



HAL
open science

Long-term impacts of extensification of grassland management on biodiversity and productivity in upland areas. A review

Carol Marriott, Michael Fothergill, Bernard Jeangros, Michele Scotton,
Frédérique Louault

► To cite this version:

Carol Marriott, Michael Fothergill, Bernard Jeangros, Michele Scotton, Frédérique Louault. Long-term impacts of extensification of grassland management on biodiversity and productivity in upland areas. A review. *Agronomie*, 2004, 24 (8), pp.447-462. 10.1051/agro:2004041 . hal-00886019

HAL Id: hal-00886019

<https://hal.science/hal-00886019>

Submitted on 11 May 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Long-term impacts of extensification of grassland management on biodiversity and productivity in upland areas. A review

Carol Ann MARRIOTT^{a*}, Michael FOTHERGILL^b, Bernard JEANGROS^c, Michele SCOTTON^d, Frédérique LOUAULT^e

^a The Macaulay Institute, Craigiebuckler, Aberdeen AB15 8QH, UK

^b The Institute of Grassland and Environmental Research, Plas Gogerddan, Aberystwyth, Ceredigion SY23 3EB, UK

^c Station fédérale de recherches en production végétale de Changins, 1260 Nyon, Switzerland

^d Università degli Studi di Padova, Agripolis, Viale dell'Università 16, Legnaro 35020, Italy

^e INRA-Unité Agronomie, Site de Crouël, 234 avenue du Brézat, 63039 Clermont-Ferrand Cedex, France

(Received 29 April 2003; accepted 18 May 2004)

Abstract – Modern rural policies that incorporate agricultural and environmental aims within the broader framework of sustainable rural development are being formulated to address the problem of declines in grassland biodiversity and the destruction of sensitive landscapes and habitats in Europe. Extensification is the process of reducing fertiliser inputs, management intensity and stocking rates, and is central to these sustainable rural policies. However, research in the Less Favoured Areas of Europe has been fragmented and highly variable reflecting the different uses and requirements of our upland areas. Information is needed to determine the nature and timescale of changes in such systems, and whether extensive management is sustainable in the long-term. This paper presents results from a range of grassland extensification experiments across Europe, mainly within the European Union, over the past 30 years that quantify the impacts on soil, plant and animal components of the system. All have the common theme of changing the focus of land management from solely the agricultural product to include a broader range of ecological and environmental objectives. Beneficial changes in biodiversity resulted from more extensive management treatments, but at the cost of reductions in total animal output, and in some cases a reduction in individual animal performance. However, it is clear that it is a long-term process to achieve many of these changes in biodiversity, and this must be recognised by policy makers. We recommend that future extensification studies adopt an approach that will allow their results to be applied throughout Europe.

biodiversity / cutting / fertiliser reduction / grazing / plant species composition

1. INTRODUCTION

Over the last five decades, agricultural intensification in some areas and abandonment of land in others have dramatically affected land use and farm structures and led to the impoverishment of biodiversity on agricultural land. The intensification of production was encouraged by post Second World War agricultural policy within European Union (EU) countries, and this led directly to a substantial decline in the conservation value of large areas of grassland and a growing concern over the destruction of sensitive landscapes and habitats and a degradation of the environment [34]. At the other end of the spectrum, economic pressures had forced the abandonment of traditional farming practices, particularly in mountain areas, leading to the reduction of 'open' semi-natural grassland habitats through shrub encroachment and natural succession into forests or woodlands [21, 22, 34, 47, 90, 103]. Great numbers of species of plants and insects depend on such semi-natural grasslands, e.g. around 70% of the vascular plants under threat in Sweden depend on an 'open' and varied agricultural landscape [22].

It is clear that agriculture plays a major role in shaping the landscape and sustaining rural livelihoods, and its products must be viewed in a more holistic way [34, 56]. Modern EU policies are now being formulated in an effort to move towards more sustainable forms of production that consider environmental quality and ecological soundness, plant and animal productivity as well as socio-economic viability. Environmental policy measures that require integration of environmental objectives within agricultural practices include the Habitats Directive (92/43/EEC), the Birds Directive (79/409/EEC), the Nitrate Directive (91/676/EEC) and the Water Framework Directive (2000/60/EEC). Current Common Agricultural Policy (CAP) following the Agenda 2000 agreement now delivers a framework encouraging more consideration of the environment, aimed at optimizing the benefits of farming activities, especially low intensity agricultural systems, and minimising the negative impacts on the environment. In most Member States, Agri-Environment measures (Council Regulation No. EEC 2078/92) have been implemented. These include support for farming with environmental improvements (by reducing or phasing out the use of fertiliser and pesticides and grazing at

* Corresponding author: c.marriott@macaulay.ac.uk

low stock densities) and maintenance of existing low-intensity systems (existing practices, with a maximum ceiling stock density of 1.4 LU ha⁻¹ or less, depending on the specific measure). Similar measures exist in non-EU countries, e.g. in Switzerland, higher income support payments are made to farmers in return for allocating at least 7% of their land for 'ecological compensation', for example as extensive pasture or a strip planted with traditional wild flowers. These types of measures support the viability of agriculture throughout Europe and thus contribute to the maintenance of viable rural communities.

Generally farmers remain the most logical managers of the land and modern agricultural policies encourage farmers to regard themselves as guardians of the rural environment [21]. CAP support, notably through the Less Favoured Areas (LFAs) measures, plays a pre-eminent role supporting farmers to maintain threatened agricultural systems, where agricultural activity could otherwise be abandoned for economic reasons, i.e. in areas where farming practices are affected by natural handicaps which restrict the choice and structure of agricultural systems and result in higher production costs. Outside the EU, similar policies are also implemented, e.g. in Norway. In the hill and upland areas of Europe, much of the grassland has limitations on the potential yield due to geological, altitude or climatic characteristics. Inputs of fertiliser and stocking rates tend to be low, and yields are relatively low compared with lowland systems. Many of these areas have high conservation value and are prized for their environmental, biodiversity, archaeological and cultural heritage status. Such areas are covered by the LFA measures and are eminently suitable for the adoption of extensive animal production systems. In the United Kingdom, LFAs account for almost half the agricultural land and 60% of sheep and beef cattle numbers [65]. Within this area approximately 33% of the land area is improved grassland and accounts for 85% of the production [26, 43, 65].

Support for extensive production methods and extensification, particularly in the stock farming sector are key elements of the EU Biodiversity Plan for Agriculture [22]. Extensive systems are seen to be integral to the general aims of sustainable agriculture. [56]. Extensification of management implies a reduction of inputs into a system, and this may involve developing a new set of management skills. It can involve one or several of the following: reductions in some or all fertiliser inputs; reductions in stocking rate; flexibility in grazing management through changes in the timing or season of grazing, animal species/sex/age (e.g. more appropriate local sheep or cattle breeds, ewes and lambs or wethers), combining grazing and cutting regimes and reductions in animal feeding; reductions in cutting frequency; and reductions in fixed costs including labour. A range of different systems may develop under extensification, e.g. ranching or even a resurgence of traditional shepherding, low input organic systems and pluriactive (hobby) farming. Abandonment of farming practices could be regarded as the most extreme form of extensification of land use. However, the consequences of such action have already adversely affected biodiversity and the viability of rural communities in many areas of Europe, and it is well recognised that there must be support for at least some utilisation of the land [22].

In the development of Agri-Environment policies it was assumed that extensification would benefit the environment, improve diversity of flora and fauna and be more sustainable

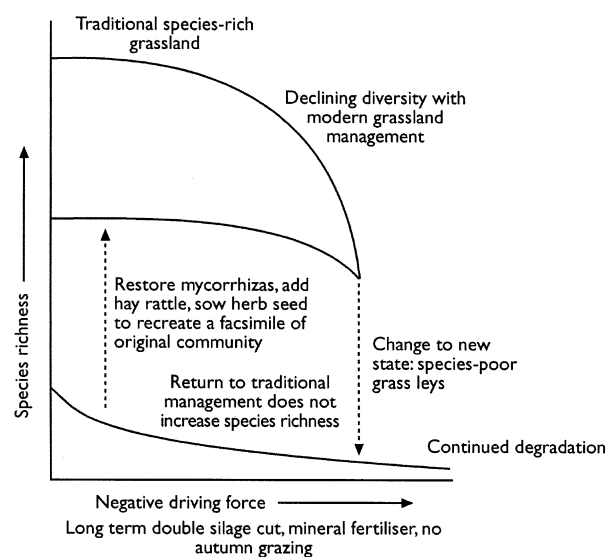


Figure 1. Model of vegetation change in grassland in response to different driving forces, based on Firbank's catastrophe model [35].

in terms of the impact on soil fertility, nutrient flow and animal output. Generally the highest biodiversity is found in predominantly rural areas, mountain areas and in areas where appropriate extensive or traditional management practices are found. There is a high correlation between EU biodiversity resources and LFAs [21]. However, experimental studies to support the assertion that extensification leads to biodiversity gains had been limited to a few vegetation communities in mainly lowland areas, and while there were some grazing experiments, the focus was largely on reductions of fertiliser inputs in mown grasslands [e.g. 3, 17, 85, 88]. In hill and upland grasslands, there was little knowledge of what were appropriate extensification management practices [21, 22, 37], what changes would occur, how long it would take before any changes became evident, and whether the desired changes could be sustained in the long-term. It is not necessarily true that a return to past management will result in a return to past vegetation composition, albeit over a long time scale, as can be seen in the Firbank et al. catastrophe model of vegetation change [35] (Fig. 1). The relationship between factors such as initial vegetation structure and composition, soil fertility, previous management history and seed availability with the extent and time-scale of changes needs to be explored in experimental studies before such models can be refined to accurately predict the changes following extensification in different plant communities. Information is needed particularly on the impact of reductions in stock densities on species diversity and functional diversity within grazed plant communities. Filling such gaps of knowledge has been identified as one of the essential steps to successfully achieve the objectives of the European Community Strategy on Biodiversity within the Agriculture sector [22].

The objective of this paper is to bring together current knowledge on the effect of more extensive management of hill and upland grasslands on biodiversity, productivity and the long-term sustainability of the grassland system. It is based on

the results from experiments on a range of grassland communities across Europe over the past 30 years in which a variety of more extensive management treatments have been implemented. The specific objectives of the different experiments varied, e.g. some aimed primarily at devising management regimes to conserve/restore species rich grassland, and grazers were simply a management tool to achieve this objective, whereas others were concerned primarily with quantifying the impact of extensive management on plant and animal productivity. However there was a general focus on management to achieve a broad range of ecological and environmental objectives and not only agricultural production. The lower levels of utilisation and changed patterns of grazing/cutting under extensive management are ultimately expected to result in increases in microbial, plant and animal diversity of grassland communities. The results from the experiments reviewed here quantify the extent and timescale of changes in plant species composition, nutrient cycling, animal output and broader aspects of biodiversity.

