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Annex 2: Sward Management

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1 Introduction & background

The Brief: *Establish the intervention logic for supporting the diversification of swards in improved grassland. Establish the Greenhouse Gas (GHG), water quality, air quality and economic benefits. Establish the environmental outcomes including GHG emissions reduction, biodiversity, water quality and air quality, which will be secured through diversification of sward management. Identify the contribution that sward diversification will make to the economic resilience and sustainability of Welsh agriculture.*

The main objective of this review was to establish the intervention logic for supporting the diversification of swards in improved grassland in Wales.

Sward diversification in this context is defined as increasing plant species diversity through the addition of grass, forb and legume species. This is normally carried out through field operations such as reseeding, oversowing or slot seeding.

Improved grassland is defined as land dominated by grasses or herbaceous forage that has been improved through the installation of an underdrainage system, sowing of productive grassland plant species or the addition of lime and/or chemical or organic fertiliser to raise soil nutrient reserves and increase grass and/or herbaceous forage production potential. It can be inferred from the Environmental Impact Assessment (Agriculture) (Wales) Regulations 2017 that improved grassland includes grassland that contains more than 25% improved agricultural grass species and/ or white clover; short-term grass leys; and grassland that has been intensively cultivated and fertilised in recent years (Welsh Government, 2017). However, it should be noted that not all the research papers referenced in this report will have used the above definition of improved grassland.

In Wales, grasslands, including rough grazing, but excluding common land, occupy 88% of all land on agricultural holdings (Figure 1.1; Welsh Government, 2018). This includes 1,083,587 ha of permanent grassland (which has not been part of an arable rotation for at least five years) and 153,723 ha of temporary grassland (Table 1.1), representing 86% of the Utilised Agricultural Area (UAA).

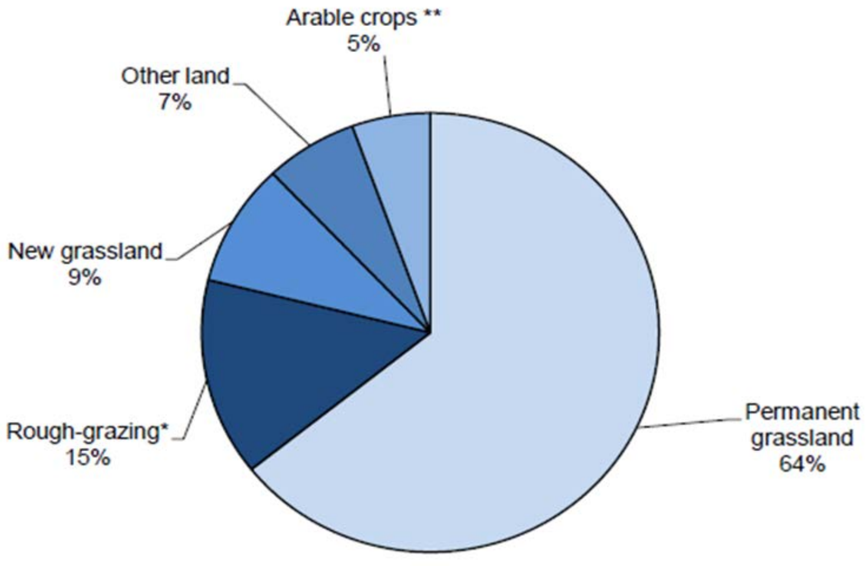

Figure 1.1. Split of land on agricultural holdings in Wales by usage 2018 (Welsh Government, 2018).

*Rough grazing where holder has sole rights (i.e. excludes common rough grazing)
** Includes horticulture (vegetables and fruit grown in the open, hardy nursery stock and glasshouses)

Land use	Area (ha)
Rough grazing	248,678
Permanent grass	1,083,587
Temporary grass	153,723
Winter cereals	28,819
Spring cereals	19,707
Maize	12,022
Oilseed rape	4,348
Potatoes	3,358

Table 1.1. Agricultural land use in Wales (Welsh Government, 2018).

Statistics on reseeding are not available for Wales, but Defra provides data on reseeding frequency in England, which provide an indication of current practice in Wales. According to Farm Practices Surveys of England (2015-2018), c. 70% of livestock holdings with temporary grassland had sown a proportion of their temporary grassland with a clover mix; and c. 30% had sown all their temporary grassland with a clover mix (Defra, 2018). High sugar grasses were sown on c. 60% of livestock holdings with temporary grassland. The most common frequency for reseeding clover or high sugar grass swards was every three to five years, with c. 30% of holdings reseeding clover and c. 33% of holdings reseeding high sugar grasses at this frequency. Around one third of farms never reseeded with clover and around 20% never reseeded with high sugar grasses. A high proportion of farms with temporary grassland are therefore reseeding at a frequency of every two to ten years. There is no data on the frequency of sward renewal or improvement on permanent grassland fields, but anecdotal evidence indicates that this is less common (Cotswold Seeds, pers. comm. 2017).

The use of diverse swards or herbal leys appears to be on the increase, but anecdotal evidence and total sales of seed indicate that such multi-species swards occupy a small proportion of the grassland area (Cotswold Seeds, pers. comm. 2017).

2 Outcomes

The principal outcomes that could be expected from supporting the diversification of swards in improved grasslands are potentially:

i. Improved productivity (including improved margin per unit of production)
ii. Holistic long-term business planning that allows social, economic and environmental future proofing
iii. Improved water use efficiency
iv. Improved nutrient use efficiency (including reduced use of manufactured nitrogen fertilisers)
v. Increased carbon sequestration in degraded soils
vi. Reduced greenhouse gas (GHG) emissions
vii. Increased biodiversity in terms of species numbers and/or abundance of invertebrates and vertebrates (this will be dependent upon the scale of the change as some species will have a minimum habitat area requirement)
viii. Improved water infiltration
ix. Improved contribution to high air quality (reduction of air pollutants)
x. Flood risk mitigation

3 Policy Relevance and Policy Outcomes

The policy outcomes associated with supporting the diversification of swards in improved grasslands are principally aligned with (and could potentially contribute to) the following Well-Being of Future Generations (Wales) Act Well-being Goals:

