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Trends, over 14 years, in the ground cover on an unimproved western hill grazed by sheep, and associated trends in animal performance

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Abstract

The frequency of individual plant species at ground level and the species composition of the unimproved vegetation on a western hill farm, stocked with Scottish Blackface sheep, were monitored from 1995 to 2008. Performance criteria of the flock that relied totally, or almost totally, on this vegetation for sustenance from 1994 to 2011 were evaluated. The frequency of vegetation increased over time (from 65% to 82% of the surface area; $P < 0.05$), with a corresponding decline in the frequency of bare soil, thus reducing vulnerability to soil erosion. This increased incidence of vegetation cover reflected increases in 'other forbs' ($P < 0.01$), heather ($P < 0.05$) and grass ($P < 0.08$). A significant change ($P < 0.05$) also occurred in the species composition of the vegetation, reflecting an increase in the proportions of 'other forbs' ($P < 0.05$) and heather ($P = 0.14$), and a decline in the proportion of sedges ($P = 0.14$). A similar pattern occurred in the two main habitats: blanket bog and wet heath. Annual stocking rate (ewes per hectare, based on actual ewe grazing days) on the unimproved hill grazing averaged 0.9 (0.13 livestock units) per hectare prior to 1999 and 0.78 (0.11 livestock units) per hectare subsequently. There was no trend in weight gain of replacement females while confined to the unimproved hill area between weaning (14 weeks old) and first joining at 18 months of age. A negative trend ($P < 0.01$) occurred in the pre-weaning growth rate of lambs on the hill. The average number of lambs reared per ewe joined (reflecting fertility, litter size and ewe/lamb mortality) was 1.0, and this showed no evidence of change over time. The study flock performed 10% to > 60% better, depending on the variable, than similar flocks in the National Farm Survey at comparable stocking rates. A well-defined rational management system can sustain a productive sheep enterprise on unimproved hill land without negative consequences for the frequency or composition of the vegetation.

Keywords

blanket bog • Scottish Blackface • sheep productivity • stocking rate • wet heath

Introduction

The hill-and-mountain landscape of Western Ireland, which extends from County Donegal in the north to western County Cork in the south, contains farmland dating from Neolithic times (O'Connell, 1990). Large-scale deforestation and burning of trees, as indicated by palaeobotanical records and buried charcoal dating from Neolithic and Bronze Age times, played a key role in soil and vegetation change (O'Connell, 1990; Moles *et al.*, 1999; Clavin, 2000; Moles and Moles, 2002; Feeser and O'Connell, 2009). A long and complex geological, geomorphological and land-use history has produced a mosaic of soil and vegetation patterns that are difficult to characterise and map. Agricultural land use, mainly extensive livestock systems, is a feature of the hill and mountain landscape (Frawley and Commins, 1996). Soil erosion in this landscape, from the early decades of the 19th century to the last decade of the 20th, exceeded those in similar landscapes in Western and Northern Europe

(Huang and O'Connell, 2000). Intensive arable and livestock farming, steep topography and the high rate of precipitation were cited as the main contributory factors. Further studies on soil erosion in this landscape were reported by Walsh *et al.* (2000), Guinan (2005) and Mulqueen *et al.* (2006).

The physical impact of sheep and other grazers on the soil and micro-topography was examined by Tallis (1964, 1965), Bayfield *et al.* (1988), Moles (1992), Clavin (2000) and Lynch (2010). Issues related to appropriate management of sheep in relation to the hill environment are addressed in Council Regulation (EC) No. 1782/2003, Moravec and Zemeckis (2007), Farmer *et al.* (2007), Williams *et al.* (2009, 2011) and García *et al.* (2013). Although Osoroa *et al.* (2013) report a reversal, over time, in the live weight of Gallega sheep in the Cantabrian heathlands, little attention appears to have been given to the productivity of sheep that rely almost totally on unimproved hill vegetation for sustenance.

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Coincident with Ireland's EU accession, legislation was enacted (Council Directive 72/159-161 EEC) to improve the living standards of farmers. Subsequent payments to farmers, i.e., headage payments in less favoured areas, and ewe premia (DoA, 1980) resulted in average annual increases, between 1980 and 1991, of 10% to 13% in sheep numbers in the west and west-border areas (Lafferty *et al.*, 1999). Claims of substantial soil erosion in the western hill landscape were made in the early 1990s, both anecdotally (public media) and formally (Bleasdale and Sheehy-Skeffington, 1992), citing overgrazing by sheep as the main driver. A number of corrective schemes (e.g., 'Ewe Supplementary Measure', DAF, 1998) resulted in the reduction, by 2008, of the number of hill sheep to approximately that of 1980.

Despite the fall in the number of hill sheep, the structure, function and future prospects of EU-protected habitats that are associated with the western hill-and-mountain landscape (wet heath, blanket bog and others) were deemed 'bad' due to perceived abandonment of traditional agricultural practices and over-stocking (NPWS, 2013; Lynn, 2013). O'Rourke and Kramm (2012) indicated the need for research on problems, constraints and opportunities related to 'high nature value' farming in biodiversity-sensitive landscapes such as those existing in the western hill area. In the Irish context, from the early 1990s through to the present, there has been a clear lack of objective information on the impact of hill sheep farming on the unimproved hill vegetation, which, allied with farm management system and animal performance indicators, could provide a basis for sustainable and productive farm management systems.

Teagasc leased a farm in 1990 in the hill-and-mountain landscape of Western Ireland with the aim of providing a focus for management and production aspects related to hill sheep in a western hill environment. The present study was established on that farm in 1995 as part of a programme aimed at developing a better understanding of the interaction between hill sheep production and the physical environment. The specific objectives were as follows: a) monitor time trends in the frequency of vegetation species and exposed/bare soil on a regular and spatially repetitive basis; b) quantify the species composition of vegetation on a similar basis; c) monitor stocking rate; d) assess trends in the productivity of sheep that relied almost solely on the hill vegetation for sustenance; and e) use the information to form an assessment of flock productivity in relation to sustainability of the resource.

Materials and methods

Location

The study was conducted on a hill farm that was leased by Teagasc between autumn 1990 and autumn 2011, and stocked with Scottish Blackface sheep throughout this period.

The farm is situated on a south-facing slope of Ben Gorm (Mweelrea mountain range) in the south of County Mayo, approximately 5 km north-east of the village of Leenaun (Figure 1). It is part of the Mweelrea/Sheeffry/Erriff Complex Special Area for Conservation (NPWS, 2013; Lynn, 2013b). Altitude varies from 15 m to 280 m above mean sea level and the farm consisted of approximately 250 ha of unimproved, semi-natural hill vegetation and 20 ha of reclaimed lowland. A mosaic of habitats occurs on the unimproved hill, the dominant ones being blanket bog and wet heath, which occupy 53% and 35% of the unimproved hill area, respectively (Williams *et al.*, 2012). Mean annual rainfall for the years 1993 to 2009, recorded on site, was 2,123 mm, which is much higher than that reported in analogous studies conducted in other parts of Western Europe. The minimum (1,676 mm) occurred in 2001 and the maximum (2,610 mm) in 1998. Variation in average monthly rainfall is presented in Figure 2.

