Appendix C - Lowland grassland habitats

Jefferson, R.G., Curson, J., Drewitt, A., Cox, J., Taylor, I. and Howe, C.

Preamble

Lowland semi-natural grasslands are largely the product of human activity, having originally been created by woodland clearance and wetland drainage to provide fodder for domestic stock. Macrobotanical evidence indicates that species-rich grasslands became especially prominent in the landscape from the Iron Age onwards (French 2017). However, it is likely that analogues of many of these grasslands will have existed in the landscape prior to the advent of settled agriculture in the Neolithic period. Their extent and position in the landscape though, may have been different to the situation post-Neolithic through to the present day.

Lowland grassland occurs either in enclosed or unenclosed situations but typically below the upper level of agricultural enclosure in any area, and, usually below 300m. The definition excludes grasslands on coastal sand and shingle, intertidal saltmarsh and maritime cliff communities. Grazing and cutting for hay have been important factors in their maintenance. However, the occurrence and species composition of the different types of semi-grassland is strongly influenced by natural physical environmental factors such as geology, soils, hydrology and climate.

Lowland grasslands and related habitats fall into six main broad (Priority) types.

- Lowland calcareous grassland
- Lowland dry acid grassland
- Lowland meadows
- Upland hay meadows
- Purple moor-grass & rush pastures
- Calaminarian grassland

Further detailed information on the composition, management, ecology and conservation of semi-natural grasslands can be found in Bullock *et al*. (2011), Jefferson *et al.* (2014), Crofts & Jefferson (1999), Robertson and Jefferson (2000), Rothero *et al*. (2016) and volumes of *British Plant Communities* (the National Vegetation Classification) edited by J.S. Rodwell (1991-2000).

C1. Lowland calcareous grassland

C1.1 Introduction

Lowland calcareous grasslands occur throughout England on mostly shallow, infertile lime-rich soils over chalk and limestone bedrock. They are occasionally found on other base-rich substrates such as basic igneous rocks and calcareous glacial drift deposits. These grasslands may be either unenclosed or enclosed, with many now being confined to steep valley slopes, escarpments, and coastal cliffs and headlands. More rarely they may occur on relatively level ground such as in the East Anglian Breckland and Salisbury Plain. They are usually managed by extensive livestock grazing by sheep and cattle. The grasslands comprise ten National Vegetation Classification types (CG1-CG10) (Rodwell 1992) all of which are plant species-rich (c 20-40 species 4m^2) when under favourable management. The current extent of the resource in England is around 38, 000 ha

C1.2 Ecological position in the landscape and influence of abiotic and biotic processes

The occurrence of lowland calcareous grassland in the rural landscape is largely determined by the occurrence of suitable calcareous geology and soils (rendzina or calcareous brown earths with a pH in the range 6.5 to 8.5) with individual species composition especially influenced by climate and microclimatic factors. The species composition is in turn, controlled by geographical location, altitude, topography and aspect. That said, there are examples of where the former quarrying of chalk or limestone, the creation of man-made structures using calcareous rock (e.g. railway embankments) or even the deposition of calcareous industrial wastes (Lee and Greenwood 1976) has resulted in the development, by natural colonisation, of calcareous grassland with very close affinities to 'ancient 'calcareous grassland (Jefferson and Usher 1986). In some cases, these dry grasslands may have developed in areas beyond their natural range due to the exposure of limestone substrates that may previously have been covered by drift or overburden.

C1.3 Human modification and impact

Similar vegetation to present day calcareous grassland was probably present in the early Holocene where it would probably have occurred on steep slopes, thin soils or exposed terrain preventing tree growth and/or maintained by native herbivores in glades amongst woodland. The limited evidence available supports this hypothesis (Bush and Flenley 1987). The clearance of forest in the Neolithic period onwards for pastoral agriculture would have led to an expansion of such grassland on suitable substrates.

Subsequently, these unproductive grasslands will have had a long history of pastoral agricultural management typically used for sheep or cattle rearing.

In the last 60 years or so these semi-natural lowland grasslands have been a particular focus for the processes of agricultural intensification. These changes have involved conversion of grassland to arable, intensification by ploughing and reseeding and improvement with fertilisers and herbicides. Thus, large areas of lowland calcareous grassland have been lost during this period, though it is rarely possible to provide accurate figures. In addition, losses of calcareous grassland to arable cultivation also predate the post-war agricultural revolution and Keymer and Leach (1990) provide some tentative figures of losses from the early 1800's to the 1980's.

Losses have also led to fragmentation of the habitat such that many sites are now small in extent. In England, it is estimated that 85% of lowland calcareous grasslands are less than 10 ha (Bullock *et al.* 2011).

Island biogeography theory predicts that the decreasing extent and fragmentation of semi-natural grasslands over the last 50-100 years will ultimately result in losses of species from remaining areas of grassland habitat. Long transient times in response to decreasing habitat area and increasing isolation due to fragmentation may cause the present plant (and animal) species distribution to reflect the historical rather than the present landscape configuration. Hence, current species populations are possibly not yet in equilibrium with the current landscape configuration but are rather reflecting historical fragment layout. Therefore, this time lag in species response may have created a so-called extinction debt resulting in species still occupying habitat fragments in which they eventually will disappear (see for example Tilman *et al.* 1994).

Although the reality of extinction debt has not been demonstrated for grasslands in England/UK, the principles outlined in Lawton *et al.* (2010) of 'better, bigger and more joined' up should be applied. Also, practically, at an individual site level, species populations on small or isolated patches are undoubtedly at a greater risk of extinction for a number of reasons: increased ratio of edge to area increases their susceptibility to external factors such as fertiliser drift; increased probability that stochastic events such as drought and fire will cause extinction across the entire site; tendency to be at greater risk of deterioration in habitat quality over time and their dependence on migrants from larger habitat patches to maintain viable populations.

There is ecological evidence of the negative effects of fragmentation and isolation on the populations of some of the characteristic vascular plants of this and other semi-natural grassland habitats through, for example, genetic erosion.

Table C1. Prevalence of state ('natural function') within the habitat resource: lowland calcareous grassland

State of naturalness	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
High	High	Moderate	Moderate	Moderate	High
Moderate	Low (none)	Moderate	Moderate	Moderate	Low
Low	Low (none)	Low	Low	Low	Low
Confidence	*High*	*Moderate*	*Moderate*	*High*	*High*
Comments	*Hydrology not a key process for a dry habitat over chalk/limestone bedrock*	*Point nutrient pollution and atmospheric N deposition There is relatively good information on the impacts of nutrient inputs on semi-natural grasslands*	*Soil 'health' currently generally moderate to high for calcareous grasslands*	*Main issue is lack of grazing and sometimes too much uniformity of the sward due to inappropriate grazing regimes*	*Invasive non-native species are only a local problem e.g. invasion by Cotoneaster species*

C1.4 Habitat mosaics

Calcareous grasslands typically form mosaics with scrub and woodland communities (such as NVC types W8 *Fraxinus excelsior-Acer campestre -Mercurialis perennis* woodland, W9 *Fraxinus excelsior Sorbus aucuparia-Mercurialis perennis*, W12 *Fagus sylvatica- Mercurialis perennis* woodland, W13 *Taxus baccata* woodland and W21*Crataegus monogyna-Hedera helix* scrub). These mosaics and transitions are mediated by past and current management which is usually related to grazing pressure, including cessation. Where soil type changes, due to drift or head deposits over calcareous rocks, then mosaics may be formed with neutral and acid grasslands. Spring lines at the base of chalk or limestone slopes or escarpments may give rise to mire or wetland communities such as M22 *Juncus subnodulosus-Cirsium palustre* fen-meadow or M10 *Carex dioica-Pinguicula vulgaris* mire).

In general terms, mosaics involving other habitats are more highly valued in conservation assessments (e.g. Jefferson *et al.* 2014) and provide an important resource for species (especially invertebrates) that may require a range of habitats or habitat patches to complete their life cycle (Webb *et al.* 2010).

At a smaller scale, calcareous grasslands may support microhabitats such as short or long turf, grass tussocks, patches of bare ground, rock outcrops and scrub of different age classes.

C1.5 Potential for restoration of natural function

The most common cause of unfavourable condition of existing sites is a lack of or inappropriate grazing. This can be readily addressed although practical reasons relating to the availability of grazing animals or the need for associated infrastructure (fencing, water supply, access etc.) can hinder progress. In some cases, nutrient enrichment from local point sources can result in unfavourable conditions which can take several decades to reverse depending on the level of intervention. Calcareous grasslands are less prone than some other types of semi-natural grassland to the impact of atmospheric nitrogen deposition as they are P-limited systems.

Restoration and creation of new calcareous grasslands has been the focus of activity as a result of Biodiversity Action planning and agri-environment schemes over the last 20 years. The targeting and methodology of grassland habitat restoration is now well understood due to a considerable body of research effort (see Pywell *et al.* 2012).

There are many examples of successful restoration (e.g. Wilson *et al*. 2013) although the timescales for such grasslands to resemble 'ancient' examples, at least in terms of their floristic composition, may take up to a century (Redhead *et al.* 2014).

The best examples of restoration though are where very infertile, exposed calcareous substrates border or are surrounded by existing calcareous grassland. These appear to readily re-colonise naturally over time.

It is important to stress that some calcareous grasslands may have historically had periods under arable cultivation before being allowed to tumble back to grassland such as during the mediaeval period. However, conditions for re-colonisation by calcareous grassland species and re-assembly of grassland community structure was much more favourable prior to the 20th Century. For example, the nutrient status of soils would have been lower and there would have been more existing habitat to provide nearby sources for re-colonisation.

Table C2. Restoration of 'natural function': lowland calcareous grassland.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	No	Yes	Yes	Yes	Yes
Comments	Hydrology not generally a significant issue for this habitat but see constraints below	Reduce or eliminate excess nutrients above critical load	Soil structure and soil biota is typical of habitat in favourable condition	Grazing levels sufficient to maintain the chalk grassland ecosystem including sward heterogeneity and appropriate stocking levels and structure of scrub. Avoidance of undergrazing/overgrazing	Needed to restore semi-natural species assemblages.
Conservation constraints	Certain associated habitats may be hydrologically 'dependent' such as calcareous flushes and springs	'Natural' nutrient levels are generally a shared conservation goal across all habitats and species	None	Potential conflicts with objectives for scrub/woodland habitats occurring in a mosaic	None

C2. Lowland acid grassland

C2.1 Introduction

These grasslands occur on non-calcareous substrata such as sandstones and igneous rocks, or over sands and gravel deposits. They can also occur over calcareous strata where leaching of bases occurs in area of high rainfall or where drift overlies the country rock. Lowland acid grassland can occur in a wide variety of topographical situations ranging from level plains such as in the East Anglian Breckland to steep valley slopes, and are especially frequent in the upland fringes. Away from the uplands, they seldom occur in large areas in isolation.

