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Enhancing floral resources for pollinators in productive agricultural grasslands

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ABSTRACT

Across N.W. Europe intensive agricultural management has increased productivity to the detriment of floral resources vital for insect pollinators like bees, butterflies and hoverflies. While the creation of wildflower habitats has been widely used to re-establish such resources into arable ecosystems (e.g. sown into field margins), comparable low cost methods for enhancing floristic diversity in production grasslands are lacking. We investigated how simple and cheep seed mixtures based around three plant functional groups (grasses, legumes and non-leguminous forbs) could be used to enhance flowering resources to benefit insect pollinator communities over a four year period. We demonstrate that the abundance and species richness of pollinators was correlated with the increased availability of legume and non-legume forb flowers. While the flowering resources provided by agricultural cultivars of legumes declined rapidly once sown, the inclusion of a forb component within seed mixtures was effective in increasing the long-term persistence of these resources. As a result the abundance and species richness of insect pollinators over the four years showed greater stability where forbs were also sown. Sward management also played a role in the persistence of floral resources, with grazing more likely to maintain legume cover than cutting. In conclusion, we demonstrate that low cost seed mixtures can be used to enhance floristic diversity to benefit pollinators, although the continued value of these grasslands over time is dependent on complementarity between sown legumes and forbs. As permanent grassland covers *c.* 40% of the UK the enhancement of their floristic diversity has a huge potential to benefit insect pollinators. The type of land sharing approaches suggested here maintain modest agricultural productivity and so may be the most likely to achieve benefit to pollinators through wide-scale farmer uptake.

1. Introduction

Across lowland Europe the intensity of management applied to grassland systems has risen dramatically through the second half of the last century, and while this has benefited livestock production it has led to a wide-scale reduction in flowering plant diversity (Blackstock et al., 1999; Bullock et al., 2011; Haines-Young et al., 2003; Littlewood et al., 2012). In the UK the cover of permanent grassland is *c.* 40%, (Defra, 2013), however as little as 1–2% of this may be considered to be high quality species rich habitat (Blackstock et al., 1999). This loss of floral diversity has been linked to the increased use of inorganic fertilisers, reseeding, improved drainage and a greater frequency of cutting and grazing (Blackstock et al., 1999; Bullock et al., 2011). For those areas that have escaped the impact of modern practices and remain under traditional extensive management systems, the diversity and cover of flowering plants represents a key resource for many insect pollinators (Forup and Memmott, 2005; Noordijk et al., 2009; Steffan-Dewenter and Tscharntke, 1999). In mixed agricultural systems (i.e. those containing both grassland and arable) the retention of such areas can play a key role in the maintenance of insect pollinators, particularly for taxa such as bees that forage at a landscape scale (Decourtye et al., 2010; Steffan-Dewenter and Tscharntke, 1999). As insect pollinators are estimated to support 9.5% of the worldwide production of key vegetables, fruits and oil producing crops (worth €153 billion), this loss of species-rich grasslands may have economic consequences for the provision of this ecosystem service (Gallai et al., 2009).

The restoration of species-rich grasslands is one potential solution to the loss of floral resources (Bullock et al., 2011; Decourtye et al., 2010; Littlewood et al., 2012). Indeed, such an approach would not only benefit insect pollinators, but would re-establish threatened grassland types to the benefit of native wildlife and a range of ecosystem services in general (Bullock et al., 2011; Littlewood et al., 2012). However, restoration of grasslands is

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technically hard to achieve, time consuming and expensive (Bullock et al., 2011; Pywell et al., 2007). Where soils have become enriched with nutrients, typically following the application of inorganic fertilisers (Edwards et al., 2007; Pywell et al., 2007) or as a result of atmospheric nitrogen deposition (Payne et al., 2013), re-establishing stress-tolerant species often meets within limited success. Furthermore, such restoration is a form of land sparing which results in the loss of agriculturally-productive land (Rey Benayas and Bullock, 2012). Rather than trying to re-instate highly diverse grassland habitats, achieving more modest enhancement of the floral diversity of productive swards using simple seed mixes may represent a viable and cost effective alternative to supporting pollinator populations in agricultural landscapes (Decourtye et al., 2010; Littlewood et al., 2012). Seed mixes based on commercially available species that establish well into nutrient enriched soils could provide a high quality foraging resources for pollinators (Mortimer et al., 2006). Where such swards are of moderate to high forage value for livestock these approaches are more likely to be perceived by farmers as land sharing compatible both with their production goals as well as enhancing biodiversity (Rey Benayas and Bullock, 2012). Such an approach would be compatible with many simple agri-environment schemes, for example the Entry Level Stewardship scheme currently in operation in England.