Surface cover

A grid (100 m × 100 m) was established on the unimproved hill area of the farm in 1995, irrespective of habitat or plant community, using a surveyor's tape, ranging rods and an optical square. A numbered peg was securely fixed in the ground at each grid intersection, resulting in a total of 226 permanent markers (Figure 3). Eight of the grid intersections represented physiographic anomalies, a further 6 occurred in permanently fenced animal-holding areas, which were expanded to enclose a further 2 in 1999. This gave a total of 212 intersections relevant for the purpose of monitoring and assessment in 1995, which was reduced to 210 from the year 2000 onwards. The habitat boundaries established by Williams *et al.* (2012) were used to assign each grid point to a specific habitat, irrespective of their mosaic pattern of occurrence. Surface features (plant species, bare soil and boulder/rock) were recorded at each grid intersection using a point quadrat method (Wilson, 1959, 1960) but based on a flexible rope/string net (1.8 m × 1.8 m, with a 20 cm square mesh). The net was placed as close as possible to the ground surface, orientated north, by reference to a handheld magnetic compass, with the grid peg at its northwest corner. The proximity of streams, open drains or other localised disturbance required that the orientation of the net be modified at a few grid intersections to ensure maximum representation of the natural surface. A pointer, with a circular footprint (5 mm diameter), was dropped vertically at each node of the net mesh (including those on its perimeter, thus the equivalent of a 2 m × 2 m quadrat) through the vegetation canopy, where present, to the ground surface. One feature (plant species, bare soil, boulder/rock/stone, standing water or faeces) was recorded for each ground hit; this yielded 100 features per quadrat. Recording was undertaken in each of 9 yr: 1995, 1996,

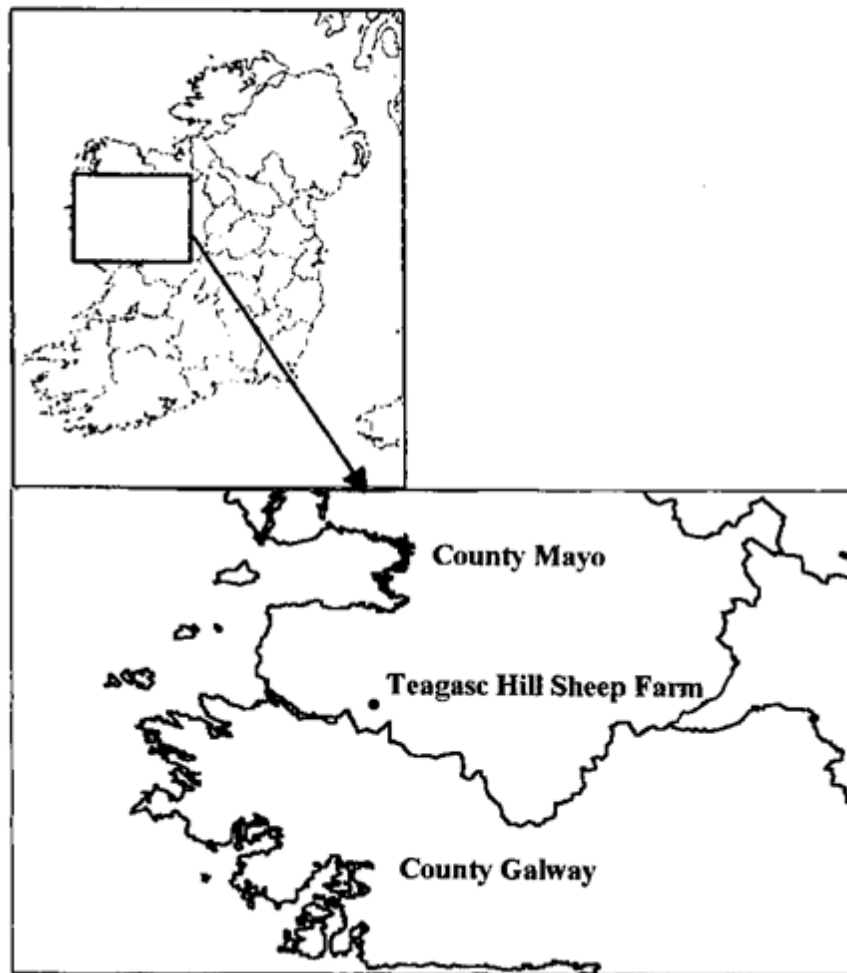


Figure 1. Location of hill farm used in study (based on country maps, Ordnance Survey Ireland, Dublin).

1997, 1998, 1999, 2001, 2002, 2004 and 2008. Because a similar procedure (i.e., using a rope/string net rather than a rigid quadrat) has not been described in the literature (Everson and Clarke, 1987), repeat recordings were completed at randomly selected grid intersections (20 to 32 per year) in 6 of the 9 yr (1997, 1998, 1999, 2002, 2004 and 2008) in order to quantify the reliability of the method. In all cases, recordings were completed during the period of maximum plant growth: mid-June to end of August. The detailed information on surface cover was summarised under the following main headings: grass, sedge, moss and lichen, heather, ‘other forbs’ and ‘no vegetation’ (consisting of bare soil, boulder/rock/stone, standing water and faeces). Results for dominant plant species in each group were also summarised, including the frequency of ‘positive indicator species’ (Perrin *et al.*, 2014) in the blanket bog and wet heath habitats. Vegetation identification and nomenclature followed Webb *et al.* (1996). All vegetation species and

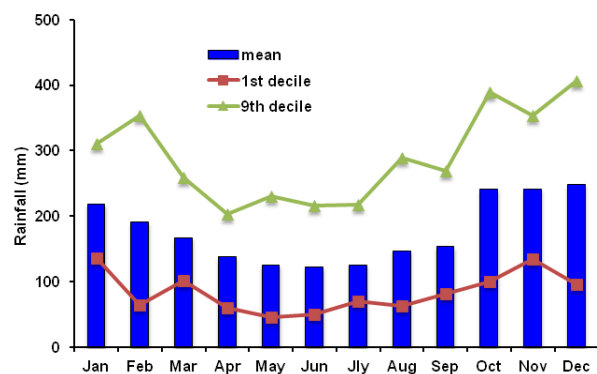


Figure 2. Mean monthly precipitation recorded on the farm over the period 1993 to 2009, with the first and ninth decile values.

surface features that were recorded at ground level during the full study period, including percentage frequency in 1995 and 2008, are listed in Appendix 1.

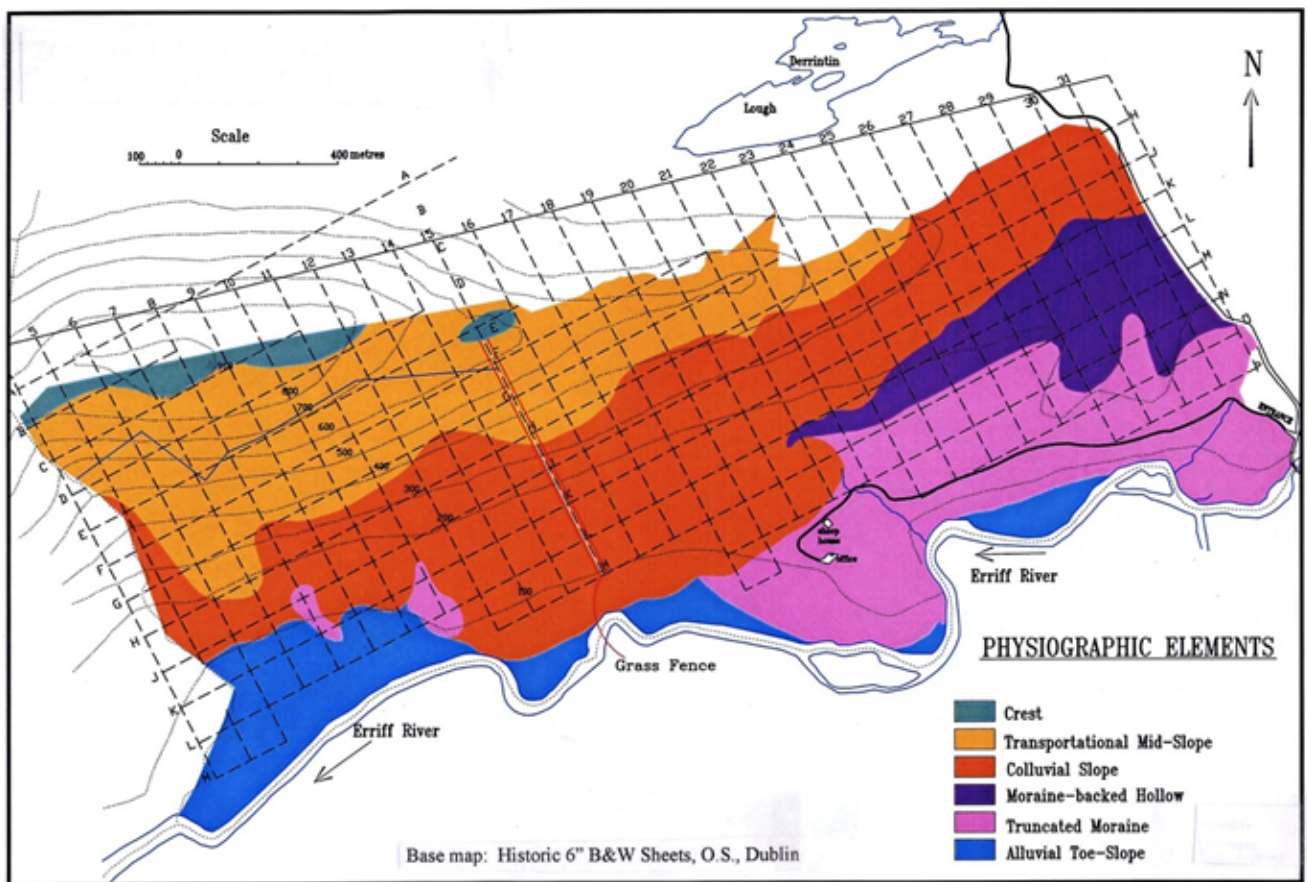


Figure 3. Stylised representation of 100 m × 100 m grid on general physiographic map of the study farm with interpolated contours (based on historic 6" sheets, Ordnance Survey Ireland, Dublin).

