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Multifunctional field margin vegetative strips for the support of ecosystem services - pollination, bio-control and water quality protection.

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“Farming is not just about the food we produce but also the landscape and environment we manage every day.”

Nature Friendly Farming Network, 2018

“Can a growing human population still leave space for wildlife?”

David Attenborough, 2007

Abstract

Vegetative strips in farmland field margins are a proven source of support for ecosystem services and are globally used to mitigate the effects of agricultural intensification. However, the increasing pressures on agricultural land command an increase in their functionality, to support multiple ecosystem services concurrently.

The plant species sown in a vegetative strip seed mix determine the establishment, resulting plant community and ecosystem services supported. With no defined or structured method of vegetative strip design currently available, systematically collated evidence on plant traits was used to develop such a method in Chapters 2 and 3. In Chapter 4 the developed method is shown to potentially improve the likelihood of establishment and persistence of sown species in the designed multifunctional and single-focus vegetative strips, but significant effects of soil type were identified. Chapters 5-7 demonstrate the benefits and drawbacks of multifunctional compared with single-focus strips, in support of ecosystem services. The multifunctional strip with an in increased proportion of forb species (from 20% to 50%) provided the highest and most diverse floral support for pollinators and aerial natural enemies, and vegetative diversity for surface active natural enemies. This strip also provided comparable support for protection against watercourse sedimentation, to the other vegetative strips, but may have decreased support for protection against run-off and pesticide spray-drift.

The exponentially increasing global human population continues to place more pressures on agricultural production and wildlife habitats. With regulating ecosystem services playing such an important role in agricultural production, a balance between support for agriculture and wildlife must be struck, otherwise we could continue to see huge losses in both. Increasing the functionality of vegetative strips in farmland field margins could support improved crop yield, protect water quality and provide support for biodiversity at the same time. The method of vegetative strip design developed in this project is an important step towards evidence-informed plant species selection, and it has been proven to produce vegetative strips that can establish and provide support for their target ecosystem services within the first three years. Further research is proposed that could strengthen the developed method of vegetative strip design and further support the findings from this article. With this research, these multifunctional strips have the potential to be part of the solution to alleviate the mounting pressures on agriculture and wildlife and even enhance agricultural production and the environment.

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Chapter 1. A review of the functionality and design of farmland vegetative strips for the support of pollination, bio-control and water quality protection

1-1 Introduction

Farming agricultural land effectively for food production is vital to support a globally expanding human population (Godfray et al., 2010; UN Population Division, 2018). A review by Robinson and Sutherland (2002) showed that, since 1945, there has been a 65% decline in farm numbers, whilst crop yield has almost quadrupled, and 50% of hedgerows have been removed. Crop rotations have become more intensive, with crops frequently sown in autumn and less land left to winter stubbles. In addition, the number and extent of pesticide and fertiliser applications has greatly increased since 1945, and despite recent reductions in pesticide use, there is evidence demonstrating the persistence of pesticides in the environment (Cuevas et al., 2018). In particular, organochlorine pesticides are known to be pervasive within water systems and have high persistence in the environment (Chang, 2018). The changes in agricultural activities, whilst increasing agricultural production, have also had substantial environmental effects within farmland and agricultural intensification has been linked with declines in floral resources (Baude et al., 2016) and pollinators (Winfree et al., 2009; Brittain et al., 2010; Le Féon et al., 2010; De Palma et al., 2017), which have been shown to be a key component of global biodiversity (Potts et al., 2010), natural enemies of crop pests (Rand and Tscharntke, 2007; Batáry et al, 2012; Rusch et al., 2016) and increased water pollution (Davies, 2000; Gevao et al., 2000; Dabrowski et al., 2002; Thorburn et al., 2003; Almasri and Kaluarachchi, 2004).

Ecosystem services are benefits that humans gain from the natural environment which can be cultural (e.g. recreational/educational), provisioning (e.g. food provision through crop production) or regulating (e.g. climate regulation) (Watson et al., 2011; Albon et al., 2014). Achieving efficient agricultural production requires regulating ecosystem services, including pollination and biological control (bio-control), which can increase crop yields and reduce crop damage (Aizen et al., 2009; Zavaleta et al., 2010; Blitzer et al., 2016). Therefore, when declines in pollinator abundance and diversity in addition to the plants that support them are observed, pollination deficits in crops such as oil-seed rape, watermelon and apple, can be inevitable (Kremen et al., 2002; Carvell, 2004; Biesmeijer et al., 2006; Brown and Paxton 2009; Williams and Osborne 2009; Winfree et al., 2009; Garratt et al., 2013; Stanley et al., 2013). When support for ecosystem services are removed and once heterogeneous landscapes are simplified, a lower level of pest control by insect natural enemies has also been observed (Rusch et al., 2016). In addition, intensified agricultural practices have led to pesticides, together with nitrates, phosphates and sediment, polluting farmland water quality through run-off, erosion and leaching to ground water (Davies, 2000; Gevao et al., 2000; Dabrowski et al., 2002).

These issues have led governmental and advisory bodies across the globe to introduce more sustainable farming options, to support ecosystem services and protect wildlife, whilst meeting food production requirements (Wentworth, 2008; Firbank et al., 2013). For example, in Europe the Common Agricultural Policy provides payments to farmers for taking environmental measures to sustainably manage natural resources (European Commission, 2019). In the UK agri-environmental schemes encourage the widely-used sown vegetative strip in farmland field margins, which has provided valuable support for water quality protection, pollination and bio-control individually (Pfiffner and Wyss, 2004; Pywell et al., 2006; Reichenberger et al., 2007; Lye et al., 2009; Haaland et al., 2011). However, increasing land restrictions and food production requirements, command an increase in vegetative strip functionality. In addition, there is scope to improve their efficacy (Kleijn et al., 2006; Reichenberger et al., 2007; Batáry et al., 2015; Wood et al., 2015a). Currently, there is no prescribed or evidence-informed method of plant species selection for vegetative strips, though some advice is available (Farming Advice Service, 2018).

The present review aims to evaluate the efficacy of support that vegetative strips provide for pollination, bio-control and water quality protection. It also explores current methods of plant species selection for these strips, and the potential for their functionality to be increased in the face of increasing pressures on agriculture and wildlife.

1-2 Support for ecosystem services in farmland vegetative strips

1-2.1 Farmland field margins and their vegetative strips

A systematic map on the multifunctional role of vegetative strips, undertaken by Haddaway et al. (2018), identified several terms used to describe them, with the most common including ‘field margin’, ‘hedgerow’, ‘shelterbelt’, ‘riparian buffer’, and ‘buffer strip’. The reason for this variation being that vegetative strips can come in various different forms and are positioned throughout the agricultural landscape, see Figure 1-1.

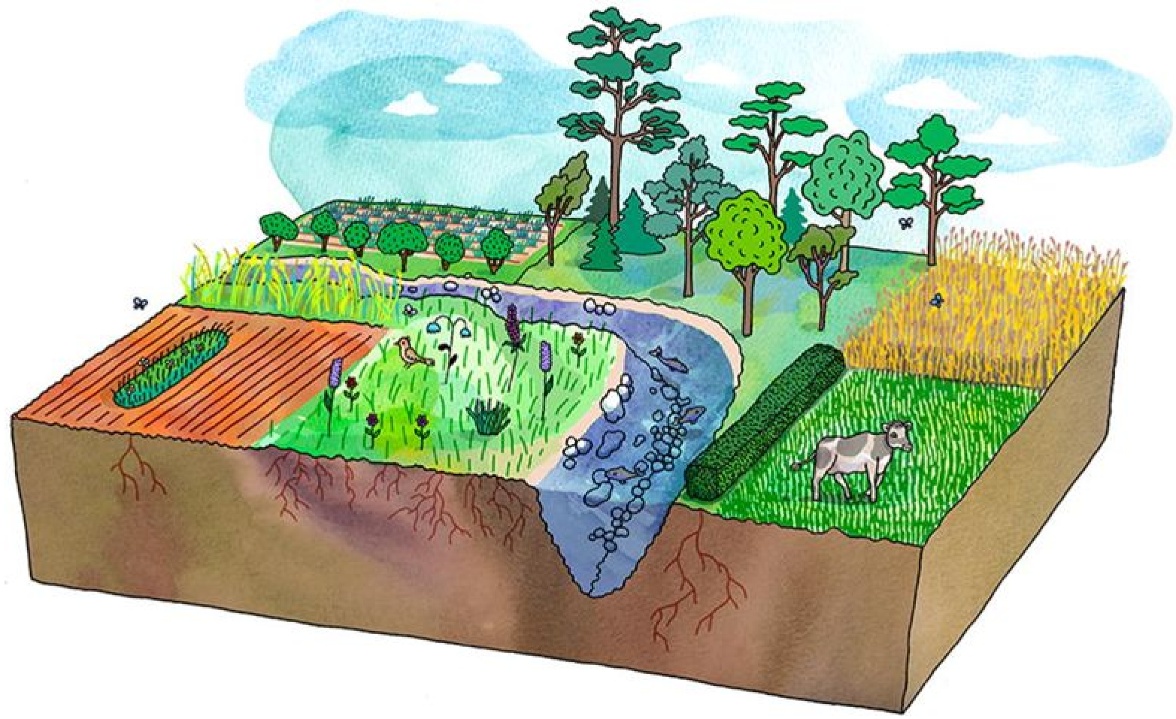

Figure 1-1 Illustration of the different vegetated strips used within and around fields in farmland. Types include: in-field strips such as beetle banks, hedgerows, forested shelterbelts, shrubs, grassy strips, and wildflower margins (Haddaway et al., 2018).

The present review focuses on vegetative strips sown within farmland field margins. Field margins exist in the agricultural landscape at the edges of fields and have three main components. These include the boundary of the field, any present vegetative strip and the crop edge (Hackett & Lawrence 2014). A boundary is essentially the barrier between two plots of land, whether this is two fields or two different types of land use. It is usually a wall, hedge or fence, but can also be a waterbody such as a ditch or stream. This is illustrated in Figure 1-1. The crop edge is the few outer metres of the crop and it can also be a part of a vegetative strip aimed at conservation such as a conservation headland. A vegetative strip is usually sown between the boundary and the crop edge of a field margin. They are designed to achieve conservation, agronomic and recreational objectives which principally influence what plant species are sown within the strip. They are often sown with grasses, wildflowers or cover crops for farmland birds, whilst others are left to natural regeneration (Marshall and Moonen, 2002; Haaland et al. 2011).

Vegetative strips can be vital for a functioning farmland ecosystem because they provide areas of habitat with a higher botanical diversity compared to the crop (Olson and Wackers, 2007). To achieve this there are two main types of vegetative strip that are regularly established within field margins, namely wildflower or grassy strips. Both usually target insect conservation. Wildflower strips are designed to provide pollen and nectar resources for pollinators and aerial natural enemies (Haaland et al., 2011, Ramsden et al., 2013). Grassy strips can be installed in-field as beetle banks to support some surface-active natural enemies (Game and Wildlife Conservation Trust, 2018) and some are installed as buffers in field margins where the boundary is a watercourse and they aim to protect the water quality within it from pollution (Davies, 1999). Also, the instalment of these strips to protect watercourses from spray-drift and other diffuse pollution is compulsory under the Common Agricultural Policy in the European Union (DEFRA, 2014). Finally, cover crops are often established on farmland to provide shelter and food sources to support declining farmland bird populations (Vickery et al., 2004). In particular, Grey partridge (*Perdix perdix*) populations have been positively affected by cover crops, and beetle banks (Ewald et al., 2010).

A review of wildflower strips for insect conservation by Haaland et al. (2011) has stated that within farmland, wildflower strips are known to support higher insect abundances and diversity than the crop section of a field, through the provision of pollen and nectar resources. An example of this is a study by Pywell et al. (2006) where 43 ± 14 bumblebees per 100m were found in wildflower strips and only 0.2 ± 01 were found in the cereal crop, where there are no pollen or nectar resources. A wildflower strip is usually sown with a mix of grass and wildflower seeds which significantly enhances the resulting botanical diversity and density of pollen and nectar sources, when compared with a standard grass seed mix (Critchley et al., 2006).

These seed mixes are often targeted at groups of invertebrates that are in need of conservation and/or that provide an important ecosystem service (Aizen et al., 2009; Lye et al., 2009). The plant species included within the seed mixes should change to meet the needs of the group of species being supported (Carreck and Williams, 1997; Carreck and Williams, 2002). Commonly used seed mixes include pollen and nectar rich mixes and grass seed mixes. Pollen and nectar mixes tend to include many forb species to benefit pollinators such as bees. Grass mixes include tussock grasses to provide in-field shelter for natural enemies or a buffer between pollution and a watercourse in a field margin.

1-2.1.1 Support for pollinators

Pollinators are the main targets of wildflower strips because of their economic value to the farmer (Losey and Vaughan, 2006; Cunningham and Le Feuvre, 2013; Stanley et al., 2013; Garratt et al., 2014; Bauer and Sue Wing, 2016). Recent declines in pollinator populations due to the intensification of agricultural practices have only further increased the need to provide support for these invertebrates within the farming landscape (Aizen et al., 2009; Carvell et al., 2004; Williams and Osborne, 2009; Potts et al., 2010; Holzschuh et al., 2012; Garratt et al., 2013; Martins et al., 2015).

A review by Potts et al. (2010) has highlighted the declines in pollinators and the plants that rely upon them. According to the UK plant atlas there have been larger declines in animal pollinated plants, with a mean relative change of 0.22 ± 0.06, than in wind-pollinated (+0.18 ± 0.14) or self-pollinated plants (0.003 ± 0.70) (Biesmeijer et al., 2006). Potential drivers of these declines include habitat loss and fragmentation, agrochemicals, pathogens, alien species, climate change and the interaction between them.

Brown & Paxton (2009) have highlighted habitat loss as one of the most important drivers of decline. Furthermore, Winfree et al. (2009) performed a meta-analysis of bees' responses to anthropogenic disturbance and they found that habitat loss was the most significant contributor to declines when compared with other forms of disturbance. This habitat loss has been further stimulated by the intensification of agriculture (Carvell et al., 2004; Williams and Osborne, 2009). As pollinators play an important role in the pollination of some crops (Aizen et al., 2009), for example bumblebees and honeybees have been found to be the best pollinators of oilseed rape (Brassica *napus*; Brassicales: Brassiceae) (Stanley et al., 2013), the restoration of supportive habitat for pollinators within farmland is essential (Lye et al., 2009).

Martins et al. (2015) showed that increased proximity to natural and semi-natural habitats can increase bee functional diversity. The introduction of wildflower vegetative strips into field margins can help restore some of the semi-natural habitat lost to intensification and help support pollinator populations within farmland. For example, Marshall et al. (2006) showed that a 6m wide wildflower vegetative strip within a field margin will have a significantly higher abundance of bees than in the centre of the crop in that same field. Also, in Scotland, Feltham et al. (2015) found that when a wildflower strip was sown adjacent to commercial strawberry crops, frequency of pollinator visits to the crop was 25% higher than those without.

These strips have been shown to have high bumblebee abundance by numerous studies i.e. Carvell et al. (2004), Pywell (2006) and Wood et al. (2015b) and the inclusion of herbaceous flowering plants (forbs) in seed mixtures for these strips is known to increase species richness and abundance of pollinators, whilst increasing the persistence of the vegetative strip long-term (Critchley et al., 2006; Woodcock et al., 2014).

A key concern in the development of wildflower strips is that the individual plant species that are included in the seed mixes for these wildflower strips are not always suitable for all pollinator species groups. For example, Wood et al. (2015b) showed that bumblebees and honeybees did indeed benefit from sown wildflower species, however, the majority of bee species had a preference for plants that are not included in the typical wildflower seed mix such as *Heracleum spondylium*, *Hypochaeris radicata* and *Tripleurospermum inodorum*. Carreck and Williams (1997 & 2002) also compared the effect of different seed mixes on pollinator diversity, including bees, bumblebees, butterflies and hoverflies. Carreck and Williams (2002) tested a seed mix that included *Phacelia tanacetifolia*, *Borago officinalis*, *Fagopyrum esculentum*, *Centaurea cyanus*, *Malva sylvestris* and *Calendula officinalis*. They found that different insect groups showed a preference for specific plant species for example *P. tanacetifolia* and *B. officinalis* attracted the highest numbers of bees and bumblebees while some hoverfly species were observed only on *C. officinalis*.

Plant species such as *Borago officinalis* and *Phacelia tanacetifolia,* whilst beneficial to numerous bee species, are likely to only be successful in vegetative strips for up to two years as they are annuals (Critchley et al., 2006). Therefore, these strips would require frequent re-sowing to ensure the benefits to pollinators are maintained. Carvell et al. (2004) assessed the value to bumblebees of wildflower strips sown with perennial and annual seed mixes. Perennial mixtures where *Trifolium pratense* was dominant were preferred by long-tongued bumblebee species, whilst the *B. officinalis* in the annual mix was preferred by honeybees (*Apis mellifera*) and short-tongued bumblebees.

In summary, wildflower vegetative strips are beneficial to various pollinator species, with the most evidence found on benefits to bumblebees. However, the plant species sown within these strips must be considered carefully so that the target species are provided for and that the support provided by the strip persists.

1-2.1.2 Support for natural enemies of insect crop pests

The main groups of invertebrates that predate upon insect crops pests include Coleoptera of the families Carabidae, Staphylinidae, Cantharidae and Coccinellidae; Hemiptera of the families Anthocoridae, Nabidae and Reduviidae; Diptera of the families Asilidae, Dolichopodidae, Empididae, Hybotidae, Scathophagidae, Cecidomyiidae and Syrphidae; Neuroptera of the families Chrysopidae and Hemerobiidae; Hymenoptera of the families Apocrita-Aculeata and Apocrita-Parasitica; Arachnida of the families Linyphiidae, Lycosidae and Phytoseiidae; and Chilopoda (Boys, 2016). The loss of non-crop habitat such as hedges and remnants of native forests, has in-turn decreased biodiversity of invertebrates in the agricultural landscape (Fournier and Loreau, 2001). Of these invertebrates that have experienced declines, some of the above natural enemy groups, which are important in ecosystem function, have been affected (Rand and Tscharntke, 2007; Batáry et al., 2012; Myrick et al., 2014; Daniels et al., 2017). Simplified agricultural landscapes, have been shown to have a 46% lower level of pest control by insect natural enemies of crop pests (Rusch et al., 2016). However, when targeting the control of a specific crop pest, not all predator species are effective and in some cases a variety of different natural enemies is required (e.g. Gontijo et al., 2015; Dib et al., 2016; Lefebvre et al., 2017; Bannerman et al., 2018; Yang et al., 2018).

The re-introduction of wildflower strips into field margins can provide essential resources for natural enemies such as shelter, overwintering sites, alternate hosts or prey and pollen and nectar (Gurr et al., 2010). Studies have shown increased numbers and diversities of natural enemies in sown wildflower strips than in the crop (e.g. Pfiffner and Wyss, 2004). Ramsden et al. (2013) investigated the key resources for aphidophagous hoverflies due to their importance in pest control in agro-ecosystems. They found that established winter habitat that combined grasses and floral resources helped promote adult syrphinae numbers. Meyer et al. (2009) showed that hoverfly species richness was affected by factors related to heterogeneity in resources such as species richness of flowering plants, the total area of grassland habitat and the landscape diversity. Hoverfly density was found to be affected by resource quantity including the amount of pollen and nectar resources available for adults and microhabitats for larvae. These studies conclude that when designing a wildflower strip for hoverflies, the habitat requirements of both the adult and larvae should be considered.

A study aimed at evaluating agri-environment measures in arable landscapes in Switzerland by Aviron et al. (2006) found that wildflower strips had more arthropod species than conventional grassland or wheat fields. In particular, percentage vegetative cover of the wildflower strip had a positive influence on carabid assemblages only. The efficiency of the strip can also be affected by the surrounding landscape such as the presence of conventional grasslands or crop fields. Also, just as with pollinator groups, each natural enemy species group has different requirements of a wildflower strip. This was also highlighted by Woodcock et al. (2008) where they monitored field margins sown with three different seed mixtures including tussock grasses and forbs, fine grasses and forbs or just grasses. They found that in seed mixtures where tussock grasses were included, overall density of predatory beetles was greatest, whereas mixtures including forbs had greatest densities of phytophagous beetles. Seed mixture was the most important factor when explaining beetle assemblages.

A review undertaken by Jonsson et al. (2008) confirms that wildflower strips and other methods of conservation biological control can attract and sometimes improve the fitness of natural enemies. However, it does highlight that there are few studies that show this increase in natural enemies in the field margin translating into decreased pest damage to crops. Büchi (2002) studied 26 oilseed rape fields in Switzerland with adjacent wildflower strips or extensively managed meadows and the mortality factors of pollen beetles within them. Though overall mortality was high at 66-96%, parasitism only caused 1-2% and predation only 16-27% of this.

In Denmark, Mansion-Vaquié et al. (2017) studied the effect of vegetative strip type (grass or wildflower), at the edge of winter wheat fields (*Triticum aestivum*), on the natural enemy guild composition and predation rates. They found that specialist natural enemy species, mostly parasitic wasps, were attracted to the wildflower strips, but generalists, including ground and rove beetles and spiders, were more active in the grass strips. Also, predation rates of the artificial caterpillars were higher in the grass strips at 48.9% than the wildflower strips at 30.7%. However, no difference in predation of the aphid sentinel species was observed between the strips. These results suggest that both grasses and wildflowers may be needed to support natural enemy populations, but again, their efficacy on predation of crop pests may be limited.

Therefore, whilst the benefits of wildflower and grass strips to natural enemies are clear and highly important in conservation and pest control, further research is needed if we are to quantify the total effect of increased natural enemies on the control of crop pests.

1-2.1.3 Vegetative strips as buffers

The increasing food production requirements of a growing human population has placed mounting pressures on agricultural production. To meet these requirements, the landscape has undergone large structural changes and there has been a rise in the use of agrochemicals increasing environmental pollution (Green et al., 1990; Dabrowski et al., 2002; Davies, 2000; Gevao et al., 2000; Dabrowski et al., 2002; Thorburn et al., 2003; Almasri and Kaluarachchi, 2004), with much of this pollution persisting in the environment today (e.g. Cuevas et al., 2018). Buffer strips are vegetative strips that are sown in field margins in-between the boundary and the crop when the boundary is a watercourse (Marshall and Moonen, 2002) and their main function is to reduce diffuse pollution. The main components of this pollution include nitrogen or phosphorus which enters the water through erosion when bound to sediment and through surface runoff (Carpenter et al., 1998). Buffer strips have been proven to be a valuable barrier to pollution, but their efficacy can vary (Muscutt et al., 1993; Davies, 1999; Dorioz et al., 2006; Reichenberger et al., 2007; Lazzaro et al., 2008; Borin et al., 2010; Campo-Bescós et al., 2015).