Unfortunately many commercially available cultivars of wild flowers, which were historically used as part of pasture management to enhance high forage quality, tend not to persist well once established into swards (Beuselinck et al., 1994; Duffey et al., 1974). For example, while red clover (*Trifolium pratense* L. Fabaceae) is important as a foraging resource for many bees, the typical persistence of agricultural cultivars is only around 2–3 years (Beuselinck et al., 1994; Mortimer et al., 2006). While reseeding could be undertaken, this would lead to considerable additional costs, practical difficulties and disturbance of the grassland. Maintaining flowering resources for periods greater than three years will require an understanding of best practice in terms of not only establishment techniques but also on-going sward management (Mortimer et al., 2006; Rochon et al., 2004). Perhaps most important is the need to develop new seed mixtures that complement each other in terms of their temporal persistence within grassland swards. For example, short lived legumes could be succeeded by other non-legume forbs that show better persistence over time.

Here we test how different combinations of grasses, legumes and non-leguminous forbs (hereafter referred to as forbs) plant functional groups can be established into productive, agriculturally improved lowland grasslands to provide floral resources for key insect pollinators (bees, hoverflies and butterflies) over a four year period. We test how seed bed preparation, management (cattle grazing or cutting) and its intensity affect the persistence of these plants and so the provision of pollen and nectar resources. We hypothesised that: (H1) wildflowers require the creation of a large amount of bare ground to establish in grassland (Bullock et al., 2001; Pywell et al., 2007) and so inversion tillage (conventional ploughing) in combination with application of non-selective herbicide is a more effective means of creating a seed bed to establish wildflowers when compared with non-inversion, minimum tillage alone. This reflects the value of inversion tillage and herbicide in controlling competitive and undesirable species (Morris et al., 2010; Pywell et al., 2007); (H2) the longevity of short-lived legume species under grazing management is increased by the resulting stochastic defoliation, disturbance and nutrient enrichment when compared with cutting management alone (Rochon et al., 2004; Whiteman, 1969). The persistence of legumes is important as they represent one of the highest quality foraging resources for pollinators (Decourtye et al., 2010; Jannersten, 1984; Mortimer et al., 2006); (H3) the inclusion of a forb component into legume based seed mixtures will promote a succession of floral resources extending the value of these grasslands for insect pollinators; (H4) the use of summer resting periods during cutting and grazing management will extended the window for the phenological development of flower heads increasing the availability of foraging resources for insect pollinators. This increase in resource availability will result in a greater abundance and species richness of pollinators utilising the grasslands (Potts et al., 2009).

2. Materials and methods

The study was undertaken on heavy clay soils of moderately high fertility (total soil phosphorous 911 mg kg^{-1}) in the mixed arable and grassland faming landscape of Warfield, Berkshire, UK (Long. 51°26′30″N Lat. 000°43′43″W). The agriculturally-improved grassland used in the study had been reseeded in the last 10 years and received on-going applications of inorganic nitrogen based fertilisers. This type of grassland is typical of the high productivity and low diversity grasslands that predominate in the UK agricultural as well as other parts of the world. The sward was floristically species-poor (3.0 ± 0.1 species m^{-2}) and dominated by the grass *Lolium perenne* L. (Poaceae). To test the effects of seed mix, management type, management intensity and seed bed cultivation, a randomised split–split–split-plot design replicated across four blocks was established in the spring of 2008. The four treatment levels (described below) were split across 96 plots with an average plot size of *c.* 875 m^2. Over the four year sampling period (2009–2012) none of these plots received inorganic fertiliser.

Establishing seed mix (SEED) was the whole-plot stratum of the split–split–split-plot design. Three combinations of grasses, legumes and forbs were used: (1) a 'grass' only seed mix (G), comprising five grass species selected for good agronomic performance under low inputs of fertiliser. These were sown at 30 kg ha^{-1} which cost *c.* €83 ha^{-1} (based on 2008 prices). This represented a control used to assess the relative value of seed mixes for insect pollinators where the establishment of flowering plants was by natural colonisation only. Note these grasses were also sown as a base to all subsequent seed mixes; (2) a 'grass and legume' seed mix (GL), comprising the same five grasses and seven agricultural legume varieties sown at 34 kg ha^{-1} (*c.* €120 ha^{-1}); (3) 'grass, legume and forb' seed mix (GLF), comprising the same five grasses and seven legumes as in GL, along with six forbs sown at 33.5 kg ha^{-1} (*c.* €190 ha^{-1}). The composition of the seed mixes is given in Appendix A. The split-plot treatment was management (MANAGEMENT) by either cattle grazing (*c.* three livestock units ha^{-1}) or cutting for silage to a height of 10 cm. Cutting was undertaken with a 6 m tractor drawn boom, which was suitable for cutting these relatively small plots. However, the relatively small plot size restricted the penning of cattle onto individual plots. We therefore used an open grazing system, whereby the cattle moved freely across the site using a central causeway to move between grazed plots that had access gates left open (Appendix B). Where appropriate, cattle were occasionally penned into subsets of plots using electric fencing to ensure even grazing intensity was achieved across the site. Superimposed on MANAGEMENT was the split-split-plot treatment of management intensity (INTENSITY), defined as either intensive (cattle grazing from May to October, or silage cuts in May and August) or extensive (grazing as before, but suspended from June–August, or a single silage cut in May). The extensive management was intended to provide a summer window to allow the full phenological development of the sward and thus provide flowers for insect pollinators (Potts et al., 2009; Woodcock et al., 2009). The combination of early and late season grazing management strategies has also been shown to have beneficial effects on floral diversity in mesotrophic grasslands (Smith et al., 2000).

