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Scientific evidence for habitat creation and restoration

It is important that habitat creation and restoration schemes adhere to best practice guidance to ensure that proposed habitat compensation including biodiversity offsetting schemes ensure no net loss of biodiversity.

Restoration ecology is an active area of research and there is a wealth of available ecological knowledge on habitat creation. However, a review of the effectiveness of habitat creation has highlighted considerable differences in the difficulties and timescales needed to create habitat of comparable conservation quality **(Morris R.K.A., et al. 2006)**. Some wetland habitats e.g. ponds and reed beds may take just a few years to create, but many terrestrial habitats, especially longer established and ancient habitats such as old grasslands may take many decades and woodlands may need to be hundreds of years old before they achieve a similar level of interest.

This guideline gives the results of a review of supporting evidence from scientific studies for creation and restoration of species-rich grassland. It focuses on the creation and restoration of species-rich grassland as this is currently a target for offsetting schemes. However, it is intended to update the document with evidence for other habitats e.g. wetlands.

Grasslands

Evidence for grassland creation and restoration

The creation or restoration of species-rich grassland is a high conservation priority in the UK. A number of agri-environment schemes support the restoration or creation of species-rich grasslands. The restoration of species-rich grasslands has also been a focus of a number of high profile projects such as Save our Magnificent Meadows, Hay Time in the Yorkshire Dales and the Hay Meadow Project in Cumbria. Grassland creation and restoration has also been the subject of considerable ecological research over the past few decades. Evidence from these studies and projects, demonstrate that is possible to create and restore species-rich grasslands of conservation value in relatively short time scales. However, whilst contributing to national biodiversity targets, they only superficially resemble old semi-natural grasslands, as subtle differences in species composition and vegetation remain **(Morris R.K.A., et al. 2006)**. In addition, the re-assembly of invertebrates assemblages is a much slower process (Mortimer, Booth, Harris, & Brown, 2002) and we know little about the development of other ecosystem components and processes such as trophic interactions, soil microbial and fungal communities and nutrient dynamics **(Walker et al., 2004).**

The document summarises the results of a desk top search of readily available, published literature. The conservation evidence website https://www.conservationevidence.com/ and the Journal of Applied Ecology http://besjournals.onlinelibrary.wiley.com are particularly useful sources of scientific evidence and many of the studies summarised in this document are copied from these websites.

Evidence from scientific research, agri-environment schemes, and grassland restoration projects has shown that it is possible to create species-rich grassland (i.e. seeding of a non-grassland area such as an arable field) or restore grassland (adding seed and reinstating traditional management to species-poor grassland degraded by intensive management such as the addition on inorganic fertiliser) but success depends on a number of factors including:

- soil type, particularly fertility;

- location e.g. is it adjacent to existing species-rich grasslands,
- Wildflower establishment method e.g. seed source;
- Management (e.g. will the site be cut for hay with cuttings removed and/or grazed, and will this be maintained)
- The interest, skills and commitment of the landowner.

Soils

Low levels of nutrient availability, particularly phosphorus, are recognised as critical for long-term species co-existence in semi-natural grasslands. Species-rich unimproved grasslands typically have very low levels of extractable P (fertility index 0-1). The level of extractable phosphorus is therefore considered important in determining whether a species-poor grassland is a suitable target for management for botanical enhancement **(Wilson, P., et al 2013)**. To be considered a high potential candidate site soil must usually have a low phosphorus index, of 0 (0-9 mg/l) or 1 (10-15 mg/l), (Keys 1 and 2c in the HLS FEP Manual, Natural England, 2010). They should also have few competitive plant species and pernicious weed problems, and management will include grazing. Sites with a phosphorus index of 3 or more (>25mg/l) are usually unsuitable for grassland creation/restoration.

Soil conditions on agriculturally improved grassland and ex-arable sites are quite different from those on species-rich semi-natural grassland. In particular, soil fertility is often considerably raised, and swards developing on such sites tend to be productive and species-poor, and dominated by a few competitive species **(Walker et al. 2004).**

Nutrient stripping

Nutrient levels can be reduced by stopping all fertiliser and herbicide applications and continuing to graze hard or take silage, haylage or hay cuts but this may take many years depending on soil type. Alternatively, the topsoil can be removed or inverted to expose nutrient poor sub-soils. **Kiehl K. & Pfadenhauer J. (2007)** found that the removal of topsoil in ex-arable fields combined with hay spreading from a nearby nature reserve increased the proportion of target hay meadow species and the persistence of species. A 2007 review of experimental evidence on how to restore species-rich grassland on old arable fields **(Diggelen 2007)** found that removing excess nutrients is very slow if done simply by grazing and cutting hay (two studies), with only 3-5% of the soil nutrient pool removed each year. Removing topsoil can effectively remove nitrogen but not phosphorus (one study; **Verhagen *et al*. 2001**). However, a randomized, replicated and controlled trial in 1999-2003 of restoration methods at two sites in the UK **(Pywell *et al.* 2007)** found that turf removal followed by seed addition was the most effective means of increasing plant diversity. Inversion ploughing should not be undertaken where there are archaeological remains, as the extensive ground works can be destructive to buried features. Also, if there is a risk of soil erosion and run-off, this method of reducing nutrients is not suitable as it can take a while for plants to grow and their roots to knit the soil together, preventing soil runoff.

Wildflower establishment method

Another major problem for the creation/restoration of grasslands is the lack of a suitable seed source.

Natural colonisation can occur when there is a local seed source and a mechanism for dispersal of this seed into the restoration site. A study at New Grove Meadows, Monmouthshire **(Winder J.S. 2013)** found that species-poor grassland when adjacent to species-rich grassland can increase in species richness in the absence of interventions such as hay strewing or seeding where there are mechanisms that dispersal of seed i.e. movement of livestock and machinery (used in hay meadow management) throughout the meadows.

However, at most grassland creation/restoration sites re-colonisation by target species tend to be very low due to short lived seed banks and isolation from near-by sources of seed and other propagules. Grassland creation/restoration will therefore often require the deliberate introduction of seed. The use of seed mixtures is a simple and effective method for creating or diversifying grassland on suitable sites that are properly prepared and managed (see below). It is important that seed mixtures are matched to site conditions e.g. pH and fertility.

Seed mixtures can be supplied by a commercial producer sourced from across the UK, or as seeds harvested directly from local donor sites. However, even where mixtures are suitable, there is a tendency to uniformity, with what appear to be very similar seed mixtures being applied to many sites **(Wilson, P., et al 2013)**. The widely used Emorsgate mixtures are dominated by a few species that germinate readily and produce flowers after relatively few years (eg *Centaurea nigra, Galium verum, Leucanthemum vulgare, Achillea millefolium, Ranunculus acris, Lotus corniculatus*). However, where soil fertility is high, seed mixtures with a limited range of competitive generalist species tolerant of higher fertility is recommended.

Using locally harvested seed has a number of advantages (e.g. assurance of local provenance, genotypes adapted to local conditions, can be cost effective). However, the timing of seed collection will determine the composition of the species that are introduced. Ideally, seed should be collected and stored throughout the season. Green hay from local species-rich meadows is also a widely used option and has a number of advantages.

Pro-active management prior to establishment including the control of existing vegetation prior to establishment of sown species is absolutely essential. They require thorough site preparation and intensive early aftercare management over the first two or three years help ensure success before reverting to a traditional low intensity management regime.

Succession in restored grassland

Competitive generalist species tolerant of higher fertility levels (e.g. oxeye daisy, common knapweed, meadow buttercup, meadow vetchling, red clover, selfheal, ribwort plantain, common bird's-foot trefoil) colonise/establish in the early stages of grassland creation/restoration. There is some evidence that early colonisers can facilitate the establishment of more specialist species (ref). However, other studies suggest that the early successional grasslands form closed communities where opportunities for seedling recruitment are rare (ref), thus slowing down or preventing further succession towards species-rich calcareous grassland.

Habitat specialists including stress-tolerators associated with species-rich grasslands on low fertility soils (such as agrimony, glaucous sedge, cowslip, great burnet, pepper saxifrage, betony, devil's-bit scabious) perform poorly in the early stages of restoration. The primary reason for failure of habitat specialists to establish and persist appears to be due to a lack of suitable microsites. These findings suggest that restored or re-created grasslands tend to lack characteristic species which are often constant components of diverse NVC communities (e.g. MG4-5, CG2). Pywell et al. (2003) suggest a number of ways to increase the establishment of these desirable species, including the selection of low fertility sites, the manipulation of abiotic factors (e.g., soil fertility) in order to encourage germination or recruitment, or the ''phased'' introduction of species over several years after restoration when environmental conditions are more favourable and less dynamic **(Walker et al, 2003).**

Wagner et al 2014 found that a large number of specialist species characteristic components of the species-rich target communities either failed to establish or persist in restored grasslands. A number of studies have concluded that the primary reason for the failure of habitat specialists to establish and persist under grassland restoration is a lack of suitable microsites.