Reichenberger et al. (2007) carried out a review of 180 publications that related to the mitigation of pesticide pollution into watercourses. They highlighted that grass vegetative buffer strips have proven to be a valuable barrier to pollution in farmland, however their effectiveness is variable. Though Reichenberger et al. (2007) state that this variability can’t be completely explained by buffer width, Mayer et al. (2007) have shown that when managing nitrogen leakage into farmland watercourses, buffer width is an important component. Also, Vought et al. (1995) showed that a buffer strip with a width of 10 metres can reduce leakage of phosphorus bound to sediment up to 95%. Therefore, the width of a buffer strip is important, but other factors such as vegetation type of the buffer must be assessed.

Muscutt et al. (1993) found several studies which reported buffer strips to have a positive effect in reducing sediment loads of phosphorus in surface runoff and the content of nitrate in diffuse subsurface flow. The reduction of phosphorus transportation to surface waters by buffer strips has also been identified by Davies (1999) and Dorioz et al. (2006).

Borin et al. (2010) conducted a study between 1998 and 2002 on a 6m wide buffer strip which consisted of two alternating rows of trees and shrubs and compared it with a control site with no buffer strip. They found that, when compared to the control, this buffer strip reduced total runoff by 33%, total losses of nitrogen by 44% and total losses of phosphorus by 50%.

The composition of a buffer strip can be variable. Mayer et al. (2007) carried out a meta-analysis on different types of buffer including forest, forested wetland, wetland, herbaceous and an herbaceous/forest mix. Results showed that buffer vegetation type did not affect the efficiency of nitrogen removal overall. Therefore, there may be potential to introduce different plant species to a buffer that could increase the functionality of this vegetative strip.

1-2.1.4 Multifunctional vegetative strips

Hackett & Lawrence (2014) and Stutter et al. (2012) have highlighted the need for vegetative strips to provide support for multiple ecosystem services, such as water quality protection and pollinator and natural enemy support. This is due to the likelihood that future land availability will be restricted as food production requirements and other land use pressures increase (Robinson and Sutherland, 2002).

As highlighted in the previous sections, there are numerous vegetative strips that have a singular focus, whether it be to support pollinators (Marshall et al. 2006), natural enemies (Aviron et al., 2006) or to provide water quality protection (Borin et al., 2010). A study conducted by Critchley et al. (2013) begun to investigate the potential value of buffer strips for biodiversity as well as water quality protection. They studied taxa in 90 sites across three demonstration test catchments in England and compared grass margins, explicitly managed for biodiversity, to buffer strips. They found buffer strips to have high structural diversity and bumblebee food plant richness, but an overall lower botanical value, lower diversity of food plants for farmland birds and butterfly larvae and a lower diversity of perennial forbs important for invertebrates. They also found that establishing a buffer strip with a species-rich seed mix or leaving it to naturally regenerate was superior to those sown with a simple grass seed mix.

As already shown, Woodcock et al. (2008) found that tussock grasses improved density of predatory beetles, and mixtures including forbs increased densities of phytophagous beetles. Also, Mansion-Vaquié et al. (2017) demonstrated that both grasses and forbs were required to provide support for both specialist and generalist natural enemies. Furthermore, Campbell et al. (2017) studied the effects of wildflower strips designed to support natural enemies and pollinators for pest control and pollination services in apple orchards. They compared wildflower strips targeting just pollinators or natural enemies to a multi-functional mix. They found that the multifunctional mix attracted both natural enemies and pollinators in similar abundances to the targeted mixes and all of the wildflower strips improved pest predation rates.

Considering this, it is likely that, because many buffer strips already include tussocky grasses (Reichenberger et al., 2007), there is potential for a mix to be developed that includes both grasses and wildflowers that would be beneficial to natural enemies and pollinators and provide water quality protection. In fact, the introduction of favourable plant species for pollinators such as *Trifolium pratense* into grass buffer strips has been shown to increase bumblebee species support (Carvell, 2002).

It has been highlighted by Wood et al. (2015b) and Ramsden et al. (2013) that plant species can directly influence abundance and diversity of individual insect groups or species. So, to create a more multifunctional vegetative strip, careful consideration should be given to the plant species included in the sown seed mix to ensure the targeted ecosystem services are supported.

1-3 Plant species selection methods for vegetative strips

Current policy does not stipulate the method by which plant species should be selected for vegetative strip seed mixes. Some seed mix options and advice are provided by charities, seed companies and other organisations (e.g. Syngenta, 2014; Buglife, 2018; Kings Seeds, 2018; Emorsgate Seeds, 2018), typically devised through experience in the field and general observation (Nowakowski and Pywell 2016). Whilst these methods could have produced suitable seed mixes, they are neither structured, transparent or, most importantly, repeatable and so cannot be applied in different environmental conditions or adapted to suit the specific aims of the strip. For example, these methods could not be easily adapted to develop a vegetative strip to support multiple ecosystem services. Some attempts at integrating support for different ecosystem services have been made (e.g. Biddinger and Rajotte, 2015), but the potential to provide water quality protection and support for pollinators and natural enemies in one vegetative strip, has been little explored. The most important consideration when developing vegetative strips is the specific plant species that are selected for inclusion as they will determine the plant community that establishes and therefore the support provided for ecosystem services. In particular, a plant species' morphological traits determine the support it may provide for ecosystem services (Kattge et al., 2011). For example, Bianchi and Wackers (2008) showed that more parasitoids were attracted to plants with a higher nectar content, Kudo et al. (2007) showed that a larger floral display size was preferred by *Bombus hypocrita* supsp. *Sapproensis* and Burylo et al. (2014) showed that a plant's leaf area positively correlated with its ability to trap sediment.

In general farming practice, evidence-informed decision support tools are already being used (e.g. Centre for Ecology & Hydrology, 2018), but so far, none exist for selecting plant species for vegetative strips. Evidence on plant traits and how they may support ecosystem services could inform a method of plant species selection that emulates the qualities of these general practice decision support tools.

1-4 Summary

The present review highlights three key points. Firstly, vegetative strips are a proven source of support for ecosystem services within the farmed landscape, but their efficacy can be varied. Secondly, continued pressures on agricultural practices command an increase in vegetative strip functionality. Finally, there is a need for an evidence-informed, structured and repeatable plant species selection method for vegetative strips. This thesis therefore aims to develop a method of vegetative strip design and use this to produce, and test the support provided by, multifunctional and single-focus vegetative strips.

1-4.1. Objectives of the study

1. Develop a structured, evidence-informed method of multifunctional vegetative strip design, using plant traits, which can be applied across temperate climate zones. Particularly targeting support for ecosystem services including pollination, biological control of insect crop pests (bio-control) and water quality protection.
2. Using vegetative strip seed mixes designed through the evidence-informed method and existing farmland buffer strips, investigate the establishment and persistence of different vegetative strip types under differing environmental conditions.
3. Compare and contrast support for pollinators (for pollination), natural enemies of insect crop pests (for bio-control) and water quality protection provided by multifunctional vegetative strips to single-focus strips.
4. Provide advice and recommendations to land managers, advisors and policy makers on increasing the functionality of vegetative strips.

Chapter 2. Part 1 - What specific plant traits support ecosystem services such as pollination, bio-control and water quality protection in temperate climates? A systematic map protocol.

Abstract

Background

Agricultural intensification has increased diffuse source pollution within water catchments, reduced heterogeneity within the landscape and caused major declines in farmland wildlife, including birds, mammals, invertebrates and wildflowers. This increase in pollution and wildlife decline, has affected three vital ecosystem services, pollination, biological pest control and water quality protection. The morphological traits of plant species, such as floral display size and leaf area, provide support to these services and vegetative strips can be established with plants that have these desirable traits. Vegetative strips are widely used across Europe and integrated into government environmental schemes such as The Common Agricultural Policy (CAP) and The Water Framework Directive. However, issues of land availability and food security require a sustainable intensification of current agricultural practices. One component of this process is to sow vegetative strips that are designed to support multiple ecosystem services. To do this, combinations of plant species that will support specific ecosystem services, have been designed. However, to enable a fully-informed design process, evidence must be collated on which specific plant traits provide the support to the target ecosystem services. We propose to systematically map all evidence on which specific plant traits provide support for three of the most vital ecosystem services, pollination, bio-control and water quality protection.

Information from this map could inform future decisions on which plant species are suitable for inclusion within a multifunctional vegetative strip that aims to provide the target ecosystem services.

The aim of this systematic map is to create a searchable database of studies that demonstrate evidence of plant traits and how they support the named ecosystem services.

Methods

Seven bibliographic databases, 25 organisational websites and 2 search engines, will be systematically searched with predefined and tested key search terms. All searches will be undertaken in English and only those undertaken in a temperate climate zone will be

considered. Studies found will be screened at title, abstract and full text levels, recording the number of excluded articles. Following full text assessment, the meta-data of included studies will be incorporated into a systematic map database in Microsoft Access. A report will summarise the evidence, highlight any knowledge gaps, and provide recommendations for future research.

Published in: Blowers, C.J., Cunningham, H.M., Wilcox, A., Randall, N.P., 2017. What specific plant traits provide ecosystem services such as pollinator support, bio-control and water quality protection? A systematic map protocol. Environmental Evidence. 6, 3.

2-1.1 Background

Around the globe, farming practices have intensified over the past 60 years, with an increase in the application of pesticides and fertilisers and the removal of off-crop habitat such as hedgerows and vegetative strips (Robinson and Sutherland, 2002; Ehrlich and Ehrlich, 2013). This has increased diffuse pollution within entire water catchments, reduced heterogeneity within the landscape and caused major declines in farmland wildlife, including birds, mammals, invertebrates and wildflowers (Flowerdew, 1997; Sotherton and Self, 2000; Donald et al., 2001; Benton et al., 2003). This increase in pollution and decline in wildlife, directly affects the services that a farmland ecosystem provides to the land-owner. For example, in 2007, 35% of global agricultural crops were animal-pollinated (Klein et al., 2007), but declines in wild pollinator numbers and their associated plants (Biesmeijer et al., 2006), have led to pollination deficits (Kevan and Phillips, 2001; Kremen et al., 2002; Garratt et al., 2014). In contrast, widespread use of pesticides has led to increased resistance in over 500 species of crop pests (Green et al., 1990) and this number is still rising (Sparks and Nauen, 2015). A recent review by Bass et al. (2015), collated evidence on the global rise in insect resistance to the widely used neonicotinoid insecticides. Within this review, using data extracted from Michigan University's Arthropod Pesticide Resistance database (Michigan State university, 2016), resistance was shown to be already present in over twenty insect pest species including some significant crop pests such as *Bemisia tabaci, Myzus persicae, Aphis gossypii and Nilaparvata lugens*. This combined with recent calls for sustainable intensification (Garnett and Godfray, 2012), drives the need to control pests using other means, such as predation by their natural enemies (biological pest control) (Fiedler et al., 2008). However, supportive habitat that provides shelter, overwintering sites, alternate hosts or prey and pollen and nectar (Gurr et al., 2010), has been widely removed (Rusch et al., 2016). These off-crop habitats within agricultural land offer other benefits too. Riparian buffer strips, for example, provide a valuable barrier to pollution, protecting water quality (Reichenberger et al., 2007). Without them, pollutants such as pesticides, nitrates and phosphates start to increase water toxicity and cause eutrophication (Kuicila and Foe, 1995; Gevao et al., 2000; Thorburn et al., 2003).

The services that an ecosystem provides are numerous, but the three outlined above, (pollination, biological pest control (bio-control) and water quality protection) are some of the most vital when making agriculture more environmentally sustainable (Bommarco et al., 2013). The morphological traits of different plant species which effect ecosystem function, or effect traits as defined by Lavorel and Garnier (2002), can provide support to these services (Kattge et al., 2011). For example, Kudo et al. (2007) found that *Bombus hypocrita* subsp. *Sapproensis,* were more attracted to a larger floral display size, Bianchi and Wackers (2008) found that a plant with a higher nectar content attracted more parasitoids, and Burylo et al. (2014) found that a plant's ability to trap sediment was positively correlated with leaf area. An illustration of how plant traits may support these three different ecosystem services can be seen in Figure 2-1.

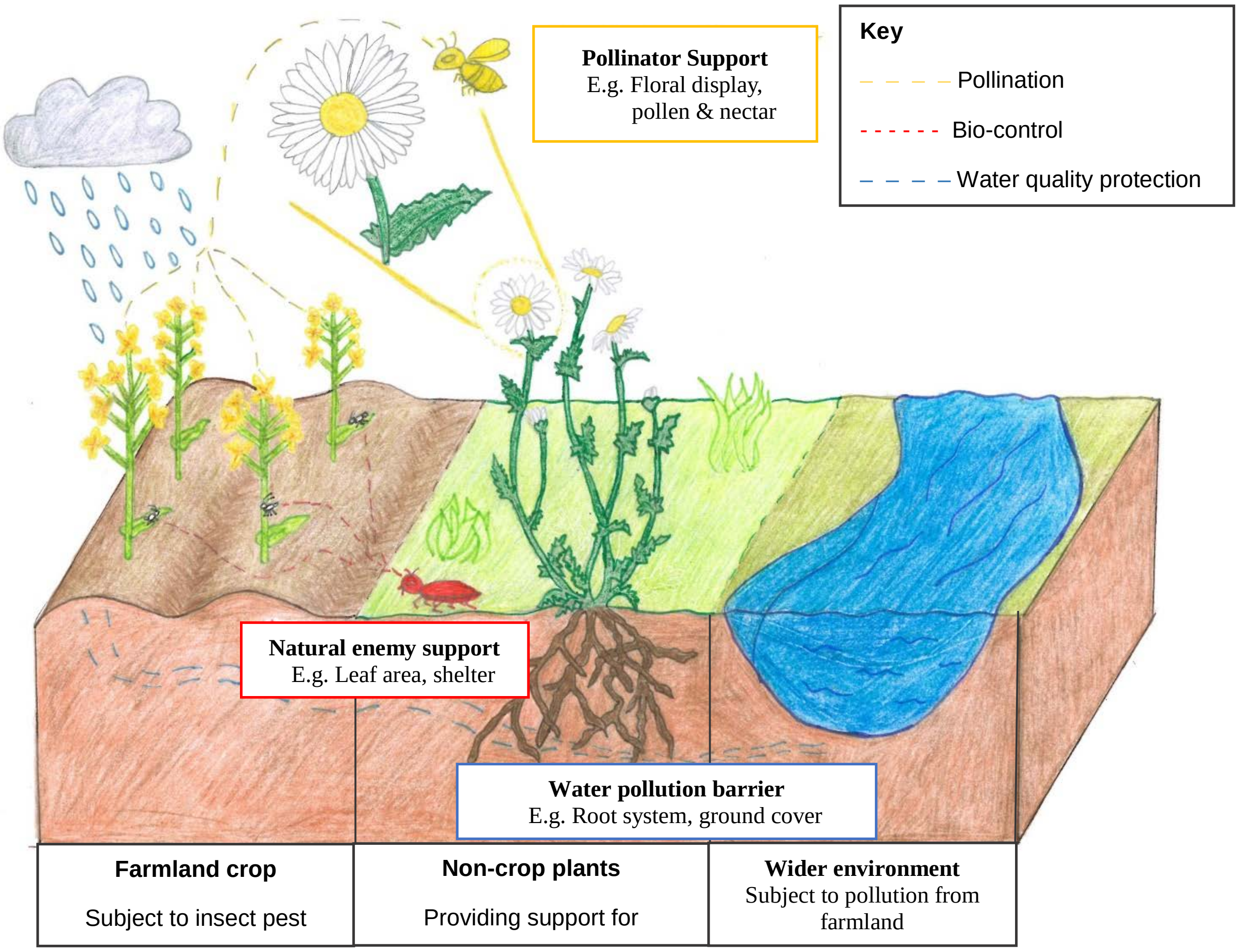

Figure 2-1 A conceptual model of the potential for non-crop plants and their traits to provide support for ecosystem services within agricultural systems. Three specific ecosystem services are presented including, pollination, bio-control and water quality protection.

Off crop habitats, such as vegetative strips, can be established with plant species that have desirable traits, to try and return support for these vital ecosystem services (Hackett and Lawrence, 2014), and support may even be made available through legislation and incentives. In Europe, for example, specified habitats, plants and animals are protected through the Habitats Directive (European commission, 2016a), and water quality through the Water Framework Directive and the Nitrates Directive. The latter specifically addresses water pollution by leaching of nitrates from agriculture into farmland watercourses (European commission, 2016b). Also, funding for the preservation of habitat biodiversity, water quantity and quality and the protection of soil from erosion is provided via the Common Agricultural Policy (CAP) (European commission, 2016c,d,e,f).

Though these policies are effective, future availability of land is likely to be restricted due to food production requirements, which have increased with consumption growth, and issues of food security such as, competition for land, climate change and other land use pressures, caused by the continued exponential increase of the human population (Godfray et al., 2010; United Nations, 2015). This has created a need to sustainably intensify agriculture, which involves increasing food production from existing agricultural land whilst minimising pressure on the environment (Garnett and Godfray, 2012).

In order to support this sustainable intensification, it may be necessary to increase the ecosystem service value of off-crop habitats by designing vegetative strips that aim to support multiple ecosystem services (Stutter et al., 2012; Hackett and Lawrence, 2015) rather than prioritising one over the others. Combinations of plant species to support specific ecosystem services, are already utilised in parts of Europe (e.g. Syngenta, 2014; Ecostac, 2016). However, to enable the maximum functionality of measures such as vegetative strips, it may be valuable to consider which specific plant traits provide support to the target ecosystem services. Therefore, we propose to systematically map all evidence on specific plant traits that provide support for three of the most vital ecosystem services, pollination, bio-control and water quality protection.

2-1.1.1 Objective of the systematic map

This systematic map will collate existing research on plant traits and how they may support pollinators, natural enemies and water quality protection. It will focus on studies undertaken in temperate climate zones, applied to any type of habitat. The study will focus on specific plant traits that provide support for the target ecosystem services. Whole plant community traits will not be included in this map. The outputs will consist of a searchable database for all the named ecosystem services and a report summarising the nature and character of the evidence.

Primary question

Which plant traits provide the following ecosystem services, within temperate climates:

Pollinator support

Crop pest natural enemy support

Water quality protection

Detailed “PECO” elements of the primary question

Population:

Water quality, pollinator species and natural enemies of insect crop pests, within temperate climates. A temperate zone has a temperature range of -3ºC to +18ºC, shown as ‘C’ in the Köppen-Geiger world map on climate classification Kottek et al. (2006).

Exposure:

Specific plant traits, for example floral display size, leaf area etc.

Comparator:

Lack of traits or alternative traits, for example no floral display.

Outcome:

Outcomes of each study will be stated as they are found within the relevant articles included and details will be coded into the map accordingly.

2-1.2 Methods

The methods used in the development of the systematic map database will be adapted from the Collaboration for Environmental Evidence (CEE) Systematic Review Guidelines (CEE, 2010) and from an existing systematic map report, Randall and James (2012).

2-1.2.1Searches

A comprehensive search will be undertaken using multiple information sources to capture an un-biased sample of literature. The search strategy was developed to identify both published and grey literature.

Key search terms

An initial scoping search was performed to validate the methodology and used to provide a preliminary indication of the volume of relevant literature. Search terms were tested between November 2014 and March 2015 for specificity and sensitivity using the Harper Adams University library electronic database, ‘Findit@Harper’, and used to indicate the volume of relevant literature. The search terms, number of articles found and general quality of the search results were recorded in Microsoft Excel [Additional file 2-1].

The following Boolean search operators will be used. A wildcard (*) will be used where accepted by a database or search engine to pick up multiple word endings, for example plant* would pick up plant, plants, etc. A keyword may be made more restrictive by the addition of a qualifier e.g. (plant*) AND (trait*) AND (beneficial) AND (invertebrate*). The combination of qualifiers and keywords will vary for each ecosystem service, based on the results of the scoping search. The exact keyword and qualifier combinations to be used are listed in Additional file 2-2.

Plant traits identified by the systematic map will then be used as keywords for further searches linking them with the specific target ecosystem services, e.g. (floral display*) AND (pollinat*). This will ensure that the searches are as comprehensive as possible.

Sources of publications

Several online sources will be searched in the English language to identify relevant literature and a record of each search will be made to enable a re-run of the search if needed. Data that will be recorded include: date search conducted, database name, search term, number of hits and any other notes.

The following online sources will be searched:

1. Bibliographic electronic databases:
   1.1. Harper Adams University Library Database ('Findit@Harper') which includes the following relevant sources (all other sources included in this database can be found in Additional file 2-3):
   1.2. ISI Web of Science involving the following products: ISI Web of Science; ISI Proceedings
   1.3. Index to Theses Online
   1.4. Agricola (United States department of Agriculture National Agricultural Library) NAL catalogue
   1.5. Copac
   1.6. Directory of Open Access Journals (DOAJ)

2. Grey literature for specialist searching
   2.1. Organisational websites

      Where possible, Boolean search terms will be used in these databases. However if the technical infrastructure of a database does not support this search method, simplified subsets of the key search terms will be used.
      2.1.1. Defra (https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs)
      2.1.2. UK Environment Agency (https://www.gov.uk/government/organisations/environment-agency)
      2.1.3. UK Forestry Commission/Forestry Research (http://www.forestry.gov.uk/)
      2.1.4. The Woodland Trust, UK (https://www.woodlandtrust.org.uk/)
      2.1.5. Natural England (https://www.gov.uk/government/organisations/natural-england)
      2.1.6. Natural Resources Wales (https://naturalresources.wales/)
      2.1.7. Scottish Natural Heritage (http://www.snh.gov.uk/)
      2.1.8. Scottish Environment Protection Agency (https://www.sepa.org.uk/)

2.1.9. Northern Ireland Environment Agency (https://www.doeni.gov.uk/)
2.1.10. European Environment Agency (http://www.eea.europa.eu/)
2.1.11. European Commission Joint Research Centre (https://ec.europa.eu/jrc/en)
2.1.12. Ministry of Agriculture and Forestry (Finland) (http://mmm.fi/en/frontpage)
2.1.13. Swedish Environmental Protection Agency (http://www.swedishepa.se/)
2.1.14. Danish Environmental Protection Agency (http://eng.mst.dk/)
2.1.15. Ministry of Environment and Food of Denmark (http://en.mfvm.dk/the-ministry/)
2.1.16. Government Norway Portal (https://www.regjeringen.no/en/)
2.1.17. Flemish Environment Agency (http://en.vmm.be/)
2.1.18. Federal Environment Agency (Germany) (http://www.bmub.bund.de/en)
2.1.19. Federal Ministry of Food, Agriculture (Germany) (http://www.bmel.de)
2.1.20. Netherlands Environmental Assessment Agency (http://www.pbl.nl/en)
2.1.21. Federal Department for the Environment, Transport, Energy and Communication (Switzerland) (http://www.uvek.admin.ch/)
2.1.22. Federal Office for Agriculture (Switzerland) (http://www.blw.admin.ch)
2.1.23. Food and Agriculture Organization of the United Nations (http://www.fao.org)
2.1.24. Ecologic Institute (http://www.ecologic.eu)
2.1.25. EU Cost (European Cooperation in Science and Technology) (http://www.cost.eu)

3. Search engines

Scirus (www.Scirus) and Google Scholar (scholar.google.com). The first 25 hits (.doc, .txt, .xls and .pdf documents where this can be separated) from each data source will be examined for appropriate data. No further links from the captured website will be followed unless to a document/pdf file.

