2005. There were significant differences between the fields ($F_{2,21}$ = 28.8; p<0.001); the field with sheep only had significantly more *Calluna* plants than the other two fields (p<0.01). Rotavated plots had a greater cover of *Calluna* than trampled plots ($F_{1,30}$ = 51.4; p<0.001) (Fig. 3) and seeded subplots had a greater cover than unseeded subplots ($F_{1,99}$ = 24.1; p<0.001). *Calluna* cover was greater in the sheep only field than either of the other two fields ($F_{2,30}$ = 19.4; p<0.001). There was a significant disturbance by fencing interaction ($F_{1,99}$ = 17.5; p<0.001); for rotavated plots the ungrazed sub-plots had significantly higher *Calluna* cover than the grazed sub-plots, but the reverse was true for trampled plots.

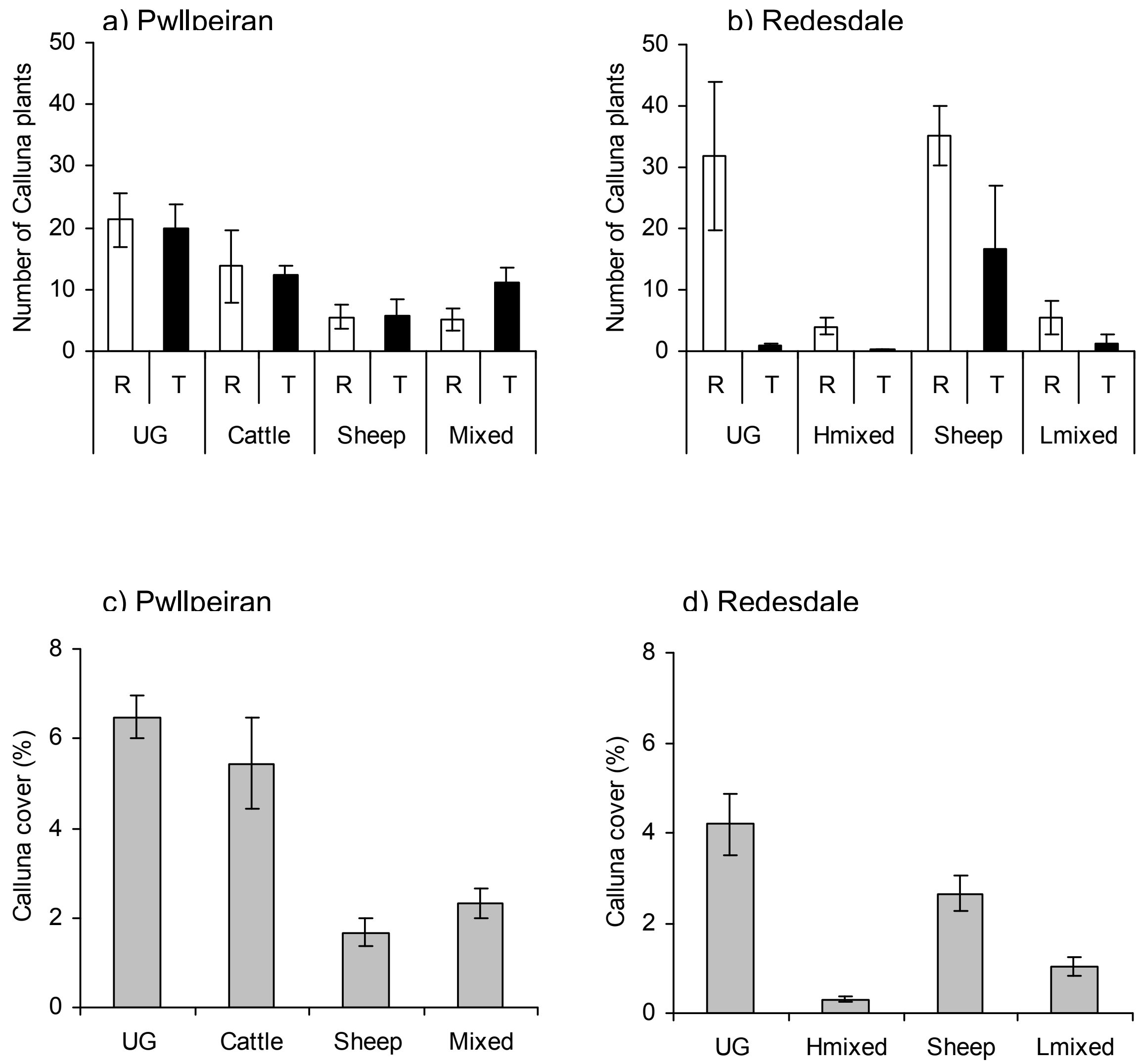


Figure 3 **The impact of grazing treatments on (a, b) number in 2005 and (c, d) cover in 2006 of *Calluna* on sown and disturbed plots**

R = rotavated and T = trampled; UG = ungrazed (fenced); Mixed = sheep and cattle; Hmixed = high sheep and cattle; Lmixed = low sheep and cattle. Bars show means ± 1 SE.

Calluna morphology

The grazing and fencing treatments significantly affected the morphology of the *Calluna* plants at both sites (Fig. 4). Grazing treatment significantly affected the number of shoots ($F_{2,36}$ = 3.7; p<0.05), the dry weight ($F_{2,31}$ = 7.7; p<0.01) and plant height ($F_{2,32}$ = 4.4; p<0.05) at Pwllpeiran. Plants had significantly more shoots, a greater dry weight and were taller in the cattle only treatment than the sheep only treatment (p<0.05) (Figure 4 a, c &d). At Redesdale, field significantly effect dry weight ($F_{2,29}$ = 4.0; p<0.05) and height ($F_{2,33}$ = 11.6; p<0.001), plants from the sheep only field being taller and heavier than plants from the field with the high mixed grazing. The *Calluna* plants had significantly more shoots (Pwllpeiran: $F_{1,37}$ = 20.6; p<0.001; Redesdale: $F_{1,35}$ = 7.2; p<0.05), greater dry weight (Pwllpeiran: $F_{1,34}$ = 61.4; p<0.001; Redesdale:$F_{1,29}$ = 56.8; p<0.001), longer distance up stem to lowest shoot (Pwllpeiran: $F_{1,35}$ = 28.9; p<0.001; Redesdale: $F_{1,30}$ = 83.0; p<0.001) and were taller (Pwllpeiran: $F_{1,33}$ = 165; p<0.001; Redesdale: $F_{1,43}$ = 118; p<0.001) in ungrazed than grazed sub-plots (Fig. 4). At Pwllpeiran there was a grazing by fencing interaction for dry weight ($F_{2,34}$ = 9.8; p<0.001) and distance up stem to lowest shoot ($F_{2,35}$ = 3.29; p<0.05). In the cattle only treatment and the mixed grazing treatment there was no difference in dry weight and distance up stem to lowest shoot between plants from grazed and ungrazed sub-plots, whereas in the sheep only treatment ungrazed plants were significantly heavier than grazed plants (p<0.001) and had a longer distance up the stem to the lowest shoot (p<0.001).

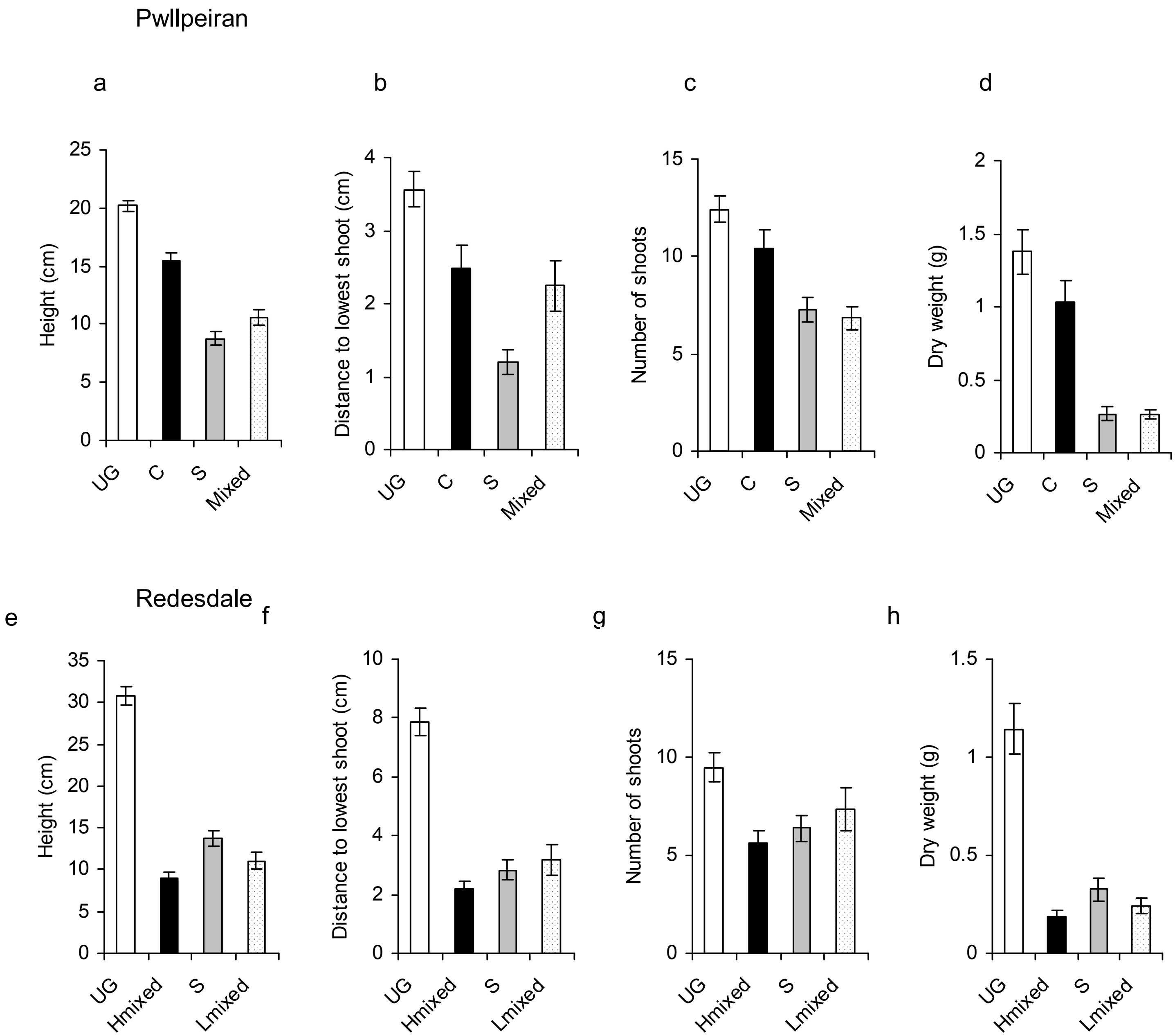


Figure 4 The effects of grazing treatment on *Calluna* morphology at Pwllpeiran (a-d) and Redesdale (e-h), viz. height (a, e), distance up stem to first shoot (b, f), number of shoots longer than 2 cm (c, g) and dry weight (d, h)

UG = ungrazed (fenced); C = cattle; S = sheep; Mixed = sheep and cattle; Hmixed = high sheep and cattle; Lmixed = low sheep and cattle. Bars show means ± 1 SE.