2. DETAILS OF EXTENSIFICATION EXPERIMENTS

There are extensification experiments on mesotrophic (M), acid (A) and calcicolous (C) grasslands in the hill and upland areas of a number of European countries, and some of these have continued for more than 20 years (Tab. I). Of the 22 studies reviewed in this paper, the majority (14) were on mesotrophic grasslands, where the dominant species at the start of the experiments commonly included *Lolium perenne*, *Trifolium repens*, *Agrostis capillaris* and *Dactylis glomerata*; one plant community (Study M7) was a more complex mosaic of species-rich wooded meadow and pastures with scattered stands of *Quercus robur*, *Betula pendula* and *Coryllus avellana*. There were four studies on upland acid grassland, where dominant species were initially *A. capillaris* and *Festuca ovina* (Studies A1, A2) and *Nardus stricta* (Studies A3, A4). Four studies were on calcicolous grasslands where the dominant species initially included *Bromus erectus* and/or *Arrhenatherum elatius* (Studies C1, C2, C4) and *Festuca rubra*, *Deschampsia caespitosa* and *Phleum pratense* (Study C3).

2.1. Management treatments in extensification experiments

The management treatments are summarised in Table I. Across the experiments, the level of inputs (fertilisers, manure, seed addition) and level of utilisation (grazing, cutting with or without mulching, burning and abandonment, plus mechanical or herbicidal control of woody plants in Study M7) were manipulated either separately or in combination.

2.1.1. Levels of inputs

The levels of inputs were manipulated in most of the studies on mesotrophic grasslands, but on only one calcicolous and none of the acid grasslands. Amounts of fertiliser applied varied greatly between experiments. Frequently there were only two levels of fertiliser treatment, with and without fertiliser (N, P and K), and the fertiliser application rate was typical of current rates in productive systems (e.g. Studies M4, M8–11). Where different fertiliser rates were applied, generally the levels of N

only were varied (Studies M5, M12). In some studies, other components of fertiliser input were also varied (Studies M1, M13, M14, C2), including different N levels combined with +/- P and K (Study C2), stepwise removal of lime, P and K (Study M13) and different rates of cattle manure (Study M1).

A seed mixture of a number of species from either local or commercial sources was sown in three studies on mesotrophic grasslands (Studies M6, M10, M14).

2.1.2. Levels of utilisation

2.1.2.1. Cutting

The cutting treatments, on mesotrophic and calcicolous grasslands only, involved different timings (date of first cut, e.g. Studies M10, M11) and frequencies (number of cuts per year or at intervals greater than one year, e.g. Studies M7, C4) separately or in combination (Studies M4, M8, M9, M14, C1, C2). For example, in Study C4 there was a comparison between traditional management (annual cutting in summer) with cutting biennially or every five years, or cutting annually in autumn. In the long-term Studies M8 and M9, the focus was on cessation of fertiliser application accompanied by a reduction in the number of cuts per year and a change in their timing. All three experiments allow comparisons to be made between conventional practice and more extensive management. The timing of hay cuts was made to achieve agricultural and/or conservation objectives. The cut herbage was removed in most of the studies, but Studies M4 and C1 included treatments that left the cut herbage in situ as a mulch. At one of these sites the frequency of mulching was varied between twice annually to once every second year (Study C1).

2.1.2.2. Grazing

Grazing treatments on all grassland types involved manipulation of stock density (Studies M2, M3, M11–M14, A1–A4, C3) and animal species (Studies M11, A2, A4, C3), but seasonal grazing patterns were manipulated only on mesotrophic grasslands (Studies M2, M11, M14). The grazing treatments were either set stocked throughout the year or for part of a year (Studies M3, M7, A2, C1), rotational systems (Studies M2, M13, C3) or continuous stocking systems for all or part of the year with adjustments in animal numbers determined by sward heights (Studies M11–M14, A1, A3, A4). The importance of managing grassland swards to prescribed heights and structures has long been recognized in both agriculture and conservation [49, 107]. The studies that adjusted stock numbers based on sward height had the greatest control over vegetation height and structure. Furthermore, objectives based on achieving certain targets of sward height and structure are much more likely to be applicable across a range of sites rather than prescriptions based on stocking rate. The sward height of 4 cm used in Studies M11 and M13 is within the range of heights where net herbage production is at a maximum in continuously-stocked, fertilised, ryegrass-dominated swards, but the 8cm sward height used in Study M11 is above this range [11]. As well as uniform height management throughout the year, some swards in Study M11 were also maintained at different heights during summer and autumn, thus creating a range of sward structures that may favour different species. To create a greater range of differences

Table I. Details of extensification experiments in grasslands in the uplands and Less Favoured Areas of Europe. Grassland types are distinguished by the prefix M for mesotrophic, A for acid and C for calcicolous. An open-ended timespan indicates the study is ongoing. Rep indicates the number of replications of the treatments. The presence of different inputs and utilisation treatments are indicated by ✓. For the cut treatments, m = presence of a mulching treatment. For the grazed and cut+grazed treatments, letters are used to indicate the species of grazer: s = sheep, c = cattle, g = goats, sc = sheep+cattle. Where available, reference details ✓ for the different measurements recorded.

Grassland Study	Location and Altitude	Timespan	Rep	Inputs		Utilisation					Measurements											
				Fertiliser	Manure	Seed	Cut	Grazed	Cut+ Grazed	Burn	None	Species	Structure	Biomass/ yield	Quality Traits	Seedbank	Nutrient cycling	Animal performance	Utilisation/ selection	Biodiversity		
Mesotrophic																						
M1	Austria	1993-1996	?		✓		✓							[15]		[15]	[15]					
M2	France 890 m	1989-	2							s				[60]		[62]		[64]		[42]		
M3	France 890 m	1988-1992 1994-1999	1	✓				s											[12]	[63]		
M4	Germany 580 m	1987-	?	✓			✓ m							[13]			[13]					
M5	Germany	1987-1990	?	✓			✓							[25]	[25]	[59]	[59]					
M6	Norway 30 m	1996-1997	3			✓	✓		s					[61]					[61]			
M7	Sweden 140 m	1997-	2				✓	c		✓	✓			[106]								
M8	Switzerland 566 m	1990 -	3	✓			✓					✓		[57]		[57]	[57]			[57]		
M9	Switzerland 500 m	1991-	2	✓			✓					✓		[52, 53]		[52, 53]	[52, 53]			[52, 53]		
M10	UK 350 m	1990-	3	✓	✓	✓				sc				[98-100]		[98-100]		[98-100]	[101]		[101]	
M11	UK 220 m, 245 m, 367 m	1990-	2	✓			✓	s,c				✓	[75]	[69,71,74]	[67,70,77]	✓	[75]	✓	[9]	[73]	[48, 72, 86, 87]	
M12	UK 175 m	1990-1994	3	✓						s				[97]	[97]	[97]	[97]			[97]		
M13	UK 380 m	1991-	3	✓			✓	s		s		✓	[38,40,41, 81,82]	[38,40,41, 81,82]	[27]		✓		[39]		[6,8]	
M14	UK 70 m	1992-1996	3	✓		✓				s				[54]								
Acid																						
A1	UK 245 m, 428 m	1989-1995	2							s		✓	[51]	[29, 51]							[29]	
A2	UK 220-480 m	2002-	6							s,sc		✓	[1]	[1]							[1]	
A3	UK 360-520 m	1988-1993	2							c				[23]	[23]					[23]	[23]	
A4	UK 450-500 m	1991-1995	2							s,sc				[50]	[28, 30]					[50]	[50]	[28, 30]
Calcicolous																						
C1	Germany 560 m, 760 m	1975-2000	1				✓ m	s		✓	✓		[83]								[55]	
C2	Italy 1000 m	1995-2000	3	✓			✓					✓	[32]	[32]	[32]					[95]		
C3	Italy 1050 m	1991-1996	1							c,g,s				[96]	[96]						[96]	
C4	Switzerland 720 m	1997-2001	3				✓			✓	✓		[92]		[92]					[58]		

in sward structure, the seasonal height treatments in this study were discontinued 10 years into the experiment and replaced with a lower intensity continuous stocked sheep grazing treatment and a treatment grazed by cattle in late summer [76].

One grazing experiment focused on withdrawal of nutrients rather than on varying sward height (Study M13), and maintained swards at a single sward height of 4 cm. Since there were two grazed treatments that were common to Studies M11 and M13, results could be directly compared across four sites. Neither of these two experiments involved a complete sheep production system, e.g. weaned lambs were not fattened, there was no herbage conservation or return of manure from in-wintered ewes and no winter grazing. However two sheep systems experiments (Studies M3, M12) addressed some of these issues and examined the impact of reduced stock densities and N application rate. Generally grazing treatments compared only one species of grazer, but cattle, sheep and goat grazing were compared in calcicolous grassland (Study C3). Two studies in acid grassland compared sheep grazing alone and in combination with cattle (Studies A2, A4).

2.1.2.3. Integration of cutting and grazing management

Some studies on mesotrophic grasslands had treatments that integrated cutting with grazing (Studies M2, M6, M10, M12–M14). For example, hay cutting and rotational grazing treatments were combined to provide different levels of herbage utilisation in Study M2. In Study M10, hay cutting and grazing with cattle or sheep (or both) at set stocking rates for different periods was combined with fertiliser and seed addition to facilitate restoration of ‘traditional’ species composition of meadows. Study M14 had a similar objective to restore an intensive agricultural sward to wildflower grassland and also included fertiliser, seed addition, cutting and grazing treatment combinations. In this study, the grazing treatments were continuous sheep grazing from April to November or in autumn/winter to achieve a sward height of 6 cm.

2.1.2.4. Abandonment and control of woody species

In some areas pastoral farming is threatened and may no longer be an economically feasible method of land management. Abandoned treatments were included in several studies in mesotrophic, acid and calcicolous grasslands (M7, M8, M11, M13, A1, A2, C1, C2, C4). Different management options were studied on mesotrophic and calcicolous grassland types. Studies M7 and C1 examined if cutting or some other cheaper methods of utilisation could be used instead of traditional grazing management to prevent shrub encroachment. Treatments such as different cutting frequencies, burning (also used in Study C4), mulching and control of woody plants by herbicide or mechanical removal were compared with abandonment.

3. EFFECTS OF EXTENSIFICATION ON PLANT SPECIES COMPOSITION

3.1. Reduction in fertiliser inputs

Cessation or reduction of fertiliser inputs had no effect on species richness in many of the studies on mesotrophic swards

Table II. Temporal changes in the number of plant species in fertilised and unfertilised meadows managed with previous and reduced cutting frequency since 1991. Previous cuts = 4 cuts per year, reduced cuts = 3 cuts per year. In unfertilised treatment there were only 2 cuts per year in each treatment after 1998. Adapted from Jean-gros and Bertola [53].