4. Other literature searches

Other specific/specialised databases will be searched where identified or recommended by experts within the field.

5. Key studies through stakeholder consultation

Bibliographies of articles viewed at full text will be searched for relevant articles missed by previous searches. Recognised experts, practitioners and authors will be contacted for further recommendations and to provide relevant unpublished material or missing data.

2-1.2.2 Article screening and study inclusion criteria

Screening process

The results of each search term on each database will be imported into a separate EndNote X7 library file. All the database libraries will be incorporated into one library, recording the number of references captured. Using the automatic function in the EndNote X7 software, any duplicates will be removed.

The inclusion criteria will be applied by one reviewer to all potential articles at the title and abstract level. Where there is insufficient information to make an informed decision regarding an article's inclusion, relevance to full text assessment will be assumed. A second reviewer will examine a random subset of at least 10% of the reference list to assess repeatability of the selection criteria. A kappa analysis will be performed to determine agreement between reviewers, with a score of 0.6 or above indicating substantial agreement. Disagreement between reviewers will be discussed and resolved by consensus. This same method will be used to assess the quality assessment and data extraction methods.

A full list of articles excluded at full text with reasons for exclusion will be provided.

Inclusion criteria

All retrieved studies will be assessed for relevance using the following inclusion criteria:

Relevant subject(s): Studies that investigate some aspect of plant traits and how they provide support for the target ecosystem services will be considered for inclusion into the systematic map.

Relevant climate zone: Studies that have been undertaken in a region with a temperate climate, i.e. those classified as 'C' in Kottek et al. (2006).

Language: All languages will be included in initial searches. Only studies published in English will be included in full text assessment. This is due to limited resources and the languages known by the study reviewers.

Date: No date restrictions will be applied.

Relevant ecosystem service provided: The following support for ecosystem services provided by plant traits will be included: support for pollinators and crop pest natural enemies and water quality protection.

Relevant Population: Water quality, pollinator species and natural enemies of insect crop pests.

Relevant exposure: Specific plant traits, for example floral display size, leaf area, root length, plant height.

Relevant comparator: Lack of traits or alternative traits, for example no floral display.

Relevant outcome: Outcomes of each study will be stated as they are found within the relevant articles included and details will be coded into the map accordingly. Examples of outcomes may include:

- Effects on pollinator abundance and diversity, visitation rates and attractiveness.
- Effects on natural enemy abundance and diversity or predation rates
- Effects on water quality protection including inhibiting pollution from nitrogen, phosphorus, pesticides and sediment levels.

Relevant study design: Any primary research study that collects experimental or quasi-experimental data to investigate the effect of specific plant traits on provision of the named ecosystem services.

Potential sources of bias

Due to limitations on resources, only English language articles will be included in full text assessment. This does limit the number of articles discovered. Further funding to translate relevant articles or employ a reviewer that can understand multiple languages, could help increase the geographical scale of this systematic map.

2-1.2.3 Study quality assessment

This quality assessment method has been informed by the systematic review guidelines' hierarchy of evidence used in medicine and public health (Stevens and Milne, 1997) and conservation (Pullin and Knight, 2001). A generic list of variables used for quality assessment developed by Haddaway et al. (2014) will be modified and combined with topic-specific quality measures. These may include an assessment of the sampling methodology used (e.g. number, frequency and period of sampling, quality of measure, standards adhered to etc). An example of a good quality of measure could refer to the sampling technique, such as ensuring the ground is flush with a pitfall when setting the trap. Standards adhered to refers to any known standards for that method of sampling, for example, observations of pollinators such as bees should be undertaken between 10am and 4pm. Terms including ‘yes’, ‘partially’ or ‘not at all’ will be applied to each study for these methodological factors during the creation of the systematic map database. Studies will be assessed on three categories, degree of replication, sample selection methods and other sources of bias, as shown in Table 2-1.

Table 2-1 Study quality assessment categories. Modified from Haddaway et al. (2014).

Quality assessment term applied	**Replication**	**Sample Selection**	**Other Sources of bias**
Yes	Well-replicated (>10 samples per group)	Random or blocked or exhaustive	None evident
Partially	Moderate level of replication (4-10 samples per group)	Not stated but clearly random or blocked	Potential confounder
Not at all	Poorly-replicated or not stated (1-3 samples per group)	Purposive or not stated	Clear confounder

For example, a replicated, randomised control trial with no obvious bias would be categorised with the term ‘yes’ in all cases. No articles will be excluded from the database based on study quality.

2-1.2.4 Data coding strategy

Studies that pass the inclusion criteria will be imported into a database. Generic and topic specific keywords were discussed with experts to assess their suitability. Each article will be coded and categorised according to these terms, which are as follows:

- Author
- Title
- Publication date
- Reference type
- Target system (e.g. a specific plant species)
- Plant trait
- Target organism (e.g. specific pollinator species)

- Outcome
- Target Ecosystem service
- Study country
- Study region/state
- Study site (e.g. greenhouse, pine forest etc.)
- Study timing (specific date(s) that the study took place)
- Study length
- Study type
- Linked study (ID numbers from the article(s) in which the linked study took place will be cross-referenced here)

The following potential effect modifiers have been compiled following discussion with subject experts and will also be coded in the map:

- Country of origin
- Climate (e.g. annual average rainfall values), only studies undertaken in temperate regions are to be included
- Soil properties (e.g. free or poor draining/nutrient levels)
- Time of planting
- Sampling method
- Species of crop pest natural enemy
- Species of pollinator

Data regarding the study characteristics, quality of design and results will be recorded. A notes section will identify any other interesting results such as other ecosystem services provided (e.g. nutrient or carbon cycling or carbon sequestration) but will not be included in further analysis. Where there is more than one article found for a study, each article will be recorded and cross referenced in the database. Also, where there is more than one study within an article, information about each study will be included in the database.

The systematic map database will describe the extent of the research in the field. It will be searchable by topic and can be arranged according to topic areas, publication date, type of ecosystem service, plant species, plant trait, country of study etc. Simple numerical accounts of the frequencies in each category will be able to be obtained from the systematic map. Pivot tables will be generated in order to identify trends in the research.

Where information regarding the reasons for heterogeneity is presented in the studies, it will be recorded e.g. species of pollinator, time of sampling etc. Where necessary and feasible, authors will be contacted for missing/suitable data.

Subject experts will review the completed systematic map database to ensure that all relevant categories have been defined.

2-1.2.5 Study mapping and presentation

The systematic map will be presented in an Access database, accompanied by a report describing the nature and character of the evidence. Summary graphs and tables of the study characteristics and quality will be presented. Possible knowledge gaps will also be identified, and recommendations will be made for future research based on the findings of the map.

Chapter 2. Part 2 - What specific plant traits support ecosystem services such as pollination, bio-control and water quality protection in temperate climates? A systematic map.

Abstract

Background

Agricultural intensification has contributed to increased diffuse source pollution within water catchments, reduced heterogeneity within the landscape and caused major declines in farmland wildlife. This decrease in biodiversity has been shown to decrease vital ecosystem services such as pollination, biological pest control (bio-control) and water quality protection. The morphological traits of plant species, such as floral display size and leaf area, provide support to these services and vegetative strips can be established with plants that have these desirable traits to try and restore ecosystem service support to farmland. Vegetative strips are widely used across the world, especially in Europe, however, there is a need to increase their functionality due to issues of land availability and food security. To do this, combinations of plant species that will support specific ecosystem services, have been developed. However, to enable a fully-informed development process, evidence must be collated on which specific plant traits provide the support to the target ecosystem services. The primary objective of this study was to systematically map all evidence for specific plant traits that may provide support for pollinators, bio-control and water quality protection in temperate climates.

Methods

Both published and grey literature were obtained through databases and NGO websites using key search terms. An initial 34,077 articles were identified with a total of 11,705 individual articles, after duplicates were removed. These were screened for inclusion based on criteria such as subject, climate and language. Each article was coded into a Microsoft Access database using generic (e.g. author, publication date, study length) and topic specific (e.g. target system, organism and ecosystem service) keywords.

Results

After screening 56 articles were coded into the systematic map. A total of 40 articles identified 37 plant traits for pollinator support, seven identified eight traits for bio-control and nine identified 26 for water quality protection. All articles were published between 1983 and 2017 and they were undertaken in 22 different countries.

Discussion

This systematic mapping process produced a searchable database of literature available on plant traits and the target ecosystem services. It has highlighted that more research has been conducted on plant traits for pollinator support than for bio-control and water quality protection, identifying potential research gaps in these areas. Evidence presented in this map could inform decisions related to the suitability of plant species for inclusion within multifunctional vegetative strips, providing targeted ecosystem services. This information could be used by policy makers to develop an option that could benefit landowners and farmland wildlife concurrently.

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2-2.1 Background

The intensification of agricultural practices since the 1940s has led to increased diffuse source pollution in farmland water catchments through cultivation, the use of pesticides and fertilisers and the removal of off-crop habitat (Robinson and Sutherland, 2002; Ehrlich and Ehrlich, 2013). These practices have been attributed to major declines in farmland wildlife, including wildflowers, invertebrates, mammals and birds (Flowerdew, 1997; Sotherton and Self, 2000; Donald et al., 2001; Benton et al., 2003). Numerous reports have shown that a decline in farmland biodiversity can negatively affect the provision of multiple ecosystem services (Tilman et al., 2006; Hector and Bagchi, 2007; Zavaleta et al., 2010). In particular pollination, biological control (bio-control) and water quality protection have been effected and evidence of this can be seen in global pollination deficits caused by pollinator declines (e.g. Kevan and phillips, 2001; Kremen et al., 2002; Biesmeijer et al., 2006; Garratt et al., 2014) and in declines in water quality through pesticide, sediment, nitrate and phosphorus run-off and erosion (e.g. Kuivila and Foe, 1995; Thorburn et al., 2003; Tang et al., 2015), although riparian buffer strips could mitigate this pollution (Reichenberger et al., 2007). Also, as there are continuing reports of insecticide resistance since the 1990s (e.g. Green et al., 1990; Whalon et al., 2008; Bass et al., 2015), there is an increasing need to restore support for natural enemies used in bio-control (Fiedler et al., 2008; Gurr et al., 2010; Rusch et al., 2016).

To help mitigate some of these effects and develop more sustainable agricultural practices, semi-natural habitat resources that support pollinators, natural enemies and water quality protection, can be returned to farmland (Bommarco et al., 2013). The morphological traits of specific plant species, such as nectar content, floral display size or leaf area (Kattge et al., 2011), provide support for these services (Diaz et al., 2007; Garnier and Navas, 2012). For example, Bianchi and Wackers (2008) showed that more parasitoids were attracted to plants with a higher nectar content, Kudo et al. (2007) showed that a larger floral display size was preferred by *Bombus hypocrita* supsp. *Sapproensis* and Burylo et al. (2014) showed that a plant’s leaf area positively correlated with its ability to trap sediment.

A widely-used and effective method to re-establish these services within farmland is the sowing of plant mixtures outside of the cropped areas, such vegetative strips in field margins (Hackett and Lawrence, 2014), and the inference is that these could be optimised if they were established using plant species with desirable traits. Policy support for this is already available through legislation and incentives across Europe. For example, within the European Union (EU), the Habitats Directive protects specific animals, plants and habitats (European Commission, 2016a), and the Water Framework and the Nitrates Directives protect water quality, the latter specifically addressing effects on water quality arising from the leaching of nitrates into watercourses on farmland (European Commission, 2016b). In addition, the EU Common Agricultural Policy (CAP) provides funding to help preserve habitat biodiversity, enhance water quality and reduce soil erosion in the form of greening and agri-environment schemes (European Commission, 2016c,d,e,f).

These policies have been highly influential in the restoration of biodiversity and ecosystem services to farmland habitat (Batáry et al., 2015). Future land availability for these schemes is being increasingly restricted due to increased food production requirements which have been exacerbated by climate change, competition for land, and other pressures on land use (Godfray et al., 2010; UN, 2015). One recent potential solution to these issues is the sustainable intensification of agriculture, which often promotes the increase of food production from existing land whilst minimising pressure on the environment (Garnett and Godfray, 2012; Garnett et al., 2013; Tittonell, 2014). An approach within this solution is to increase the ecosystem service value of non-cropped areas on farmland by selecting the most supportive plant species for multiple ecosystem services (Stutter et al., 2012; Hackett and Lawrence, 2014). Supportive combinations of plant species have been investigated in parts of Europe (e.g. Ecostac, 2009; Syngenta, 2014), but they have not considered which plant traits actually support the target ecosystem services.

Stakeholders from Syngenta UK Ltd are interested in developing vegetative strip seed mixes that they distribute to farmers. They have funded this work alongside the Biotechnology and Biological Sciences Research Council as part of a PhD project to develop a multifunctional seed mix, based on scientific evidence. Discussions with stakeholders from the Game and Wildlife Conservation Trust and Fera Science Ltd encouraged a focus on plant traits as these are what define a plants ability to provide support for ecosystem services. Also, the initial ideas for the project arose from two previous systematic maps, one funded by Defra and the Natural Environment Research Council to investigate interventions to reduce water pollution (Randall et al., 2015) and one investigating interventions for enhancing farmland biodiversity (Randall and James, 2012). In order to provide an evidence base to inform the design of future multifunctional non-cropped planted areas we systematically mapped all evidence on what specific plant traits provide support for ecosystem services including pollination, bio-control and water quality protection.

2-2.1.1 Objective of the systematic map

The primary objective of this systematic map was to collate existing research evidence on specific plant traits that may support pollinators and natural enemies and provide water quality protection. Studies undertaken in any type of habitat within temperate climate zones were included. A detailed summary of the nature and character of the evidence is presented alongside a summary of the specific plant traits that have been linked with the target ecosystem services.

Primary question

Which plant traits provide support for the following ecosystem services, within temperate climates:

Pollination through pollinator support

Bio-control through crop pest natural enemy support

Water quality protection?

Detailed “PECO” elements of the primary question

Population: Waterbodies, pollinator species and natural enemies of insect crop pests, within temperate climates. A temperate zone has a temperature range of -3ºC to +18ºC, shown as ‘C’ in the Köppen-Geiger world map on climate classification Kottek et al. (2006).

Exposure: Specific plant traits, for example floral display size or leaf area etc.

Comparator: Lack of traits or alternative traits, for example no floral display.

Outcome: Derived from studies that investigated any potential changes in the populations, for example, increased pollinator or natural enemy visits to a flower, improved water quality within a water body or reduced soil erosion.

2-2.2 Methods

The methods used in the development of the systematic map database were adapted from the Collaboration for Environmental Evidence (CEE) Systematic Review Guidelines (2018) and from an existing systematic map report by Randall and James (2012). The detailed methods are presented in the protocol in Chapter 2 Part 1. A summary of these methods and any deviations are presented here.

2-2.2.1 Searches

In November 2014, specific search term combinations with Boolean search operators were entered into multiple online databases to capture an un-biased sample of the relevant published and grey literature. The search terms were established as stated in the protocol in Chapter 2 Part 1. In January 2017, the searches were updated to capture articles published after November 2014. For these updated searches the search terms stayed the same, but single search strings were used instead of multiple searches. This was the only deviation from the original methods stated in the protocol and did not change which articles may have been discovered by the searches. Full lists of search terms, strings and databases can be found in Additional files 2-1, 2-2 and 2-3.

2-2.2.2 Article screening and study inclusion

The results from the searches were imported into an EndNote X7 library file and any duplicates removed. The inclusion criteria were agreed prior to screening to ensure that only articles relevant to the objective were included in the systematic map.

Inclusion criteria

All retrieved studies were assessed for relevance using the following inclusion criteria:

Relevant subject(s): Studies that investigated some aspect of plant traits and how they could provide support for the target ecosystem services were considered for inclusion into the systematic map.

Relevant climate zone: Studies that had been undertaken in a region with a temperate climate, i.e. those classified as 'C' in Kottek et al. (2006).

Language: All searches were conducted in English, however any article that was found in another language was also included in the initial searches. Only studies published in English were included in full text assessment, due to limited resources and the languages known by the study reviewers.

Date: No date restrictions were applied to initial searches, however the update searches restricted the date to articles published after November 2014.

Relevant ecosystem service provided: The following support for ecosystem services provided by plant traits were included: support for pollinators and crop pest natural enemies and water quality protection.

Relevant Population: Water bodies, pollinator species and natural enemies of insect crop pests.

Relevant exposure: Specific plant traits, for example floral display size, leaf area, root length, plant height.

Relevant comparator: Lack of traits or alternative traits, for example no floral display.

Relevant outcome: Any study that investigated potential changes in the populations including:

- Effects on pollinator abundance and diversity, visitation rates and attractiveness.
- Effects on natural enemy abundance and diversity or predation rates

- Effects on water quality in water bodies including inhibiting pollution from nitrogen, phosphorus, pesticides and sediment levels.

Relevant study design: Any primary research study that collected experimental or quasi-experimental data to investigate the effect of specific plant traits on provision of the named ecosystem services.

Article screening was undertaken by one reviewer at the title level. A second reviewer, that was blind to decisions made by the first reviewer, examined a random subset of 10% of the articles at abstract level and a kappa analysis showed a statistic of 0.836 demonstrating a very high level of agreement. Any disagreement was discussed and resolved by consensus. Any articles that passed the inclusion criteria at abstract level were then taken forward for full-text assessment by one reviewer. Each article was screened according to the inclusion criteria and any that did not meet the criteria were excluded, these can be found in Additional file 2-4. Review articles were not included but reference lists of relevant review articles were hand searched for potentially relevant primary research studies.

2-2.2.3 Coding of articles and study data

Studies from articles that passed the inclusion criteria after full-text assessment were imported into a Microsoft Access database and coded according to author, title, year of publication, reference type, study country, study region/state, study site, study dates, study length, study type, type of access and language. More specific terms were also used including type of ecosystem service, response organism/system, plant trait, target organism/system, outcome and the critical assessment decisions on replication, sample selection and other sources of bias. All coding was undertaken by one reviewer and any queries were discussed with a second reviewer and a consensus decision made.

2-2.2.4 Study critical assessment

The critical assessment method was informed by the systematic review guidelines' hierarchy of evidence used in medicine and public health (Stevens and Milne, 1997) and conservation (Pullin and Knight, 2001). A generic list of variables used by Haddaway et al. (2014) were modified by the authors and combined with topic-specific quality measures. Terms including 'yes', 'partially' or 'not at all' were applied by one reviewer to each study based on degree of replication, sample selection methods and other sources of bias, as shown in Table 2-2. Any queries were discussed with a second reviewer and a consensus decision made.

Table 2-2 Study critical assessment categories. Modified from Haddaway et al. (2014).

Critical assessment term applied	Replication	Sample Selection	Other Sources of bias
Yes	Well-replicated (>10 samples per group)	Random or blocked or exhaustive	None evident
Partially	Moderate level of replication (4-10 samples per group)	Not stated but clearly random or blocked	Potential confounder
Not at all	Poorly-replicated or not stated (1-3 samples per group)	Purposive or not stated	Clear confounder

For example, a well-replicated, randomised control trial with no obvious bias was categorised with the term 'yes' in all cases. No studies were excluded from the database based on the critical assessment criteria.

2-2.2.5 The systematic map database

A systematic map database was developed to describe the extent of the research in this field, see Additional file 2-5. It was created in Microsoft Access and is searchable by topic and arranged according to the generic coding terms. Also, it was designed so that it may be arranged by the specific coding terms, providing detailed information on the plant traits described by the articles in the map and how they have been related to support for the target ecosystem services.

2-2.3 Results

2-2.3.1 Summary of the evidence

In total the searches in November 2014 and January 2017 identified 34,077 articles, with a total of 11,705 once duplicates were removed. These were screened for inclusion according to the schematic in Figure 2-2.

Of the screened articles, 56 contained studies that met the inclusion criteria and were subsequently included in the systematic map database. See Additional file 2-6 for a list of these studies. All the included studies were from journal articles containing primary research. There were no relevant studies found for inclusion from the grey literature searches. Each article contained one relevant study, but some studies investigated multiple plant traits. In the systematic map database each row details one study, with each column providing further details e.g. ‘Author’, ‘Study Site’, ‘Study Length’ ‘Plant Trait(s)’ etc. In each cell a drop down menu shows the possible keyword options and indicates where multiple keywords have been chosen. For example, in the ‘Plant Trait(s)’ column the drop down menus indicate each of the traits that have been selected according to the evidence provided in the article. Each column can also be filtered according to the keywords included. For example, the ‘Ecosystem Service’ column can be filtered for articles that present evidence on one specific ecosystem service.

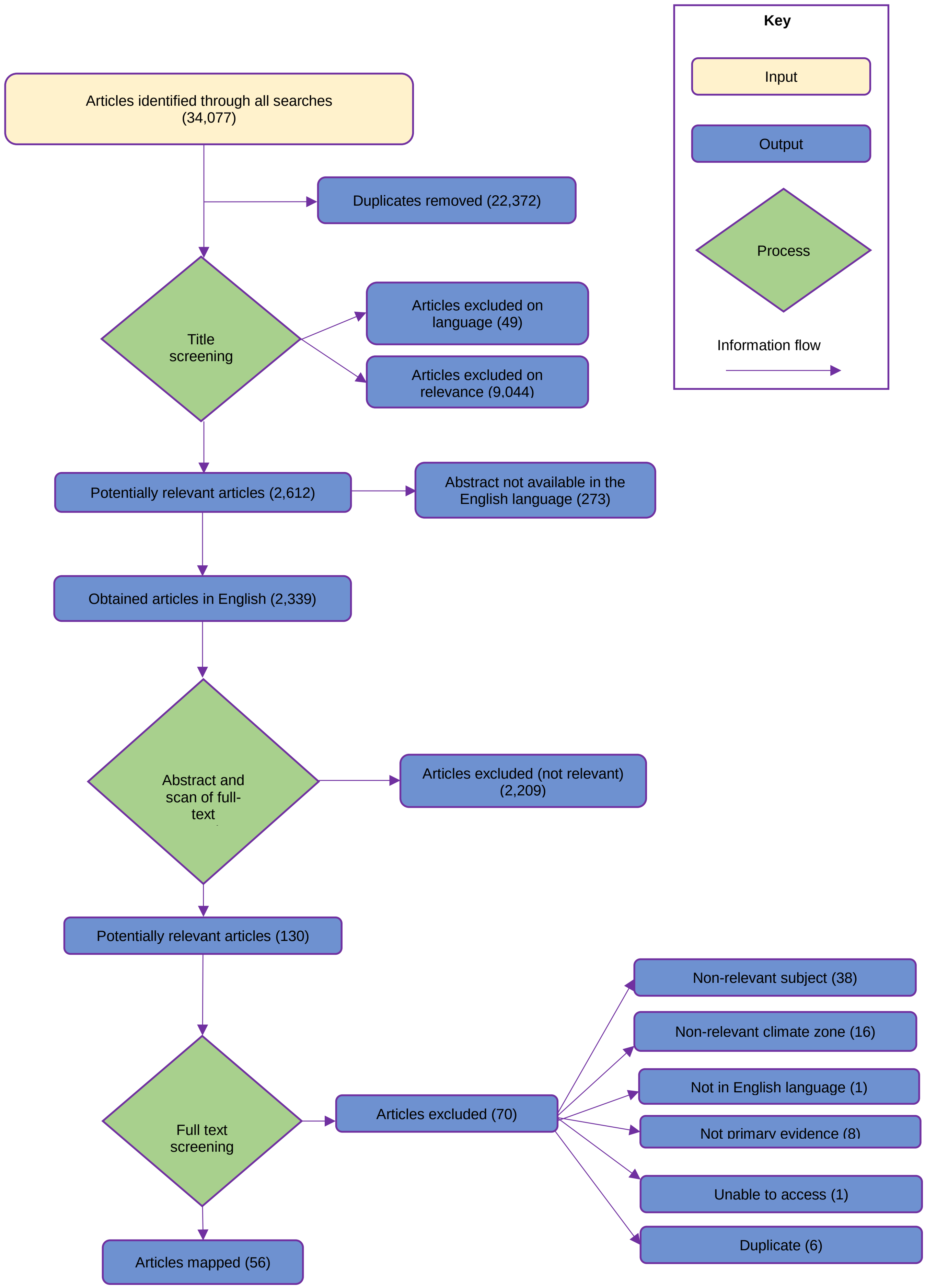

Figure 2-2 Schematic of screening stages for the systematic map that led to 56 articles that were obtained and subsequently mapped.