- A prosperous Wales – using resources efficiently and proportionately, including acting on climate change
- A resilient Wales – maintaining and enhancing a biodiverse natural environment with healthy, functioning ecosystems that support social, economic and ecological resilience and the capacity to adapt to change
- A globally responsible Wales – making a positive contribution to global well-being

They also support the United Nations Sustainable Development Goals, which underpin the Welsh Government legislation:

- Good Health and Wellbeing – ensuring healthy lives and promoting well-being for all at all ages - principally through reduced ammonia emissions and nitrate leaching losses
- Clean Water – potentially improving the availability and sustainable management of water - through improved water infiltration and reductions in nitrate leaching losses
- Responsible Consumption and Production – contributing to the sustainable management and efficient use of natural resources - principally through improved nutrient use efficiency
- Climate Action – principally through reducing direct and indirect nitrous oxide emissions
- Life on Land – principally through improved ecosystem functioning and resilience

Supporting the diversification of swards in improved grasslands could also make a small contribution towards the sustainability and management of natural resources principles in the Environment (Wales) Act by potentially improving air quality, reducing Greenhouse Gas (GHG) emissions, sequestering carbon, improving water quality, mitigating flood risk and increasing ecosystem resilience.

The policy outcomes could also be relevant to the following Natural Resources Policy priorities:

- Restoration of our uplands and managing them for biodiversity, carbon, water, flood risk and recreational benefits
- Resilient ecological networks
- Maintaining, enhancing and restoring hydrological systems to reduce flood risk and improve water quality and supply

4 Sward management

4.1 Supporting the diversification of swards in improved grasslands

4.1.1 Causality

4.1.1.1 Carbon sequestration and greenhouse gas (GHG) emission reduction

Where inputs of carbon through photosynthesis exceed outputs through respiration (plant, soil and animal), erosion and offtakes (in the form of crops, milk and meat) it is possible to increase soil organic carbon (SOC) (Smith *et al*., 2014). Therefore, genuine carbon sequestration in grasslands is theoretically possible through increasing net primary productivity, introducing deeper rooting plant species (Dignac *et al*., 2017; Garcia-Pausas *et al*. (2008), deepening the topsoil layer and moving organic matter into the subsoil through biological pedoturbation, i.e. the activity of earthworms, dung beetles etc., particularly where these methods do not also result in an increase in decomposition/soil respiration (Powlson *et al*., 2011; Garnett *et al*., 2017).

There is good evidence to indicate that increasing net primary productivity can increase SOC (e.g. Johnston et al., 2009). Therefore, if increasing sward diversity can result in increased productivity without an increase in manufactured nitrogen (N) fertiliser use, then genuine C sequestration is achievable. The best evidence for this is from the Jena experiment (Weisser *et al.*, 2017).

On a 10 ha area in the floodplain of the Saale river in Jena, Thuringia, Germany, Weisser *et al*. (2017) investigated the effect on productivity of plant species richness (six levels from 1 to 60 species) and plant functional diversity in a grassland sward at three levels of manufactured N fertiliser use: 0 kg N/ha, 100 kg N/ha and 200 kg N/ha (Figure 4.1.1.1.1).

They found that grassland productivity increased with plant species richness, and that the effects of plant diversity on productivity (average difference between monocultures and 16-species mixtures: 4.5 t DM/ha/yr) were stronger than the effect of manufactured N fertiliser (average difference between 0 and 200 kg N/ha: 3.2 t DM/ha/yr) (Weigelt *et a*l., 2009; Figure 4.1.1.1.1). SOC content also increased with increasing plant species richness (Lange *et al*., 2015; Weisser *et al*., 2017; Figure 4.1.1.1.2).

To put the effect of manufactured N fertiliser in the Jena experiment into context, the average difference in yield between 0 and 200 kg N/ha in the Jena experiment ('Average' Grass Growth Class - GGC - based on average summer rainfall and soil type) was 3.2 DM t/ha/yr, whereas in the 'Average' to 'Very good' GGC regions of Wales, the difference in yield (at applications of 0-200 kg N/ha/yr) varied from 2.2 to 6.8 t DM/ha/yr (Newell Price *et al*., 2016). 'Good' and 'Very good' GGC areas in Wales, therefore, responded well to manufactured N fertiliser inputs with yields of up to 13 t DM/ha/yr from 200 kg manufactured N/ha applied (Figure 4.1.1.1.3). Similarly in the German state of Thuringia (where the Jena experiment is located), Weisser *et al*. (2017) state that "species poor grasslands which are agriculturally optimized for hay production (e.g. clover-grass mixtures using particular varieties) with fertiliser input (ca. 200 kg N/ha^{-1} yr^{-1} and other nutrients) and up to six cuts per year can generally achieve forage yields between 1000 and 1400 g/m^{2}/yr" (10 to 14 t DM/ha/yr).