Finally, the split–split–split plot factor was cultivation technique (CULTIVATION), which was undertaken in the autumn of 2008 to create a seed bed. CULTIVATION had two levels: (1) herbicide application (Glyphosate at five l ha^{-1} *a.i.*) followed by inversion tillage using a conventional reversible plough turning soil to a depth of 25–30 cm; (2) a non-inversion minimum tillage approach, whereby surface soil disturbance over c. 40% of its area was created to a depth of *c.* 5 cm using tractor-drawn multiple sets of discs (Vaderstadt Ltd., Grantham, UK). Loss of vegetative cover using this method is short lived as most grass tillers are not killed and can rapidly re-establish. While the minimum tillage approach has low fuel requirements, uses no herbicides and helps maintains soil carbon stocks, it is relatively ineffective in terms of controlling competitive weed species (Edwards et al., 2007; Morris et al., 2010). This limits the window of opportunity for small seeded, slow-growing wildflowers to establish (Edwards et al., 2007; Pywell et al., 2007).

2.1. Vegetation sampling

From 2009 to 2012 the species composition and percentage cover of plants was recorded using vertical projection in five randomly positioned 1 m × 1 m^2 quadrats in each plot. This was undertaken yearly in late July to allow swards between 4 and 6 weeks to recover after the initial cut. As management affects the phenological development of flowering plants, their establishment in the sward does not necessarily translate into increased availability of flower heads and thus foraging resources for insect pollinators (Potts et al., 2009). To assess the availability of flower resources for insect pollinators we quantified the density of flower 'units' on three separate occasions each year. On each occasion six randomly positioned 0.5 m × 0.5 m quadrats were used to count the density of flower 'units' of legumes and forbs. Flowering 'units' describe any amalgamation of flower heads that a visiting pollinator can walk rather than fly between, such as an umbel in Apiaceae. The timing of each flower head assessment corresponded to the insect pollinator surveys described below. All plant parameters were collated into yearly averages for subsequent analyses.

2.2. Pollinator sampling

In each plot, two fixed parallel 20 m × 2 m transects were established. Each transect was surveyed for insect pollinators on three occasions in each year from 2009 to 2012. Pollinators were identified without catching when resting on flowers, although if necessary identification was confirmed by collecting individuals with a net. Surveys were undertaken between 10.00 and 16.00 h following the standard limits for weather conditions given by Pollard and Yates (1993). The three pollinator surveys occurred yearly in mid-May before the first cut, late July c. 4–6 weeks after the first cut, and early August before the final sward cut. Note that surveys of grazed and cut plots occurred simultaneously. Pollinators were identified at the following taxonomic resolution: (1) all butterflies to species; (2) honeybee (*Apis mellifera*); (3) bumblebees to species *Bombus lapidarius*, *Bombus terrestris/lucorum*, *Bombus pascuorum*, *Bombus pratroum*, *Bombus hortorum*, *Bombus hypnoroum*, *Bombus vestalis*, *Bombus rupestris* and the parasitic sub-genus *Psithyrus* spp.; (4) total abundance of all solitary bees; (5) total abundance of all hoverflies. These were used to derive a measure of total pollinator abundance and pollinator species richness for each plot for each year. Species richness was derived from the *Apis*, *Bombus* and butterflies only, reflecting the higher degree of taxonomic resolution applied to these groups.