They are usually managed by extensive livestock grazing by sheep and cattle. The grasslands comprise three main National Vegetation Classification types (U1 *Festuca ovina-Agrostis capillaris-Rumex acetosella* grassland, U3 *Agrostis curtisii* grassland & U4 *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland) (Rodwell 1992). The plant species-richness ranges considerably between types and localities but can range from rather species-poor (5 species /4m^2) to species rich (25 species/4m^2) when under favourable management. The current extent of the resource is estimated to be less than 20, 000 ha.

C2.2 Ecological position in the landscape and influence of abiotic and biotic processes

The occurrence of the various types of lowland acid grassland is determined by similar factors to calcareous grassland, that is occurrence of suitable substrate of acid rocks or superficial deposits such as sands and gravels and soils that are typically infertile with pH less than 5 and range from being summer parched to moist in character. Individual species distribution and community composition is also influenced by climate and microclimatic factors. As with lowland calcareous grassland, additional areas, sometimes in areas which would not have originally supported the habitat, have developed in old quarries and pits and on substrates such as acid mine waste spoil heaps.

C2.3 Human modification and impact

As with calcareous grassland, it is likely that acid grasslands were present in the post-glacial landscape, at least locally on suitable substrates, prior to the development of human agriculture although their species composition may have changed over the last 10, 000 years.

These grasslands are typically agriculturally unproductive and are thus most suitable for extensive livestock grazing, like their calcareous counterparts.

As with other types of semi-natural grasslands (Section C1.3), there have been large losses of acid grasslands, though it is rarely possible to provide accurate figures (Sanderson 1998). Losses have also led to fragmentation of the habitat such that many sites are now small in extent. In England, it is estimated that around 80% of lowland dry acid grasslands are less than 10 ha (Bullock *et al.* 2011).

Decreasing extent and fragmentation, according to predictions from island biogeography theory, will result in losses of species from remaining areas of grassland habitat through so-called 'extinction debt' (Tilman *et al.* 1994). See Section C1.3 above for more detail.

Table C3. Prevalence of state ('natural function') within the habitat resource: lowland acid grassland.

State of naturalness	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
High	High	Moderate	Moderate	Moderate	High
Moderate	Low (none)	Low	Moderate	Moderate	Low
Low	Low (none)	Moderate	Low	Low	Low
Confidence	*High*	*Moderate*	*Moderate*	*High*	*High*
Comments	*Hydrology not a key process for a dry habitat over acid rocks/superficial deposits*	*Point nutrient pollution and atmospheric N deposition There is relatively good information on the impacts of nutrient inputs on semi-natural grasslands*	*Soil 'health' is currently generally moderate for acid grasslands*	*Main issue is lack of grazing and sometimes inappropriate grazing regimes*	*Invasive non-native species are only a local problem*

C2.4 Habitat mosaics

Acid grasslands typically form mosaics with scrub and woodland communities (such as NVC types W10 *Quercus rober-Pteridium aquilinum-Rubus fruticosus* woodland, W15 *Fagus sylvatica-Deschampsia flexuosa* woodland, W16 *Quercus* spp.-*Betula* spp.- *Deschampsia flexuosa* woodland, W23 *Ulex europaeus-Rubus fruticosus* scrub and W25 *Pteridium aquilinum-Rubus fruticosus* underscrub) and stands of bracken (U20 *Pteridium aquilinum-Galium saxatile* community). These mosaics are mediated by past and current management which are usually related to grazing pressure, including cessation but also factors such as topography, exposure and soil depth. In addition, mosaics and transitions to lowland heathland (e.g. NVC types H1 *Calluna vulgaris-Festuca* *ovina* heath, H2 *Calluna vulgaris-Ulex minor* heath, H3 *Calluna vulgaris-Agrostis curtisill* heath and H9 *Calluna vulgaris-Deschampsia flexuosa* heath) may occur which probably relate to edaphic and management factors.

Where acid sands patchily overlie calcareous rocks such as in the Brecks, then complex mosaics of the two types of grassland may occur. Mosaics and transitions may also be formed with neutral grasslands, mediated by soil type but also by agricultural treatment such as input of fertilisers.

In general terms, mosaics involving other habitats are more highly valued in conservation assessments (e.g. Jefferson *et al.* 2014) and provide an important resource for species (especially invertebrates) that may require a range of habitats or habitat patches to complete their life cycle (Webb *et al.* 2010).

At a smaller scale, acid grasslands may support microhabitats such as short or long turf, grass tussocks, patches of friable sandy bare ground, rock outcrops, and scrub of different age classes.

C2.5 Potential for restoration of natural function

The most common cause of unfavourable condition of existing sites is a lack of or inappropriate grazing. This can be readily addressed although practical factors relating to the availability of grazing animals or the need for associated infrastructure (fencing, water supply, access etc.) can hinder progress. In some cases, nutrient enrichment from local sources can result in unfavourable conditions which can take several decades to reverse depending on the level of intervention. Acid grasslands have been shown to be susceptible to atmospheric nitrogen deposition which has caused negative changes in species composition (Stevens *et al*. 2010).

Restoration and creation of new acid grasslands has been the focus of activity as a result of Biodiversity Action planning and agri-environment schemes over the last 20 years. The targeting and methodology of grassland habitat restoration is now well understood due to a considerable body of research effort (see Pywell *et al.* 2012).

There are some examples of successful restoration (Hewins 2012, Wilson *et al.* 2013) although the timescales for such grasslands to resemble ‘ancient’ examples may be measured in decades. The best examples of restoration though are where very infertile, exposed acid substrates border or are surrounded by existing acid grassland. These appear to readily re-colonise naturally over time.

Some acid grasslands, such as those on sandy soils in the Brecklands, may have historically had periods under arable cultivation before being allowed to tumble back to grassland. However, conditions for re-colonisation by acid grassland species and re-assembly of grassland community structure was much more favourable prior to the 20th Century. For example, the nutrient status of soils would have been lower and there would have been more existing habitat to provide nearby sources for re-colonisation.

Table C4. Restoration of ‘natural’ function: lowland dry acid grassland.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	No	Yes	Yes	Yes	Yes
Comments	Hydrology not generally a significant issue for this habitat	Reduce or eliminate excess nutrients above critical load	Soil structure and soil biota is typical of habitat in favourable condition	Grazing levels sufficient to maintain the acid grassland ecosystem including sward heterogeneity and appropriate stocking levels and structure of scrub. Avoidance of undergrazing/cessation of grazing/overgrazing	Needed to restore semi-natural species assemblages.
Conservation constraints	None	‘Natural’ nutrient levels are generally a shared conservation goal across all habitats and species	None	Potential conflicts with objectives for scrub/woodland habitats occurring in a mosaic	None

C3. Lowland meadows

C3.1 Introduction

These occur mostly within enclosed field systems on free-draining or moist infertile or moderately fertile brown soils such as clay loams, with pH in the range 5.0 to 6.5. Taken together, they once covered a large proportion of lowland Great Britain. However, individual areas are now small in extent, seldom exceeding 10ha, and are highly fragmented. They comprise 3 main National Vegetation types MG4 *Alopecurus pratensis-Sanguisorba officinalis* grassland, MG5 *Cynosurus cristatus-Centaurea nigra* grassland and MG8 *Cynosurus cristatus-Caltha palustris* and related types. They are usually managed as hay meadow or as pasture although some types are maintained solely by cutting or episodic grazing. The current extent of the resource is less than 8, 000 ha.

C3.2 Ecological position in the landscape and influence of abiotic and biotic processes

The soils of the component lowland meadow types are often developed over superficial deposits (e.g. head deposits, drift, till or alluvium) and are brown earths including clay loams, usually with a pH in the range 5.0 to 6.5. The damper MG8 may occur over gleyed brown earths with humic profiles.

The drier type of lowland meadow – MG5 – can potentially occur anywhere in the lowland landscape and upland fringes where relatively infertile, neutral soils occur and there is an appropriate management of cutting and or grazing. In addition to the agricultural landscape, such grasslands have developed over time in artificial situations such as on road and railway verges, and in churchyards.

Both dry (MG5 *Cynosurus cristatus-Centaurea nigra grassland*) and damper types (MG4 *Alopecurus pratensis-Sanguisorba officinalis* grassland and MG8 *Cynosurus cristatus-Caltha palustris* grassland) may, at least in some situations, have been originally ‘won’ from different vegetation (dwarf shrub heath, acid and calcareous grassland and fens or mires) by enclosure, limited drainage, manuring and liming. MG4 and lowland types of MG8 are largely confined to flood plains in the lowlands with periodic winter flooding or seasonally high water tables but the meadow grassland is also maintained by an efficient artificial surface drainage system. Some sites are underlain by river-terrace deposits of coarse sand or gravel which may supply water during summer by sub-irrigation and facilitate sub-surface drainage in winter.

C3.3 Human modification and impact

The origin of lowland old meadows and pastures is unclear and received wisdom has tended to consider such grasslands as an artefacts of post-Neolithic farming. However, it is not inconceivable that meadow-like vegetation communities analogous to modern-day examples, at least of MG5 and MG8, may have existed prior to the Neolithic period (Ingrouille 1995, Peterken 2009). However, there is no doubt that many are the product of historic interventions such as drainage, liming and manuring with subsequent management by grazing and/or cutting.

As with other types of semi-natural grasslands (Section C1.3) there have been large losses of lowland meadows, though it is rarely possible to provide accurate figures. For example, a survey of Berkshire's neutral grassland in 1995 (previously surveyed between 1984 and 1987), showed that 50% of sites (60% by area) had been damaged or destroyed (Redgrave 1995).

Losses have also led to fragmentation of the habitat such that many sites are now small in extent. In England it is estimated that around 80% of lowland meadow grasslands are less than 5 ha (Bullock *et al* 2011). Decreasing extent and fragmentation, according to predictions from island biogeography theory, will result in losses of species from remaining areas of grassland habitat through 'extinction debt' (Tilman *et al.* 1994). See Section C1.3 above for more detail.

Table C5. Prevalence of state ('natural function') within the habitat resource: Lowland meadows.

State of naturalness	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
High	Moderate - High	Moderate-High	Moderate	Moderate	High
Moderate	Low -Moderate	Moderate	Moderate	Moderate	Low
Low	Low	Low	Low	Low	Low (none)
Confidence	*Moderate*	*High*	*Moderate*	*High*	*High*
Comments	*A range of issues may affect the wetter types of lowland meadows including excessive flooding, lack of maintenance of drainage features, water abstraction*	*Point nutrient pollution, excessive agricultural inputs via fertilisers and atmospheric N deposition There is relatively good information on the impacts of nutrient inputs on semi-natural grasslands*	*Soil 'health' is currently generally moderate for lowland meadow grasslands*	*Main issue is lack of aftermath grazing and sometimes inappropriate cutting regimes or none*	*Invasive non-native species are rarely problem*

C3.4. Habitat mosaics

Lowland meadow neutral grasslands can form mosaics with a wide range of other grassland types and other habitats depending on the landscape context in which they occur. In flood plains, MG4 and MG8 may form transitions to drier MG5 grassland or to wetter grassland, mire, fen and swamp communities such as MG11 *Festuca rubra-Agrostis stolonifera-Potentilla anserina* grassland and MG13 *Agrostis stolonifera-Alopecurus geniculatus* grassland, M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture and S5 *Glyceria maxima* swamp and occasionally wet woodland.

