GRASSLANDS

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1. KEY POINTS

1. Over 40% of land cover in the United Kingdom (UK) is grassland. Currently, only 2% of the UK's grassland cover comprises of biodiverse carbon rich semi-natural grassland. Protecting this grassland is of high importance for biodiversity and avoided emissions.
2. Acid grasslands, predominantly found in the uplands, contain around 30% more soil carbon per unit area than other grassland types. Neutral (semi-improved) grasslands, richer in species than improved grasslands also contain marginally more soil carbon in the top 15cm of soil. Maintaining and improving species diversity in neutral grassland is critical for mitigating greenhouse gas (GHG) emissions and increasing wider biodiversity.
3. Restoring permanent grassland via reversion from improved grassland or arable land, including the restoration of wet or chalk grasslands as part of a varied mosaic style landscape, can positively impact biodiversity and reduce GHG emissions. For example, figures from the UK Land Use, Land Use Change and Forestry (LULUCF) GHG inventory indicate that conversion of arable land to grassland has the potential for removing 8.72 million tonnes of carbon dioxide (CO_2) per hectare per year (t.CO_2/ha/yr) across the UK.[1] In contrast, conversion of grassland to arable land can result in net emissions of 14.29 megatons (Mt.CO_2e/ha/yr)[1].
4. Further research is needed to identify optimal sward composition, structure and associated grazing practices for GHG mitigation and enhanced grassland biodiversity which fit with production needs on intensively managed grassland. Continuous set stocking may result in reduced carbon sequestration and biodiversity and associated impacts on ecosystem services, including water-holding capacity.
5. Some types of grassland may be suitable for carefully selected tree planting with native species, e.g. for agroforestry or wood pasture. Agroforestry has the potential to mitigate climate change through increased carbon sequestration in vegetation and soils, storing up to 63 tonnes of carbon per hectare in temperate regions.[2] However, a good understanding of site characteristics including vegetation communities, soil carbon at depth and hydrology is essential to avoid perverse outcomes.
6. As well as decreasing animal numbers overall, grazing by a diverse range of animals (e.g. sheep, cattle, horse, goats, alpaca) on the same pastures can also have positive effects on grassland sward diversity and resultant GHG emissions[3]. Shifts in grazing patterns, for example the adoption of rotational or mixed grazing, can also reduce emissions compared to continuous grazing[4].

2. INTRODUCTION

Effectively managed healthy grassland ecosystems can provide vital environmental, social, cultural and economic benefits[5,6,7]. Grassland covers almost 40% of the UK land area[8,9] and is generally classified into lowland (below 350m) and upland types[1]. The lowlands tend to be drier and less exposed than the generally wetter and cooler uplands[10]. Grasslands vary from intensively managed agriculturally improved grasslands and arable leys in lowland agricultural areas, through a range of semi-improved grasslands (usually ploughed and sown at some stage) to semi-natural grasslands on neutral, acidic and calcareous soils. Grazing pastures tend to be significant for both food production and the ecosystem functions and services which they provide, whilst meadows are primarily associated with production of the latter[11,12]. Grasslands that are not cultivated and re-sown within five to seven years or more are generally defined as permanent grassland; those that are cultivated within this period are classified as temporary grassland[13,14].

Grasslands in the UK are almost entirely under agricultural management. Therefore the future design of Environmental Land Management Schemes (ELMS) (as currently being tested and trialled in England) and other devolved nations agri-environment schemes[15,16], which will replace the Common Agricultural Policy (CAP) will play a crucial role in deciding the extent to which grasslands can fulfil their potential as nature-based solutions (NbS).

The future provision of ecosystem services[5] and public goods from grasslands needs to be addressed through appropriate management interventions. Where possible this will create win-wins for both food production and the provision of wider public goods. The following sections focus on human wellbeing, the biodiversity value of grasslands and practices that can help to address issues affecting climate change mitigation and adaptation, whilst ensuring effective management and maintaining food production.