Mean species richness for the period 1995 to 2004 was based on the hits at each mesh node, while it was based on a complete assessment of the species within each quadrat in 2008. Mean vegetation height was based on the first 20 plants that were encountered at the mesh nodes on the quadrat diagonals in each of 5 yr: 1999, 2001, 2002, 2004 and 2008. Individual plants/plant parts were raised to full height and measured with a steel tape.

Stocking rate

Electronic tags were used on all sheep on the farm from spring 2004 onwards. This enabled the collection of precise information on the number of sheep grazing on the unimproved hill on a daily basis throughout the year. These data, together with information in stock management diaries for the years prior to 2004, were used to establish the stocking rate (adult ewe equivalents per hectare) on the unimproved hill area on a monthly basis. Annual stocking rates for the national hill (Scottish Blackface) flock were estimated from the Teagasc National Farm Survey (NFS) data from 2001 to 2010, inclusive. Stocking rate was expressed in livestock

units (LU) per hectare using NFS equivalents for the various classes of farm livestock; thus, 1 adult hill ewe = 0.14 LU (www.teagasc.ie).

Farm management and flock productivity

The farming system prior to the commencement of the lease was based on hill sheep, with some cattle on agistment during the winter period; this was altered to exclusively sheep (Scottish Blackface breed) in 1990. Details on farm management and related issues are presented in Hanrahan and O'Malley (1999) and Nolan *et al.* (2003). Briefly, the number of ewes joined was increased from approximately 280 initially to a maximum of approximately 400 in 1994 and reduced to approximately 350 ewes from 1999 onwards, with approximately 80 ewe lambs being retained annually as replacements. The sheep were managed in a single system until autumn 1998, when a two-flock system was established: one flock, containing approximately 200 young ewes (2 to 4 yr old at lambing), plus flock replacements, was used for purebred production and was grazed mostly on the unimproved hill; the other flock, containing approximately 150

older ewes (≥ 5 yr at lambing), was used for crossbreeding and was managed almost exclusively on part of the reclaimed lowland.

Throughout the full period covered by the present study, ewes with single-born, purebred female lambs were housed on the unimproved hill except for a period from birth, which took place during April on a section of the reclaimed lowland, until the lambs were 3 to 4 wk of age. Flock replacements came predominantly from this set of ewe lambs and they remained on the hill until December or early January, when they were housed and offered silage and a concentrate supplement. They were put back to the hill in late April and remained on the hill until early October, when the ewe flock for the following season was assembled on the reclaimed lowland prior to joining. Thus, apart from the winter housing period between 8 and 12 mo of age, sustenance was entirely from the vegetation on the unimproved hill area until just prior to first joining at about 18 mo of age. Consequently, the performance of these animals up to and including first joining was used as the primary index of the capacity of the vegetation resource on the hill to sustain animal performance. The full set of variables used to provide evidence on time trends in animal performance was as follows:

1. Live-weight gain for purebred, single-born female lambs between weaning and housing (early January) for winter and that between turnout (in April at ~ 1 yr of age) and transfer to lowland in early October at ~ 1 mo prior to first joining (a total period of about 12 mo during which hill vegetation was the sole sustenance available);
2. Growth rate of single-born ewe lambs from birth to weaning (in mid-July, at about 14 wk of age);
3. Number of lambs reared per ewe joined, for 2-yr-old ewes; and
4. Fertility and litter size at 2 yr of age.

Overall performance data (number of lambs reared per ewe joined, the incidence of barren ewes, and ewe and lamb mortality) for the flock used for purebred production were compared with the values recorded for Scottish Blackface hill flocks in the NFS. The NFS data, for the period 2004 to 2007, comprised 78 flock-years and an average flock size of > 200 ewes.

Data analysis

Vegetation distribution diagrams were compiled using ArcGIS®. Observations on the frequency of the components of surface cover, using data from the individual grid intersections each year, were summarised using Proc MEANS of SAS (2003). Time trends in means for vegetation variables were examined using regression on year. Trends in the species composition of the vegetation were analysed using multivariate analysis of variance (Proc GLM; SAS, 2003). Animal performance data were analysed using Proc GLM with fixed effects for year and ewe age (where appropriate) to yield least-squares estimates of the annual mean values. The significance of change with

time was evaluated using a regression model that included year as a random term. Outliers from the regression of performance on year were evaluated using studentized deviations from the regression line and the procedures in Zar (1999).

Results

Quality control

Correlations between repeated, within-year, assessments of surface cover are summarised in Table 1. The pooled within-year estimates ranged from 0.41 for species richness to 0.82 for incidence of 'other forbs'. Repeatability for the 'no vegetation' group, which consisted mostly of bare soil largely covered by vegetation litter and algae, was 0.81. Grass and sedge, which dominated the vegetation, yielded values of 0.64 and 0.68, respectively, but, when combined, yielded a value of 0.72 and exhibited a smaller range among years. The correlations for species richness were consistently low.

Table 1. Correlation coefficients (within-year basis) for repeat observations on frequency of individual components of surface cover, and for vegetation height and species richness

Variable	Correlation [†]
No vegetation	0.81
Grass	0.64
Sedge	0.68
Grass plus sedge	0.72
Heather	0.68
Moss plus lichen	0.78
Other forbs	0.82
Vegetation height	0.73
Species richness	0.41

[†]The number of paired values was 156 in all cases except vegetation height ($n = 100$); all values were significant at $P < 0.01$.

Surface cover

A spatial representation of the frequency of vegetation at ground level in 1995 and 2008 is presented in Figure 4. It is clear that the frequency of vegetation was higher in 2008 compared with that in 1995 and that the increase was observed across all areas of the hill. The mean frequencies of the main components of the surface cover, including rush species ($< 0.6\%$ in all years), in 1995 and 2008 are given in Table 2. Annual means for vegetation frequency and for bare soil and boulder/rock are presented in Figure 6a and b, respectively. The mean frequency of vegetation increased significantly with time ($P < 0.02$), by a factor of 1.27 between 1995 and 2008 (using the regression line). An associated significant decline ($P < 0.05$) was evident in bare soil. Mean vegetation height

Table 2. Percentage of the surface of the unimproved area of the hill farm accounted for by various vegetation groups, including some dominant species, and other surface components, in 1995 and 2008

Vegetation group/surface component	Year	
	1995	2008
Grass (<i>Molinia caerulea</i>)†	24.6 (93.1)†	30.4 (92.4)†
Sedge (<i>Schoenus nigricans</i>)	22.6 (44.5)	25.3 (51.3)
Heather (<i>Erica tetralix</i>)	3.0 (70.6)	7.6 (75.2)
Other forbs (<i>Narthecium ossifragum</i>)	6.3 (70.7)	9.6 (53.1)
Moss plus lichen	7.4	9.0
Rush	0.6	0.3
No vegetation	35.5	17.8
Total vegetation	64.5	82.2

†The dominant species (and its percentage of the corresponding vegetation group).

