Vegetation response to the reintroduction of cattle grazing on an English lowland valley mire and wet heath

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SUMMARY

We report the results of a nine year study of the effects of restoring low-intensity cattle grazing on the post-fire recovery of vegetation on the lowland valley mire and wet heath of Folly Bog, Surrey, UK. Four distinct vegetation communities were studied, with repeated recording of quadrats (n = 652) inside and outside grazing exclosures. Species richness increased across the valley mire, largely as a result of grazing-induced decreases in purple moor-grass *Molinia caerulea* and litter and increases in bare ground. Uncompetitive liverworts and waterlogging tolerant graminoids were particularly favoured. Purple moor-grass and litter removal also encouraged the spread of bog-mosses *Sphagnum* spp., although trampling in the wettest vegetation resulted in locally severe damage to the moss layer. On the firmer substrates of the wet heath there were no such deleterious trampling impacts. Here, both bog-moss cover and species richness increased significantly, largely due to suppression of shade-producing heather *Calluna vulgaris* and litter, and the maintenance of bare ground. Our results reveal that the resumption of low intensity cattle grazing had many positive conservation benefits. However, site managers need to consider grazing on a site-by-site basis and retain flexibility to change stocking times and levels as conditions dictate. Other forms of management to supplement grazing will most likely continue to be required.

BACKGROUND

The reintroduction of grazing as a conservation management tool for European lowland heaths has increased considerably in recent years (Newton *et al*. 2009). Despite this, there has been little research on the impacts of grazing, especially on wet heaths and valley mires (Lake *et al*. 2001, Newton *et al*, 2009). Frequently cited works suggest that grazing is important, if not essential, for maintaining these habitats (Clarke 1987, Byfield & Pearman 1996). However, there have been no long-term replicated comparative studies of the impacts of livestock grazing on lowland wet heath or valley mires where it has been restored following decades of grazing abandonment.

The aim of this study was to identify the impact on vegetation composition of reintroducing cattle grazing to a lowland valley mire and wet heath site, following a period of at least five decades of grazing abandonment. Of particular interest was the effect that livestock grazing would have on bog-mosses, purple moor-grass, dwarf shrubs and overall floristic diversity.

ACTION

Study site and the reintroduction of cattle grazing: Folly Bog (51°20'N, 0°40'W) lies on the northern margins of one of the most extensive tracts of lowland heathland in southeast England: the Ministry of Defence's Pirbright Ranges. It is known to have last been grazed by livestock (both sheep and cattle) prior to the 1950s. The valley mire covers an area of approximately 4.7 ha and is fed by soligenous inputs from a catchment of oligotrophic acid sands and gravels and spring seepages arising at the junction of the underlying free-draining Camberley Sands and the more-or-less impermeable Windlesham Formation. Southern and western margins of the valley mire give way to wet heath overlying low productivity stagnogleyic podzols (Groome 2006).

Folly Bog was included within a 21.4 ha fenced grazing enclosure in summer 2005. In addition to the valley mire and adjacent wet heath, this included a much larger area of dry and humid heath, acid grassland, scrub and woodland. At the same time as perimeter fencing, three large monitoring exclosures were installed (Figure 1). Cattle grazing was restored to the site in August 2005. Water was available naturally on site and despite there being no supplementary feeding, stock maintained condition throughout. Cattle breed, age and period of grazing varied throughout the study period (Table 1).

Vegetation sampling: valley mire. The vegetation within 174 1 x 1 m quadrats previously set out on a permanent 15 x 15 m stratified random grid across the Folly Bog valley mire in 1999 was recorded in June-July 2003 immediately following a wildfire in April 2003; 58 were within exclosures (the ungrazed plot), the remainder were outside (the grazed plot). All quadrats had been assigned to one of three communities following 1999 recording using TWINSPAN and described in relation to water level, hydrochemical properties and National Vegetation Classification (NVC) communities (Rodwell 1991) by Groome (2006):

- purple moor grass-bog myrtle *Molinia caerulea-Myrica gale* (MM) mire, a community transitional between the NVC classifications of M21 and M25 (Sphagnetum-Molinietum);

