Managing biodiversity in upland calcareous grassland landscapes:

A case study of spiders and ground beetles

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Preface

This document is the product of a research project that examined the impacts of contrasting grazing management on plants, carabid beetles and spiders in upland calcareous grasslands and associated habitats in Britain. The project was funded by Edge Hill University and conducted by researchers at the same institution between 2013 and 2017. The initial project idea was developed following discussion with Natural England site managers who highlighted a knowledge gap on the impacts of commonly used management practices. Throughout the project a series of meetings were held between the authors and practitioners from a range of organisations involved in upland calcareous grassland management (including: Natural England, The National Trust, The Yorkshire Dales National Park Authority) to ensure research was as relevant and as reflective to practice as possible.

This document summarises results of this project and makes management recommendations based on these results and wider information known about the ecology of spiders, beetles and plants. The full project can be accessed at: https://www.edgehill.ac.uk/biology/calcareous-grassland-research/. Details of publications resulting from this work are available from the authors or: https://www.researchgate.net/profile/Ashley_Lyons/publications?pubType=article.

Suitability of management recommendations presented in this document were discussed with practitioners, academics and graziers at the *Upland Calcareous Grassland Workshop* at Ingleborough NNR on 15th August 2017, and where required they were amended based on input from the workshop. The document has been written in discussion with Natural England and is intended to assist conservation practitioners and policy makers in making management decisions that contribute to the conservation of spiders, ground beetles and plants in upland calcareous grassland landscapes.

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Executive summary

- **Upland calcareous grasslands are internationally rare, diverse habitats that have undergone decline and degradation.**
- **The UK has large areas of extensive, unfragmented calcareous grassland of significant international importance.**
- **Suitable management is vital to conserve biodiversity in this habitat.**
- **Invertebrates play an important role in calcareous grassland ecology.**
- **Grazing intensity alters vegetation structural complexity.**
- **Ground beetle and spider fauna respond to grazing intensity.**
- **Ungrazed calcareous grasslands have distinct spider and ground beetle communities that differ from those grazed by cattle or sheep.**
- **Calcareous grasslands grazed at a high intensity with sheep have a distinct spider community, though this consists of common, non-specialised species.**
- **Heather habitats associated with the calcareous grassland matrix house distinct spider communities and rare species.**
- **Varied grazing management across the landscape is recommended, including introduction of areas temporarily left without grazing, the continuation of low intensity sheep grazing and low intensity cattle grazing.**
- **The cessation of high intensity sheep grazing is urged.**
- **Encouraging the development/recovery of heath patches on deposits of acidic soil is recommended.**
- **Targeted management of mature heather patches is recommended to introduce further successional stages.**

1.1 - Upland Calcareous Grassland – a rare and changing landscape

With an exceptional diversity of plants and invertebrates, calcareous grassland is one of the most species rich habitats in Europe[1,2]. In order to maintain biodiversity it requires careful management, which is typically undertaken through grazing or mowing. However, following 1950s agricultural intensification calcareous grasslands in Great Britain and across Europe underwent large-scale loss and degradation due to increased use of fertilisers, greater stocking densities and occasionally abandonment[1,2,3,4]. This has resulted in a dramatic decline in plant and invertebrate species richness[5,6] in these grasslands and led to their inclusion in Annex I of the EC Habitats Directive, with an estimated 595 973 ha protected in the Natura 2000 network across the EU member states[7].

In Great Britain, high densities of sheep were implicated as a major cause of habitat deterioration and the decline of associated plants, invertebrates and birds in upland regions[8,9]. Increased grazing pressure between the 1960s and 1990s coincided with the 37% loss of upland calcareous grassland in England between 1960 and 2013[10]. Upland calcareous grassland now covers just 0.1% (22 000 - 25 000 ha) of total UK land cover[11,12], making it an important and rare habitat both nationally and internationally.

1.2 - Upland calcareous grassland habitat mosaic

Upland calcareous grassland occurs on thin, well drained, lime rich soils found overlying limestone bedrocks interspersed with superficial deposits of glacial till which give a deeper acid soil. This results in a matrix of calcareous grassland, acid grassland, dry heath and limestone pavement. Whilst the presence of each habitat type within this matrix is ultimately determined by underlying geology, appropriate management is necessary to produce a truly varied landscape which is of great importance for biodiversity.

2.0 - Managing upland calcareous grassland landscapes to maximise biodiversity - Overview

Outlined in the following pages are a series of management recommendations aimed at enhancing and maintaining biodiversity in upland calcareous grassland landscapes. Table 1 presents evidence based recommendations with the aim of enhancing spider, carabid beetle and plant diversity through contrasting management of upland calcareous grassland. Sub headings (4.1 – 4.3) provide further detail on each of the recommendations presented and the evidence basis for each of the recommendation is presented on pages 14 – 20.

Vegetation quadrat and pitfall traps set in calcareous grassland at Ingleborough NNR, North Yorkshire. ©Ashley Lyons

Table 1 - Upland Calcareous Grassland Management Recommendations

Management recommendation	Biodiversity benefit	Implementation in practice	Information in sections
Promote heterogeneous vegetation structural complexity across the landscape	Enhances the range of plant and invertebrate communities supported Provides additional habitat for rare species	Ensure there is a range of grazing regimes across the landscape (including no grazing) Will require collaboration from a number of organisations	4.1, 4.2, 4.3, 7.1, 7.4
Cessation of high intensity grazing (>0.26 LU/ha/yr)	Increased vegetation structural complexity provides increased niche availability for specialist species Habitat for distinct, less common (nationally) spider and beetle communities Enable recovery of botanical diversity	Reduce stocking levels to less than 0.26 LU/ha/yr Or Convert to ungrazed areas to promote structural complexity across the landscape	4.2, 7.4
Introduce targeted ungrazed areas to produce a rotational time series of ungrazed sites across the landscape	Provide habitat for specialist species Regeneration of heather in areas of suitable soil type	Remove grazing sequentially in targeted areas Promote connectivity of ungrazed areas to provide suitable transition habitat Reintroduce grazing when scrub encroachment approaches ten per cent or after ten years (whichever is sooner)	4.3, 7.4
Reintroduce grazing to ungrazed areas showing signs of severe scrub encroachment	Maintain open grassland Restore botanical diversity	Reintroduction of grazing with sheep from local calcareous grassland to re-establish plant species richness via seed dispersal	4.3

3.0 – Managing non-target habitats within the upland calcareous grassland landscape to maximise biodiversity - Overview

Outlined in the following pages are a series of management recommendations aimed at maximising biodiversity in associated habitats of the upland calcareous grassland landscape. Table 2 presents evidence based recommendations with the aim of enhancing spider and carabid beetle diversity in dry heath patches that occur within the calcareous grassland matrix. Sub headings (5.1 – 5.3) provide further detail on each of the recommendations presented and the evidence basis for each of the recommendation is presented on pages 14 – 20.