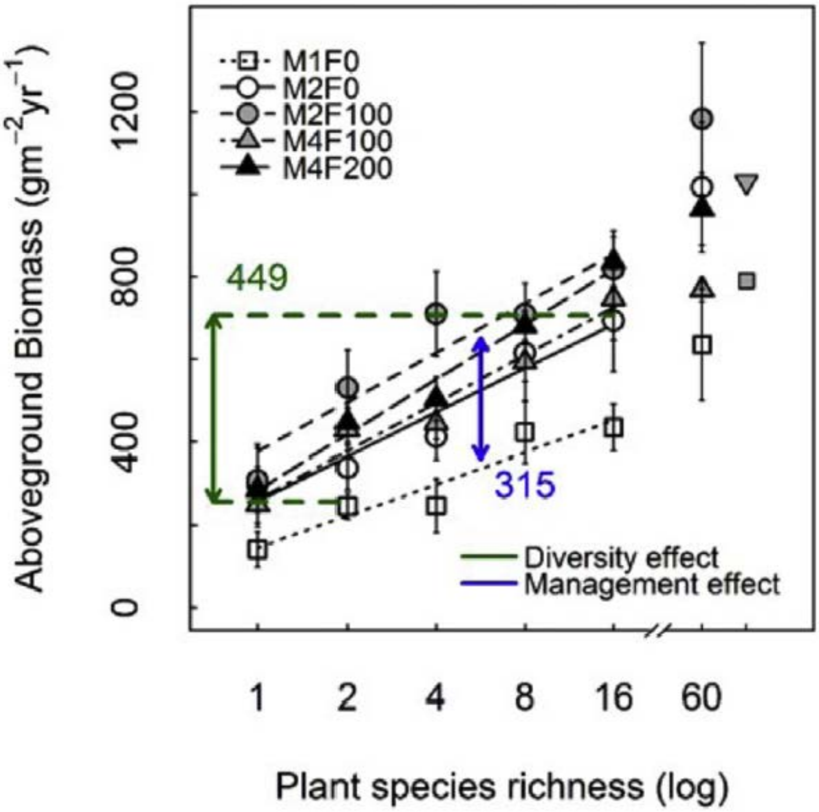

Figure 4.1.1.1.1. Effect of grassland management on the plant species richness–productivity relationship. Values are mean annual forage yields as sum of the total yield production per year (Source: Weisser *et al*., 2017).

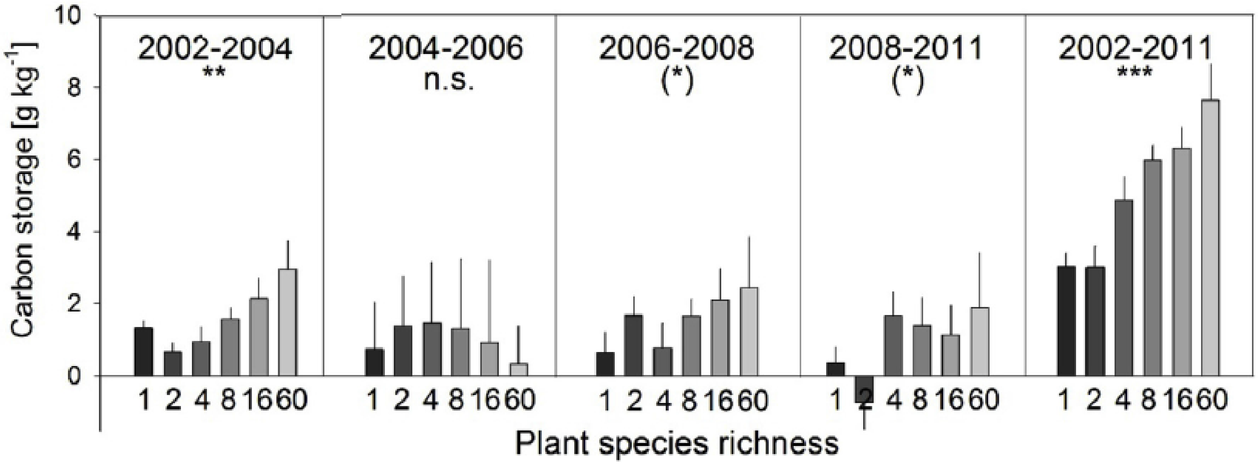

Figure 4.1.1.1.2. Development over time of the relationship between species richness and carbon storage in the top 5 cm (source: Weisser *et al*., 2017).

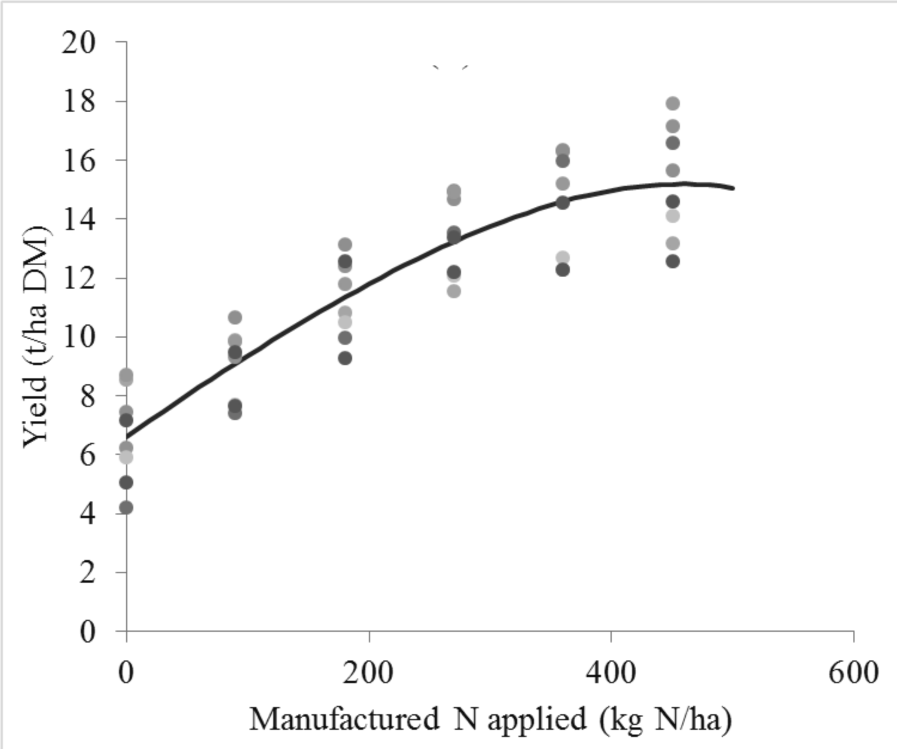

Figure 4.1.1.1.3. Mean grass DM yield response to manufactured N fertiliser from Defra IF01121 field experiments in 2013-15 on grass and grass/clover swards in England and Wales (source: Newell Price *et al*., 2016).

Nevertheless, results from the Jena experiment indicate that maintaining sward diversity in a grassland should likely increase some ecosystem functions such as biomass production, and simultaneously favour other functions such as C storage and water- or nutrient-use efficiency. However, it should be noted that the Jena experiment was established on a field previously under arable management in 2002, so the effects of the diverse sward may be underpinned by the legacy effect of converting from arable to grassland, as grasslands will not act as a perpetual sink for carbon (Smith, 2014). Furthermore, establishing and then maintaining the level of sward diversity that was achieved in the Jena experiment (8, 16 and 60 plant species) can be a challenge within productive grassland farming systems, particularly at higher levels of manufactured N fertiliser use (Muto et al., 2019; Weisser et al., 2017); and would also reduce the options for weed control (e.g. control of *Rumex* and *Asteraceae* species).