3. HUMAN WELLBEING VALUE

Semi-natural grasslands are of significant cultural importance for the UK[17]. They cover such a large extent of our landscape, including areas of key importance for human access such as our National Parks[12]. Twenty eight percent of UK National Parks and Areas of Outstanding Natural Beauty (AONB) consist of semi-natural grasslands[18]. For example, the North Pennines in England which contain 40% of the UKs upland hay meadows. Grassland can deliver cultural, biodiversity and climate benefits for a region. For example, County Fermanagh in Northern Ireland has semi-natural, species rich wet grassland concentrated in the area, but is not designated as an AONB or National Park[19,20].

Grassland characterises many UK landscapes. For example, UNESCO world heritage sites and extensive areas of the Lake District[21]. National Parks are rated as important for human wellbeing by the UK public[22]. However, they are often criticised for failing biodiversity. This can be due to high visitor numbers and management practices and policies that focus on cultural landscape value[23,24]. Despite sometimes damaging practices, like sheep overgrazing[25], grasslands remain important habitats for biodiversity. For example, they provide breeding sites for wading birds, such as Curlews which are in decline across the UK[26,27].

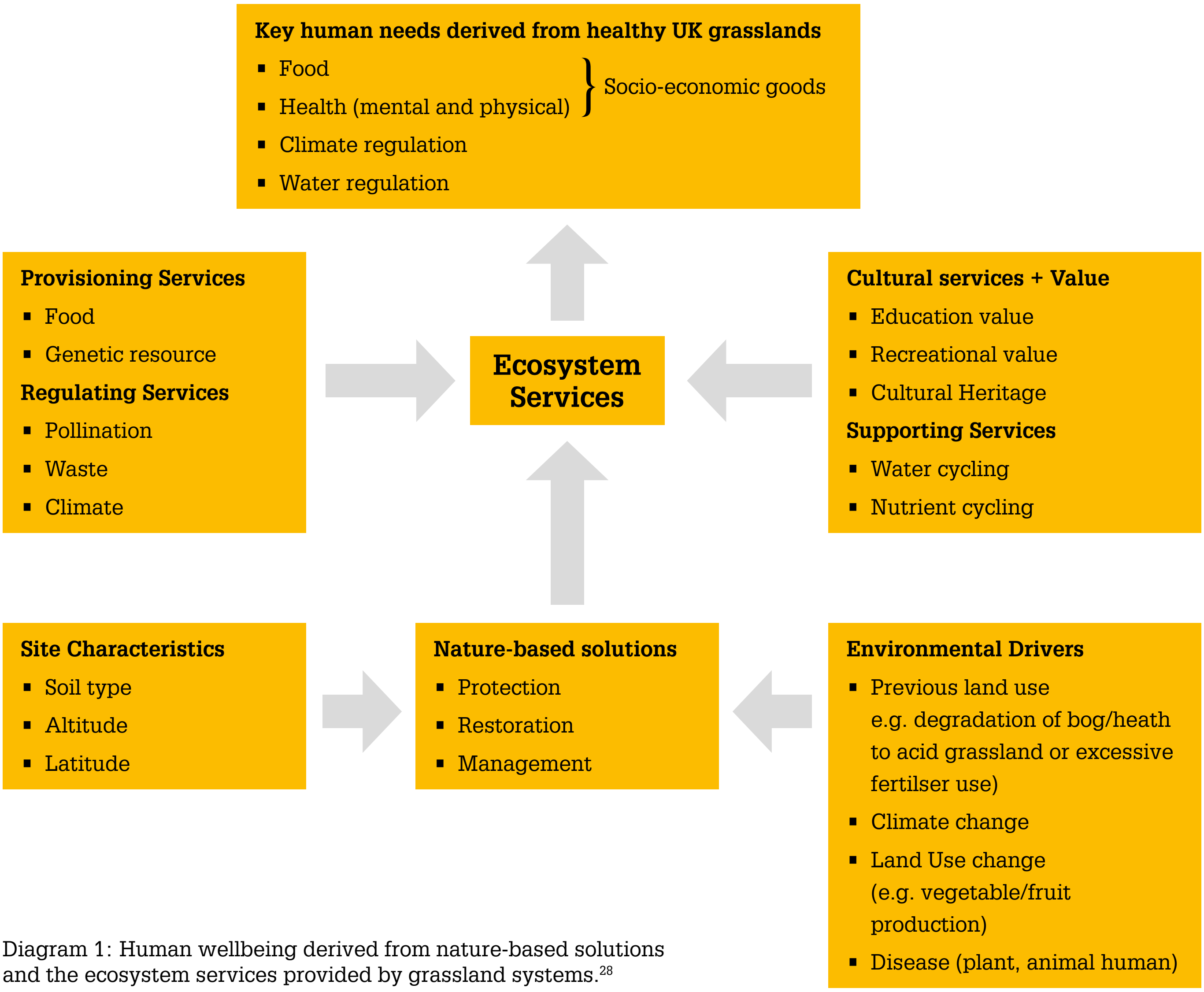

Diagram 1: Human wellbeing derived from nature-based solutions and the ecosystem services provided by grassland systems.[28]

4. BIODIVERSITY VALUE

There was an estimated 97% loss of enclosed semi-natural grasslands in England and Wales between 1930 and 1984, with only 2% of the remaining UK's current grassland area considered to have a high diversity[12]. In lowland meadows and pastures up to 35 or more plant species may occur in a 2m x 2m sample, including a range of grasses and herbs, e.g., Knapweed (*Centaurea nigra*) and Bird's-foot trefoil (*Lotus corniculatus*) and in some meadows, rarer species like Snake's Head Fritillary (*Fritillaria meleagris*)[18,29]. Well established lowland meadows provide excellent habitat for invertebrates, such as butterflies and other pollinating species, which has a direct value for food security[30].