MG5 grassland may form the upslope vegetation from marshy grasslands (M23, M24 *Molinia caerulea-Cirsium dissectum* fen-meadow) on drier soils or conversely may juxtapose calcareous grassland where deeper less alkaline soils occur over calcareous rocks.

However, a high proportion of MG5 sites occur as isolated fragments in intensively farmed landscapes of improved grassland and/or arable. In these situations it is rare for the habitat to form mosaics or transitions to other habitats except perhaps limited amounts of scrub and hedgerow.

In general terms, mosaics involving other habitats are more highly valued in conservation assessments (e.g. Jefferson *et al.* 2014) and provide an important resource for species (especially invertebrates) that may require a range of habitats or habitat patches to complete their life cycle (Webb *et al.* 2010).

At a smaller scale, those types of lowland meadows that may be managed as pasture (MG5 and MG8) may support microhabitats such as short or long turf, grass tussocks, bare ground, scrub of different age classes and, for MG4 and MG8, habitats associated with grips and drains. Those managed as hay meadows have generally fewer microhabitats due to the nature of the management (see Jefferson and Porter 2014).

C3.5 Potential for restoration of natural function

Lowland meadows are arguably some of the most anthropogenic of the English semi-natural grasslands given their likely origins and maintenance by relatively intensive but traditional agricultural management. This means that the concept of 'natural function' is much less applicable for these habitats which are valued for their cultural value in addition to their high biodiversity value. However, they are still dependent on well-structured, relatively infertile soils which retain fungi-dominated soil microbial communities. They are also dependent on continuation of some form of vegetation management of grazing and/or cutting.

The most common cause of unfavourable condition of existing meadow sites is often a lack of aftermath grazing. For pastures, this can be readily addressed although practical reasons relating to the availability of grazing animals or machinery or the need for associated infrastructure (fencing, water supply, access etc.) can hinder progress. In some cases, nutrient enrichment from local sources can result in unfavourable conditions which can take several decades to reverse depending on the level of intervention. These grasslands may also be susceptible to atmospheric nitrogen deposition which leads to negative changes in species composition.

The maintenance of surface drainage systems for rapidly removing water from sites is critical for ensuring the floodplain meadow types (principally MG4 but also MG8) are not replaced by inundation grassland or swamp communities (Crofts and Jefferson 1999, Rothero *et al.* 2016).

Many floodplain meadows occur on floodplains with highly modified river or stream systems that have been straightened, re-profiled and embanked. Increasingly there are initiatives designed to restore more naturally-functioning river systems. In such cases, there may be a risk that areas of floodplain meadow may be negatively impacted in their current position on the floodplain. This should not debar river restoration but careful consideration will need to be given as to how to conserve floodplain meadow interest within a more dynamic river-floodplain habitat mosaic. An approach will be needed that accepts a dynamic picture of habitat loss and creation as the river moves across the floodplain. Consideration also needs to be given to the potential for adverse effects caused by inundation with heavily enriched river water – restoration of more natural nutrient status in the river may be needed.

Restoration and creation of new lowland meadow grasslands has been the focus of activity as a result of Biodiversity Action planning and agri-environment schemes over the last 20 years. The targeting and methodology of grassland habitat restoration is now well understood due to a considerable body of research effort (see Pywell 2012).

There are many examples of successful restoration of lowland meadows (Hewins 2012, Wilson *et al.* 2013, Rothero *et al.* 2016) although the timescales for such grasslands to resemble 'ancient' examples may be measured in many decades (Gibson 1998).

Table C6. Restoration of 'natural function': lowland meadows.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes where relevant	Yes	Yes	Yes	Yes
Comments	For wet types (MG4 & MG8) restoration of low – level water course management may be required (see Section C3.5)	Reduce or eliminate excess nutrients above critical load	Soil structure and soil biota is typical of habitat in favourable condition	Grazing levels sufficient to maintain the lowland meadows ecosystem including sward heterogeneity. Avoidance of undergrazing/cessation of grazing/overgrazing	Needed to restore semi-natural species assemblages.
Conservation constraints	Yes potentially - See Section C3.5	'Natural' nutrient levels are generally a shared conservation goal across all habitats and species.	None	Need to harmonise with objectives for breeding/wintering waterfowl on wet meadows	None

C4. Upland hay meadows

C4.1 Introduction

Upland hay meadows and related vegetation are confined to upland landscapes between 200 and 400m on flat or gently sloping ground on relatively infertile neutral soils, with climate being a factor in maintaining their particular species composition. There are major concentrations in the north Pennine and Cumbrian Dales. Typically they are now often small in extent and highly fragmented. The meadow sites are typically managed as part of upland hill farming systems with a July hay cut and both spring and autumn grazing by sheep and/or cattle with periodic dressings of low levels of farmyard manure. The grassland conforms to MG3 in the National Vegetation Classification (Rodwell 1992) but in some cases may occur in association with damper neutral grassland and mires (see Section C4.4). The current extent of the resource is less than 1000 ha.

C4.2 Ecological position in the landscape and influence of abiotic and biotic processes

Upland hay meadow and allied vegetation conforming to NVC MG3 occurs in valley grasslands, road verges and on river-banks and in open woodland.

The habitat occurs on relatively infertile, neutral (pH 5.1 to 6.6) loamy brown earths or calcareous brown earths soils which may be free-draining or partially gleyed and prone to winter water logging. Where the vegetation occurs in enclosed fields, it has usually been subject to farming practices, particularly the addition of liming materials and low levels of fertilisers and, in some cases, the installation of sub-surface drainage.

C4.3 Human modification and impact

The origin of upland old meadows is somewhat unclear but there is no doubt that many in agricultural settings are the product of historic interventions such as drainage, liming and manuring. Some have been 'won' from different vegetation (dwarf shrub heath, acid grassland and fens or mires) by enclosure, limited drainage, manuring and liming. Others may have developed from the field layer of open woodland by canopy clearance and cutting and grazing. Vegetation analogous to upland hay meadows still occurs in open woodlands such as W7 *Alnus glutinosa-Fraxinus excelsior-Lysimachia nemorum* woodland and W9 *Fraxinus excelsior-Sorbus aucuparia-Mercurialis perennis* woodland, on riversides and on steep slopes or cliff ledges but is mostly of small extent. Also, roadsides verges support vegetation akin to upland hay meadows albeit with a higher tall-herb content due to the less intensive management compared to enclosed meadows which are hay cut and grazed in spring and autumn.

As with other types of semi-natural grasslands (Section C1.3), there have been large losses of upland meadows, though it is rarely possible to provide accurate figures (Jefferson 1985). Losses have also led to fragmentation of the habitat such that any sites are now small in extent. In England, it is estimated that around 86% of upland meadow grasslands are less than 5 ha (Bullock *et al*. 2011).

Decreasing extent and fragmentation, according to predictions from island biogeography theory, will result in losses of species from remaining areas of grassland habitat through 'extinction debt' (Tilman *et al.* 1994). See Section C1.3 above for more detail.

Table C7. Prevalence of state ('natural function') within the habitat resource: Upland meadows

State of naturalness	Hydrology	Nutrients	Soil/ sediment	Vegetation control	Species composition
High	High	Low	Low	Moderate	High
Moderate	Low	Moderate	Moderate	Moderate	Low (none)
Low	Low	Moderate	Low	Low	Low (none)
Confidence	*Moderate*	*High*	*Moderate*	*High*	*High*
Comments	*Hydrology is a potential issue for some of the habitats associated with upland hay meadows such as wet grassland (MG8), purple moor-grass/rush pastures (M26) & alkaline fen (M10)*	*Excessive agricultural inputs via fertilisers and atmospheric N deposition continue to be a significant reason for unfavourable condition of sites. There is relatively good information on the impacts of nutrient inputs on semi-natural grasslands*	*Soil 'health' is currently generally moderate for upland meadow grasslands*	*Main issue is too intensive spring grazing and trend towards later 'shut up' dates both of which can have negative impacts on species-richness*	*Invasive non-native species are rarely problem*

C4.4 Habitat mosaics

On wetter ground, these meadows are accompanied or replaced by MG8 *Cynosurus cristatus-Caltha palustris* grassland , whereas steeper banks in the meadows that have somewhat less base-rich and more free-draining soils, may support species-rich vegetation such as the U4 *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland: *Lathyrus montanus-Stachys betonica* sub-communty (U4c).

In addition, two mire communities can occur in association with MG3 upland meadow. In locally flushed places, there is often M10 *Carex dioica-Pinguicula vulgaris* small sedge mire and, more rarely on deeper organic soils, species-rich M26 *Molinia caerulea-Crepis paludosa* mire may occur.

In the limited areas where the vegetation occurs away from enclosed meadows, such as on river sides or roadside banks, transitions to or a mosaic with dwarf shrub, scrub (W21) and woodland communities may occur.

The MG3 vegetation managed as hay meadows will have generally fewer microhabitats due to the nature of the management (see Jefferson and Porter 2014). More near-natural examples on river margins or open woodland will generally be more favourable for a suite of invertebrates but will not support the breeding bird assemblages (especially waders) associated with managed meadows.

C4.5 Potential for restoration of natural function

Upland meadow MG3 vegetation, at least where it occurs in meadows (a high proportion of the resource) is dependent on maintenance by relatively intensive but traditional agricultural management. This means that the concept of ‘natural function’ is much less applicable for a large part of the resource and which is valued for its cultural value in addition to nature conservation value. However, it is still dependent on well-structured relatively infertile soils which retain fungi-dominated soil microbial communities. It also requires a continuation of some form of vegetation management of grazing and/or cutting.

The most common cause of unfavourable condition of existing meadow sites is excessive inputs of nutrients from agricultural or atmospheric sources. This can, in theory, be readily addressed when from agricultural sources but restoration of favourable condition can take several decades depending on the level of intervention.

Maintaining the condition of existing meadow sites has proved challenging due to the range of pressures facing this habitat including nutrient enrichment from agricultural or atmospheric sources, changes in management such as increased grazing pressure, later hay meadow shut up times and, potentially climate change (Jefferson 2005, Smith *et al.* 2017).

One school of thought is that more effort should be put into maintaining and restoring more near-natural examples in suitable localities including on upland river banks and slopes or glades in woodland rather than continuing to invest effort in maintaining this vegetation in meadow environments (Clare Pinches pers comm). In addition, consideration could perhaps be given to a re-appraisal of cutting and aftermath grazing as the ‘desired management regime’ across the whole resource at least in agriculturally-managed fields. One example, might be to manage some by extensive grazing in a manner that benefits both the botanical composition but other taxa such as invertebrates and birds.

Restoration of upland meadow grasslands has been the focus of activity as a result of Biodiversity Action planning and agri-environment schemes over the last 20 years. The targeting and methodology of grassland habitat restoration is now well understood due to a considerable body of research effort (see Pywell 2012).