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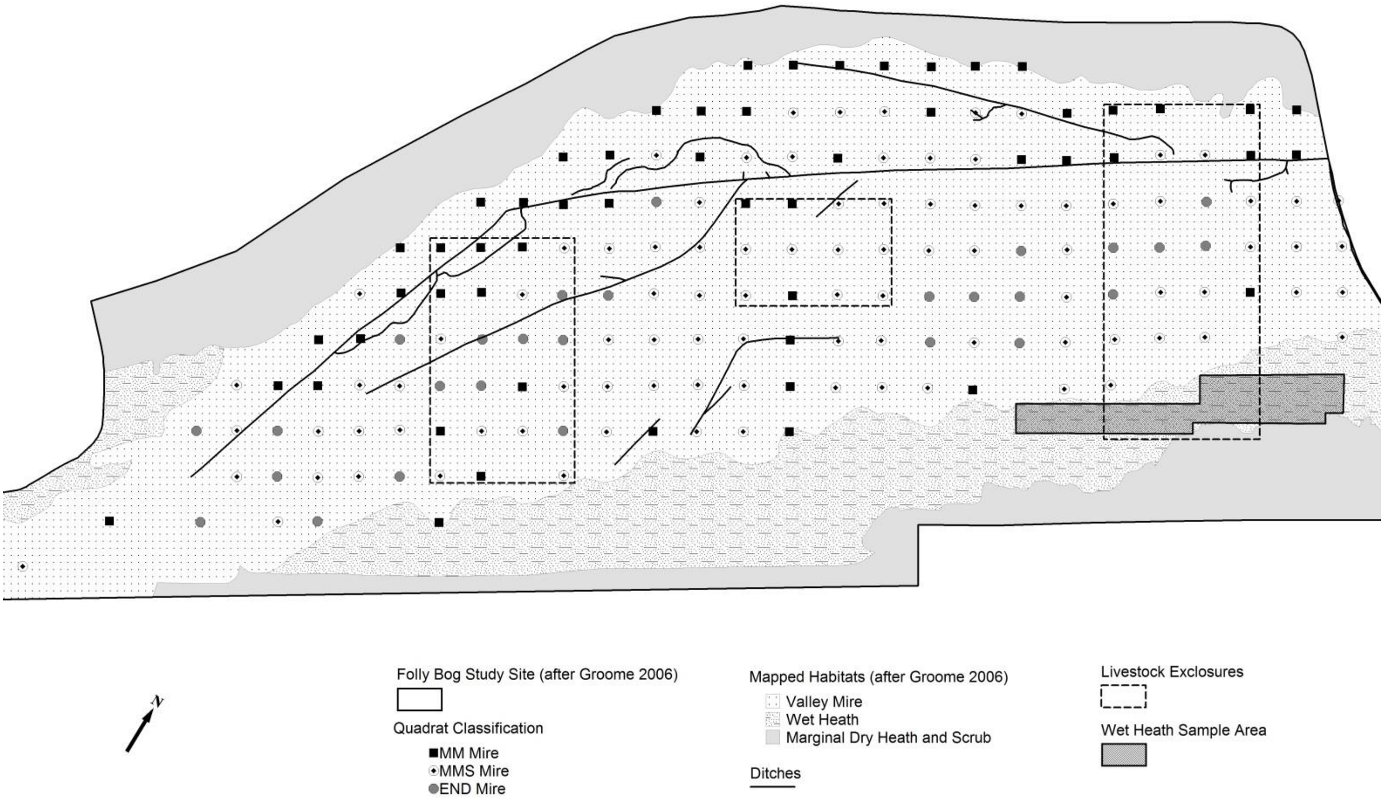

Figure 1. Folly Bog valley mire and wet heath study site

- purple moor grass-bog myrtle-papillose bog-moss *Molinia caerulea-Myrica gale-Sphagnum papillosum* (MMS) mire, directly related to M21 (Sphagnetum);
- cross-leaved heath-bog asphodel-round-leaved sundew *Erica tetralix-Narthecium ossifragum-Drosera rotundifolia* (END) mire, a transitional community between M21 and M14 (Sphagnetum-Schoenetum).

Sampling methodology followed that adopted in 1999 (Groome 2006) when the aerial percentage cover of all vascular plants, bryophytes and lichens was recorded, along with that of litter, open water and bare ground. All quadrats were re-surveyed in 2010 (seven years post-burning and five years after the reintroduction of grazing) and again in 2012 (nine years post-burning; seven years after the reintroduction of grazing).