Grasslands also provide important habitats for many British fungi that provide decomposition benefits for the soil[31,32]. Many species of fungi thrive in nutrient poor semi-natural grasslands. The UK's Waxcap mushroom species are dependent on grasslands in Wales, Scotland and Northern Ireland in particular[33,34,32]. Many of these high value semi-natural grasslands are now under protection from conservation charities or within national nature reserves where they may be managed by conservation grazing under agri-environment schemes. There are also 122 endemic vascular plant species in Britain that rely on grasslands for their habitat[35].

Semi-improved and improved grasslands tend to be less biodiverse than semi-natural grassland, largely due to management influences including ploughing and sowing with productive species, the use of fertilisers (organic and mineral) and intensive grazing management[36,37]. However, their extent means that they remain important habitats for many of our common species. For example, they provide crucial feeding areas for wintering birds such as Fieldfare (*Turdus pilaris)*, Redwing (*T. iliacus*) and other farmland birds[18,27].

While the UK's 'landscape designations' (such as National Parks and AONBs) contain a significant proportion of the UK's upland grasslands, many are not designated specifically for nature conservation and do not necessarily contain high amounts of biodiversity. They do remain important for carbon storage a high percentage of UK carbon stock is located within our soils[7]. Designated landscapes may include high concentrations of sites designated for nature within them, such as Sites of Special Scientific Interest (SSSI) or Areas of Special Scientific Interest (ASSI). However, these are often in poorer condition, in terms of biodiversity, than SSSIs in the countryside outside of designated landscapes[38,23]. For grasslands this has in many cases been attributed to overgrazing.