Management

The importance of long-term management

Constant effort is needed to manage and maintain the quality of species-rich grasslands. Many remnant species-rich grassland sites are not in favourable condition often as a result of poor management e.g. inappropriate cuttings dates, under or overgrazing, abandonment or improvement. A 2005 survey of English non-SSSI semi-natural grassland sites found only 21% of the grassland sample was in 'favourable' condition. (The condition of lowland BAP priority grasslands: results from a sample survey of non-statutory stands in England English Nature Research Report number 636, 2005)

The crucial role of grazing

Several studies have demonstrated the importance of grazing in the restoration and maintaining species-rich grassland. A long running restoration of a flood plain meadow on the river Thames has shown the benefits of aftermath grazing **(McDonald 2001)**. Over a 22 year period, the plots with aftermath grazing diverged from the cut-only plots, becoming progressively more similar to the composition of nearby reference MG4 floodplain grasslands, while the cut-only plots remained relatively species poor MG1 communities. **Hayes & Tallowin (2007)** demonstrated that the most effective management for natural restoration involves hay cutting followed by aftermath grazing combined with no fertilizer input. Plots managed with just hay cutting, or just grazing, did not show strong increases in plant species richness. A 2005 review **(Jefferson 2005)** of seven studies exploring the role of cutting, grazing and fertilizer in maintaining species richness of upland UK hay meadows concluded that the best management involves spring and autumn grazing, a mid-July hay cut and no inorganic fertilizer.

Where grazing is not an option, additional mowing can be used as a substitute (like grazing, mowing removes biomass and will help to maintain low nutrient status providing cuttings are removed), however, unlike grazing, mowing does not create bare patches that are essential as regeneration niches for seed germination and establishment.

Evidence for timescales for grassland restoration/creation

The Conservation Evidence website gives details of 22 studies from seven European countries that include information on the length of time taken to restore grassland communities (including 16 replicated trials of which nine also controlled and three reviews). Six studies saw positive signs of restoration in less than five years, 11 studies within 10 years and two studies found restoration took more than 10 years. Six studies found limited or slow changes in plant communities following restoration. Two studies from Germany and the UK (one replicated controlled trial) found differences in vegetation between restored and existing species-rich grasslands nine or 60 years after restoration.

A number of studies have shown that is it possible to create or restore species-rich grasslands of conservation value within a relatively short period of time. **Stevenson et al. 1995** found that hand-sowing chalk grassland plants on rotavated ex-arable plots created a community partly resembling the target plant community (NVC CG2a) after two years. A review of agri-environment schemes found that UKBAP Priority grasslands (with recognisable NVC communities) can be created or restored in timescales of typically 8-15 years. However, although some of this vegetation is well established and of extremely high quality, in many sites successional processes were in a relatively early stage, and while vegetation could be identified as a UKBAP priority habitat, there were frequently considerable differences from semi-natural communities **(Wilson, P., et al 2013)**.

Other studies have also found that it is possible to create or restore floristically rich grassland that superficially resemble old semi-natural grasslands, but subtle differences of species composition and vegetation pattern remain **(Morris et al., 2006)**. In addition, the re-assembly of invertebrate assemblages appears to be a much slower process (Mortimer et al., 2002). In part, this may be due to the absence of poor-performing plant species on restoration sites, but also because many invertebrates are unable to disperse between isolated sites. Other processes about which we know even less include the development of food and pollinator webs, trophic interactions as well as the functional roles of soil microbial and fungal communities during secondary succession **(Walker et al.; 2004)**.

A study of data from a long running restoration of flood plain meadow on the river Thames found after 22 years of management, complete recreation of a floodplain meadow still remains an elusive goal, both in terms of plant community structure and the re-establishment of functional trait characteristics **(Ben A. Woodcock et al 2011)**. Similarity to the target grasslands was seen to increase over time during recreation, although only when considering the presence or absence of colonizing species. There was a failure to replicate the relative rooted frequencies of plant species characteristic of the target floodplain meadows. Under typical grazing management colonization by the majority of species that characterize the target habitat type is predicted to take over 150 years. This failure to achieve closer similarity over two decades could have several explanations, such as uneven distribution of species in the original sowing mix, less than ideal environmental conditions at the sowing site (such as hydrology and fertility), or management regimes differing subtly from the previous, historic regimes from the which the MG4 community developed **(Blakesley and Buckley, 2016)**.

A randomized, paired site comparison in five areas of southern England found distinct differences in vegetation between restored and ancient chalk/limestone (calcareous) grasslands, even after 60 years **(Fagan *et al.* 2008)**. A study of an abandoned ex-arable field at Oxford University Farm at Wytham, Oxfordshire, UK found that 10 years after abandonment, heavily grazed treatments (particularly spring-and-autumn grazing, at 3-6 sheep/ha) more closely resembled target ancient chalk/limestone (calcicolous) communities than lightly grazed or ungrazed treatments. However, the species composition of the site differed markedly from that of nearby ancient chalk/limestone grassland (where later-successional and stress-tolerator species were more common), indicating that restoration may take decades **(Brown & Gibson 1994).**

A review by **Walker et al, 2004** found on sites that have received minimal inputs of fertiliser, the re-introduction of extensive management has been sufficient to overcome these constraints and restore calcareous and mesotrophic grasslands of conservation value in less than 20 years (e.g., Gibson et al., 1987; Mountford et al., 1996). In these studies hay-cutting and aftermath grazing have been shown to reduce the cover of competitive grass species, overall biomass yield and in some cases soil fertility, with cutting and grazing being more successful than either cutting or grazing alone. In contrast, where soils have received repeated fertiliser inputs natural reversion to species-rich grassland has been shown to take several decades, even on sites adjacent to natural seed sources.

In France, **Forey & Dutoit (2012)** recently showed that even after more than 100 years of natural regeneration, ex-arable sites on limestone still differ from old grassland in terms of vegetation, soils, and soil seed bank. There is anecdotal evidence from another study, based on a single site containing many fields of different successional age, suggesting that a similar timeframe may apply to mesotrophic MG5 grassland in the south of England, even when conditions for colonisation from nearby species-rich grassland are optimal (Gibson, 1998).

Supporting Evidence

1. **R.K.A. Morris, I. Alonso, R.G. Jefferson, K.J. Kirby. 2006. The creation of compensatory habitat – Can it secure sustainable development? Journal for Nature Conservation.**

Summary: we review the effectiveness of habitat creation in an attempt to better understand the potential for delivery of compensatory habitat as part of sustainable development solutions, or for the establishment of habitat banking. Our review highlights considerable differences in the timescales needed to create conservation habitat of a comparable quality. Some wetlands may take just a few years, some grasslands of nature conservation value are known to be relatively young (<80 years old), but woodlands may need to be hundreds of years old before they achieve a similar level of interest. Our knowledge of the abiotic requirements for some habitats, for example hydrological conditions for alkaline fens, is poor and suitable conditions are rare, making re-creation of such habitats highly problematic.

Some faunas, such as some dragonfly and water beetle assemblages, may be readily catered for; others are dependant both on structural aspects of the habitat and on the mobility of individual species, and are far more difficult to accommodate, e.g., invertebrates associated with ancient trees. Historic examples of habitat regeneration are poor models of habitat regeneration on modern arable soils. Considerable changes in soil structure, pH and chemistry have resulted from the introduction of modern soil preparation techniques, fertilisers and pest control. Recent studies also suggest that mycorrhiza are fundamental to establishment of many habitats of conservation interest.

Compensatory habitat creation can probably be used in some wetlands and inter-tidal environments, but the prospects for success in many terrestrial situations are far less certain. It therefore follows that compensatory habitat creation (also called "offsets") cannot be relied upon in all circumstances as means of offsetting loss of the highest quality habitat, and cannot be seen as a consistent and reliable delivery mechanism for sustainable development.

2. **Wilson, P., Wheeler, B., Reed, M. & Strange, A. 2013. *A survey of selected agri-environment grassland and heathland creation and restoration sites: Part 2*. Natural England Commissioned Reports, Number 107**

The aim of this survey was to provide data on the success of grassland and heathland creation and restoration carried out under agri-environment schemes.

Seventy-three grassland parcels at 62 separate sites and nine heathland parcels at seven sites were surveyed. These were selected by Natural England local staff, and were distributed throughout England from East Devon to Cumbria. Forty-three grasslands had been created on former arable land by drilling a seed mixture, spreading green hay or by natural regeneration. Thirty grasslands had been restored using a variety of methods including restoration of traditional management, raising water levels, seed supplementation and scrub clearance. All the heathlands had been restored by removal of scrub or woodland.

Standard Farm Environment Plan (FEP) survey methods were followed in order to determine whether vegetation stands could be considered as UKBAP Priority Habitat grassland or heathland. A complete species list was recorded from ten quadrats placed in each vegetation stand and a range of other parameters of vegetation structure was also recorded. Soil samples were collected from each field and analysed for major plant nutrients. Data from each stand was analysed using the keys in the FEP manual to determine whether the vegetation was a UKBAP Priority Habitat and to assess its condition. Reasons for failure to qualify as UKBAP Priority Habitat included high cover of Trifolium repens white clover, low number of species per m2 and low cover of wild flower species and sedges.