Table 2 - Upland Calcareous Grassland Non-Target Habitats Management Recommendations

Management recommendation	Biodiversity benefit	Implementation in practice	Information in sections
Maintain established heather patches	Provides habitat for rare spiders	Continue low intensity grazing	5.1, 7.5
Promote a range of successional stages among existing heather patches	Increases habitat heterogeneity and provides resources for specialist species	Introduce management of selected heather patches	5.2, 5.3, 7.5
Development or restoration of heather patches in targeted areas	Provides habitat for specialist and rare spider species	Remove stock for a period of time/reduce grazing intensity – preferably use sheep to graze.	5.2, 4.3

4.0 - Managing upland calcareous grassland landscapes to maximise biodiversity - Explanation

4.1 - Managing for heterogeneity

Species utilise different habitat features depending on their life history traits and habitat requirements.

The low-input-low-intensity systems which benefit botanical diversity in upland calcareous grasslands also provide important habitat conditions for a range of invertebrate species. The benefits of such systems can be maximised by promoting heterogeneity across the landscape. Landscape scale structural heterogeneity enhances the range of plant and invertebrate communities that can be supported and provides additional habitat for rare and specialist species.

Landscape scale structural heterogeneity can be achieved by implementing a range of grazing management practices. Where compartments are owned or managed by several organisations there will be a requirement for collaboration to ensure a range of management, and thus structural heterogeneity. Such collaboration can take into account landscape features and resource availability (e.g. access, water availability, limestone pavement outcrops) ensuring that management is not only beneficial to overall biodiversity but also practical to implement.

Section 8.0 (pages 21 – 26) presents an idealised landscape management regime based on recommendations in this document.

4.2 - Planning grazing prescriptions – reducing grazing intensity on heavily grazed calcareous grassland

Upland calcareous grassland under high intensity grazing has a uniformly low structural complexity and reduced botanical diversity, which results in a spider community comprised of a suite of common and non-specialised species[13]. This community is common to highly disturbed areas and is not unique to calcareous grassland. Indeed, overgrazing is recognised as the greatest threat to the condition of upland calcareous grasslands[14] as it leads to loss of vegetation structure and failure of more palatable or vulnerable plant species to reproduce and establish[14].

The reduction of high intensity grazing (> 0.26 LU ha^{-1} yr^{-1}) is recommended in order to establish increased structural complexity and for recovery of botanical diversity. Doing so would provide habitat for distinct, less common spider and carabid beetle communities associated with low intensity grazed or ungrazed upland calcareous grasslands.

4.3 - Planning grazing prescriptions – targeting areas for removal of grazing

Distinct spider and carabid beetle communities occur in areas left without grazing for a prolonged time, the high structural complexity providing conditions for a number of specialist and rare species. This management practice is rare and the establishment of additional ungrazed compartments across the upland landscape is recommended.

However, loss of botanical diversity due to scrub encroachment or loss of the seed bank can occur over time. Whilst this will differ between sites, previous research suggests seed bank species composition in ungrazed grassland is significantly different after 11 years of no grazing [15]. Therefore, across the landscape individual compartments need to be managed on a cycle of no grazing and grazing. It is recommended that grazing is reintroduced either when the first signs of scrub encroachment are observed or after a maximum of 10 years. Further, the method of reintroduction of management may assist in botanical restoration of ungrazed calcareous grasslands. Reintroduction of sheep grazing can re-establish species richness via dispersal of seeds from other calcareous grasslands[16]. It is unknown if cattle fulfil the same role and as such it is recommended that reintroduction of grazing includes sheep that have been grazing on local calcareous grasslands. Where significant outcrops of limestone pavement are present these should either be fenced to avoid browsing by sheep or where grazing is reintroduced, it should be with cattle.

It is emphasised that removal of grazing is not abandonment, rather it mimics the way grasslands may have been grazed by natural herbivores before enclosure. Permanent cessation of grazing is only recommended in areas which have currently been without grazing for more than 11 years due to the expected loss of the seedbank after this length of time[15]. Such areas may also act as a stable refuge for invertebrates that require this specific habitat type.

It is recommended that areas selected for removal of grazing are targeted to provide maximum benefit to long-term botanical and invertebrate diversity. For example, reducing grazing in areas with deposits of glacial till may encourage patches of heather regeneration, which have been demonstrated to benefit spider fauna[17]. Further, limestone pavement has a distinct flora and is often diminished when grazed in places accessible to livestock. Areas with limestone pavement outcrops are potentially good candidates for removal of grazing which could benefit limestone pavement plant communities in addition to invertebrate communities in calcareous grassland. Targeting areas containing limestone outcrops for the removal of grazing may also benefit endangered species such as the cave living spider *Porrhomma egeria* which is recorded from ungrazed calcareous grassland. Though little is known about its ecology, its presence in ungrazed calcareous grassland may be due to the presence of limestone outcrops within the calcareous grassland matrix.

5.0 – Managing non-target habitats within the upland calcareous grassland landscape to maximise biodiversity - Explanation

5.1 - Managing associated habitats in the upland calcareous grassland matrix

The presence of patches of acid grassland and dry heath in the calcareous grassland matrix increases the heterogeneity of the landscape. The value of these habitats is important for spider diversity, providing habitat for a distinct community and a number of rare species. The biodiversity value of heather patches within this landscape may be improved by targeting conservation management towards some of them.

5.2 - Targeting areas for restoration of heath

The presence of mature heather in an otherwise treeless landscape provides suitable habitat conditions for a distinct spider community comprised of several species usually associated with woodland. The acidic soils found at deposits of glacial till provide suitable conditions for acid grassland or heath. Where grazing intensity is low enough, remnant acid grassland patches occur. These are likely to be degraded heath with the potential to recover. Due to the greater value of heath than acid grassland to spider diversity, demonstrated by the distinct community and association of specialist species[17], the recovery of heather patches is recommended.

Incorporating removal of grazing in areas with significant deposits of glacial till maximises the potential for heath development/recovery as pioneer heather plants are able to establish, free from browsing by livestock. Heather patches in areas of ungrazed calcareous grassland will also increase the biodiversity value of both habitats, the undisturbed ungrazed calcareous grassland providing additional habitat for some species.

Sites earmarked for dry heath restoration should be surveyed to determine if they are in fact degraded heath. Where this is confirmed, they should be carefully monitored for establishment or recovery of heather. If heather fails to establish it may indicate lack of seed which may need to be reintroduced from a donor crop.

5.3 - Managing established heath patches

The introduction of management to some patches of heath to promote a range of successional stages would further increase habitat heterogeneity in the upland calcareous grassland landscape, providing greater niche availability for a range of invertebrates.

This may be achieved by cutting, in which case care must be taken to remove resultant litter to ensure germination of seedlings is not inhibited. Such material may be used as donor seed in patches where heath establishment is planned. Controlled burning may also assist in the development of diversification of structure and pioneer growth of heather, though care must be taken to prevent the spread of fire and must only be performed during the wetter winter months. Burning in areas with *Molinia caerulea* is discouraged as the dominance of this tussocky grass species is encouraged by fire. Fire is noted as being beneficial to the vulnerably listed spider species *Agyneta subtilis*, which is able to maintain high densities in mature heather after burning[18].

Regardless of the method of management, heath patches subjected to management should be targeted to encourage positive conservation outcomes e.g. target patches close to limestone outcrops to provide a transition for species such as *Walckenaeria monoceros* which is found under stones and as a pioneer of burned heath. Equally, avoiding management of heath patches where species such as *Porrhomma egeria*, a cavernicolous species which may rely on the shade of mature heather, are present is recommended.