***Calluna* cover at the 2 m x 2 m scale**

Calluna was present at low cover at the start of the experiment at both sites (Pwllpeiran: <1%; Redesdale: <5%). At Pwllpeiran, there was no difference in *Calluna* cover between any of the grazing treatments or blocks at the start of the experiment, and cover increased to over 10% by the end of the experiment in sub-plots that were seeded and disturbed and were either ungrazed or grazed by cattle only (Fig. 5a). At Redesdale, there was a significant difference between fields in the cover of *Calluna* at the start of the experiment ($F_{2,45}$ = 5.5; $p<0.01$), cover being greater in the sheep only grazed field than in the field with the low mixed grazing ($p<0.05$). This difference between fields remained at the end of the experiment, although cover had increased, attaining over 10% in ungrazed rotavated plots (Fig. 5b).

By 2006, *Calluna* cover was significantly affected by disturbance (Pwllpeiran: $F_{2,43}$ = 18.4; $p<0.001$; Redesdale: $F_{2,45}$ = 25.9; $p<0.001$), seeding (Pwllpeiran: $F_{1,151}$ = 159; $p<0.001$; Redesdale: $F_{1,151}$ = 24.4; $p<0.001$) and fencing (Pwllpeiran:$F_{1,151}$ = 7.6; $p<0.01$; Redesdale: $F_{1,151}$ = 26.7; $p<0.001$). At Pwllpeiran, *Calluna* cover was significantly greater in rotavated and trampled plots than undisturbed plots ($p<0.001$), whereas at Redesdale only rotavated plots were significantly different from undisturbed plots ($p<0.001$). At both sites *Calluna* cover was greater in ungrazed than grazed plots ($p<0.01$) and seeded than unseeded plots ($p<0.001$). At Pwllpeiran, grazing treatment affected *Calluna* cover ($F_{2,43}$ = 4.3; $p<0.05$); there was greater *Calluna* cover in plots grazed by cattle only than sheep only or mixed grazing ($p<0.05$). The significant grazing by fencing interaction at Pwllpeiran ($F_{2,151}$ = 4.6; $p<0.05$) showed that in the cattle only and mixed grazing treatments there was no difference in *Calluna* cover between the grazed and ungrazed sub-plots, whereas in the sheep only grazing the ungrazed sub-plots had significantly greater *Calluna* cover than the grazed sub-plots ($p<0.05$). There was a significant disturbance by fencing interaction at both sites (Pwllpeiran: $F_{2,151}$ = 3.4; $p<0.05$; Redesdale: $F_{2,151}$ = 3.8; $p<0.05$). At Pwllpeiran, the ungrazed rotavated sub-plots had greater *Calluna* cover than grazed rotavated sub-plots ($p<0.01$), whereas there was no difference between the grazed and ungrazed sub-plots for the trampled or undisturbed treatments. At Redesdale, the rotavated fenced plots had significantly greater *Calluna* cover than all other combinations of fencing and disturbance ($p<0.001$). The disturbance by seeding interaction ($F_{2,151}$= 27.5; $p<0.001$) showed that seeded rotavated and trampled sub-plots at Pwllpeiran were not significantly different from each other, but had greater *Calluna* cover than any other combination of seeding and disturbance. The significant fencing by seeding interaction ($F_{1,151}$ = 7.95; $p<0.01$) at Pwllpeiran showed that ungrazed seeded sub-plots had significantly greater *Calluna* cover than grazed seeded plots ($p<0.001$). There was no difference between unseeded grazed and ungrazed plots. The field by seeding interaction at Redesdale ($F_{2,151}$ = 4.1; $p<0.05$) showed that seeded sub-plots in the sheep and high mixed grazing treatment had significantly greater cover than the unseeded sub-plots ($p<0.01$), whereas in the low mixed grazing treatment there was no difference between the seeded and unseeded sub-plots.

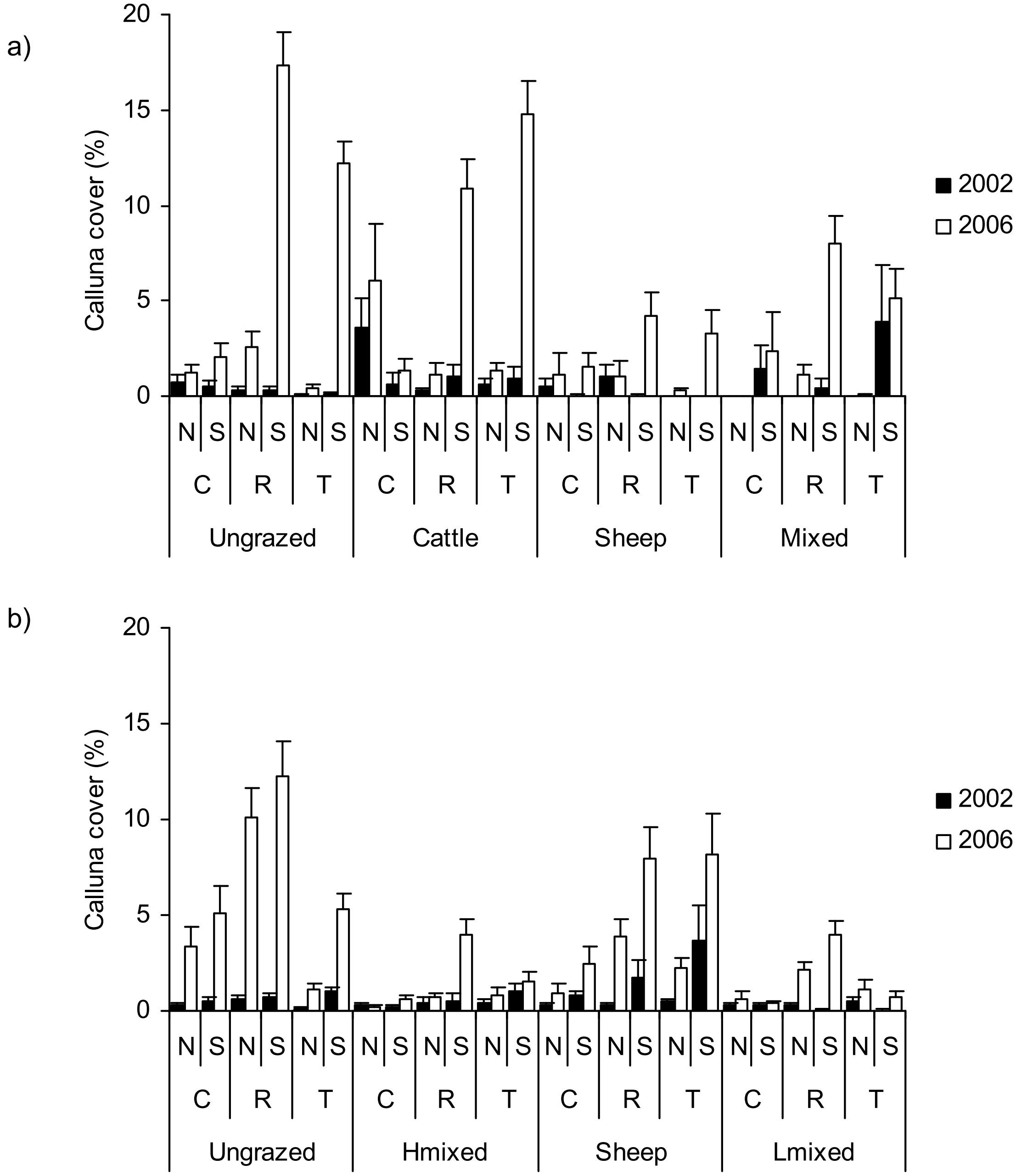


Figure 5 **Mean *Calluna* cover in 4 m² quadrats prior to experimental treatments (2002) and after four years (2006) at (a) Pwllpeiran and (b) Redesdale**

N = not seeded, S = seeded, C = undisturbed, R = rotavated; T = trampled;
Hmixed = high sheep and cattle grazing; Lmixed = low sheep and cattle grazing. Error bars show 1 SE.

Juncus effusus cover

Mean *Juncus effusus* cover on the plots at both sites was very low, less than 0.1% on undisturbed plots and about 3% on disturbed plots (Fig. 6a&b). As most quadrats had no *J. effusus* present, the impact of disturbance on cover could not be examined. Instead, the probability of its being present in a 1 m^2 quadrat was analysed.

There was a significant effect of disturbance on *J. effusus* presence at both sites (Pwllpeiran: $F_{2,42}$ = 9.1; p<0.001; Redesdale: $F_{2,48}$ = 4.07; p<0.05) (Fig. 6c&d). *J. effusus* occurred more frequently on rotavated and trampled plots than undisturbed plots (p<0.05 at both sites). *J. effusus* presence was greater on the grazed than the ungrazed plots (Pwllpeiran: $F_{1,266}$ = 6.6; p=0.01; Redesdale: $F_{1,291}$ = 19.2; p<0.001) and it increased over time (Pwllpeiran: $F_{2,439}$ = 37.7; p<0.001; Redesdale: $F_{2,427}$ = 41.2; p<0.001).

Bare ground cover

The disturbance treatments created different amounts of bare ground at the two sites (Fig. 7). The rotavation created 15% bare ground at Pwllpeiran and 4% at Redesdale, trampling created 15% bare ground at Pwllpeiran and <1% bare ground at Redesdale. The disturbance treatments had a significant effect on the amount of bare ground present 6 months after they were carried out (Pwllpeiran: $F_{2,44}$ = 150; p<0.001; Redesdale: $F_{2,45}$ = 53.5; p<0.001). At Pwllpeiran, both rotavated and trampled plots had significantly more bare ground than the undisturbed plots (p<0.001) and the two forms of disturbance were not significantly different from each other. In contrast, at Redesdale, only the rotavated plots had significantly more bare ground than the undisturbed plots (p<0.001), and the rotavated plots also had more bare ground than the trampled plots (p<0.001). There was a significant effect of fencing at both sites, where there was more bare ground on the grazed sub-plots than the ungrazed sub-plots (Pwllpeiran: $F_{1,181}$ = 42.3; p<0.001; Redesdale: $F_{1,205}$ = 133; p<0.001). Bare ground declined over time (Pwllpeiran: $F_{2,413}$ = 318; p<0.001; Redesdale: $F_{2,451}$= 25.9; p<0.001), but there was a significant visit by treatment interaction at both sites (Pwllpeiran: $F_{4,413}$ = 69.0; p<0.001; Redesdale: $F_{4,451}$ = 27.6; p<0.001), where the cover of bare ground decreased more quickly in the trampled than rotavated plots ($p<0.001$). The cover of bare ground also decreased more rapidly at Redesdale than at Pwllpeiran; by 2005 there was no difference in the cover of bare ground between disturbed and undisturbed plots at Redesdale whereas at Pwl a) there was still significantly more b) ground on the rotavated and trampled plots than the undisturbed plots ($p<0.001$, Fig. 7a).