There are examples of successful restoration of upland meadows from semi-improved swards due to series of externally funded projects and initiatives in the North Pennines, Yorkshire Dales and Cumbria (see for example Gamble 2010). The timescales for such grasslands to resemble ‘ancient’ examples may be measured in many decades.

Table C8. Restoration of ‘natural function’: upland meadows.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Yes	Yes
Comments	Mostly applies to mosaic habitats (NVC types MG8, M10 and M26)	Reduce or eliminate excess nutrients above critical load. FYM application levels should follow best practice guidance.	Soil structure and soil biota is typical of habitat in favourable condition	Grazing levels sufficient to maintain the upland meadows ecosystem including sward heterogeneity. Avoidance of undergrazing/cessation of grazing/overgrazing in spring/autumn. Cutting dates should follow best practice guidance	Needed to restore semi-natural species assemblages.
Conservation constraints	None	‘Natural’ nutrient levels are generally a shared conservation goal across all habitats and species	None	Need to harmonise with objectives for breeding waders, where relevant	None

Although all grasslands support high number of invertebrates, upland grasslands are relatively species-poor, compared with lowland grasslands; Pantheon recognises some 250 species that are associated with upland grasslands and moors, compared with the more than 2800 associated with taller swards with scrub and nearly 1350 associated with short sward/ bare ground in lowland grasslands. This is due both to altitude and latitude: upland grasslands are, by their nature, cooler than their lowland counterparts, and they also tend to occur in northern Britain, which also makes them cooler and less sunny, as well as being outside the geographical range of many of the invertebrates of southern UK.

The fact that upland grasslands tend to be managed relatively intensively, and are largely grazed by sheep (which as described under calcareous grasslands, tend to reduce the structural heterogeneity) means that they are often less structurally diverse and do not have the same intricate pattern of small-scale mosaics (with bare ground patches, short sward and longer tussocks intermixed) and this will further reduce both the species diversity and the biomass.

There are some species which are specialists of upland grasslands, for example the Mountain Bumblebee *Bombus monticola* and the beetle *Ctenicera pectinicornis*. Mountain Bumblebee occurs in such grasslands as well as in the moorlands with which it is more often associated. It seems to be reliant on areas where bilberry is plentiful, whether on grassland or moorland, as this is a major nectar/ pollen source. *Ctenicera pectinicornis* seems to be reliant on flower-rich upland meadows, further demonstrating the importance of high quality grasslands for invertebrates.

In terms of management for invertebrates, the same principles apply here as they do for lowland hay meadows. Structural heterogeneity is important to maintain the full suite of invertebrates associated with the habitat and so aftermath grazing of meadows by cattle as well as/ or instead of, sheep will be better for invertebrates and the grazing should not be so intensive that this structural heterogeneity is decreased or destroyed. Upland pastures should be cattle grazed where possible, and summer grazing at low density will be beneficial.

C5. Purple moor-grass & rush pastures

C5.1 Introduction

These marshy grassland communities occur on infertile, seasonally-waterlogged soils mostly on flat and gently sloping ground. They tend to be dominated by purple moor-grass and/or rush species and various sedges can be abundant. Vegetation is typically species-rich when managed by appropriate levels of grazing with typically in the range 17-30 species/4m^2. Bullock *et al* 2011 give a figure of around 22, 000 ha remaining in England but this is probably an overestimate and a more accurate estimate is probably around 11, 0000 ha (Robertson and Jefferson 2000).

The type consists of five National Vegetation Classification types (M22 *Juncus subnodulosus-Cirsium palustre* fen-meadow, M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture, M24 *Molinia caerulea-Cirsium dissectum* fen-meadow, M25 *Molinia caerulea - Potentilla erecta* mire and M26 *Molinia caerulea-Crepis paludosa* mire).

C5.2 Ecological position in the landscape and influence of abiotic and biotic processes

These marshy grassland communities are restricted to infertile, seasonally-waterlogged sites with slowly permeable, humic or peaty gleys, as well as peat soils. Depending on the individual NVC type, they are associated with a range of different rock types ranging from acid (slates and sandstones to alkaline (limestones). The pH range for the component NVC types is wide, ranging from 4.7 (acidic) to 7.4 (alkaline). The hydrological regime consists of a sub-surface water table during the summer (range -2 to -48 cm below ground level) and a winter water table more or less at the surface. Inundation is absent or only occasional to a minor degree in winter. Lateral and horizontal water movement at various depths may be important but there is little information on what constitutes a sustainable regime.

The habitat occurs mostly on flat and gently sloping ground, often associated with valley-side springs and seepage lines, but also on river and lake floodplains. Thus, theirs occurrence in the landscape is determined by substrate and hydrology. The species composition of the different types of purple moor-grass/rush pasture vegetation are also influenced by factors such as geology and soil type, hydrology and water chemistry and climate.

Existing examples are though, largely ‘derived’ habitats, with their species composition and structure resulting from past low-level drainage of other mire or fen types together with a history of traditional management by extensive grazing and, more rarely, by hay cutting. More near-natural examples though may occur as part of transitions between mire vegetation and drier grassland or heathland habitats reflecting variations in the soil-water regime.

Nonetheless, this habitat is valued for conservation in its own right (Ratcliffe 1977, Jefferson *et al.* 2014) and has its own peculiar suite of plant and animal species. Neglect of grazing or cutting management results in dominance by tall grasses or herbaceous species, potentially leading to the development of tall-herb fen and/or invasion of woody species. Neglect of ditch maintenance or other changes in hydrology or water chemistry may lead to a shift to different more mire/fen-like vegetation communities.

C5.3 Human modification and impact

The origin of purple moor-grass is somewhat unclear but there is no doubt that many examples in agricultural settings are the product of historic interventions to fen or wet woodland vegetation such as limited drainage coupled with grazing, burning and cutting. Similar vegetation to present day was probably present in the early Holocene where it would probably have occurred in more ‘natural’ settings as part of a toposequence with other mire vegetation, with its open nature maintained by native herbivores or processes such as fires and windthrow of trees in wet woodland.

As with other types of semi-natural grasslands (Section C1.3) there have been substantial losses of purple moor-grass & rush pastures, though it is rarely possible to provide accurate figures. For example, Devon Wildlife Trust (1990) recorded a 62% loss of Culm grassland sites (mostly comprising purple moor-grass and rush pasture) between 1984 and 1989/90. Losses of the habitat overall were largely due to drainage and agricultural improvement although in some areas, sites may have been planted with coniferous species for timber production.

Losses have also led to fragmentation of the habitat such that many sites are now small in extent. In England it is estimated that around 80% of purple moor-grass/rush pastures are less than 5 ha (Bullock *et al.* 2011).

In addition, habitat degradation has probably occurred due groundwater abstraction and soil or water eutrophication from diffuse pollution (Tallowin *et al.* 2014).

Decreasing extent and fragmentation, according to predictions from island biogeography theory, will result in losses of species from remaining areas of grassland habitat through 'extinction debt' (Tilman *et al.* 1994). See Section C1.3 above for more detail.

Table C9. Prevalence of state ('natural function') within the habitat resource: purple moor-grass & rush pastures.

State of naturalness	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
High	Moderate	Moderate	Moderate	Low	High
Moderate	Moderate	High	Moderate	Moderate - High	Moderate
Low	Low	Low	Low	Low	Low (none)
Confidence	*Moderate*	*Moderate*	*Moderate*	*High*	*High*
Comments	*A range of issues may affect the this habitat including lack of maintenance of drainage features and to a lesser extent, water abstraction*	*Point nutrient pollution, groundwater eutrophication and atmospheric N deposition. There is relatively good information on the impacts of nutrient inputs on semi-natural grasslands*	*Soil 'health' generally moderate for lowland grasslands*	*Main issue is lack of grazing and sometimes inappropriate grazing regimes*	*Invasive non-native species are rarely problem*

C5.4 Habitat mosaics

These marshy grasslands may form mosaics and transitions to a wide range of vegetation types. Firstly with scrub, carr and woodland communities, such as NVC types W2 *Salix cinerea-Betula pubescens-Phragmites australis* woodland and W4 *Betula pubescens-Molinia caerulea* woodland, as a result of seral changes mediated by past and current management which is usually related to grazing pressure, including cessation. Hydrological and management variation can lead to mosaics or transitions to wet heath, fen or swamp communities such as M13 *Schoenus nigricans-Juncus subnodulosus* mire, S24 *Phragmites australis-Peucedanum palustre* tall-herb fen, S4 *Phragmites australis* swamp and reed bed and drier soils upslope may result in transitions to neutral, acid or calcareous grassland.

At a smaller scale, purple moor-grass/rush pastures may support microhabitats such as short or long turf, grass or rush tussocks, patches of damp bare ground, moss carpets (*Sphagnum* spp), and scrub of different age classes.

C5.5 Potential for restoration of natural function

The most common factors leading to unfavourable condition of existing examples of the habitat is lack of management by grazing. This can be readily remedied, in most cases. However, unfavourable condition due to adverse hydrological conditions due to factors such as drainage or abstraction or soil or water eutrophication are more challenging to remedy. This may require action at a catchment scale in some cases.

An interesting conundrum for the existing resource of purple moor-grass/rush pasture that occurs as managed 'agricultural' habitat (a large proportion of the resource) is the extent to which it is desirable to restore a more naturally functioning drainage system. The likelihood is that this would cause a shift in species composition towards a different plant community such as another fen or mire type. If such a initiative was considered desirable, it would need to occur as part of a strategy to restore this habitat in places in the landscape where it forms a more natural vegetation toposequence such as in valleys or in natural depressions with other mire/fen vegetation. The scope for achieving this in the landscape at an appropriate scale and to an extent that would compensate for losses may be very limited.

For restoration from non-priority habitat (e.g. semi-improved damp grassland), the restoration of suitable hydrology and soil conditions are much more challenging and successful restoration could conceivably take many decades or more. As yet there are a few examples of where restoration has commenced, such as on the Culm Measures of Devon but it may be some years before such projects can achieve the objective of restoring the target plant community.

Table C10. Restoration of 'natural function': purple moor-grass/rush pastures.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Yes	Yes
Comments	Need for restoration of low-level watercourse management (see Section C5.5) and cessation of abstractions causing unfavourable condition	Reduce or eliminate excess nutrients above critical load including eutrophication of groundwater	Soil structure and soil biota is typical of habitat in favourable condition	Grazing levels sufficient to maintain the wet grassland ecosystem including sward heterogeneity and appropriate stocking levels and structure of scrub. Avoidance of undergrazing/cessation of grazing/overgrazing	Needed to restore semi-natural species assemblages.
Conservation constraints	Potential for conflict with maintenance of mosaic habitats?	'Natural' nutrient levels are generally a shared conservation goal across all habitats and species	None	Potential conflicts with objectives for scrub/woodland habitats occurring in a mosaic	None

C6. Calaminarian grassland

C6.1 Introduction

This habitat type consists of vegetation occurring on skeletal, nutrient-poor soils enriched with heavy metals such as lead, zinc and copper and other minerals. Calaminarian grassland occurs on artificial mine waste, metal-enriched river shingle or more rarely in near-natural situations over serpentine and mineral vein outcrops. The habitat is usually associated with limestones and granites, and is found in both the lowlands and the uplands.