6.0 – Importance of managing calcareous grassland – a case study from Germany

The loss of calcareous grassland across Europe is attributed to changes in land use, through agricultural intensification as well as abandonment followed by shrub encroachment[19, 20, 21].

In Germany, changes in land use resulted in the loss of 60% of calcareous grassland during the 20th century in some areas[22]. This loss was exacerbated by the great reduction in the national sheep flock, dropping from 30 million sheep in 1860 to 0.78 million sheep in 1965, before increasing slightly to 2.7 million by 2002[23]. Currently there are 1.57 million sheep in the German national flock[24].

The most recent estimate of the extent of calcareous grassland in Germany is 31 079 ha, an area comparable to that found in Britain[25]. However, the 33 419 ha of calcareous grassland in Britain occurs on 62 sites whilst the comparable area in Germany occurs on 924 sites[25]. Consequently, the calcareous grasslands of Germany are much smaller (with many sites less than one ha), fragmented and isolated, highlighting the international importance of uniquely large areas such as those in Great Britain.

Remnants fragment of calcareous grassland in the foreground displaying signs of succession due to relaxed grazing, surrounded by intensive arable farming. Site grazed by donkeys. Location: Lower Saxony, Germany.

Sparse resource availability for calcareous grassland management in Germany creates further challenges for conservation (Figure 1). In addition to nationally reduced sheep numbers, a relatively small number of conservation practitioners are stretched over many sites. Where livestock are available, these small sites often remain abandoned due to low economic value. Though agricultural subsidies are available, they are often not large enough to render grazing these remnant fragments financially viable. Because of these three factors, conservation managers are unable to manage remnant fragments under one ha, despite the significant number of them. Consequently, many of these smaller fragments have undergone succession to forest.

Figure 1: Factors influencing the loss and fragmentation of calcareous grassland in Germany

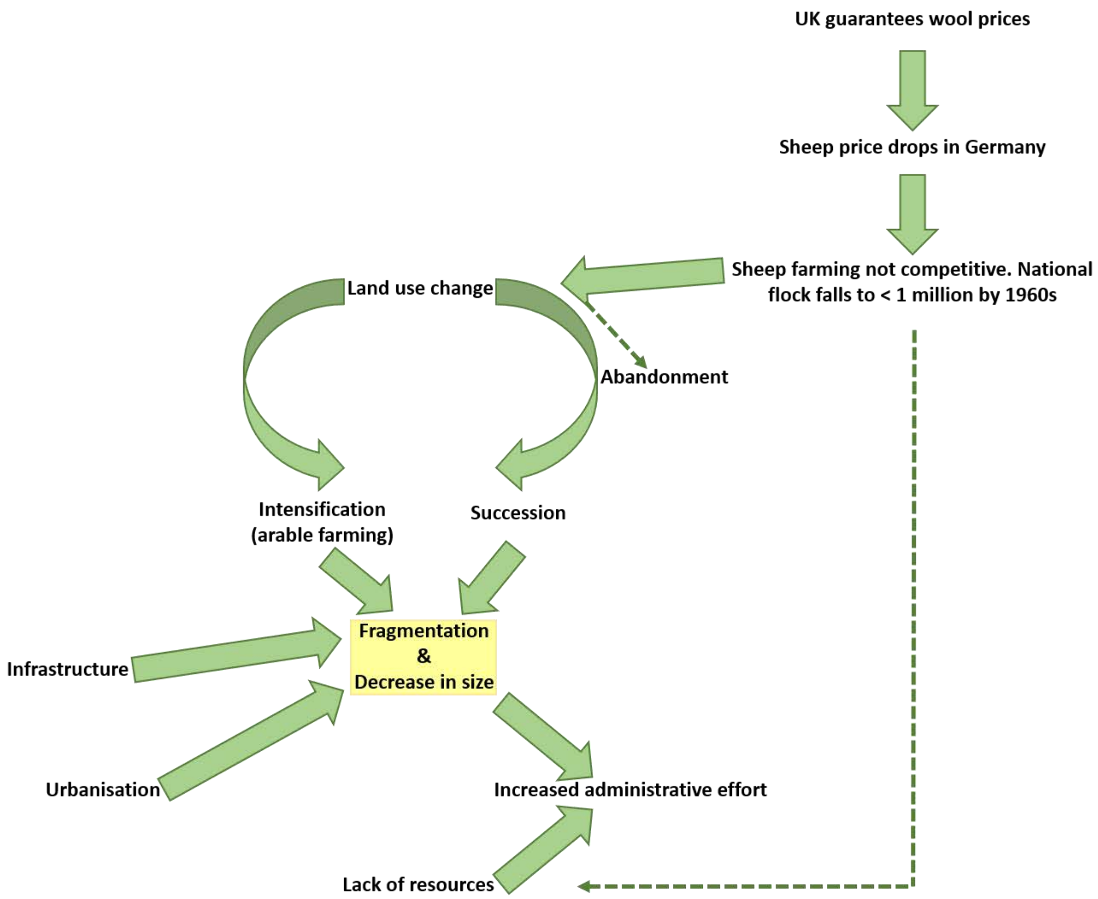


Figure 1 credit: Jacqueline Loos, Georg-August University Göttingen

7.0 – Evidence from research

This section outlines the evidence and rational from which the management recommendations outlined in Tables 1 and 2 are derived.

7.1 - Grazing impacts on vegetation in upland calcareous grassland

Grazing intensity of upland calcareous grassland influences both structural complexity and plant species composition[13,26] (Figure 2). Areas left without grazing have comparatively high structural complexity which is variable throughout the sward, a well-developed thatch layer and a distinct plant species composition[13,26]. In contrast, areas of high stocking density (>0.26 LU/ha/yr) have a uniform sward of low structural complexity and lack a thatch layer[14]. Plant species composition also differs in areas grazed either by cattle or sheep at comparably light stocking densities (<0.18 LU/ha/yr)[26]. However, under these grazing types sward height and vegetation structural complexity are comparable, being intermediately complex compared to areas of no grazing or high intensity grazing[14].