2.3. Data analysis

Due to the potential proliferation of interaction terms resulting from the split–split–split plot design we restricted analyses to testing the specific hypotheses given in the introduction. All analyses were undertaken using general linear mixed effects models in R version 3.0 (R Development Core Team, 2013) with the 'lme4' package (Bates et al., 2013). All models used the same hierarchical structure of random effects to account for the split–split–split plot design, with INTENSITY nested within MANAGEMENT nested within SEED nested within BLOCK. To account for the repeated measures a unique plot subject identifier was also included as a random effect with intercepts and slopes defined by YEAR. Estimation of model parameters was by the Residual Maximum Likelihood approach. The following models were used to test each hypothesis. **Hypothesis 1**: To test the effect of seed bed cultivation on the establishment of legumes and forb species richness the fixed effects of SEED, CULTIVATION and the interaction between these two terms were tested. As we were only interested in establishment success, this analysis was restricted to the establishment year of 2009. **Hypothesis 2**: To test the effect of management type on the persistence of legumes, we analysed the response of legume species richness and summed percentage cover against the fixed effects of SEED, MANAGEMENT, YEAR and all higher order interactions. **Hypothesis 3**: To test whether the inclusion of forbs promoted a succession of floral resources over the length of the study, the density of legume and forb flower heads was tested against the fixed effects of SEED, YEAR and their higher order interactions. **Hypothesis 4**: To test if summer rest periods for management promote resource utilisation by pollinators, we analysed the response of pollinator species richness and the total abundance of all pollinators against the fixed effects of SEED, MANAGEMENT, INTENSITY, YEAR and all their higher order interactions. The density of floral resources was not included as an explanatory variable in this model as this parameter covaries with the other treatment fixed effects. This would confound the identification of best management practices intended to support pollinator abundance and species richness. However, to test if the density of floral resources represents the underlying mechanism explaining changes in pollinator abundance and species richness, addition correlations between the density of legume and forb flower heads with the abundance and species richness of the pollinators were made using the same model structure. Model simplification was by deletion of least significant effects and where a higher order interaction was included its individual terms were always retained in the model. Significance values were determined using conditional *F*-tests with the Kenward Roger approximation for degrees of freedom derived from the 'pbkrtest' package of R (Højsgaard, 2013). All count data were $\log_e N + 1$ transformed.

3. Results

Over the four year sampling period a total of 8572 insects (bees $N = 6320$; species richness = 8), butterflies ($N = 728$; species richness = 16) and hoverflies ($N = 1524$) were recorded. The honeybee (*A. mellifera*) was the most frequent species ($N = 2283$), while all solitary bees were rare ($N = 38$). Bumblebees were abundant ($N = 3999$), of which *B. lapidarius* was the commonest comprising of 53.7% of all observations from this genus. Establishment success of sown plant species was on the whole high, although the legumes *Melilotus officinalis* (L.) (Fabaceae) and *Onobrychis viciifolia* Scop. (Fabaceae) did poorly. Where legumes were sown, *Trifolium repens*, *Trifolium pratense* and *Trifolium hybridum* had the highest summed percentage cover over the five year period at 20.5% (±1.18), 9.54%

(±0.76) and 6.92% (±0.73). With the exception of *Cichorium intybus* L. (Asteraceae) (16.6% ± 0.99), forbs tended to have low cover at between 0.23% (±0.14) for *Rumex acetosa* L. (Polygonaceae) and 1.78% (±0.23) for *Leucanthemum vulgare* Lam. (Asteraceae). The average density of legume flower heads (37.1 m^{-2}, ±1.96) was consistently higher than that of forbs (9.47 m^{-2} ± 0.82) where they were sown.

3.1. Seed bed cultivation and seed mix in the establishment year

In 2009 the establishment of legumes was significantly influenced by seed mix ($F_{2,5.6} = 468.8$, $p < 0.001$) with more species being found in the GL (4.53 species ± 0.19) and GLF plots (4.12 species ± 0.13) than in those of G (0.21 species ± 0.08). Establishment of legumes did not differ between the GL and GLF seed mixes ($p > 0.05$). Seed bed cultivation and its interaction with seed mix had no effect on the number of legume species establishing into the sward ($p > 0.05$). In the case of the forbs an interaction between seed mix and seed bed cultivation practice was found to affect species establishment (seed × cultivation: $F_{2,48.1} = 4.79$, $p = 0.01$; Fig. 1). Overall the number of forbs establishing in the GLF seed mix was higher than that of the G or GL plots, reflecting the absence of forbs from either of the seed mixes of these two treatment levels or the underlying seed bank. For the forbs, inversion tillage using conventional ploughing increased species establishment, but only where forbs were not a component of the establishing seed mix. Therefore inversion tillage promoted the establishment of naturally colonising forbs, but where forbs were sown as part of the establishing seed mix it had no effect on promoting species colonisation.

3.2. The role of management type in the persistence of legumes in the sward

Management type (cutting vs grazing) had no effect on the species richness of legumes, either on its own or as an interaction with seed mix or year ($p > 0.05$). However, legume species richness did not remain constant over the four year period, rather it tended to decline in the GL and GLF plots from *c.* 4–5 species in 2009 to 2–3 species in 2012. This trend was reversed for the G only seed mix, so that by 2012 one or occasionally two legume species had established by natural colonisation (seed × year: $F_{6,279} = 40.3$, $p < 0.001$; Fig. 2).

While the number of legume species tended to decline over time, their summed percentage cover was affected by the management of the different seed mixes (seed × management × year: $F_{6,270} = 4.73$, $p < 0.001$; Fig. 3). As for species richness, where legumes were part of the seed mix their cover was highest in the establishing year (2009). This was particularly the case where cutting was used to manage the sward. Although the summed cover of legumes was highest in the GL as opposed to the GLF plots, the persistence of legume cover generally tended to be superior where grazing management was used. This was best seen in the GLF plots where the cover of legumes effectively collapsed by the fourth year (2012) where cutting management was applied. The natural colonisation of legumes into the G seed mix also resulted in a small increase in the cover of legumes over the four years independent of management type. It is likely that this process was also aided by the movement of cattle between experimental plots.