5. CLIMATE CHANGE MITIGATION POTENTIAL

5.1 RETAINING PERMANENT GRASSLAND IN SITU

Grasslands store carbon below ground and due to their large coverage they hold a considerable proportion of the UK carbon stock. Acid grasslands, predominantly found in the uplands, contain almost four times as much soil carbon in the top 15cm of soil than other grassland types. However they are considerably less dense than either neutral (semi-improved), or improved grasslands resulting in stocks of soil carbon being around 30% higher in acid grassland. Neutral or semi-improved grasslands contain around 15-20% more soil carbon than improved grasslands in the top 15cm. However they are also less dense leading to only marginally higher soil carbon per unit area on neutral grasslands[8]. The UK Land Cover Change product for 1990-2015 shows losses of 7668km^2 of grassland across the UK over that time period.[39] Whilst the definition used to assess this change is broad (due to use of satellite data), this loss of grassland is of concern, particularly where grassland is being lost to less carbon rich arable or urban areas.

Whilst we still do not fully understand the processes involved in carbon storage and sequestration at depth, we know that habitat loss can lead to GHG emissions. For example, protecting permanent grassland from conversion to croplands strongly mitigates against the loss of soil carbon[40]. Similarly, reducing the incidences and/or frequency of ploughing-tilling and reseeding on improved grasslands could impact significantly on soil carbon stocks and overall GHG emissions.[41] In contrast, the conversion of croplands to more permanent grasslands can enhance soil carbon sequestration[42].

Different estimates of habitat loss across the period from 1930 to 2016 indicate that up to 97% of semi-natural grassland has been lost[43], that it remains in significant decline in some areas[1] and is highly fragmented everywhere. Habitat losses for semi-natural grassland are considered to be more likely to be significant for diminishing carbon stocks than management factors[1,44]. A small proportion of semi-natural grasslands may now be owned and managed for conservation, e.g Chinnor Hill owned and managed by the Wildlife Trusts, and maintenance and protection of these biodiverse, carbon-storing habitats continues to be of key importance. Similarly, grasslands that have a high carbon stock (but may not necessarily be species rich), including acid grassland in upland areas on peat soils, should also be protected (or where appropriate, restored to former bog habitat) and soil disturbance minimised.

Traditional management of semi-improved/improved grassland, including ploughing and re-seeding every five to eight years with simple species mixes (and more frequently than that for leys on arable land), results in net losses of soil carbon[13,7] Shallow rooting depths of sown species (e.g. annual ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*))[45,46] constrain soil carbon[14] and have low levels of species diversity. This management model was targeted primarily at increasing productivity, with grass (usually *Lolium perenne*) as the main crop species. They are often enhanced by nutrient inputs, which themselves affect GHG mitigation through N_20 emissions, the fertiliser manufacturing process and their application. This management model also reduces the diversity of species that are present.[47]

Organic inputs like slurry and mineral fertilisers and, to a lesser extent, farmyard manure (FYM), can significantly increase soil CO_2 and N_2O emissions (although FYM may also constitute a significant carbon input). The effect is highly dependent on the fertiliser used and the timing and type of application. Increasing soil pH through liming can reduce N_2O production, as production is higher in acidic grassland soils generally[48].

In addition to emissions of GHG pollutants from agricultural grasslands, losses of phosphorus (P) and nitrogen (N) due to fertiliser application and, for P in particular, nutrient rich animal waste, remain a key source of diffuse pollution in UK water bodies[49]. A shift away from traditional ploughing and reseeding practices and associated nutrient management practices, towards practices using more diverse permanent pastures which require lower levels of nutrients, would better enable grasslands to fulfil their potential as an NbS for climate mitigation and biodiversity enhancement. It is however, very important to establish whether there would be a the trade-off between food production and a focus on public goods that would result from such a management change.