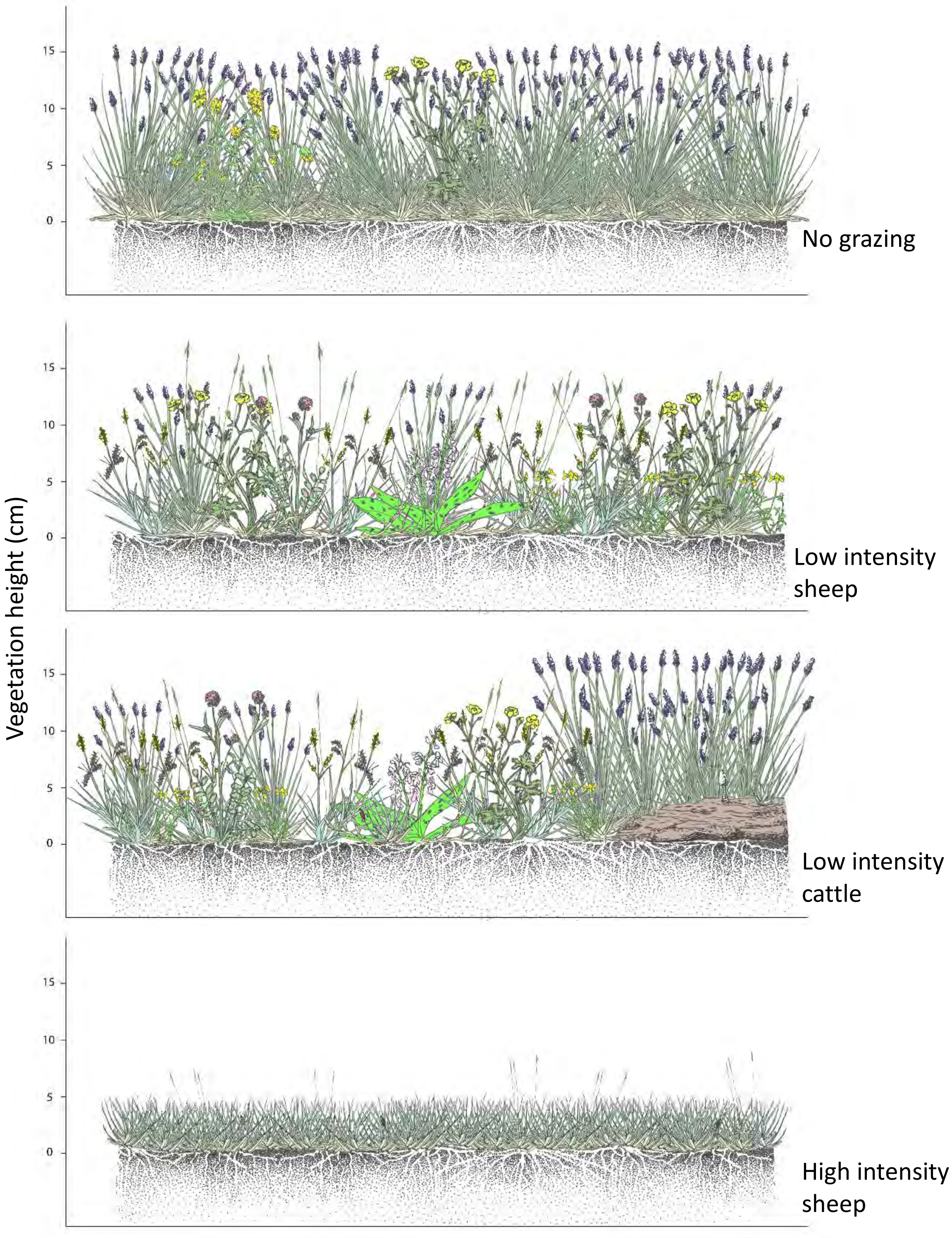
The intermediate structural complexity under low intensity grazing is variable throughout the sward, reflecting the grazing behaviour of sheep and cattle[13]. Plant species associated with different grazing types reflect a combination of the competitive relationships of plants and the feeding characteristics of sheep and cattle[26]. Under low stocking intensity with cattle, patch forming species are able to colonise bare patches via vegetative spread, such as *Carex panicea, Carex flacca* and *Thymus polytrichus*, while the tussock forming *Danthonia decumbens* spreads via seed[26]. These species are able to colonise bare gaps left when cattle indiscriminately remove tufts of vegetation. Where there is comparably low intensity grazing with sheep, *Anthoxanthum odoratum* is associated[26], a competitive grass that is grazed less preferentially by sheep when other more palatable grasses are available[27].

It is intensity, rather than livestock type that drives the main differences in plant structural complexity

Where grazing is absent *Stachys officianalis* is associated, a species which relies on setting seed to maintain its population[26]. Under these conditions plants are able to produce flowers free from browsing by livestock and thus set seed.

The contrasting plant species compositions and structural complexity associated with each of the grazing treatments contributes to overall landscape heterogeneity, a factor important for enhancing biodiversity at this scale.

Figure 2: Diagram illustrating vegetation structural complexity of each grazing intensity (From top to bottom; no grazing, low intensity sheep grazing, low intensity cattle grazing, high intensity sheep grazing)[13]. Illustration by Thom Dallimore.



7.2 - Upland calcareous grassland – habitat for invertebrates

In grasslands, invertebrates occupy and interact with all levels of the food web, from primary producers to top predators[28]. Consequently, they provide a wide range of important ecosystem services e.g. pollination, nutrient cycling, seed dispersal, decomposition, food web stability, disease regulation etc. They are directly and indirectly affected by management[28,29,30]. For instance, abundance of invertebrates on foliage can be depressed by large herbivores due to competition for the same plant resources and inducement of defensive plant structures[8,31,32]. In contrast, grazing may also facilitate invertebrate diversity by increasing plant species richness, developing structural heterogeneity and increasing the range of microhabitats[32,33,34]. Importantly, the low-input-low-intensity systems which benefit botanical diversity in upland calcareous grasslands also provide important habitat conditions for invertebrates.

7.3 - Importance of spiders in ecosystem function

Spiders are among the most abundant animals in terrestrial ecosystems and occupy an important role in grassland food webs[35,36]. As predators of other arthropods they are important in the regulation of invertebrate populations, and as prey they provide food for other invertebrates, small mammals, reptiles and birds. Though exclusively predators, they encompass a wide range of foraging strategies and dispersal capabilities and as such are sensitive to variations in vegetation structure and disturbance[37,38,39,40]. They can be classified into groups based on their hunting strategies (e.g. active hunters, ambush hunters, sheet web weavers, space web weavers and others) which can provide insight into how they utilise habitats.

Spiders are strongly influenced by changes in vegetation structure rather than plant species composition

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Spiders are influenced by variation in microclimatic conditions (e.g. temperature, humidity, light exposure) which can occur with varying vegetation structural complexity. As such, their habitat requirements in grasslands differ among species. Some species favour structurally complex vegetation with deep litter layers, whilst others favour less structurally complex vegetation with high levels of disturbance[13,24,42,43,44,45]. Some species require a heterogeneous sward of open patches to search for prey and taller vegetation for refuge and overwintering[45], others select structurally complex vegetation that

provides increased anchorage points for web building, whilst some shade intolerant species require minimal structural complexity [39,46,47].

Further, spiders may also be indirectly effected by vegetation structure through influences on prey availability and abundance[48]. For example, accumulation of thatch increases organic material which is utilised by collembola, a preferred food source for some moneyspiders[48].

7.4 - Impact of contrasting grazing in upland calcareous grassland on spiders

Areas of upland calcareous grassland that have been left without grazing for a prolonged period provide a unique habitat, with high structural complexity and increased thatch layer. Increased structural complexity provides a more stable microclimate than grazed vegetation by protecting from extreme climatic conditions[29,42,49]. This in turn produces a distinct spider community consisting of species that require a specific microclimate such as the money spiders *Palliduphantes ericaeus, Pocadicnemis pumila, Walckenareia acuminata*[13], all of which require humid conditions. The well-developed layer of thatch further provides suitable microhabitat conditions for specialist species known to have a preference for leaf litter such as the money spiders *Monocephalus fuscipes, Palliduphantes pallidus*[13] and the scaffold web spinner *Robertus lividus*. The lack of disturbance by livestock in upland calcareous grasslands without grazing also provides suitable habitat for two species categorised as endangered in Britain[44] *Porrhomma egeria* and *Jacksonella falconeri*[13], and three listed as vulnerable[49] *Agyneta subtilis*, *Walckenaeria incisa* and *Walckenaeria obtusa*[13].