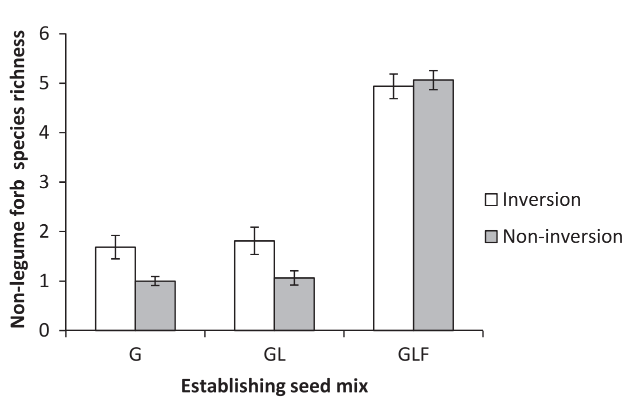

Fig. 1. The effect of either inversion (conventional deep ploughing) or non-inversion (minimum tillage) seed bed cultivation on the establishment of forbs into swards sown with 'grass' (G), 'grass and legume'(GL) or 'grass, legume and forb'(GLF) seed mixes.

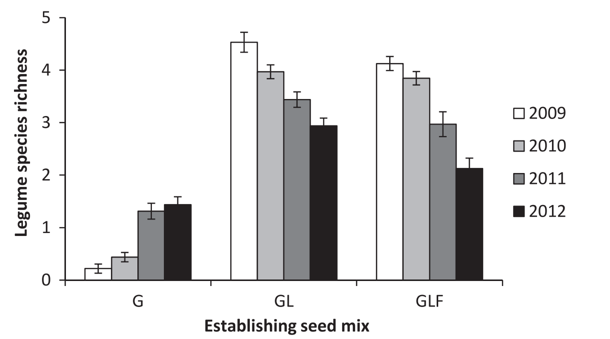

Fig. 2. The change in legume species richness in 'grass' (G), 'grass and legume' (GL) and 'grass, legume and forb' (GLF) seed mixes over a four years period.

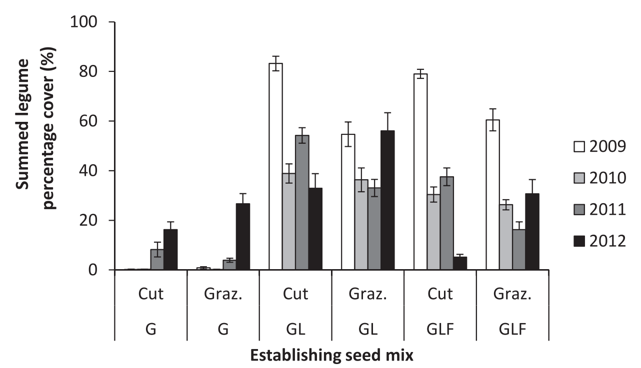

Fig. 3. Effect of establishing seed mix, subsequent sward management (cutting or grazing) and the number of years of establishment on the summed percentage cover of legumes.

3.3. Promoting a succession of flower resources using legumes and forbs

Where legumes were sown in the seed mix (GL and GLF) the density of their flowers, although initially high at *c.* 60 heads m^{-2} in 2009, had collapsed to *c.* 10 m^{-2} by 2012. Again, the natural colonisation of legumes into the G seed mix meant that there was a small increase in the density of legume flowers, although this rarely exceeded 5 heads m^{-2}. For the forbs, flower heads were for the most part absent from those plots where this functional group was not part of the establishing seed mix (e.g. G and GL). However, in the GLF seed mix the density of forb flowers increased over the four years from *c.* 5 m^{-2} to 20 m^{-2}. The responses of legume and forb flower heads were indicated by a significant interaction between establishing seed mixture and year (Legume: $F_{6,279} = 19.6$, $p < 0.001$; Forbs: $F_{6,279} = 40.8$, $p < 0.001$; Fig. 4).