The vegetation usually consists of an open mixture of metal-tolerant strains of grasses and dicotyledonous herbs, including metallophyte species such as spring sandwort *Minuartia verna* and alpine penny-cress *Thlaspi caerulescens*. Some stands are characterised by varied assemblages of lichens and/or bryophytes including metallophyte species such as the endemic *Ditrichum cornubicum*. Bare ground may make up a high proportion of overall cover in examples with particularly high heavy metal concentrations. The vegetation conforms to the NVC type OV37 *Festuca ovina - Minuartia verna* but this type does not fully embrace types of Calaminarian grassland where lower plants make up the bulk of the vegetation (Rodwell *et al.* 2007).

It is estimated that there is around 130 ha remaining in England. Most sites are not managed by domestic livestock but may occasionally occur in enclosures with grassland or heathland that is grazed. Rabbit grazing and associated soil disturbance may be a feature of some sites.

C6.2 Ecological position in the landscape and influence of abiotic and biotic processes

In England, there are probably no remaining sites developed in near-natural situations over metal ore vein outcrops due to outcropping ore veins being eliminated from the landscape by mining activity. The occurrence, composition and structure of the vegetation is strongly influenced by the mineralogy of the metal-rich substrate or parent material.

The majority of Calaminarian grassland now occurs on artificial waste from former metal mining activity and on metal-enriched river shingle originating from mining in the catchments. The main concentrations are in the North Pennines, Cumbria and the Derbyshire White Peak. Such sites are thus artificial examples of the type but they clearly occur within the same area as the original ore veins or in the same catchment where metal-enriched mine water has led to the development of metal-enriched shingles downstream, such as in the north and south Tyne rivers.

C6.3 Human modification and impact

It is likely that metallophyte vegetation associated with ore veins had been present in the landscape but with natural examples largely eliminated by heavy metal (lead, zinc, copper) mining activity, which probably commenced in the Iron Age, expanded in Roman times and reached its zenith in the 19^{th} Century. Thus, as mentioned in Section C6.2 remaining examples occur in highly artificial situations (mine spoil or waste) or semi-artificial (river shingles).

Sustaining the plant communities of the river shingle sites, in particular, in the longer term will be challenging as surface toxicity declines over time with ecological succession, and for those sites that still flood, metal content in the river is likely to decline due to the need to reduce metal pollution in the rivers draining former mining areas.

Perturbation of the soil by rotavation, for example, to re-invigorate the metal toxicity may offer some prospect of conserving these artificial examples of Calaminarian grassland.

Table C11. Prevalence of state ('natural function') within the habitat resource: Calaminarian grassland.

State of naturalness	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
High	High	High	Low	High	High
Moderate	Low	Low	Low	Low	Low
Low	Low (none)	Low (none)	High	Low	Low
Confidence	*Moderate*	*Moderate*	*High*	*Moderate*	*High*
Comments	*Sites that occur on riverine shingles may be adversely affected by flooding, erosion and sediment deposition*	*The probably has low vulnerability to atmospheric N deposition or other sources of nutrients due to limitation of plant growth by low soil P and metal toxicity*	*Declining metal toxicity due to build-up of soil organic matter, lack of replenishment of metal inputs especially in river shingle sites and deposition of sediment on sites vulnerable to flooding*	*Vegetation management is rarely required as metal toxicity is generally sufficient to prevent succession. However, where this toxicity is alleviated, it is possible that some form of mechanical perturbation will be required to restore surface soil metal toxicity*	*Very rarely an issue*

C6.4 Habitat mosaics

Current examples of the habitat occur in a mosaic with calcareous, acid or neutral grasslands and dwarf shrub heath. Such mosaics are controlled primarily by edaphic factors. However, where surface toxicity has declined due to ecological succession, this may result in the development of grassland, scrub or woodland vegetation over time which may form a mosaic with areas of metallophyte vegetation in patches with remaining high levels of heavy metals in the surface soil or substrate.

Microhabitats associated with Calaminarian grassland include extensive often rocky bare ground and small grass tussocks and moss cushions.

C6.5 Potential for restoration of natural function

There is no scope for restoration of naturally-functioning Calaminarian grassland in a strict sense as there are no places in the landscape where this can be achieved. As detailed in Section C6.3 and in Table C11, even conserving and restoring favourable condition to existing artificial examples is challenging and may require interventionist management by soil perturbation, for example.

Existing sites may also be in poor condition due to other factors such as lack of grazing or due to excessive inputs of nutrients from atmospheric nitrogen deposition.

C7. Provision of habitat for priority species

C7.1 Mammals

The majority of native mammals are primarily adapted to woodland and few are grassland specialists. However, there are quite a few species that use grassland and associated hedgerows for shelter, breeding and feeding including mole, brown hare, badger and various species of bats may forage over grasslands (see Crofts and Jefferson 1999, Harris and Yalden 2008). The focus below has thus been narrowed to cover species of bats and harvest mouse.

All species of bats found in the United Kingdom are insectivorous and although they all have different specialised habitat requirements, they all feed over grassland habitats to some extent.

Intensively managed grasslands however are not favoured by most bat species (e.g. Russ and Montgomery 2002, Walsh and Harris 1996) as they have reduced prey availability and often reduced connectivity within the landscape through the removal of hedgerows to increase field sizes. Bats can be limited by the availability of optimal habitats for foraging and subsequently a reduction in prey availability through intensive management of grasslands can adversely affect bat populations (Entwistle *et al.* 2001).

Insect species richness is positively related to plant species richness (Haddad *et al.* 2001). Less intensively-managed and organic grasslands are generally more biodiverse and offer better foraging opportunities and are therefore important for bat populations (Wickramasinghe *et al*. 2004). For example bat activity was found to be 61% higher on organic farms, and foraging activity was 84% higher on organic farms than on conventional farms (Wickramasinghe *et al.* 2003).

The greater horseshoe bat has suffered dramatic declines over the past century due to roost disturbance and loss of foraging sites such as permanent pasture which juveniles rely on heavily for dung beetle prey in early August. Grazing regimes are therefore very important for this species although the use of antihelminthic drugs such as avermectin in cattle and sheep can lead to a reduction in insect fauna in dung (Strong 1992) and resulting negative impacts on greater horseshoe populations (Duvergé and Jones 2003). Agri-environment schemes have been targeted in south-west England to improve habitat around maternity colonies and may have contributed to a 58% increase in greater horseshoe bats recorded at maternity sites in Devon since 1995 (Longley 2003), however it Is likely that climate change has also played a significant part in the recovery of populations (Froideveaux *et al.* 2017).

The harvest mouse is Britain's smallest rodent weighing 6 g. They are the only rodent that builds nests of woven grass leaves well above ground level and favour areas of ungrazed tall, dense grassy vegetation in which to do this. Harvest mice feed on seeds, shoots and flowers as well as grain from cereal heads and occasionally invertebrates (Harris and Yalden 2008). The loss of field margins and undisturbed grassland habitat is a threat to this species.

Restoring natural function of grasslands will benefit British bat and harvest mouse populations by providing and maintaining diverse and structurally varied habitats.

This in turn will support suitable habitat for harvest mice to breed in and a wide selection of insect prey for bats.

C7.2 Birds

A range of Section 41 bird species use grassland habitats for at least part of their life cycle (Table C12).

Table C12. Priority bird species associated with grassland habitats. (B = breeding, NB = not breeding)

Species	Breeding status	Grassland habitat
Bewick's Swan	NB	Lowland wet grassland
European White-fronted Goose	NB	Lowland wet grassland
Brent Goose	NB	Lowland wet grassland
Black Grouse	B & NB	Upland pasture and upland hay meadows
Grey Partridge	B & NB	Lowland grassland
Corncrake	B	Lowland grassland
Stone-curlew	B & NB	Lowland calcareous and acidic grassland
Lapwing	B & NB	Lowland and upland wet grassland

Black-tailed Godwit	B & NB	Lowland wet grassland
Curlew	B & NB	Lowland wet grassland, rush pasture and hay meadows
Woodlark	B	Lowland acidic grassland
Skylark	B & NB	Grassland and hay meadows
Yellow Wagtail	B	Lowland wet grassland and upland hay meadow
Ring Ouzel	B	Upland grassland
Twite	B	Upland grassland and hay meadows
Reed bunting	B & NB	Rush pasture

Bewick’s swan, white-fronted goose and brent goose, in common with large numbers of other waterbirds, depend on extensive areas of coastal and floodplain grassland for foraging during the winter. Other species, such as grey partridge, lapwing and skylark, require large areas of grassland, in a mosaic with other farmland habitats, for both foraging and nesting. Breeding waders, in particular, favour extensive, open areas of lowland wet grassland which is regularly inundated during the winter, and which provides rich foraging areas for breeding birds in the spring.

In the uplands, rush pastures are important for breeding curlew and reed buntings, and traditionally managed hay meadows also support nesting curlews along with other waders and yellow wagtail. Landscape scale patchworks of grassland, moorland and scrub are necessary for the restricted and declining population of Black Grouse.

Short-grazed lowland calcareous and acidic grasslands are important breeding habitats for the scarce and restricted stone-curlew, and acidic grassland is an important habitat for woodlark, particularly in a mosaic with taller heathland vegetation.

Natural processes such as the temporary inundation of flood meadows are important for the creation of shallow water features favoured by breeding waders. The restoration of natural floodplain hydrology will favour these breeding species, most of which have declined greatly in lowland England because of the loss and fragmentation of lowland wet grassland resulting from drainage and agricultural improvement.

Extensive grazing by livestock is also essential to create and maintain suitable grassland swards. Curlews, for example, require a mosaic of taller rushes for nest and chick concealment and shorter areas for adult and chick foraging, conditions which often result from low intensity cattle grazing. Lapwings, on the other hand, require generally short swards with some tussocks for nesting and foraging, often a product of light grazing by sheep or mixed sheep and cattle grazing. As well as the creation of suitable sward conditions, low level stocking, preferably with cattle, also reduces the risk of stock trampling eggs and chicks.

Agricultural improvement, through drainage and the use of artificial fertilisers, reduces sward heterogeneity and increases the rate of grass growth and sward density and height, which reduces the suitability for breeding birds. It also reduces the abundance of flowering plants and their seeds, which are an important food source for the rapidly declining and highly threatened population of twite in the English uplands.

Similarly, traditional hay meadow management, with low nutrient inputs (i.e. well-rotted farmyard manure rather than artificial fertilisers) and later cutting dates are more likely to support nesting curlews, lapwings and skylarks than improved meadows and silage fields.

In the lowlands, short, calcareous or acidic grasslands suitable for foraging stone-curlews (mainly in the Brecks and Salisbury Plain) and woodlarks depend on adequate grazing by livestock and rabbits.