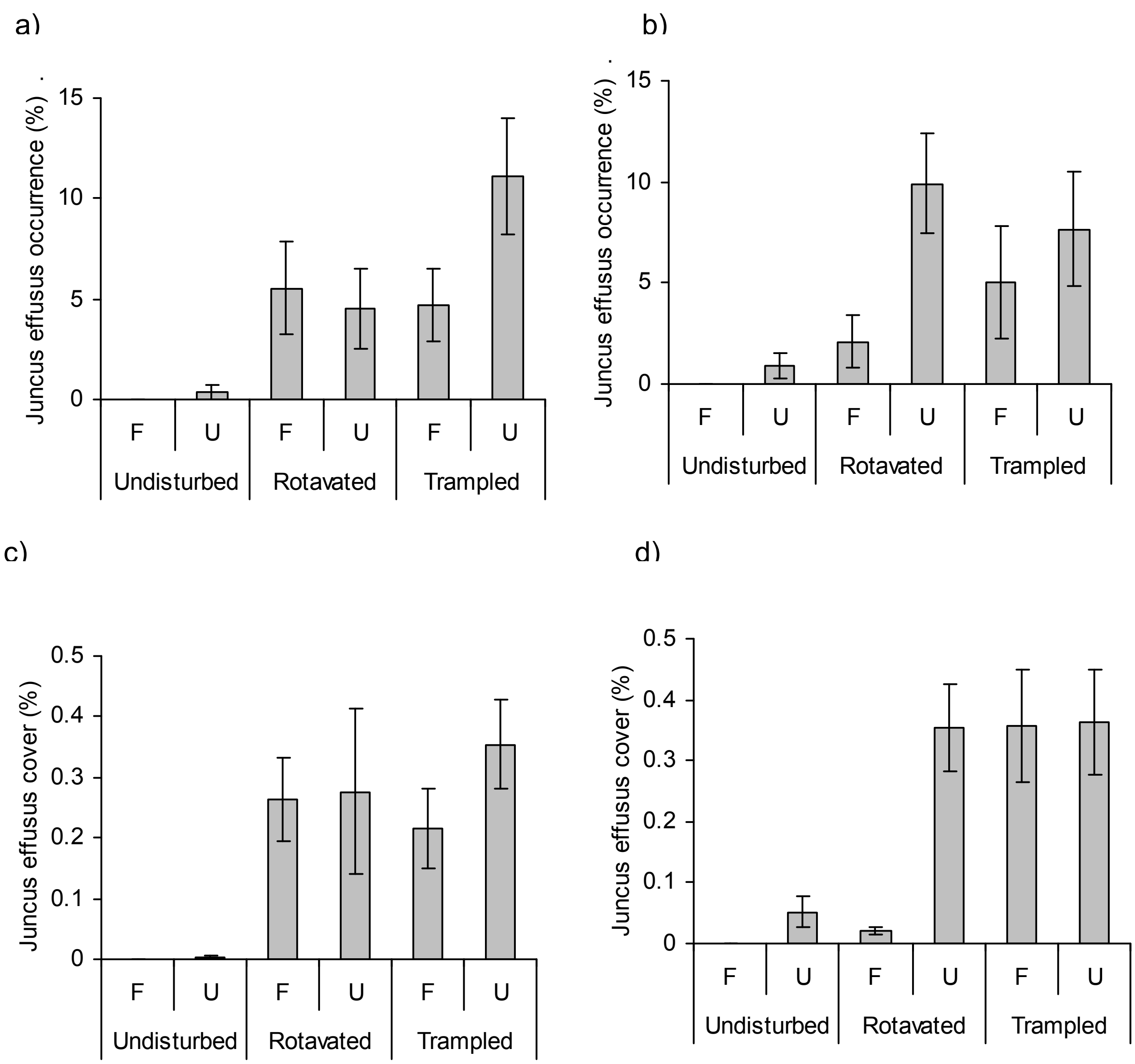
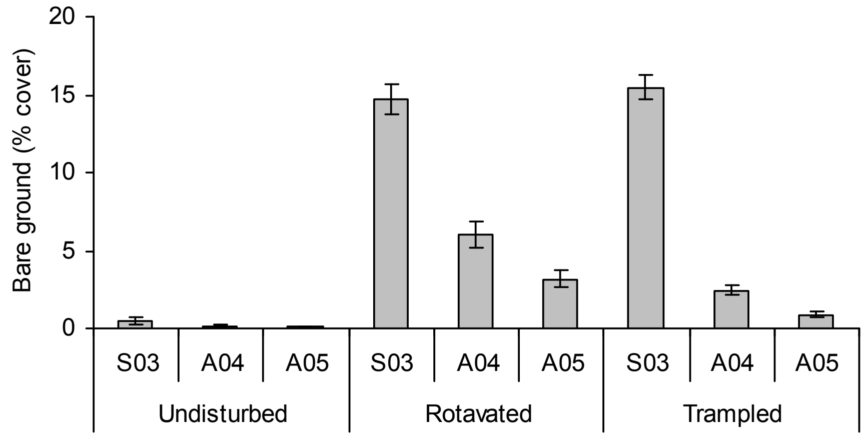


Figure 6 **Mean (a, b) cover and (c, d) presence of *Juncus effusus* in 1 m^2 quadrats at (a, c) Pwllpeiran and (b, d) Redesdale after three years on unfenced (U) and fenced (F) sub-plots that were disturbed by trampling or rotavating or left undisturbed.**

Error bars show ± 1 SE

a)



b)

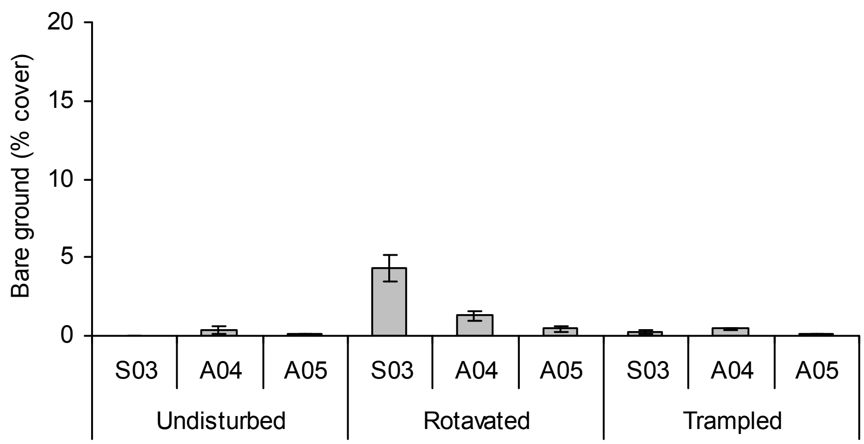


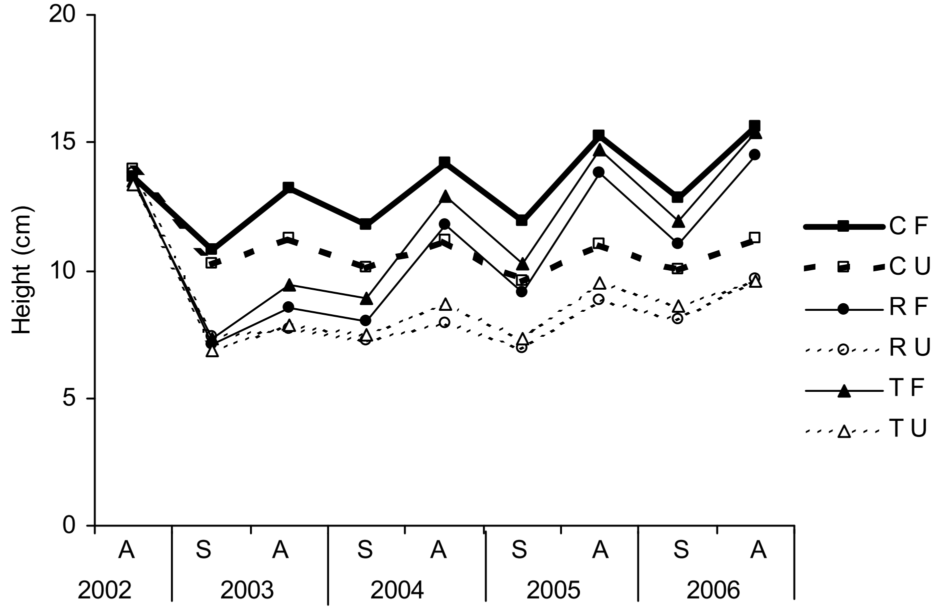
Figure 7 **Mean cover of bare ground at (a) Pwllpeiran and (b) Redesdale in spring 2003 (S03), autumn 2004 (A04) and autumn 2005 (A05) following three disturbance treatments (undisturbed, rotavated and trampled)**

Vegetation height

At Pwllpeiran, there was a significant difference in vegetation heights between blocks at the start of the experiment, the vegetation in block B being significantly taller than that in either blocks A or C ($p<0.05$). Analysis of vegetation heights from 2003 onwards (i.e. after the disturbance treatments had been applied) showed that both spring and autumn vegetation heights were significantly affected by the grazing treatment (spring: $F_{2,44} = 5.4$; $p<0.01$; autumn: $F_{2,43} = 6.0$; $p<0.01$), disturbance (spring: $F_{2,44} = 42.2$; $p<0.001$; autumn: $F_{2,43} = 22.7$; $p<0.001$), fencing (spring: $F_{1,179} = 222$; $p<0.001$; autumn: $F_{1,174} = 790$; $p<0.001$) and seeding (spring: $F_{1,179} = 13.1$; $p<0.001$; autumn: $F_{1,174} = 11.7$; $p<0.001$). Vegetation height was higher in cattle and mixed grazing treatments than the sheep only treatment, on the undisturbed plots than the rotavated or trampled plots, on the ungrazed than the grazed sub-plots and on the seeded than the unseeded sub-plots. There was a significant increase in vegetation height from 2003 to 2006 (spring: $F_{3,548} = 146$; $p<0.001$; autumn: $F_{3,544} = 228$; $p<0.001$). The significant disturbance by fencing by visit interaction (spring: $F_{6,548} = 2.4$; $p<0.05$; autumn: $F_{6,544} = 5.5$; $p<0.001$) showed that the disturbed plots recovered (i.e. were not significantly different in height from the corresponding grazed/ungrazed plot undisturbed plot) at different rates (Fig. 8a). The ungrazed trampled sub-plots had recovered two years after the disturbance treatments, whereas the ungrazed rotavated plots took a year longer. The grazed disturbed plots took longer to recover than the ungrazed disturbed plots, three years for trampled plots and four years for rotavated plots.