Spider species composition is influenced more by grazing intensity than type of grazing animal used

Where grazing intensity is low (<0.24 LU ha^{-1} yr^{-1}) the spider species community is comparable whether grazing is conducted by cattle or sheep, reflecting the plant structural complexity in these regimes[13]. However, there are notable differences in individual spider species associations with the two grazing types. Under sheep grazing there is an association of the dwarf sheet spider *Hahnia nava*, and the money spiders *Agyneta cauta and Peponocranium ludicrum*, all of which are species found close to the ground on low vegetation. Under cattle grazing the most notable associated species is the ground hunter *Pardosa pullata*. *P. pullata* utilises tussocks within grasslands[50], using them as refuge from predators whilst hunting in the more open patches around. Their association with cattle grazing reflects the plant species associated with this grazing treatment such as *Danthonia decumbens* as discussed earlier.

Under high intensity grazing (>0.26 LU ha^{-1} yr^{-1}) the sward is maintained at a short height and the structure is of uniformly low complexity. Here spiders are subjected to high levels of disturbance by livestock, fluctuating temperatures and high light intensities. There are limited web anchorage points and little shade. The reduced structural complexity provides conditions for a pioneer community of species associated with short vegetation and good dispersal abilities which are well known from disturbed habitats e.g. the money spiders *Erigone atra*, *Oedothorax fuscus* and *Tiso vagans*[13,51]. A reduction in web anchorage points due to low structural complexity favours the versatile foraging strategies of *Erigone* and *Oedothorax* species[52], which dominate the spider fauna under high intensity grazing[13]. The functional roles of this community differ from areas without grazing and low intensity grazing, having a reduced proportion of sheet web weavers and ground hunters and an increased proportion of species which are supported due to their more versatile foraging strategies[13] e.g. *Erigone* species which vary their mode of foraging between actively catching prey and capturing prey in a small web which is not reliant on tall vegetation but is usually constructed very close to the surface of the ground[45,52]. The association of the shade intolerant ambush hunter *Xysticus cristatus*, which can adopt a hunting position on the ground surface, thus not relying on complex vegetation, also reflects the influence of reduced vegetation structural complexity and low levels of thatch under high intensity grazing[13,50].

Differences in spider species community are influenced more by grazing intensity than the type of grazing animal used[13]. Despite this, the association of different species with each grazing type highlights the importance of varied structural complexity across the landscape.

7.5 - Spiders in associated habitats in the upland calcareous grassland matrix

Within the calcareous grassland matrix, dry heath patches are particularly important, having a spider species community that is distinct from calcareous grassland or acid grassland (which do not differ from each other)[17]. The spider fauna found in dry heath also has a different proportion in functional roles compared with grassland habitats[17], being dominated by sheet web weavers with a reduced proportion of ground hunters, reflecting differences in ground level vegetation structure, microclimate and shade[17]. These differences in structure, microclimate and shade result in an association of a number of species whose known habitat preference is for woodland (e.g. *Agyneta subtilis*, *Tenuiphantes zimmermani*, *Robertus lividus*).

Dry heath patches have a distinct spider community and provide habitat for rare species

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Heath patches also support spiders of conservation importance including two endangered species and three classed as vulnerable: *Porrhomma egeria* which is classed as endangered in Britain[49], this is predominantly a cave living species which usually occurs in low numbers[50] and is noted as having suffered decline of 70%[53]. Though the phenology and ecology of this species is relatively unknown, its presence within patches of dry heath highlights the importance of this habitat type within the calcareous grassland matrix beyond providing a distinct spider community. *Jacksonella falconeri*, listed as endangered in Britain, is also found in dry heath patches. This species has experienced steep decline over the last 20 years[53]. Threats to this species include degradation and loss of calcareous grassland and heathland. The close proximity of these two habitat types in the upland calcareous grassland matrix may be beneficial for its long-term conservation. In addition to the endangered species mentioned, dry heath patches also support three species classed as vulnerable in Britain[49]; *Allomengea scopigera*, *Walckenaeria dysderoides* and *Agyneta subtilis*, the latter of which has been noted as maintaining high densities in mature heather after burning[54].

Whilst the spider species community does not differ between acid grassland and calcareous grassland, the functional roles do. Both had a greater proportion of ground hunters than dry heath, which reflects the crucial role of refuges within the sward, such as those of tussock forming grasses, in habitat suitability for ground dwelling predators[45,55]. For example, *Trochosa terricola*, which is associated with calcareous grassland, utilises tufts of *Festuca ovina*[56], the second most abundant plant species in upland calcareous grasslands[26]. In both grassland habitats the ground hunter guild is dominated by *Pardosa*

species, a genus known to also utilise different components of vegetation structure for prey capture, overwintering and refuge from predators[45,57].

In acid grassland there is a reduced proportion of sheet web weavers compared to calcareous grassland, instead there is a greater proportion of ground hunters due to the greater abundance of *Pachygnatha degeeri*. *P. degeeri* is an indicator of less intensively managed sites. The association with acid grassland within the calcareous grassland matrix may be a product of sheep grazing behaviour. Sheep are preferential grazers, able to select preferred plant species within a sward[58]. Where preferred vegetation is available sheep avoid *Nardus stricta*[58], the dominant species in the acid grassland patches. This results in reduced grazing pressure in the acid grassland compared to the calcareous grassland, thus providing suitable conditions for *P. degeeri*.

Pachygnatha degeeri. ©ARABEL image bank/©Gilbert Loos

Pardosa pullata. Photo credit: ©Jim Lindsey

The endangered *Jacksonella falconeri* occurs in acid grassland and heath, though with greater abundance in the latter[17]. The vulnerable *Agyneta subtilis* occurs in both grassland types, again most abundantly in calcareous grassland though not as abundantly as in dry heath. The vulnerable *Walckenaeria dysderiodes* is recorded from both calcareous grassland and dry heath[17] and is known to have a preference for heathland, open stony areas and calcareous grassland, a combination of habitat features regularly encountered in upland calcareous grassland landscapes. The vulnerable *Trichopternoides thorelli* is recorded in the patches of acid grassland, the structure of which may fulfil its preference for moss and grass in damp areas as the acid grassland often retains more moisture than the calcareous grassland due to its deeper soil.

7.6 - Importance of carabid beetles in ecosystem function

Carabid beetles, though mostly predatory, occupy a range of trophic levels, as predators, scavengers, granivores, herbivores and omnivores[58,59]. These functional roles provide important ecosystem services in grasslands in pest control, food provision for other taxa and seed dispersal. They are sensitive to changes in habitat quality, particularly their larvae which are intolerant of microclimate extremes[60,61]. As such they are sensitive to vegetation change following alteration of management practices[62,63]. Carabid beetles have experienced substantial overall decline in Britain over the last decades, with some species losing as much as 60-70% of their population[64].