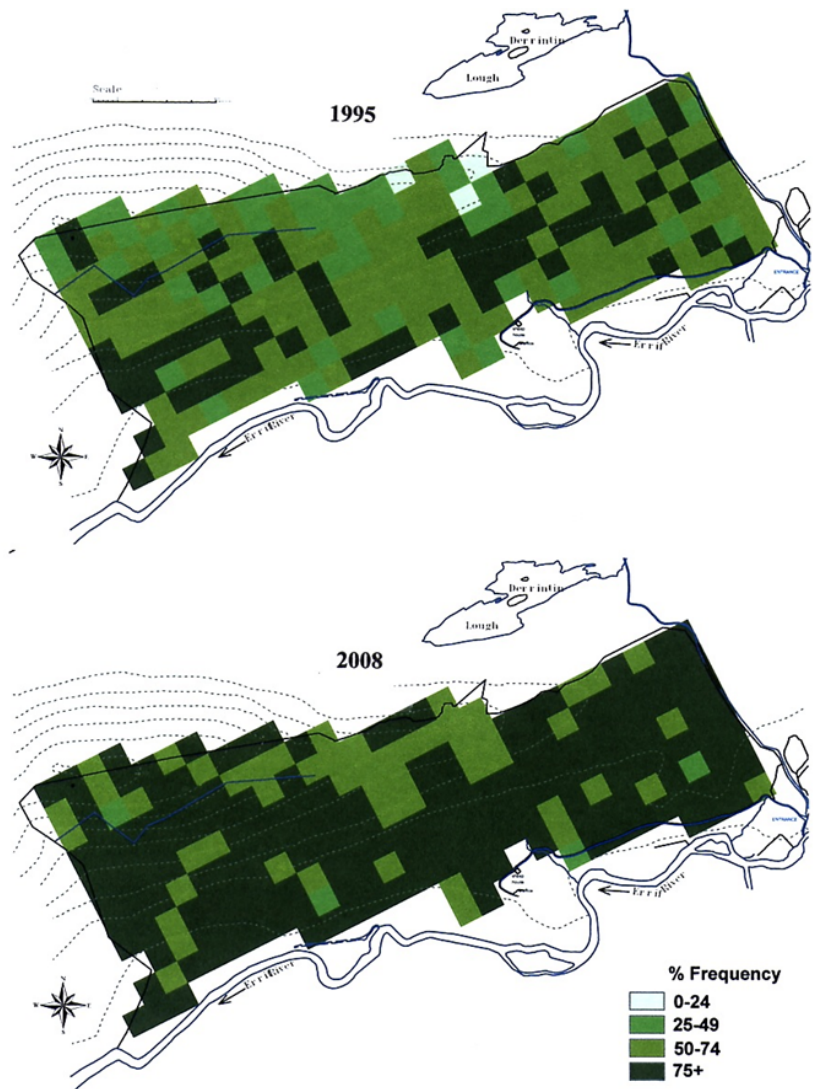


Figure 4. Spatial comparison of frequency of total vegetation species at ground level in the years 1995 and 2008.

was 21.4 (s.e. 0.6) cm in 1999, when first recorded, and 21.9 (s.e. 0.6) cm in 2008.

The mean annual frequencies for grass (Gramineae) and sedge (Cyperaceae), and for the dominant species in each, are presented in Figure 7a and b, respectively. Grass, in which 10 species were identified, consisted predominantly (88% to > 90%) of purple moor grass (*Molinia caerulea* L. Moench) and was the group with the highest frequency. It was followed closely by sedge, in which 12 species were identified, among which black bog-rush (*Schoenus nigricans* L.) was dominant (45 to > 50%). Regression analysis indicated an increasing trend with time for grass ($P = 0.07$) and its dominant species; there was no evidence for any trend in the frequency of the sedge group or its dominant species.

Results for the 'other forbs', heather (Ericaceae) and 'moss-plus-lichen' groups are presented in Figure 8a, b and c, respectively. The 'other forbs' group, in which 30 species were identified, was dominated (71% in 1995 and 53% in 2008) by bog asphodel (*Narthecium ossifragum* L. Huds.) and the frequency of this vegetation group increased by a factor of 1.5 ($P < 0.01$) over the study period. The frequency of the 'moss plus lichen' group, in which 7 species were identified, averaged 8.2% over all years and there was no evidence for a temporal trend. Heather, which consisted of 4 species, occupied < 8% of the surface and was dominated (> 70%) by cross-leaved heath (*Erica tetralix* L.). Regression analysis indicated an increasing trend with time ($P < 0.05$) for heather

and its dominant species. Time trends in the frequency of each of the foregoing groups were also examined for data restricted to the grids associated with the two dominant habitats (blanket bog and wet heath); the trends did not differ significantly between these habitats and were consistent with the time trends for the total area.

Mat grass (*Nardus stricta* L.) plus heath rush (*Juncus squarrosus* L.) averaged 1.4% of the surface over the study period. The rush group, which consisted of five species, occupied < 1% of the surface throughout the period.

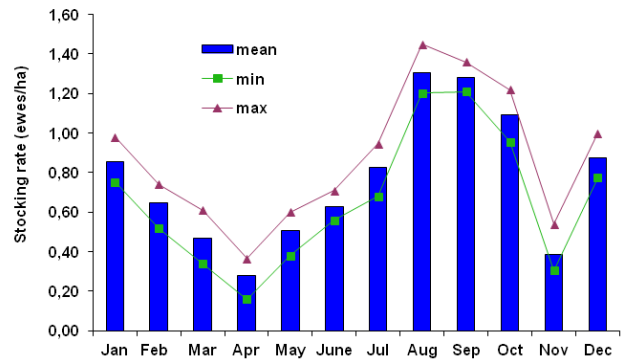


Figure 5. Mean monthly livestock density (ewes per hectare) on unimproved hill vegetation over the period 1999–2008, with minimum and maximum values.

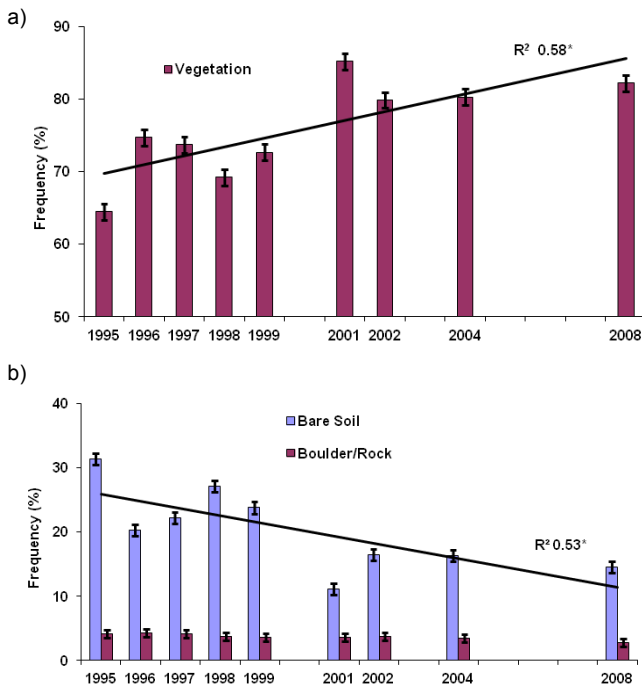


Figure 6. Variation and trends in percentage frequency, expressed as least-squares means (\pm s.e.), with fitted regression lines for: a) vegetation frequency and b) bare soil.

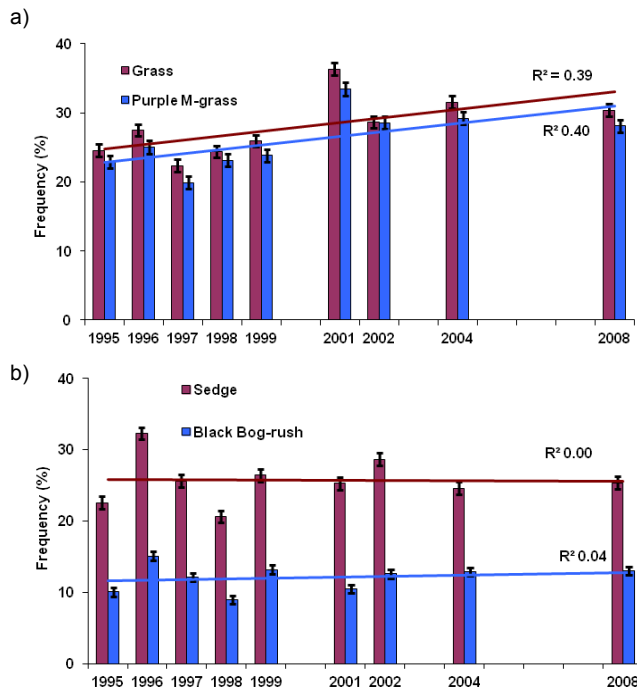


Figure 7. Variation and trends in percentage frequency, expressed as least-squares means (\pm s.e.), with fitted regression lines for a) grass and b) sedge, with individual dominant species.