2-2.3.2 Key findings of the systematic map

Article publication dates ranged from 1983 to 2017, see Figure 2-3, and the vast majority (n=47) of articles were published within the last 10-15 years.

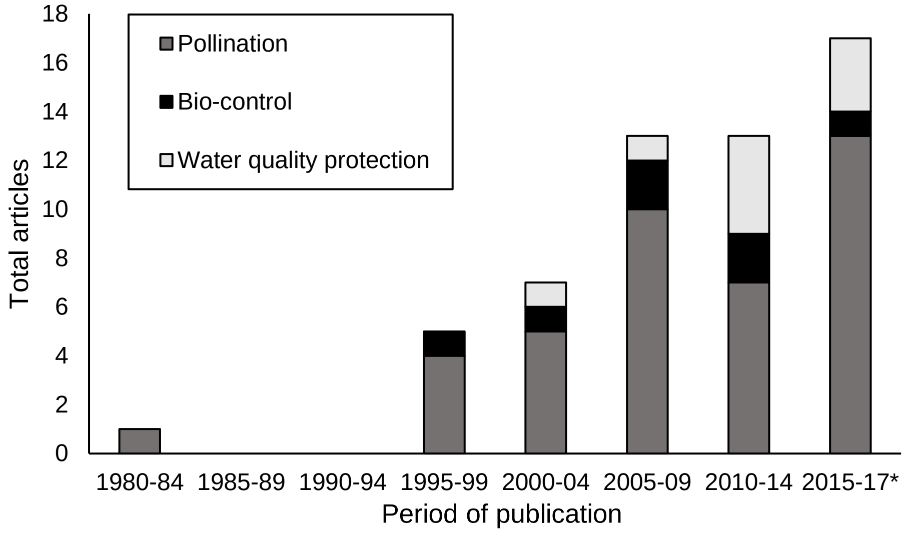

Figure 2-3 The total articles published in each five-year period from 1980, for each target ecosystem service.

*Note that this period is two years shorter than the others.

Studies from these articles were performed in a wide variety of countries, see Figure 2-4, however there were no studies from Eastern Europe and the most studies were undertaken in the USA (n=12).

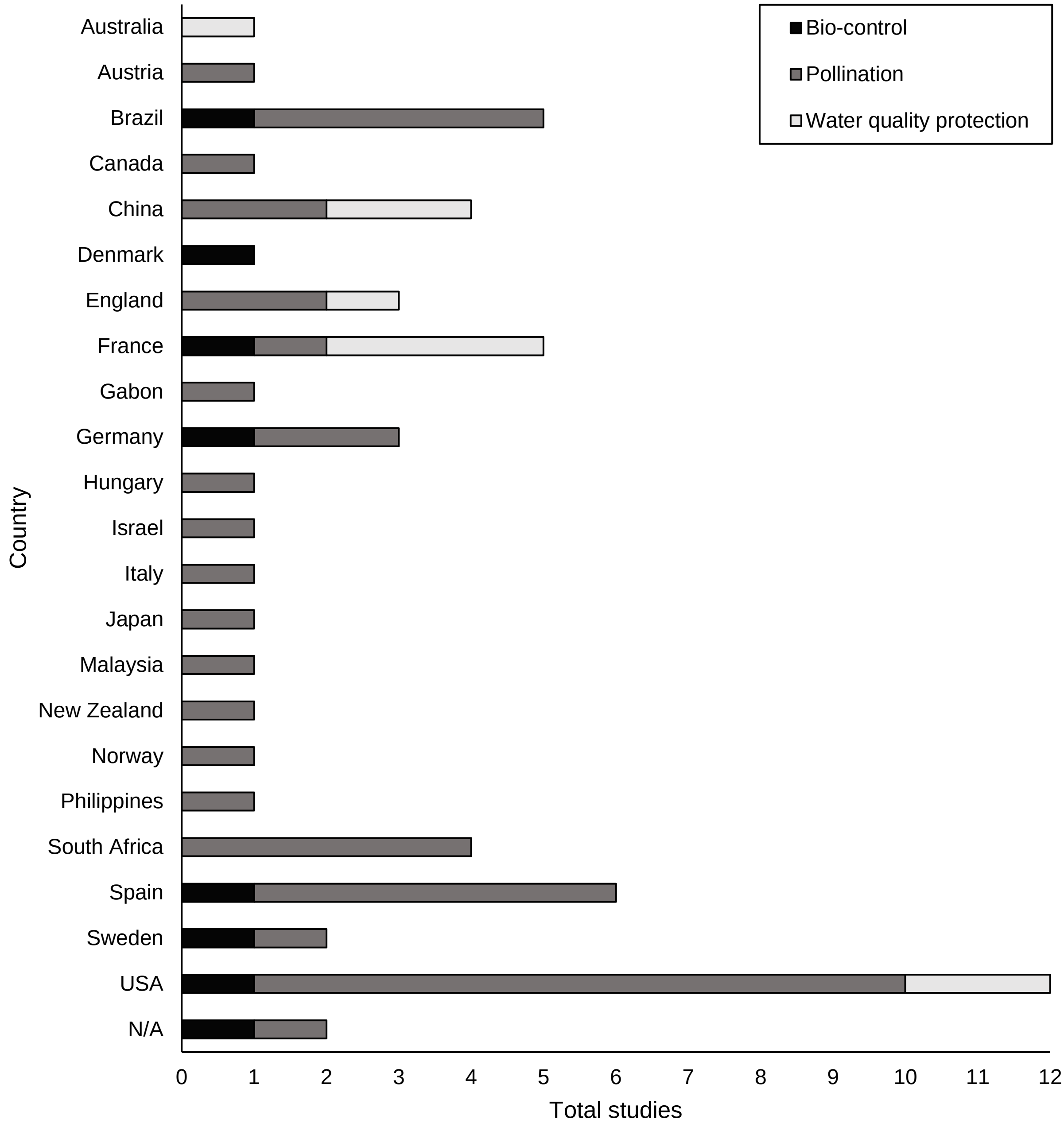

Figure 2-4 The total studies carried out in each country for each ecosystem service. N/A refers to studies where the country was not stated in the text.

The decisions made in the critical assessment are displayed in Figure 2-5. A total of 45 studies showed moderate to high replication with at least four samples per group, 43 showed randomised sample selection and 49 showed no other evident sources of bias using our critical assessment method. Decisions were not possible if the relevant information for the assessment criteria could not be accessed.

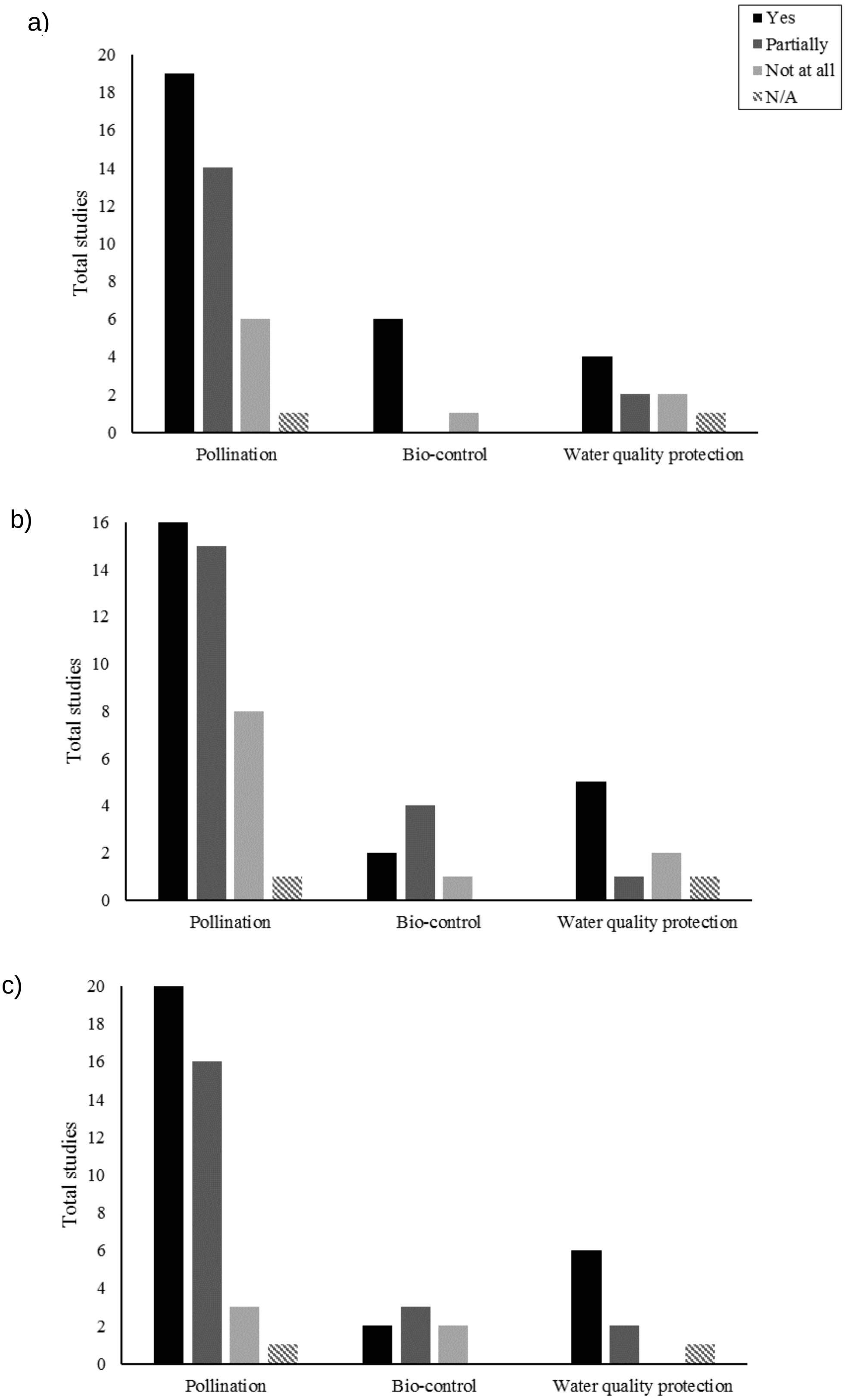

Figure 2-5 Decisions made in the critical assessment of studies according to a) degree of replication, b) sample selection methods and c) other sources of bias. N/A denotes the studies where a decision was not possible.

2-2.3.3 Plant traits and ecosystem services

For each article information on the studied plant traits was coded into the systematic map database. This included the plant trait (e.g. floral display size), the response organism or system that was monitored (e.g. plant species), the target organism (e.g. pollinator species), the outcome of the study (e.g. increased visitation) and the ecosystem service it was linked with (e.g. pollination).

Out of the 56 articles that were included in the systematic map, 40 related to pollination (through pollinator support), seven related to bio-control (through crop pest natural enemy support) and nine related to water quality protection. The specific plant traits and the ecosystem service(s) that they were related to in these articles are shown in Table 2-3. In total, 68 plant traits were studied. With regards to pollinator support, 33 of the plant traits were related to the flower of a plant, three were related to the leaf and one to the stem. Also, six traits studied to support natural enemies were related to the flower of the plant, two to the leaf and one to the stem. In contrast, three traits studied to support water quality protection were related to the leaf of the plant, 17 were related to the roots and five to the plant as a whole.

Table 2-3 Plant traits and related ecosystem services investigated in the literature. Numbers in brackets indicate where more than one article studied the plant trait.

Plant anatomy section	**Plant trait**	**Ecosystem service**		
		Pollination	**Bio-control**	**Water quality protection**
Flower	Achromatic component	✓		
	Anthers	✓		
	Anthesis	✓		
	Availability of nectar		✓	
	Bloom intensity	✓		
	Bract size	✓		
	Calyx width	✓		
	Chromatic component	✓		
	Colour stimulus	✓		
	Disc floret area	✓		

	Distyly	✓	
	Diurnal anthesis		✓
	Floral display size	✓(11)	✓
	Floral nectar	✓(3)	✓(2)
	Floral odour	✓(4)	
	Floral scent	✓	
	Floral symmetry	✓	
	Floral thermogenesis	✓	
	Floral tubes	✓	
	Floral UV reflectance	✓	
	Flower colour	✓(9)	✓
	Flower number	✓	
	Flower orientation	✓	
	Flower radial symmetry		✓
	Flower shape	✓(3)	
	Flower size	✓(2)	
	Flower venation	✓	
	Nectar guides	✓(2)	
	Number of open flowers	✓	
	Petal width	✓(2)	
	Pollen quantity	✓	
	Pollen reward	✓	
	Spadices heat generation	✓	
	Spur length	✓	
	Stamen condition	✓	

	Total capitulum area	✓		
Leaf	Epicuticular wax		✓	
	Leaf area			✓(5)
	Leaf biomass			✓
	Leaf gelsemine	✓		
	Leaf trichome		✓	
	Number of leaves			✓
	Resin gland size	✓		
	Staminal hairs	✓		
Stem	Stalk length	✓		
Root	Belowground biomass			✓
	Fibrous root diameter			✓
	Fibrous root length			✓
	Fibrous root surface			✓
	Percentage fine roots			✓(3)
	Root area			✓
	Root biomass			✓(2)
	Root density			✓
	Root diameter			✓
	Root length			✓(3)
	Root length density			✓
	Root mass			✓(2)
	Root slenderness			✓
	Root surface			✓
	Root system density			✓
	Root system topology			✓

	Root tensile strength	✓(2)
	Rooting depth	✓
Whole plant	Aboveground biomass	✓
	Canopy density	✓(2)
	Height	✓
	Plant biomass	✓
	Plant roundness	✓

The nine articles found for water quality protection studied 26 individual plant traits, 18 of which related to the roots of a plant. The 40 articles found for pollination studied 37 individual plant traits that related to pollinator support. Nineteen of which related to the floral display of the plant, for example floral display size (n=11) and flower colour (n=9). The seven articles found for bio-control studied 8 individual plant traits that were related to support for crop pest natural enemies. Furthermore, floral display size, flower colour and flower nectar were all investigated in studies relating to pollinator support and natural enemy support.

2-2.4 Discussion

The aim of this systematic map was to discover evidence on specific plant traits in relation to pollination, bio-control and water quality protection within the literature. In light of this, we discuss the key findings made by the systematic map in relation to each ecosystem service and any potential limitations to the map.

2-2.4.1 Key findings

This systematic map collated evidence on specific plant traits and how they may support the target ecosystem services. Due to the specificity of the inclusion criteria, just 56 articles were suitable for inclusion within the map. According to our critical assessment method, over half of the articles included studies that demonstrated moderate to high replication, randomised sample selection and no other source of bias. The publication dates of the articles span 34 years, with 41 published within the last 12 years, showing a recent increase in the volume of research in this topic area. A total of 68 plant traits were studied and related to the support of the target ecosystem services, spanning the entire plant anatomy.

Pollination through pollinator support

As the overwhelming majority of these articles studied plant traits linked with pollination through pollinator support (n=40), this shows a clear bias in the research. This bias is to be expected due to the highly dependent, mutualistic relationship between flowering plants and pollinators and current pollinator declines are driving further research to try and understand this relationship (Hector and Bagchi, 2007; Potts et al., 2010; Nicolson and Wright, 2017). Interestingly, studies that showed traits relevant for pollinator support were the most numerous from the USA (n=9) followed by Spain (n=5), Brazil (n=4) and South Africa (n=4). This could be due to the size of the country (both land mass and population) and the large proportion of it that is within a temperate climate zone [49]. Also the articles that studied pollination through pollinator support were published from 1983 to 2016, indicating that research on how plant traits support pollinators has been carried across 33 years at least. It was also noted that the majority of plant traits that were studied for pollinator support, related to some aspect of the flower of a plant, in particular the floral display size (n=11) and flower colour (n=9), and the traits that related to the flower varied greatly.

Bio-control through crop pest natural enemy support

A total of eight individual plant traits for bio-control through crop pest natural enemy support were studied by seven articles. This small number of articles indicates that there is a knowledge gap in this area. The studies were undertaken across Europe and North and South America, with one study undertaken in each of the following countries: Brazil, Denmark, France, Germany, Spain, Sweden and USA. This high variation in study country origin reduces any effects if bias on the information presented by the systematic map. Also, the publication dates for articles that studied bio-control through natural enemy support ranged from 1998 to 2015, showing that research in this area started 16 years after similar research for pollinator support. The plant traits that were studied related to the flower (6) and leaf (2) of a plant. This indicates that only above ground plant traits have been studied or identified in relation to the support of natural enemies. Also there was a cross-over between plant traits that were studied for natural enemy and pollinator support because floral display size, floral nectar and flower colour were researched for both.

Water quality protection

Similar to bio-control, only nine articles studied plant traits and how they may support water quality protection, however, they did look into 23 individual traits. Over a third of these studies were undertaken in Europe (France (n=3) and England (n=1)), with the remaining studies spread across China (n=2), USA (n=2), and Australia (n=1). Also, water quality protection plant traits were studied slightly more recently than the other two ecosystem services with publication dates ranging from 2000 to 2017. Although three articles studied leaf traits and five studied whole plant traits for water quality protection, 18 traits were related to plant roots. This showed an overwhelming focus in the research on below ground traits for the support of this ecosystem service.

2-2.4.2 Limitations to the searches

As only articles available in English could be included in the map, this may have biased the studies included to only those that are from English speaking countries. There were over 20 articles that provided some valuable information on support for the target ecosystem services, but these were excluded because they studied plant community traits rather than individual plant traits. These types of traits are more complex and were not relevant for this systematic map.

Although access to article full-text can be a limitation to a systematic map, only one article had to be excluded on this basis.

Limited time and funding meant that the initial title screening was undertaken by one reviewer and this may have introduced a bias at this stage. Only one reviewer conducted the critical assessment of the studies presented by the articles, so in order to avoid a potential limitation to the map, no articles were excluded based on the decisions made.

2-2.3 Conclusion

This systematic map identified and coded 56 articles that could answer the primary question “What specific plant traits support ecosystem services such as pollination, bio-control and water quality protection in temperate climates?”. It highlighted that over 68 plant traits have been studied, spanning the entire plant anatomy. It also identified a large bias in the research towards plant traits for pollinator support.

2-2.3.1 Implications for research

It is recommended that more primary research is undertaken on plant traits that may potentially support natural enemies or water quality protection. This research should aim to identify any other influential plant traits but also test those that have been identified so far, to develop the evidence base. Whilst a significant amount of evidence has been collated by this map, it is yet to be seen exactly how the identified plant traits provide significant support for the targeted ecosystem services. Whilst large numbers of studies imply a consistency of evidence across the literature, for example the 11 articles that studied floral display size, they do not necessarily demonstrate how and why floral display size may effect pollinator support, Therefore, in Chapter 3 a review of the study findings from the articles in this map will investigate exactly how each of the plant traits may support the ecosystem services that they have been related to and provide recommendations for any further primary research that should be undertaken.

2-2.3.2 Implications for policy and management

The evidence collated so far could inform policy makers and land-owners on the design of vegetative strips to support pollination, bio-control and water quality protection. If such evidence-informed decisions are made, the efficacy of vegetative strips to support ecosystem services could be improved, providing benefits to the land-owner and farmland wildlife concurrently.

Chapter 3. A trait-based approach to plant species selection to increase functionality of farmland vegetative strips

Abstract

Farmland vegetative strips are a proven source of support for ecosystem services and are globally used to mitigate the effects of agricultural intensification. However, increasing pressures on agricultural land require an increase in their functionality, so supporting multiple ecosystem services concurrently, would be desirable.

The plant species utilised in a vegetative strip seed mix will determine the establishment, resulting plant community and ecosystem services that are supported. Currently there is no clearly defined or structured method to select plant species for multifunctional vegetative strips.

Plant traits determine how a plant species may support an ecosystem service, and the establishment and persistence of plant communities is influenced by key external factors and the characteristics of the plants themselves. A novel, evidence-informed method of multifunctional vegetative strip design is proposed, based on these essential traits, factors and characteristics.

This study had three distinct stages. The first stage identified plant traits that support water quality protection, pollinators and/or crop pest natural enemies, using existing research evidence. Then, plant characteristics and environmental factors essential for plant community establishment and persistence were identified. Finally, these standardised methods were applied to design a multifunctional vegetative strip for a specific case study (lowland farmland within the United Kingdom).

Key plant traits identified, included floral display size, flower colour, nectar content, leaf surface area, leaf trichome density, percentage fine roots, root length, rooting depth and root density. Key plant community characteristics and environmental factors included life history, native status, distribution, established competitive strategy, associated floristic diversity, flowering time and duration and preferred soil type and pH. In the UK case study five different plant traits and all of the identified plant characteristics and environmental factors were used to design a seed mix for a multifunctional vegetative strip.

Here, a transferable method of vegetative strip design is presented, that can be adapted for other ecosystem services and climate zones. It provides landowners and advisors with an evidence-informed approach to increase field margin functionality whilst supporting farmland biodiversity.

Under review: Cresswell, C.J., Cunningham, H.M., Wilcox, A., Randall, N.P., 2018. A trait-based approach to plant species selection to increase functionality of farmland vegetative strips. Ecology and Evolution.