3.4. Breaks in management increases resource provision to pollinators

Both the abundance and species richness of pollinators within the grassland swards was correlated with the availability of floral resources, particular those of flowers typical of the GL and GLF seed

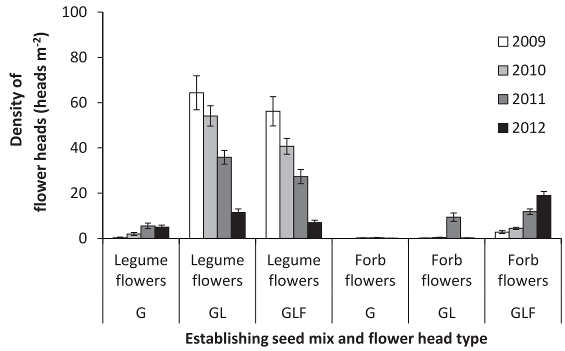

Fig. 4. Changes in the availability of legume and forb flower heads as a resources for insect pollinators over a four year period for the seed mixes 'grass'(G), 'grass and legume' (GL) and 'grass, legume and forb' (GLF).

mixes. Pollinator species richness was positively correlated with the density of both legume ($F_{1,264} = 18.2$, $p < 0.001$; regression slope $\beta = 0.006$) and forb flower heads ($F_{1,227} = 49.5$, $p < 0.001$; $\beta = 0.015$). These positive correlations were also seen for the abundance of bees (Legumes: $F_{1,209.7} = 123.0$, $p < 0.001$, $\beta = 0.02$; Forbs: $F_{1,175.9} = 201.6$, $p < 0.001$, $\beta = 0.06$), butterflies (Legumes: $F_{1,103.4} = 31.7$, $p < 0.001$; $\beta = 0.01$; Forbs: $F_{1,88.1} = 45.1$, $p < 0.001$; $\beta = 0.03$) and hoverflies (Legumes: $F_{1,22.6} = 181.6$, $p < 0.001$; $\beta = 0.01$; Forbs: $F_{1,187.8} = 24.4$, $p < 0.001$; $\beta = 0.08$).

This link between flower resources and the pollinators is reflected in the G seed mix which supported only low levels of pollinator abundance and species richness. The management of the G plots had little effect on the pollinator communities. In contrast, where establishing seed mixes were rich in flowering plants, far greater abundances and species richness of pollinators were found. This was particularly the case where extensive cutting management (a single cut) was applied to the GL seed mix in the establishing year of 2009. A characteristic of the GL seed mix was for a decline in the abundance and species richness of pollinators over the four year succession, although typically cutting management remained superior to grazing, and extensive management was better than intensive. For the more floristically diverse GLF seed mix, both the abundance and species richness of pollinators remained at a more consistent level over the four years, although was never as high as that seen for the GL seed mix in 2009. Note that a severe drought in 2010 depressed abundance and species richness of pollinators across all treatments. These responses were supported by significant higher order interaction between seed mix, management type, management intensity and year for both the abundance ($F_{24,252} = 2.53$, $p < 0.001$; Fig. 5) and species richness of pollinators ($F_{24,252} = 1.71$, $p = 0.02$; Fig. 5).

4. Discussion

4.1. Seed bed cultivation and seed mix in the establishment year

Overall we have shown that it is possible to provide resources for pollinators in agriculturally improved grasslands using simple and low costs methods. However, we were unable to find evidence

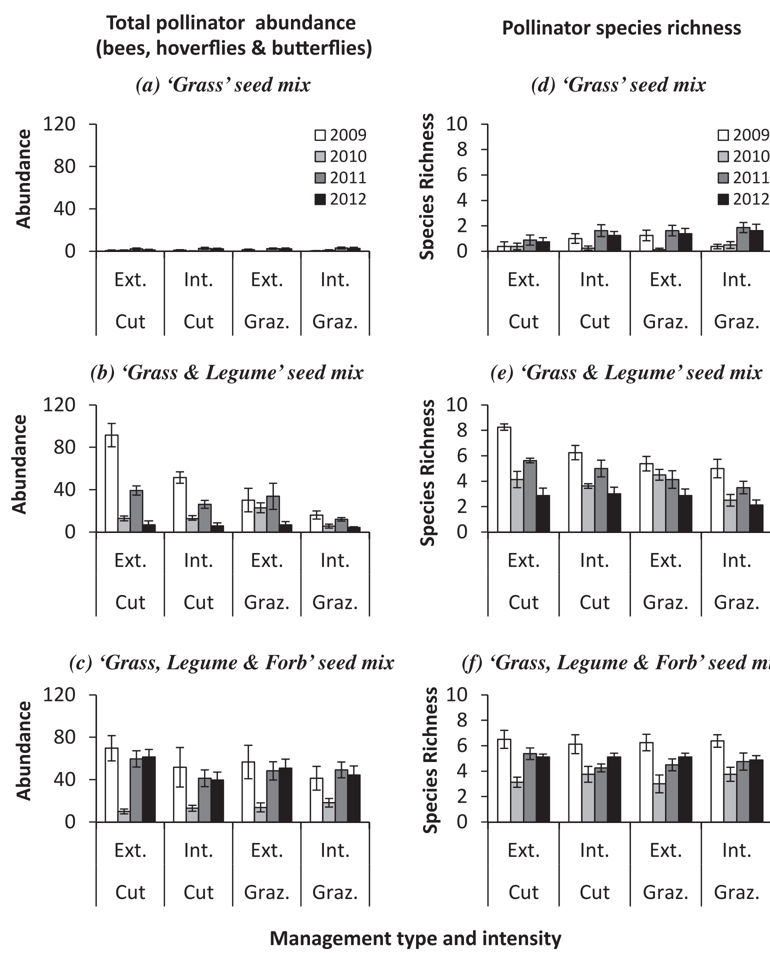

Fig. 5. The effect on pollinator abundance and species richness of establishing seed mixture, management type (cutting and grazing) and its intensity (intensively managed from May to October, or extensive with a summer rested period) over a four year period.