Vegetation sampling: wet heath. In 1999 a fourth classification, purple moor grass-cross-leaved heath-heather *Molinia caerulea-Erica tetralix-Calluna vulgaris* wet heath, wholly referable to the NVC community of M16 (Ericetum), was defined (Groome 2006). However, insufficient grid quadrats in this habitat could be excluded from grazing in 2005. Therefore a new set of randomly located 1 x 1 m quadrats was established across a single expanse of marginal wet heath immediately prior to the resumption of grazing. These comprised 31 quadrats within a grazing exclosure (the ungrazed plot) and 34 across a comparable area outside (the grazed plot). Quadrats were surveyed in 2005 and 2010 using the same methodologies as on the valley mire.

Data analysis: The set of 174 valley mire quadrats comprised 54 samples of MM mire (37 grazed; 17 ungrazed), 93 samples of MMS mire (64 grazed; 29 ungrazed); and 27 samples of END mire (15 grazed; 12 ungrazed). The set of wet heath quadrats comprised 65 samples (34 grazed; 31 ungrazed).

The effect of grazing in the valley mire was assessed by a two stage procedure. Firstly the extent of regrowth in each plot was calculated by subtracting the cover of each species in each plot in 2003 from the mean cover in 2010/2012. The effect of grazing treatment on this difference was then analysed using Kruskal-Wallis ANOVA, where each plot was treated as a separate observation and there were two levels of treatment (grazed or ungrazed). There were three discrete vegetation communities in the valley mire data and we repeated analysis of each species for each community as well as running a global analysis. Such repeated analyses need correction to avoid falsely inflating the type I error rate. Therefore we applied the Dunn-Šidák correction method (Šidák 1967) with N = 4 (i.e. the number of communities for which each species was tested, plus 'across all communities'), so that after running multiple tests the overall probability of a type I error was 0.05 for each species included in the analysis. Because data included 57 variables (53 species, plus litter cover, bare ground, open water and species per quadrat), a total of 228 tests were performed. Although the probability of claiming "significance" should be 0.05 in random data, the large number of variables tested means that two or three significant results per community tested should be expected by chance.

Grazing effects in the wet heath data were analysed using Kruskal-Wallis ANOVA on the change in species' percentage cover between 2005 and 2010. In this case 40 variables (36 species, plus litter cover, bare ground, open water and species per quadrat) were tested and therefore two significant ($p \leq 0.05$) results could be expected by chance. Species richness was correlated with the percentage cover of individual species using Spearman's correlation coefficient, after removal of that species from the species richness total. All analyses were performed in R 2.9.2 (R Development Core Team 2009).

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Table 1. Cattle numbers since the restoration of grazing. No. cattle = total number of animals (excluding calves born on-site). LU = livestock units, calculated separately for stock < 1yr old (0.30), 1-2 years old (0.54) and > 2 years old (0.80) and based on the total area open to stock (21.36 ha – 1.76 ha of the exclosures), excluding woodland (3.76 ha), bracken (5.08 ha) and hard standing (0.53 ha) which provided almost no available forage. MM = *Molinia-Myrica* mire, MMS = *Molinia-Myrica-Sphagnum* mire, END = *Erica-Narthecium-Drosera* mire (see Vegetation sampling: valley mire).

Year	No. cattle	Type	Grazing period	LU days/ ha	LU/ ha/ yr	Notes on cattle movements
2005	16	Highlands	end of August to end of November	51.1	0.14	frequent on wet heath, rare on MM and MMS mire, not seen on END mire
2006	15	9 Highlands 5 Belted Galloways 1 Dexter	beginning of August to mid-November	48.3	0.13	frequent on wet heath, occasional on MM and MMS mire, not seen on END mire
2007	6	Highlands	beginning of August to mid-November	28.4	0.08	frequent on wet heath, rare on MM and MMS mire, not seen on END mire
2008	10	White Parks	mid-July to mid-November	16.1	0.04	frequent on wet heath, rare on MM and MMS mire, not seen on END mire
2009	20	14 Belted Galloways 6 Sussex	beginning of April to mid-October	67.1	0.18	frequent on wet heath, MM mire and MMS mire, occasional on END mire
2010	5	Belted Galloways	beginning of September to end of October	18.7	0.05	frequent on wet heath, occasional on MM mire, rare on MMS mire, not seen on END mire
2011	11	Belted Galloways	mid-September to mid-November	37.4	0.10	frequent on wet heath, occasional on MM mire, rare on MMS mire, not seen on END mire
2012	10	Belted Galloways	end of August to mid-October	13.9	0.04	frequent on wet heath, occasional on MM and MMS mire, not seen on END mire

CONSEQUENCES

Valley mire: Between 2003 and 2010/12 the combined cover of dwarf shrubs (heather, cross-leaved heath, bog myrtle and dwarf gorse *Ulex minor*) increased across all communities in both grazed and ungrazed treatments. These species had been the most severely affected by the April 2003 fire. However, following seven years of grazing, total dwarf shrub cover was markedly greater in ungrazed samples (Figure 2).