3-1 Introduction

Agricultural land use covers 37.4% of global land area as of 2015 (FAO, 2018). Farming it effectively for food production is vital for a globally expanding human population (Godfray et al., 2010; UN Population Division, 2018). Recent research has shown that achieving efficient agricultural production requires regulating ecosystem services, including pollination and biological control (bio-control), which support the provisioning ecosystem service of food production (Aizen et al., 2009; Zavaleta et al., 2010; Blitzer et al., 2016). However, declines in both pollinator abundance and diversity in addition to the plants that support them, have led to pollination deficits in crops such as oil-seed rape, watermelon and apple (Kremen et al., 2002; Carvell, 2004; Biesmeijer et al., 2006; Brown and Paxton 2009; Williams and Osborne 2009; Winfree et al., 2009; Garratt et al., 2013; Stanley et al., 2013). Simplified, intensive agricultural landscapes have also been shown to have a 46% lower level of pest control by insect natural enemies of crop pests (Rusch et al., 2016). In addition, since 1945 increased applications have led to pesticides, together with nitrates, phosphates and sediment, polluting farmland water quality through run-off, erosion and leaching to ground water (Davies, 2000; Gevao et al., 2000; Dabrowski et al., 2002). Whilst pesticide applications have reduced more recently, there is evidence demonstrating their persistence in the environment (Cuevas et al., 2018). In particular, organochlorine pesticides are pervasive within water systems and have high persistence in the environment (Chang, 2018).

To support ecosystem services and protect wildlife, whilst meeting food production requirements, a ‘sustainable intensification’ approach has been proposed (Wentworth, 2008; Firbank et al., 2013). This involves increasing food production from the existing agricultural land whilst minimising pressure on the environment (Garnett and Godfray, 2012). One mechanism of this would be to increase the functionality of off-crop habitats, such as vegetative strips in field margins, that support valuable ecosystem services within the farm, including water quality protection, pollination and bio-control (Pfiffner and Wyss, 2004; Reichenberger et al., 2007; Lye et al., 2009; Haaland et al., 2011). Wildflower vegetative strips can increase pollinator visits to the crop by 25% (Feltham et al., 2015). If sown with grasses and wildflowers, they can provide shelter and food resources for natural enemies, which can reduce pest-induced crop damage and increase yield to adjacent crops (Gurr et al., 2010; Tschumi et al., 2016). Also, vegetative strips sown along farmland watercourses are a proven method of water quality protection (Muscutt et al., 1993; Davies, 1999; Dorioz et al., 2006; Reichenberger et al., 2007; Haukos et al., 2016).

As a result, farmers in Europe are required to buffer any waterbody next to arable land with a 2m wide vegetative strip under the Common Agricultural Policy and Water Framework Directive (DEFRA, 2014; European Commission, 2018). They often have very low botanical diversity (Mayer et al., 2007), but studies have shown that the introduction of other plant species should not affect their efficacy at protecting water quality (Mayer et al., 2007; Critchley et al., 2013; Cole et al., 2015). Consequently, there is scope to sustainably increase the number of ecosystem services that vegetative strips support whilst still provisioning for wildlife. This could aid food production in the face of mounting restrictions on land availability and pressures on landowners and wildlife (Stutter et al., 2012; Hackett and Lawrence, 2014).

Some attempts at integrating support for different ecosystem services have been made (e.g. Biddinger and Rajotte, 2015), but the potential to provide water quality protection and support for pollinators and natural enemies in one vegetative strip, has been little explored. The plant species included in a vegetative strip seed mix will determine the establishment, resulting plant community and therefore ecosystem services that are provided (Grime et al., 2007). From current literature, there is no evidence of a clearly defined or structured method of plant species selection for vegetative strips. Numerous seed companies, charities and other organisations provide seed mix options and advice to support biodiversity or ecosystem services (e.g. Syngenta, 2014; Buglife, 2018; Kings Seeds, 2018; Emorsgate Seeds, 2018). Typically, these were developed by observation and experience in the field (Nowakowski and Pywell 2016), but this method is not transparent, structured or repeatable. Evidence-informed decision support tools have been developed for general farming practices (e.g. Centre for Ecology & Hydrology, 2018), but so far, none exist for selecting plant species for multifunctional vegetative strips.

Plant functional traits and their uses in determining species performance, in predicting changes in community compositions and their effect on ecosystem functioning, are increasingly being investigated (Lavorel and Garnier, 2002; Diaz et al., 2007; Violle et al., 2007; Violle and Jiang, 2009; de Bello et al., 2010; Lavorel et al. 2013). The specific morphological traits of a plant, or effect traits as defined by Lavorel and Garnier (2002), such as nectar content, floral display size or leaf area (Kattge et al., 2011), determine how it supports specific ecosystem services (Diaz et al., 2007; Garnier and Navas, 2012). For example, Bianchi and Wackers (2008) showed that more parasitoids were attracted to plants with a higher nectar content, Kudo et al. (2007) showed that a larger floral display size was preferred by *Bombus hypocrita* supsp. *Sapproensis* and Burylo et al. (2014) showed that a plant’s leaf area positively correlated with its ability to trap sediment. In addition, plant characteristics such as their life history and established competitive strategy, can significantly affect the establishment of the desired plant community. For example, if a plant species has a perennial life history it should return each year suitable (Marshall and Moonen, 2002), and if non-competitive grasses are sown with the forbs, this could enhance the chance of the desired forbs establishing (Laskey and Wakefield, 1978). Therefore, they should also be considered when selecting species for a seed mix.

There are many sources of plant trait and characteristic data for UK species, (*e.g.* Fitter and Peat, 1994; Grime et al., 2007; Baude et al., 2016; Biological Records Centre, 2018), providing an extensive evidence base for plant species selection. There are also reviewing methods, such as systematic mapping, that provide a structured and comprehensive process to discover evidence that may explain which specific plant traits support the target ecosystem services.

In the pursuance of designing a vegetative strip to support multiple ecosystem services, a novel, evidence-informed method which utilises plant traits is proposed, which can be applied to a wide range of farmland environments within temperate climates. The target ecosystem services to be supported by this vegetative strip include water quality protection, pollination and bio-control.

3-2 Materials and methods

This study was undertaken in three distinct stages. The first stage identified plant traits that support water quality protection, pollinators and/or crop pest natural enemies, using existing research evidence. The second stage identified plant characteristics and environmental factors essential for plant community establishment and persistence within a vegetative strip. Stage three applied the standardised methods from the first and second stages to a specific case study for lowland farmland within the United Kingdom, where plant species were selected for a multifunctional vegetative strip.

3-2.1 Stage One: The identification of plant traits that support the target ecosystem services

A standardised, systematic reviewing method was used to collate existing research on plant traits that support the target ecosystem services. A systematic map approach was used as it is a transparent, repeatable, structured and un-biased method to collate evidence (Grant and Booth, 2009; Collaboration for Environmental Evidence, 2018). The exact methods used to carry out the systematic map can be found in Chapter 2 Part 1.

In summary, a combination of published peer-reviewed, and grey (i.e. non-commercially available) literature sources were comprehensively searched using specific key terms to capture an un-biased sample of the literature. Articles were considered relevant where they investigated a plant trait and its provision of the target ecosystem services in a temperate region. Any experimental or correlative study, that collected primary data and that met the above criteria, was included in the database created in Chapter 2 Part 2.

Each article was categorised using a combination of generic (e.g. country of study, publication date, authors etc.) and topic specific (e.g. plant trait, target organism and ecosystem service provided) keywords. Only findings from studies that met predefined critical appraisal requirements (i.e. adequate replication or randomisation of samples and no clear confounder), were used to inform the final assessment of the plant traits. For each included study, the specific plant trait, target organism and outcome were identified. Data were extracted from the map to make cross-comparisons between the findings to build a robust evidence base for plant species selection.

3-2.2 Stage Two: Identification of plant characteristics and environmental factors that aid in establishment and persistence of plant communities

The establishment and persistence of plant communities is influenced by key external factors and the characteristics of the plants themselves (Laskey and Wakefield, 1978; Grime et al., 2007). These could include preferred soil type or the plant's competitive nature.

A group of topic experts were consulted to ascertain what information was required and how to effectively collate it. Information sources were searched, including Laskey and Wakefield (1978), Landis et al. (2000), Marshall and Moonen (2002), Grime et al. (2007), Wentworth, J. (2008), Kirk and Howes (2012) and Biological Records Centre (2018).

3-2.3 Stage Three: Case Study on UK plant species

Information from stages one and two were applied to a case study, in this case UK lowland farmland. A list of all UK, native, perennial forbs and grasses that showed an indication of good distribution across the UK, according to the Online Atlas of the British and Irish Flora (Biological Records Centre, 2018), was compiled. Data on their traits (identified in stage one) and characteristics and environmental factors (identified in stage two) were then collected and coded into a database. The full database and details on the sources searched for this information can be found in Additional File 3-1.

Plant characteristics and environmental factors identified in stage two formed an initial criterion for plant species selection. Plant species were then ranked relative to their ability to aid in the provision of the target ecosystem services (water quality protection, and support for pollinators and natural enemies) according to the traits and characteristics already identified. Some of the characteristics from stage two were weighted for importance in lowland temperate environments. The ranks for each plant species were totalled and those with the highest rank carried forward to be considered for inclusion within a final multifunctional seed mix. The plant communities were developed so that a range of plant traits would be present.

3-3 Results

3-3.1 Stage One: Overview of the systematic map

From a total of 11,705 from the initial search, 56 articles met all the relevant criteria to be included for data extraction. Data extracted from the systematic map report created in Chapter 2 Part 2, on the identified plant traits and their corresponding ecosystem service, is shown in Figure 3-1.

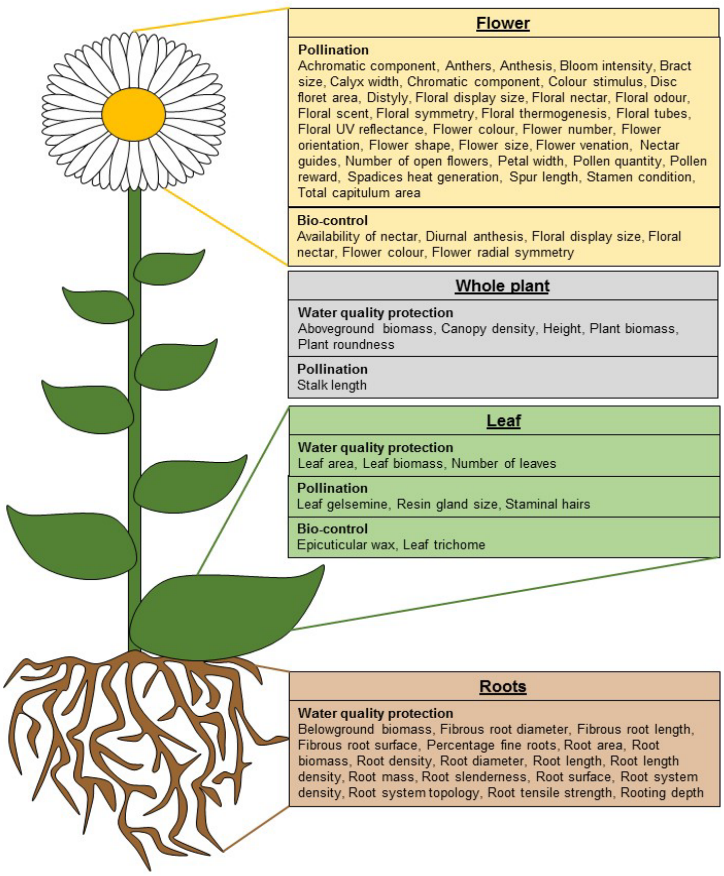

Figure 3-1 Plant traits and related ecosystem services investigated in the literature. (Data adapted from Chapter 2 Part 2)

Pollinator support was the most commonly studied ecosystem service and many of the included articles investigated plant traits that focussed on different aspects of the floral display of a plant, for example floral display size (n=11), flower colour (n=9) and flower shape (n=3). Some of the articles collated on crop pest natural enemy support also studied flower colour and floral nectar. Both floral and leaf traits such as flower radial symmetry and leaf shape were found to influence invertebrates. Out of the articles collated on water quality protection 17 related to the roots and root system of the plant.

Articles that studied the same plant trait all drew the same conclusions, e.g. the articles investigating floral display size all identified that a larger display was preferred by the test species of pollinator (Table 3-1).

Table 3-1 Data extracted from the systematic map showing the important aspects for the chosen plant traits and the corresponding references. The full references can be found in Additional File 3-2.

Plant trait	**Aspect of trait**	**Target organism/system**	**Outcome**	**Reference**
Floral display size	Larger	*Apis mellifera*, Bombus sp., Osmia sp., Bombylius sp., Usia bicolor, Diptera, Hymenoptera, Coleoptera, Heteroptera, Lepidoptera, Syrphidae, Pollinators, Flower visiting insects	Preference shown	Shykoff & Bucheli (1995); Galen (1996); Johnson & Dafni (1998); Møller & Sorci (1998); Elle & Carney (2003); Sánchez-Lafuente & Parra (2009); Barrio & Teixido (2015)
	Larger	Flying hawkmoth	Increased reproduction of plant	Herrera (1993)
	Larger	*Bombus hypocrita* subsp. *Sapproensis*	Increased attractiveness	Kudo et al. (2007)
	Larger	Pollinators	Attracted more	Ohashi & Yahara (2004)
	Larger	Andrena spp., *Anthophora acervorum, Apis mellifera, Bombus impatiens, Bombus pascuorum, Bombus pratorum, Bombus terrestris*, Pollinators, Muscid and Anthomyiid flies, Syrphidae, Others	Increased visitation	Conner & Rush (1996); Totland (2004); Sánchez-Lafuente et al. (2005); Brunet et al. (2015); Garbuzov & Ratnieks (2015)

Flower colour	Yellow	Crab spiders, Coleoptera, Syrphid flies (Allograpta and Platycheirus)	Preference shown	Campbell et al. (2010); Rocha-Filho & Rinaldi (2011); Reverte et al. (2016)
	UV-yellow	Ants, wasps & diptera	Preference shown	Reverte et al. (2016)
	White	Crab spiders, Solitary bees (Hylaeus), Coleoptera, Pollinators	Preference shown	Campbell et al. (2010); Mu et al. (2011); Rocha-Filho & Rinaldi (2011); Reverte et al. (2016)
	Blue	*Philoliche aethiopica*	Preference shown	Jersáková et al. (2012)
	Pink	*Usia bicolor*, Crab spiders, Lepidoptera	Preference shown	Johnson & Dafni (1998); Rocha-Filho & Rinaldi (2011); Reverte et al. (2016)
	Ultramarine blue/Bee-UV-blue	*Melipona mondury*	Preference shown	Koethe et al. (2016)
	Bee-green	*Melipona quadrifasciata*	Preference shown	Koethe et al. (2016)
	Green	Ants	Preference shown	Reverte et al. (2016)
	Colour change	*Bombus hypocrita* subsp. *Sapproensis*	Susceptible to display patterns and floral display size	Kudo et al. (2007)

	Purple	Bees	Preference shown	Reverte et al. (2016)
	Red	Pollinators	Preference shown	Shang et al. (2011)
Nectar content	Higher	*Aphidius ervi*, Bees and flies	Preference shown	Ashman et al. (2000); Vollhardt et al. (2010)
	Higher	*Apis mellifera, Andrena nigrihirta, Andrena tridens, Andrena carlini, Nomada perplexa, Xylocopa virginica virginica, Augochlora pura, Augochlorella striata*, *Osmia conjuncta, Osmia lignaria*, Dialictus sp., Osmia sp., Honeybees, Bumblebees, Parasitoids	Attracted more	Motten (1983); Bianchi & Wackers (2008); Schmidt et al. (2015)
Leaf area	Larger	Soil erosion	Reduced soil erosion	Burylo et al. (2012b)
	Larger	Sediment	Reduced soil erosion	Burylo et al. (2014)
	Larger	Runoff, soil erosion, sediment & sediment concentration	Reduced soil erosion	Chau & Chu (2017)
	Larger	Rainfall interception	Increased	Li et al. (2016)
	Larger	N & P removal	Increased N & P removal from soil	Read et al. (2010)

Leaf trichomes	More	Pea leaf weevils	Increased abundance	Chang et al. (2004)
Percentage fine roots	Higher	Soil erosion	Reduced soil erosion	Burylo et al. (2012a)
Root length	Longer	Soil aggregate stability	Increased	Gould et al. (2016)
	Longer	Nitrate uptake	Increased nitrate uptake rate	Sullivan et al. (2000)
Rooting depth	Deeper	N & P removal	Increased N & P removal from soil	Read et al. (2010)
	Deeper	Nitrate uptake	Increase nitrate uptake rate	Sullivan et al. (2000)
Root density	Higher	Runoff, soil erosion, sediment & sediment concentration	Reduced soil erosion	Chau & Chu (2017)

3-3.2 Stage Two: Identified plant community characteristics and environmental factors

Information gathered on plant community characteristics and environmental factors and their aspects that are essential to multifunctional vegetative strip establishment are shown in Table 3-2.

Table 3-2 Plant community characteristics and environmental factors, their desirable aspect for a multifunctional vegetative strip, the justification and the associated reference.

Plant characteristic	**Aspect**	**Justification**	**Reference**
Life history	Perennial	Vegetative strips along farmland watercourses should last 5-10 years, without re-sowing, so annuals are not suitable	Marshall and Moonen, 2002
Status	Native	To avoid introduction of invasive non-natives	Wentworth, J., 2008
Distribution	Regional	Well-regionally distributed will ensure seed is more widely applicable within the region	Biological Records Centre, 2018
Established competitive strategy	Non-competitive	Grasses have been shown to outcompete wildflowers, so must their competitive strategy must be considered	Laskey and Wakefield, 1978
Associated floristic diversity	High	High associated floristic diversity increase the chance of wildflowers establishing well	Grime et al., 2007
Flowering time and duration	Duration of beneficial invertebrate season of activity	To provide pollen and nectar sources throughout season	Landis et al., 2000
Soil type	Suitable for varied types	To ensure growth and good establishment of the plant	Grime et al., 2007; John Szczur, GWCT

Soil pH	Suitable for varied soil pH	To ensure growth and good establishment of the plant	Grime et al., 2007, John Szczur, GWCT
Suitability to native beneficial invertebrates	High	To ensure selected species provide support for the target beneficial invertebrates	e.g. Kirk and Howes, 2012

3-3.3 Stage three: UK plant species case study, the ranking system and the results of the application

The traits and characteristics for each plant species were ranked using the parameters and associated scores detailed in Table 3-3.

Table 3-3 Plant trait ranking and weighting system used to identify suitable forbs and grasses.

	Plant trait/characteristic	**Ranking parameter and suitability value**	**Data source**
Forbs	Floral display size*	0: <10 mm, 1: ≥10mm	Baude et al., 2016
	Trichome density	0: Sparse, 1: Numerous	Grime et al., 2007
	Leaf area	0: <25 mm^2, 1: ≥25 mm^2	Grime et al., 2007
	Root system	0: Tap-root, 1: Adventitious	Fitter and Peat, 1994; Grime et al., 2007
	Leaf phenology	0: Aestival, 1: Evergreen	Fitter and Peat, 1994; Grime et al., 2007
	Soil type	0: Not suitable for all soils, 5: Suitable for all soils.	Expert advice: John Szczur, GWCT cross-referenced with data from: Grime et al. 2007;

		These scores were heavily weighted as suitability to most soil types was essential for establishment of the multifunctional vegetative strip.**	Biological Records Centre, 2015
Grasses	Leaf area class	1: <15, 2: 15-20, 3: 20-25, 4: 25-30, 5: >:30 mm^2	Grime et al., 2007
	Established strategy	0: C or SC or CR, 1: CSR or R or S or SR Where C = Competitor, R = Ruderal, S = Stress-tolerator, CR = Competitive-Ruderal, SC = Stress-tolerant Competitor, SR - Stress-tolerant Ruderal and CSR = C-S-R strategist	Grime et al., 2007
	Height (maximum)	0: ≥2000, 1: 1500-2000, 2: 750-1500, 3: ≤750 mm	Fitter and Peat, 1994
	Associated floristic diversity	1: 10.0 species or fewer, 2: 10.1-14.0, 3: 14.1-18.0, 4: 18.1-22.0, 5: >22.0	Grime et al., 2007

*Size of total floral display, not individual florets

**This ranking parameter can be adapted to target specific soil types, for example targeting a sandy loam soil – 0: not suitable for sandy loam soil, 5: suitable for sandy loam soil.

Forbs ranked highly if they had a large floral display size and leaf surface area, leaves with numerous trichomes, an adventitious root system and evergreen leaves. All grasses were required to have an adventitious root system but also scored highly if they had a large leaf surface area, a less competitive established strategy, a lower comparative height and a high associated floristic diversity. Once the higher scoring forbs and grasses were identified they were then combined to create the final seed mix.

All plant species highlighted in Tables 3-4 and 3-5 were included in the seed mix for the multifunctional vegetative strip. Due to cost restrictions and standard practice, the seed mix consisted of 20% forbs and 80% grasses. An alternative mix was also created with a ratio of 50% forbs and 50% grasses to investigate the effect of this difference on establishment of the desired community. Two further multifunctional plant mixes were developed, one for a heavy clay soil and one for a sandy loam soil. The same method was used, with the exception that rankings considered plant suitability for the respective soil types.

Table 3-4 Grasses assessed for inclusion in the multifunctional seed mix and their corresponding rank.

Botanical name	Leaf area	Established strategy	Height (maximum)	Associated floristic diversity	Total
Agrostis capillaris	5	1	3	2	11
Festuca pratensis	4	1	2	4	11
Phleum pratense	5	0	1	3	9
Dactylis glomerata	4	0	2	3	9
Alopecurus pratensis	4	0	2	3	9
Festuca rubra agg.	2	1	2	3	8
Festuca arundinacea	2	0	0	4	6

Table 3-5 Forbs assessed for inclusion in the multifunctional seed mix and their corresponding ranks. Ranked forbs all showed signs of support for all groups of bees according to Kirk and Howes (2012).

Botanical name	**Floral display size**	**Trichome density**	**Leaf area**	**Root system**	**Leaf phenology**	**Soil type**	**Total**
Trifolium pratense	1	1	1	0	1	5	9
Trifolium repens	1	0	1	1	1	5	9
Centaurea nigra	1	1	1	0	0	5	8
Taraxacum officinale agg.	1	0	1	0	1	5	8

Stachys sylvatica	1	1	1	0	0	5	8
Leucanthemum vulgare	1	0	0	1	1	5	8
Prunella vulgaris	0	1	1	?	1	5	8
Lotus corniculatus	1	0	1	0	0	5	7
Daucus carota	0	0	1	0	1	5	7
Achillea millefolium	0	0	1	0	1	5	7
Galium verum	0	1	0	?	1	5	7
Ranunculus acris	1	0	0	0	0	5	6
Silene dioica	1	0	0	0	0	5	6
Veronica chamaedrys	1	1	1	1	1	0	5
Hypochaeris radicata	1	1	0	1	1	0	4
Primula vulgaris	1	1	1	?	1	0	4
Heracleum sphondylium	1	1	0	0	0	0	2
Vicia cracca	0	1	1	0	0	0	2
Potentilla erecta	1	?	0	1	0	0	2
Scrophularia nodosa	?	0	1	0	0	0	1
Knautia arvensis	1	0	0	0	0	0	1
Malva moschata	?	0	0	0	1	0	1
Potentilla anserina	1	0	0	0	0	0	1
Geranium pratense	1	0	0	0	0	0	1

‘?’ denotes where data was not available on the plant trait for a specific plant species.