Of the 43 created grassland stands, 22 were UKBAP Priority Habitat Lowland Meadows, ten were Lowland Calcareous Grassland, one was Lowland Dry Acid Grassland, two were Purple Moor Grass and Rush Pastures, one was Upland Hay Meadows and seven were non-priority habitat semi-improved grasslands. Twenty three of the created grasslands were in Condition A, one in Condition B and 13 in Condition C. The main reason for failing the condition assessment was the low frequency of indicator species. Use of species-rich seed mixtures and green hay both gave good results, natural regeneration was also effective where a species-rich seed-source was present in close proximity.

Of the 30 restored grasslands, 14 were UKBAP Priority Habitat Lowland Meadows, five were Lowland Calcareous Grassland, four were Lowland Dry Acid Grassland two were Purple Moor Grass and Rush Pastures, one was Upland Hay Meadows and four were non-priority habitat semi-improved grasslands. Eleven of the restored grasslands were in Condition A, one in Condition B and 14 in Condition C. Grasslands were usually assigned to Condition C because of the low frequency of indicator species. Under these circumstances, it is likely that condition can be improved through suitable management. In the absence of detailed botanical assessments of the starting condition of these swards it is possible they were already of UKBAP quality although probably in poor condition.

The suitability of sites for creation of species-rich grasslands on arable land and semi-improved grassland can be assessed using Keys 1 and 2c in the FEP manual. In both of these, available phosphorus (P) in the soil is important: sites with a P index of 2 are regarded as having only moderate potential and an index of 3 or more as having low potential, unless other factors increase their suitability. Only 5 of the 73 sites in this study had a P index of 3 or more and, of these, 3 nevertheless had high potential due to drought-stress or permanent waterlogging. Key 2c assessed the other 2 sites as being of low potential and their botanical composition reflected this. The FEP keys appear to be a useful guide to suitability for creation and restoration of species-rich

3. BD5101 Final Report: Improving effectiveness of grassland restoration and creation options: development of a methodology for setting indicators of success and assessing progress (RP00421)

This was a Defra funded research project to develop and test a rapid methodology to assess the progress and timescales that restored or re-created grassland swards take to develop into BAP priority grasslands. The methodology will be used primarily for monitoring the progress and outcomes of HLS agreements and to assist in setting indicators of success.

Evidence for timescales for grassland restoration/creation were reviewed. The review of studies on changes in plant communities, invertebrate assemblages and soil parameters from grassland restoration highlighted the paucity of data that might allow the definition of expected timescales for indicators. For LCG and LM it was possible to identify plant and butterfly species typical of early, mid and late stages of restoration. No data were available to allow generalisations to be made about changes in soil parameters, or for plants and invertebrates in other grassland types covered by this study (LDAG, PMGRP, UHM).

Evidence for timescales is presented in the Evidence Project Final Report evid4BD5101FINAL.pdf and in Annex 4: Evidence of Timescales for Restoration of Priority Grasslands – Characterising Trajectories of Restoration Success Based on Component Plant Species and in Annex 5 Evidence of Timescales for Restoration of Priority Grasslands – Characterising Trajectories of Restoration Success Based on Associated Fauna.

BD5101 Annex 4: Evidence of Timescales for Restoration of Priority Grasslands – Characterising Trajectories of Restoration Success Based on Component Plant Species

Some of the findings of Annex 4 are:

Due to agricultural intensification, species-rich semi-natural grassland now covers a much smaller area than it did 100 years ago (Fuller, 1987; Green, 1990; Bullock et al., 2011), and is also much more fragmented (Burnside et al., 2003; Hodgson et al., 2005). This means that the chances of a grassland creation or restoration site being located in close proximity to species-rich grassland are likely to be much smaller now than they were several decades ago. However, the mere presence of species-rich source grassland in proximity to a creation site may not necessarily be sufficient. In the absence of suitable grazing regimes promoting the movement of plant propagules between source grassland and creation site, colonization by target species may still be slow even if the source grassland is immediately adjacent to an ex-arable site (Hutchings & Booth, 1996). Accordingly, a number of authors have emphasized the key role of such grazing regimes for target species colonization (Poschlod et al., 1998; Barbaro et al., 2001; Ruprecht 2006).

Compositional differences between c.60-year old ex-arable calcareous grassland and ancient calcareous grassland have also been documented by Cornish (1954). Other studies suggest that in excess of 100 years may be required for ex-arable calcareous grassland to become more or less indistinguishable from ancient calcareous grassland (Wells et al., 1976; Gibson & Brown, 1991). The findings of the Upper Seeds experiment, a long-term experiment investigating ex-arable succession on limestone, suggest that the timeframe of natural regeneration of calcareous grassland vegetation also depends on external boundary conditions such as the grazing regime (Gibson & Brown, 1992; Gibson, 2011). Based on small-scale colonisation patterns at the site of this experiment, it has been suggested that succession may not be limited simply by rates of species dispersal into a site; a number of late-successional species may be able to colonise successfully once environmental site conditions have become suitable (Gibson, 2011)

The research carried out by Hirst et al. (2005) on Salisbury Plain Training Area (SPTA), which indicated that it may take calcareous grassland substantially more than 50 years to recover from heavy disturbance by military training activities, supports these results by other studies. In fact, the SPTA study illustrates that a full recovery of calcareous grassland can take many decades, even if the starting point and boundary conditions are favourable. The military training activities would have been expected to have had less impact on soil fertility levels and seed bank composition than a prolonged history of arable cultivation, and took place close to the greatest expanse of unimproved chalk grassland in north-west Europe, providing better opportunities for target species colonization than on ex-arable sites situated in the highly fragmented modern agricultural landscape.

Similar timescales for natural regeneration to the ones documented in our study have been confirmed by studies on other types of semi-natural grassland in the UK and in Europe. In France, Forey & Dutoit (2012) recently showed that even after more than 100 years of natural regeneration, ex-arable sites on limestone still differ from old grassland in terms of vegetation, soils, and soil seed bank. There is anecdotal evidence from another study, based on a single site containing many fields of different successional age, suggesting that a similar timeframe may apply to mesotrophic MG5 grassland in the south of England, even when conditions for colonisation from nearby species-rich grassland are optimal (Gibson, 1998). In Romania, Ruprecht (2006) found that old-fields left to regenerate into steppe grassland became increasingly similar to their target in the first 15-20 years after arable abandonment; progress levelled off for older sites, and grasslands of 20-40 years of age, while showing structural and compositional similarity with the target community, remained deficient in target species. Similarly, grassland resulting from 25-38 years of natural regeneration on Hungarian old-fields, while overall being rather similar in species composition to ancient loess steppe reference grassland, was still lacking some specialist species (Molnár & Botta-Dukát, 1998).

The sowing of species-rich mixtures also appears to produce variable results. Some studies suggest that these mixtures suppress colonization by unsown target species (Jongepierová et al., 2007; Mitchley et al., 2012), and that they may do so even more comprehensively than commerciallow-diversity mixtures (Leps et al., 2007). Other results suggest that sowing of species-rich seed mixtures produces vegetation resembling the reference much faster than natural regeneration (Rydgren et al., 2010), and that colonization by unsown target species can still take place, provided that there are species-rich source grasslands in close proximity to a site (Prach et al., in press).

Although sowing of both commercial and targeted species-rich seed mixtures may affect colonization by unsown target species, it enables land owners to quickly establish a productive cover, with the added benefit of weed suppression (Jongepierová et al., 2007; Török et al., 2010, 2012). Finally, as shown here, when species-rich mixtures are used that are specifically designed to establish a particular target community, it is possible to obtain vegetation resembling the reference much faster than by natural regeneration. Accordingly, the importance of species introduction has also been emphasized in various reviews dealing with the subject of grassland creation and restoration, and it has been particularly recommended when species-rich grassland does not occur nearby as a potential source of target species (Manchester et al., 1999; Walker et al., 2004; Hedberg & Kotowski, 2010; Kiehl et al., 2010).

4. **Fagan K.C., Pywell R.F., Bullock J.M. & Marrs R.H. (2008) Do restored calcareous grasslands on former arable fields resemble ancient targets? The effect of time, methods and environment on outcomes.** ***Journal of Applied Ecology*****, 45, 1293-1303**

A randomized, paired site comparison in five areas of southern England (Fagan *et al.* 2008) found distinct differences in vegetation between restored and ancient chalk/limestone (calcareous) grasslands, even after 60 years. Successful restoration of calcareous grasslands is achievable but the process is slow. Sites seeded with just grasses remained dominated by a few grass species. Seeding restoration sites with a low diversity mix appeared detrimental to restoration. Sites allowed to regenerate naturally moved towards the target plant community over time, although success was limited by proximity to ancient grasslands. Some features of restored grassland (such as the proportion of perennial plants) became more like ancient grasslands with increasing age. High soil phosphorus concentration (due to former fertilizer application) was detrimental to restoration. Forty restored grassland sites were randomly selected from all those available, to give equal representation in four age classes and the five areas (North Downs, South Downs, South Wessex Downs, Chilterns, Cotswolds). Sites were one to 103 ha in size. They were restored either by natural regeneration, seeding with grasses, or seeding with a flower-rich seed mix. All sites were grazed and some occasionally mown. The Authors recommended the selection of restoration sites with low phosphorous concentrations that adjoin patches of ancient calcareous grassland. Seed mixes should be devised carefully to prevent the assembly of low-value, competitive, stable communities dominated by grasses; natural regeneration may avoid this but will only be effective close to sources of propagules.