It should also be noted that soil carbon was measured to 30 cm depth in the Jena experiment, while other studies have highlighted the potential to sequester and/or maintain stores of carbon deeper in the soil profile (Ward *et al*., 2016).

Other demonstrations and experiments, where plant species richness has been manipulated, have also shown that increased plant diversity can enhance yield in low to moderate input/output systems (Döring *et al*., 2012; Finn *et al*., 2013; Hector *et al*., 1999; Kirwan *et al*., 2007; Suter *et al*., 2015).); increase SOC storage (Fornara & Tilman, 2008; Hungate *et al*. 2017), and decrease greenhouse gas emissions both from the soil (De Vries *et al*., 2015; Fontaine *et al*., 2005; Ribas *et al*., 2015) and from livestock per unit of feed intake (Enriquez-Hidalgo *et al*., 2014). Hungate *et al*. (2017) found that increasing species richness from 1 to 10 had twice the economic value of increasing species richness from 1 to 2. Increasing home-grown forage production (yield) also has the potential to reduce GHG emissions associated with feed purchased from elsewhere, leading to overall reductions in GHG emissions (Styles *et al*. 2018).

In the UK, Döring *et al*. (2012) found that seed mixes with higher agronomic productivity contained both lucerne and white clover, while the overall performance improved by including a third or fourth legume species. The three best multifunctional mixtures all contained black medic, lucerne and red clover. However, while red clover was generally more productive than white clover, it was less persistent and less tolerant to high grazing pressure (Smetham, 1973). Compared with grasses, legumes and herbs (e.g. red clover, white clover and chicory) can also provide greater digestibility and higher amounts of minerals per kg DM of grazed forage (Andueza *et al*., 2013; Lindstrom *et al*, 2013).

Most of the research on the diversity-function relationship in grasslands has been carried out in ungrazed systems, with few in grazed fields. The effect of diverse swards on productivity are also not consistent across studies. For example, Zaralis (2015) reported that pasture productivity from a diverse sward ley was slightly lower than that in a comparable grass-clover ley. The effects are also location- and system-specific, e.g. lucerne can be very productive on soils with high pH under a cutting or rotationally grazed regime but does not persist under continuous grazing or on acidic soils.

Nevertheless, according to the experimental data available, increased plant diversity in grassland swards provided stability to beneficial functions (Finn et al., 2013), even in a long-term grazing experiment (Laliberté & Tylianakis, 2012). Studies suggest an important role for biodiversity and plant functional types or traits in promoting stability in ecosystem benefits (Finn *et al*., 2013; Shi *et al*., 2016). The benefits of mixtures seem to last even after the initially sown species have disappeared (Connolly et al., 2017). However, more long-term experiments are needed, particularly for grazed systems.

4.1.1.2 Water quality

Grasslands are generally effective at maintaining or improving water quality (Newell Price *et al*., 2011; Defra project NT0605), due to the presence of vegetation cover throughout the year to protect the soil surface and take up nutrients. The permanent vegetative cover takes up N, and N immobilisation into accumulating soil organic matter provides a long-term sink for N, while protection of the soil surface minimises particulate P losses in surface runoff, provided that the grassland is not poached or badly compacted by vehicle traffic.

Diverse swards introduce N-fixing and deeper rooting species. Compared with a ryegrass sward, there is, therefore, potential for a reduction in manufactured N fertiliser use at the same level of production and improved nutrient use efficiency (Meyer *et al*. 2018a). Reductions in manufactured fertiliser use from the introduction of legumes in diverse swards have the potential to reduce nitrate leaching losses by up to 20% at the field scale; and direct and indirect N_2O emissions by up to 50% (Cuttle & James, 1995; Cuttle & Scholefield, 1995; Defra project WQ0106).

An important factor controlling the impact of diverse swards on water quality is the method of establishment and utilisation, e.g. whether seedbeds are prepared using inversion or reduced tillage, and whether the new species are incorporated into permanent grasslands or used as three to four year herbal leys within a grass/arable rotation. In the latter case, the N fixed during the herbal ley phase may be mineralised during cultivations in preparation for the arable phase. This may be an important part of nutrient supply within arable-ley systems, but can also increase the risk of nitrate leaching losses (Chalmers *et al*., 2001; Silgram, 2005; Defra projects NT1318 & NT1504).

4.1.1.3 Flood risk

Increasing sward diversity could potentially improve soil structure and impart greater resistance to soil compaction and increase water infiltration rates. The Jena experiment provides some evidence of increased water infiltration rates with increasing plant species richness under a cutting regime (Weisser *et al*., 2017), and resulting increased water-use efficiency. By contrast, there was no detectable increase in water infiltration rates when a single deep-rooting herbs and legume mix was introduced to permanent grassland swards at four sites in England and Wales (Defra project BD5001). Other studies working on monocultures have demonstrated increases in water infiltration (Fychan *et al*., 2013) or reductions in surface runoff (MacLeod *et al*., 2013). There may, therefore, be some potential to reduce flood risk through the introduction of diverse swards. The establishment of deep-rooting herbs and legumes, and the resultant flood risk mitigation may be more effective where swards are reseeded rather than overseeded, due to a more effective establishment and cover of the sown species. However, such reseeding operations on sloping land would result in greater runoff and flood risk during the reseeding phase, particularly if the reseeding operations result in soil being exposed to raindrop impact and surface runoff in the early stages of establishment.

Ultimately, the flood risk associated with grass, grass/clover and diverse swards may be more closely related to how the sward is managed (e.g. stocking rates and amount of heavy machinery when soils are ‘wet’) than to the nature of the sward itself (Defra project BD5001).

4.1.1.4 Air quality

Diverse swards can fix atmospheric nitrogen and therefore reduce manufactured N fertiliser use (Cuttle & Scholefield, 1995). They can potentially also result in increased water infiltration rates (Weisser *et al*., 2017). The combination of reduced N fertiliser use and improved infiltration has the potential to reduce ammonia emissions following slurry applications and improve air quality (Harrison & Webb, 2001; Misselbrook *et al*. 2004; Smith *et al*., 2000). Improved infiltration could also reduce ammonia emissions from urine patches.