Years	Unfertilised		Fertilised	
	Reduced	Previous	Reduced	Previous
	Number of plant species			
1991–1994	32	32	28	29
1995–1997	40	39	29	32
1998–2000	40	41	30	32

[25], even after 10 years or longer [13, 41, 75, 100]. However, the number of species increased in two studies, within six years of the cessation of fertiliser in Study M9 (Tab. II), and after 10 years in Study M13 [41]. In both cases there was evidence of low soil P.

In most studies, there were changes in individual species in response to changes in fertiliser inputs. Within four years there was a lower proportion of grasses in unfertilised treatments than in fertilised grassland in Study M9 [53]. In Study M10, the absence of farmyard manure resulted in decreased cover of *Poa trivialis* and *Rumex acetosa*, and an increase in five other species, while the absence of fertiliser gave a similar response, but *A. capillaris* declined [100]. In Study M11, the proportion of *L. perenne* remained high in the absence of any fertiliser input, and there was more *T. repens* than in the fertilised swards [67]. N inputs from N₂ fixation were likely to be higher in the unfertilised swards, and this, in part, offset the absence of fertiliser inputs. In Study M13, there was more *T. repens* in a treatment receiving Ca only than in one receiving Ca, P, K and N, but when Ca was combined with P and K, the amount of *T. repens* was even higher [38]. In calcicolous mountain meadows with low levels of soil P (Study C2), P and K fertilisation was also required for higher legume abundance [95].

The results show that the response to fertiliser reductions depends to a great extent on initial site fertility, and rapid changes in species composition are unlikely to occur in many mesotrophic grasslands, where nutrient levels will remain high in the absence of fertiliser inputs.

3.2. Abandonment

A general result seen across the range of grassland types is the rapid change in plant species composition when grazing or cutting ceases [41, 51, 57, 75, 83, 92]. The resulting vegetation is dominated by tall herbs and coarse grasses, and woody plants can develop in the long-term [106]. The species composition that results following abandonment is very much site-specific, depending on the initial species composition and its previous management history, as well as the surrounding vegetation.

The species composition of mesotrophic grassland changed dramatically within two years of abandoning swards in Study M11 (Fig. 2), where the sown species were replaced by different species at three sites [75]. In Study M13, there was an immediate reduction in species number as the sown species declined

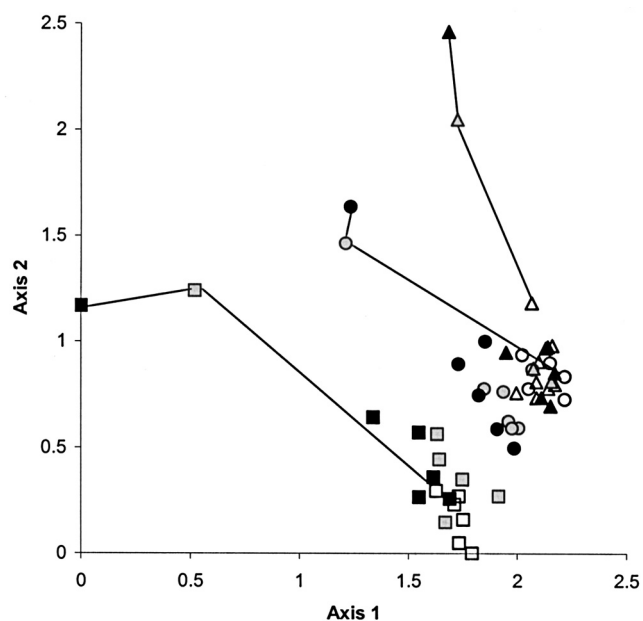


Figure 2. Detrended correspondence analysis showing rapid changes in overall species composition of ungrazed swards compared with grazed swards at three sites in Study M11. Each site is identified by a different symbol (squares, circles and triangles). Shading of symbols shows the time from the start of the experiment (open symbols indicate the start, grey indicates two years after the start and black indicates four years after the start). The lines join the points for the different years in the ungrazed treatment. From Marriott et al. [75].

and a number of forbs were lost, and there was little or no recruitment of new species over a ten-year period [41]. In Study M7, the transition from species-rich semi-natural mesotrophic grassland to species-poor deciduous forest vegetation took less than 30 years, and was already evident after 13 years [106]. In acid grassland (Study A1), abandonment resulted in increased cover of grazing intolerant species, e.g. *Deschampsia flexuosa* and *Molinia caerulea*, and dwarf ericoid shrubs, where present [51]. In calcicolous grassland, species richness declined following abandonment (Studies C1 and C4, [83, 92]). There was local dominance of the coarse grass *Brachypodium pinnatum*, and trees and shrubs established at two sites in varying amount [83].

Abandonment of sites, therefore, often results in lower species richness, with a few dominant species typical of late successional communities taking over from the early successional communities where higher species richness can be found.

3.3. Lower intensity of cutting and grazing

In contrast to abandonment, the changes in species composition are much slower when grazing (Figs. 2, 3) or cutting frequency is reduced. In many grassland communities (e.g. Studies M11, A1) there were no major changes in species dominance, or the loss or colonisation of many species over a five to ten year period of more extensive grazing management [51, 75]. There were also no important differences in the proportion of

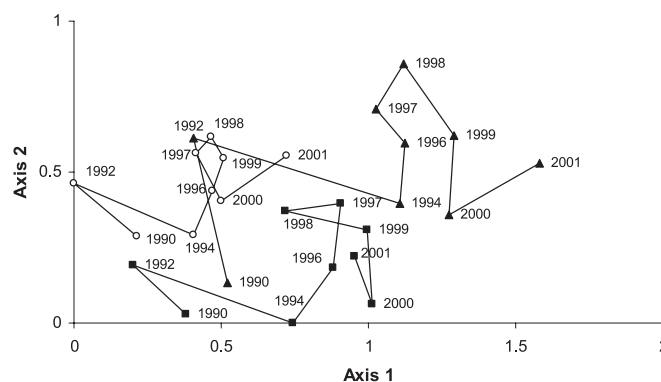


Figure 3. Detrended correspondence analysis showing changes over time in overall species composition of grazed swards under different intensities of management one site in Study M11. Treatments are 4F, sward height of 4 cm + fertiliser addition, ○; 4U, sward height of 4 cm, unfertilised, ■; 8U, sward height of 8cm, unfertilised, ▲. Movement along Axis 1 was associated with significant increases in *A. capillaris*, *Poa trivialis*, *H. lanatus*, *Juncus* and *Carex* species. The movement on Axis 2 was much smaller and was due to minor changes in the other species present. From Marriott et al., unpublished.

grasses or plant diversity between different cutting frequencies in Study M9 [53]. Changes in species composition were more obvious in the two longer-term studies on calcareous grassland and one study on mesotrophic grassland, and differences in the intensity of management required to maintain the desired species composition were evident. Thirteen to 15 years into an experiment with different management in species-poor calcareous grassland (Study C4), the number of species was highest in treatments with a cut at least every second year [92]. Comparing the other treatments in this study, there were similar numbers of species in swards that were burned annually, cut every fifth year or abandoned. In Study C1, mowing and mulching twice a year over a 25 year period gave the most similar species composition to traditional sheep grazing [83]. Mulching every second year and particularly controlled burning resulted in the loss of species typical of these grasslands. However, in Study M7, it was concluded after 28 years of different management that there were no suitable long-term alternatives to annual mowing or grazing to maintain species composition of species-rich wooded meadows in southern Sweden [106]. The loss of species and change in species composition under mowing every third year was relatively slow, slower than when land was abandoned, while burning and mechanical removal led to low species richness and differences in species composition to the target community.

Experiments on both mesotrophic and calcicolous grasslands included attempts to understand the mechanisms involved in determining the changes in species composition, and thus help to predict the impact of extensification beyond the experimental framework (e.g. Studies M2, M7, M10, M11, C1, C3, C4). One approach used in Study M11 is examination of the response of individual species to different management [73]. The amount of biomass removed, the impact of defoliation on plant growth, responses to animal trampling and nutrient inputs (urine and faeces), as well as the ability to colonise bare areas or gaps in the sward are key factors in determining the outcome

of competition and survival in the sward [14, 18, 71]. However in multi-species swards it is impossible to consider all individual species using such an approach. Mechanisms can also be detected by examining community changes in species diversity, composition and abundance of different species groups, an approach used in Studies M7, M10, C1 and C4 [55, 92, 98, 106]. A further approach is to correlate species strategies [46] and functional traits [78] with their response to different management. In meadows in Study M10, the absence of fertiliser favoured ruderal and stress-tolerant ruderal species, and species whose seed required chilling before germination [98]. A decline in utilisation level of rotationally grazed grassland in Study M2 resulted in taller and less digestible vegetation with dense leaves, large seeds and a late flowering period [64]. The changes were mediated by selection of species able to overcome higher competition for light in the taller less-utilised vegetation.

The changes in levels or seasonal patterns of utilisation affect plant morphology, allowing an increase in flower production and, thus, a greater potential for species to produce seed. However, in grazed plant communities where perennial species dominate and there is a closed canopy, regeneration is mainly by vegetative reproduction and there is little opportunity for seedling regeneration. For example, in sheep grazed swards (Study M11), where tall swards (8 cm) were maintained in summer to encourage seed production and then sward heights were reduced (to 4 cm) in autumn to create a more favourable sward environment for seed regeneration, there was little difference in species composition compared to maintaining tall swards throughout the year [75]. In plant communities that have a more open sward structure and a greater number of species that reproduce by seed, more extensive management creates a greater opportunity for seedling regeneration. Studies in hay meadows and semi-natural grasslands have shown that improvements in plant species diversity can be achieved by a combination of grazing and cutting treatments (e.g. Studies M6, M7, M10). While any increase in plant species diversity is an important aim of less-intensive management, a long-term aim is the restoration of the functional ecology of specific plant communities, e.g. traditionally managed hay meadows such as *Geranium sylvaticum*-*Anthoxanthum odoratum* grassland. Many of the desired species for target plant communities are not present in the seedbank [79, 100], so the addition of new species has to come from outside the site. This can be either through normal seed dispersal, a slow process because the dispersal of many species is limited by lack of nearby target communities [4], or more quickly by seed addition. Seed sowing in Studies M6 and M10 has achieved increases in the number of species and has had some success in increasing the numbers of endangered or indicator species of hay meadows [61, 98]. Seed sowing of a mixture of local and commercial species in hay meadows in the absence of fertiliser and farm yard manure produced a plant community similar to the target *Geranium sylvaticum*-*Anthoxanthum odoratum* grassland [101]. In both studies there was greater success under traditional management, i.e. including both cutting and grazing. A combination of cutting and grazing also benefited the survival of sown species in a former species-poor fertilised, sheep-grazed pasture (Study M14) [54]. Grazing animals have potential use as agents of seed dispersal at the landscape scale to introduce new species

into plant communities, either via their dung (endozoochory) after grazing plant communities of different species composition [e.g. 66, 80] or on their coats or fleeces [36]. For example, the fleeces of transhumant sheep in an extensive grazing system held propagules of up to 85 vascular plant species, nearly 50% of the total calcareous grassland species [36]. Transhumant sheep farming appears to be essential to the restoration of such grasslands threatened by abandonment, and traditional shepherding may play a key role in species transport between isolated habitats.