The species composition of the vegetation was examined by expressing the frequency values for each species group as a proportion of total vegetation frequency. A multivariate analysis of these data showed that there was a significant ($P < 0.05$) trend over time. This reflected a significant increase in the proportion of vegetation accounted for by the 'other forbs' group ($P < 0.05$), with a negative, though non-significant, trend for the proportion accounted for by sedge ($P = 0.14$) and an upward trend for heather ($P = 0.14$). There was no evidence for any trend for either the grass ($P = 0.4$) or the moss-plus-lichen ($P > 0.9$) groups. The proportion accounted for by *Juncus* spp. was < 0.01 in all years, but this value also exhibited a negative trend over time ($P < 0.05$). Mean values for the frequency of total vegetation on the two dominant habitats are given in Table 3 for 1995 and 2008; the habitat difference was significant ($P < 0.01$) at both time points. The species composition of the vegetation cover on these habitats is also shown in Table 3, together with the relative contribution of 'positive indicator species' (Perrin *et al.*, 2014). 'Positive indicator species' that were recorded are indicated in Appendix 1, and they occupied approximately half the vegetation in each habitat over the study period. A multivariate analysis of the species composition data failed to reveal any significant difference ($P > 0.4$) between blanket bog and wet heath in the observed time trends. The changes between 1995 and 2008, calculated from the regression lines for each vegetation group and expressed in units of the corresponding standard deviation about the regression line, are plotted in Figure 9 for the results from the total area and from the two dominant habitats.

Mean species richness, based on 100 points per quadrat, varied between 9 and 10 during the period, with no evident trend. Mean species richness based on all occurrences within a quadrat, which was assessed only in 2008, yielded an average of 10. Total species richness for the farm was > 60 (Appendix 1).

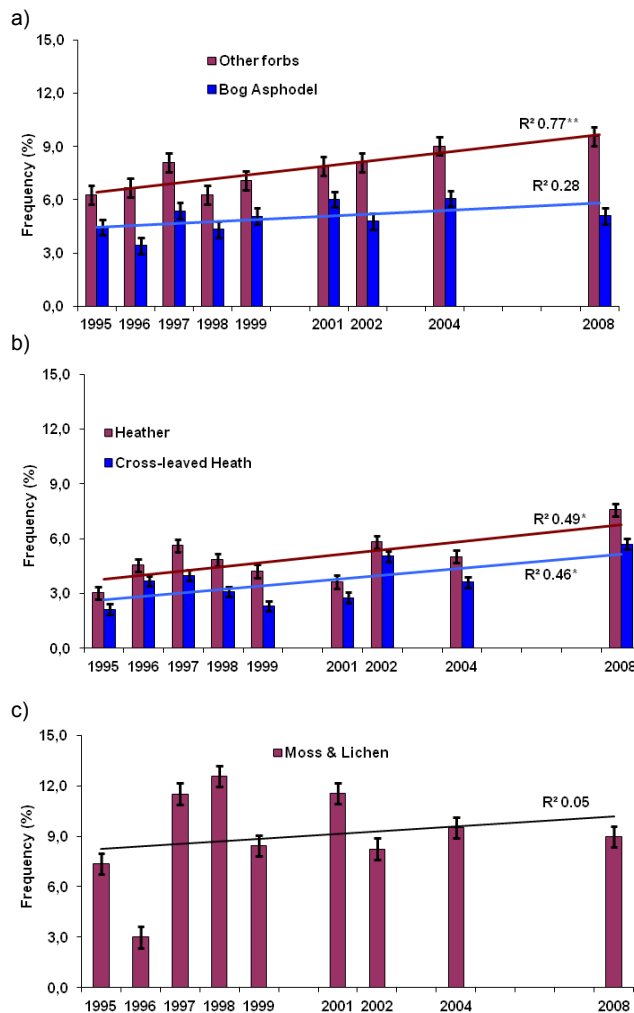


Figure 8. Variation and trends in percentage frequency, expressed as least-squares means (\pm s.e.), with fitted regression lines for a) 'Other forbs' including bog asphodel b) heather, including cross-leaved heath, and c) moss plus lichen.

Table 3. The total frequency of vegetation cover on blanket bog and wet heath habitats and the relative contribution of vegetation groups and 'positive indicator species' to the total vegetation in these habitats in 1995 and 2008

Vegetation Group	Blanket bog (n = 103) [†]		Wet heath (n = 79)	
	1995	2008	1995	2008
Total vegetation	68.3	85.9	59.5	78.4
Relative contribution (%) to total vegetation cover				
Grass	32.5	31.8	43.2	41.7
Sedge	40.6	34.9	28.3	26.2
Heather	4.9	9.7	5.1	9.2
Other forbs	9.7	11.6	10.0	12.6
Moss plus lichen	11.5	11.5	12.6	10.1
Rush	0.7	0.5	0.8	0.3
Positive indicator species [‡]	56.1	61.3	47.0	50.6

[†]The number of grid points within the habitat area.

[‡]Perrin *et al.* (2014).

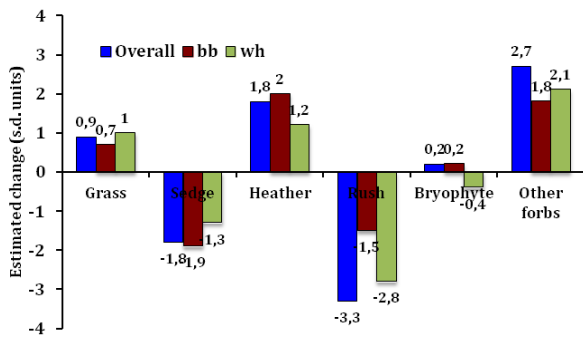


Figure 9. Estimated changes, between 1995 and 2008, in the proportion of total vegetation accounted for by each vegetation group for the whole farm and for the two dominant habitats (bb = blanket bog; wh = wet heath); changes are expressed relative to the residual s.d. calculated from the corresponding regression-on-time analysis.

Stocking rate

Mean monthly stocking rate (Figure 5) on the unimproved hill varied from 0.3 ewes (0.04 LU) per hectare in February to 1.3 ewes (0.18 LU) per hectare in August, with only minimal inter-annual variation. The annual stocking rate averaged 0.9 ewes (0.13 LU) per hectare up to and including 1998 (Hanrahan and O'Malley, 1999) and averaged 0.78 ewes (0.11 LU) per hectare between 1999 and 2010. The stocking rate for the national hill (Scottish Blackface) flock, which is associated with a hill environment similar to that of the study flock, was estimated at 0.7 ewes (0.10 LU) per hectare (see Appendix 2).