5. **Kevin J. Walker, Paul A. Stevens, David P. Stevens, J. Owen Mountford, Sarah J. Manchester, Richard F. Pywell. 2003. The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. Biological Conservation 119 (2004) 1-18.**

Intensive agriculture has resulted in the loss of biodiversity and the specialist flora and fauna associated with the semi-natural grasslands of low-intensity pastoral systems throughout northwest Europe. Techniques employed to restore and re-create these grasslands on agricultural land in the UK are reviewed. Extensive cutting and grazing management have been shown to diversify improved swards and facilitate re-colonisation on ex-arable soils, although rates of re-assembly of plant communities with affinity to existing semi-natural grasslands have generally been slow. On former agriculturally improved swards, nutrient depletion has accelerated this process, especially where “gaps” for establishment have been created. Similarly, on ex-arable soils “nutrient stripping” and sowing with diverse seed mixtures has led to the rapid development of species-rich swards. On free draining brown earths such an approach may be required to restore grassland communities where soil phosphorous concentrations exceed semi-natural levels by more than 10 mg/l (using Olsen's bicarbonate extractant). However, the appropriateness of this threshold for other soil types requires further sampling. Although restored grasslands are likely to contribute to national biodiversity targets success will ultimately depend on the reinstatement of the communities and ecological functions of semi-natural references. Although this is technically feasible for a few plant assemblages, less is known about the re-assembly of microbial and faunal communities, or the importance of trophic interactions during grassland succession. As a consequence, more research is required on the functional attributes of semi-natural grasslands, as well as the methods required to restore localised types, novel nutrient depletion techniques, the “phased” introduction of desirable but poor-performing species and the performance of different genotypes during grassland restoration.

6. **Winder J.S. (2013) Restoring species-rich grassland at New Grove Meadows, Monmouthshire, Wales, UK. Conservation Evidence, 10, 20-23**

A study at New Grove Meadows, Monmouthshire, quantified the rate of natural colonisation of species into semi-improved grassland from adjacent unimproved species rich grassland over a 12 year period. During this period the grassland was managed traditionally with an annual hay cut followed by aftermath grazing and no input of fertilizer or farm yard manure. Vegetation surveys were carried out in 2000 and 2012 on two unimproved fields (MG5a) and two semi-improved fields (MG6). These data were analysed for species-richness using two variables; Total species and Wildlife Site Indicator species. Species-richness increased significantly in the semi-improved meadows during the study period. These meadows now meet the criteria for Wildlife Site designation and the National Vegetation Classification community is shifting from MG6 to the target community MG5. The species in these fields that showed the greatest increase in occurrence were cat’s-ear, red clover and yellow-rattle. Quaking-grass, spring-sedge, glaucous sedge and cowslip occur frequently in the unimproved fields but remained absent from the semi-improved fields after 12 years.

This study provides evidence that species poor grassland when adjacent to species-rich grassland can increase in species richness in the absence of interventions such as hay strewing or seeding in. Within 12 years this has been achieved at New Grove Meadows, with the instigation of traditional hay meadow management combined with no input of fertilizer or farm yard manure. This result provides further evidence to support the conclusions of Hayes & Tallowin (2007). It is considered that the following mechanisms probably aid the dispersal of seed: the access gates created between the species-rich and the species-poor meadows allowing movement of stock and machinery; hay meadow management involving the turning and bailing of hay with movement of the machinery throughout all the meadows; and aftermath grazing of sheep throughout the meadows.

7. **Wagner, M., Bullock, J.M., Hulmes, S., Hulmes, L., Peyton, J., Amy, S., Savage, J., Dos Santos Pereira, G., Tallowin, J.R.B., Dunn, R.M., Pywell, R.F. 2014. Techniques to enhance the establishment and persistence of poor-performing species in grassland restoration: Results from a 4-year experimental study.**

A Defra-funded analysis (BD1433) of attempts to restore species-rich grassland on farmland identified a large number of specialist species which either failed to establish or persist in the long-term. As a result, restored grasslands often lack these species which are characteristic components of the species-rich target communities. Failure to address the issue of poor-performing, specialist species could lead to a uniformity of restored grasslands across Britain, thus harming, or at least diminishing, the potential benefits of habitat restoration for regional and national biodiversity. A number of studies have concluded that the primary reason for the failure of habitat specialists to establish and persist under grassland restoration is a lack of suitable microsites. Research is therefore urgently required to determine the precise microsite requirements of these poor-performing species and, in light of this, adapt existing field-scale techniques to enhance the establishment of these species under agri-environment schemes.

8. **McDonald, A.W. 2001. Succession during the re-creation of a flood-meadow 1985-1999. Applied Vegetation Science, Volume 4 Issue 2, pages 167-176.**

Abstract. The study site, Somerford Mead, is located on the river Thames floodplain and was a species-rich flood-meadow in the 1950s. In the 1960s and 1970s it was subjected to intensive grassland management with regular NPK additions and occasional herbicide treatment. In 1981 Somerford Mead was ploughed for the first time and converted to arable land. Seeds of an Alopecuruspratensis-Sanguisorba officinalis flood-meadow community (MG4; Rodwell 1992) were sown onto prepared soil in the autumn of 1986, and botanical records were made from 1985 to 1999. From 1989 to 1999, three replicates of three treatments: cow-grazing, sheep-grazing and no-grazing were introduced after hay-cutting. Analysis successfully separated the establishment phase from the experimental phase and showed a significant difference between the grazed and ungrazed treatments. Abiotic and biotic factors which might contribute to successional trends are discussed. A convoluted pattern for each treatment could be attributed in part to intrinsic‘cycles’ of perennial hemicryptophytes behaving as short-lived species and in part to the percentage frequency of many species which was reduced in 1990 and 1995/1996, years of drought. After the initial inoculation of MG4 seed and the disappearance of arable therophytes, recruitment of new species was very slow. Coefficients for Somerford Mead matched against MG4 (Rodwell 1992) produced an equilibrium within three years. It subsequently fluctuated over a 10-yr period well below the level of Oxey Mead, the donor site.

Land managers should ensure that their proposed site has the right soils and hydrology for MG4 grassland and that traditional management of hay-cutting and aftermath grazing is practised. Only one cut a year in July could lead to a reduction in percentage frequency of most species except *Arrhenatherum elatius*.

9. Can long-term floodplain meadow recreation replicate species composition and functional characteristics of target grasslands? Authors Ben A. Woodcock, Alison W. McDonald, Richard F. Pywell. Journal of Applied Ecology, First published: 6 June 2011

The recreation of species-rich grassland represents a key EU agri-environment policy initiative intended to maintain native biodiversity and to support the provision of ecosystem services. Understanding the long-term potential for recreation success is crucial to the evaluation of such schemes.

We use a single-site long-term data set (22 years) to test the consequences of grazing recreation management in re-establishing plant community composition and functional trait structure as assessed relative to pristine examples of target floodplain meadows.

Following a July hay cut, late summer grazing of the re-growth by either sheep or cattle resulted in an increase in the similarity of plants species composition to the target floodplain meadows, but only in terms of what species had colonized, not in terms of their relative frequencies.

Where grazing in late summer was applied, the functional traits of the meadows undergoing recreation became similar to those of the target floodplain meadows only where grazing management was used. When plant traits were divided into subcategories (e.g. regeneration, seed biology, life-form, environmental associations), only those traits linked with plant phenology failed to show evidence of a temporal shift towards the functional trait structure of floodplain meadows.

After 22 years of management, complete recreation of a floodplain meadow still remains an elusive goal, both in terms of plant community structure and the re-establishment of functional trait characteristics.

Synthesis and applications: Under typical grazing management colonization by the majority of species that characterize the target habitat type is predicted to take over 150 years. In contrast, recreation of functional trait structure can occur over a considerably shorter time-scale (>70 years). The potential to provide functionally equivalent grasslands that deliver analogous ecosystem services to those of the target habitat type is therefore a more realistic goal for recreation. We suggest that the time-scale needed to recreate grasslands puts into question the benefits of compensation schemes that allow grasslands to be lost to development (i.e. gravel extraction) in exchange for future recreation at other sites.