At lower intensities of utilisation whether under grazing or cutting there is the potential for increases in less desirable species, e.g. persistent 'weeds' such as thistles, rushes and nettles increased in Study M13 [82]. The increasing spread of these species created species/height heterogeneity in the sward since these species tend to be avoided by sheep for much of the growing season. Management strategies need to be carefully formulated to maintain some control over their spread.

The choice of species of grazer is another important component in determining species composition, since they have different feeding style attributes and impacts on the vegetation [16]. Cattle are less selective than sheep and more willing to graze taller vegetation. These differences have been exploited in previous studies in acid grassland to control tussock grasses *N. stricta* and *Molinia caerulea* [44, 45]. Cattle grazing reduced *N. stricta*, increased more productive grasses and potentially increased species diversity. At an inter-tussock sward height of 4.5 cm, the diet of cattle contained more dead material, *N. stricta*, sedges and rushes, but less forbs and fine-leaved grasses than the diet of sheep [44]. However, at the lower rate of utilisation (6–7 cm sward height) necessary to maintain the performance of lactating cows and calves the reduction in *N. stricta* is more gradual (Study A3) [23]. In Study A4, greater species diversity and increased utilisation of *N. stricta* was achieved by mixed grazing of sheep and cattle [50].

Although changes in species composition at a field scale may take a long time to occur, changes in sward structure to reductions in utilisation are rapid and some can be seen within a growing season. There are large changes in the distribution of plant parts in the canopy as vegetation increases in height and flowers develop. In addition there is more dead material and greater heterogeneity in heights across grazed swards (Fig. 4) due to the greater opportunity for animals to select their diet. Changes in the spatial distribution patterns of species can also develop and this will impact on subsequent grazing behaviour [68]. The changes in the spatial structure of the swards in more extensive systems play a key role in providing the opportunities for biodiversity to increase.

4. EFFECTS OF EXTENSIFICATION ON BIOMASS PRODUCTION AND NUTRIENT CYCLING

A reduction in utilisation and fertiliser application reduces biomass production, and the nutritive value of herbage declines [13, 53, 95], due to morphological changes in the composition of the biomass (in terms of leaf, stem and flower components). An increase in the amount of dead material in the standing biomass occurs when utilisation is reduced, as shown in Study

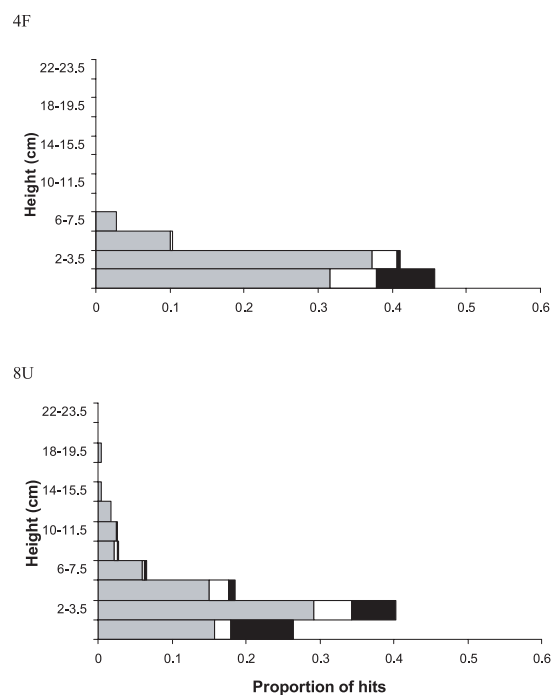


Figure 4. Sward vertical structure in intensively managed (4F, sward height 4 cm + fertiliser addition) and more extensively managed (8U, sward height 8 cm and unfertilised) swards at one site in Study M11. Inclined point quadrat measurements give the proportion of hits with different categories of plant material (green ■, dead □ and litter ■) at 1.5 cm intervals above ground level. Adapted from Marriott et al. [74].

M11 (Tab. III). The quantity and composition of litter returning to the soil is altered and thus will impact on nutrient cycling processes. However, changes in soil fertility following changes in utilisation patterns or the cessation of fertiliser inputs are likely to be slow, particularly in grazed systems where animal excretal returns are equivalent to 60–90% of ingested nutrients. After 12 years less intensive management of unfertilised swards in Study M2, the quantity of dead plant material returning to the soil was increased but decomposition was slower due to the higher C:N ratio of the litter and there was no effect on soil N supplying capacity [42, 102]. In grazed swards in Study M11, pH declined over time in all treatments, but there was no evidence of significant divergence in soil nutrients in the 10 years following the reduction in utilisation or cessation of fertiliser applications [67, C.A. Marriott pers. comm.]. However, levels of soil phosphate in Study M13 fell to low levels (less than 5 ppm) following cessation of fertiliser inputs over a ten-year period even under grazing [M. Fothergill pers. comm.]. It was estimated that soil phosphate in previously fertilised meadows in Study M10 would take a total of 20 years to fall to a level similar to that in meadows that were always traditionally managed [101]. After 22 years of abandonment of calcicolous meadows in Study C4 there was still no effect on soil P, although availability of N was slightly higher than in meadows that were mown annually [58].

Table III. Percentage of dead material in the standing biomass during the fourth year of imposing different grazing treatments on a sown upland sward in Study M11. Treatments are 4F, maintained at 4 cm + fertiliser application, i.e. productive control; 4U, maintained at 4 cm, no fertiliser applied; 8U, maintained at 8 cm no fertiliser applied. Standard errors of difference for comparing treatments, harvests and treatments*harvests are 1.62, 1.54 and 3.2 respectively [74].

Treatment	May	July	September	November	Treatment mean
	% dead in biomass				
4F	7.6	20.0	14.1	21.4	15.8
4U	6.8	13.2	9.0	23.3	13.1
8U	40.8	38.9	42.2	44.1	41.5
Harvest mean	18.4	24.0	21.7	29.6	

5. EFFECTS OF EXTENSIFICATION ON ANIMAL OUTPUT

In many long-term extensification studies, the main interest was usually the effect of extensification on pasture yield and botanical composition. In these studies, the grazing animal was often used as a means to effect changes in diversity with little or no animal production data being recorded. Only 6 of the 22 studies detailed in this paper (Studies M3, M11–M13, A3, A4) collected data that allowed determination of the degree to which animal performance was affected by more extensive management of mesotrophic and acid grassland. The majority of these studied sheep and lamb performance, with only two studies of cattle performance (Studies A3, A4). Such data are expensive and time consuming to acquire but provide information on a vital component of sustainable systems. Since stocking rates are the main determinant of total output, lower stock densities in more extensively managed systems will generally result in lower output on an area basis. However there may be a range of impacts on individual animal performance.

Cow and calf performance was measured over a 6-year period in acid grassland in Study A3 [23]. Earlier studies with non-lactating cows had shown that animal performance could be maintained on swards maintained at a short inter-tussock height (4–5 cm) designed to effect a reduction in *N. stricta* [2]. However the high level of utilisation of *N. stricta* was incompatible with high animal performance over the whole summer grazing period for cattle with a higher nutrient demand, i.e. lactating cows and their calves [23]. At a lower level of *N. stricta* utilisation, an inter-tussock height of 6–7 cm, the liveweight gain of cows was high until the end of June, and similar to that on high-quality ryegrass pasture, but then it declined rapidly. Calf liveweight gain also declined, but to a lesser extent. Over the whole summer grazing period the daily liveweight gain of cows averaged 0.3 kg d⁻¹, and the liveweight gain of calves was 1.44 times greater than that on the short treatment. The taller sward treatment maintained animal performance but there was a more gradual reduction in *N. stricta* than in the shorter sward treatment. If the aim is to achieve a rapid reduction in *N. stricta* by maintaining a short sward height, then shorter grazing periods of 5–6 weeks only in early summer could give acceptable animal performance. Study A4 provides some evidence that

mixed grazing of sheep and cattle could increase sheep and lamb performance [50].

There is some evidence that individual sheep or lamb performance can be sustained or increased in more extensively managed mesotrophic grassland. In farm-scale studies (Study M3), the impact of managing sheep flocks at different stock densities across the range of vegetation types within a farm was investigated, by increasing the area of land used for the enterprise within the whole farm [104]. This increase in allocation of land provided a means to limit the expansion of shrub cover into grassland areas and an opportunity to manage the land with lower inputs. The performance of ewes was not reduced under extensification, and lamb carcass weight increased by 6%. Indeed the economic balance was in favour of the extensive system; the additional Gross Margin surplus, 75% of which was a result of input reduction (N fertiliser and concentrates), more than covered the structural changes due to extensification. Further studies at this site examined strategies for grazing at low stock densities to either optimise the gross margin or maintain the vegetation to control shrub expansion [63]. Through modifications to the seasonal distribution of lambing, the liveweight of lambs marketed, the role of grazing areas near the farm and more-remote grazing areas as main or buffer grazing areas within the system, shrub expansion could be halved without adverse effect on the annual number of lambs per ewe, income per ewe from lamb sales or the Gross Margin per ewe.

In the more uniform vegetation of sown swards, nitrogen fertiliser was removed or reduced without compromising individual ewe or lamb performance over a three-year period in a sheep systems experiment in Study M12 [97]. This effect was attributed to the higher amounts of white clover in the unfertilised swards. Furthermore, at relatively low stocking rates in the absence of fertiliser there was a surplus of feed supply from the pasture in the summer that could be used outwith the sheep enterprise and reduce differences in Gross Margins associated with the different stocking rate and N input treatments. In the longer-term Study M11, individual lamb performance was greater in unfertilised swards than in fertilised swards, and highest when the unfertilised swards were maintained at a taller sward height [9]. At the lower stocking densities in the taller (8 cm) sward treatment there was a greater opportunity for animals to select a diet of better quality than the sward average, while in the shorter (4 cm) unfertilised treatment there was higher amount of white clover in the herbage. The fertilised treatment produced 623 kg ha⁻¹ year⁻¹ of lamb, and the 4 cm and 8 cm unfertilised treatment produced 77% and 55% of this amount, respectively. Over a ten-year period there was no decline in lamb output per ha, sheep liveweight gain or ewe condition score in the more extensive management treatments.