Sheep performance

Results for live-weight gain of flock replacements and purebred single-born female lambs are presented in Figure 10a and b, respectively. The trend in total live-weight gain by flock replacements while grazing unimproved hill vegetation (i.e., between weaning and housing plus that between April and early October) was not significant ($P = 0.3$). The value for animals born in 1993 was a significant ($P < 0.01$) outlier and was excluded from the trend analysis. The annual means for daily growth rate pre-weaning varied from just under 160 g in 1999 to almost 230 g in 1997 but were generally around 180 g. The value for 1997 was a significant ($P < 0.001$) outlier relative to the regression line and so was not included in the estimation of the time trend, which was negative ($P < 0.01$) and corresponded to an annual decline equivalent to 0.7% of overall mean growth rate. Annual mean values, associated with first joining, for live weight at joining, number of lambs reared per ewe joined and litter size are presented in Figure 11a, b and c, respectively. Live weight at joining exhibited a significant quadratic pattern over time ($P < 0.01$). There was no evidence of any time trend for the number of lambs reared per ewe joined or for fertility. There was, however, a negative

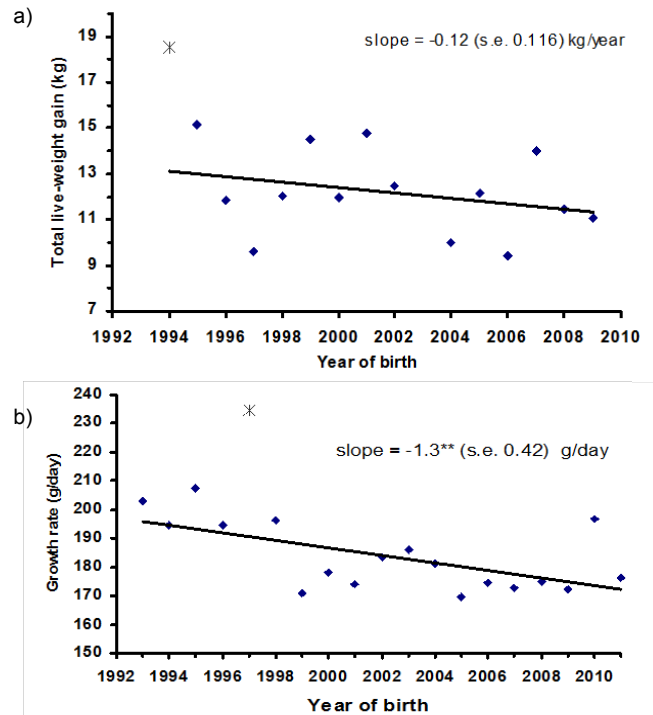


Figure 10. Growth performance of immature sheep: a) cumulative gain in live weight by flock replacements on the hill for the periods from weaning to housing for winter and from post-housing turnout until they were moved off the hill to reclaimed lowland for joining (* indicates significant [$P < 0.01$] outlier); b) growth rate (g/day) of single-born ewe lambs between birth and weaning (14 wk of age) (* indicates significant [$P < 0.001$] outlier).

linear trend in litter size ($P < 0.05$); the value for 1998 was a significant ($P < 0.025$) outlier.

A comparison of overall performance of the flock used for purebred production for the years 2004 to 2007 with that recorded for Scottish Blackface hill flocks in NFS for the same period is outlined in Table 4. The incidence of barrenness was lower and the average litter size was higher than in the NFS flocks. The number of lambs reared per ewe joined was substantially higher than in the NFS flocks (1.0 compared with 0.81), while mortality was substantially lower for both lambs and ewes.

Discussion

Quality control

The repeatability of measurements of the frequency of vegetation and 'no vegetation' were considered acceptable, considering the nature of the assessment and the difficulty of exact replacement of the net quadrat at the grid intersections. The close association of grass and sedge species in tussocks was characteristic of the vegetation, which probably accounts for the slightly better repeatability for their combined value. The low repeatability for species richness may be due to a

Table 4. Overall summary for performance of the study flock and comparison with NFS flocks

Item	Study flock	NFS flocks [†]
Fertility	0.90 (0.83 – 0.95) [‡]	0.87 [§]
Litter size	1.17 (1.05 – 1.36)	1.06 [¶]
Lambs reared per ewe joined	1.00 (0.91 – 1.10)	0.81
Ewe mortality (%)	4.5 (1.1 – 9.3)	7.5
Lamb mortality (%)	4.4 (1.8 – 9.2)	12.2

[†]Unpublished analysis of flock mean values from National Farm Survey (NFS) data on flocks classified as ‘Scottish Blackface Hill Sheep System’ for the years 2004 to 2007 (J.P. Hanrahan, personal communication). [‡]Inter-annual range of mean values.

[§]Not directly reported in NFS; the estimate is based on average incidence of barren ewes (8.2%) for NFS and assuming that the proportion of reported ewe deaths that occurred prior to lambing was 0.65 (based on data for Study flock).

[¶]Estimate derived by combining reported values for lambs weaned per ewe joined and lamb mortality with the derived estimate for fertility.

combination of factors, such as grazing and plant dieback, as the interval between repeat and original recordings could be as long as 8 wk.

Surface cover

The substantial increase in the frequency of vegetation at ground level was essentially reflected in the reduction in the incidence of bare soil. This implies that there was a substantial reduction in the risk of soil erosion due to surface overflow/run-off, which is particularly high in this landscape (Mulqueen *et al.*, 2006). There was a significant change over time in the frequency of vegetation; the ‘other forbs’ group (Tables 2 and 3) showed the highest proportional increase. The species composition of the vegetation, based on the proportion of total vegetation accounted for by each vegetation group, changed significantly over the period of the study mainly due to increases in the proportions of ‘other forbs’ and heather, and a decline in the proportion accounted for by the sedge group. There was no indication that grass, or its dominant component species (purple moor grass), increased proportionally. Hester and Sydes (1992) and Grant *et al.* (1982) suggested that the dominance of grass and sedge, in what was largely a wet heath/blanket bog complex on Scottish moorland, may have been the result of grazing rather than burning. An increase in the occurrence of purple moor grass was attributed to grazing pressure by Hulme *et al.* (2002), Milligan *et al.* (2004) and Critchley *et al.* (2008), and this increase was seen as a major threat to moorland conservation by Marrs *et al.* (2004). The foregoing authors and others (e.g., Mitchella *et al.*, 2008; Fraser *et al.*, 2009) applied a variety of methods (including herbicide use, seeding, grazing with sheep and cattle separately and together, burning and repeated cutting) to reverse the trend towards increased occurrence but with limited success. Such

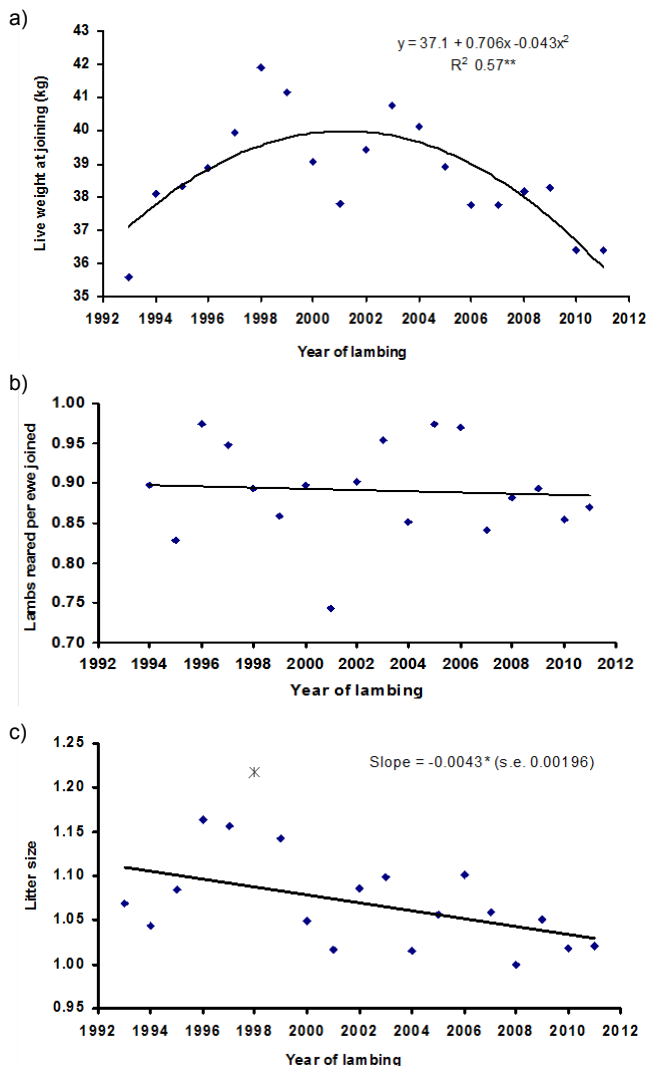


Figure 11. Performance of 2-yr-old ewes: a) live weight at joining, b) number of lambs reared per ewe joined and c) litter size (* indicates significant [$P < 0.025$] outlier).