10. Hand sowing chalk grassland plants establishes a community resembling the target in two years, Stevenson M.J., Bullock J.M. & Ward L.K. (1995) Re-creating Semi-natural Communities: Effect of Sowing Rate on Establishment of Calcareous Grassland. *Restoration Ecology*, 3, 279-289

A randomized, replicated controlled trial from 1993 to 1994 in Hampshire, UK (Stevenson *et al.* 1995) found that hand-sowing chalk grassland plants on rotavated ex-arable plots created a community partly resembling the target plant community after two years. Computer analysis showed a 45-62% fit to a UK National Vegetation Classification scheme chalk/limestone grassland community (CG2a – sheep's fescue *Festuca ovina*- meadow oat-grass *Avenula pratensis* grassland, dwarf thistle *Cirsium acaule*-squinancy wort *Asperula cynanchica* subcommunity). Higher sowing rates gave a better fit, and a higher percentage cover of chalk grassland plants (from 10% cover at the lowest sowing rate to 100% at the highest rate). The three higher sowing rates had similar numbers of chalk grassland species in the plots (28, 30 and 31 species respectively), by 1994. Control plots and plots sown at 0.1 g/m^2 had around six and 20 species chalk grassland species respectively. Seed was sown at 0.1, 0.4, 1 or 4 g/m^2. The mixture contained 22 grass/sedge species and 25 herb species. Each rate was sown in four replicate 6 m^2 plots, and four control plots were not sown. Plots were rotavated in March 1993, sown by hand, raked and left unmanaged (lightly grazed by rabbits). Plant cover was measured in two 1 m^2 quadrats/plot in August 1993 and 1994.

11. The effects of sheep grazing and gap creation on vegetation change in a species-poor grassland in Oxfordshire, England, Bullock J.M., Hill B.C., Dale M.P. & Silvertown J. (1994) An experimental study of the effects of sheep grazing on vegetation change in a species-poor grassland and the role of seedling recruitment into gaps. *Journal of Applied Ecology*, 31, 493-507

A replicated controlled trial from 1984 to 1990 at Little Wittenham Nature Reserve, Oxfordshire, UK (Bullock*et al.* 1994) found that plant composition on a previously improved pasture hardly changed in response to reduced sheep grazing intensity and no fertilizer. Plant species diversity was still low after six years. The vegetation remained dominated by perennial grasses, with four species making up 80% of records. Herbaceous plants (non-grasses) made up just 0.4% of records. Seventy percent of seedlings growing in artificial gaps in the grass cover were of two grass species, perennial rye grass *Lolium perenne* and meadow barley *Hordeum secalinum*. Only 4% of seedlings were non-grass species, and none were species not already found in the paddocks. There was no evidence of a seed bank (gaps with original topsoil did not differ from gaps with topsoil replaced by sterile soil). There were eight levels of sheep grazing: summer grazing to a height of either 3 cm (more intensive) or 9 cm (less intensive), with or without winter and/or spring grazing, but grazing intensity had only small effects on the vegetation. Each treatment was replicated in two 50 x 50 m paddocks. Plants were surveyed using a point quadrat at 64 points/paddock in 1990. Vegetation and topsoil or vegetation-only were removed in September 1990 in five 10 cm diameter circles/paddock and seedlings growing in these areas counted and removed regularly until January 1992.

12. Species-rich grassland restored over ten years, by cutting for hay and aftermath grazing, in Ceredigion and the Cambrian Mountains, Wales, Hayes M.J. & Tallowin J.R.B. (2007) Recreating biodiverse grasslands: long-term evaluation of practical management options for farmers. Pages 135-140 in: J.J. Hopkins, A.J. Duncan, D.I. McCracken, S. Peel & J.R.B. Tallowin (eds.) *High Value Grassland: Providing Biodiversity, a Clean Environment and Premium Products. British Grassland Society Occasional Symposium No.38*. British Grassland Society (BGS), Reading.

A randomized, replicated, controlled trial at two experimental farms in Wales (Hayes & Tallowin 2007) (results from the two farms are presented in (Jones & Hayes 1999) and (Morgan et al. 2008)) found that plant species richness on grasslands increased over 10-13 years in response to imposing traditional management practices, providing the management involved both hay cutting and aftermath (autumn-winter) grazing. In the final year, these sites had over 13 plant species/quadrat (over 15 at the upland site) and over 40 plant species on each plot (over 50 at the upland site), compared to 8-9 species/quadrat and 24 species/plot in control plots. They were colonized by desirable plant species, such as yellow rattle *Rhinanthus minor* and heath spotted orchid *Dactylorhiza maculata*. Plots managed with just hay cutting, or just grazing, did not show strong increases in plant species richness. The experiments took place in Ceredigion (lowland) from 1992 to 2005 and the Cambrian Mountains (upland fringe) from 1995 to 2005. Six or seven treatments were each replicated three times on 0.15 ha plots. The control plot was species poor pasture sheep-grazed from April to November, fertilized (with nitrogen, phosphorous, potassium NPK fertilizer) at a rate of 150 kg nitrogen/ha, and limed once, in the second or third experimental year. Other plots were not fertilized at all, but had various combinations of cutting, grazing and liming. Adding lime slightly enhanced plant species richness in summer grazed treatments at the upland site. Plants were monitored in summers of 1992-1997 and 2000, 2003 and 2005 in ten quadrats in each plot.

13. **Management by hay cutting and grazing rapidly increases plant species richness, on an improved upland grassland in the Cambrian Mountains, West Wales, Morgan M., McLean B.M. & Davies O.D. (2008) Long term studies to determine management practices to enhance biodiversity within semi-natural grassland communities. Pages 992-994 in: *Grassland Science in Europe*. 13, Swedish University of Agricultural Sciences, Uppsala.**

A replicated controlled trial at the Pwllpeiran Research Centre, in the Cambrian Mountains, west Wales (Morgan *et al.* 2008) (partly the same study as (Hayes & Tallowin 2007)) found that plant species richness increased and rye grass *Lolium perenne* cover declined on improved upland grassland after ten years of management with hay cutting and/or grazing but no fertilizer addition. In the restoration plots, rye grass cover declined from 58% to just under 10% on average. All treatments enhanced plant species richness, but the hay cut and grazing combined treatments were the most effective. These plots had an average of 51 species/plot by 2005, compared to 24 species in control plots. They also had almost 50% cover by non-grass, desirable herbaceous species (forbs). Treatments with hay cut but no grazing had 29-30 species on average in 2005, and those with grazing only had 31-35 plant species in 2005. Both had an increase in weedy, undesirable species. Seven management treatments were set up in 1994 on 0.15 ha plots with three replicates of each treatment. Control plots had standard intensive management, fertilized with nitrogen, phosphorous, potassium (NPK) fertilizer, limed and grazed by sheep. Six restoration treatments were either grazed from April to November, cut for hay in July/August without grazing, or hay cut and grazed from September to November, each with or without lime added in 1998. Plots with an application of lime had more desirable species by 2005 than those without lime.

14. **Topsoil removal on ex-arable fields enhances establishment and persistence of target vegetation in newly created calcareous grasslands near Garchinger Heide nature reserve, Bayern, Germany, Kiehl K. & Pfadenhauer J. (2007) Establishment and persistence of target species in newly created calcareous grasslands on former arable fields. *Plant Ecology*, 189, 31-48**

A replicated controlled trial near Munich, southeast Germany from 1993 to 2002 (Kiehl & Pfadenhauer 2007) (same study as (Kiehl & Wagner 2006)), found that spreading hay from a nearby nature reserve rapidly increased the number of plant species, and the number of target hay meadow species in ex-arable fields managed to restore hay meadow vegetation. The removal of topsoil combined with hay spreading increased the proportion of target species and the persistence of species, but led to a very low hay crop even after nine years. Mowing (once or twice) also increased plant species richness, and the number of target plant species. Nine years after restoration, the best plots in this experiment (mown, with hay spreading) still had a different plant community from species-rich grassland on a nearby nature reserve (Garchinger Heide). Restoration was tested on four ex-arable fields, 1.3-3.2 ha in size, beginning in 1993. Half of each field had hay added between July and September 1993 (once only) and the other half did not. Experimental plots within these treatments were either mown once, mown twice, mown with cuttings left as mulch, or grazed through spring and summer. One field had the upper 40 cm of topsoil removed. This field was either mown once in July or left unmanaged. Plant species were monitored every year on thirty 4 m^2 plots per field.