3-3.4 Discussion

The knowledge gaps identified by the systematic map, for example, there were less articles found for water quality protection and crop pest natural enemy support when compared with pollinator support, emphasise a need for additional research to be undertaken in these areas. However, the articles that were included provided sufficient evidence to utilise in the plant trait decision-making. In addition, the concurrence of the findings in the articles in the systematic map, allowed increased confidence in the evidence used in the plant species selection process.

For some of the plant traits identified in Stage One, the information relating to their presence or absence in individual UK plant species was unavailable. For example, the research identified specific traits such as fibrous root length or depth as indicative of an adventitious root systems to aid water quality protection type, but only the overall root system could be identified (e.g. in Grime et al. 2007). This influenced what could be presented in the database of UK plant species (Additional File 3-1). In other cases, the data available on traits was incomplete for some plant species (indicated by ‘?’ in Table 6) potentially impacting an individual species ranking. For plant species where the trait information is lacking, further primary research, would strengthen this method of vegetative strip design. Screening experiments could be undertaken to record measurements of specific plant trait parameters such as maximum and minimum size of floral display.

Although the three-stage approach identified the top scoring plants, other UK lowland farmland-specific issues were also considered. The commercial availability of the seed affected the final seed mixes. Where this was an issue lower scoring plants that covered a similar flowering period were substituted. For example, two high scoring UK forbs, lady's bedstraw (*Galium verum*) and selfheal (*Prunella vulgaris*), could not be sourced from seed companies and so were not included in the multifunctional seed mix, see Table 3-5. A slightly lower scoring plant, primrose (*Primula vulgaris*), though not guaranteed to grow well in all soil types, was included because it has many of the desirable traits, but also flowers early in the season and some higher scoring plants do not. Similarly, the grass species cock's foot (*Dactylis glomerata*), had a slightly lower score than some others due to its competitive nature, but was included as its pollen is often gathered by pollinators (Kirk and Howes, 2012).

The plant species chosen for these seed mixes were all selected for use within the UK, however the methods used can be applied to other temperate regions by choosing plant species native to that country. The TRY Plant Trait Database created by Kattge et al. (2011) can be used to access information gathered from numerous plant trait databases across the world.

3-4 Conclusions

In this study an evidence-informed method to design multifunctional vegetative strips has been outlined and demonstrated.

By using this three-stage approach for the first time in vegetative strip design, a method has been developed that focusses on exactly what is required of individual plants, and of plant communities, to support ecosystem services in farmland. This method is widely applicable to different environmental conditions within temperate farmland and allows a more informed decision-making process when choosing plant species for vegetative strip seed mixes.

In-field experiments are currently underway to test the long-term establishment and viability of the test seed mixes. If establishment of the desirable plant community is achieved and sustained, then this method of vegetative strip design could be a proven, useful tool that could inform agricultural environmental policies. For example, the European Common Agricultural Policy does not currently stipulate that vegetative strips, along farmland watercourses, need to be sown with anything but a standard grass seed mix (European Commission, 2018). If payments to farmers could be offered as an incentive to sow a more enhanced, multifunctional seed mix along watercourses on their land, this could positively affect biodiversity within farmland whilst increasing support for regulating services to the farmer. Field margins need to become multifunctional due to restricted land availability, increased food production requirements and farmland biodiversity declines. This novel method could allow land owners to increase the functionality of their field margins or other vegetative strips by supporting three vital ecosystem services, whilst re-introducing biodiversity into the landscape. In addition, the method has the potential to be adapted for other ecosystem services and climate zones.

Chapter 4. Vegetative strips in UK farmland field margins – establishment, management and development of plant communities

Abstract

Vegetative strips have been widely used across Europe to mitigate the effects of agricultural intensification. In Great Britain, farmers are required to maintain a vegetative strip on land adjacent to a watercourse, to act as a buffer against pollution, but their management is not specifically prescribed, and neither are the seed mixes that are sown. Within Great Britain, plant species richness has declined by 7.5% between 1998 and 2007 alongside watercourses, and there is a need to determine how to establish more diverse plant communities within buffer strips.

This study investigated the kind of plant communities that could be expected, dependent on buffer strip management, age, sown seed mix and soil type and whether an evidence-informed method of plant species selection could enhance vegetative strip establishment and persistence.

A preliminary case study investigated resultant plant communities found in existing buffer strips, and evaluated previous management, age, sown seed mix and soil type. In addition, designed seed mixes using the methods in Chapter 3, for multifunctional and single-focus vegetative strips, were sown in a field experiment to test the effects of environmental conditions, namely soil type, and management on the establishment of the desired plant communities.

Across the preliminary case study and field experiment, every buffer and vegetative strip type on sandy or sandy loam soils (less-fertile soils) consistently had the highest species richness, proportion of forb cover and proportion of sown species cover. Targeting seed mixes towards specific soil types had no effect on the proportion of sown species present. The majority of buffer strips in the case study had less than 50% forbs. The multifunctional vegetative strip designed for all soils sown with 50% forbs and 50% grasses, had the highest average proportion of forb species and species richness.

The findings from the case study provide further evidence for the need for careful consideration of environmental factors, such as soil type, when developing seed mixes for buffer strips. The findings from the field experiment demonstrate that using a structured, evidence-based decision-making tool when selecting plant species for vegetative strips could increase the chance of establishment of the sown plant species and intended plant communities.

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4-1 Introduction

Farmland vegetative strips have been used across Europe to mitigate the effects of agricultural intensification for over 20 years (Marshall and Moonen, 2002; Pfiffner and Wyss, 2004; Reichenberger et al., 2007; Haaland et al., 2011). In Great Britain, land managers are required by government policy to maintain a buffer strip on land within two metres of the centre of a watercourse (DEFRA, 2018). The United Kingdom government-funded Farming Advice Service recommends that buffer strips be sown with grass, wild bird seed or pollen and nectar mixes, however, there is no specifically prescribed selection of plant species or management regime (Farming Advice Service, 2018). The Countryside Survey (Centre for Ecology and Hydrology, 2008a) showed plant species richness alongside rivers and streams in the UK to have decreased by 7.5% between 1998 and 2007, with continued decreases observed in the ratio of forbs to grasses. This has likely contributed to the nationwide decrease in plant species richness by 9.2% between 1978 and 2007 (Centre for Ecology and Hydrology, 2008b) and the observed parallel declines in pollinators and the plants that rely upon them (Biesmeijer et al., 2006; Wood et al., 2007).

In order to incentivise farmers to increase biodiversity on their land, a new approach to the application of agri-environment schemes has been trialled in England. It is a 3-year, European Union funded, Results Based Agri-environment Payment Scheme (RBAPS) pilot study (Natural England, 2017). Currently the options for arable vegetative strips in this scheme target support for wild birds & pollinators, through winter bird food, and floral mixes to support pollinators. Preliminary results show evidence of increased farmer input as they became increasingly motivated to make the RBAPS plots establish and persist (Natural England, 2017). This method of payment by results could be used to encourage farmers to enhance their buffer strips by providing them with the option to sow a more diverse seed mix. If seed mixes establish successfully and help increase botanical diversity whilst continuing to protect water quality, payments to the farmer could be increased above those provided for standard buffer strips.

These incentives could be used to motivate farmers to increase the functionality of vegetative strips as well as their diversity. This is of growing importance as food production requirements continue to rise and land availability becomes further restricted (Godfray et al., 2010; Stutter et al., 2012). Specific ecosystem services such as the aforementioned water quality protection and pollination, as well as biological control of insect crop pests, can be supported by vegetative strips. The current commonly used buffer strips, often sown with simple grass seed mixes, are not designed to support multiple ecosystem services. There is a need to develop alternative seed mixes, to be sown along farmland watercourses, with increased diversity and functionality to provide improved ecosystem service support to the farmer and support to wildlife.

Establishing more diverse and functional buffer strips may present some challenges. It is known that seed mixes containing forbs and grasses often become less diverse over time, as grasses have a more competitive growth strategy (Huusela-Veistola and Vasarainen, 2000; Noordijk et al., 2011; Grime et al., 2007). One method to replenish forb populations is to re-sow once they have diminished, but this could impair the ability of the buffer strip to protect water quality. Buffer strips are usually long-term establishments and are not frequently re-sown to ensure that the soil and ground cover provided by a well-established plant community is preserved (Reichenberger et al., 2007).

In order to fully understand how to establish a botanically diverse buffer strip, resultant plant communities found in vegetative buffer strips were investigated in a preliminary case study, and the effects of previous management, age, originally sown seed mixes and soil type, were evaluated. Then the effects of environmental conditions and management on the establishment of the desired plant communities in sown seed mixes, developed using an evidence-informed method, for multifunctional and single-focus vegetative strips, were tested.

4-2 Methods

4-2.1 Case study on existing buffer strips in England

Landowners were contacted via staff and student networks associated with Harper Adams University (a major UK Higher Education Institution within the land-based sector). Once a potential lead had been identified, the landowner was contacted and informally questioned about their buffer strips. If a landowner had a vegetative strip alongside a watercourse on their land and possession of a history of management they were deemed suitable for inclusion in the study and they progressed to the next stage. This method of selection of sites and landowners could not be randomised as they were included in the study on a voluntary basis. To address this potential bias full histories of the sites were collected and bias is acknowledged in the analysis of the data. Questionnaires were distributed to 32 volunteer landowners in five counties across the Midlands, Great Britain. The questions sought to gain information on their buffer strips, including sown seed mixes, management, age, width, adjacent watercourse and soil type. A copy of the distributed questionnaire can be found in Additional File 4-1. If a complete history of all of the above parameters was gathered for the buffer strips on the holding, then it was included in the study. In total, 26 farms were included and farm locations were mapped out using ArcGIS (ESRI, 2011). All buffer strips were surveyed between 1st and 12th August 2016, to capture an impression of the plant communities at the peak of plant growth. A linear transect was walked through the middle of each buffer strip and DAFOR scores were applied to any discovered plant species (Wheater et al., 2011). Scores were applied as follows: D: Dominant (>75% cover), A: Abundant (51-75% cover), F: Frequent (26-50% cover), O: Occasional (11-25% cover), R: Rare (<11% cover). Plant species richness, community variation, dominant species and proportions of grasses to forbs were also recorded. A GPS location and sample photos of the recorded plant species and the whole buffer strip were taken.

4.-2.1.1 Statistical analyses

All analyses for the case study data were conducted in Minitab 18. A Mixed Effects Model with the Kenward-Roger approximation was used to analyse the effect of the multiple random and fixed effects of the known variables (farm, soil type, seed mix type and buffer strip age) on species richness and proportional percentage cover of forbs observed.

4-2.2 Field experiment using designed vegetative strip seed mixes

4-2.2.1 Vegetative strip seed mixes

Five different seed mixes of UK plant species were designed using a ranking methodology developed using systematically collated evidence on plant traits (see Chapters, 2 and 3). These included three different multifunctional mixes to support pollination, bio-control and water quality protection concurrently, one designed for establishment in all soil types (MVS), another for sandy loam soils (MVS_s) and the third for heavy clay (MVS_c). Single-focus mixes were also developed to support pollination (PSVS), and to protect water quality (WQVS). For comparison, a commercially available example of a multifunctional seed mix (OPVS) was included. A list of the plant species included in each of the seed mixes can be found in Table 4-1. In addition, another multifunctional mix for all soils was sown, to test the effect of alternative management on establishment (MVS_M) and the same species mix with 50% forbs and 50% grasses, sown at a lower sowing rate of $1g/m^2$ (MVS_H), to test the effect of forb proportions on establishment. Other seed mixes that contained a mixture of forbs and grasses consisted of 20% forbs and 80% grasses, as is commonly used for such seed mixes (e.g. Syngenta, 2014; Buglife, 2018; Kings Seeds, 2018; Emorsgate Seeds, 2018).

Table 4-1 Seed mixes, relevant codes and included plant species and their percentage weight contribution. MVS, MVS_H & MVS_M - Multifunctional for all soil types ($_H$ = 50% forbs, 50% grasses & lower sowing rate; $_M$ = alternative management), MVS_S - Multifunctional for sandy loam soils, MVS_C – Multifunctional for heavy clay soils, WQVS – Water quality protection, PSVS – Pollination support and OPVS – Operation Pollinator (commercially available multifunctional example).

	Plant species	Percentage weight contribution to the following seed mixes:						
		MVS & MVS_M	MVS_H	MVS_S	MVS_C	WQVS	PSVS	OPVS
Forbs	*Achillea millefolium*	2.00	5.00	2.00	2.00			2.00
	Centaurea nigra	2.00	5.00	4.00	3.00		12.50	2.00
	Daucus carota ssp carota	2.00	5.00					3.00
	Frageria vesca			2.00				
	Galium album							2.00
	Heracleum sphondylium			1.00	1.00		4.00	
	Hypochaeris radicata	0.50	1.25	0.50			0.25	
	Leontodon hispidus						12.00	
	Leucanthemum vulgare	2.00	5.00		2.00		12.50	2.00
	Lotus corniculatus	2.00	5.00	3.00	2.00			
	Primula vulgaris	0.50	1.50		1.00		2.00	
	Ranunculus acris	2.00	6.25		3.00		12.25	2.00
	Silene dioica	2.00	5.00				12.00	2.00
	Stachys sylvatica	1.00	2.50		2.00			2.00
	Succisa pratensis			2.50				
	Taraxacum officinale agg.	2.00	5.00	5.00	2.00		10.00	
	Trifolium pratense	0.50	1.25	1.00	1.00		10.00	1.00
	Trifolium repens	0.50	1.25	1.00	1.00		10.00	
	Veronica chamaedrys	0.50	1.00					
	Vicia cracca			0.75				2.00
Grasses	*Agrostis capillaris*	10.00	6.25	5.00	5.00	10.00		
	Alopecurus pratentsis					30.00		
	Cynosurus cristatus			30.00	30.00			
	Dactylis glomerata	10.00	6.25	10.00	10.00	15.00		10.00

	Festuca rubra	50.00	31.25	25.00	20.00			30.00
	Phleum pratense					30.00		10.00
	Schedonorus arundinaceus					15.00		10.00
	Schedonorus pratensis	10.00	6.25	10.00	15.00			20.00

4-2.2.2 Study sites and plot management

In April 2015 the eight seed mixes were hand-sown with five replicates in a randomised-block design on sandy loam soil at Harper Adams University, Shropshire, England (52.7795° N, 2.4271° W) and on heavy clay soil at the Game and Wildlife Conservation Trust Loddington Farm, Leicestershire, England (52.6135° N, 0.8361° W). All seed mixes were sown at 2 g/m^2, apart from the pollinator support strip (PSVS) and the multifunctional strip with 50% forbs and 50% grasses (MVS_H), which were sown at 1 g/m^2 (due to the increased forb proportions), on 4m by 4m plots with a 1m grass buffer in-between. After a month of initial growth, the plots at both sites were carefully hand-weeded for non-sown plant species between May and June 2015, to aid the establishment of the sown species. The plots were also cut twice in 2015 (August & October), and then once in 2016 (September) and 2017 (October). The cuttings were removed from each site after every cut. In addition to this, all plots apart from the multifunctional strip with alternative management (MVS_M), were weed-wiped with Pastor Pro (Dow AgroSciences Ltd, 2014) prior to being surveyed in June 2016.

4-2.2.3 Vegetative surveys

Between July 2015 and April 2018, the vegetative cover (percentage of ground cover) of each plant species was recorded every month. Vegetative cover could total more than 100% due to overlap amongst the plant canopies. Surveys were conducted within two days to ensure that very little plant growth occurred within the surveying period. All surveys were undertaken by one researcher, to ensure consistency in the measurements taken.

4-2.2.4 Statistical analyses

All analyses were conducted in R version 3.4.4. We evaluated the effect of vegetative strip type on vegetative cove, plant community height rand root structural density with repeated measures ANOVAs. Specific elements of vegetative cover were analysed including percentage cover of sown species, percentage bare ground, proportion of cover from forb species and plant species richness. *Post hoc* (LSD) tests were performed for significant factors in the analyses. All ANOVA assumptions were achieved. Sown species percentage cover and percentage bare ground were arcsine square root transformed to achieve normality.

4-3. Results

4-3.1 Case study on existing buffer strips in England

Cutting was the preferred method of buffer strip management by farmers as 95% of the 37 buffer strips were cut once or twice a year with the exception of one buffer which had no management and one which was regularly grazed. The majority of buffers (76%) were between 2 and 6 metres wide, but the others ranged up to 24 metres wide. The youngest buffer strip was 2 years old and the oldest, 70 years old. The most buffer strips (41%) of one age were found at 10 years old.

The fit of each model and the effects of farm, soil type, buffer strip age and seed mix type on plant species richness and proportional cover of forbs can be seen in Table 4-2. In each model less than 72% of error is accounted for. This is due to the wide variation in the data and indicates further data points are needed to increase the reliability of the test results. Despite this, trends can be seen in the data indicating potential effects of the variables and areas for further research.

Table 4-2 Results from Mixed effects model on plant species richness, proportions of grasses and forbs.

	Farm	Soil type	Buffer strip age	Seed mix type	Model fit
Plant species richness	$Z_{7.0} = 1.94$, $P = 0.027$	$F_2 = 1.06$, $P = 0.365$	$F_{21.9} = 0.23$, $P = 0.633$	$F_2 = 0.24$, $P = 0.788$	S = 3.0, R-sq(adj) = 71.5%
Forb species proportional cover	$Z_{131.7} = 0.28$, $P = 0.388$	$F_2 = 0.85$, $P = 0.444$	$F_{28.25} = 1.74$, $P = 0.197$	$F_2 = 0.05$, $P = 0.948$	S = 23.9, R-sq(adj) = 6.1%

4-3.1.1 Plant species richness

A total of 63 different plant species were observed across the buffer strips, ranging from 2 to 23 species per strip, see Figure 4-1. Over half (51%) of surveyed buffer strips were on a clay soil, 27% on loam soil and 22% on sandy soil. Identical management of buffer strips on the same farm did not guarantee similar species richness on both clay and loam soils. For example, on one farm on clay soil all buffer strips were left to natural regeneration 10 years prior and cut once a year, but their species richness ranged from 4 to 14.

On clay soil a positive trend with species richness and buffer strip age was indicated for vegetative strips sown with a pollinator mix and those left to natural regeneration (Figure 4-1). Surprisingly, the highest species richness on clay soil (22) was found in a buffer strip sown with a grass mix and the lowest (2) in a strip sown with a pollinator mix.

The mean species richness found on buffer strips sown with a grass mix on a clay soil (16) was higher than those sown on loam (10) or sandy (11) soils. An even more marked difference was observed in buffers sown with a pollinator seed mix where the mean species richness was highest on loam soils (19) when compared to those sown on clay (10) or sandy (12) soils. In addition, the highest mean species richness for buffers left to natural regeneration was found in sandy soils (15) when compared to those on clay (7) and loam soils.

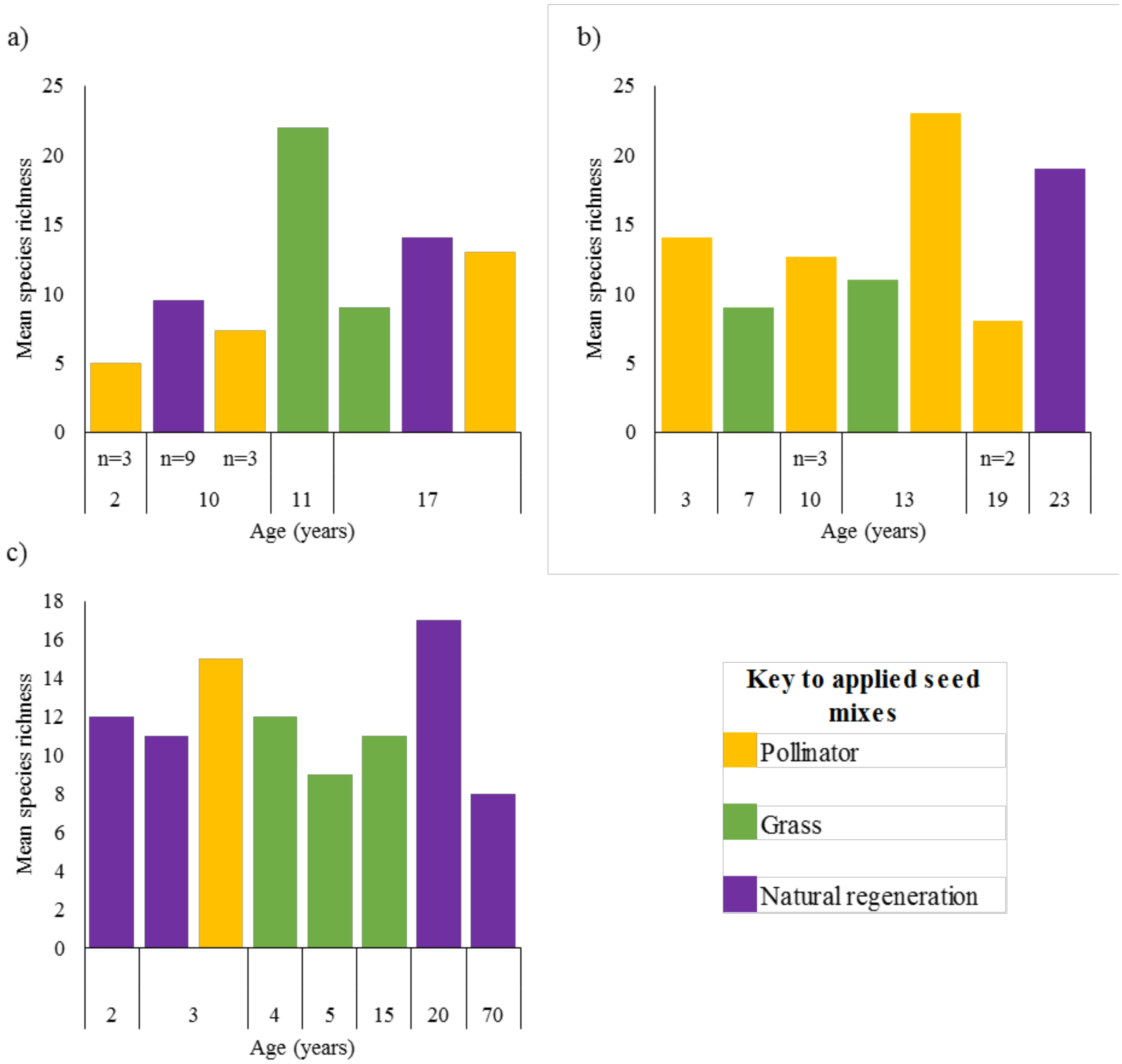


Figure 4-1 Mean species richness of vegetative cover at different ages on a) clay, b) loam and c) sandy soils. Where there was more than one buffer strip contributing to the mean, the number of buffer strips (n) are presented on the x-axis.