4.1.1.5 Biodiversity

Successful diversification of grassland swards will increase plant species diversity and have implications for other above-ground and below-ground species. However, scale is an important consideration: while benefits for, say, air quality tend to vary linearly with the area managed in a particular way, species benefits will often be scale-dependent via thresholds or non-linear relationships.

Alison *et al*. (2017) demonstrated that created grasslands with a higher diversity of chalk grassland wildflowers, including key legumes such as *Lotus corniculatus*, supported a higher abundance of chalk grassland moths. Woodcock *et al*. (2013) showed that the introduction of simple seed mixtures into agriculturally improved grasslands could help support increased diversity of spiders and beetles; and while seed mixtures did not necessarily need to be of the highest diversity to achieve these benefits, the inclusion of legumes did appear to be crucial.

By contrast, Defra project BD5001 found that the introduction of deep-rooting herbs and legumes had no effect on earthworm biomass, earthworm numbers (Lees *et al*., 2016) or the foraging success/behaviour of starlings (*Sturnus vulgaris*). Meyer *et al*. (2018a) state that management of grass swards for increased ecosystem function will not necessarily protect diversity: “ecosystem service provisioning cannot replace high biodiversity as the aim of conservation management”. Sward diversity is one factor that may influence the ability of habitats to support particular species, but there are many other habitat and non-habitat factors that will determine the success or failure of high biodiversity conservation projects. For example, grassland sward structure and management is a critical factor in providing suitable habitat for some bird species (e.g. Atkinson *et al*., 2005; Buckingham & Peach, 2006).

4.1.1.6 Economic resilience

Increasing sward diversity, particularly the introduction of legume and forb species, should improve the environmental resilience of the sward (the ability to cope with drought or waterlogged conditions) and, through increasing productivity and nutrient use efficiency, should also improve economic resilience in low to moderate output systems. A focus on increasing the efficiency of production and the proportion of milk or liveweight gain from grass will typically lead to greater profitability and economic resilience. For example, Mihailescu *et al*. (2015) emphasised the importance of optimising inputs to improve economic sustainability. Humphreys *et al*. (2012) also found that grass-legume mixes yield well and can be used to reduce costs and improve profitability when fertiliser prices are high and milk commodity prices low. Ryan *et al*. (2011), who evaluated nitrogen efficiency as a key indicator of economically sustainable production on grass-based and high-concentrate dairy production systems in Ireland, reported that as N concentrate increased, N surplus per hectare increased and N use efficiency per hectare decreased. This highlights the importance of optimising productivity and nutrient use efficiency from grass, grass/clover and diverse swards.

The nature of a diverse sward itself can contribute towards nutrient use efficiency and economic resilience (through more efficient resource capture, particularly in dry years), but ultimately it is the nature of the grazing and cutting management, which is linked to the efficiency of grassland utilisation that will help determine the level of profitability in grazing livestock systems.

Introducing diverse swards could have several potential benefits. However, there are a few uncertainties associated with their use. For example, Peyraud et *al*. (2009) and Phelan *et al*. (2014) outlined a number of limitations surrounding the use of legumes that require further research. It can be difficult to predict DM production in diverse swards and maintaining optimum legume content in swards can be challenging, particularly in grazed and higher input/output systems. In addition, legumes can be difficult to conserve as silage or hay, and can increase the risk of bloat in livestock.

Phelan *et al*. (2014) outlined that further research into forage legumes, should take a “back to basics” approach and focus on the effects of management practices including sowing dates, regrowth/rest periods and post-grazing heights.

4.1.2 Co-benefits and trade-offs

Supporting the diversification of swards in improved grassland should help to increase a number of ecosystem services and functions such as biomass production, water-use efficiency and nutrient-use efficiency. Indeed, Scherber *et al*. (2010) found that higher plant species richness increased abundance of various organism groups, such as many animal taxa; and Allan *et al*. (2013) found that about 45% of investigated ecosystem processes were significantly affected by plant species richness. However, management to optimise a single ecosystem service or function is likely to decrease provisioning of other services, potentially even decreasing multifunctionality (Meyer *et al*., 2018b). For example, increasing biomass production through the use of manufactured nitrogen fertiliser (e.g. > 100 kg N/ha) makes it more difficult to maintain sward diversity, particularly legume persistence (Meyer *et al*., 2018a). It can also be more difficult to maintain plant species richness within a grazing rather than a cutting system, although a combination of cutting and grazing can be optimal for managing multi-species swards at the field level and encouraging diversity at the regional level (Natural England, 2010a; Sebastià *et al*., 2011).

4.1.3 Magnitude

This section provides some commentary on the magnitude of the outcome from the diversification of swards, i.e. an increase in plant species richness through practices such as reseeding, oversowing and slot seeding. It is assumed that the sown seed mix would include grasses, forbs/herbs and legumes. The baseline under consideration is pure ryegrass swards within temporary grassland and greater than 50% productive species, but low clover content in improved permanent grassland.

4.1.3.1 Carbon (C) sequestration and greenhouse gas (GHG) emission reduction

The ability of diverse swards to sequester C can be compared against the general potential for grassland to do the same. Based on a careful analysis of flux measurements in nine European grasslands (not diverse swards), Soussana *et al*. (2007) found that the grasslands at nine European sites were acting as a sink for carbon (C), with a measured flux of -2.4 ± 0.7 t C ha^{-1} yr^{-1}. Diverse swards could potentially increase this rate (I.e. greater plant species diversity can lead to a higher rate of C sequestration), in proportion to their ability to increase productivity, increase rooting depth or increase topsoil depth. For example, Smith *et al*. (2008) reported potential C sequestration rates of 0.22 t C ha^{-1} yr^{-1} in the cool-moist (temperate) bio-climatic region as a result of improved grassland management. However, it is important to note that it is highly likely that grasslands cannot increase soil C stocks indefinitely. Based on evidence from repeated soil surveys, long-term grassland experiments and simple mass balance calculations, Smith (2014) concluded that “it is untenable that grasslands act as a perpetual carbon sink, and the most likely explanation for observed grassland carbon sinks over short periods is legacy effects of land use and land management prior to the beginning of flux measurement periods”. The use of diverse swards may, therefore, be able to sequester C close to rates measured by Soussana (2007), particularly when moving from poor to optimal management or on previously degraded soils, but it will not be possible to sequester C at these rates in the longer term. However, policy should certainly prioritise the importance of protecting large grassland carbon stocks.