Pterostichus madidus. ©Ashley Lyons

7.7 - Impact of contrasting grazing in upland calcareous grassland on carabid beetles

In upland calcareous grassland where cattle grazing and sheep grazing are at a comparable low intensity (<0.2 LU ha^{-1} yr^{-1}) there is no distinction in the carabid beetle species community[26]. However, in upland calcareous grasslands that have been without grazing for a prolonged period there is a distinct species community compared to cattle or sheep grazed areas[26]. The distinct species communities are likely to be a product of differences in plant structural complexity between areas with or without grazing, influencing the food availability (e.g. prey, seeds) and microclimate[65]. Differences in plant structural complexity may also account for the greater abundance of carabid beetles in areas of low intensity grazing compared to areas without grazing[26].

Ground beetle species composition is not influenced by livestock type at low intensity grazing

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Grazing also enhances the number of individuals found from the genus *Carabus*[26]. The tussock forming grasses (*Anthoxanthum odoratum* and *Danthonia decumbens*) identified

as associated with sheep and cattle grazing respectively, may act as places of refuge for *Carabus* species[26]. The removal of selected plant species during sheep grazing, or larger tufts under cattle grazing produces patches of shorter vegetation with taller tufts which are the preferred conditions for many carabid beetle species[66,67].

The importance of providing areas of intermediate structural complexity produced under low intensity grazing with sheep or cattle[13] is highlighted by the association of *Carabus violaceaus* and *Carabus arvensis*. These two species have declined nationally by 10 – 20% and 60 – 70% respectively[27]. Furthermore, the presence of the nationally scarce *Pterostichus aethiops* across a number of sites under low intensity sheep grazing highlights the importance of the continuation of this grazing type, even though the overall carabid fauna is similar to that under cattle grazing[27].

8.0 – Idealised grazing management across the landscape

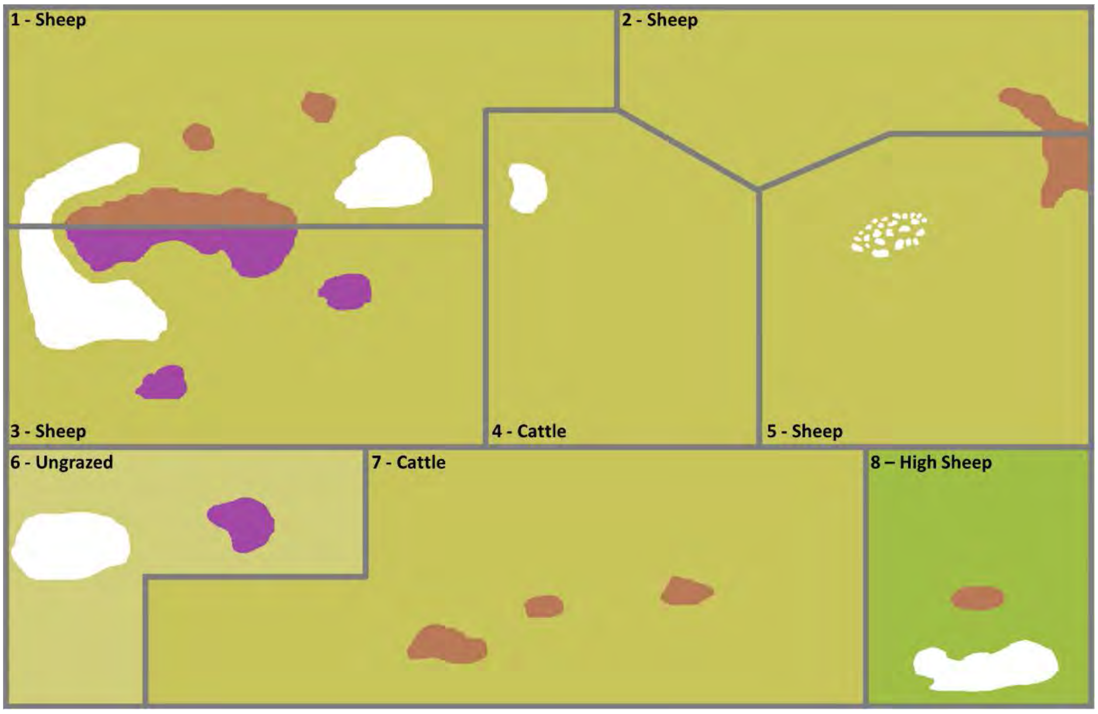
The following section presents proposed management across a hypothetical calcareous grassland landscape with the aim of producing varied plant community composition, varied sward structural complexity, development/restoration of heather and protection of limestone pavement flora. Table 3 presents the suggested grazing types in each compartment across the landscape at five points in time 'rotations' in order to achieve these aims. Each rotation in this example lasts for five years. Figures 3.a – 3.e show possible habitat development over the rotations. Note that the management of fields 2, 4 and 6 remain unchanged in order to provide stable habitats within the landscape.

Table 3: Grazing types in each of the fields in each of the rotations in figures 3.a – 3.e below. Sheep = sheep grazing < 0.2 LU/ha/yr, Cattle = cattle grazing < 0.2 LU/ha/yr, Ungrazed = no grazing, High Sheep = Sheep grazing > 0.26 LU/ha/yr. In this example each rotation lasts for five years.

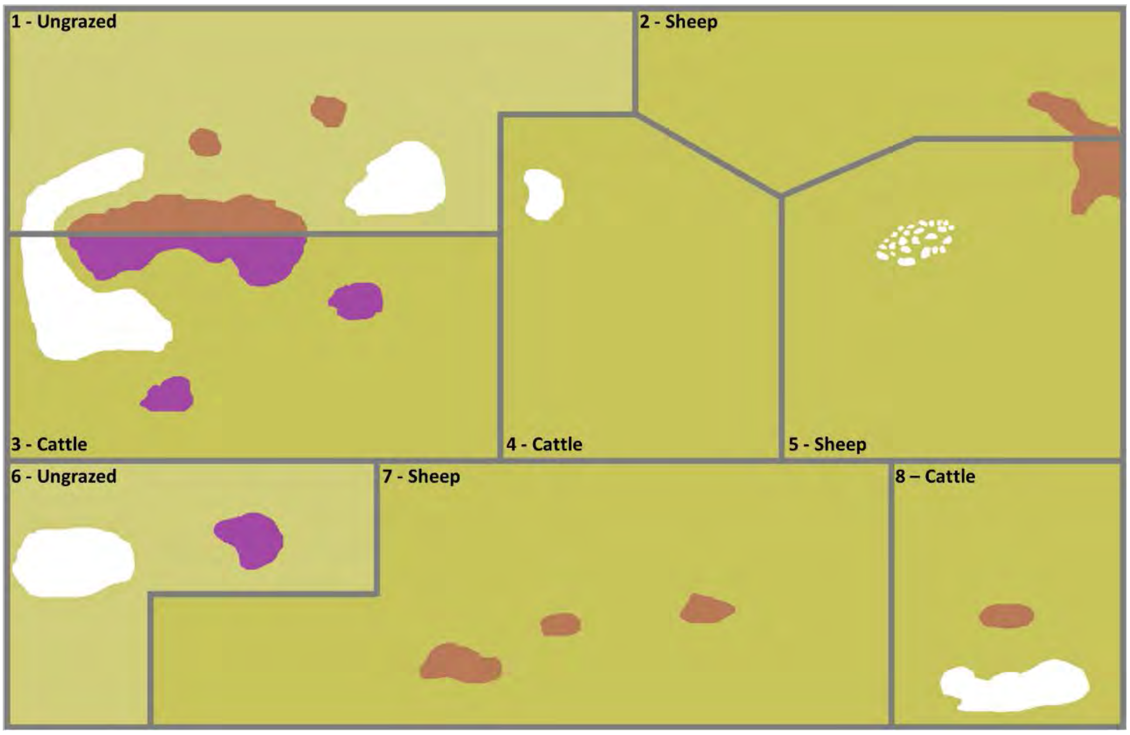
Field Number	Historical Management	Rotation 2	Rotation 3	Rotation 4	Rotation 5
1	Sheep	Ungrazed	Ungrazed	Cattle	Cattle
2	Sheep	Sheep	Sheep	Sheep	Sheep
3	Sheep	Cattle	Cattle	Ungrazed	Ungrazed
4	Cattle	Cattle	Cattle	Cattle	Cattle
5	Sheep	Sheep	Cattle	Cattle	Sheep
6	Ungrazed	Ungrazed	Ungrazed	Ungrazed	Ungrazed
7	Cattle	Sheep	Sheep	Sheep	Ungrazed
8	High Sheep	Cattle	Ungrazed	Ungrazed	Cattle