to support the use of non-selective herbicide with inversion tillage as a means of promoting the establishment of pollen and nectar providing seed mixes (Hypothesis 1). This may be linked to the greater effectiveness of minimum tillage approaches in limiting the development of large soil clods that can create a poor seed bed in the kind of clay soils typical of the study site (Morris et al., 2010). However, as care was taken to ensure such clod formation was minimised, it is perhaps more likely that minimum tillage was acting to break up the organic-rich surface soil horizon promoting mineralisation and so increasing soil fertility. Inversion tillage in contrast buries the organic rich surface soil horizon resulting in a less fertile seed bed with a poorer tilth structure. As a result differences between deep and shallow cultivation were detected in terms of their effects on species establishment. Even so, the use of the pre-emptive herbicide application before inversion tillage was expected to reduce competition with other undesirable pernicious weedy species, such as thistles like *Cirsium arvense* (L.) (Asteraceae). It is possible that the failure of inversion tillage to promote the establishment of the sown component may reflect the limited number of species that were sown, all of which had been chosen for their good establishment qualities (Mortimer et al., 2006). However, previous studies points to the need for soil disturbance to ensure establishment of even these species, although how much cultivation is required will vary on a species by species basis (Pywell et al., 2007). Indeed, it is likely that only the total absence of soil disturbance would result in failure for many of the species to establish (Edwards et al., 2007; Pywell et al., 2007). Given that non-inversion tillage uses less energy and has benefits in terms of the conservation of soil carbon stocks it would appear to be the preferable approach to be used when establishing wildflowers into existing grassland swards (Batjes, 2002; Morris et al., 2010).

4.2. The role of management type in the persistence of legumes in the sward

Legumes are important not simply in terms of their high resource value for foraging pollinators (Decourtye et al., 2010; Jannersten, 1984; Mortimer et al., 2006), but also because they are nitrogen fixing and so can reduce dependencies on inorganic fertiliser inputs (Beuselinck et al., 1994; Rochon et al., 2004). Indeed, establishing legumes into silage based forage systems has been shown to translate into befits for farmers averaging 137 € ha^{-1} in Europe (Rochon et al., 2004). In the establishment year of this study average dry matter yield was 8.16 (±0.31) tonnes ha^{-1} where legumes were part sown compared to 2.9 (±0.57) tonnes ha^{-1} in the grass only plots. Although this still falls short of the 10–12 tonnes ha^{-1} possible under conventional intensive grasslands systems, it does point to the moderate levels of biodiversity compatible production benefits that may be achieved without fertiliser use (Bullock et al., 2011). While we found that annual and short-lived perennial legumes were lost over time due to their low ability to re-establish into existing swards (Beuselinck et al., 1994), management was not seen to either enhance or decrease the rate at which this occurred. It is possible that reseeding on over the life of this grassland (using the minimum intervention approach described here) may be an effective way to ensure species persistence (Beuselinck et al., 1994).

Our second Hypothesis was not entirely rejected as grazing management tended to promote a more long-lived cover of legumes. This was most apparent for the GLF seed mix which when managed by cutting effectively lost its legume cover by the fourth year. Previous studies have identified the greater persistence of legumes under grazing than cutting regimes (Whiteman, 1969). One of the principal factors driving this may be the negative impact of cutting on seed production for crown-forming perennial species that are poor at persisting vegatively via stolons or rhizomes (Beuselinck et al., 1994). Cutting management may have other negative consequence for native biodiversity as the catastrophic loss of vegetation can result in high levels of mortality for grassland invertebrates (Humbert et al., 2009).