15. Creating new habitats in intensively used farmland, Brown V.K. & Gibson C.W.D. (1994) Creating new habitats in intensively used farmland. *British Grassland Society Occasional Symposium*, 28, 125-136

A controlled, replicated trial from 1982 to 1993 on an abandoned ex-arable field at Oxford University Farm at Wytham, Oxfordshire, UK (Brown & Gibson 1994) found that 10 years after abandonment, heavily grazed treatments (particularly spring-and-autumn grazing, at 3-6 sheep/ha) more closely resembled target ancient chalk/limestone (calcicolous) communities than lightly grazed or ungrazed treatments. Over the experimental site, 250 plant species colonized, 77 of which were typical of chalk/limestone grassland. However, the species composition of the site differed markedly from that of nearby ancient chalk/limestone grassland (where later-successional and stress-tolerator species were more common), indicating that restoration may take decades. Arable cultivation was abandoned in 1982 and five grazing treatments began in 1985. Three treatments were replicated six times in 30 x 30 m paddocks (ungrazed control, short-period spring and short-period autumn grazing) and two treatments were applied in larger areas (spring-and-autumn grazing and long-period autumn grazing, not replicated). Plants were surveyed four times a year in 12 quadrats (1 m^2) in each replicate and in nearby ancient grassland patches. This study was part of the same experimental set-up as (Gibson *et al.* 1987a, Gibson *et al.* 1987b, Watt & Gibson 1988).

16. The effect of time, seeding and environment on outcomes of calcareous grassland restoration schemes in the North Downs, South Downs, South Wessex Downs, Chilterns and Cotswolds, southern England, Fagan K.C., Pywell R.F., Bullock J.M. & Marrs R.H. (2008) Do restored calcareous grasslands on former arable fields resemble ancient targets? The effect of time, methods and environment on outcomes. *Journal of Applied Ecology*, 45, 1293-1303

A randomized, paired site comparison in five areas of southern England (Fagan *et al.* 2008) found distinct differences in vegetation between restored and ancient chalk/limestone (calcareous) grasslands, even after 60 years. Sites seeded with just grasses remained dominated by a few grass species. Sites allowed to regenerate naturally moved towards the target plant community over time, although success was limited by proximity to ancient grasslands. Some features of restored grassland (such as the proportion of perennial plants) became more like ancient grasslands with increasing age. High soil phosphorus concentration (due to former fertilizer application) was detrimental to restoration. Forty restored grassland sites were randomly selected from all those available, to give equal representation in four age classes and the five areas (North Downs, South Downs, South Wessex Downs, Chilterns, Cotswolds). Sites were one to 103 ha in size. They were restored either by natural regeneration, seeding with grasses, or seeding with a flower-rich seed mix. All sites were grazed and some occasionally mown. Each was paired with an ancient grassland no more than 9.3 km away. Plants were surveyed in ten 0.25 m^2 quadrats at each site, in summer 2004, and soil analysed in September 2004.

17. Long-term enhancement of agricultural production by restoration of plant diversity in sown hay meadows in the Norfolk Broads and Upper Thames, southeast England, Bullock J.M., Pywell R.F. & Walker K.J. (2007) Long-term enhancement of agricultural production by restoration of biodiversity. *Journal of Applied Ecology*, 44, 6-12

A replicated study in 1995-1998 and 2002 of former arable fields at two sites in England (Bullock *et al.*2007) found that after eight years, plots sown with species-rich mixtures resembled target grassland community types. Plots sown with a species-poor mix, although colonized by some additional species, had fewer grass, legume and other broadleaved species. Hay yield increased in the species-rich plots in the first years of the experiment and the increased yield was still apparent after eight years (43% higher yield than species-poor plots). This was largely due to differences in numbers of non-leguminous broadleaved plants. There were four replicate blocks of plots (6 x 4 m). The species-rich mixture comprised 11 grasses and 28 broadleaved species, to resemble species-rich hay meadows. The species-poor mixture comprised seven grasses to establish moderately diverse grassland. Vegetation was sampled in early June in three quadrats (0.4 x 0.4 m) per plot in 1995-1998 and 2002. During the hay cut in July, a 6 x 1.2 m sample of hay was removed from each plot and weighed and a 500 g sub-sample was dried to calculate hay yield.

18. Effects of restoration on plant species richness and composition in Scandinavian semi-natural grasslands, Lindborg R. & Eriksson O. (2004) Effects of restoration on plant species richness and composition in Scandinavian semi-natural grasslands. *Restoration Ecology*, 12, 318-326

A replicated, controlled, site-comparison study of 26 restored semi-natural grasslands in south-eastern Sweden (Lindborg & Eriksson 2004) found that continuously grazed control sites had higher plant species diversity and a higher proportion of typical grassland species in the community than restored grasslands. Plant species diversity at restored sites was 16-20 species/m² compared to 24-30 species/m² at continuously grazed control sites. Total species richness was positively associated with time since restoration (1-7 years) and the abundance of trees and shrubs. Overall species composition differed between restored and control sites, with control sites having a higher proportion of typical grassland species than restored sites. However within grassland types (dry, dry to damp (mesic) or damp to wet), species composition was similar between each pair of restored and control sites. Restored damp to wet grassland was dissimilar in species composition to all other plots. Abundance of 10 grazing-indicator species tended to be lower at restored sites. Restored site area (3-35 ha), time between abandonment and restoration, time since restoration and abundance of trees and shrubs were not related to species composition among restored sites or the 10 grazing-indicator species. Restored sites were grazed before abandonment and after restoration, control sites had been grazed continuously. The six control sites were compared to restored sites in the same region. Plants were sampled within 10 randomly distributed plots (1 m²) in July-August 2001. Trees and shrubs were counted within a 40 m diameter circle at each site.

19. Restoration of species-rich grassland by sowing, hay-cutting and sheep grazing on arable land in lowland England Pywell R.F., Bullock J.M., Hopkins A., Walker K.J., Sparks T.H., Burke M.J.W. & Peel S. (2002) Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. *Journal of Applied Ecology*, 39, 294-309

A randomized, replicated study in 1994-1998 in arable fields in five lowland areas in the UK (Pywell *et al.*2002) found that ploughing to 30-40 cm depth and sowing with a species-rich seed mixture created a community similar to the target community on neutral soils. This was significantly more successful than natural regeneration or sowing with a species-poor mix. Sites on acidic or calcareous soils were less similar to their specific target communities. Sowing a nurse crop had no beneficial effects. All treatments reduced nutrient levels. The five sites had four replicate blocks each containing seven experimental plots with different treatments. Vegetation was cut and removed each year in June or July, and sheep were grazed between October and December at 25-40 sheep/ha for six to eight weeks. Vegetation sampling used three 40 x 40 cm quadrats randomly placed within each plot in June each year. Nutrient sampling used ten soil samples per plot in September 1994 and 1998.

20. The effects of season and duration of sheep grazing on seedling establishment and survival in a calcareous grassland at Wytham Woods, Oxfordshire, England, Watt T.A. & Gibson C.W.D. (1988) The effects of sheep grazing on seedling establishment and survival in grassland. *Vegetatio*, 78, 91-98

A replicated, controlled study in 1986 and 1987 of an abandoned arable field in Oxfordshire, England (Watt & Gibson 1988) found that sheep grazing increased seedling establishment compared to ungrazed plots. The most heavily grazed treatment had the highest levels of seedling establishment, whereas few new seedlings were recorded on ungrazed paddocks. Treatments with some autumn grazing had a peak of seedling establishment the following spring. Seedling survival was not affected by grazing treatment or gap size. The two short-grazing treatments (lasting 10 days) had the least bare ground whilst April-November grazed areas had the most. Insecticide use increased seedling establishment in October in ungrazed and spring-grazed paddocks but decreased establishment in autumn-grazed paddocks. In 1985, three treatments were applied in six replicate (30 x 30 m) paddocks: 10 days grazing in spring or autumn, and ungrazed controls. Two 3 x 3 m permanent quadrats were treated weekly with malathion insecticide in each paddock and four permanent 1 x 1 m sampling quadrats were established. Another two paddocks were grazed from April-November with or without a short break in summer, twelve 1 x 1 m quadrats were established in each. Gap type and seedling sampling was undertaken in all quadrats seven times from April 1986 to July 1987. Vegetation height was recorded in September 1986. This study was part of the same experimental set-up as (Gibson *et al.* 1987a, Gibson *et al.* 1987b, Brown & Gibson 1994).

21. Grazing, July hay cut and seed addition provide the best plant diversity in restoring an upland meadow, Colt Park Meadows, Ingleborough National Nature Reserve, North Yorkshire, England, Smith R.S., Shiel R.S., Millward D. & (2000) The interactive effects of management on the productivity and plant community structure of an upland meadow: an 8-year field trial. *Journal of Applied Ecology*, 37, 1029-1043

A replicated trial from 1990 to 1998 of combined management treatments on an agriculturally-improved meadow in the Pennine Dales Environmentally Sensitive Area, North Yorkshire, England (Smith *et al.* 2000) (same study as (Smith *et al.* 2002)) found that the highest increase in plant species diversity was achieved with a combination of autumn and spring grazing, 21 July hay cut date and sowing native plant species. The study took place in 6 x 6 m plots on a 2.75 ha meadow within the Ingleborough National Nature Reserve. Plots were either sown with many native grassland species (including yellow rattle *Rhinanthus* minor) or not. The experiment also included three different grazing treatments (sheep and cattle), plots with or without fertilizer and three earliest dates for hay cut. Yellow rattle spread to most plots after its introduction as a constituent of the seed addition treatment. By 1996 it was particularly abundant in treatment combinations that included autumn grazing, no mineral fertilizer and a July hay cut. Populations of over 40 plants/m^2 were associated lowest hay yields, presumably as it suppressed grass growth.