However, in another study in mesotrophic grassland where fertiliser inputs were reduced, the results showed that more extensive management may also lead to a decline in sheep performance in the long-term (Study M13) [39]. The complete withdrawal of fertiliser inputs had a dramatic effect, reducing total lamb production, ewe stocking rate and length of grazing season but with little initial impact on the individual lamb liveweight gain. Over ten years, total lamb production (kg ha⁻¹) fell to 87%, 58% and 42% of the fertilised control (receiving Ca+N+P+K) for treatments receiving Ca+P+K, Ca only and no fertiliser (Nil) respectively. During the latter part of the study

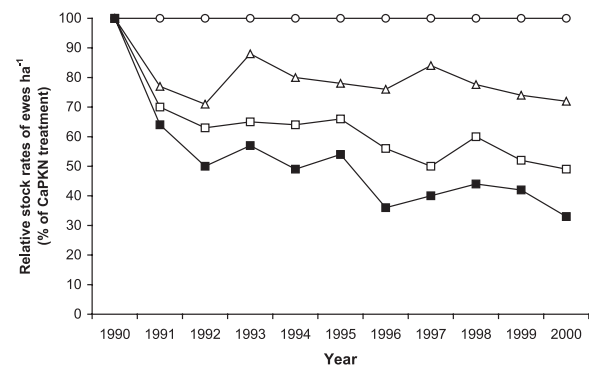


Figure 5. Stock carrying capacity (ewes ha⁻¹) relative to that of the CaPKN (○) treatment in each year for CaPK (△), Ca (□) and Nil input (■) treatments over the total grazing period 1991–2000 in Study M13. Adapted from Fothergill et al. [39] and Fothergill et al., unpublished.

(1997–2000) the individual performance of the lambs on the Nil treatment was significantly lower than those on the fertilised control. The reduction in lamb output of the unfertilised treatment relative to the fertilised treatment was much greater than that seen over the same period of time in Study M11. Why such a large difference should occur is not entirely clear, but differences in site fertility and species composition are likely to be involved. Soil pH was lower in Study M13, the sown sward was older and had differences in species abundance (less *L. perenne* and more *A. capillaris*) compared to the swards in Study M11.

The marked reduction in ewe stocking rate caused by the lowering of fertiliser inputs is shown in Figure 5. Ewe stocking rate in the Nil treatment declined to 63% of that in the CaPKN treatment over the first six years, and thereafter it stabilised. As the experiment progressed, the ewes failed to attain adequate condition scores during the end of the summer (Fig. 6). The effect seemed to increase with the increasing duration of the experiment even though the swards were managed in the same way each year. Such trends indicate that grazing low input swards to the 4cm sward surface height guidelines may cause problems for the long-term health and fecundity of the flock.

6. EFFECTS OF EXTENSIFICATION ON BROADER ASPECTS OF BIODIVERSITY

The extensification experiments reviewed in this paper concentrated primarily on vegetation responses and animal output, and they included limited measurements of other aspects of biodiversity. However some interesting insights into the potential responses of different organisms (e.g. soil microflora and fauna, arthropods, small mammals and birds) to the introduction of more extensive management regimes can be gained from study of the literature. This is particularly the case where survey approaches have been used to study the diversity and ecology associated with vegetation under different managements.

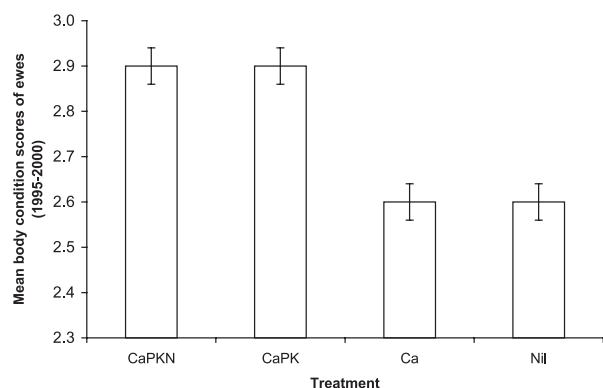


Figure 6. Mean body condition scores of ewes in CaPKN, CaPK, Ca and Nil management treatments of Study M13 at the end of the autumn, averaged over 1995–2000. Vertical bars show standard errors. Adapted from Fothergill et al. [39] and Fothergill et al., unpublished.

6.1. Soil microflora

In mesotrophic grassland (Study M13), significant reductions in microbial biomass and activity could be seen in both sheep-grazed and ungrazed swards after 2–3 years of ceasing fertiliser and lime application [6]. In the unfertilised, grazed treatment fungal substrate-induced respiration increased by 65% compared with the limed and fertilised grazed control [8]. In Study M10 there was evidence of a higher fungal biomass after removal of N fertilisation, and an increase in the proportion of fungi relative to bacteria [101]. The fungal:bacterial biomass ratio is regarded as an important indicator of improvements in the efficiency of nutrient cycling and decomposition in these systems. A doubling of the ratio has been suggested as a useful indicator of conversion from an intensive system previously reliant on N fertiliser to a low-input or organic system relying mainly on soil biological processes of nutrient cycling for plant nutrition [7]. On this basis, with a continued linear rate of change in the unfertilised plots, it was estimated that it would take 36 years for complete conversion to a low-input system.

6.2. Invertebrates

None of the extensification experiments reviewed here quantified changes in soil faunal populations. However, below-ground soil invertebrate trophic relationships were studied (using stable isotopes $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) in Study M11, five years after introducing extensive management treatments [72, 86, 87]. The removal of sheep grazing had altered plant species composition and these changes were propagated through the soil food web to detritivores, herbivores and omnivores/carnivores. The greater ^{15}N enrichment of omnivores/carnivores (beetles and spiders) than primary producers in the grazed compared to the ungrazed treatments suggested that the below-ground food chain was longer in the grazed plots. In contrast, the cessation of fertiliser had no measured effects on soil invertebrates or their trophic relationships. Grassland management has a major impact on soil fauna via alteration to the quality and quantity of organic matter input and the soil physical and

chemical environment. Comparisons of sites with different management histories have shown that intensive management of grassland (high inputs of inorganic fertilisers and high stock densities) favours opportunistic, bacterial feeding fauna and has a negative impact on soil faunal diversity, but not necessarily faunal density [5]. In contrast, systems with lower inputs develop a more heterogeneous habitat and resource supply, and contain a more diverse fauna, characterised by more persistent species and in general fungal feeders. Although little information exists from abandoned grasslands there is some evidence of a reduced density and diversity of fauna in these soils.

The importance of vegetation structure to arthropods and the maintenance of their diversity is well established [84]. Thus any changes in management that effect changes in vegetation structure will affect arthropod diversity and ecology. These include changes in the timing, duration, cessation and intensity of grazing, timing of cutting, burning and fertiliser application. Some studies of upland grassland have examined the response of different species groups to management. In acid grassland in Study A4, sheep and cattle grazing to an average between tussock height of 6–7 cm favoured a larger number of coleopteran species associated with indigenous grassland and heathland and prevented the expansion of *N. stricta* over time [28]. In the same experiment most arachnid species were found in the ungrazed and less intensively grazed treatments with a taller average vegetation height [30]. It was concluded that a combination of varied grazing management was most favourable for both arachnid and coleopteran fauna since no single grazing treatment supported the total number of species represented across all grazing treatments [29]. In Swiss meadows, there was greater variation in species composition of Heteroptera (true bugs) in extensively managed meadows (unfertilised and cut once or twice a year after July) than in intensively managed meadows which received regular slurry applications and were cut two to three times per year from the end of May [31]. The extensive meadows had some rare and specialised species, whereas the intensive community was dominated by more widespread and less specialist species.

Biodiversity is a major criterion used in judging the effectiveness of measures to enhance ecological quality of rural areas, but methods based on selected groups of indicator organisms are time-consuming and knowledge-intensive. A simpler method of assessment of biodiversity has been developed in Swiss meadows under different management intensities: extensive (not fertilised, cut once or twice a year), low (lightly fertilised with manure and cut twice a year) or intensive (regularly fertilised with slurry and cut two to three times a year) [94]. Canopy parameters (including canopy density, plant biomass distribution and plant height) explained at least 50% of the variation in species richness in three indicator groups (angiosperms, spiders and true bugs). A combination of parameters describing the canopy, surrounding land use and an inventory of the angiosperms present provided an acceptable estimate of biodiversity on a large-scale.

6.3. Birds

A number of studies, mainly on arable and lowland farmland, have highlighted the association between intensification of agriculture and the decline in populations of bird species [e.g.

10, 19, 91, 105]. Increases in the intensity of management of grasslands have had an adverse impact on their suitability as breeding and feeding habitats for birds. In particular the reductions in arthropod abundance in intensive systems are thought to play a key role in the decline of bird populations, but there is little empirical data to test this hypothesis [10, 105]. Within upland areas there is little information available to determine the effect on upland bird populations of changes in grazing intensity, despite significant knowledge of factors affecting the dynamics of vegetation structure and composition of grazing systems. To begin to address these issues, the Royal Society for the Protection of Birds has correlated the abundance of a suite of breeding birds with detailed moorland vegetation assessments in relation to grazing pressure (vegetation on a scale from deep heather to short grass) at the scale of 2 km² study plots in the Southern Uplands of Scotland and Pennines of northern England [89]. This work has provided some evidence of the impacts of grazing related changes in vegetation composition and structure on some bird species, but also shown that other moorland birds have quite catholic distributions at this large scale. In Study A2, an experimental approach is being used in a collaborative project between five research organisations to investigate the relationship between grazing intensity and upland birds in semi-natural acid grassland [1, P. Dennis pers. comm.]. This project will identify how variations in the structural heterogeneity of upland grassland habitats (dominated by *A. capillaris*–*F. ovina*), derived from experimental manipulation of mammalian herbivore species and grazing intensity, affects the distribution and abundance of arthropod populations and associated bird foraging behaviour. Since the areas of study are restricted to treatment plots in experimental studies, it is necessary to choose appropriate bird species. Meadow pipits (*Anthus pratensis* L.) are an ideal model species, because they occur at relatively high density, have small foraging ranges and feed on arthropods in the ground vegetation. The experimental data will be used in conjunction with complementary field surveys at existing sites, where vegetation state, grazing history and bird populations have been assessed, to consider the landscape scale and establish whether habitat structure or the supply of insect food most affects bird populations.