4-3.1.2 Proportion of cover provided by forbs

Of the buffer strips sown on clay soil, 75% had less than 50% forb cover. There were no obvious trends in these proportions relating to buffer strip age for clay soil as even younger buffer strips had low proportions of forbs, see Figure 4-2.

Higher proportions of forbs were observed in the buffer strips on a loam soil when compared with those on clay soil, but 60% of buffer strips on loam soil were still observed to have less than 50% forb cover. Whilst only eight buffer strips were surveyed on sandy soil, over half (57%) still had less than 50% forb cover. These data indicated no effect of buffer strip type on the proportion of cover provided by of forbs, see Figure 4-2, and there is an indication that forb proportions decline over time in all vegetative strip types.

Key differences were observed in the overall means of forb proportions. The highest overall mean proportion of forbs was found in the pollinator mix sown on sandy soils at 80%, whilst the lowest was this same mix, but on clay soils, at 31%. This trend was not apparent in buffer strips left to natural regeneration or those sown with a grass mix as the highest overall proportion of forbs was actually found on clay soils for buffers sown with a grass mix (60%) and buffer strips left to natural regeneration (45%).

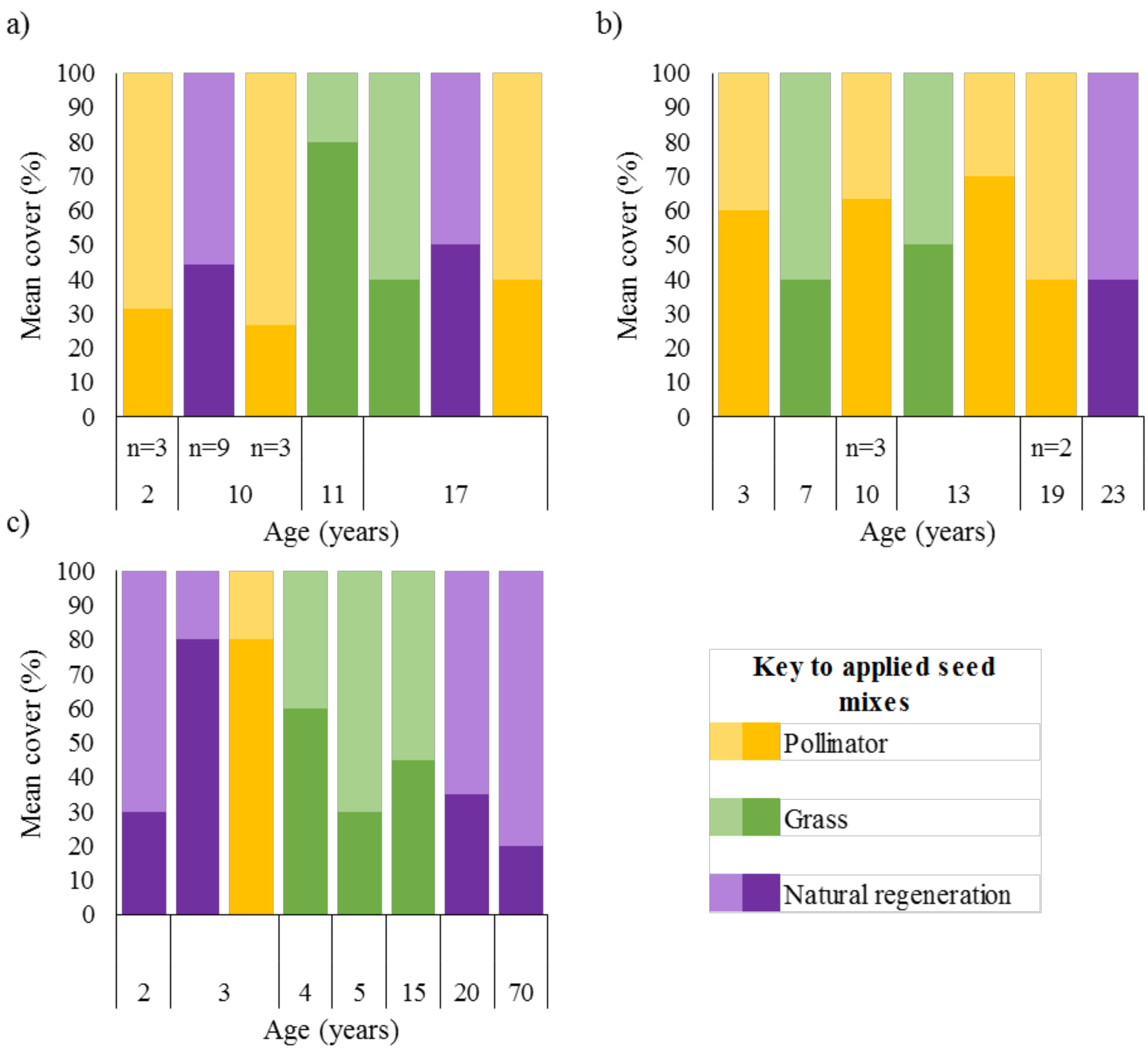


Figure 4-2 Mean percentage vegetative cover at different ages on a) clay, b) loam and c) sandy soils. In each bar, forbs are presented as the darker shade and grasses as the paler. Where there was more than one buffer strip contributing to the mean, the number of buffer strips (n) are presented on the x-axis.

4-3.2 Field experiment of different vegetative strip seed mixes

At the Harper Adams site on sandy loam soil, survey month significantly affected the differences between the vegetative strip types (Table 4-3). In contrast, at the Loddington site on heavy clay soil, there was only a significant effect of survey month on the proportion of cover provided by forb species found in each vegetative strip. Where there was a significant effect of survey month, the results from the analysis of each month can be found in Additional File 4-2 and 4-3.

Table 4-3 Results from repeated measures ANOVA analyses on each site - Harper Adams University and Loddington.

Element of vegetative cover	Site	Vegetative strip type	Survey month	Vegetative strip type* survey month
Sown species proportional cover	Harper Adams	$F_{4,7}$ = 195.44, $P < 0.001$	$F_{4,33}$ = 90.86, $P < 0.001$	$F_{4,231}$ = 3.07, $P < 0.001$
	Loddington	$F_{4,7}$ = 112.34, $P < 0.001$	$F_{4,33}$ = 15.91, $P < 0.001$	$F_{4,231}$ = 1.14, $P = 0.091$
Percentage bare ground	Harper Adams	$F_{4,7}$ = 22.58, $P < 0.001$	$F_{4,33}$ = 95.91, $P < 0.001$	$F_{4,231}$ = 2.64, $P < 0.001$
	Loddington	$F_{4,7}$ = 5.18, $P < 0.001$	$F_{4,33}$ = 95.78, $P < 0.001$	$F_{4,231}$ = 0.48, $P = 1$
Forb species proportional cover	Harper Adams	$F_{4,7}$ = 342.30, $P < 0.001$	$F_{4,33}$ = 270.15, $P < 0.001$	$F_{4,231}$ = 3.42, $P < 0.001$
	Loddington	$F_{4,7}$ = 354.18, $P < 0.001$	$F_{4,33}$ = 52.73, $P < 0.001$	$F_{4,231}$ = 1.28, $P = 0.007$
Plant species richness	Harper Adams	$F_{4,7}$ = 184.82, $P < 0.001$	$F_{4,33}$ = 185.60, $P < 0.001$	$F_{4,231}$ = 1.19, $P = 0.040$
	Loddington	$F_{4,7}$ = 73.52, $P < 0.001$	$F_{4,33}$ = 50.70, $P < 0.001$	$F_{4,231}$ = 1.15, $P = 0.081$

4-3.2.1 Proportion of percentage cover provided by sown species

Across the survey period at both sites, the pollinator support vegetative strip (PSVS) had a consistently lower mean proportion of sown species than the other vegetative strips (Figure 4-3). On the Harper Adams site on sandy loam soil, the overall cover from sown species steadily increased over time for all vegetative strips, apart from the pollinator strip (PSVS). In contrast, at the Loddington site on heavy clay soil, there was little to no change. Targeting the multifunctional vegetative strips towards specific soil types did not significantly affect their establishment as there were no significant differences between the multifunctional vegetative strips designed for sandy loam (MVS_S) and heavy clay (MVS_C) soil at either site. On the Harper Adams site on sandy loam soil the multifunctional strip designed for all soils (MVS) had a consistently higher proportion of sown species cover than the multifunctional strip for sandy loam soils (MVS_S) and it was comparably similar to the multifunctional strip for heavy clay soils (MVS_C) at both sites. The water quality protection vegetative strip (WQVS) had a consistently higher proportion of sown species than the other vegetative strips across the survey period on the Loddington site on heavy clay soil, however it was consistently lower on the Harper Adams site on sandy loam soil.

The weed-wiping in June 2016 had no effect on the proportion of sown species in the multifunctional strips as the multifunctional strip that was not weed-wiped (MVS_M), was never significantly different to the multifunctional vegetative strip that was weed-wiped (MVS).

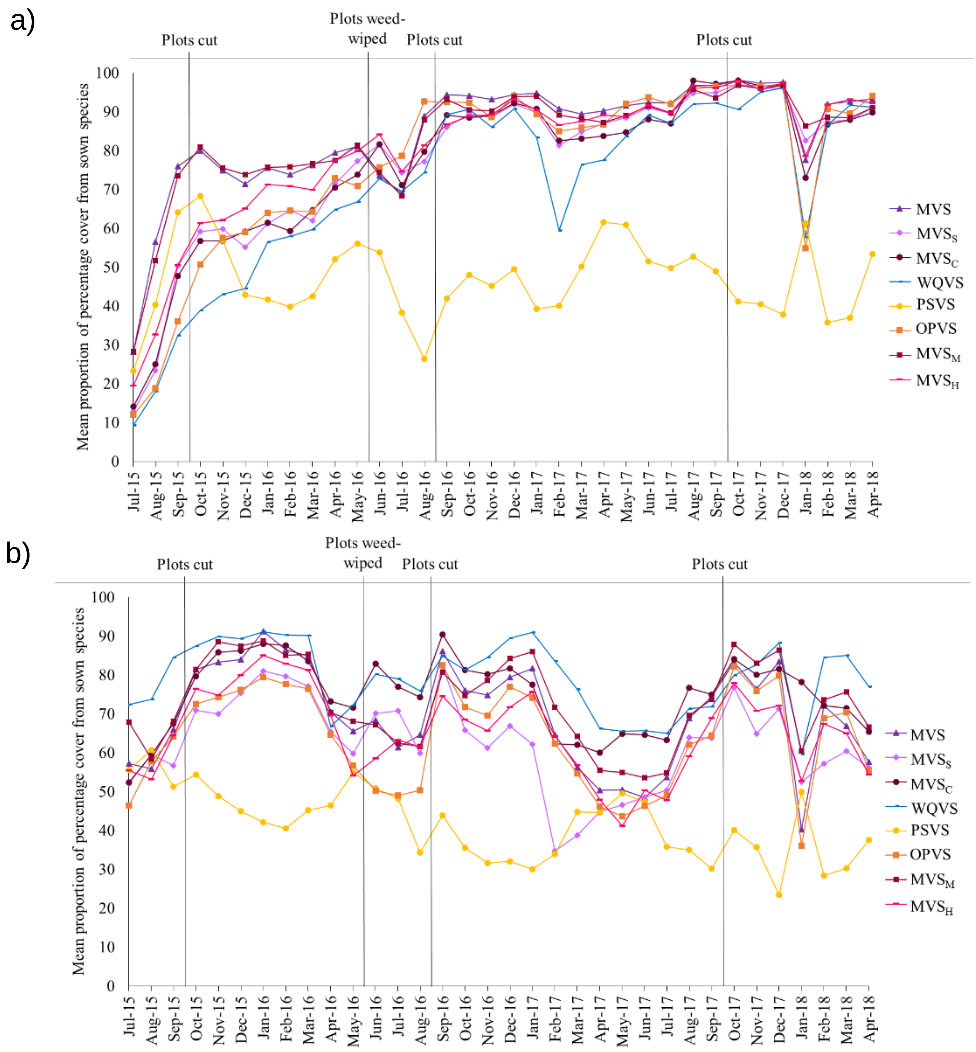


Figure 4-3 Mean proportion of percentage cover from sown species at sites a) Harper Adams University on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as: MVS = Multifunctional strip for all soil types, MVS_H =

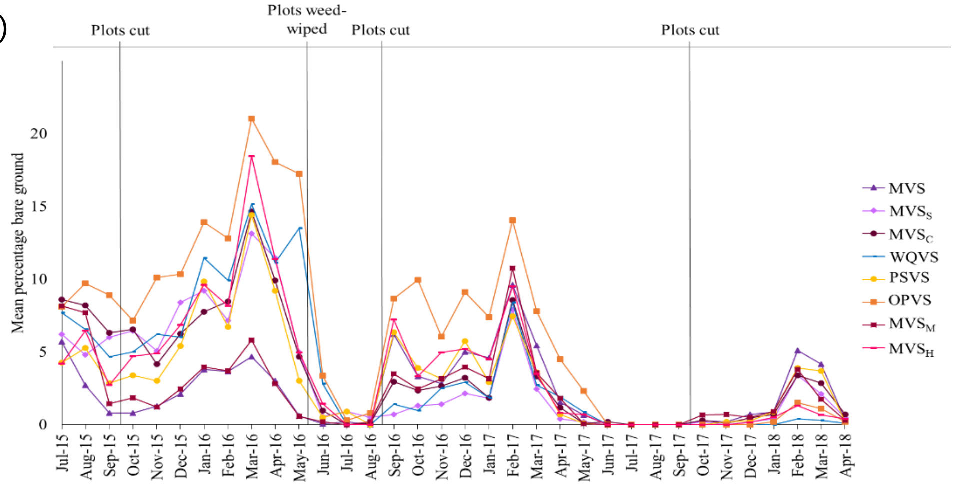
Multifunctional strip for all soil types with 50% forbs and 50% grasses and a lower sowing rate, MVS_M = Multifunctional for all soil types with no weed-wiping, MVS_S = Multifunctional for sandy loam soils, MVS_C = Multifunctional for heavy clay soils, WQVS = Water quality protection (100% grasses), PSVS = Pollination support (100% forbs) and OPVS = Commercial example of multifunctional strip. Unless stated otherwise, seed mixes were sown with 20% forbs and 80% grasses. Management was undertaken at the dates indicated on the graph.

4-3.2.2 Percentage bare ground

At the Harper Adams site on sandy loam soil, in the first winter and spring after establishment, there was 10-20% less bare ground in the multifunctional vegetative strips (MVS & MVS_M), than the other strips, see Figure 4-4. At this same site, the commercial example of a multifunctional strip (OPVS) had consistently more percentage bare ground than the other vegetative strips for the majority of the survey period.

The percentage bare ground in the vegetative strip for water quality protection (WQVS) on the Loddington site on heavy clay soil was significantly lower over the late winter months than the other vegetative strips apart from the multifunctional vegetative strip that had alternative management (MVS_M). The highest percentage bare ground was found in the vegetative strip for pollinator support (PSVS) during this season.

a)



b)

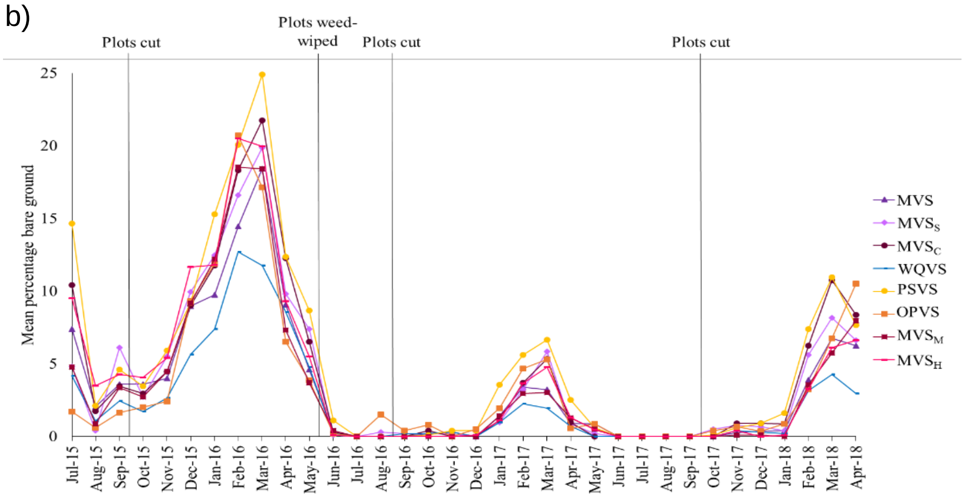


Figure 4-4 Mean percentage bare ground at sites a) Harper Adams University on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as:

MVS = Multifunctional strip for all soil types, MVS_H = Multifunctional strip for all soil types with 50% forbs and 50% grasses and a lower sowing rate, MVS_M = Multifunctional for all soil types with no weed-wiping, MVS_S = Multifunctional for sandy loam soils, MVS_C = Multifunctional for heavy clay soils, WQVS = Water quality protection (100% grasses), PSVS = Pollination support (100% forbs) and OPVS = Commercial example of multifunctional strip. Unless stated otherwise, seed mixes were sown with 20% forbs and 80% grasses. Management was undertaken at the dates indicated on the graph.

4-3.2.3 Proportion of percentage cover provided by forbs

At both sites, the pollinator support vegetative strip (PSVS) had the highest forb cover consistently and the water quality protection vegetative strip (WQVS) had consistently less forb cover, see Figure 4-5. After the pollinator support vegetative strip (PSVS), the multifunctional mix with increased forb proportions and a lower sowing rate (MVS_H), had the next highest forb cover at both sites and was distinctly higher than the remaining vegetative strips.

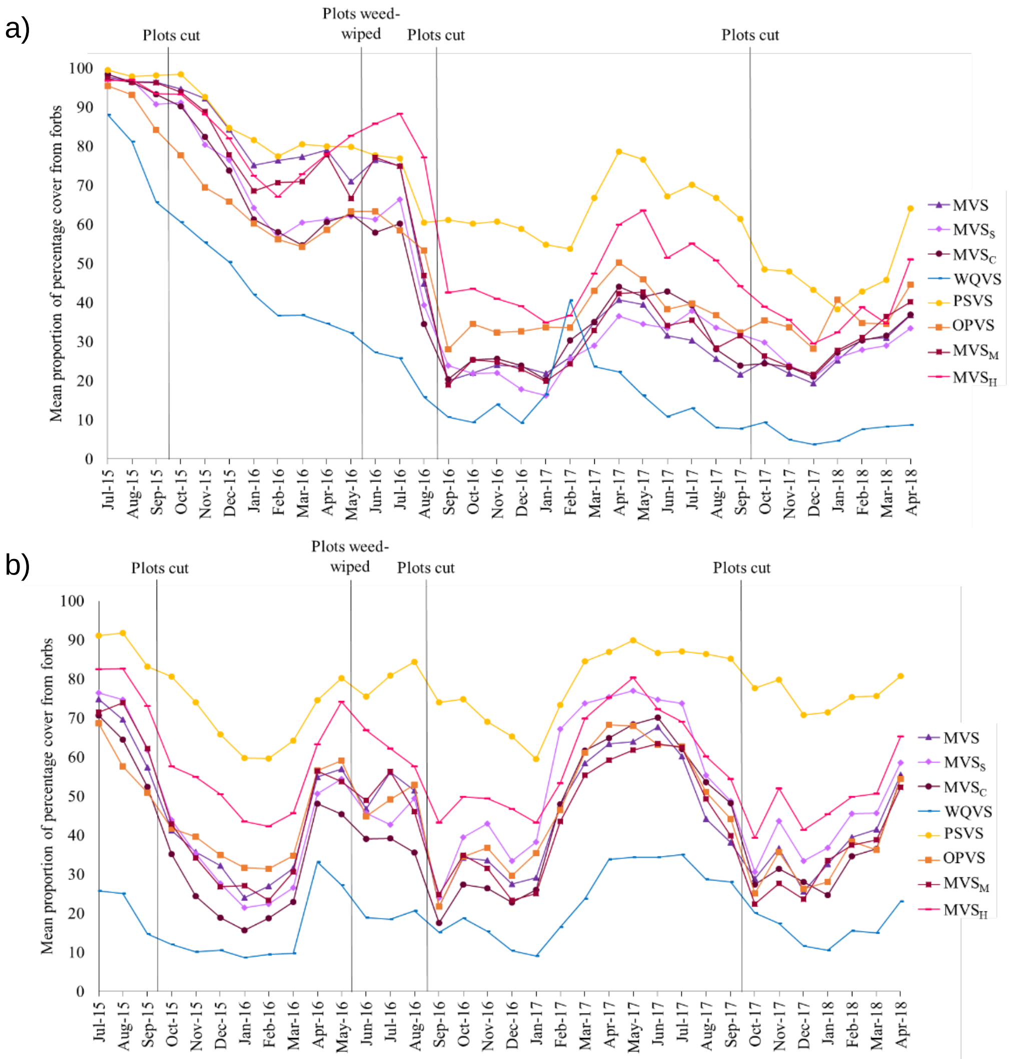


Figure 4-5 Mean proportion of percentage cover from forbs at sites a) Harper Adams University on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as: MVS = Multifunctional strip for all soil types, MVS_H = Multifunctional strip for all soil types with 50% forbs and 50% grasses and a lower sowing rate, MVS_M =

Multifunctional for all soil types with no weed-wiping, MVS_S = Multifunctional for sandy loam soils, MVS_C = Multifunctional for heavy clay soils, WQVS = Water quality protection (100% grasses), PSVS = Pollination support (100% forbs) and OPVS = Commercial example of multifunctional strip. Unless stated otherwise, seed mixes were sown with 20% forbs and 80% grasses. Management was undertaken at the dates indicated on the graph.

4-3.2.4 Plant species richness

Mean plant species richness in each vegetative strip type was initially between 15 and 28 at both sites but decreased over time for all vegetative strips. Excluding the vegetative strip for water quality protection (WQVS), the species richness in all of the vegetative strips followed the same trend. Plant species richness was always significantly lower in the WQVS than all other vegetative strips at both sites and consistently highest overall in the multifunctional vegetative strip with increased forb proportions and a lower sowing rate (MVS_H), see Figure 4-6.