The response of purple moor-grass to grazing varied not only between treatments but also vegetation types (Figure 3). In MM and MMS mire cover was reduced significantly by grazing. However, in the little accessed END mire there was little impact and cover remained lower in the ungrazed plot throughout.

Bog-mosses were variably affected by burning in 2003. In drier situations some hummocks were killed. However in wetter areas burning removed considerable quantities of surface litter, allowing the rapid expansion of newly light-exposed plants (Groome 2006). The build-up of litter after the 2003 fire (mostly purple moor-grass litter, shed and then trapped amongst tussocks and dwarf shrubs) did not prevent increases in total bog-moss cover in the ungrazed plot by 2010/12, although none were significant (Wilcoxon signed rank test, with Dunn-Šidák correction for N=4 giving corrected alpha level of 0.0127: MM: W = 9, p = 0.02; MMS: W = 92.5, p = 0.01; END: W = 24 p = 0.27; all communities combined: W = 31, p = 0.25). By contrast, bog-moss cover increased significantly in grazed MMS mire between 2003 and 2010/12 (Wilcoxon test W = 237, p < 0.0001) (Figure 4). It remained about the same in MM mire (W = 195, p = 0.89) despite the marked reduction in purple moor-grass here, and decreased, albeit not significantly, in grazed END mire (W = 77, p > 0.05).

Individual bog-moss species responded differently to treatment depending on community-type with *Sphagnum subnitens* increasing only in grazed relative to ungrazed MMS mire and cover of *S. tenellum* increasing in ungrazed areas more than grazed areas across all quadrats (Table 2).

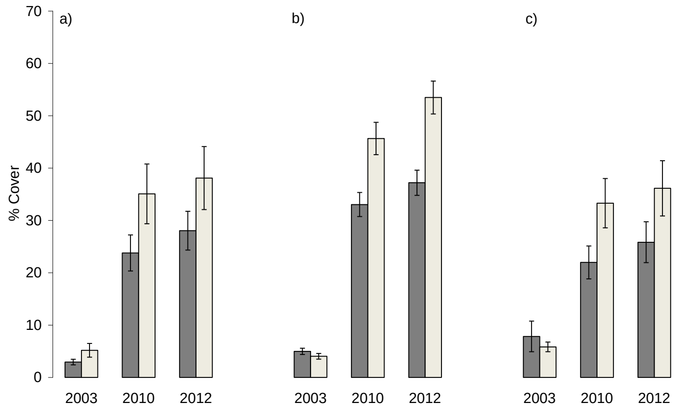

Figure 2. Changes in mean percentage cover (± S.E.) of dwarf shrubs across grazed (■) and ungrazed (□) valley mire plots (2003-2012): a) MM mire, b) MMS mire, c) END mire.

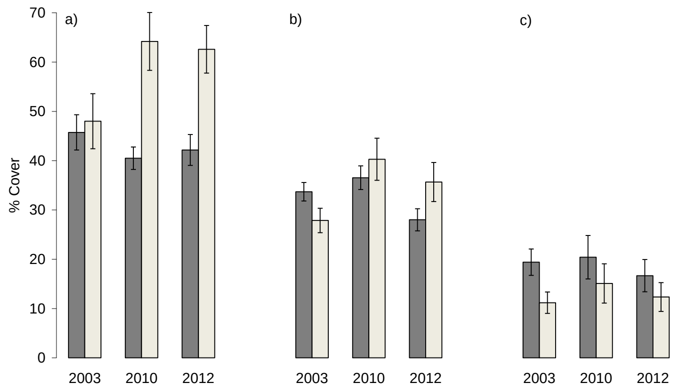

Figure 3. Changes in mean percentage cover (± S.E.) of purple moor-grass across grazed (■) and ungrazed (□) valley mire plots (2003-2012): a) MM mire, b) MMS mire, c) END mire.