7. RECOMMENDATIONS FOR FUTURE EXPERIMENTS AND GENERALISATION OF RESULTS

7.1. Experimental design

Four main recommendations emerge from this review of extensification studies. Firstly, clear objectives for the study must be set out before the start of experimentation. These are likely to include the increase in abundance of certain plant, insect or bird species, a target vegetation structure or plant community. A target could also be set to ascertain when animal output starts to fall relative to more intensive management options. Secondly, the duration of the experiments should be appropriate to the particular objectives of the study. While some changes, such as vegetation vertical structure, may be rapid, others such as species composition and soil nutrient levels may take in excess of 10 years to occur. Properly designed, replicated trials

with control treatments need to be continued to observe threshold effects, when changes appear long after treatments have started simply because some slowly changing factor has passed a threshold. The timing of the appearance of such thresholds is unknown, but crucial. For example, impact of controlled burning in preventing shrub encroachment and its effect on grass species composition after 25 years could not have been predicted from a 10 period of observation [83, 93]. Thirdly, results can only be interpreted correctly if measurements are made at the appropriate time intervals. Some measurements can be made less frequently than an annual basis without compromising our understanding of treatment responses, whereas others (e.g. vegetation height, herbage growth, nutrient content and animal liveweight) may need to be measured several times within a growing season. Fourthly, long-term experiments require long-term planning and support. Clear protocols are necessary when embarking on long-term studies, as the personnel working on the experiment may change over time. Furthermore, secure long-term funding for the experiments can be problematic. Few sites have been maintained for more than 20 years. In southern Sweden, where extensification experiments were started at around ten sites in 1973, only one remains with the same seven management treatments. In this case, as research funding failed, the local conservation authorities took over the experiment as it was considered an invaluable demonstration site (P. Milberg, pers. comm.). An appropriate experimental design that allows an experiment to be modified to include new treatments can help in securing new funding, e.g. the use of split plot designs, as in Study M10 [100], where the original starter treatments can be maintained alongside new treatments.

The great variety of experiments in Table I highlights the diverse vegetation, geographical location and farming structure of the LFAs in the Europe. However it is clear that the inclusion of a suitable reference treatment representing more intensive practice is essential. Only in this way can the effect of extensive management be compared accurately over time. Ideally the experiments should be replicated across a number of sites. We have seen many site-specific effects and it is clear that such replication would allow the extraction of general principles from the data. However this is costly particularly when grazing treatments are included. In some cases, particularly in the larger farm-scale studies, there is no replication of treatments within the site, thus confounding site and treatment effects. This should be avoided wherever possible. Nevertheless, such farm-scale experiments have advantages over simply comparing different treatments on commercial farms, because it is possible to exercise control of the allocation of animals from the same flock or herd and similar land resources on the same or different farms to the different treatments. Perhaps the most important recommendation that can be made here is to encourage dialogue at the planning stages between experimenters to examine the possibility of including some common treatments and measurement protocols. For example, there are three similar treatments in Studies M11 and M13 (productive control, one extensive grazing treatment and the abandoned treatment) and the methodology used to determine stock density is standard. Both research groups benefit from an extended ability to distinguish between site specific and general treatment responses. Multi-site experiments either within one research group,

between groups in the same country or in different countries also help in this respect.

7.2. Further studies

In upland areas of the UK there is some evidence that the range of habitats and the biodiversity goals that are desired cannot be achieved by changes in sheep grazing intensity alone and grazing by cattle is required [108]. Traditional breeds of animals form part of the cultural heritage of these areas, and their production characteristics may be suited to these environments. There is a need for research to establish the impact of rare and traditional breeds on vegetation and their role in contributing to wider biodiversity. There is also a requirement to identify if particular breeds are suited to systems which use species-rich pastures, whether hay making can be integrated into farming systems with traditional breeds and methods for ensiling species-rich swards at a more advanced physiological stage than is usually used for silage. Since some breeds of cattle are apparently more suited to out-wintering than others, research is needed to investigate the effects on vegetation of year-round grazing rather than summer-only grazing.

Little is known of the effect of species-rich feed, either as pasture or conserved forage, on the health and fecundity of the grazing animal. In terms of the animal product, the impact of extensification on meat, milk or cheese has not been studied in a broad range of grassland types, but there is evidence that certain plant species have an effect on the chemical composition and flavour of meat, milk and cheese [20, 24]. Possibilities may exist for enhancing the value of the agricultural product by encouraging plant species selected for their potential health benefits as well as those included for their high nutritional properties. Additionally it is possible that the introduction of medicinal herbage could act in a prophylactic manner by improving an animal's immune status, thereby contributing to better general resistance to systemic infection, fly-strike and parasitism. It also introduces the potential for self-medication when required.

7.3. Methods and monitoring for generalisation

The costs associated with maintaining extensification experiments are high and wherever possible means of achieving 'added value' from the sites should be sought. The measurement programmes should be developed so that the general principles behind any changes are understood rather than simply measuring the changes to extend the relevance of the work beyond the experimental site. For example combining state (species composition, sward structure and plant biomass) and rate (leaf appearance, leaf extension and defoliation frequency) measurements can be used to understand why some species increase and others decline, and the use of plant traits or functional types/groups may be useful in interpreting changes where many species are present. One approach that could be used to investigate the relationship between initial site fertility and the rate of change in species composition following extensification could involve the use of Ellenburg numbers, a classification system that assumes that the distribution of different plant species in the field is a reasonable guide to their fundamental requirements and tolerances in relation to moisture, soil

reaction, nutrient status and light [33]. In relation to biodiversity, there is some evidence that a reliable estimate of broader diversity in hay meadows can be made if appropriate vegetation structural parameters and species composition are measured [94]. In addition experimental results can be combined with survey data where available and modelling can be applied to increase understanding and the applicability of the findings. Where possible an integrated approach across a range of disciplines to exploit the resource is recommended. For example, collaboration between plant and animal ecologists and entomologists would be highly desirable in studies of the impact of extensive management on sward structural heterogeneity. Furthermore, an input from soil microbiologists is needed to provide information on organic matter decomposition and nutrient cycling in order to determine the biological sustainability of more extensive systems.

8. CONCLUSIONS

There were many objectives in the experiments reviewed in this paper and they differed between the different grassland types. The most diverse objectives were in mesotrophic grasslands, where the impact of different types of extensification of management on species composition and production and quality of herbage and animals were quantified. In acid grassland, cattle grazing played an important role in the control of tussock species and could potentially increase species diversity. In calcicolous grasslands, different management regimes were ranked in their ability to conserve/ increase species richness.

The results from the different experiments reviewed in this paper show that changes in vegetation in hill and upland areas occur only slowly when there are reductions in utilisation under grazing or cutting management. The changes are, to some extent, site specific but some generalities can be made about the outcomes of more extensive management. In many cases 'target' plant communities cannot be created by simply reducing fertiliser and the level of utilisation because seed sources of desirable species are not present. Interventionist measures such as sowing seeds or introducing animals that have grazed plant communities containing these species may be required under these circumstances. Irrespective of changes in species composition the rapid changes in vegetation structure will be beneficial to other aspects of biodiversity. Animal output on an area basis is less in extensive systems, but individual animal performance may be increased compared to more intensively managed systems because animals may be able to select higher quality herbage from the heterogeneous sward. However the sustainability of animal output depends on a number of factors including the species composition of the sward, site fertility and level of utilisation and care must be exercised in relation to animal health issues. In light of the slow changes following introduction of extensive management, appropriate indicators that take this into account must be used when assessing the success of environmental policies, e.g. a change in vegetation height and structure or insect numbers may be a more appropriate indicator of success in the short-term than an increase in the number of plant species. Nevertheless the results from the studies reviewed here show that increases in biodiversity in upland semi-natural grasslands can be achieved in the long-term by

adopting more extensive management. Such information is central to the design of future management strategies to maintain and restore the ecological diversity of grasslands in the upland areas of Europe.

Acknowledgements: We thank Peter Dennis, Martin Elsaesser, Mary Losvik, Per Milberg, Roger Smith and Peter Ryser for providing additional information about their studies.