Figure 3: Idealised calcareous grassland landscape depicting associated habitats within the matrix. ● = calcareous grassland, ● = acid grassland, ● = heath, ○ = limestone pavement. Field numbers relate to those in table 3.

a) **Hypothetical calcareous grassland landscape with grazing types as stated in 'Historical Management' of table 3. Each grazing type has been in place for 10 years.**

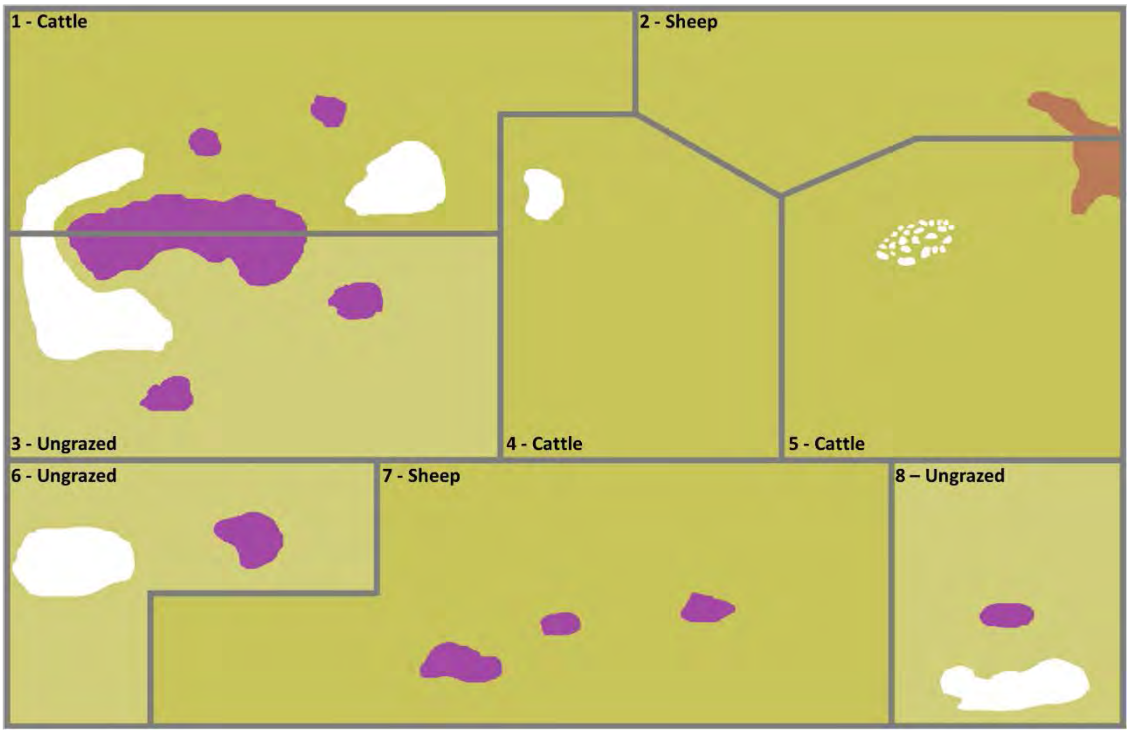


b) **Hypothesised changes in grazing types as stated in 'Rotation 2' of table 3 to encourage protection of limestone pavement flora, development of heather and incorporation of further grassland successional stages. Major changes include:**
Field 1: Removal of grazing to develop successional stages of grassland across the landscape which will also serve to develop structural complexity, protect limestone pavement flora and encourage the development of heather in patches of acid soil.
Field 3: Introduction of cattle in place of sheep to protect limestone pavement flora.
Field 7: Introduction of sheep grazing in place of cattle in order to maintain varied grazing types across the landscape.
Field 8: Replacement of high intensity sheep grazing with cattle grazing to protect limestone pavement flora, restore botanical diversity and increase sward structural complexity.



c) **Hypothesised changes in grazing types as stated in 'Rotation 3' of table 3. Major changes to management include:**
Field 5: Replace sheep grazing with cattle grazing to compensate for the loss of cattle grazing in field 8.
Field 8: Removing cattle grazing to develop further successional stages of grassland across the landscape and thus increase vegetation structural complexity whilst also encouraging heather development on deposits of acid soil.
Note that removal of grazing in field 1 in previous rotations is now leading to heather development.

d) **Hypothesised changes in grazing types as stated in 'Rotation 4' of table 3. Major changes to management include:**
Field 1: Reintroduction of grazing in order to ensure recovery of botanical diversity from the seedbank. Note cattle are recommended here due to the extensive limestone pavement.
Field 3: Removal of grazing to compensate for the reintroduction of grazing in field 1 and to ensure a range of successional stages across the landscape.
Note the expected development of heather over time due to the previous relaxation of grazing in field 8.



e) **Hypothesised changes in grazing types as stated in 'Rotation 5' of table 3. Major changes to management include:**
   Field 5: replace cattle grazing with sheep grazing to ensure varied grazing treatments are maintained across the landscape.
   Field 7: removal of grazing
   Field 8: reintroduction of grazing, again using cattle to protect limestone pavement flora.