Where the addition of legumes is effective in reducing manufactured N fertiliser use and in optimal soil and agro-climatic conditions, direct and indirect nitrous oxide emissions could be reduced. However, where legumes are added to swards that did not previously receive manufactured N fertiliser, the additional fixed N can result in a net emission of nitrous oxide.

In principle, introducing legumes promotes sequestration, both by stimulating grass root growth, and through their own root biomass. However, nitrous oxide fluxes can be an unwanted consequence, particularly on poorly draining waterlogged soils, or soils in wet regions (Garnett *et al*., 2017; Henderson *et al*., 2015). At a global scale, Henderson *et al*. (2015) estimated that on only 10% of the grazing land did C sequestration from legume addition exceed their effect on nitrous oxide emissions. Legumes sown on these 'favourable', soils could sequester C at a rate of about 0.5 t C/ha/yr.

Henderson *et al*. (2015) also note that the increases in grassland productivity that arises from the addition of legumes also enables higher ruminant numbers to be supported. As a result, methane emissions would also increase and would offset 26% of the global net soil C sequestration potential of legume sowing. However, enhanced livestock performance (i.e. higher growth rates and reduced finishing times) would result in reduced methane emissions per livestock unit relative to the baseline (Smith *et al*., 2014), i.e. "more GHG-efficient livestock production". It is also important to consider the effect of deep-rooting herb species in a diverse sward. If roots can penetrate deeper into the topsoil and upper subsoil, the C from the dead roots could be less prone to release due to lower decomposition rates deeper in the soil profile (Garnett *et al*., 2017).

4.1.3.2 Water quality

Diverse swards may be able to improve water quality through the introduction of legumes that fix nitrogen (thereby partially replacing the need for manufactured N fertiliser) and through increasing N use efficiency. The use of legumes has been estimated to reduce nitrate leaching losses by up to 20% where N inputs in manufactured fertiliser and organic manures are reduced to account for N fixed from the atmosphere (Newell Price *et al*., 2011).

4.1.3.3 Flood risk

Very little is known about the impact of the use of diverse swards at catchment scale. However, it is conceivable that improved soil structure could help reduce the height of the peak of the hydrograph in some runoff and flooding events, through higher water infiltration rates and improved soil water storage. Grassland can be a significant source of runoff and sediment (Collins *et al*., 2010) and there is a need to improve understanding of the implications of using diverse swards to increase water infiltration in grassland soils, and potentially reduce peak flow in catchments that have recognized flooding and erosion problems.

4.1.3.4 Air quality

The legume content of diverse swards could reduce the need for manufactured N fertiliser use on some Welsh grasslands (i.e. improved grassland suitable for the introduction of diverse swards) and, where the intervention is applied, could potentially reduce ammonia emissions from the manufactured fertiliser application loss pathway by up to *c*.50% (Newell Price *et al*., 2011) Manufactured fertiliser application on all UK agricultural land accounts for *c*. 18% of ammonia emissions from UK agriculture (Misselbrook & Gilhespy, 2019).

4.1.3.5 Biodiversity

For biodiversity, there are too many potential response variables to have meaningful measures of "magnitude of effect". The measurements would need to include abundance/cover of multiple species at scales from quadrat to national, as well as numerous possible diversity indices; measurement in different seasons and at different life stages, etc. Nevertheless, some general trends and patterns are discussed below.

Plant species diversity will be increased by the successful establishment of diverse swards. There will be concomitant increases in the richness of associated soil- and foliage-dwelling species such as moths, spiders and beetles, but decreases in the abundance of species directly associated with the previously dominant plant species. However, for many species, the management and associated structure of grassland could be as important as plant species composition for high biodiversity goals. This particularly applies to vertebrate and soil-dwelling species, for which access to the soil surface and/or physical cover from vegetation (e.g. for nesting and protection from predators) are critical for the maximum resource benefits to be derived from swards. Furthermore, while the dense vegetation in improved swards can provide high densities of invertebrates and seeds, sparser or shorter structure is required for access to these resources (Atkinson *et al*. 2004). Diversification of structure can be achieved by changing grazing regimes or mowing, or creating fine-scale topography. Note that the scale of the heterogeneity in structure (i.e. patch size) is critical for many more mobile species, because it is patch edges that provide access to vegetation of different heights for individual animals, for example for nesting and foraging, as a source of food and access to that food, or for use at different stages of the breeding cycle (Douglas *et al*. 2010, Atkinson *et al*. 2004, Eglington *et al*., 2010).

Greater plant species diversity in grasslands could also support and potentially increase the pollination role of grasslands. A range of evidence shows that the greater the extent of low-intensity management and the closer such patches exist to a crop, the higher the numbers of pollinating insects in the vicinity (Whittingham, 2014). The spatial configuration of the landscape is of particular importance in maximising pollination and crop productivity (Manning *et al*., 2018). Note that the ecosystem service provided by pollinator populations is dependent upon crops that benefit from insect pollination being sufficiently close to the (grassland) sources of those populations.

A general issue with relationships between biodiversity and function or service provision is that they are not necessarily linear or symmetrical. Hence, while there is ample evidence that pollination potential, for example, increases qualitatively with pollinator species richness, adding a given species does not necessarily increase function because of redundancy. Similarly, functionality could be increased by increasing the abundance of key species, with no change in species richness.

4.1.3.6 Economic resilience

The use of diverse swards can help improve the economic resilience of farming enterprises based on grazing livestock, particularly when manufactured fertiliser prices are high and milk and meat prices are low (e.g. Humphreys *et al*., 2012). However, quantifying the benefits of economic resilience is challenging and will depend on the amplitude and duration of commodity price cycles.