An additional pressure on grassland is tree planting. The UK Land Cover Change product for 1990-2015 indicated that whilst open grassland habitats decreased over that time period, woodland increased[50]. Going forward, most of the land identified as suitable for tree planting in the UK is grassland[51,52]. Tree planting may have significant impacts on all grassland types from improved grassland to grassland habitats protected by law for their ecological, scientific, scenic, or cultural value[51]. Some evidence suggests that planting trees on grassland can have temporary negative impacts on soil carbon[53]. This is because site preparation for planting trees releases carbon from the soil[54]. This initially creates a "carbon debt" which may be small, but needs to be repaid before it can deliver any climate benefit[55]. Whilst afforestation is effective at sequestering carbon, impacts are likely to be complex and dependent on a range of interacting factors including soil type, grassland type and management. It can also be dependent on how the trees are planted and what species they are. Similarly, tree planting for climate change mitigation may have positive or negative impacts on biodiversity depending on the above factors and habitat context. While the introduction of trees into pastureland (silvopasture) is likely to be positive for biodiversity[56], outcomes are highly dependent on the starting point of the pasture, with tree planting on species rich semi-natural grasslands likely to be highly damaging to the biodiversity of this now uncommon habitat.

5.2 GRAZING MANAGEMENT

Grazing ruminants on grassland contribute to GHG through the production of methane (CH_4) emissions, primarily from belching (as a result of enteric fermentation) and excreta as well as through the management of the grassland on which they graze[57]. Semi-natural grasslands are generally associated with lower methane and nitrous oxide emissions than agriculturally improved grasslands due to lower stocking densities and inputs.

Appropriate management of grazing animals and the grasslands on which they graze can help to maximise the climate change mitigation potential of UK grasslands. As well as reducing the incidences and/or frequency of ploughing-tilling, reseeding and fertilizer use (above), reductions in the numbers of animals and grazing pressure may help to reduce overall GHG emissions from grasslands[58]. As well as decreasing animal numbers overall, grazing by a diverse range of animals (e.g. sheep, cattle, horse, goats, alpaca) on the same pastures can also have positive effects on grassland sward diversity and resultant GHG emissions[3]. Shifts in grazing patterns, for example the adoption of rotational or mixed grazing, can also reduce emissions compared to continuous grazing[4].

‘Mob grazing’, is a type of grazing management that is attracting a lot of attention in some farming circles, for example, one of the Innovative Farmers groups currently being run by the Soil Association is focused on it. Whilst it is used across a variety of approaches (often with other descriptors), it generally refers to short term, high density grazing which may or may not occur on tall grass but always includes a long recovery time for the pasture to re-grow (both above and below ground) and may result in some trampling of the pasture.

Its use is based on adopting grazing patterns that mimic herd grazing patterns in nature. It has been used under various conditions and on both arable land and rangeland, with evidence from some parts of the world indicating positive benefits for soil health, soil carbon, and plant diversity as well as animal productivity[59,60]. Despite this evidence, as it is a relatively novel practice in the UK, our data set is limited, particularly in terms of understanding potential additional long-term benefits for soil carbon (C) and soil health in comparison to current UK grazing management practices. Hence, more research in this area is required.

6. CLIMATE CHANGE ADAPTATION POTENTIAL

Grassland soils absorb and filter water, cycle nutrients and store carbon on a large scale[13,61] making them a potentially valuable NbS for climate mitigation and adaptation lower density extensive grazing can increase water infiltration rates and reduce flood risks by avoiding soil compaction[62,63]. Grasslands can provide resilience to extreme weather events. For example, chalk grassland can act as a natural buffer to reduce the likely impact of flooding. Grassland can also provide naturally functioning floodplains that can evolve into new wetland habitats and allow for greater water storage[64]. There is evidence that land use change from grassland to wetland can result in sequestration of 2.39 to 14.30 t.CO_2/ha/yr[1].

Ecological restoration of grassland sward plant diversity could offer a valuable means to increase the adaptive capacity of UK grasslands to a changing climate[74,7]. The introduction of native species mixtures that include legumes has also been shown to benefit soil carbon sequestration[71,72,73] and to reduce the need for synthetic nitrogen fertilisers. However, the capacity of UK grasslands to naturally adapt to climate change through increasing in species diversity is severely limited by the presence and connectivity of habitats including suitable species in the wider landscape.