The vegetation in the grazed undisturbed sub-plots was significantly shorter, by about 1 cm, than the vegetation on the rest of the field in both spring ($F_{1,20} = 25.2$; $p<0.001$) and autumn ($F_{1,19} = 21.0$; $p<0.001$) (Fig. 9). This effect did not change with time.

a)



b)

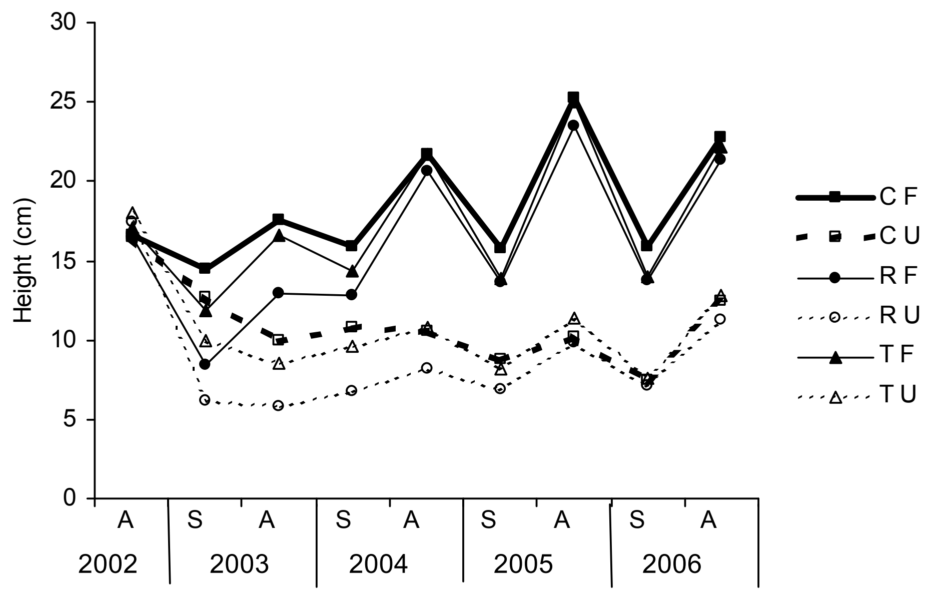


Figure 8 **Mean vegetation height as measured using a drop disc in autumn (A) and spring (S) from 2002 to 2006 at (a) Pwllpeiran and (b) Redesdale in plots with the following disturbance treatments: undisturbed (C); rotavated (R); trampled (T) and that were either fenced (F) or unfenced (U)**

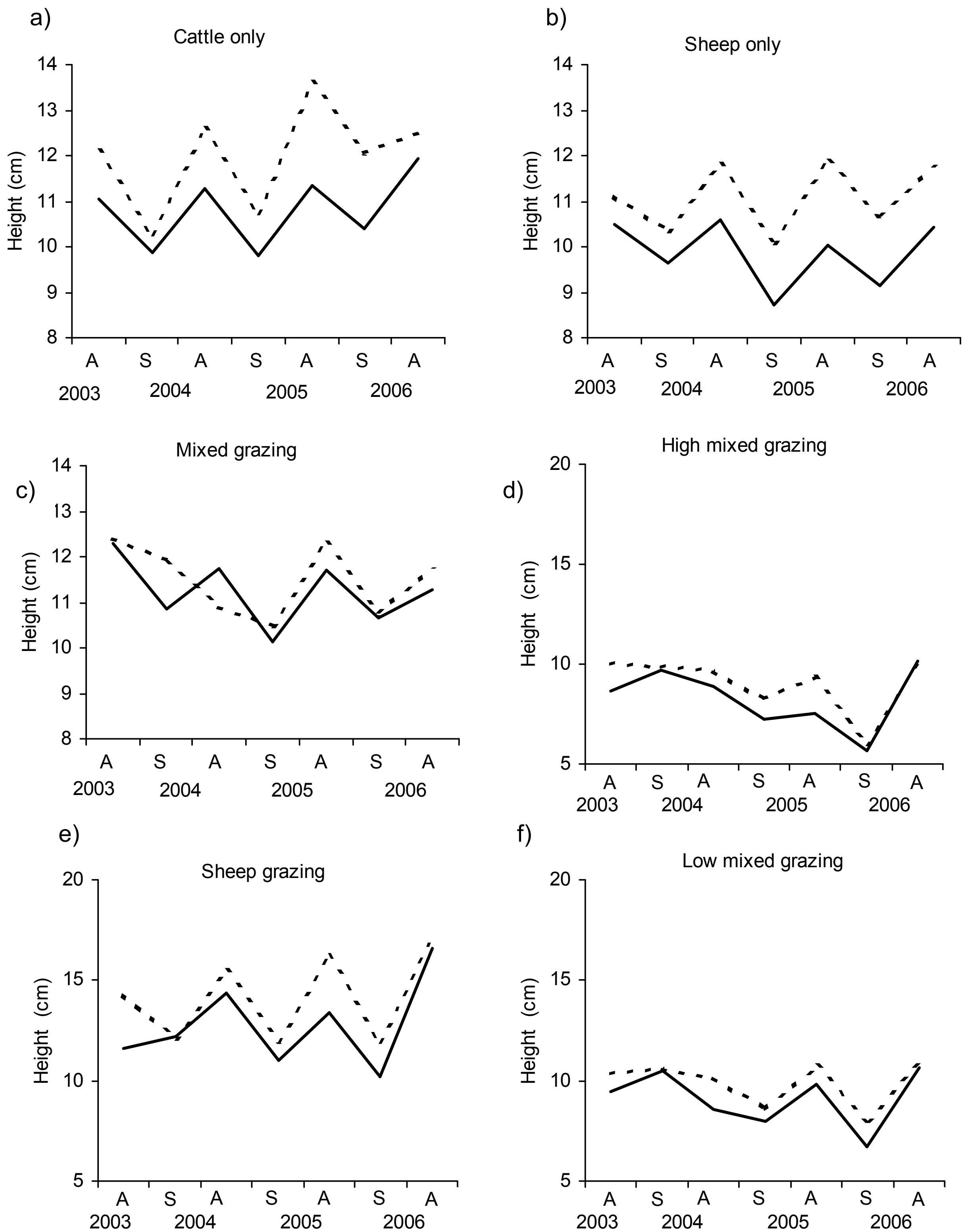


Figure 9 Mean seasonal vegetation height on undisturbed grazed plots and the surrounding field under different grazing regimes at (a, c, e) Pwllpeiran and (b, d, f)

Redesdale. ——— undisturbed grazed plot, – – – surrounding field; A = autumn, S = spring.

At the start of the experiment, there was a significant difference in vegetation heights between the fields at Redesdale, the vegetation being taller in the field with mixed low grazing than in the field with mixed high grazing. Vegetation heights in both the spring and the autumn were significantly affected by field (spring: $F_{2,46} = 32.8$; $p<0.001$; autumn: $F_{2,46} = 60.4$; $p<0.001$), disturbance (spring: $F_{2,46} = 112$; $p<0.001$; autumn: $F_{2,46} = 27.2$; $p<0.001$), fencing (spring: $F_{1,168} = 1490$; $p<0.001$; autumn: $F_{1,199} = 3590$; $p<0.001$) and visit (spring: $F_{3,512} = 33.7$; $p<0.001$; autumn: $F_{3,541} = 371$; $p<0.001$). The vegetation was taller in the fenced than unfenced sub-plots. Spring vegetation height was significantly different between all three disturbance treatments, being greatest on the undisturbed plots and least on the rotavated plots. In the autumn, there was no difference in height between the undisturbed and trampled plots, but the vegetation on these plots was significantly taller than that on the rotavated plots. The significant interaction between disturbance, fencing and visit (spring: $F_{6,512} = 3.2$; $p<0.01$; autumn: $F_{6,541} = 3.9$; $p<0.001$) showed that the grazed disturbed plots recovered more quickly than the ungrazed plots (Fig. 8b). The grazed trampled plots had recovered one year after the disturbance treatment and the grazed rotavated plots after three years. The fenced sub-plots showed a more complicated pattern of recovery. In the autumn, vegetation heights on trampled sub-plots were not significantly different from undisturbed sub-plots one year after the treatment had been carried out and rotavated sub-plots were not significantly different after two years; yet spring vegetation heights remained significantly lower on disturbed than the undisturbed sub-plots even after four years.

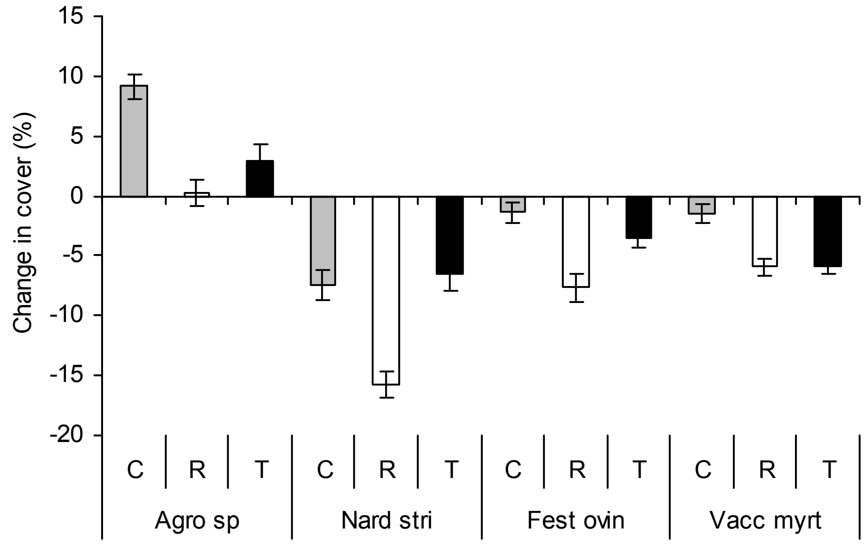
Vegetation height in the grazed undisturbed sub-plots was lower than in the surrounding field in both spring ($F_{1,16} = 9.33$; $p<0.01$) and autumn ($F_{1,27} = 28.1$; $p<0.001$) by about 1 cm (Fig. 9). This effect interacted with time (spring: $F_{2,54} = 3.3$; $p<0.05$; autumn: $F_{3,84} = 6.6$; $p<0.001$). Vegetation heights were significantly higher in the surrounding vegetation than the plot in autumn 2003-2005 but not in 2006. Spring vegetation heights showed a different pattern, the vegetation on the plot being the same height as the surrounding field in 2004 but significantly shorter in the springs of 2005 and 2006.