4.1.4 Timescale

4.1.4.1 Carbon sequestration and greenhouse gas (GHG) emission reduction

Detectable changes in soil C storage would be > 10 years.
GHG emission reduction through the introduction of legumes, where applicable, could occur in the first year of implementation particularly where legumes are substituting the use of manufactured N fertiliser.

4.1.4.2 Water quality

Reductions in nitrate leaching losses could occur in the winter following successful establishment of a diverse sward.

4.1.4.3 Flood risk

Reductions in flood risk could occur once deep-rooting herbs have become well established and soil structure has improved; so in 0-5 years.

4.1.4.4 Air quality

Air quality would be improved in the year of implementation where legumes in diverse swards substitute for manufactured N fertilisers.

4.1.4.5 Biodiversity

Timescales depend on scale and the response variable chosen. Measures of local animal abundance/activity/habitat use are likely to respond almost as quickly as the vegetation, but population-level responses will be slower and could take several years.

Plant species diversity should be improved in the year of implementation, with associated improvements at higher trophic levels taking longer, particularly where the introduction of diverse swards needs to be aligned with other changes in management as well as other changes at the landscape scale (5-10 years or >10 years).

4.1.4.6 Economic resilience

Improvements in economic resilience could be seen in the short to medium term (0-5 years).

4.1.5 Spatial issues

4.1.5.1 Carbon sequestration and greenhouse gas (GHG) emission reduction

The introductions of diverse swards should be targeted on better drained soils where improvements in productivity are likely to be greater and nitrous oxide emissions lower.

4.1.5.2 Water quality

The improvements in water quality due to reduced nitrate leaching losses should be broad-scale in nature.

4.1.5.3 Flood risk

Reduced flooding risk is most likely in catchments dominated by grassland and where soils have been in moderate to poor condition in the past. However, the introduction of diverse swards would need to be associated with changes in grassland management such as stocking rates and the timing of grazing, e.g. avoiding grazing at high stocking rates when soils are ‘wet’.

4.1.5.4 Air quality

Changes in air quality would be broad scale in nature, with the impacts at any location greatest downwind of the prevailing wind direction.

4.1.5.5 Biodiversity

Impacts on biodiversity can operate at the sub-field, field, farm or landscape level, depending on the species affected.

There are likely to be threshold areas at which effects begin for many species. Connectivity of smaller patches can also be critical in producing a larger effect on species richness and/or abundance.

4.1.5.6 Economic resilience

Improved economic resilience may operate at the scale of the enterprise, farm or rural community.

4.1.6 Displacement

There may be displacement issues where new diverse swards are created on former arable land. Displacement or leakage may occur where land use change to increase carbon stocks in one area leads to land use change that causes carbon release in another area. Converting arable land to grassland would promote C sequestration on that land but might also trigger the compensatory conversion of forests or pasture elsewhere to cropland, with corresponding carbon losses (Garnett *et al*., 2017).

For biodiversity, there is good evidence that promoting landscape heterogeneity (i.e. inserting contrasting habitats in a landscape dominated by grass or arable) is positive for a range of bird species. However, in Wales, this would mostly require conversion from grassland to arable rather than *vice versa*.

4.1.7 Longevity

Where the introduction of diverse swards is successful, resulting in an increase in productivity or an improvement in animal health or performance, the conversion is likely to be permanent. However, where the benefits in terms of increased productivity are not perceived to outweigh the costs of implementation, the sward can easily be changed back to a ryegrass-dominated or grass/clover sward, and the effect would be ephemeral in nature.

Diverse swards require regular management in terms of adopting a precise cutting and/or grazing regime and the need for regular overseeding. Therefore, where this level of management is not sustained the nature of the diverse sward would rapidly change within the space of a few years.

4.1.8 Climate interactions

The introduction of diverse swards can contribute to climate change mitigation and adaptation. The mitigation effect is particularly great and clear where fixation by legumes substitutes for the use of manufactured N fertilisers. The climate adaptation effect may be particularly clear during drought or waterlogged conditions. Depending on the plant species composition, the diverse nature of the sward could enable the grassland to cope better with both extremes of weather conditions due to niche complementarity effects (Hofer *et al*., 2017).

4.1.9 Social and economic barriers

Farmers in high output grassland systems, reliant on the response of high sugar grasses to manufactured N fertiliser, are not likely to be interested in introducing diverse swards on their production platform, as the species in diverse mixes do not perform well within a high nutrient environment and tend to be outcompeted by the more responsive grass species and varieties.

Within moderate input systems, the cost of establishing (and managing) diverse swards should be offset by savings in manufactured fertiliser N use. Potential increases in productivity would be additional. However, the productivity gains within moderate input systems (say 50-100 kg N/ha in the form of manufactured N fertiliser) are less certain for Welsh agro-climatic conditions.

Within low input systems (<50 kg N/ha) the increases in productivity relative to a pure ryegrass sward should offset the cost of seed and establishment and there could be additional gains in animal health and performance. The grass productivity gains relative to a grass/clover sward would be lower and difficult to detect.

The most significant barriers to uptake are most likely to be social, practical and psychological, and can only be overcome through a better understanding of each specific farming system (enterprises, machinery availability, labour availability, market) and of farmer behaviour. It is vital to understand the practical limitations of adopting a certain practice in different landscapes, microclimatic conditions and soil type situations; and the individual farmer's outlook and vision for the future will be key to determining their innovative capacity (Brooks & Loevinsohn, 2011).

If there is a major shift towards the introduction of more diverse swards the availability of seeds from merchants could be a constraint. However, there are other ways of introducing a more diverse range of plant species, such as by spreading species-rich green hay (Natural England, 2010a; 2010b).

4.1.10 Metrics and verification

Suitable metrics to monitor the effect of introducing diverse swards on environmental and economic outcomes are listed below.