22. Winter grazing and locally-sourced seed create the best conditions for re-establishing plant species on a hay meadow experiment at Trawsgoed Research Farm, Aberystwyth, Wales, Jones A.T. & Hayes M.J. (1999) Increasing floristic diversity in grassland: the effects of management regime and provenance on species introduction. *Biological Conservation*, 87, 381-390

A replicated, controlled trial in Trawsgoed Research Farm, Aberystwyth, Wales (Jones & Hayes 1999) (partly the same study as (Hayes & Tallowin 2007)) found that seedlings established best, and survived best in plots that were cut twice with aftermath grazing by sheep in winter. The lowest rates of seedling establishment and plant survival (lower than the control) were in plots cut twice but without grazing. The authors conclude that winter grazing is very important when re-introducing plants to restore hay meadows. By September 1996, seeds from the local area; yarrow *Achillea millefolium*, purple betony *Stachys officinalis*and self-heal *Prunella vulgaris* had survived better than non-local seeds, with no difference in two other species (black knapweed *Centaurea nigra*, ribwort plantain *Plantago lanceolata*). The five plant species were sown in October 1994, two years after the management experiment began. Fifty seeds of each species and provenance were sown in each of three 1 m^2 quadrats/plot. Seeds were either gathered from within 8 km or purchased from a seed supplier (from elsewhere in the UK). Plants were monitored every month after sowing until April 1995, then in April and September 1996.

23. Effects of cattle and sheep grazing regime on beetle and plant assemblages during re-creation of a floodplain meadow at Somerford Mead, Oxfordshire, England, Woodcock B.A., Lawson C.S., Mann D.J. & McDonald A.W. (2006) Effects of grazing management on beetle and plant assemblages during the re-creation of a flood-plain meadow. *Agriculture, Ecosystems and Environment*, 116, 225-234

A replicated trial from 1987 to 2004 at Somerford Mead, Oxfordshire, UK (Woodcock *et al.* 2006) found that both plant and beetle (Coleoptera) communities on an experimentally restored meadow were closest to the flood meadow restoration target under a regime of hay cutting and aftermath grazing. For plants, sheep grazing was slightly better, but for beetles, cattle grazing was better. There were fewer beetles and beetle species on plots cut for hay but without aftermath grazing. After 18 years, neither the plant nor the beetle communities were fully restored to floodplain meadow species assemblages. The site was characterized by a high percentage cover of red fescue *Festuca rubra*. A former arable field was sown with seed harvested from a local floodplain meadow in 1985. From 1987 it was cut in July and aftermath grazed. From 1989, three aftermath grazing treatments were tested: sheep, cattle or no grazing, on three 0.4 ha plots each. Plants and invertebrates were monitored in 2004 and compared with communities on two nearby floodplain meadows.

24. A review recommends management for maintaining or restoring upland hay meadows in UK, including spring and autumn grazing, a mid-July cut, no inorganic fertilizer, and (for restoration) introduction of seed, including Rhinanthus minor hay rattle, Jefferson R.G. (2005) The conservation management of upland hay meadows in Britain: a review. *Grass and Forage Science*, 60, 322-331

A 2005 review (Jefferson 2005) of seven studies exploring the role of cutting, grazing and fertilizer in maintaining species richness of upland UK hay meadows concluded that the best management involves spring and autumn grazing, a mid-July hay cut and no inorganic fertilizer. The review recommends using only low levels of farmyard manure as Edwards *et al*. 2002 and Tallowin 2005 found that it can lead to a shift towards improved grassland plant communities, and is unlikely to assist seed dispersal.

Additional references:

Edwards A.R., Younger A. & Chaudry A.S. (2002) The role of farmyard manure in the maintenance of botanical diversity in traditionally managed hay meadows: the effects of rumen digestion on seed viability. Pages 159-162 in: J. Frame (ed.) *Conservation Pays? Reconciling Environmental Benefits with Profitable Grassland Systems. Occasional Symposium No. 36*, British Grassland Society, Reading, UK.

25. Tallowin J.R.B. (2005) The impact of organic fertilizers on semi-natural grasslands. *Defra* BD1415.

A 2005 review of six studies exploring the best management for restoring upland hay meadow vegetation on semi-improved grassland in the UK (Jefferson 2005) suggested that the highest plant species richness is produced by spring and autumn grazing, a mid-July hay cut and no inorganic fertilizer. Addition of seed from outside the site (either from natural dispersal or sowing) is also likely to be necessary. Three studies found that adding *Rhinanthus minor* hay rattle seed can help the colonization of other sown species (Smith *et al*. 2003, Pywell *et al*. 2004, Smith 2005). One study in North Yorkshire (Smith 2005) found that adding farmyard manure had a generally harmful effect on restoration of upland hay meadow communities, and recommended that this should be avoided, at least in the early stages of restoration. However, results were based on using larger quantities of manure than under traditional management.

Additional references:

Smith R.S., Shiel R.S., Bardgett R.D., Millward D., Corkhill P., Rolph G., Hobbs P.J. & Peacock S. (2003) Soil microbial community, fertility, vegetation and diversity as targets in the restoration management of meadow grassland. *Journal of Applied Ecology*, 40, 51–64.

Pywell R.F., Bullock J.M., Walker K.J., Coulson S.J., Gregory S.J. & Stevenson M.J. (2004) Facilitating grassland diversification using the hemiparasitic plant *Rhinanthus minor*. *Journal of Applied Ecology*, 41, 880–887.

Smith R.S. (2005) Ecological mechanisms affecting the restoration of diversity in agriculturally improved meadow grassland. *Defra Project* BD1439.

26. Review of evidence on how to restore species-rich grassland Diggelen R.V. (2007) Habitat creation: nature conservation of the future? *Aspects of Applied Biology*, 82, 1-11

A 2007 review of experimental evidence on how to restore species-rich grassland on old arable fields (Diggelen 2007) found that removing excess nutrients is very slow if done simply by grazing and cutting hay (two studies), with only 3-5% of the soil nutrient pool removed each year. Removing topsoil can effectively remove nitrogen but not phosphorus (one study; Verhagen *et al*. 2001). The authors argued it is necessary to introduce plants by sowing because rare grassland species are under-represented in the seed bank. They found one review (Pywell *et al*. 2003) showing that plants that were good colonizers and competitors, associated with fertile soils were most likely to establish in restoration experiments. Two sets of experiments demonstrated that seedlings of grassland or wet grassland plants survive less well in low light conditions (as in a dense productive grassland).

27. Management to enhance plant diversity of species-poor agricultural grasslands at North Wyke (Devon) and Edgcott (Buckinghamshire), England, Pywell R.F., Bullock J.M., Tallowin J.B., Walker K.J., Warman E.A. & Masters G. (2007) Enhancing diversity of species-poor grasslands: an experimental assessment of multiple constraints. *Journal of Applied Ecology*, 44, 81-94

A randomized, replicated and controlled trial in 1999-2003 of restoration methods at two sites in the UK (Pywell *et al.* 2007) found that turf removal followed by seed addition was the most effective means of increasing plant diversity. Multiple harrowing was moderately effective and was enhanced by applying snail/slug pesticide and sowing yellow rattle *Rhinanthus minor* (which reduced competition from grasses). Grazing, slot-seeding and inoculation with soil microbial communities from species-rich grasslands did not increase botanical diversity, and different grazing management regimes had little impact. Thirteen treatments were applied to 15 x 15 m plots at sites in Devon and Buckinghamshire, with eight replicates of each treatment. All treatments were managed with a single July hay cut.

28. **Harrowing increases the effectiveness of seed addition by hay strewing and brush harvesting during restoration of an agriculturally improved hay meadow at Rocks Farm, East Sussex, England Edwards A.R., Mortimer S.R., Lawson C.S., Westbury D.B., Harris S.J., Woodcock B.A. & Brown V.K. (2007) Hay strewing, brush harvesting of seed and soil disturbance as tools for the enhancement of botanical diversity in grasslands. *Biological Conservation*, 134, 372-382**

A randomized, replicated, controlled trial from 2000 to 2004 at a farm in East Sussex, UK (Edwards *et al.*2007) found that hay spreading was the most effective technique for restoring a hay meadow plant community similar to the seed donor site. Both hay spreading and the addition of brush-harvested seed increased plant species richness, and harrowing increased the effectiveness of the seed addition treatments. Hay spreading was thought more effective because it captured seeds from a greater range of heights in the sward, and allowed for seeds to mature on the restored site after the restoration activity. Eight different combinations of harrowing and the two methods of applying seed were tested, on land that had been improved agricultural grassland, with two different rates of hay application. There were four replicates of each combination of treatments. Plants were monitored before treatment (July 2000) in two random plots from each block, and every June from 2001 to 2004, in ten 50 x 50 cm quadrats in each plot.