Nutrient enrichment from atmospheric and diffuse pollution could be a significant problem in some areas if it encourages vegetation growth to the point where grassland conditions become unsuitable for these species.

The restoration of natural process and more extensive, traditional management would therefore benefit many breeding bird species which are currently declining a result of agricultural intensification in both upland and lowland areas.

C7.3 Reptiles and amphibians

Of the ten species native (non-marine) reptiles and amphibians, all but common frog (*Rana temporaria*), common toad (*Bufo bufo*), smooth newt (*Triturus vulgaris*) and palmate newt (*T. helveticus*), are Section41 priority species.

Most of the native British reptiles and amphibians (herpetofauna) rely to some extent on lowland grassland habitats in parts of their range. Common frogs *Rana temporaria*, pool frog (*Pelophylax lessonae*), common toads *Bufo bufo*, smooth newts *Triturus vulgaris*, palmate newts *T. helveticus* and great crested newts *T. cristatus* will all use grasslands for foraging and shelter where they occur in proximity to breeding ponds or other water bodies.

Natterjack toad *Bufo calamita* have very different habitat requirements compared to the more widespread species of amphibians. They do occur in grassy habitats but usually where the sward is short and open and forms part of a mosaic with heathland, grazing marsh or dune habitats.

Lowland grassland of various types is of vital importance for the native reptiles. Adder *Vipera berus* and common lizard *Lacerta vivipara* are frequently associated with grassland, especially calcareous and acid grasslands, or where the latter it occurs in a mosaic with heathland. The interface between grassland and another habitat type, such as scrub or broad-leaved woodland, will often be of particular importance. In some areas, adders are found almost exclusively in a small range of habitats of which calcareous (chalk) grasslands are of prime importance.

Slowworm *Anguis fragilis* is recorded from grassland more frequently than any other habitat type. Grass snake *Natrix helvetica* is similarly often found on grassland, particularly in wetter areas. Although the rare reptiles (sand lizard *Lacerta agilis* and smooth snake *Coronella austriaca*) are much more restricted in their requirements, most commonly being associated with lowland dry heath, they may also take advantage of adjoining unimproved grassland, particularly short dry acid grassland.

Section C8 sets out the main sorts of actions necessary to restore natural function to the suite of semi-natural priority lowland grasslands. In brief, these are:

- Restore low soil and water nutrient status where practicable, and where this has been enhanced by agricultural or atmospheric sources
- Where, appropriate restore more natural hydrological functioning
- Ensure grasslands are managed by grazing or mowing to achieve heterogeneous conditions that are suited to maintaining suites of priority species or important species assemblages (e.g. invertebrates, reptiles etc) – e.g. some scrub of different age classes for certain grassland types and variation in sward height and extent of bare ground etc in habitats such as calcareous & acid grassland.
- Where present, ensure components of the mosaic are maintained – this may include features such as ant hills, springs and natural bare ground/rock
- Reduce or eliminate any invasive aliens such as *Cotoneaster* species in calcareous grasslands

As far as these actions are concerned these are generally compatible with ensuring the viability of population of reptile and amphibian species associated with grasslands including the populations of threatened species. However, habitat management is a key factor for herpetofauna (relates to bullet

3 above) as inappropriate habitat management can have drastic negative effects on resident herpetofauna. For example, this is particularly the case with adder, where evidence suggest that factors such as intensive grazing and large-scale removal of scrub (especially gorse and bramble) and bracken, undertaken to restore calcareous grasslands, can destroy adder hibernacula (Gleed-Owen and Langham 2012).

Thus, the importance of heterogeneity incorporating scrub habitats (bullet 3 above) is key to the conservation of this species. In addition, other reptile species may also utilise scrub and features such as stands of bracken and tussocks of purple moor-grass (*Molinia caerulea*) for over-wintering.C7.4 Invertebrates

C7.4.1 General

All grasslands support very high number of invertebrates, both in terms of species and biomass. Pantheon recognises nearly 4500 species of invertebrate as being associated with grasslands and heathlands (it doesn't differentiate the two) with structure being important here. Of this number, more than 2800 are associated with taller swards and some scrub, nearly 1350 are associated with short sward/ bare ground and some 250 species are associated with upland grasslands and moors. Thus grasslands and other open habitats are very important for invertebrates and calcareous grasslands in England generally support the highest diversity of invertebrates.

As well as the large scale mosaics discussed in sections above, the small scale habitat mosaics that may be associated with grasslands are particularly important for invertebrates associated with calcareous grasslands. Such mosaics are required in order to maintain the full suite of invertebrates associated with this habitat. Some species will require bare ground and emergent vegetation, others the short turf that is considered characteristic of this habitat and still others longer grass tussocks. Many species will require more than one such feature – many butterflies such as Small Blue *Cupido min*imus require early successional areas for egg laying and larval feeding, and also longer grass and some scrub for shelter. Other calcareous grassland butterflies such ad Adonis Blue *Polyomattus bellargus* are generally thought of as open grassland species but also require longer grass tussocks in the short turf for shelter. The wart-biter *Decticus verrucivorus* is particularly specialised and requires an intricate mosaic for its survival. Small patches of bare ground are required for ovipositing, short turf is required by the nymphs for feeding and dense tussocks for the adults to shelter and hide from predators. The grassland must also be of high quality and flower-rich in order to support these omnivorous bush crickets. This specialisation may explain in part why they are so rare these days, as the loss of any one of these features can result in their rapid extinction from the site.

C7.4.2 Calcareous grassland

Calcareous grassland is a semi-natural habitat and the correct management is essential to maintain it in good condition. With this habitat, grazing is the only management that will achieve this and an appropriate grazing regime with appropriate livestock is very important. Sheep are the traditional grazing stock in many areas and many people associate sheep with calcareous grasslands. However, while sheep grazing may be appropriate for maintaining the botanical diversity, they are not suitable, on their own, for maintaining the invertebrate diversity. This is because of the way they graze – they nibble the grass and act a bit like lawnmowers, producing a rather short, uniform sward. This will not provide the small scale structural heterogeneity that is so important in maintaining the full site of invertebrate interest. Cattle grazing is much better for maintaining the invertebrate interest as cattle graze by tearing up clumps of grass, which leads to variation in the sward height, and being heavier their hooves cause localised poaching which maintains small and regular patches of bare ground. Where calcareous grassland has deteriorated through lack of adequate grazing and has become dominated by dense swards of coarse grasses such as *Brachypodium pinnatum*, hardy stock such as Exmoor ponies can be used very effectively to restore these grasslands. This has been achieved with very good results on the Firle Escarpment and other sites on the South Downs in Sussex.

As well as the stock type, the timing of grazing is important in maintaining invertebrate (as well as floral) interest on calcareous grassland. Generally, grazing should be avoided in spring and summer, with September/ October through March being the best time for grazing management to occur. If spring/ summer grazing is necessary on a site (for essential commercial or other reasons) then it should be at a low enough stock density that the flowering of the plants is not significantly affected and excessive poaching/ trampling is avoided.

C7.4.3 Lowland dry acid grasslands

Lowland dry acid grasslands in England, though not supporting as diverse a community of invertebrates as calcareous grasslands, are nevertheless very important as a habitat for this group, supporting many rare and specialised species.

As well as the large scale mosaics discussed under C2.4, the small scale habitat mosaics that may be associated with grasslands are important for invertebrates associated with acid grasslands. Such mosaics are required in order to maintain the full suite of invertebrates associated with this habitat as described under 1.6, and many species will require more than one such feature of the mosaic. This habitat is particularly important for the very rare field cricket *Gryllus campestris* – all of the extant meta-populations (there are currently only five) are on acid grasslands in West Sussex/ adjacent Hampshire and Surrey. This species is often perceived as requiring very short turf but it actually requires areas with extensive areas of short turf but interspersed with small, regular patches of bare ground and longer grass tussocks. Such a micro-habitat is best maintained by grazing and wavy hair-grass *Deschampsia fl*exuosa is frequently the dominant species as it forms the ideal structure for field crickets when tightly grazed.

Invertebrates more associated with freshwater (e.g. Odonata) will, in their adult form, use lowland acid grasslands for hunting and shelter. Dragonflies and damselflies more often associated with heathland such as Four-spotted Chaser *Libellula quadrimaculata*, Keeled Skimmer *Orthetrum coerulescens* and Golden-ringed Dragonfly *Cordulegaster boltonii* will also use acid grassland habitats for feeding and shelter as adults.

As already mentioned, grazing is the ideal way to maintain a good structure acid grasslands, with mixed cattle/ pony and sheep grazing producing a better structure than just sheep grazing (as described under calcareous grasslands). In some areas, manual bracken control (through cutting, burning or both) may be required to prevent complete domination of the grassland areas by bracken and scrub control may also be required to prevent encroachment (though some patchy scrub should be maintained in order to maintain the full suite of invertebrate species associated with this habitat).

As well as the stock type, the timing of grazing is important in maintaining invertebrate (as well as floral) interest on lowland acid grassland. Generally, grazing should be avoided in spring and summer, with September/ October through March being the best time for grazing management to occur. If spring/ summer grazing is necessary on a site (for essential commercial or other reasons) then it should be at a low enough stock density that the flowering of the plants is not significantly affected and excessive poaching/ trampling is avoided. Autumn/ winter is also the best time of year for bracken control as it avoids excessive disturbance when the majority of insects are active.

C7.4.4 Lowland meadows

Lowland meadows provide a very important habitat for many invertebrates and especially those which rely on a variety of flower species as a nectar/ pollen resource. As well as the large scale mosaics discussed under C3.4, small scale mosaics are also important in maintaining structural heterogeneity in meadows. This structure is important in order to maintain the full suite of invertebrate species associated with this habitat.

Bumblebees and other bee species are particularly characteristic of these habitats and as lowland meadows have been lost over the decades, so bumblebee species which were once considered fairly common have become rare and restricted (some very seriously so). Two species of bumblebee have been lost from English lowland meadows since 1980. They are the great yellow bumblebee *Bombus distinguendus* (which still occurs very locally in north and west Scotland), and short-haired bumblebee *Bombus subterraneus* (which is currently the subject of a re-introduction programme at Dungeness in Kent). Five other species of bumblebee have declined sufficiently over the past few decades that they are now listed on Section 41 of the NERC (1981) Act: *Bombus muscorum*, *B. humilis*, *B. ruderarius*, *B. ruderatus* and *B. sylvarum*.

Another enigmatic species formerly associated with lowland meadows is the glow-worm *Lampyris noctiluca*. It requires a good structure to the grassland with patches of bare ground and a variable sward height with longer grass tussocks among the sward. These days it seems to be more associated with calcareous grassland and some heathlands; but this is probably due to the large scale improvements to, and loss of, lowland meadows after the Second World War. On calcareous grasslands it can disappear when large rabbit populations overgraze the area and remove the grassland structure that it requires, further emphasising the need for structural heterogeneity in all grassland types.