a trend, according to Marrs *et al.* (2004) and Walker *et al.* (2007), is difficult to reverse. However, the proportion of total vegetation accounted for by grass and sedge combined was lower in 2008 than in 1995 on the Teagasc hill farm; however, the difference was not statistically significant. Newton *et al.* (2009), working on lowland heathland, concluded that grazing increased the ratio of grass to ericoid shrub cover. This trend was not evident in the present study but rather a tendency towards the opposite trend was seen (Figure 8c). Thus, on the basis of the foregoing evidence from previous studies, the present results are consistent with the view that the existing grazing regime tended to benefit the species composition of the unimproved vegetation on the study farm. It is notable that a significant increase in the proportions of heather and ‘other forbs’ in blanket bog and wet heath

occurred in conjunction with the expansion of total vegetation in these habitats (Table 3). The significantly lower value for total vegetation frequency in wet heath than in blanket bog throughout the study period suggests a more intensive use of the former for grazing, which is consistent with the conclusions on habitat preference from a study of grazing behaviour of the flock (Williams *et al.*, 2010). Intensive/excessive grazing, which may result in an increased extent of bare soil in this environment, is often associated with an increased occurrence of the unpalatable mat grass (Chadwick, 1960). Mat grass, together with heath rush, also an unpalatable species (Welch, 1966), accounted for an average of 1.4% of the cover on the farm and there was no evidence for any increase in frequency over the 14-yr period. The lack of change in the mean height of the vegetation and the increased frequency of vegetation over the study period also support the proposition that the grazing regime exerted no detrimental effect.

Stocking rate

The average annual stocking rate calculated for the years since 1999 was lower than the value (0.9 ewes per hectare) reported for this farm by Hanrahan and O'Malley (1999) for the years up to and including 1998. The lower stocking rate for the years since 1998 is consistent with the overall reduction in number of ewes on the farm following the change in system in autumn 1998 (Nolan *et al.*, 2003). There appears to be no comparable well-defined information on stocking rate of Scottish Blackface sheep on hill vegetation in Ireland. In order to place the stocking rates recorded for the unimproved hill grazing on the study farm in the context of similar farms, information was extracted from the NFS for hill farms with Scottish Blackface sheep. The available evidence yielded an estimate of 0.7 ewes per hectare for annual stocking rate on rough grazing. The consistency between the estimates suggests that the grazing pressure on unimproved land on hill farms in the hill-and-mountain landscape of western Ireland is similar to that on the farm used for the present study. Although O'Rourke *et al.* (2012) report a value of 0.28 LU per hectare for the annual stocking rate on upland areas of farms on the Iveragh Peninsula in south-west Ireland, their estimate is problematical because it is totally unclear how common grazing (accounting for '32% of the area farmed') was treated by the authors and they do not define what their 'LU' represents. Furthermore, they provide no information related to the basis for the information on 'upland grazing days' or the components of the farm livestock involved. An estimate of 0.13 LU (0.9 ewes) per hectare for the stocking rate on Scottish hill farms can be derived using data of Morgan-Davies *et al.* (2012) (Appendix 2).

These stocking rates are lower than those reported in similar habitats throughout Europe, which are mostly in areas of

lower rainfall and drier soils, such as the Welsh and English uplands (Merrell *et al.*, 2001; Adamson *et al.*, 2004), and where high stocking rates were applied occasionally to facilitate habitat recovery. Significantly, both Britton *et al.* (2000) and Critchley *et al.* (2008) recommend caution in prescribing stocking rates, regardless of livestock species, due to extreme variability in regeneration dynamics that may prevail at individual sites in unimproved uplands. Furthermore, the substantial monthly (Figure 2) and annual variation in rainfall plus increasing trends in certain aspects of driving rain (Walsh, 2011), which are highly influential on soil stability and on plant growth, when combined with the minimal inter-year variation in stocking rate (Figure 5), underline the necessity for continuous monitoring and shepherding to ensure appropriate grazing management regimes in this environment.

Sheep performance

The live-weight gain of female replacements is arguably the most important indicator variable among those examined. It reflects a 12-mo grazing period that corresponds with the initial phase of the animal's dependence on hill vegetation without any maternal contribution and, thus, should reflect any change in the capacity of the vegetation resource to provide nutritional support. The significant negative trend in lamb growth rate from birth to weaning may suggest a decline in the capacity of the hill vegetation to support lactating ewes and their lambs, but such an interpretation is confounded by the possible impact of late pregnancy nutrition on ewes' lactational performance. Furthermore, an examination of the scatter around the regression line in Figure 10b suggests a preponderance of positive deviations from the trend line in the period up to 1998 and of negative deviations thereafter. This pattern was significantly non-random ($P < 0.01$; runs test: Zar, 1999) and most probably reflects the change in system management that was introduced in autumn 1998 (see 'Materials and methods' section). Thus, it is concluded that the capacity of the hill to support animal performance did not deteriorate over time. The absence of any time trend in the number of lambs reared per ewe joined supports this contention. The significant linear decline in litter size is likely to reflect, at least in part, the clear temporal changes in live weight at joining; the evident variation in this latter variable is most probably a reflection of the grass available on the reclaimed lowland where the animals were assembled for ~1 mo prior to joining. Thus, live weight at joining reflects the live weight at removal from the hill prior to joining plus the live weight gained while being flushed on improved pastures for the month prior to joining. Consequently, weight at joining is a somewhat problematical indicator of the nutritional capacity of the hill vegetation. It is possible, however, that the negative trend recorded for some of the indicators of animal

performance may reflect the grazing and selection habits of the flock and, thus, indicate subtle negative changes in the vegetation actually used by the animals.

Williams *et al.* (2010), using almost 8,800 field observations taken on the farm on a seasonal basis over a period of 13 mo (June 2004 to July 2005), indicated a consistent selection of the same areas on the unimproved hill for grazing during this time interval; namely, those that were classified, following the method outlined by Dúchas and DAF (1999), as moderately damaged and those that contained numerous/extensive grazing lawns – the result of intensive grazing. Furthermore, Williams *et al.* (2010) reported that there was a higher preference for severely damaged areas in spring and summer than in other seasons. Significantly, these results largely reflect those based on locational data (> 80,000 locations) from GPS® collars, timed on a 10-min interval round the clock, which were worn by selected sheep (2 yr old and familiar with the unimproved hill) on the farm on a seasonal basis from spring 2004 to spring 2006 (Williams *et al.*, 2009). Thus, the evidence indicates that the sheep exhibited a preference for grazing on specific parts of the hill; the capacity of these favoured areas to support animal performance may have declined despite the overall improvement in vegetation cover. It must be borne in mind that these preferences are based on relatively short time scales and may not necessarily be indicative of preferences over a 14-yr period. The study flock, however, with its almost complete reliance on unimproved, semi-natural hill vegetation, clearly outperformed the national hill (Scottish Blackface) flock in terms of fertility, lambs per ewe joined and the levels of ewe and lamb mortality (Table 4). The apparently small difference in stocking rate (in the more intensive direction) between this flock and NFS flocks cannot account for the differences in performance, suggesting that the differences resulted from a more appropriate management system on the Teagasc farm.

It is clear that appropriate management and shepherding practices are required both to achieve and to maximise sustainable returns from hill grazing in this environment. The use of 'virtual fencing' (e.g., strategically placed, sound-emitting sensors [Tiedemann *et al.*, 1999; Anderson, 2007]) or more recent technology, such as unmanned aircraft systems

(drones), would enable active management of flocks on the hill while circumventing time/labour constraints that likely dictate the abandonment of traditional management practices.

Conclusion

Changes in vegetation over time did not differ between the two dominant habitats on the farm, namely, blanket bog and wet heath. The increase in the frequency of vegetation at ground level over time, in the absence of any specific regenerative measures, suggests that the management system facilitated a beneficial contribution from the combination of natural factors that encourage plant growth and soil stability.