29. **Recreating species rich hay meadows using regional seed mixtures in the White Carpathians Protected Landscape Area, Czech Republic, Jongepierova I., Mitchley J. & Tzanopoulos J. (2007) A field experiment to recreate species rich hay meadows using regional seed mixtures. *Biological Conservation*, 139, 297-305**

A replicated trial in the White Carpathians Protected Landscape Area, in the eastern Czech Republic (Jongepierova *et al.* 2007), found that sowing a regional seed mixture over the entire plot was the most effective treatment for establishing hay meadow vegetation. Four restoration treatments were tested, each in four 55 x 20 m plots, replicated within a single 3 ha arable field. The experimental treatments were sowing seven grasses and 20 herb species throughout the plot, or sowing 2.5 m-wide strips of just the herb species with or without a commercial grass mix. Control plots were left to naturally regenerate. In the fully sown plots, 19 of the 20 herb species, and all seven grass species had established by 2004, providing 30% and 55% cover on average. The cover of sown herb and grass species in the strip-sown or unsown treatments were less than 5% and 2-9% respectively. Plots were sown in spring 1999, and vegetation monitored in June 2002-2004. All plots were cut once in July and the hay removed, following restoration.

30. **A review of techniques to restore species-rich grassland in the UK finds that introducing plants species and removing nutrients are important to effective restoration, Walker K.J., Stevens P.A., Stevens D.P., Mountford J.O., Manchester S.J. & Pywell R.F. (2004) The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. *Biological Conservation*, 119, 1-18**

A 2004 review of published and unpublished literature from the UK (Walker *et al.* 2004) found that introducing plant species and removing nutrients are important to effective grassland restoration. The review identified eight studies that tested effects of reinstating cutting and grazing management on grassland, and ceasing fertilizer use and concluded that this could enhance the number of plant species, but it was slow and did not always work. Just one study, in west Wales, found a marked increase in the number of plant species over eight years (Hayes & Sackville Hamilton 2001). Five found a slight or gradual increase, over 4-14 years ((Bullock *et al.* 1994), Oomes 1990, Olff & Bakker 1991, Hayes *et al*. 2000, (Smith *et al.* 2000)). Two studies found no change or a decrease (Oomes 1990, Mountford *et al*. 1994). Increases in the number of species were modest and slow. Cutting and grazing together were generally more effective than cutting or grazing alone. On existing grassland, the review found nine studies that tested various methods of adding plant species: adding seed (over-sowing), drilling seed (slot-seeding) and planting small plants (plug-planting), with effects monitored over two to eight years. Three studies found that over-sowing was most effective when combined with either cutting and grazing or de-turfing (Hopkins*et al.* 1999, Jones & Hayes 1999, Smith *et al.* 2000). Five studies found that slot-seeding was not very effective (Wells *et al*. 1989, (Hopkins *et al.* 1999, Coulson *et al.* 2001)). Of five studies that tested plug-planting, three found it was initially effective, but survival of the introduced plants fell after two to five years (Wells *et al*. 1989, (Hopkins *et al.* 1999), Barratt *et al*. 2000). Two found 60-70% of plants established (over two or five years) (Boyce 1995, (Hopkins *et al.* 1999)). On ex-arable land, ten studies tested sowing grassland species, monitoring effects for between one and 20 years. All found increased plant species diversity and enhanced similarity to the target plant community, which was either upland, chalk or neutral (mesotrophic) grassland. Similarity to the target community was quantified for six of these studies and fell between 50% and 81%, usually after two to five years (20 years in one case) (McDonald 1992, Wells *et al*. 1994, (Stevenson *et al.* 1995), Pywell *et al*. 2000, (Pywell *et al.* 2002)). Cultivation, followed by a relatively high seeding rate, seemed the most effective approach. On upland grassland, adding sulphur to acidify the soil prior to seeding led to effective establishment of sown species in two studies.

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Synthesis and applications: These results demonstrate that biodiversity goals for upland meadows need to plan beyond the typical 5–10-year management agreement period of agri-environment schemes. Combination treatments, in which seed addition is vital, alongside appropriate fertilizer, FYM, hay-cut date and grazing regimes, are needed for grassland restoration. However, even after 14 years the most effective treatment combinations had still not restored the target species composition and diversity. The demonstrated change in soil microbial communities, linked to the growth of legumes, might be important to facilitate future increases in plant diversity.

Overall, our findings indicate that biodiversity goals for upland meadows need to plan beyond the typical 5–10-year management agreement period of agri-environment schemes. There appears to be a limit to what is rapidly achievable. It has taken 14 years for the apparent fertility (from Ellenberg scores) to decline and the vegetation to become similar to that of the target MG3b community in the most effective treatment combinations, but the species diversity was still well below target. Twenty-year management agreements might need to be the minimum expectation for policy planning.

Such experiments have identified some of the key management features and ecological processes that control plant species diversity in mesotrophic grassland. They have also shown that it can take many years to increase plant diversity successfully and return grass swards to some semblance of their traditional character.

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Wetlands

Ponds

Countryside Survey, Ponds Report from 2007, P. Williams, J. Biggs, A. Crowe, J. Murphy, P. Nicolet, A. Weatherby, M. Dunbar. January 2010.

This Countryside Survey technical report describes the current state of ponds in Britain and assesses how they have changed over the last decade. Pond biodiversity value and ecological quality of 259 ponds surveyed in detail in 2007 were assessed using plant community measures. Temporal trends were evaluated for lowland areas only, by comparing plant data gathered in 2007 with plant data collected from the same ponds in the 1996 Lowland Pond Survey.

Countryside Survey 2007 data provided consistent evidence that ponds in England and Wales were widely degraded, with around 80% of ponds Poor or Very Poor quality. Ponds were poorer in quality or had fewer plant species where: (i) they had elevated nutrients levels, (ii) were located in areas of arable land, or (iii) had inflows. There was also a strong relationship between poorer pond quality and greater tree shade.

Lowland Pond Survey 1996 indicated that ponds associated with intensive urban and rural land management were likely to be impaired, particularly ponds associated with the broadly arable landscape (Williams *et al.* 1998). There is also evidence that isolation played a role in degradation.

Set against this, ponds with a higher proportion of waterbodies and wetlands in their surrounds were more likely to maintain their quality over the last decade, particularly where these habitats were closely adjacent to the pond. A number of studies, including the 1996 Lowland Pond Survey, have shown that ponds tend to be better quality, richer or support more uncommon species where they occur in proximity to other wetlands (Linton and Goulder 2003, Williams *et al.* 1998). The current findings support this, by suggesting that ponds may be more resistant to degradation if they occur in proximity to other wetlands. This may be evidence of the protective effects of freshwater networks.

Good quality, biodiverse ponds were significantly less polluted by nutrients than poor quality ponds and also less likely to be located in intensively managed landscapes, particularly arable farmlands. Good quality ponds were also less likely to have an inflow, were typically less shaded than impacted ponds, and also more likely to have other waterbodies, (including ponds, streams, ditches and wetlands like fens and bogs), in their near surrounds.

The value of new ponds

Ecological data from 0-9 year old ponds surveyed in 2007 indicate that new ponds were relatively species-rich, supported uncommon species and were likely to be of higher quality than older waterbodies. 24% of the new ponds were of Good Quality and qualify as Biodiversity Action Plan (BAP) Priority Ponds on this basis. Approximately 6% of older sites were Good Quality.

The richness of new ponds was not an unexpected finding. New ponds are known to colonise rapidly with plants, macroinvertebrates and amphibians (Baker and Halliday 1999, Gee *et al*. 1997, Biggs *et al.* 2005), and a number of other studies have provided evidence which corroborate these findings showing that, in both semi-natural and degraded landscapes, the richness of new ponds typically exceeds the mean richness of older ponds within a few years of their creation (Williams *et al*.1998, 2008, Petranka *et al*. 2003).

The critical question is will new pond quality be maintained in the longer term? Evidence from other surveys suggests this is possible, but likely to depend on the quality of the ponds' surrounding land use and range of other impacts to which they are subjected (Williams and Whitfield 2009, Davies *et al*. 2004, Williams *et al*. 2008). The very limited 2007 data (5 ponds') available supports this view: indicating that 11-23 year old ponds increased in species-richness after 1996 if they were located in semi-natural surrounds, but decreased in richness when located in areas of more intensive land use.

On this basis, assessment of the land use around new (0-9 year old) Countryside Survey ponds in 2007 suggests that most ponds are likely to be sub-optimal for biodiversity in the medium to long term: with the majority (73%) of new ponds surrounded by between 25% - 100% intensive land use, and around half of the ponds fed by streams or ditches.

However, the extent to which new ponds can support biodiverse assemblages in the longer term is likely to depend on the quality of their surrounds and the level of impacts they experience. CS data suggest that to achieve this, new ponds should be located where they are buffered from agricultural or other intensive land-use with few pollutant inputs. Of the new ponds studied in detail, only 6% had semi natural surrounds, and all these were in Scotland. The quality of most new CS ponds studied may therefore decline as the waterbodies age.