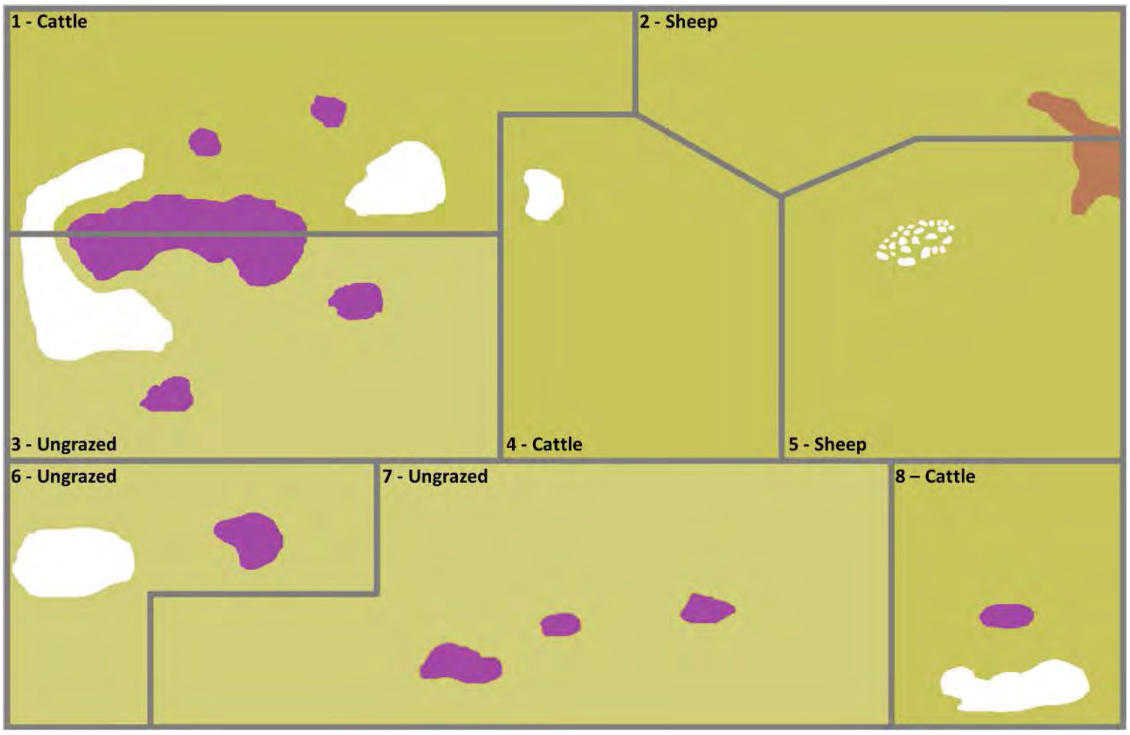


Figure 3 illustrates suggested management of an idealised landscape with the aims of creating varied vegetation structural complexity, development of heather and protection of limestone pavement in order to maximise biodiversity. Although habitat features will not always be as illustrated, the principles of removal and reintroduction of grazing in individual compartments on a rotation, along with the inclusion of both low intensity cattle and low intensity sheep grazing will maximise the biodiversity value of upland calcareous grassland landscapes.

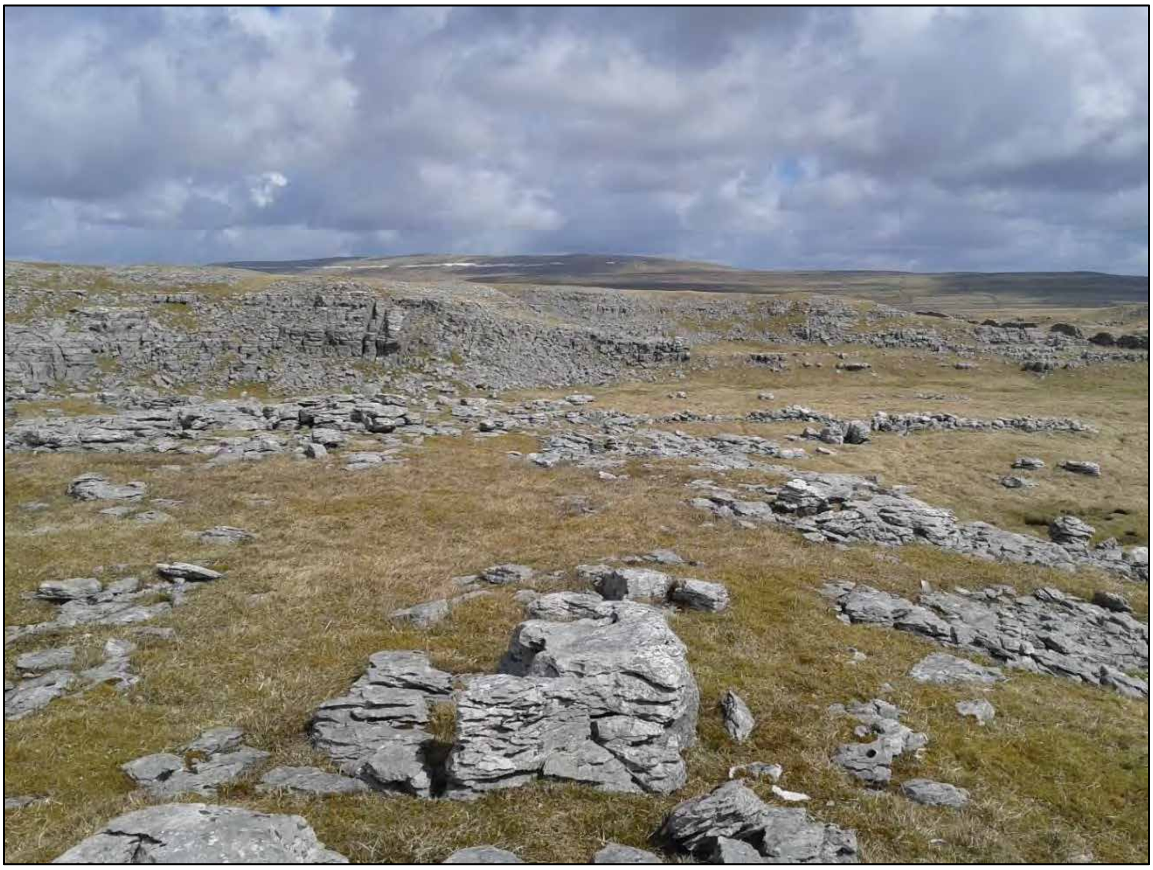
9.0 – Conclusion

The inclusion of a range of grazing treatments across the landscape is import to maximise the biodiversity value of upland calcareous grasslands. This includes increasing the range of successional stages through a rotation of removal and reintroduction of grazing in individual compartments.

It is acknowledged that sheep/cattle mixed grazing is not included in this document. This was beyond the scope of this document as evidence on the impacts of such systems on spiders and ground beetles is not yet available.

It is acknowledged that under the current subsidy system removing grazing from whole fields may be financially detrimental. In such instances, there may be some benefit to biodiversity in fencing off small areas within a field. However, such a suggestion is beyond the scope of this document as there is not yet an evidence base for this.

The importance of monitoring management impacts on a range of taxonomic groups is stressed as they do not always respond in the same way, as evidenced in this document with spiders, ground beetles and plants.



Upland calcareous grassland with exposed limestone. Location: Fells above Cool Scar Quarry, Kilnsey, North Yorkshire. ©Ashley Lyons

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Appendix – Calculation of stocking levels

Stocking levels in the text are calculated as:

Annual Equivalent Stocking Density = (N * GLU/H)*(M/12)

Where: N = Number of individuals, GLU = Grazing Livestock Unit (see table A1 below), H = Hectares and M = Number of months grazed.

Animal	Grazing Livestock Unit (GLU)
Dairy cow	1
Beef cow (excluding calf)	0.75
Heifers in calf (rearing)	0.80
Bulls	0.65
Upland ewes	0.08
Tups	0.08

Table A1: Grazing livestock units (GLU) (or cow equivalents) are ratios based on feed requirements of different livestock types. GLUs here are taken from Nix (2004).

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