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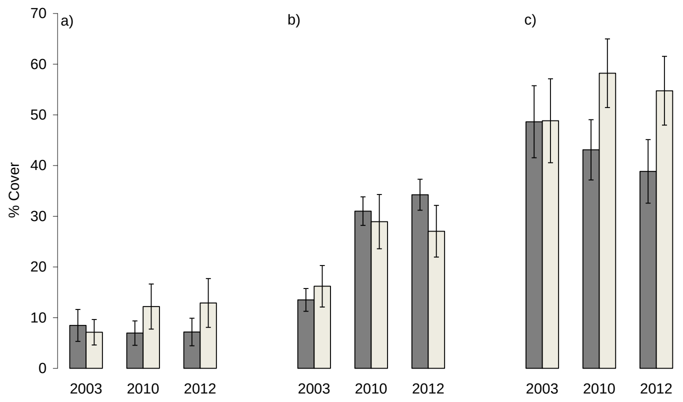

Figure 4. Changes in mean percentage cover (± S.E.) of bog-mosses across grazed (■) and ungrazed (□) valley mire plots (2003-2012): a) MM mire, b) MMS mire, c) END mire.

Heather, cross-leaved heath and purple moor grass also favoured ungrazed areas where a huge increase in litter occurred. By contrast, litter cover was reduced in the grazed plot, exposing bare ground and open water for colonisation by a number of species of liverwort, round-leaved sundew *Drosera rotundifolia* and several rhizomatous and/or semi-aquatic graminoids. Species richness was significantly greater in grazed vegetation than in ungrazed vegetation. Correlation analyses revealed that the percentage cover of purple moor-grass and litter both had a significant effect on diversity (r_s = -0.53, p < 0.0001 and r_s = -0.47, p < 0.0001, respectively), although the best predictors of species richness were the cover of *Sphagnum papillosum* (r_s = 0.60, p < 0.0001) and round-leaved sundew (r_s = 0.55, p < 0.0001).

Wet heath. Between 2005 and 2010 mean species richness in the wet heath increased in the grazed plot (from 9.4 species per quadrat to 12.1), but declined slightly in the ungrazed plot (from 9.5 to 9.3 species). There were significant correlations between 2010 species richness and the increase in 2005-2010 litter cover (r_s = 0.58, p < 0.0001) and the decrease in 2005-2010 cover of bare ground (r_s = -0.72, p < 0.0001). The increase in heather cover from 2005 to 2010 was highly significantly negatively correlated with species richness (r_s = -0.58, p < 0.0001).

Increased species richness in the grazed plot was confirmed by the results of ANOVA analyses (Table 3). Eleven species showed significantly greater increases in percentage cover in the grazed plot compared to the ungrazed plot, whereas only two species increased more in the ungrazed plot.

DISCUSSION

Valley mire: Prior to the resumption of cattle grazing, Folly Bog had been maintained to a large degree by repeated wildfire burning. This had occurred on a broadly 8-10 year cycle, corresponding with the accumulation of highly combustible material in the form of woody material built up in dwarf shrubs and abscised purple moor-grass leaf litter (Groome 2006). All four pre-fire dominant vascular plants quickly re-established themselves as the dominant species following 2003 burning, although the cover of three (heather, cross-leaved heath and purple moor-grass) was significantly greater in ungrazed vegetation than in stands open to seven-nine years of cattle grazing. Largely as a result of the consequent reduction in shade (both by the plants themselves and, in the case of purple moor-grass, its litter) and increases in bare ground and open

Table 2. Results of Kruskal-Wallis ANOVA for differences in change in percentage cover between grazed and ungrazed valley mire plots (2003-2010/12). Only significant results are shown (see Appendix I for species that did not see a significant difference in cover change). After applying a Dunn-Šidák correction for multiple testing at the species level (N=4), the adjusted threshold for significance is p < 0.0127. Bold values indicate a significantly greater increase in grazed plot samples. Underlined values indicate a significantly greater increase in ungrazed plot samples. All = all mire samples combined. MM = *Molinia-Myrica* mire, MMS = *Molinia-Myrica-Sphagnum* mire, END = *Erica-Narthecium-Drosera* mire.