The impact of restoration treatments on moorland species other than *Calluna vulgaris*

Pwllpeiran

There was a significant effect of the disturbance treatments on the cover of *Vaccinium myrtillus* ($F_{2,43}$ = 6.9; p<0.01), *Agrostis* sp. ($F_{2,43}$ = 8.1; p<0.001), *Nardus stricta*, ($F_{2,43}$ = 10.0; p<0.001), *Festuca ovina* ($F_{2,43}$ = 4.4; p<0.05) and litter ($F_{2,43}$ = 99.3; p<0.001) one year after the treatments had been carried out (Fig. 10a). *V. myrtillus* declined in cover by 5-10% in the disturbed plots, which was significantly more than in the undisturbed plots. In the rotavated plots, *N. stricta* and *F. ovina* declined in cover by 15 and 7% respectively, which was significantly more than in the trampled or undisturbed plots. *Agrostis* sp. increased in cover significantly more in the undisturbed plots (10%) than in the trampled plots (5%) which in turn increased significantly more than the rotavated plots (no change). The disturbance treatments had no effect on *Carex pilulifera* or *Deschampsia flexuosa*, the other main graminoids present. The cover of litter also increased more in the rotavated plots than the trampled plots, which in turn had a greater change in cover than the undisturbed plots. After four years, the disturbance treatments were not significant in explaining the change in cover for any of the above species except *V. myrtillus* ($F_{2,43}$ = 12.0; p<0.001), which declined in the disturbed plots by 5-10 % but remained unchanged in the undisturbed plots.

a)



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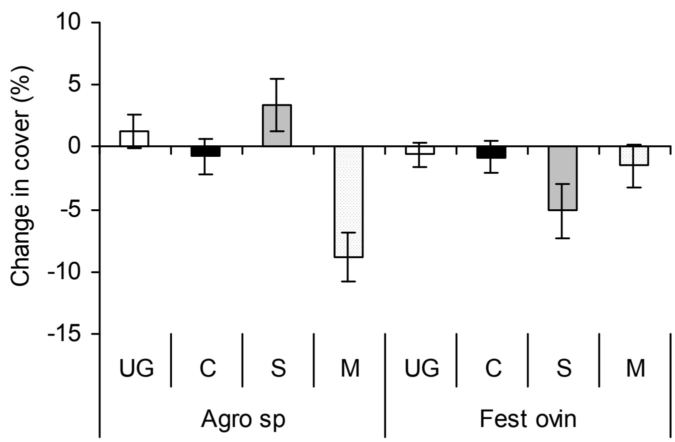

Figure 10 Changes in mean cover of (a) *Agrostis* sp., *Nardus stricta*, *Festuca ovina* and *Vaccinium myrtillus* at Pwllpeiran one year after disturbance treatments

undisturbed (C), rotavation (R) and trampled (T), (b) *Agrostis* sp. and *Festuca ovina* at Pwllpeiran after four years of grazing regimes: ungrazed (UG), cattle only (C), sheep only (S) and mixed (M) Error bars show ± 1 SE

Grazing and fencing treatments had no effect on the change in species cover in the first year at Pwllpeiran, but after four years, grazing treatment was significant in explaining the change in cover of *Agrostis* sp. ($F_{2,43}$ = 7.8; p<0.01) and *F. ovina* ($F_{2,43}$ = 4.4; p<0.05); fencing was also significant in explaining the change in *Agrostis* sp. cover ($F_{1,148}$ = 5.0; p<0.05). *Agrostis* sp. cover increased when grazed by sheep only or when ungrazed, decreased in cover under the mixed grazing regime and remained unchanged in the cattle only grazing treatment (Fig. 10b). *F. ovina* decreased in cover in the sheep only grazing treatment but remained unchanged in the other grazing treatments (Fig. 10b).

<u>*Redesdale*</u>

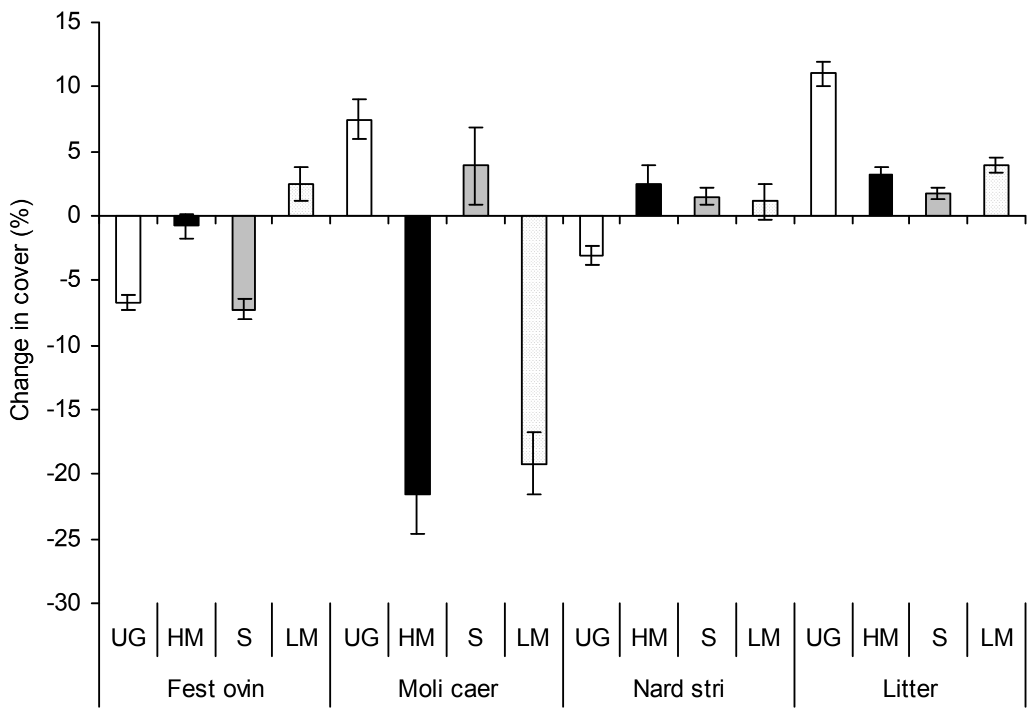

Figure 11 Changes in mean cover of *Festuca ovina*, *Molinia caerulea, Nardus stricta* and litter at Redesdale after four years of grazing regimes ungrazed (UG), high mixed grazing (HM), sheep only (S) and low mixed grazing (LM). Error bars show ± 1 SE.

The disturbance treatments did not explain any of the change in the cover of *Molinia caerulea, Agrostis* sp., *Festuca ovina, Nardus stricta* or litter within the first year. After four years, changes in *M. caerulea* , *F. ovina* and litter cover differed significantly between fields ($F_{2,45}$ = 15.7, $F_{2,45}$ = 20.0 and $F_{2,48}$ = 9.0 respectively, all p<0.001; Fig. 11). Fencing was significant in explaining the change in cover of *M. caerulea* ($F_{1,148}$ = 98.9; p<0.001), *F. ovina* ($F_{1,148}$ = 41.2; p<0.001), *N. stricta* ($F_{1,148}$ = 28.5; p<0.001) and litter ($F_{1,148}$ = 103; p<0.001) (Fig. 11). *M. caerulea* increased by 5 to 10 % in the ungrazed sub-plots and in the field with sheep only grazing, in contrast it decreased by about 20% in the two fields with mixed grazing. *F. ovina* decreased by about 5% in ungrazed sub-plots and in the field with sheep only grazing. *F. ovina* did not change in the field with high mixed grazing and increased slightly (less than 5%) in the field with low mixed grazing. Field had no effect on *N. stricta*, but fencing did, its cover decreasing in the fenced sub-plots and increasing in the grazed sub-plots. However, in both cases, the change in cover was small, averaging less than 5%. Litter increased by over 10% in the ungrazed sub-plots and by less than 5% in the grazed sub-plots. The field with low mixed grazing had a significantly greater increase in litter than the other two fields.

Change in community composition and proximity to target communities

Pwllpeiran

DCA of the plant community composition at Pwllpeiran explained 11% of the variation on the first axis and a further 8% on the second axis. In total the first four axes explained 31% of the species variation. Samples from target communities occurred in the top left of the ordination diagram (Fig. 12) corresponding to a high cover of *Calluna*, *Carex pilulifera*, bare ground, *Campylopus* sp., litter and *Erica tetralix* (Fig. 13). Samples from 2002, at the start of the experiment, occurred in the lower right corner of the ordination diagram (Fig. 12) corresponding to high cover of *Agrostis* sp. *Festuca ovina*, *Nardus stricta*, *Vaccinium myrtillus* and *Deschampsia flexuosa* (Fig. 13). Samples from 2006 were more scattered, ranging from trampled or rotavated fenced and seeded sub-plots which occurred close to the target communities to fenced unseeded control sub-plots which occurred in the lower right part of the ordination diagram close to the samples from 2002.

Rotavated, fenced and seeded sub-plots and trampled, fenced and seeded sub-plots were closer to T90 than any other treatment. Undisturbed plots were furthest away from the T90, and were not even close to T30. Analysis of the effect of treatment on distance in multivariate space from the target community showed that fencing (T30: $F_{1,45} = 5.1$; $p<0.05$; T50: $F_{1,45} = 4.5$; $p<0.05$; T70: $F_{1,45} =7.9$; $p<0.01$; T90: $F_{1,45} = 12.1$; $p<0.005$) and seeding (T30: $F_{1,45} = 30.5$; $p<0.000$; T50: $F_{1,45} = 33.4$; $p<0.0001$; T70: $F_{1,45} = 45.3$; $p<0.0001$; T90: $F_{1,45} = 58.1$; $p<0.0001$) had a significant effect on distance to all four of the target communities. The fenced and seeded sub-plots were closer to the target communities than the unfenced or unseeded sub-plots. There was a significant disturbance by seeding interaction on distance to T70 ($F_{2,45} = 3.5$; $p<0.05$) and T90 ($F_{2,45} = 4.6$; $p<0.05$) and significant disturbance by fencing ($F_{2,45} = 4.1$; $p<0.05$) and disturbance by fencing by seeding ($F_{2,45} = 3.4$; $p<0.05$) interactions on the distance to T90. The seeded rotavated and trampled sub-plots were closer to the T90 target than the unseeded sub-plots ($p<0.001$), but there was no difference between the seeded and unseeded undisturbed plots. The fenced rotavated sub-plots were closer to the target than the unfenced rotavated sub-plots, but there was no difference between the fenced and unfenced trampled or undisturbed plots. The seeded and fenced sub-plots in the rotavated and trampled plots were closer to the target than other combinations of seeding and fencing ($p<0.001$), but in the undisturbed plots it was the seeded and unfenced sub-plots which were closer than other combinations. Grazing treatment had no impact on how close the vegetation was to the target community.