REFERENCES

- [1] Anon, Bird study at Glen Finglas, Broadleaf, Mag. Woodland Trust 59 (2002) 8.
- [2] Armstrong R.H., Grant S.A., Common T.G., Beattie M.M., Controlled grazing studies on *Nardus* grassland: effects of between tussock sward height and species of grazer on diet selection and intake, *Grass Forage Sci.* 52 (1997) 219–231.
- [3] Bakker J.P., Nature management by grazing and cutting, Kluwer Academic Publishers, Dordrecht, 1989.
- [4] Bakker J.P., Berendse F., Constraints in the restoration of ecological diversity in grassland and heathland communities, *TREE* 14 (1999) 63–68.
- [5] Bardgett R.D., Cook R., Functional aspects of soil animal diversity in agricultural grasslands, *Appl. Soil Ecol.* 10 (1998) 263–276.
- [6] Bardgett R.D., Leemans D.K., The short-term effects of cessation of fertilizer applications, liming, and grazing on microbial biomass and activity in a reseeded upland grassland soil, *Biol. Fert. Soils* 19 (1995) 148–154.
- [7] Bardgett R.D., McAlister E., The measurement of soil fungal: bacterial biomass ratios as an indicator of ecosystem self-regulation in temperate meadow grasslands, *Biol. Fert. Soils* 29 (1999) 282–290.
- [8] Bardgett R.D., Hobbs P.J., Frostegard A., Changes in soil fungal: bacterial biomass ratios following reductions in the intensity of management of an upland grassland, *Biol. Fert. Soils* 22 (1996) 261–264.
- [9] Barthram G.T., Marriott C.A., Common T.G., Bolton G.R., The long-term effects on upland sheep production in the UK of a change to extensive management, *Grass Forage Sci.* 57 (2002) 124–136.
- [10] Benton T.G., Bryant D.M., Cole L., Crick H.Q.P., Linking agricultural practice to insect and bird populations: a historical study over three decades, *J. Appl. Ecol.* 39 (2002) 673–687.
- [11] Bircham J.S., Hodgson J., The influence of sward condition on rates of herbage growth and senescence in mixed swards under continuous stocking management, *Grass Forage Sci.* 38 (1983) 323–331.
- [12] Brelurut A., Louault F., Benoit M., Tournadre H., de Montard F.X., Thériez M., Liénard G., Dedieu B., Laignel G., Adaptation de conduites d'élevage ovin allaitant à une diminution du chargement. Exemple en moyenne montagne, *Ann. Zootech.* 47 (1998) 483–490.
- [13] Briemle G., Elsaesser M., Grassland extensification, the first ten years of the 'Aulendorf experiment', in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 770–771.
- [14] Briske D.D., Strategies of plant survival in grazed systems: a functional interpretation, in: Hodgson J., Illius A.W. (Eds.), *The Ecology and Management of Grazing Systems*, CAB International, Wallingford, UK, 1996, pp. 37–68.
- [15] Buchgraber K., Effects of grassland extensification on species composition and on yield of high quality, Bericht über die 2. Pflanzensoziologische Tagung, Pflanzenengesellschaften im Alpenraum und ihre Bedeutung für die Bewirtschaftung, Bundesanstalt für Alpenländische Landwirtschaft Gumpenstein, Irnding, Austria, 1997, pp. 63–71.
- [16] Bullock D.J., Armstrong H.M., Grazing for environmental benefits, in: Rook A.J., Penning P.D. (Eds.), *Grazing Management*, BGS Occasional Symposium No. 34, British Grassland Society, Reading, UK, 2000, pp. 191–200.
- [17] Bullock J.M., Clear Hill B., Dale M.P., Silvertown J., An experimental study of the effects of sheep grazing on vegetation change in a species-poor grassland and the role of seed recruitment into gaps, *J. Appl. Ecol.* 31 (1994) 493–507.
- [18] Bullock J.M., Marriott C.A., Plant responses to grazing and opportunities for manipulation, in: Rook A.J., Penning P.D. (Eds.), *Grazing Management*, BGS Occasional Symposium No. 34, British Grassland Society, Reading, UK, 2000, pp. 17–26.
- [19] Chamberlain D.E., Fuller R.J., Bunce R.G.H., Duckworth J.C., Shrub M., Changes in the abundance of farmland birds in relation to the timing of agricultural intensification in England and Wales, *J. Appl. Ecol.* 37 (2000) 771–788.
- [20] Collomb M., Butikofer U., Sieber R., Jeangros B., Bosset J.O., Correlation between fatty acids in cows' milk fat produced in the lowlands, mountains and highlands of Switzerland and botanical composition of the fodder, *Int. Dairy J.* 12 (2002) 661–666.
- [21] Commission of the European Communities, Rural Developments, CAP2000 Working Group Document, Directorate-General VI Agriculture, European Commission, Brussels, 1997. Available at the EU website: http://europa.eu.int/comm/agriculture/publi/pac2000/rd/rd_en.pdf.
- [22] Commission of the European Communities, Biodiversity Action Plan for Agriculture, Volume III, COM(2001), Communication from the Commission to the Council and the European Parliament, European Commission, Brussels, 27 March 2001. Available at the European Community Clearing House Mechanism (EC CHM) website: http://biodiversity-chm.eea.eu.int/convention/cbd_ec/strategy/agri/ENV-2000-681-EN-02-02-AGRI.pdf.
- [23] Common T.G., Wright I.A., Grant S.A., The effects of grazing by cattle on animal performance and floristic composition in *Nardus*-dominated grassland, *Grass Forage Sci.* 53 (1998) 260–269.
- [24] Coulon J.B., Priolo A., Influence of forage feeding on the composition and organoleptic properties of meat and dairy products, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 513–524.
- [25] Dahmen P., Kuehbauch W., Sward changes as a consequence of converting its utilization from a conventional system under cutting and grazing to extensive cutting at the location Rengen Eifel Hills Germany, *Wirtschaftseig. Futter* 36 (1990) 175–185.
- [26] Davies D.A., Improved upland pastures: the Bronydd Mawr story, IGER Technical Advisory Report No. 2, 1998.
- [27] Davies D.A., Morgan C.T., Fothergill M., Effect of nutrient input on the sustainability of sward composition and animal productivity, in: Fisher G., Frankow-Lindberg B. (Eds.), *Lowland grasslands of Europe: utilisation and development*, REU Technical Series No. 64, 2002, pp. 93–96.
- [28] Dennis P., Young M.R., Howard C.L., Gordon I.J., The response of epigeal beetles (Col.: Carabidae, Staphylinidae) to varied grazing regimes on upland *Nardus stricta* grasslands, *J. Appl. Ecol.* 34 (1997) 433–443.

- [29] Dennis P., Young M.R., Gordon I.J., Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands, *Ecol. Entomol.* 23 (1998) 253–264.
- [30] Dennis P., Young M.R., Bentley C., The effects of varied grazing management on epigeal spiders, harvestmen and pseudoscorpions of *Nardus stricta* grassland in upland Scotland, *Agric. Ecosyst. Environ.* 86 (2001) 39–57.
- [31] Di Giulio M., Edwards P.J., Meister E., Enhancing insect diversity in agricultural grasslands: the role of management and landscape structure, *J. Appl. Ecol.* 38 (2001) 310–319.
- [32] D'Ottavio P., Scotton M., Ziliotto U., Effects of different management on vegetation cover in mountain meadows (Asiago, NE Italy), in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 780–781.
- [33] Ellenberg H., Weber H.E., Düll R., Wirth V., Werner W., Paulißen D., *Zeigwerte von Pflanzen in Mitteleuropa*, 2nd ed., *Scr. Geobot.* 18 (1992) 1–258.
- [34] European Environment Agency, Environment in the European Union at the turn of the century, Environmental Assessment Report No. 2, EAA, Copenhagen, 1999. Available at the EAA website: <http://reports.eea.eu.int/92-9157-202-0/en>.
- [35] Firbank L.G., Smart S.M., van de Poll H.M., Bunce R.G.H., Hill M.O., Howard D.C., Watkins J.W., Stark G.J., Causes of change in British Vegetation. ECOFACT Vol. 3, Centre for Ecology and Hydrology (2000).
- [36] Fischer S.F., Poschlod P., Beinlich B., Experimental studies on the dispersal of plants and animals by sheep in calcareous grasslands, *J. Appl. Ecol.* 33 (1996) 1206–1222.
- [37] Fisher G.E.J., Rahmann G., Extensification – benefits and disadvantages to grassland biodiversity, in: *Management for grassland biodiversity*, Proceedings of the International Occasional Symposium of the European Grassland Federation, 1997, pp. 115–123.
- [38] Fothergill M., Davies D.A., Morgan C.T., The effect of extensification of upland pasture on white clover, in: Pollot G. (Ed.), *Grassland into the 21st century: challenges and opportunities*, BGS Occasional Symposium No. 29, 1995, pp. 170–171.
- [39] Fothergill M., Davies D.A., Morgan C.T., Extensification of grassland use in the uplands: sheep performance in years 1–6, *Grass Forage Sci.* 56 (2001) 105–117.
- [40] Fothergill M., Davies D.A., Morgan C.T., Fluctuations in white clover content of sheep grazed swards, in: Fisher G., Frankow-Lindberg B. (Eds.), *Lowland grasslands of Europe: utilisation and development*, REU Technical Series No. 64, 2002, pp. 259–262.
- [41] Fothergill M., Davies D.A., Morgan C.T., Jones S., Rees E., Changes in floristic diversity associated with reductions of fertilizer inputs and grazing to upland pasture, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 784–785.
- [42] Gillier C., Loiseau P., Louault F., Long-term effects of a reduced exploitation of a semi-natural grassland. III. Below-ground organic matter and nitrogen storage, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 684–685.
- [43] Government Statistical Service, *Agricultural Statistics*, United Kingdom, 1980–1999.
- [44] Grant S.A., Torvell L., Sim E.M., Small J.L., Armstrong R.H., Controlled grazing studies on *Nardus* grassland: effects of between-tussock sward height and species of grazer on *Nardus* utilization and floristic composition in two fields in Scotland, *J. Appl. Ecol.* 33 (1996) 1053–1064.
- [45] Grant S.A., Torvell L., Common T.G., Sim E.M., Small J.L., Controlled grazing studies on *Molinia* grassland: effects of different seasonal patterns and levels of defoliation on *Molinia* growth and responses of swards to controlled grazing by cattle, *J. Appl. Ecol.* 33 (1996) 1267–1280.
- [46] Grime J.P., Hodgson J.G., Hunt R., *Comparative Plant Ecology*, Unwin Hyman, London, 1988.
- [47] Hansson M., Fogelfors H., Management of a semi-natural grassland; results from a 15-year-old experiment in southern Sweden, *J. Veg. Sci.* 11 (2000) 31–38.
- [48] Haslam I.A., The effects of changes in sheep farming practices upon upland Auchenorrhyncha and carabid populations, Ph.D. Thesis, Univ. Lancaster, UK, 1994.
- [49] Hopkins A., *Grass: its production and utilization*, Blackwell Science, Oxford, UK, 2000.
- [50] Howard C.L., Wright I.A., Effects of mixed grazing by sheep and cattle on *Nardus stricta* dominated grassland, in: Haggard R.J., Peel S. (Eds.), *Grassland Management and Nature Conservation*, BGS Occasional Symposium No. 28, British Grassland Society, Reading, UK, 1994, pp. 292–294.
- [51] Hulme P.D., Pakeman R.J., Torvell L., Fisher J.M., Gordon I.J., The effects of controlled sheep grazing on the dynamics of upland *Agrostis-Festuca* grassland, *J. Appl. Ecol.* 36 (1999) 886–900.
- [52] Jeangros B., Bertola C., Changes during six years in botanical composition, species diversity and productivity of a permanent meadow after cessation of fertilizer application and reduction in cutting frequency, in *Proc. EGF Int. Symp. on Management for Grassland Biodiversity*, 1997, pp. 75–79.
- [53] Jeangros B., Bertola C., Long-term evolution of an intensively managed meadow after cessation of fertilisation and reduction of cutting frequency, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 794–795.
- [54] Jones A.T., Hayes M.J., Increasing floristic diversity in grassland: the effects of management regime and provenance on species introduction, *Biol. Conserv.* 87 (1999) 381–390.
- [55] Kahmen S., Poschlod P., Schreiber K.-F., Conservation management of calcareous grasslands. Changes in plant species composition and response of functional traits during 25 years, *Biol. Conserv.* 104 (2002) 319–328.
- [56] Kirchmann H., Thorvaldsson G., Challenging targets for future agriculture, *Eur. J. Agron.* 12 (2000) 145–161.
- [57] Koch B., Masé G., Extensivierung von intensiv bewirtschafteten grassland, *Schriftenreihe der FAL (Zurich)* 39 (2002) 61–68.
- [58] Köhler B., Ryser P., Gusewell S., Gigon A., Nutrient availability and limitation in traditionally mown and in abandoned limestone grasslands: a bioassay experiment, *Plant Soil* 230 (2001) 323–332.
- [59] Kuehbauch W., Dahmen P., Thome U., Changes in forage production as a consequence of an alteration from a conventional combination of grazing and cutting to an extensive cutting system at the location of Rengen, *Wirt. Futter* 37 (1991) 100–112.
- [60] Loiseau P., Louault F., L'Homme G., Gestion des écosystèmes pâturés en situation extensive : apports de l'écologie fonctionnelle et perspectives de recherches appliquées en moyenne montagne humide, *Ann. Zootech.* 47 (1998) 395–406.