Species/attribute		**All**		**MM**		**MMS**		**END**	
		χ^2	***P***	χ^2	***P***	χ^2	***P***	χ^2	***P***
Liverworts	*Cephalozia* spp.	**16.6**	**<0.0001**	**13.3**	**0.0003**	**7.0**	**0.0080**		
	Riccardia spp.	**17.0**	**<0.0001**			**12.8**	**0.0003**		
Mosses	*Sphagnum subnitens*					**7.7**	**0.0055**		
	Sphagnum tenellum	7.9	0.0050						
Graminoids	Carnation sedge *Carex panicea*	**6.8**	**0.009**						
	Common cottongrass *Eriophorum angustifolium*	**15.6**	**<0.0001**			**22.2**	**<0.0001**		
	Sharp-flowered rush *Juncus acutiflorus*	**13.1**	**0.0003**	**8.1**	**0.0044**				
	Purple moor-grass *Molinia caerulea*	19.9	<0.0001	9.1	0.0025	9.2	0.0023		
Dwarf shrubs	Heather *Calluna vulgaris*	6.8	0.0090			9.8	0.0017		
	Cross-leaved heath *Erica tetralix*	29.2	<0.0001	6.5	0.01	17.2	<0.0001		
Forbs	Round-leaved sundew *Drosera rotundifolia*	**20.8**	**<0.0001**			**12.3**	**0.0005**	**7.2**	**0.0071**
Litter		59.5	<0.0001	18.0	<0.0001	40.1	<0.0001	6.9	0.0084
Bare ground		**71.3**	**<0.0001**	**26.4**	**<0.0001**	**27.1**	**<0.0001**	**18.0**	**<0.0001**
Open water		**38.9**	**<0.0001**	**18.6**	**<0.0001**	**21.7**	**<0.0001**		
Species per quadrat		**13.7**	**<0.0001**	**10.5**	**0.0023**	**6.3**	**0.01**		

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Table 3. Results of Kruskal-Wallis ANOVA for differences in change in percentage cover between grazed and ungrazed wet heath plots between 2005 and 2010. Only significant results are shown (see Appendix II for species that did not see a significant difference in cover change). Bold values indicate a greater increase (or lesser decrease) in grazed plot samples compared to ungrazed plot samples. Underlined values indicate a greater increase in ungrazed plot samples.

Species/attribute		χ^2	***P***
Liverworts	*Cephalozia* spp.	**5.7**	**0.02**
	Gymnocolea inflata	**4.9**	**0.03**
	Kurzia pauciflora	**4.2**	**0.04**
Mosses	*Campylopus* spp.	**23.9**	**<0.001**
	Sphagnum compactum	**14.2**	**0.002**
	Sphagnum tenellum	**5.4**	**0.02**
Graminoids	Carnation sedge *Carex panicea*	**4.6**	**0.03**
	Sharp-flowered rush *Juncus acutiflorus*	**6.8**	**0.009**
	Purple moor-grass *Molinia caerulea*	**3.9**	**0.04**
Dwarf shrubs	Heather *Calluna vulgaris*	4.6	0.03
Forbs	Tormentil *Potentilla erecta*	**11.2**	**<0.001**
Trees/shrubs	Scots pine *Pinus sylvestris* seedling	**5.4**	**0.02**
	Dwarf gorse stump regeneration	9.0	0.003
Species per quadrat		**24.9**	**<0.001**

water, species richness was significantly greater in grazed vegetation. In separate studies of the responses of county rare mire species, 2012 numbers of flowering flea sedge *Carex pulicaris*, tawny sedge *C. hostiana* and early marsh-orchid *Dactylorhiza incarnata* ssp. *pulchella* were all considerably greater in grazed than ungrazed stands. Flowering spikes of bog asphodel *Narthecium ossifragum* were significantly greater in grazed than ungrazed vegetation in all years following the reintroduction of livestock, other than in 2009 when cattle ate the majority of inflorescences (unpublished data).

Bog-mosses, especially the primary peat forming species of *Sphagnum* Sect. *Sphagnum*, can be regarded as the most important species of oligotrophic peatlands (see for example Clymo & Reddaway 1971, van Breemen 1995). However, bog-mosses, both as a group and as individual species, responded variably according to location, the different breeds of cattle employed, grazing intensity and the type of vegetation being grazed. For example, *Sphagnum papillosum* saw a two-fold increase in grazed MMS mire between 2003 and 2012, but a 25% decline in END mire (by comparison it increased by approximately 36% in ungrazed MMS mire and by approximately 10% in ungrazed END mire). Declines in END mire were largely related to cattle trampling in the wettest stands toward the head of the valley mire in 2009. These stands support little humified peat and trampling could readily result in hummocks being pushed up to 30 cm below surface water level. A similar response to the resumption of cattle grazing was recorded at Coombe Bog, Dorset, UK (Lake 2002), where, following increases in the wild sika *Cervus nippon* population, the combined damage to bog mosses became so great that livestock were eventually removed altogether (S. Lake, pers. comm.).