The absence of significant change over time in the key indicators of live-weight gain and flock productivity (lambs reared per ewe joined for 2-yr-old ewes) is evidence that the sustenance capacity of the hill, on which these indicators were largely dependent, did not change significantly over time. It must be recognised, of course, that the evidence available is based on evaluation of association. While the performance of the study flock was clearly superior to that of the national flock, the suggestion of a downward numerical trend in some indicators, coupled with the evidence from other studies on the grazing habits of the sheep on this hill farm, support the general view that active management/shepherding is important in this landscape.

Continuous research and monitoring of these and other factors, including socio-economic and socio-ecological variables, are required in order to enable the development and maintenance of 'high nature value' systems in this fragile environment.

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Appendix 1. Complete list of individual vegetation species and other surface features recorded on Teagasc Hill Sheep Farm between 1995 and 2008 and the percentage frequency (at ground level) of those recorded in 1995 and 2008

Item	1995	2008	Item	1995	2008
Grasses	(24.58)	(30.40)	Other forbs	(6.29)	(9.58)
<i>Agrostis</i> spp.	0.02	0.14	<i>Anagallis tenella</i>	0.11	0.58
<i>Anthoxantum odoratum</i>	0.01	0.42	<i>Drosera rotundifolia</i> [§]	0.22	0.57
<i>Deschampsia flexuosa</i>	0.00	0.00	<i>D. anglica</i> [†]	0.08	0.09
<i>Elymus repens</i>	0.68	0.00	<i>D. intermedia</i> [§]	0.05	0.13
<i>Festuca</i> spp.	0.00	0.00	<i>Euphrasia nemorosa</i>	0.00	0.04
<i>Holcus lanatus</i>	0.00	0.00	<i>Galium saxatile</i>	0.42	0.24
<i>Molinia caerulea</i>	22.89	28.10	<i>Menyanthes trifoliata</i> [†]	0.03	0.04
<i>Nardus stricta</i>	0.98	1.73	<i>Myrica gale</i> [†]	0.19	0.48
<i>Poa annua</i>	0.00	0.00	<i>Nartheicum ossifragum</i> [§]	4.45	5.09
Sedges	(22.58)	(25.34)	<i>Pedicularis sylvatica</i> [§]	0.06	0.31
<i>Carex panicea</i> [†]	1.04	0.61	<i>Pinguicula grandiflora</i>	0.01	0.00
<i>C. demissa</i> [†]	0.58	0.41	<i>Pinguicula vulgaris</i>	0.01	0.05
<i>C. echinata</i> [†]	0.30	0.20	<i>Polygala serpyllifolia</i> [§]	0.17	0.51
<i>C. lasiocarpa</i> } <i>C. vesicaria</i> }	0.02	0.13	<i>Potamogeton polygonifolius</i>	0.05	0.00
<i>Eleocharis</i> spp.	1.14	0.35	<i>Potentilla erecta</i> [†]	0.34	1.01
<i>Eriophorum</i> spp.	2.73	1.89	<i>Pteridium aquilinum</i>	0.07	0.20
<i>Rhynchospora alba</i> [§]	5.67	7.23	<i>Rumex acetosella</i>	0.00	0.11
<i>Schoenus nigricans</i> [§]	10.05	12.99	<i>Cirsium</i> spp.		
<i>Tricophorum caespitosum</i> [§]	1.04	1.54	<i>Dactylorhiza maculata</i>		
Heathers	(3.03)	(7.58)	<i>Lemna</i> spp.		
<i>Calluna vulgaris</i> [§]	0.42	1.18	<i>Linum catharticum</i>		
<i>Erica tetralix</i> [§]	2.14	5.70	<i>Luzula campestris</i>		
<i>E. cinerea</i>	0.47	1.18	<i>Pedicularis palustris</i>		
<i>E. ciliaris</i>	0.00	0.00	<i>Pinguicula lusitanica</i>	0.04	0.13
Rushes	(0.60)	(0.33)	<i>Plantago lanceolata</i> /spp		
<i>Juncus bulbosus</i>	0.28	0.11	<i>Plantago major</i>		
<i>J. effusus</i>	0.00	0.02	<i>Polygala vulgaris</i>		
<i>J. squarrosus</i>	0.31	0.10	<i>Rhododendron</i> spp.		
<i>J. articulatus</i> } <i>J. conglomeratus</i> }	0.00	0.11	<i>Succisa pratensis</i>		
Mosses and lichen [§]	(7.38)	(8.97)	<i>Viola</i> spp.		
<i>Campylopus atrovirens</i> } <i>Hypnum jutlandicum</i> } <i>Rhytidiadelphus squarrosus</i> } <i>Selaginella selaginoides</i> } <i>Sphagnum</i> spp. } <i>Cladonia</i> spp.	7.29	8.72	Surface features	(35.52)	(17.80)
	0.09	0.25	Bare soil (+ algae/litter)	31.34	14.54
			Rock/boulder/stone	4.14	2.75
			Water: surface	0.04	0.01
			Faeces: sheep/other	0.00	0.50

Note: Vegetation species within braces were not differentiated in one or both years and were recorded as 'other spp.' within the relevant group.
[§]Indicates a 'positive indicator species' (Perrin *et al.*, 2014) common to blanket bog and wet heath. [†]Indicates 'indicator species' for blanket bog.
[†]Indicates 'indicator species' for wet heath.

Appendix 2. Stocking rate on hill farms

The authors could find no published data for the stocking rate on unimproved hill grazing associated with Scottish Blackface sheep systems in Ireland apart from that of O'Rourke *et al.* (2012), which is considered to be seriously problematical. An estimate was derived using standard farm data collected as part of the National Farm Survey (NFS) (www.teagasc.ie). Records for farms classified as 'hill farms' and with a sheep enterprise based on Scottish Blackface ewes were extracted for the years 2001 to 2010, inclusive. The variables included were 'Utilised agricultural area' (UAA), area (of land) owned, area of grassland, area of rough grazing (defined in NFS as 'grazed unreclaimable bogland, grazed mountain of known area and grazed lowland partially covered by scrub, bushes or rock'), total number of grazing livestock units (LU), LU represented by sheep, and the number of ewes let to the ram (for further information, see www.teagasc.ie). Records that included a dairy enterprise were eliminated as were those for which the area of land owned did not match (± 5 ha) UAA to eliminate complications due to use of commonage or rent/lease. Finally, records were eliminated if UAA was < 9 ha.

The remaining records were edited to form 2 mutually exclusive groups. The first group consisted of those records for which the area of rough grazing was ≤ 2 ha. The data from this group were used to estimate a stocking rate for grassland. The second group involved records relating to farms with a mixture of grassland and rough grazing and which satisfied the following conditions:

- the area of rough grazing was > 2 ha.
- the number of ewes let to the ram was ≥ 80 .
- the proportion of total LUs accounted for by sheep was > 0.7 .

These data were used to estimate a stocking rate for the area of rough grazing.

In order to minimise distortions due to extreme values, the median was used as the measure of central tendency. Because the number of records (years) per farm varied, the median for each farm was used to estimate the median value for each group. The data in the first group yielded an estimate of 1.38 LU per hectare for the median stocking rate on grassland (based on 57 records representing 20 individual farms). This estimate was then applied to the grassland area for each individual record in the second group to calculate the number of LU that could be accommodated on the grassland area and, thus, the number of LU that relied on the rough grazing area for sustenance and hence the stocking rate on this area. The median value for this variable (based on 30 records representing nine individual farms) was 0.096 LU per hectare. This stocking rate is equivalent to 0.7 ewes per hectare because the equivalence used in NFS is 1 adult hill ewe = 0.14 LU.

Data from a recent study of farms in Scottish hill farming areas (Morgan-Davies *et al.*, 2012) can be used to calculate an approximate upper limit for stocking rate on the hill portion of these farms. This was done by converting flock size and herd size to LUs after inflating each component to allow for replacements and young calves/cattle using replacement rates of 15% and 23% for cows and ewes, respectively, and assuming 0.92 calves reared/cow and that calves averaged 280 d of age at sale. No information was available to allow adjustment for such factors as 'away wintering' of replacements; the contribution of in-bye land (5.6% of farm size) to animal sustenance was ignored. The estimate of average stocking rate per hectare of hill was 0.13 LU (using NFS equivalents to combine the various categories of stock).