As with other grasslands, grazing is an important part of management for the invertebrate communities associated with them, and cattle as well as, or instead of, sheep will produce a better structure to the grassland than sheep grazing alone. But of course, annual cutting for hay in late summer has been an important part of meadow management historically, with aftermath grazing restoring the structure and preventing excessive growth over the autumn.

The timing of any hay cut is also important for invertebrates. Obviously, such a sudden drastic change in the structure of the grassland could be catastrophic for invertebrates, particularly by destroying eggs, larvae and pupae that are on the grass. But many have adapted to this regime by completing these most vulnerable parts of their life cycle over the winter and spring, so that when the hay is cut it is the more mobile adults that can avoid this. Good examples of this are many butterflies and moths of meadows and pastures.

Other invertebrates such as bumblebees have active nests over the spring and summer and need a reliable nectar and pollen source throughout this period. However, the nests are generally in old vole or mouse nests in hedgerows and field edges and so are not very likely to be destroyed by a hay cut. The worker bees can travel extensively to find nectar and collect pollen for the nest, so as long as there are other flower sources fairly close to the nest they will not be significantly affected by the cut.

Lowland pasture will often have the same suite of invertebrates and as they are grazed rather than cut for hay, there will not be the same sudden change in the grassland structure. One way of minimising the effects of a hay cut would be to have a mixture of pasture and meadow in any one area and alternate the hay cut on a rotational basis. Pastures should be lightly grazed with cattle through the summer so as not to overgraze and reduce the sward height too much.

C7.4.5 Upland hay meadows

All grasslands support very high number of invertebrates, both in terms of species and biomass, as described in the first paragraph of section C7.3.1 upland grasslands are less species-rich than those in lowlands; Pantheon recognises some 250 species that are associated with upland grasslands and moors; compares with the more than 2800 associated with taller swards with scrub and nearly 1350 associated with short sward/ bare ground in lowland grasslands. This is due both to altitude and latitude: upland grasslands are, by their nature, cooler than their lowland counterparts, and they also tend to occur in northern Britain, which also makes them cooler and less sunny, as well as being outside the geographical range of many of the invertebrates of southern UK. Having said this, upland hay meadows tend to be in valleys and are relatively flower-rich, compared with other upland grasslands, and so in terms of invertebrates are likely to be richer in both species and biomass.

Upland hay meadows are similar in their provision for invertebrate communities as lowland meadows are but as mentioned above, they generally occur in northern England, especially in the valleys of the Pennines and Cumbrian Hills. Although less species-rich than lowland meadows, they provide a very important habitat for many invertebrates and especially those which rely on a variety of flower species as a nectar/ pollen resource. As well as the large scale mosaics discussed under C3.4, small scale mosaics are also important in maintaining structural heterogeneity in meadows. This structure is important in order to maintain the full suite of invertebrate species associated with this habitat.

The invertebrate communities associated with upland hay meadows are not as well-known as those of southern ones. Bumblebees are a group that is characteristic of upland hay meadows habitats, although the variety of species is not as extensive as in lowland ones. Many species of bumblebee have declined significantly over the past decades and five species are now listed on Section 41 of the NERC (1981) Act. The only one of these that is likely to occur in upland hay meadows (if they are fairly damp and flower-rich) is the moss carder bee Bombus muscorum. Two other upland species may occur in upland meadows – the heath bumblebee Bombus jonellus (most likely if there is heathland or moorland nearby) and bilberry bumblebee Bombus monticola – if there is at least some bilberry either on site or close by.

As mentioned in the lowland hay meadow section, another enigmatic species associated with meadows and other grasslands is the glow-worm Lampyris noctiluca. Although it is more common in southern England it does occur more sparsely in upland valleys, especially on calcareous/ limestone grasslands. It requires a good structure to the grassland with patches of bare ground and a variable sward height with longer grass tussocks among the sward. These days it seems to be more associated with calcareous grassland and some heathlands; but this is probably due to the large scale improvements to, and loss of, lowland meadows after the Second World War. Nevertheless it still sometimes occurs in upland meadows on calcareous soils. Beetles (Colepotera) may also be well represented in upland meadows though this has not been studied in detail.

As with lowland meadows, grazing is an important part of management for the invertebrate communities associated with them, and cattle as well as, or instead of, sheep will produce a better structure to the grassland than sheep grazing alone. But of course, annual cutting for hay in late summer has been an important part of all hay meadow management historically, with aftermath grazing restoring the structure and preventing excessive growth over the autumn.

The timing of any hay cut is important for invertebrates. Obviously, such a sudden drastic change in the structure of the grassland could be catastrophic for invertebrates, particularly by destroying eggs, larvae and pupae that are on the grass. But many have adapted to this regime by completing these most vulnerable parts of their life cycle over the winter and spring, so that when the hay is cut it is the more mobile adults that can avoid this.

Bumblebees have active nests over the spring and summer and are potentially vulnerable to a July hay cut. However, the nests are generally in old vole or mouse nests in hedgerows and field edges and so are not very likely to be destroyed by a hay cut. The worker bees can travel extensively to find nectar and collect pollen for the nest, so as long as there are other flower sources fairly close to the nest they will not be significantly affected by the cut.

Upland pasture will often have the same suite of invertebrates and as they are grazed rather than cut for hay, there will not be the same sudden change in the grassland structure. One way of minimising the effects of a hay cut would be to have a mixture of pasture and meadow in any one area and alternate the hay cut on a rotational basis. Pastures should be lightly grazed with cattle through the summer so as not to overgraze and reduce the sward height too much.

C7.4.6 Purple moor-grass and rush pasture

Purple moor-grass and rush pasture may be less species-rich, in terms of invertebrates, than calcareous and acid grasslands or lowland meadows, but a well-managed rush pasture can still be very important for invertebrates, supporting a variety of species.

Insects which specialise in this kind of habitat include the Small Pearl-bordered Fritillary *Boloria selene*. It is a species typical of good quality rush pastures, where the larvae feed on marsh violets. Marsh Fritillary *Euphydryas aurinia* and Narrow-bordered Bee Hawk Moth *Hemaris tityus* will also specialise in this habitat, the larvae feeding on devil's bit scabious. Interestingly, both these species will also utilise calcareous grasslands, feeding on the same foodplant. Among other groups of insect, Moss Carder Bee *Bombus muscorum* is often found in rush pastures, as well as in other damp grasslands and meadows, nectaring on a variety of flowers, especially legumes, and nesting on the ground in dense clumps of vegetation.

Management for invertebrates follows the same principles as for other grasslands, with the emphasis being on maintaining a good structure. Extensive grazing with hardy cattle or ponies is the ideal way to do this, as they will trample vegetation locally and pull up clumps of vegetation as they graze, both of which maintain the structure that invertebrates require. However, rush is unpalatable even to them and dense areas of rush may still need to be managed as described below, otherwise it will come to dominate large areas and shade out the low-lying plants on which invertebrates, including those mentioned above, depend.

If it is necessary to cut rush by hand, it should be cut above ground level to avoid damaging mosses and ground level plants. The cut rush should be removed as soon as possible to avoid smothering low-growing plants and ground-dwelling invertebrates. The rush should not all be cut in any one year but on a rotation. Glyphosate should not be used unless this is absolutely essential for restoration, and then as sparingly as possible.

C7.4.7 Calaminarian grasslands

Calaminarian grasslands are very scarce and localised, are not generally grazed and may require physical intervention to preserve them. As such, their value for invertebrates, especially those specialising in high quality grasslands, may be rather limited. However, they tend to be dominated by a very short, open sward of grasses and mosses, intermixed with areas of bare ground, and so they can be important areas for ground nesting insects such as solitary bees, which require this biotype. Where they occur in a mosaic with calcareous, acid or neutral grasslands, they will form an important part of the structure of those habitats. Where they occur on river shingle, as a result of leached minerals being washed downstream, they will support invertebrates such as beetles and other invertebrates which are associated with this specialised habitat.

Management of this habitat for invertebrates is not easy. As long as the metals remain, the typical plants which are tolerant of these metals are likely to flourish, but as they are leached out, especially on river shingle sites, it will be difficult to maintain the habitat.

C7.5 Bryophytes

There are more bryophytes associated with calcareous grassland, in particular chalk grassland, than any other grassland type in Britain (Porley and Hodgetts, 2005). Some of the most conspicuous species here are common generalist species such as *Pseudoscleropodium purum*, *Calliergonella cuspidata* and *Rhytidiadelphus squarrosus*, however there are many strict calcicoles, including *Ctenidium molluscum*, *Campyliadelphus chrysophyllus*, *Homalothecium lutescens* and *Hypnum lacunosum*. On cool and damp north-facing calcareous slopes bryophytes can be so abundant that their cover exceeds that of the vascular plants. One community of bryophytes on grazed north-facing chalk slopes on a small number of downland sites is unusually rich in liverworts, including *Scapania aspera* and *Porella arboris-vitae*, and has been named the southern hepatic mat (Porley and Rose, 2001).

On south-facing calcareous slopes the combination of warmth from the sun, erosion on steep slopes and grazing by livestock may create a thin, parched and disturbed turf with many bare patches where thermophilous (warmth-loving) bryophytes thrive. Many different species of small acrocarpous mosses occur in such locations, including species from the genera *Microbryum*, *Tortula*, *Didymodon*, *Trichostomum* and *Weissia*, with some species being Nationally Scarce or Rare. In undisturbed calcareous grassland ants may create large mounds, and these anthills provide a specific habitat which is favoured by certain bryophytes, including the uncommon and attractive *Rhodobryum roseum* and small *Bryum* species.

Four Section 41 bryophytes occur in short and open calcareous turf, namely the liverwort *Cephaloziella baumgartneri* and the mosses *Acaulon triquetrum*, *Weissia condensa* and *Weissia sterilis*. In addition four other Section 41 species occur on bare soil and rock that may occur within grassland habitats, namely the liverworts *Cephaloziella calyculata* and *Southbya nigrella* and the mosses *Tortula cuneifolia* and *Tortula wilsonii*.

Acidic grassland supports fewer uncommon species than calcareous grassland, but a range of characteristic species occur, including the mosses *Pleurozium schreberi*, *Dicranum scoparium*, *Hylocomium splendens*, and in more open acidic grassland *Brachythecium albicans* and *Polytrichum juniperinum*. The Section 41 Thatch Moss *Leptodontium gemmascens* is most well-known as a rare colonist of thatched roofs, but it also occurs in a more natural habitat in rank acidic grassland, where it colonises the decaying basal sheaths of grass tussocks and rushes.