The loss of *Sphagnum papillosum* in some areas was of benefit to *S. subnitens*, a more base-tolerant species that is generally out-competed by *S. papillosum* in the more acidic parts of Folly Bog. *Sphagnum denticulatum* also increased, especially in END mire where there was an approximately 80% increase in cover. This was probably due to the increase in bare peat and open water, which also encouraged gramineaceous pool species. In ungrazed END mire the cover of *S. denticulatum* decreased by about 80%.

Rainfall was far above the long-term average throughout the study period and water levels across the valley mire increased considerably from 2005 to 2012 (unpublished data). Bog-moss cover has been shown to have increased significantly in response to previous increases in water levels at Folly Bog (Groome 2006). The recorded 2003-2012 increases in bog-mosses in the ungrazed plot may therefore have been greatly influenced by water level increases. By contrast, decreases in *S. papillosum* in grazed END mire might not have been so severe had water levels been lower.

Wet heath: Between 2005 and 2010 plots were in the pioneer phase of heather regeneration, following the 2003 fire which had removed almost all above-ground woody material (Groome 2006). Despite the wet heath being much more regularly accessed by livestock than the valley mire, heather and cross-leaved heath regenerated rapidly in both grazed and ungrazed plots. Only heather cover increased significantly more in the ungrazed plot; this was probably the chief reason why purple moor-grass cover declines were much greater here.

As in the valley mire there were significant negative correlations between species richness and increased litter/decreased bare ground. However, increased heather cover was also negatively correlated with species-richness, supporting suggestions that limiting the extent to which heather dominates the late-pioneer stage of post-fire regeneration might be important in maintaining diversity on wet heaths.

Above average summer rainfall during the study period will undoubtedly have influenced the increases in bog-mosses across the sample area. However, on the much firmer substrates of the wet heath, livestock trampling appeared to have no negative impacts on these species, other than in one area where cattle commonly congregated in the shade of a lone tree, and total mean bog-moss cover per quadrat increased by 8.8% (compared to only 1.8% in the ungrazed plot). Across the two recording plots total 2010 cover of bog-moss and litter, as well as bog-moss and heather, were significantly negatively correlated (r_s = -0.35, p = 0.004 and r_s = -0.49, p < 0.001, respectively).

Although grazing maintained patches of open sward in which diversity and bog-mosses increased significantly, it also promoted better conditions for Scots pine seedling germination.

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Browsing, and to a lesser extent trampling, evidently had a significant effect on limiting the extent to which dwarf gorse regenerated following 2003 burning, but was insufficient to prevent it becoming dominant in some quadrats. Several pine seedlings developed into saplings which were then avoided by stock. Beyond the recording area both dwarf gorse and downy birch *Betula pubescens* scrub increased markedly in parts of the grazed wet heath, indicating that low intensity grazing was insufficient to prevent encroachment. An increase in birch sapling density has also been observed following grazing with belted Galloways at Rodborough Common, Gloucestershire (D.Bullock pers. comm.).

Implications for conservation: This study has shown that the reintroduction of low intensity cattle grazing to a valley mire and wet heath site following several decades of grazing abandonment resulted in a range of positive responses, as defined by conservation targets (JNCC 2009). However, the impact of stock varied with grazing period, grazing intensity, breed and, most crucially, the type of vegetation being grazed and its underlying substrate. Weather also played an important role, determining soil water levels and inter-annual productivity (and thus available forage). Not all impacts were desirable and in the wettest areas of the valley mire the primary peat-forming bog moss, *Sphagnum papillosum*, was adversely affected by trampling. On the wet heath, despite much greater pressure from stock, low intensity grazing was insufficient to prevent scrub encroachment.

Results of this study support the recommendations of numerous workers that heathland managers need to consider the most appropriate grazing regimes on a site-by-site basis. The variation in vegetation response to grazing different floristic assemblages within individual sites also needs to be carefully and regularly monitored (Newton *et al*. 2009), along with fauna, and management flexibility maintained to respond as conditions dictate. Other forms of management, such as controlled burning, turf cutting, mowing and/or scrub removal, will most likely continue to be required to supplement grazing.

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REFERENCES

Byfield A.J. & Pearman, D. (1996) *Dorset's Disappearing Heathland Flora*. Report for Plantlife, London and RSPB, Sandy.

Clarke M.J. (1987) Past and present mire communities of the New Forest and their conservation. PhD thesis. Southampton University.