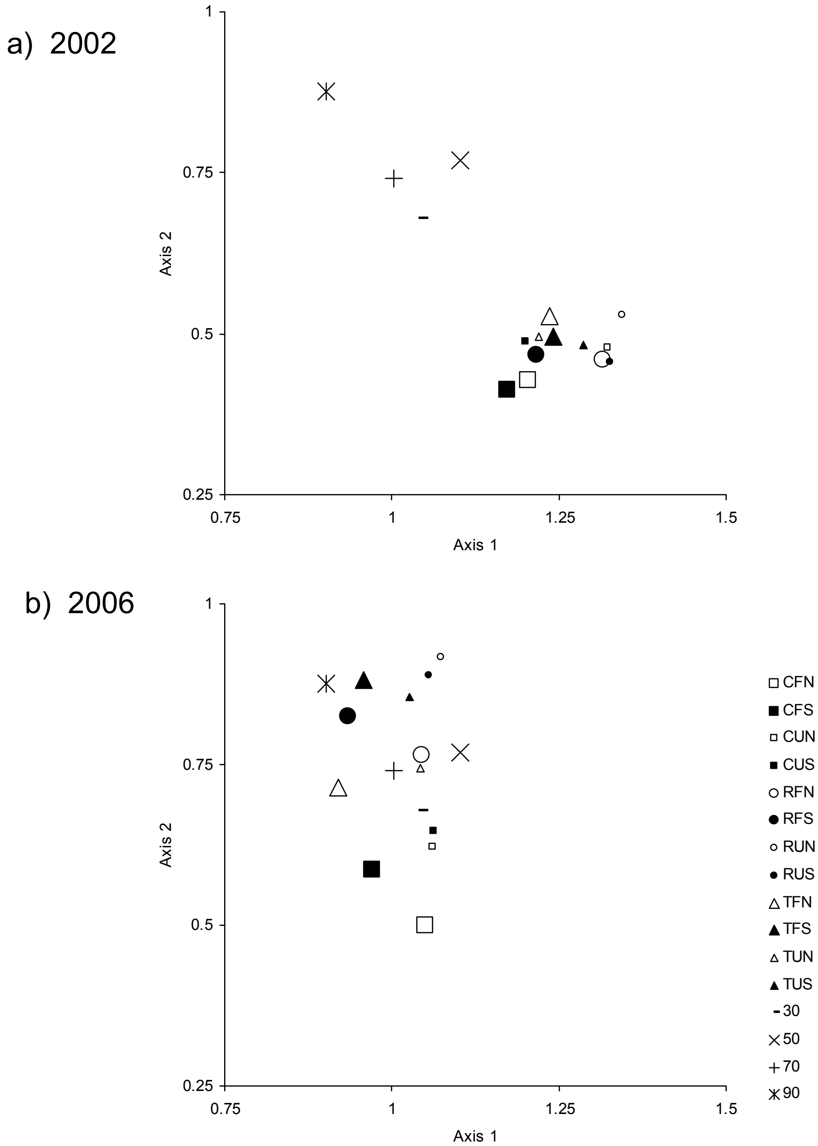

Figure 12 Plant community composition at Pwllpeiran prior to experimental treatments (2002) and after four years (2006) in relation to target communities with 90, 70, 50 and 30 % *Calluna vulgaris* cover

Axis 1 and Axis 2 of Detrended Correspondence Analysis are shown. For clarity the two years are plotted on separate graphs although all data come from a single DCA. C = undisturbed, R = rotavated, T = trampled, F = ungrazed, U = grazed, S = seeded, N = not seeded. 30, 50, 70, 90 = target communities as described in the text.

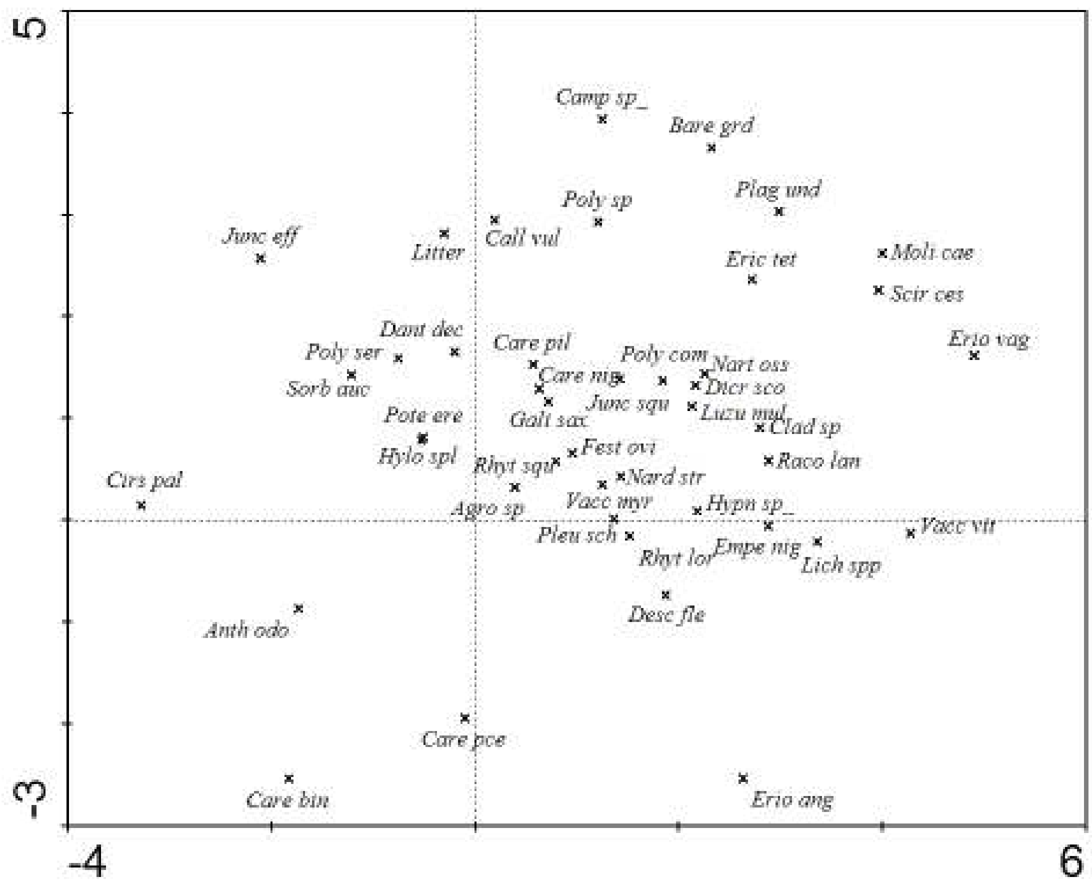

Figure 13 Species ordination diagram from DCA of experimental plots in 2002, 2006 and target communities from Pwllpeiran

Agro sp = *Agrostis* sp.; Anth odo = *Anthoxanthum odoratum*; Bare grd = Bare ground; Call vul = *Calluna vulgaris*; Camp sp. = *Campylopus* sp.; Care bin = *Carex binervis*; Care nig = *C. nigra*; Care pce = *C. panacea*; Care pil = *C. pilulifera*; Cirs pal = *Cirsium palustre*; Clad sp = *Cladonia* sp.; Dant dec = *Danthonia decumbens*; Desc fle = *Deschampsia flexuosa*; Dicr sco = *Dicranum scoparium*; Empe nig = *Empetrum nigrum*; Eric tet = *Erica tetralix*; Erio ang = *Eriophorum angustifolium*; Erio vag = *E. vaginatum*; Fest ovi = *Festuca ovina* agg.; Gali sax = *Galium saxatile*; Hylo spl = *Hylocomium splendens*; Hypn sp. = *Hypnum* sp.;Junc eff = *Juncus effusus*; Junc squ = *J. squarrosus*; Lich spp. = Lichen spp.; Litter = litter; Luz mult = *Luzula multiflora*; Moli cae = *Molinia caerulea*; Nard str = *Nardus stricta*; Nart oss = *Narthecium ossifragum*; Plag und = *Plagiomnium undulatum*; Pleu sch = *Pleurozium schreberi*; Poly ser = *Polygala serpyllifolia*; Poly sp = *Polytrichum* sp.; Pote ere = *Potentilla erecta*; Raco lan = *Racomitrium lanuginosum*; Rhyt lor = *Rhytidiadelphus loreus*;

Rhyt squ = *R. squarrosus*; Scir ces = *Trichophorum cespitosum*; Sorb auc = *Sorbus aucuparia*; Vacc myr = *Vaccinium myrtillus*; Vacc vit = *V. vitis-idaea*.

Redesdale

DCA explained 17% of the variation in species composition along axis 1 and a further 9% along axis 2. In total the four axes explained 37% of the variation. The target communities occurred towards the positive end of the first axis and about half way along the second axis (Fig. 14), corresponding to sub-plots having a high cover of *Calluna*, *Sphagnum* sp. and *Carex nigra* (Fig. 15). The majority of the samples from 2002 occurred in the lower left corner of the ordination diagram, and contained species such as *Nardus stricta*, *Galium saxatile* and *Juncus squarrosus* (Fig. 15). However, samples from the field with sheep only grazing were separated from the other samples and occurred at the positive end of the first axis and towards the origin of the second axis and corresponded to plots having higher cover of *Eriophorum vaginatum*, *Empetrum nigrum* and *Vaccinium myrtillus*. The 2006 samples occurred higher up the second axis than the 2002 samples, the different fields and fenced and unfenced treatments separating out from each other. The grazed sub-plots from the field with sheep only grazing were closest to the T30 community. The fenced seeded and unseeded treatments in the field with sheep only grazing had changed the most in composition, occurring in the top right of the ordination diagram and close to the T70 and T90 communities.

The disturbance treatments had no effect on how close the quadrats were in 2006 to any of the target communities. There was a significant fence by seeding interaction on the distance to T70 ($F_{1,45}$ = 5.1; $p<0.05$) and to T90 ($F_{1,45}$ = 5.6; $p<0.05$). The seeded fenced sub-plots were significantly closer to the T90 community than any other combination of fencing and seeding ($p<0.05$) and closer to the T70 community than any of the unfenced sub-plots ($p<0.05$). There was a significant field by fencing interaction on the distance to all target communities (T30: $F_{2,45}$ = 6.7; $p<0.01$; T50: $F_{2,45}$ =5.6;$p<0.01$; T70: $F_{2,45}$ = 4.9; $p<0.05$; T90: $F_{2,45}$ = 4.5; $p<0.05$). In the fields with high mixed grazing and low mixed grazing, grazed sub-plots were closer to the T30 target than the fenced sub-plots, but as the cover of *Calluna* increased in the target communities, this changed, and the fenced sub-plots were closer to the T50, T70 and T90 targets than the grazed sub-plots. However, the pattern was different in the field grazed by sheep only, where the grazed sub-plots were closer to all four target communities than the fenced sub-plots.