4.1.10.1 Carbon sequestration and greenhouse gas (GHG) emission reduction

- Long-term soil organic carbon (SOC) monitoring data – Ward *et al*. (2016) suggest that both topsoil and subsoil C should be measured
- Experimental work (medium-term and long-term experimental sites)
- Eddy covariance monitoring facilities – "*a powerful tool for measuring total ecosystem fluxes of carbon. It is able to detect changes in the net ecosystem exchange (NEE) of carbon at fine temporal resolution, and enables estimates to be made of whether a given land management practice results in a net sink or source of carbon*" (Smith, 2014)
- Modelling

4.1.10.2 Water quality

- Water quality data
- Field experimentation

4.1.10.3 Flood risk

- Field experimentation and modelling

4.1.10.4 Air quality

- Field experimentation and modelling
- Air quality monitoring

4.1.10.5 Biodiversity

- Ecological survey - design would be highly dependent on the scale of implementation and the target/response variable, e.g. whether the aim is to investigate national scale effects or to demonstrate local efficacy of an intervention relative to a counterfactual
- Remote sensing

4.1.10.6 Economic resilience

- Economic benchmarking
- Farm Business Survey data (outputs, inputs and incomes; land utilisation; net farm income; livestock numbers; farm liabilities and assets by type of tenure; inter-year comparisons)

5 Evidence Gaps

Future research in this area should focus on evaluating the cost-benefit effects associated with introducing diverse swards compared to standard seed mixtures or an existing grass/clover sward (Davis, 2016); the suitability of seed mixtures, species or varieties to different soil types; and the feed value of diverse leys as forage for livestock in terms of milk production, livestock performance and animal health. Seed availability and the cost of potential mixtures (Muir et al., 2011), particularly when using native species (Oliveira et al., 2014), is also a concern. Several uncertainties, therefore, remain, particularly for Welsh conditions, including:

- The effect of grassland diversity on productivity and soil C sequestration under contrasting grazing conditions and different management regimes (e.g. different nutrient input levels; alternate grazing/cutting etc.);
- interactive effects between grazing and plant diversity and, more precisely, to determine if these effects are additive and/or species-dependent;
- type of grazing (rotational, continuous, seasonal, etc.) and livestock type and diversity (Sebastià et al., 2008, 2011)

Other key evidence gaps include:

- the effect of diverse swards on productivity in Welsh grasslands at different levels of intensity, climatic conditions, and soil properties/management; and how this relates to livestock numbers and overall net total GHG emissions and net GHG emissions per unit of production;
- the capacity of diverse swards to sequester carbon in different contexts in Welsh soil types and climate;
- nitrous oxide emissions from diverse swards with deep-rooting herbs and legumes in Welsh soil types and climate;
- the effect of diverse swards on mitigating flood risk;
- the effect of diverse swards and an increase in sward legume content on water quality, particularly where diverse swards are used in rotation with arable crops;
- the effect of contrasting cultivation systems is also an important consideration; and
- the relative benefits of different spatial patterns of implementation for the range of biodiversity that is potentially affected, e.g. for a given area diversified, how do different groups respond to the area being divided into patches of different sizes and at different distances apart?

6 Summary

A high-level summary of our conclusions is presented in Table 6.1.

Confidence	Intervention	Key Outcomes	Key Benefits	Critical concerns
Blue	Diversification of swards in improved grasslands	Increased plant species diversity	Increased: • ecosystem function • pollination • productivity • animal diversity	• Evidence for productivity benefits in Welsh agro-climatic conditions • Other factors required to increase pollination • Scale effects
Blue		Reduction in nitrate leaching losses	• Cleaner water • Improved aquatic habitats	• Mainly limited to situations where N fixed by legumes in diverse swards substitutes for manufactured N fertiliser use • Legume-based systems can also result in high nitrate leaching losses, particularly post-cultivation
Blue		Reduction in greenhouse gas emissions	• Climate change mitigation	• Most effective in situations where N fixed by legumes in diverse swards substitutes for manufactured N fertiliser use.
Blue		Reduced ammonia emissions	• Cleaner air • Improved habitat quality • Improved public health	• Limited to situations where N fixed by legumes in diverse swards substitutes for manufactured urea fertiliser use • Other interventions such as replacing urea with ammonium nitrate could have a greater impact
Amber		Increased productivity	• Improved economic resilience • C sequestration	• Effectiveness in Wales is uncertain, particularly at different levels of intensity • Effects are likely to be farm system specific • C sequestration effects most likely in temporary

Confidence	Intervention	Key Outcomes	Key Benefits	Critical concerns
				grasslands and arable reversion grassland • C sequestration effects likely to be lower and more limited in permanent grasslands
Amber		Improved soil structure	• Reduced flooding risk	• Lack of evidence in field conditions and at catchment scale
Amber		Improved economic resilience	• Potential improved farm business performance • Stable rural communities • Increased rural vitality	• Needs to be tried and tested at farm scale

Table 6.1 Key outcomes, benefits and critical concerns associated with supporting the diversification of swards in improved grasslands.

Colour Key:

- Blue = well tested at multiple sites with outcomes consistent with accepted logic chain. No reasonable dis-benefits or practical limitations relating to successful implementation.
- Amber = agreement in the expert community there is an intervention logic chain which can be supported but either evidence is currently limited and/or there are some trade-offs or dis-benefits which WG need to consider.
- Pink = either expert judgement does not support logic chain and/or whilst logic chain would suggest it should work there is evidence of one or more of the following:
    - its practical potential is limited due to a range of issues (e.g. beyond reasonable expectation of advisory support which can be supplied and/or highly variable outcome beyond current understanding or ability to target),
    - the outcome/benefit is so small in magnitude with few co-benefits that it may not be worth the administration costs,
    - there are significant trade-offs.

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Defra projects

Defra project BD5001 – Characterisation of soil structural degradation under grassland and development of measures to ameliorate its impact on biodiversity and other soil functions.

Defra project NT0605 - To quantify nitrate leaching from swards continuously grazed by cattle.

Defra project NT1318 - Effect of cultivation on soil nitrogen mineralisation.

Defra project NT1504 - N mineralisation in arable conditions.

Defra project NT1825 - Nitrate leaching in sustainable livestock. LINK project (LK0613).

Defra project NT1806 - To develop a predictive capacity for N loss from grassland.

Defra project ES0106 - Developing integrated land use and manure management strategies to control diffuse nutrient losses from drained clay soils: BRIMSTONE-NPS.

Defra project WQ0106 - Characterisation of soil structural degradation under grassland and development of measures to ameliorate its impact on biodiversity and other soil functions.

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