- [61] Losvik M.H., Austad I., Species introduction through seeds from an old, species-rich meadow: effect of management, *Appl. Veg. Sci.* 5 (2002) 185–194.
- [62] Louault F., Dynamics of dead and living plant material in grasslands under non-intensive use, *Proc. VI Int. Range Cong.*, Townsville, 19–23 July 1999, pp. 274–275.
- [63] Louault F., Dedieu B., Benoit M., Tournadre H., de Montard F.X., Designing under-stocked livestock farming systems which favour vegetation control: a system-experiment in Auvergne mountain, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 1044–1045.
- [64] Louault F., Soussana J.F., Perrodin M., Long-term effects of a reduced herbage use in a semi-natural grassland. I. Plant functional traits and plant response groups, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 338–339.
- [65] MAFF, Economic conditions in the hills and uplands of the United Kingdom. *Statistical Tables*, 2000.
- [66] Malo J.E., Suárez F., Herbivorous mammals as seed dispersers in a Mediterranean dehesa, *Oecologia* 104 (1995) 246–255.
- [67] Marriott C.A., Barthram G.T., Vegetation changes in sown grassland in the UK after nine years of extensive grazing management, in *Proc. XIX Int. Grassld Cong.*, 2001, pp. 995–996.
- [68] Marriott C.A., Carrère P., Structure and dynamics of grazed vegetation, *Ann. Zootech.* 47 (1998) 1–11.
- [69] Marriott C.A., Common T.G., Spatial dynamics of species in extensively managed sown grassland, in: Sjøgaard K., Ohlsson C., Sehested J., Hutchings N.J.H., Kristensen T. (Eds.), *Grassland Farming: Balancing environmental and economic demands*, Proc. 18th Gen. Mtng. European Grassland Federation, Denmark, 2000, pp. 293–295.
- [70] Marriott C.A., Gordon I.J., Extensification of sheep grazing systems: effects on soil nutrients species composition and animal production, *XVIII Int. Grassland Congr.*, Canada, 1997, pp. 15–3–15–4.
- [71] Marriott C.A., Fisher J.M., Hood K.J., Smith M.A., Persistence and colonization of gaps in sown swards of grass and clover under different sward managements, *Grass Forage Sci.* 52 (1997) 156–166.
- [72] Marriott C.A., Hudson G., Hamilton D., Neilson R., Boag B., Handley L.L., Wishart J., Scrimgeour C.M., Robinson D., Spatial variability of soil total C and N and their stable isotopes in an upland grassland system, *Plant Soil* 196 (1997) 151–162.
- [73] Marriott C.A., Barthram G.T., Bolton G.R., Seasonal dynamics of leaf extension and losses to senescence and herbivory in extensively managed sown ryegrass white clover swards, *J. Agr. Sci.* 132 (1999) 77–89.
- [74] Marriott C.A., Barthram G.T., Bolton G.R., Fisher J.M., Hood K., Changes in sward structure under extensive grazing management of sown swards, in: Frame J. (Ed.), *Conservation Pays? BGS Occasional Symposium No. 36*, British Grassland Society, Reading, UK, 2002, pp. 133–136.
- [75] Marriott C.A., Bolton G.R., Barthram G.T., Fisher J.M., Hood K., Early changes in species composition of upland sown grassland under extensive grazing management, *Appl. Veg. Sci.* 5 (2002) 87–98.
- [76] Marriott C.A., Barthram G.T., Pakeman R.J., Increasing plant species diversity in upland grassland, 7th BGS Research Conference, British Grassland Society, Reading, UK, 2003, pp. 101–102.
- [77] Marriott C.A., Bolton G.R., Fisher J.M., Changes in species composition of abandoned sown swards after imposing seasonal cutting treatments, *Grass Forage Sci.* 58 (2003) 37–49.
- [78] McIntyre S., Lavorel S., Landsberg J., Forbes T.D.A., Disturbance response in vegetation-towards a global perspective on functional traits, *J. Veg. Sci.* 10 (1999) 621–630.
- [79] Milberg P., Seed bank in a 35-year-old experiment with different treatments of a seminatural grassland, *Acta Oecol.* 13 (1992) 743–752.
- [80] Mitlacher K., Poschlod P., Rosén E., Bakker J.P., Restoration of wooded meadows - a comparative analysis along a chronosequence on Öland (Sweden), *Appl. Veg. Sci.* 5 (2002) 63–73.
- [81] Morgan C.T., Davies D.A., Fothergill M., Changes associated with the re-introduction of grazing in abandoned upland swards, in: *Proc. BGS 5th Res. Conf.*, Plymouth 8–10 September 1997, pp. 45–46.
- [82] Morgan C.T., Fothergill M., Davies D.A., The effect of extensification of upland pasture on thistle populations, in: *Proc. BGS 6th Res. Conf.*, Aberdeen, 11–13 September 2000, pp. 113–114.
- [83] Moog D., Poschlod P., Kahmen S., Schreiber K.-F., Comparison of species composition between grassland management treatments after 25 years, *Appl. Veg. Sci.* 5 (2002) 99–106.
- [84] Morris M.G., The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands, *Biol. Conserv.* 95 (2000) 129–142.
- [85] Mountford J.O., Lakhani K.H., Holland R.J., Reversion of grassland vegetation following the cessation of fertilizer application, *J. Veg. Sci.* 7 (1996) 219–228.
- [86] Neilson R., Hamilton D., Wishart J., Marriott C.A., Boag B., Handley L.L., Scrimgeour C.M., Robinson D., Stable isotope natural abundances of soil, plants and soil invertebrates in an upland pasture, *Soil Biol. Biochem.* 30 (1998) 1773–1782.
- [87] Neilson R., Robinson D., Marriott C.A., Scrimgeour C.M., Hamilton D., Wishart J., Boag B., Handley L.L., Above-ground grazing affects floristic composition and modifies soil trophic interactions, *Soil Biol. Biochem.* 34 (2002) 1507–1512.
- [88] Olf H., Bakker J.P., Long-term dynamics of standing crop and species composition after the cessation of fertilizer application to mown grassland, *J. Appl. Ecol.* 28 (1991) 1040–1052.
- [89] Pearce-Higgins J.W., Grant M.C., The effects of grazing-related variation in habitat on the distribution of moorland skylarks *Alauda arvensis* and meadow pipits *Anthus trivialis*, *Aspects Appl. Biol.* 67 (2002) Birds Agric., pp. 155–163.
- [90] Poschlod P., Wallis De Vries M.F., The historical and socio-economic perspective of calcareous grasslands – lessons from the distant and recent past, *Biol. Conserv.* 104 (2002) 361–376.
- [91] Robinson R.A., Sutherland W., Post-war changes in arable farming and biodiversity in Great Britain, *J. Appl. Ecol.* 39 (2002) 157–176.
- [92] Ryser P., Langenauer R., Gigon A., Species richness and vegetation structure in a limestone grassland after 15 years management with 6 biomass removal regimes, *Folia Geobot. Phytotax.* (1995) 157–167.
- [93] Schreiber K.-F., Schiefer J., Vegetations- und Stoffdynamik in Grünlandbrachen – 10 Jahre Bracheversuche in Baden-Württemberg, *Münster. Geogr. Arb.* 20 (1985) 11–153.
- [94] Schwab A., Dubois D., Fried P.M., Edwards P.J., Estimating the biodiversity of hay meadows in north-eastern Switzerland on the basis of vegetation structure, *Agr. Ecosyst. Environ.* 93 (2002) 197–209.

- [95] Scotton M., D'Ottavio P., Ziliotto U., Nitrogen fixation of legumes of mountain meadows (Asiago, NE Italy) managed with different intensity, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 730–731.
- [96] Scotton M., D'Ottavio P., Da Ronch F., Ziliotto U., Forage selection by different grazing animals in mountain pastures of Cansiglio highland (Belluno, NE Italy), 2nd Int. Congr. Environment and identity in the Mediterranean, Corsica, France, 3–5 July 2002, 2003, in press.
- [97] Sibbald A.R., Maxwell T.J., Dalziel A.J.I., Agnew R.D.M., The implications of controlling grazed sward height for the operation and productivity of upland sheep systems in the UK. 5. The effect of stocking rate and reduced levels of nitrogen fertilizer, *Grass Forage Sci.* 57 (2002) 33–47.
- [98] Smith R.S., Corkhill P., Shiel R.S., Millward D., The conservation management of mesotrophic (meadow) grassland in Northern England. 2. Effects of grazing, cutting date, fertilizer and seed application on the vegetation of an agriculturally improved sward, *Grass Forage Sci.* 51 (1996) 292–305.
- [99] Smith R.S., Shiel R.S., Millward D., Corkhill P., The interactive effects of management on the productivity and plant community structure of an upland meadow: an 8-year trial, *J. Appl. Ecol.* 37 (2000) 1029–1043.
- [100] Smith R.S., Shiel R.S., Millward D., Corkhill P., Sanderson R.A., Soil seed banks and the interactive effect of meadow management on vegetation change in a 10-year meadow field trial, *J. Appl. Ecol.* 39 (2002) 279–293.
- [101] Smith R.S., Shiel R.S., Bardgett R.D., Millward D., Corkhill P., Rolph G., Hobbs P.J., Peacock S., Soil microbial community, fertility, vegetation and diversity as targets in the restoration management of a meadow grassland, *J. Appl. Ecol.* 40 (2003) 51–64.
- [102] Soussana J.F., Mas G., Clothier K.M., Louault F., Long-term effects of a reduced herbage use in a semi-natural grassland. II. Above-ground productivity and litter decomposition, in: Durand J.-L., Emile J.-C., Huyghe C., Lemaire G. (Eds.), *Multi-Function Grasslands: Quality Forages, Animal Products and Landscapes*, Proc. 19th Gen. Mtng. European Grassland Federation, France, 2002, pp. 732–733.
- [103] Tasser E., Tappeiner U., Impact of land use changes on mountain vegetation, *Appl. Veg. Sci.* 5 (2002) 173–184.
- [104] Thériez M., Brelurut A., Pailleux J.Y., Benoît M., Liénard G., Louault F., de Montard F.X., Extensification en élevage ovin viande par agrandissement des surfaces fourragères. Résultats zootechniques et économiques de 5 ans d'expérience dans le Massif Central nord, *Prod. Anim.* 10 (1997) 141–152.
- [105] Vickery J.A., Tallowin J.R., Feber R.E., Asteraki E.J., Atkinson P.W., Fuller R.J., Brown V.K., The management of lowland neutral grassland in Britain: effects of agricultural practices on birds and their food resources, *J. Appl. Ecol.* 38 (2001) 647–664.
- [106] Wahlman H., Milberg P., Management of semi-natural grassland vegetation: evaluation of long-term experiment in southern Sweden, *Ann. Bot. Fenn.* 39 (2002) 159–166.
- [107] Wallis De Vries M.F., Bakker J.P., Van Wieren S.E., *Grazing and Conservation Management*, Kluwer Academic Publishers, London, 1998.
- [108] Wright I.A., Dalziel A.J.I., Ellis R.P., Hall S.G.J., The status of traditional Scottish animal breeds and plant varieties and implications for biodiversity, *Scott. Execut. Soc. Res. Rep.*, 2002. Available at: <http://www.scotland.gov.uk/library5/environment/tsab-00.asp>.