a) 2002 b) 2006

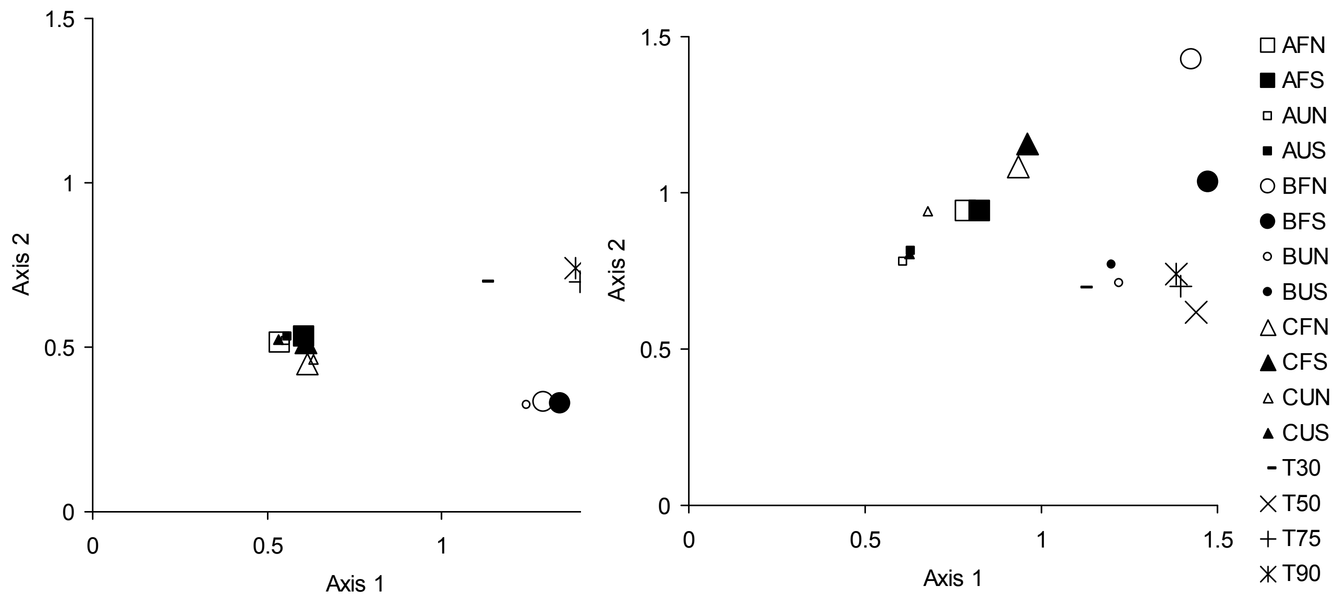

Figure 14 Plant community composition at Redesdale prior to experimental treatments (2002) and after four years (2006) in relation to target communities with 90, 70, 50 and 30 % *Calluna vulgaris* cover

Axis 1 and Axis 2 of Detrended Correspondence Analysis are shown. For clarity the two years are plotted on separate graphs although all data come from a single DCA. A = field with high mixed grazing, B = field with sheep only grazing, C = field with low mixed grazing F = ungrazed, U = grazed, S = seeded, N = not seeded; T30, T50, T70, T90 = target communities.

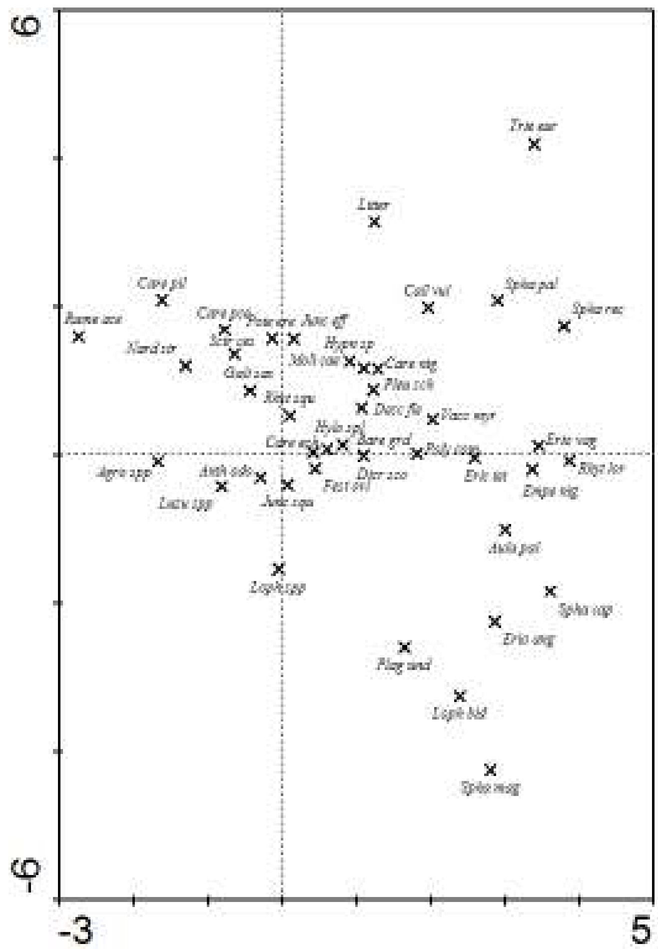

Figure 15 Species ordination diagram from DCA analysis of experimental plots in 2002, 2006 and target communities at Redesdale

Agro sp = *Agrostis* sp.; Anth odo = *Anthoxanthum odoratum*; Aula pal = *Aulacomnium palustre*; Bare grd = Bare ground; Call vul = *Calluna vulgaris*; Care ech = *Carex echinata*; Care nig = *C. nigra*; Care pce = *C. panacea*; Care pil = *C. pilulifera*; Desc fle = *Deschampsia flexuosa*; Dicr sco = *Dicranum scoparium*; Empe nig = *Empetrum nigrum*; Eric tet = *Erica tetralix*; Erio ang = *Eriophorum angustifolium*; Erio vag = *E. vaginatum*; Fest ovi = *Festuca ovina* agg.; Gali sax = *Galium saxatile*; Hylo spl = *Hylocomium splendens*; Hypn sp. = *Hypnum* sp.; Junc eff = *Juncus effusus*; Junc squ = *J. squarrosus*; Litter = litter; Loph bid = *Lophocolea bidentata*; Loph spp. = *Lophocolea* sp.; Luzu sp = *Luzula* sp.; Moli cae = *Molinia caerulea*; Nard str = *Nardus stricta*; Plag und = *Plagiomnium undulatum*; Pleu sch = *Pleurozium schreberi*; Poly com. = *Polytrichum commune*; Pote ere = *Potentilla erecta*; Rhyt lor = *Rhytidiadelphus loreus*; Rhyt squ = *R. squarrosus*; Rume ace = *Rumex acetosella*;

Scir ces = *Trichophorum cespitosum*; Spha cap = *Sphagnum capillifolium*; Spha mag = *S. magellanicum*; Spha pal = *S. palustre*; Spha rec = *S. recurvum*; Trie eur = *Trientalis europaea*; Vacc myr = *Vaccinium myrtillus*.

DISCUSSION

Disturbance and bare ground creation

Disturbance was essential for *Calluna* establishment at both sites, as it created bare ground, which is essential for *Calluna* germination (Grime *et al.*, 1996; Scandrett, 1991). At Pwllpeiran, rotavation and trampling were equally successful in promoting *Calluna* establishment, whereas at Redesdale, rotavation was more successful. More bare-ground was created at Pwllpeiran than at Redesdale, particularly in the trampling treatment. This was partly due to the differences in techniques used. The five heifers at Pwllpeiran were able to create more bare-ground than a single horse owing to the number of animals, their strength and the structure of their feet. Six months after the disturbance treatments had taken place there was no difference in the cover of bare ground between trampled and undisturbed plots at Redesdale; however, *Calluna* occurrence was still greater in the trampled than undisturbed plots. Thus even a small amount of bare ground for a short time was beneficial for *Calluna* establishment, supporting the findings of Gilbert & Anderson, (1998). The rotavation treatment at Redesdale also created less bare-ground than that at Pwllpeiran possibly in part due to the differences in the machinery used. However, for both the mechanical and animal disturbances, the differences in vegetation type between the two sites affected how easy it was to create bare-ground. The tussock growth form of the *Molinia caerulea* and the surrounding litter made it very hard for the horse to trample down the tussocks, whereas the *Agrostis/Festuca/Nardus* sward at Pwllpeiran was easier for the animals to trample. Where the cover of bare ground was low (trampled plots at Redesdale or the undisturbed plots at Pwllperian), *Calluna* occurrence was greater in the grazed than the ungrazed sub-plots; the grazing caused some disturbance and created suitable microsites for *Calluna* establishment. The importance of animals in creating microsites for germination during restoration has been observed in other habitats, e.g. prairie restoration in the USA (Martin & Wilsey, 2006) and species-poor grassland in Oxfordshire (Bullock *et al.*, 1994).

The amount of bare-ground required for successful *Calluna* establishment varied according to the grazing treatment. The treatment requiring the least disturbance was cattle only grazing. Thus, when planning restoration treatments, it is important to consider the type of grazing that will occur after the disturbance treatments have been applied.

Seed limitation

Seeding significantly increased *Calluna* presence at both sites. At Pwllpeiran, seeding was essential, as any *Calluna* seeds present in the seed-bank were below the level of detection. Those few *Calluna* plants that did establish in the unseeded sub-plots probably germinated from seed that was either blown onto these sub-plots during sowing or was introduced by animals. Observations by the authors suggest that *Calluna* occurrence declined in the unseeded sub-plot with distance from the seeded subplot. At Redesdale, seeding was not essential, as *Calluna* was present in the seed-bank. Nevertheless, seeding did significantly increase *Calluna* occurrence. Even in the field with the highest seed-bank, *Calluna* presence was greater in the seeded than unseeded sub-plots.

Successful *Calluna* establishment is possible by sowing less than the 40000 seeds m^{-2} recommended by Putwain & Rae (1988). The seeded plots in this experiment received 26000 seeds m^{-2}, giving at total of 30000 seeds m^{-2} at Redesdale in plots with a high seed-bank. Milligan *et al.*, (2004) achieved successful restoration with 15000 seeds m^{-2} on *Molinia*-dominated moorland. *Calluna* occurrence at Redesdale was related to seed supply (seed-bank plus seeds sown). However, it was not possible to use our data to identify the minimum density of seed required for successful establishment, as there were two extremes of low (unsown sub-plots) and high seed density (sown sub-plots) but few intermediate values.

Competition

As disturbance was a significant factor in explaining *Calluna* presence when fitted after the cover of bare ground, the disturbance treatments were doing more to aid *Calluna* establishment than just creating bare ground. It is possible that they were also limiting competition. At both sites, the bare ground disappeared more quickly from trampled than rotavated plots, even though both rotavated and trampled plots at Pwllpeiran had a similar amount of bare ground to start with. This implies that rotavation inhibited grass growth better than trampling. The change in grass cover during the course of this experiment at Pwllpeiran concurs with this; the cover of *Agrostis* sp. increased more in trampled or undisturbed plots than rotavated plots. The cover of *Nardus stricta* and *Festuca ovina* declined in rotavated plots. Vegetation heights were significantly lower on disturbed plots than undisturbed at Pwllpeiran and at both sites, whether grazed or ungrazed, vegetation in rotavated plots took at least a year longer than in trampled plots to recover to the height in undisturbed plots. This is further evidence that disturbance, and rotavation in particular, has a negative effect on grass growth and hence on its competitive ability.

The reduction in competition from grasses due to the disturbance treatments at Pwllpeiran appears to have lasted about three years. In the first year, there was no difference in *Calluna* occurrence between fenced and unfenced sub-plots, but in the second year, it was greater in the ungrazed sub-plots. This suggests that the grasses were not out-competing the *Calluna* in the ungrazed sub-plots, while in the grazed subplots grazing was having a negative effect on the survival of young *Calluna* plants (Scandrett, 1991). However, after three years, *Calluna* occurrence was greater in the grazed than the ungrazed sub-plots, suggesting that the grasses were starting to out-compete the *Calluna* if grazing was not present. At Redesdale, the window of reduced competition was considerably shorter, and there were more *Calluna* plants in the grazed than the ungrazed plots in all three visits, suggesting that grazing was required from an early stage in order to reduce competition. Moreover, the grazed sub-plots had more bare ground than the ungrazed sub-plots, and thus recruitment of *Calluna* seedlings continued for longer. As individual seedlings were not marked, it is unclear whether it is a reduction in competition due to grazing or continued recruitment that means *Calluna* occurrence was greater in the grazed than ungrazed sub-plots at Redesdale, but casual observations suggest the latter.