Clymo R.S. & Reddaway E.J.F. (1971) Productivity of *Sphagnum* (bog moss) and peat accumulation. *Hydrobiologia*, **12**, 181-192.

Groome G. (2006) Vegetation response to changing water levels on a lowland valley mire: Folly Bog, Surrey, England. PhD thesis. University of Surrey.

JNCC (2009) *Conservation Standards Monitoring Guidance for Lowland Heathland. Version February 2009*. JNCC, Peterborough.

Lake S. (2002) The role of livestock grazing in the conservation of lowland wet heath. PhD thesis. University of Southampton.

Lake S., Bullock J.M. & Hartley S. (2001) *Impacts of Livestock Grazing on Lowland Heathland*. English Nature Research Report No. 422.

Newton A.C., Stewart G.B., Myers G., Diaz A., Lake S., Bullock J.M. & Pullin A.S. (2009) Impacts of grazing on lowland heathland in north-west Europe: A systematic review of the evidence. *Biological Conservation*, **142**, 935-947.

R Development Core Team (2009) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.

Rodwell J.S. (ed.) (1991) *British Plant Communities, Volume 2: Mires and Heaths*. Cambridge University Press, Cambridge.

Šidák Z. (1967) Rectangular confidence regions for the means of multivariate normal distributions. *Journal of the American Statistical Association*, **62**, 626-633.

van Breemen N. (1995) How *Sphagnum* bogs down other plants. *Trends in Ecological Evaluation*, **10**, 270-275.

APPENDIX I Valley mire species that did not see a significant difference in 2005-2010/12 cover change between grazed and ungrazed plot samples

Liverworts: *Aneura pinguis*. *Calypogeia* spp., *Kurzia pauciflora, Lophozia ventricosa, Nardia scalaris*

Mosses: *Aulacomnium palustre, Bryum* spp., *Campylopus* spp., *Hypnum cupressiforme, Hypnum jutlandicum, Kindbergia praelonga, Sphagnum capillifolium, Sphagnum denticulatum, Sphagnum papillosum*

Graminoids: Velvet bent *Agrostis canina,* Star sedge *Carex echinata,* Common sedge *Carex nigra,* Many-stalked spike-rush *Eleocharis multicaulis,* Bulbous rush *Juncus bulbosus,* Compact rush *Juncus conglomeratus,* Soft rush *Juncus effusus,* White beaked-sedge *Rhynchospora alba,* Black bog-rush *Schoenus nigricans*

Dwarf shrubs: Bog myrtle *Myrica gale*

Forbs: Meadow thistle *Cirsium dissectum,* Early marsh-orchid *Dactylorhiza incarnata* ssp. *pulchella,* Bog asphodel *Narthecium ossifragum,* Heath milkwort *Polygala serpyllifolia,* Bog pondweed *Potamogeton polygonifolius,* Tormentil *Potentilla erecta,* Devil's-bit scabious *Succisa pratensis*

Trees/ shrubs: Birch *Betula* spp., Scots pine *Pinus sylvestris,* Pedunculate oak *Quercus robur,* Rhododendron *Rhododendron ponticum,* Brambles *Rubus fruticosus* agg., Grey willow *Salix cinerea,* Gorses *Ulex* spp.

Ferns and horsetails: Broad buckler-fern *Dryopteris dilatata,* Marsh horsetail *Equisetum palustre,* Water horsetail *Equisetum fluviatile,* Bracken *Pteridium aquilinum*

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APPENDIX II Wet heath species that did not see a significant difference in 2005-2010 cover change between grazed and ungrazed plot samples

Liverworts: *Calypogeia* spp.
Mosses: *Aulacomnium palustre, Ceratodon purpureus, Hypnum jutlandicum, Pohlia nutans, Sphagnum denticulatum, Sphagnum papillosum, Sphagnum subnitens*
Graminoids: Common cottongrass *Eriophorum angustifolium*
Dwarf shrubs: Cross-leaved heath *Erica tetralix*, Creeping willow *Salix repens*
Forbs: Round-leaved sundew *Drosera rotundifolia*, Meadow thistle *Cirsium dissectum*, Heath milkwort *Polygala serpyllifolia*, Devil's-bit scabious *Succisa pratensis*
Trees/shrubs: Birch *Betula* spp. seedling, Birch sapling, Birch shrub, Scots pine *Pinus sylvestris* sapling, Pedunculate oak *Quercus robur* seedling, Pedunculate oak sapling, Gorses *Ulex* spp. seedling
Ferns: Bracken *Pteridium aquilinum*

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