Although the variety of grasslands across the UK provides some resilience to environmental drivers, some grassland types, may be more sensitive than others, e.g. hay meadows in the uplands, which may be particularly sensitive to climatic change[74,7]. These meadows may adapt to climate change by transitioning to less notable habitats, but even as wetter grassland they will remain important for carbon and water storage.

7. CHALLENGES

Only 2% of the biodiverse and carbon rich semi-natural grassland that was present in the UK a century ago remains; protecting this grassland is a key priority. Two thirds of UK grassland is intensively managed for agricultural use[8]. Going forward, one of the challenges will be rethinking grassland management practices for the maintenance and enhancement of biodiversity, carbon storage and sequestration, alongside food production. This will include consideration of management practices which affect the production, maintenance and long-term use (grazing, hay, silage) of a productive biodiverse grass sward whilst avoiding excess carbon loss (e.g., ploughing,

CASE STUDY 1: FLOODPLAIN MEADOWS DELIVERING NBS[65,66].

Floodplain meadows are a beautiful and ancient agricultural system that has evolved over many hundreds of years through an annual hay cut followed by aftermath grazing. The result of such management has been the development of communities of grasses and herbs that thrive with the flood and drought cycles on floodplains than against it. Floodplain meadows hold one of the UK's most diverse plant communities, with up to 40 plant species m^{-2}. The Natural Capital of Floodplains (2018)[67] argues that the value of the benefits provided by seasonally inundated floodplain meadows far outweigh those provided by land in intensive agriculture.

From left to right: Floodplain meadows at work © Irina Tatarenko, Belted galloways Clattinger Farm © Mike Dodd and Yarnton meadow Oxfordshire, species rich grassland © Mike Dodd

Floodplain meadows regulate flood events by providing space outside the river channel for floodwater to occupy. They capture sediment, absorb nutrients and filter water, whilst also delivering sustainable agricultural production with minimal inputs, and constituting a rich cultural resource. Their alluvial soils are particularly important for carbon sequestration because they grow deeper with each flood event[68]. In this respect they are probably second only to peat soils in the UK in their ability to store carbon. Organic carbon within the top 10 cm of soil at North Meadow Cricklade (a species-rich floodplain meadow) was observed to be 0.11 tC/yr[69] values much higher than those previously reported for neutral grassland and extensively managed grasslands in a survey of grassland soil carbon[8,44]. The deep rooting strategies and diversity of plants and roots are the keys for carbon storage. Recently published research Tilman 2019[70] comparing carbon storage between species poor swards and species-rich grasslands restored from species- poor swards show that higher species-richness increases the rate of carbon sequestration in grassland communities.

seeding, inputs).

Another challenge for grassland management is the research needed to assist in transforming grassland management. Lack of understanding about the processes leading to carbon storage at depth, its relationship with biodiversity above and below ground and how it is affected by field management practices needs to be addressed. Gaining a better understanding of these processes and how they relate to food production (both quantity and quality[75]), preferably alongside farmers, will help to determine appropriate land management practices in relation to mitigating or reversing biodiversity loss and climate change impacts. For grassland in areas of particular cultural interest (e.g., for tourism, recreation and inspiration), such as the National Parks and AONB's, there is a challenge around how to enhance biodiversity and carbon storage whilst continuing to maintain and enhance these cultural ecosystem services which result in vital income for many of these areas, e.g., maintaining profitable livestock enterprises.

Common sense would suggest that grassland with low carbon stocks and biodiversity both above and below ground is the best land on which to plant trees. Some research on approaches to planting trees on or around grassland for maximising grassland and biodiversity, whilst enhancing or minimising agricultural outputs, is already available[76]. However, to mainstream these and other practices it is likely to be important to work with land managers to gather further evidence across a range of approaches and locations and to understand how to encourage and motivate farmers to take up novel practices. Tree planting on carbon and biodiversity rich grassland or on ecologically important wetlands should be avoided to avoid carbon and biodiversity loss; an understanding of site history and ecology is therefore crucial.

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