4.3. Promoting a succession of flower resources using legumes and forbs

The inclusion of both legumes and forbs in seed mixtures extended the value of these grasslands over a four year period by increasing the provision of flower heads for insect pollinators. While the legume component of the sward was by far the more productive in terms of the density of flower heads early in the initial years of plot establishment, by the fourth year this had fallen dramatically so that in the GL seed mix only around 10 flowers m^{-2} were found. However, the GLF seed mix produced around 25 flowers m^{-2}. Whilst there was a large decline in flower availability in both of these seed mixes, the inclusion of forbs buffered that reduction to the loss of agricultural legume cultivars. In addition the forbs tended to flower over a longer total period throughout the year compared to the legumes, providing a more persistent resource for pollinators to feed on. Although legumes are valuable for many insect pollinators (Decourtye et al., 2010; Jannersten, 1984; Mortimer et al., 2006), different pollinator species will show preferences for other plants (Branquart and Hemptinne, 2008; Forup and Memmott, 2005; Stout et al., 1998). Whether or not these preferences are the result of interspecific competition (Stout et al., 1998), increasing the diversity of forage plants would still be likely to have positive consequences for insect taxa that utilise the grassland (Ebeling et al., 2008; Potts et al., 2009; Woodcock et al., 2013). Indeed positive correlations between the availability of floral resources and pollinator species richness point to the importance of diversifying the seed mixtures in this study. As plateauing relationships between plant species richness and the diversity of pollinators have been reported elsewhere (Ebeling et al., 2008), the modest increases in floral diversity achieved in this study may represent a more cost effective approach to supporting pollinators than more diverse but expensive seed mixtures. Finally, by diversifying the resource base utilised by these insects we are likely to establish more robust networks of trophic interactions that will be less sensitive to future environmental change (Montoya et al., 2006; Woodcock et al., 2012).

4.4. Breaks in management increases resource provision to pollinators

The use of summer resting periods when applying cutting and grazing management had direct benefits for the abundance and species richness of pollinators in the GL seed mix, although none of the management approaches considered prevented the general decline in flowers and thus pollinators over time. As proposed in Hypothesis 4, the rest periods that characterised extensive management allowed a window for the development of flowers that were subsequently foraged upon by pollinators (Potts et al., 2009; Woodcock et al., 2013). In the case of intensive cutting management, the catastrophic loss of all flower heads following the second sward cut in August resulted in a complete loss of foraging resources for pollinators. While this loss was not as sudden under grazing, continuous pressure from cattle from May through to October had a negative effect on flower heads availability and so on the pollinators. The slight superiority of cutting management in supporting higher abundances of pollinators may reflect the benefits of a single early cut stimulating the growth and subsequent flowering of some wild flowers, in particular the legumes (Noordijk et al., 2009).

The importance of extensifying management over the summer was far less pronounced for the pollinators in the GLF than in the GL seed mix. It appears that the inclusion of a forb component within seed mixtures helped to buffer the abundance and species richness of pollinators to decline over the four years. It is also possible the higher diversity of plants within this seed mix acted to increase the resilience of this system to management related perturbations allowing a greater continuity of flower resources. Over the four years an increase in the availability of forb flower heads compensated for the decline in legume flowers and this appears to have been of far greater importance than management in stabilising insect pollinator populations. Even so, at least in the case of grazing management agricultural cultivars of legumes may have been selectively fed upon by cattle in preference to the forbs (Beuselinck et al., 1994). Certainly chicory (*C. intybus*) sown into the GLF plots produced woody stems that once established were unpalatable and so often remained ungrazed. The buffering of pollinator abundances within seed mixed containing forbs was to a large extent due to hoverflies, which tended to show a stronger preference for forbs with large inflorescences and flat corollae (e.g. Asteraceae and Rosaceae) (Branquart and Hemptinne, 2008; Mortimer et al., 2006). This does have some ramification for the delivery of pollination services to arable crops, as the replacement of bees with hoverflies will not necessarily translate to the same delivery of pollination services. For example, the hairy bodies of bees are particularly efficient at transferring pollen (Forup and Memmott, 2005). However, asynchrony in the sowing dates of different fields would compensate this problem to a large extent, and in the case mobile bees provide a continuity of legume resources at a landscape scale that could support their populations (Decourtye et al., 2010; Noordijk et al., 2009).

5. Conclusions

The importance of maintaining and enhancing functional connectivity at landscape scales is increasingly being understood as vital to mitigate against future environmental change, such as shifts in climate (Lawton et al., 2010). In what are largely fragmented agricultural landscapes the establishment of new areas of semi-natural grassland represents one component of the applied conservation tool box that could be used to achieve such connectivity. While the recreation or restoration of species-rich grasslands may be considered as a gold standard, the high expense, practical difficulties and uncertainty of success mean that their wide-scale implementation is unrealistic (Littlewood et al., 2012). Here we have demonstrated how simple, low-cost seed mixtures sown into improved grasslands can be used as an alternative that will also support populations of insect pollinators that deliver core ecosystem services to agriculture (Gallai et al., 2009). The establishment of such grasslands would also be important for both a variety of other insect taxa (Littlewood et al., 2012; Woodcock et al., 2012, 2013). Significantly this enhancement of floristic diversity can be achieved at costs (*c.* €190 ha^{-1}) that are equivalent to those currently accepted by farmers when establishing other simple agri-environment schemes options, such as arable field margin (Natural England, 2010). The use of simple approaches that enhanced the value of grasslands at national scales, such as those implemented through the policy mechanism of agri-environment schemes, therefore have the scope to contribute to the maintenance of biodiversity and ecosystem service delivery into the future.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2014.01.023.

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