Grazing impacts

At Pwllpeiran, the cattle only grazing treatment was most successful in terms of *Calluna* establishment and growth, and the sheep only treatment the least successful. There was greater *Calluna* establishment, taller and heavier *Calluna* plants with more shoots and greater *Calluna* cover at both the 400 cm^2 and 4 m^2 scales in the cattle only than the sheep only grazing treatments. Values for the above measures were also greater in the mixed grazing than the sheep only treatment, but rarely significantly so. The cattle only grazing was better than, or not significantly different from, no grazing in terms of *Calluna* establishment, dry weight, distance to lowest branch and cover at both the 400 cm^2 and 4 m^2 scales. The cattle only treatment provided a method whereby the site could be grazed without detriment to the restoration process.

As the grazing treatments at Redesdale were not replicated, it is impossible to conclude which grazing treatment was most successful for *Calluna* establishment. The results show greater *Calluna* occurrence, *Calluna* cover, number of plants and taller, heavier plants in the sheep only field than the other fields. However, one cannot be sure that these results are not due to factors other than grazing. Analysis of the fenced sub-plots also showed that *Calluna* presence was greater in the sheep only field than other fields. This could have been due to the higher seed-bank present in this field compared to the other fields, the greater soil moisture in this field allowing better seedling establishment or other differences in vegetation or environmental variables between the fields.

Most upland moors are grazed by sheep, but the use of cattle for restoration purposes is currently under discussion. At Pwllperian, the cattle only treatment was clearly the best grazing treatment. The use of mixed grazing, sheep and cattle, gave conflicting results between the two sites. At Pwllpeiran, the mixed grazing regime was better for *Calluna* establishment than the sheep only treatment, but at Redesdale it is suggested that the sheep only treatment is better. At Redesdale, the *Molinia* was only reduced in cover and height if cattle were included in the grazing regime. A reduction in the competition from *Molinia* is required for restoration purposes. However, the reduction in vegetation height made the *Calluna* seedlings more visible to the sheep, which are more selective in their grazing than the cattle and specifically target *Calluna* if grass quality is poor (Anon, 2000). In some instances, *Calluna* seedlings were found pulled up, typical of sheep damage (Anon, 2000). In the sheep only treatment, the vegetation was taller than in either of the two mixed grazing regimes, thus reducing the apparency of the *Calluna* seedlings. It is regrettable that a cattle only grazing regime was not trialled at Redesdale, as this may have reduced the *Molinia* cover and height with out the risk of the *Calluna* seedlings being targeted by the sheep. In addition, differences between the animal breeds used at the two sites may have affected the amount of *Calluna* eaten. Welsh mountain sheep, the breed used in the Pwllpeiran experiment, have been found to eat less *Calluna* than the Scottish black face sheep, the breed used in the Redesdale experiment (IGER unpublished data). Thus, in a mixed grazing system, where the cattle reduce vegetation height making *Calluna* plants more visible, the *Calluna* is more likely to be grazed if the sheep are Scottish black face sheep rather than Welsh mountain.

At both sites, the vegetation height on the grazed undisturbed plots was significantly shorter, by 1-2 cm, than the surrounding field. This suggests that the animals were preferentially grazing the plots. The disturbance treatments resulted in a flush of grass growth to which the animals were probably attracted. It is suggested that the animals associated this flush of grass growth with the plots and preferentially grazed them whether disturbed or not. However, this difference is unlikely to be meaningful biologically, as there would not be a localised patch of increased attractiveness if the restoration was carried out over a larger area.

At Pwllpeiran, the vegetation heights were higher in the cattle only treatment and the mixed grazing treatment than the sheep only treatment, which may in part be due to the cattle grazing for only two months of the year. The vegetation was taller on the grazed than ungrazed sub-plots at both sites, but it responded more quickly to a reduction in grazing at Redesdale, where it was taller in the undisturbed fenced sub-plots than the undisturbed grazed sub-plots less than six months after fencing, than at Pwllpeiran, where it took a year for this difference to occur.

Grazing effected *Calluna* morphology, as has been reported by Hulme *et al.* (1999). Plants from grazed plots (other than those from the cattle only grazed sub-plots at Pwllpeiran) were shorter, weighed less and had fewer branches. The difference in height maybe due to grazing, but tall grasses in the ungrazed sub-plots, particularly at Redesdale, will have encouraged the *Calluna* plants to grow tall and straggly. In addition, grazing resulted in a change in the structure of the *Calluna* plant by reducing the distance up the stem to the lowest shoot, as was predicted to occur by Macdonald *et al.* (1995).

Impact of restoration treatments on the plant community other than *Calluna*

Grazing treatment had no effect on how close the vegetation was to the target community at either site, which may be due to the vegetation responding slowly to the grazing. With time, there maybe an impact of the grazing treatments on the rest of the community. However, the grazing treatments did influence the cover of individual grass species. *Agrostis* sp. increased when grazed by sheep only or ungrazed, decreased under a mixed grazing regime and remained unchanged in the cattle only treatment at Pwllpeiran. *Festuca ovina* is more palatable to sheep than the other grass species found at these sites, and decreased in cover in the sheep only grazing treatment at both sites. When restoring dwarf shrubs on *Agrostis/Festuca* grassland, the grazing regimes must not only reduce the cover of grasses, but give consideration to which species within the sward are capable of replacing the grasses and achieving dominance (Hulme *et al.*, 1999). *Molinia caerulea* increased with sheep only grazing or no grazing and declined with mixed grazing; thus if it is to be reduced by grazing, cattle must be included within the grazing regime. In experiments where sheep are used to control *Molinia*, mechanical cutting is also required (Milligan *et al.*, 2004). *Nardus stricta* is not palatable to sheep (Hulme *et al.*, 1999), and increased in cover in grazed plots at Redesdale and declined when not grazed.

The disturbance treatments affected the cover of grasses, *Juncus effusus* and *Vaccinium myrtillus*. The impact of the rotavation and, to a lesser extent, trampling on grasses was beneficial, as it reduced competition allowing the *Calluna* to establish. However, the impact of the disturbance on *J. effusus* and *V. myrtillus* was detrimental. *J. effusus* occurrence increased with both rotavation and trampling at both sites; even at Redesdale, where trampling did not result in any more bare ground being present than on the undisturbed plots after six months, *J. effusus* occurrence was still greater on the trampled than undisturbed plots. However, the cover of *J. effusus* was low, and therefore it is unlikely it would become a long-term problem following disturbance. *Vaccinium myrtillus* declined in cover in rotavated and trampled plots at Pwllpeiran. While the grasses had recovered four years after the disturbance, there was still a significant decline in *V. myrtillus*, although only by about 6%. Methods to increase dwarf shrubs other than *Calluna* are rarely studied and require further work. Ideally, desirable species such as *V. myrtillus* should be encouraged to spread through restoration treatments, not reduced in cover, even if only by a small amount.

Implications for restoration at larger scales

Restoration of grass-dominated moorland should not attempt the total eradication of grasses, but achieve a reduction in their dominance and an increase in the dwarf shrub component of the vegetation, especially *Calluna* (Milligan *et al.*, 2004). Moreover, the final mosaic will form an ecosystem with complex interactions between vegetation communities and livestock utilization (Palmer & Hester, 2000). This experiment has shown that it is possible to establish *Calluna* on grass-dominated swards and for it to survive under various grazing regimes for four years. At Pwllpeiran, particularly within the cattle only grazing treatments, the results indicate that the *Calluna* plants have the potential to grow into mature bushes that will be able to compete with the grasses and survive a low intensity of grazing. At Redesdale, the *Calluna* plants in the grazed plots were small and the number of plants declined with time. It is unlikely that these plants will grow into substantial *Calluna* bushes; indeed, it is possible that within a few years the newly-established *Calluna* plants will be grazed out if current grazing levels are continued. However, only a continuation of this work will be able to determine the long-term survival and growth of the *Calluna* under these grazing regimes.

The results show that cattle grazing is the best grazing treatment for *Calluna* establishment in a fine-leaved grassland sward, and in a *Molinia*-dominated sward, cattle are essential to reduce the height and cover of the *Molinia*. Most restoration experiments involving grazing use sheep (Anderson & Radford, 1994; Hill *et al.*, 1992; Hulme *et al.*, 1999, 2002; Milligan *et al.*, 2004; Newborn, 2000), and although some species of sheep are better than others at controlling *Molinia* (Newborn, 2000), our results indicate that more consideration should be given to the use of cattle. If implemented at a landscape scale, this would involve a considerable change in farming practices in the British uplands, a move away from sheep and an increase in cattle. The cattle at Pwllpeiran were only on the site for 2 months of the year. For hill farms, such a grazing regime may not be viable both economically and logistically if there is nowhere else to graze the cattle for the rest of the year. In addition, our results and those of Scandrett (1991) suggest that the removal of grazing for the first 2-3 years after disturbance and seeding is beneficial for *Calluna* establishment. It may be difficult to fence out animals on restored areas in large tracts of open moorland, but the alternative is to remove grazing from the whole hillside, which will have economic implications. In a *Molinia* grassland sward, the results do not suggest a clear grazing regime; removal of grazing results in too much competition from the grasses, but none of the grazing regimes trialled in this experiment allowed good *Calluna* growth. Further work is needed to establish a suitable grazing regime.

The disturbance treatments were carried out in small plots, but need to be applicable at a larger scale. If access by machinery is possible, then rotavation can be carried out on a larger scale and has been shown here and by Scandrett (1991) to be successful in allowing *Calluna* seedlings to establish. The limiting factor is the man-power and time to carry out the treatment. The trampling treatment cannot be carried out in an identical manner at a larger scale, but running a herd of cattle across the hillside, mob stocking or placing feeders in areas to be trampled (Hetherington, 2000) are all ways of carrying out this trampling treatment at a larger scale.

CONCLUSION

This experiment has shown that it is possible to establish *Calluna* on grass-dominated swards and for it to survive under various grazing regimes for four years. Disturbance to create bare ground is essential for *Calluna* establishment. Rotavation and trampling by animals are both successful techniques to create patches of bare ground suitable for *Calluna* germination and establishment in a fine leaved grass sward but rotavation is a more successful technique in a *Molinia* grassland. Both disturbance techniques are suitable for use on a larger scale (hillside rather than plot scale). Seeding with *Calluna* seed increased *Calluna* establishment irrespective of whether a seed-bank was present. On a fine leaved grass sward, such as at Pwllpeiran, 0.5 cow/ha for two months was identified as the best grazing regime. Further work is required to identify suitable grazing regimes on a *Molinia* grassland, such as that at Redesdale. The restoration methods used allowed the site to continued to be grazed, although the long-term (greater than 4 years) impact of such grazing regimes on *Calluna* survival needs to be tested.

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