Neutral grassland supports few uncommon bryophytes, with most species occurring being common generalists such as the mosses *Brachythecium rutabulum*, *Kindbergia praelonga* and *Calliergonella cuspidata* and the liverwort *Lophocolea bidentata.*

The restoration of natural processes on lowland grassland is likely in most cases to be beneficial for bryophytes, for example by restoring low nutrients status where practicable, keeping the vegetation structure open by grazing or mowing, creating suitable microhabitats, and preventing bryophytes from being overwhelmed by the build-up of litter and taller vegetation, including invasive aliens such as *Cotoneaster* in calcareous grassland. However in the case of the rarer species, in particular those listed within Section 41, care will need to be taken within individual sites to ensure that large-scale management actions do not have a negative effect on species that may be restricted to very small areas of habitat. An example of this might be where the encouragement of scrub of different age classes might be beneficial for certain priority species of invertebrates, but such scrub growth would be detrimental to uncommon bryophytes of short turf and open ground. In such a situation an ideal solution would be to locate the scrub creation in an area where it would not harm other priority species.

C7.6 Vascular plants[1]

Collectively, lowland grasslands support a large number of vascular plant species. Walker (2008), for example, estimated that around 356 species could be described as 'grassland' species although it is acknowledged that such an estimate is fraught with definitional issues. In reality, habitats merge one into another and the ecological ranges of many species encompass plant associations which might, conventionally, be considered elements of different habitats. In addition, further species are associated with micro-habitats that may occur in close association with grasslands. These include areas of open ground, rocky outcrops, springs and seepages, small and/or temporary water bodies and scrub or woodland edges. This blurring of habitat boundaries that accompanies an autecological perspective can contribute significantly in the development of a more holistic management approach. Of this rich diversity of species, lowland grasslands in the widest sense also support a very large proportion of England's threatened vascular plant species including some that are s.41 Priority Species or listed on Annex II of the Habitats & Species Directive. For example, around 81 vascular plant species typical of lowland grassland are listed as threatened in the Vascular Plant Red List for Great Britain (Cheffings *et al*. 2005).

Grassland plant species classified as threatened or near-threatened in the recently-published Vascular Plant Red List for England include purple milk-vetch (*Astragalus danicus*) (LCG), orchids such as lesser butterfly-orchid (*Platanthera bifolia*) (PMGRP), burnt orchid (*Neottinea ustulata*) and man orchid (*Orchis anthropophorum*), (LCG), devil's bit-scabious (*Succisa pratensis*) (LM, UHM, LCG & PMGRP), heath lobelia (*Lobelia urens*) (PMGRP), melancholy thistle (*Cirsium heterophyllum*) (UHM) and allseed (*Radiola linoides*) (LDAG). Some of these species are range-restricted (such as *Lobelia urens*) whilst others remain widespread (*Succisa* for example) but all have suffered significant declines in recent years leading to their current Red List status.

Around two-thirds of the threatened/near threatened grassland species are associated with calcareous grassland. Many of these species, plus some of those typical of lowland dry acid grassland, are specialists of open, short swards normally maintaining by grazing animals, both wild and domestic. This guild includes, for example, pasque flower (*Pulsatilla vulgaris*) which has suffered a 34% decline in Area of Occupancy over the Red List assessment period in part due to a decline in

[1] The following abbreviations are used in this section: LCG = Lowland calcareous grassland; LDAG = Lowland dry acid grassland; LM = Lowland Meadows; UHM = Upland hay meadows; PMGRP = Purple moor-grass & rush pastures

short swards as a result of lack of grazing (Walker & Pinches) and is now regarded as "vulnerable to extinction" (VU). Another example of this guild is field fleawort (*Tephroseris integrifolia*), also classed as VU. A recent study showed a 45% decline in populations at 22 sites in southern England over the period 1964-1967 to 2014-2016 (Stroh et al 2017). The key factor in its decline was undergrazing or periods of management neglect.

While many of the threatened species do not have any special management requirements beyond that of the grassland types within which they occur (JNCC 2004), a number may require bespoke management. This is particularly true when populations are depleted or find themselves stranded in situations which are sub-optimal – the fate of many rare plants. In such circumstances tailored management may be required until population levels are improved and more natural ecological processes are restored. However, such targeted management should always be seen as transitional and temporary – the ultimate goal being to re-incorporate the species into a long-term, sustainable management regime.

Section C8 sets out the main sorts of actions necessary to restore natural function to the suite of semi-natural priority grasslands. For vascular plants the following factors are most important, although it must be remembered that these are generalisations and some species may have more exacting or atypical requirements.

- Vascular plant diversity is generally best served by low soil and water nutrient status and where this has been elevated by agricultural or atmospheric sources the aim should be to restore natural levels.
- Herbicides, selective or otherwise, should be avoided unless non-native species are present which cannot be eliminated in other ways. Significant native weed infestations should always be countered primarily by improved grassland husbandry. If herbicides must be employed then they should always be applied in a targeted way (whether the active chemical is selective or not).
- Across England most grasslands are maintained by grazing/browsing by a combination of wild herbivores (deer/voles/rabbits) and livestock resulting in heterogeneous conditions suited to maintaining suites of priority species or important plant and invertebrate communities – e.g. resulting in some scrub of different age classes for certain grassland types and variation in sward height and extent of bare ground in habitats such as calcareous and acid grassland. In some situations (LM & UHM) this is traditionally supplemented by mowing, following a period when grazing animals are excluded.
- However, whilst it may be required for agricultural reasons or to maintain traditional management systems, mowing generally results in a degree of homogenisation of sward structure which can supress the development of more diverse assemblages. Historically the mowing of relatively small areas in extensive flower-rich landscapes was compatible with the maintenance of biodiversity. When widely employed in the limited remaining areas of flower-rich habitats within generally flower-poor landscapes however, it will inhibit the potential expression of biodiversity. In meadows, even relatively biodiverse ones, it is noticeable that many vascular plant species, including some which are threatened such as northern hawk's-beard (*Crepis mollis*), are largely restricted to uncut margins or steep slopes within the enclosed area. Also the flowering and, in particular, seeding of many late-flowering species (such as common knapweed (*Centaurea nigra*) and devil's bit-scabious (*Succisa pratensis*)) is seriously curtailed in most seasons under a typical cutting regime. On the other hand earlier-flowering, "bulky" grassland species, such as great burnet (*Sanguisorba officinalis*) and some of the lady's-mantles (*Alchemilla* spp.) benefit from the period of exclosure associated with traditionally managed meadows. An alternative to cutting which might be considered in such situations involves the exclosure of livestock during the early summer period with restoration of grazing in late summer – effectively producing a "standing hay" crop. This allows the flowering associated with a hay meadow (and all the benefits that brings – see below) whilst avoiding the sudden "ecological catastrophe" and structural homogenisation of the cut.
- Flowering is critically important to most vascular plants – whether wind or insect pollinated it ensures the genetic exchange critical in the adaptation of populations to changing

environmental conditions. Even in apomictic genera (in which asexual reproduction predominates) such as the hawkweeds (*Hieracium*) or lady's-mantles (*Alchemilla*) seed dispersal remains important and for that flowering and fruiting is required (e.g. Rich and Scott 2011). In addition the presence of an abundance of flowers throughout the growing season is critical in maintaining the diversity and abundance of pollen- and nectar-feeding invertebrates leading to enhanced connectivity of insect-pollinated vascular plant species. In turn, the enhanced survival of fruiting inflorescences of species such as common knapweed into the autumn provides energy for a range of seed-eating birds such as goldfinches at a critical time of year.

- Additionally structural complexity in vegetation is important to most invertebrate groups and this too ultimately supports the diversity and connectivity of insect-pollinated vascular plants. Dynamic scrub patches, wherever possible maintained by browsing animals is key to this but the juxtaposing of other species-rich habitats such as woodland or heath may be equally important in providing other organisms with structures or species key to their long-term sustainability. Wherever possible the degree of segregation of grasslands from other diverse habitats should be ameliorated and diffuse transitions encouraged.
- Where conditions permit, allow structurally contrasting components within grasslands to develop or ensure they are maintained if already present – this may include features such as ant hills, springs, natural bare ground/rock natural, areas of impeded drainage and ponds. In particular many grassland sites have artificial drainage which can significantly reduce potential vascular plant diversity by homogenisation of hydrological profiles – wherever possible and appropriate natural hydrological function should be restored.
- Due to their tendency to graze in a very selective manner, sheep can significantly reduce vascular plant diversity – particularly where grazing pressure is high and in acid and upland fringe situations. In the long-term sheep also tend to reduce vegetation structure with concomitant negative consequences (see above). Cattle grazing, in particular, is preferred from the perspective of vascular plant diversity and suitable breeds of pony can assist where more browsing is needed. Whilst it is appreciated that sheep breeds vary considerably in their grazing habits and that LCG may be relatively resilient in the face of selective grazing pressure, more natural herbivory can be achieved by supplementing grazing/browsing by native species with suitable cattle breeds (acting as proxy for the lost native Auroch)
- Reduce or, preferably, eliminate any invasive aliens such as low-growing *Cotoneaster* species and evergreen or Turkey oaks (*Quercus ilex* & *Q. cerris* respectively) in LCG.

In combination, these actions are generally compatible with ensuring the diversity and sustainability of the vascular plant component of grasslands, the populations of threatened vascular plant species and their intimately associated invertebrate and fungal biota. However, it is vital that on those sites that are particularly important for short sward or open ground species that the populations of these species are not compromised by managing for more heterogeneous swards with taller swards. On small/isolated sites, especially, it may be more important to emphasise the botanical (or other) strengths of the particular sward than to aim for more generalised diversity.

C8. Key messages – all lowland semi-natural grasslands

- For semi-natural grasslands, restoring natural function to existing habitat is usually about ensuring suitable soil and hydrological conditions plus restoring or maintaining appropriate vegetation management. The latter also needs to be able to deliver heterogeneous conditions supporting a range of microhabitats to ensure suitable conditions for associated fauna (Webb *et al.* 2010).
- In practical terms, this involves reducing non-site based sources of harm from atmospheric nitrogen deposition and diffuse pollution and particularly for wetter grasslands addressing issues relating to abstraction and intensive drainage.
- Site based issues include restoration of extensive grazing and reducing agricultural inputs of fertilisers and herbicides.
- Where semi-natural grasslands occur in a mosaic with other habitats, the actions to restore more natural function for grasslands is in most cases consistent with the requirements of other elements of the mosaic. Particular care may be required where the

objectives are to restore more naturally functioning hydrology to other habitats such as rivers and fens to ensure grasslands such as flood plain meadows or types of purple moor-grass/rush pasture are not adversely affected. In some cases, this may require some form of compensatory habitat creation or restoration elsewhere within the immediate catchment or landscape.

- There may also be a need to consider the nature of the mosaic in relation to the needs of species or species assemblages such as the extent of scrub/tree cover on the managed habitats (grasslands, heathlands etc.) that from part of the mosaic.
- As described in Lawton *et al.* (2010), restoring biodiverse grassland to make existing sites larger, creating more grassland habitat and ensuring the resource is more connected may make it easier to restore natural function to core sites and to ensure species populations are more sustainable. For example, increasing the area of habitat suitable for pollinating insect species may have benefits for the populations of plants of the core semi-natural grassland habitats (Potts *et al.* 2010).
- The approach advocated in Lawton *et al.* (2010) will also contribute to climate change adaptation for grassland habitats and associated species.

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