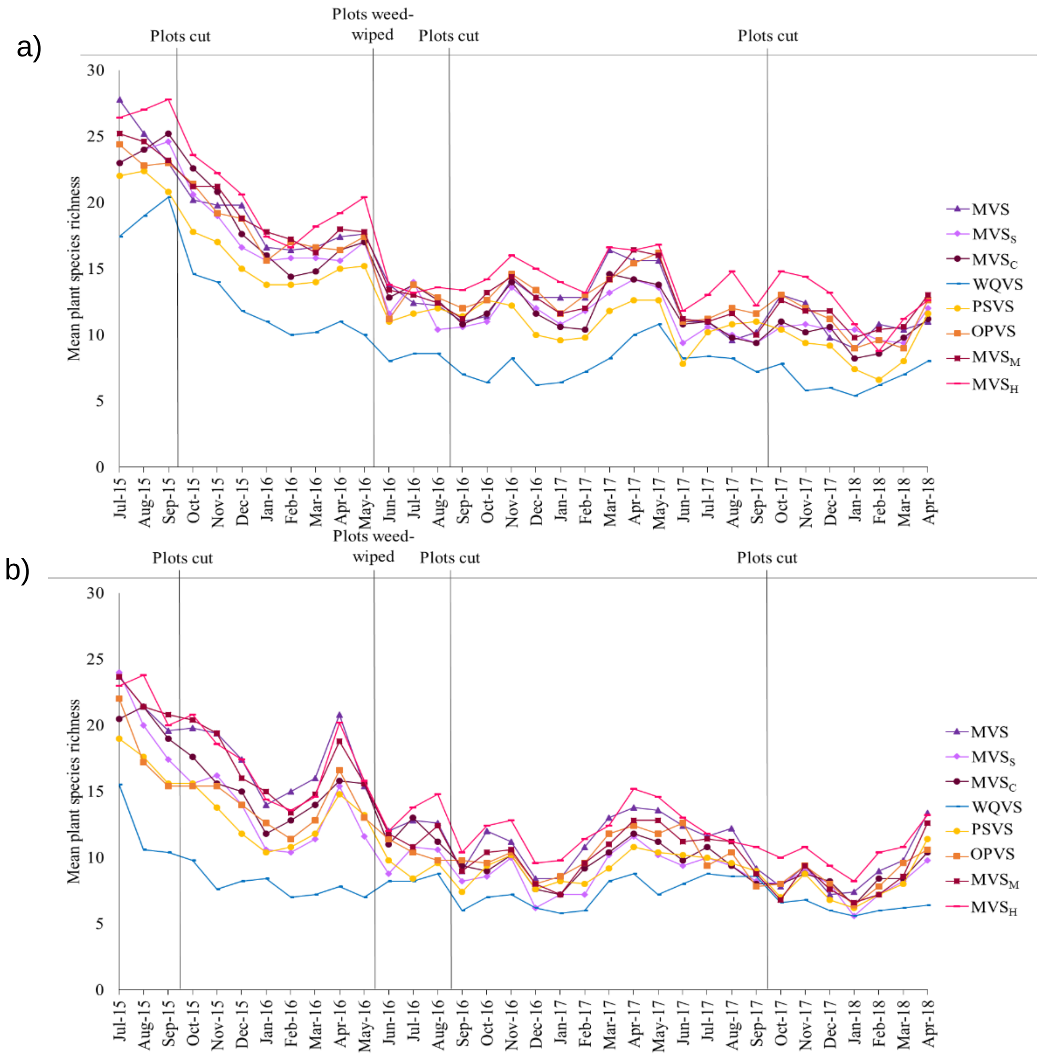


Figure 4-6 Mean plant species richness at sites a) Harper Adams University on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as: MVS = Multifunctional strip for all soil types, MVS_H = Multifunctional strip for all soil types with 50% forbs and 50% grasses and a lower sowing rate, MVS_M = Multifunctional for all soil types with no weed-wiping, MVS_S = Multifunctional for sandy loam soils, MVS_C = Multifunctional for heavy clay soils, WQVS = Water quality protection (100% grasses), PSVS = Pollination support (100% forbs) and OPVS = Commercial example of

multifunctional strip. Unless stated otherwise, seed mixes were sown with 20% forbs and 80% grasses. Management was undertaken at the dates indicated on the graph.

4-4 Discussion

The establishment of a vegetative strip is highly dependent on the seed mix sown, management undertaken, soil type and other factors such as soil seed bank and environmental conditions. Many forb species that are sown to provide floral support prefer less fertile soils (Grime et al., 2007; Syngenta, 2014; Kings Seeds, 2018; Emorsgate Seeds, 2018) and so will not establish as effectively on soils with a higher fertility. Sandy and loam soils tend to be less fertile and free-draining, whereas heavy clay soils tend to be much more fertile and slow-draining. Whist no significant effects of the sown seed mix and soil type were observed in the case study, clear overall trends were observed across vegetative strips of up to 70 years of age, on the proportion of forbs and species richness. In addition, the effects of seed mix type were discovered on the proportion of sown species and bare ground across the initial three years of establishment.

The evidence from the case study and field experiment demonstrated that lower fertility soils are likely to support the highest species richness, proportion of forb cover and proportion of sown species cover. For clay soils, which have higher fertility, the combined evidence from the case study and field experiment suggests that, in the first few years of growth, species richness in vegetative strips can be low, but if sown with a pollinator mix (which includes forb species) it can still increase over the subsequent 10-15 years. So, whilst establishment of a more diverse buffer strip on sandy loam soils may be more successful early on, there is still scope for their establishment on clay soils. Targeting a seed mix towards a specific soil type may not aid establishment as there was no significant effect in the field experiment, but, the sown species in the multifunctional vegetative strip designed for most soil types (MVS) did provide an average of 84.3% (on sandy loam soil) and 69.6% (on heavy clay soil) of the vegetative cover, throughout the three years. Other environmental factors such as weather, soil seed bank and the management of the adjacent land, are likely to influence establishment as well, and so it is recommended that only species that are robust and known to establish well on various soil types should be selected.

In the 2016 case study, the proportion of cover provided by forbs was frequently under 50% across all soil types, vegetative strips and at different ages (see Figure 4-2), with the remaining cover provided by grasses. The competitive nature of grasses and their management are extremely influential in the establishment of a botanically diverse vegetative strip. It is known that species richness tends to decrease over time due to the nature of successional changes (Huusela-Veistola and Vasarainen, 2000; Noordijk et al., 2011; Tscharntke et al., 2011). As succession takes place, grasses begin to outcompete the less-competitive wildflowers and tend to become the dominant species (Grime et al., 2007). The method of evidence-informed plant species selection in Chapter 3 facilitated the design of seed mixes that support ecosystem services, but also that could combat natural succession. Plant species were chosen based on desirable traits for the provision of ecosystem services, but also on essential characteristics for establishment as shown in Table 4-4. The effects of this method can be clearly seen in the field experiment where the water quality protection vegetative strip (WQVS), which was sown with 100% grasses had a three-year average of 19.5% forb cover (on heavy clay soil) and 26.6% (on sandy loam soil), whilst the multifunctional vegetative strip sown with 50% forbs and 50% grasses had a three-year average of 57.9% forb cover (on heavy clay soil) and 60.2% (on sandy loam soil). Increasing the proportion of forbs included in the sown seed mix also directly increased the species richness of a vegetative strip. A three year species richness average of 7.8 (on heavy clay soil) and 9.5 (on sandy loam soil) was observed for the water quality protection vegetative strip and an average of 13.9 (on heavy clay soil) and 16.3 (on sandy loam soil) for the multifunctional vegetative strip with 50% forbs and 50% grasses. Using this method of vegetative strip design allowed the development of mixes that could establish significant, species-rich forb cover that also persisted across these initial years.

Table 4-4 Plant community characteristics and environmental factors, their desirable aspect for a multifunctional vegetative strip and the justification. Adapted from Chapter 3.

Plant characteristic	Aspect	Justification
Life history	Perennial	Vegetative strips along farmland watercourses should last 5-10 years, without re-sowing, so annuals are not suitable.
Status	Native	To avoid introduction of invasive non-natives
Distribution	Regional	Well-regionally distributed will ensure seed is more widely applicable within the region
Established competitive strategy	Non-competitive	Grasses have been shown to outcompete wildflowers, so must their competitive strategy must be considered
Associated floristic diversity	High	High associated floristic diversity increase the chance of wildflowers establishing well
Flowering time and duration	Duration of beneficial invertebrate season of activity	To provide pollen and nectar sources throughout season
Soil type	Suitable for varied types	To ensure growth and good establishment of the plant

Soil pH	Suitable for varied soil pH	To ensure growth and good establishment of the plant
Suitability to native beneficial invertebrates	High	To ensure selected species provide support for the target beneficial invertebrates

There was also no significant difference in the proportion of sown species between the multifunctional vegetative strip designed for most soil types (MVS) and the same strip but with no weed-wiping in June 2016 (MVS_M) throughout the surveyed time period. This could be because some of the plants that were weed-wiped were potentially in late stage growth, where this chemical would not have been as effective. All but two of the sites in the case study were cut once or twice a year, and so further insight into the effects of management could not be gained here.

Out of all the vegetative strips sown in the field experiment, the multifunctional strip with 50% forbs and 50% grasses (MVS_H) looked to be the most successfully established vegetative strip. It consistently provided high proportions of sown species and forbs, and plant species richness, whilst having similar percentage bare ground to the other vegetative strips.

4-5 Conclusions

The preliminary 2016 case study gives valuable but limited insight into the effects of age, management and seed mix type on buffer strip plant communities across three broad soil types. The field experiment allowed further insight into the effects on plant species selection on the early establishment of a more diverse and functional buffer strip. The findings demonstrate that using a structured, evidence-based decision-making tool when selecting plant species for vegetative strips, can affect their initial establishment and overall resulting plant communities. Also, the management of a vegetative strip, especially of grasses, is vital for the long-term persistence of a diverse plant community. Grasses can be managed with frequent cutting and the removal of cuttings after each cut, but this is much more time-consuming work. This is where the Results Based Agri-environment Payment Scheme (RBAPS) (Natural England, 2017), for land managers could be a valuable incentive for the continued maintenance of a diverse buffer strip.

Further trials of the developed multifunctional seed mixes on different soil types and at a larger landscape-scale could provide additional insight into the establishment and long-term persistence of vegetative strips.

Chapter 5. Support for pollinators in farmland: A comparison of multifunctional and single-focus vegetative strips

Abstract

Habitat loss, partly stimulated by agricultural intensification over the past 60 years, has caused parallel declines in pollinators and insect pollinated plants. This has directly reduced crop pollination services, and deficits have been observed in crops such as sweet cherry, watermelon and oil-seed rape. A widely-used method to return support for pollinators to farmland is the sowing of vegetative strips in field margins. However, reduced land availability and increased food production requirements has led to a need for increased functionality from all farmland vegetative strips. The concern with this is that an increase in functionality could potentially compromise the support provided for pollinators.

From April 2015, in a three year experiment, on two distinct sites, using seed mixes developed with a standardised, evidence-informed method (Chapter 3), the floral support of multifunctional vegetative strips (one with 50% forbs and 50% grasses and one with 20% forbs and 80% grasses) and a commercially available multifunctional strip, was compared to a single-focus strip (100% forbs) for pollinators. Pollinator visitation preferences to the forb species included in these strips was also investigated. Floral cover and richness was surveyed monthly and pollinator visitation surveys were conducted in Spring & Summer 2016 and 2017.

Overall pollinators made the most visits to *Achillea millefolium, Centaurea nigra, Daucus carota, Heracleum sphondylium* and *Leucanthemum vulgare.* These all had large floral displays, which was a key trait for pollinators identified and used in Chapter 3.

An increase in the functionality of a vegetative strip was found to positively affect the support provided for pollinators, depending on the proportion of forbs sown. The multifunctional vegetative strip with 50% forbs and 50% grasses provided the most floral support at both sites with the most variety and the most preferred plant species by pollinators.

The findings from this study could begin to inform policy makers and land-owners on how to begin to increase the functionality of a vegetative strip and enhance support for pollinators at the same time.

In prep: Cresswell, C.J., Wilcox, A., Cunningham, H.M., Randall, N.P. Support for pollinators in farmland: A comparison of multifunctional and single-focus vegetative strips. Intended for submission to: Agriculture, Ecosystems and Environment.

5-1 Introduction

The intensification of agricultural practices to meet food production requirements (Robinson and Sutherland, 2002; Godfray et al., 2010; Stutter et al., 2012; Hackett & Lawrence, 2014), has led to declines in farmland wildlife (Sotherton, 1998; Robinson and Sutherland, 2002; Benton et al., 2003), and ecosystem services, such as crop pollination (Kevan and Phillips, 2001; Kremen et al., 2002; Garratt et al., 2014). In Britain, parallel declines in pollinators and insect pollinated plants have been observed (Biesmeijer et al., 2006), caused by habitat loss which has been stimulated by the intensification of agriculture (Brown and Paxton 2009; Williams and Osborne 2009; Winfree et al., 2009).

Insect pollinators benefit 87 different crops globally and the provision of these services is of great value to farmers (Aizen et al., 2009). Declines in bumblebees and honeybees could decrease yield in oil-seed rape as they are known to be the most effective pollinators for this crop, which is grown in several countries such as Canada, China, India, Australia and across Europe (Stanley et al. 2013; FAO, 2017). Other crops such as watermelon, have suffered a pollination deficit caused by declines in bee diversity due to reduced floral and nesting resources (Kremen et al., 2002), and sweet cherry have been shown to have a much lower yield when not pollinated by insects (Holzschuch et al., 2012).

A widely-used method to return support for pollinators to farmland is the sowing of vegetative strips in field margins (Carvell et al., 2004; Lye et al., 2009; Haaland, et al., 2011). When sufficient support for pollinators is present in off-crop habitats, increased yields in insect pollinated crops have been observed (Kremen et al., 2002; Holzschuch et al., 2012). When compared with the crop, wildflower strips have been shown to support a higher insect biodiversity (Pywell et al., 2006; Haaland et al., 2011). Furthermore, the frequency of pollinator visits to crops has been shown to increase in fields with adjacent wildflower strips (e.g. in strawberry crops in Feltham et al., 2015). In addition, there is some evidence that wildflower strips can support other beneficial insect species, such as natural enemies of crop pests (e.g. Grass et al., 2016). In fact, Tschumi et al. (2016) observed that when wildflower strips were sown adjacent to winter wheat fields this resulted in a reduction in cereal leaf beetle numbers which led to a 40% reduction in crop damage from pests and a 10% increase in crop yield. This potential to increase the functionality of a vegetative strip could be useful in the face of further pressures which are now facing agriculture, including reduced land availability and continued increases in food production requirements for an expanding human population and climate change (Godfray et al., 2010; UN DESA, 2015).

One opportunity could be to increase the functionality of vegetative strips sown adjacent to farmland watercourses to protect water quality from pollution via soil erosion, run-off and pesticide spray-drift (Kuivila and Foe, 1995; Thorburn et al., 2003; Reichenberger et al., 2007; Tang et al., 2015). These are often sown with a simple grass seed mix, but there is evidence to show that the efficacy of the strip to protect water quality may not be affected when other plant species are included (Mayer et al., 2007). Consequently, there may be scope to include wildflowers in these vegetative strips so that they may provide support for other ecosystem services such as crop pollination and bio-control.

To test the potential of a multifunctional vegetative strip a standardised method of vegetative strip design was developed, based on plant traits and used this to produce seed mixes for multifunctional and single-focus vegetative strips (Chapters 2 and 3).

In this study the following questions are addressed: (i) How does functionality of a vegetative strip affect the floral support provided to pollinators? (ii) What plant species received the most visits by different pollinator groups? (iii) What vegetative strip type provided the plant species that were most visited by pollinators?

5-2 Methodological approach

This study is part of a three-year experiment which investigated the effects of eight different vegetative strips on the establishment and persistence of plant communities (Chapter 4) and provision for pollinators, natural enemies of crop pests and water quality protection. Seven of the vegetative strips were developed using evidence on plant traits that was systematically collated (Chapters 2 and 3), and the last was a commercial example of a multifunctional vegetative strip. A full methodology of all of the vegetative strip seed mixes, study sites, plot management and vegetative surveys can be found in Chapter 4, a summary of those methods is included here as well as the additional methods used in this experiment.

5-2.1 Vegetative strip seed mixes

In this study, four different seed mixes of perennial UK plant species were considered, three of which were designed using a plant species ranking methodology that was developed using systematically collated evidence on plant traits (Chapters 2 and 3). These included two multifunctional seed mixes designed to support pollination, bio-control and water quality protection. The same plant species were included in both of these, but one consisted of 20% forbs and 80% grasses (MVS) and one of 50% forbs and 50% grasses (MVS_H). This was to investigate whether the different proportions of forbs and grasses would affect the support provided. This was a key comparison as standard practice is to include only 20% forbs, and 80% grasses, mainly to reduce the cost of the seed mix (e.g. Syngenta, 2014; Buglife, 2018; Kings Seeds, 2018; Emorsgate Seeds, 2018), Lastly, a single-focus seed mix of 100% forb species for pollinator support (PSVS), was designed. Both the MVS_H and PSVS had a lower sowing rate of $1g/m^2$, due to the higher proportion of forbs and associated increased cost of the seed mix. An additional mix was included to compare the designed seed mixes to a commercially available mix. This was a multifunctional mix from Syngenta's Operation Pollinator programme (Syngenta, 2014). A list of plant species included in the designed seed mixes and the commercially available example can be found in Table 5-1.

Table 5-1 Seed mixes, relevant codes, included plant species and their percentage weight contribution. MVS - Multifunctional vegetative strip for all soil types (20% forbs, 80% grasses), MVS_H - Multifunctional vegetative strip for all soil types (50% forbs, 50% grasses & lower sowing rate), PSVS – Pollination support and OPVS – Operation Pollinator (commercially available multifunctional example).

	Plant species	Percentage weight contribution to the following seed mixes:			
		MVS	MVS_H	PSVS	OPVS
Forbs	*Achillea millefolium*	2.00	5.00		2.00
	Centaurea nigra	2.00	5.00	12.50	1.00
	Daucus carota ssp carota	2.00	5.00		3.00
	Galium album				2.00
	Heracleum sphondylium			4.00	
	Hypochaeris radicata	0.50	1.25	0.25	
	Leontodon hispidus			12.00	
	Leucanthemum vulgare	2.00	5.00	12.50	2.00
	Lotus corniculatus	2.00	5.00		
	Primula vulgaris	1.00	1.50	2.00	
	Ranunculus acris	2.00	6.25	12.25	2.00
	Silene dioica	2.00	5.00	12.00	2.00
	Stachys sylvatica	1.00	2.50		2.00
	Taraxacum officinale agg.	2.00	5.00	10.00	
	Trifolium pratense	0.50	1.25	10.00	1.00
	Trifolium repens	0.50	1.25	10.00	
	Veronica chamaedrys	0.50	1.00	2.50	
	Vicia cracca				2.00
Grasses	*Agrostis capillaris*	10.00	6.25		
	Alopecurus pratentsis				
	Dactylis glomerata	10.00	6.25		10.00

	Festuca rubra	50.00	31.25		30.00
	Phleum pratense				10.00
	Schedonorus arundinaceus				10.00
	Schedonorus pratensis	10.00	6.25		20.00

5-2.2 Study sites and experimental design

In April 2015, the seed mixes were hand-sown with five replications in a randomised-block design on sandy-loam soil at Harper Adams University, Shropshire, England and on heavy clay soil at Game and Wildlife Conservation Trust Loddington Farm, Leicestershire, England. The multifunctional vegetative strip with 20% forbs and 80% grasses (MVS) and the commercial example of a multifunctional strip (OPVS) were sown at 2 g/m^2 and the multifunctional strip with 50% forbs and 50% grasses (MVS_H) and pollinator support vegetative strip (PSVS) at 1 g/m^2, on 4m by 4m plots with a 1m sown grass buffer in-between.

5-2.3 Floral cover and pollinator visitation surveys

Starting on 20th July 2015, percentage floral cover (% ground cover) of each plant species, as a measure of floral support for pollinators, was recorded every month. Percentage floral cover was also recorded on the same day as each pollinator survey, in addition to the monthly surveys, so that the influence from this variable could be included in the final analysis.

Pollinator visitation surveys were conducted during Spring and Summer in 2016 and 2017. At Harper Adams, five full surveys of the site were conducted in 2016 and 13 in 2017. At Loddington, 17 full surveys were conducted in 2017. The observer stood at each corner of a randomly selected plot, in a randomly selected block, for one minute. This was repeated for each plot on the site. The observer watched any pollinators that visited a plant and recorded the pollinator species and the plant species it visited. Pollinator species were collated into groups including ‘Hoverflies’, ‘Other flies’, ‘Beetles’, ‘Solitary bees’, ‘Bumblebees’, ‘Honeybees’, ‘Wasps’, ‘Moths’ and ‘Butterflies’. A ‘pollinator visit’ was defined as any collection of pollen or nectar by the insect, no scoping flights were included. Surveys were conducted approximately 10 days apart and only between 10am and 4pm on dry, sunny days with an ambient temperature above 15°C.

5-2.4 Statistical analyses

All analyses were conducted in R version 3.4.2. We evaluated the effect of vegetative strip type on percentage floral cover and floral species richness with repeated measures ANOVAs. *Post hoc* (LSD) tests were performed for significant factors in the analyses. All ANOVA assumptions were achieved. A general linear model (GLM) was used to analyse the pollinator visitation data, with either a poisson or quasipoisson distribution, depending on the level of dispersion in the data. Visits to each plant species were analysed as a whole and then also split into the individual pollinator groups. The identification of the different observers was included in the analysis and was found to have no significant effect on pollinator visitation rates made to different plant species.

Pollinator species group richness and diversity were calculated and analysed using the GLM.

Pollinator species group diversity was calculated with the Shannon diversity index using the following equation:

$$Shannon\ diversity\ Index\ (H) = -\sum_{i=1}^{s} p_i \ln p_i$$

where *p* is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N) and s is the number of species.

5-3 Results

5-3.1 Floral resources

5-3.1.1 Percentage floral cover

A significant interaction ($F_{4,7} = 5.14$, $P < 0.001$) between survey month and vegetative strip type for floral cover was observed, due to this, floral cover was analysed for each month individually. Across the three years there was less overall floral cover in the vegetative strips at Loddington than at Harper Adams (Figure 5-1 a and b). In the first year of establishment in 2015, at both sites, the 20-40% floral cover that was provided across the vegetative strips came from non-sown annual species from the seed bank in the soil. These included species such as *Polygonum aviculare*, *Veronica persica* and *Matricaria perforata*.

The greatest difference in floral cover for all vegetative strip types at both sites between 2016 and 2017, was seen in July, August and September. Some plant species observed were the same, including *Daucus carota* and *Silene dioica* at Harper Adams and *Centaurea nigra* and *Leucanthemum vulgare* at Loddington, however there was considerably less *D. carota* at both sites in 2017 than 2016.

From April/May 2016 differences were observed between the vegetative strips at both sites, but these varied across the flowering seasons. At both sites, the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) had consistently higher floral support than the multifunctional vegetative strip with 20% forbs and 80% grasses (MVS), see Figure 5-1. Also, the pollinator support vegetative strip (PSVS) had significantly higher floral cover early in the flowering season when compared with the other vegetative strips.

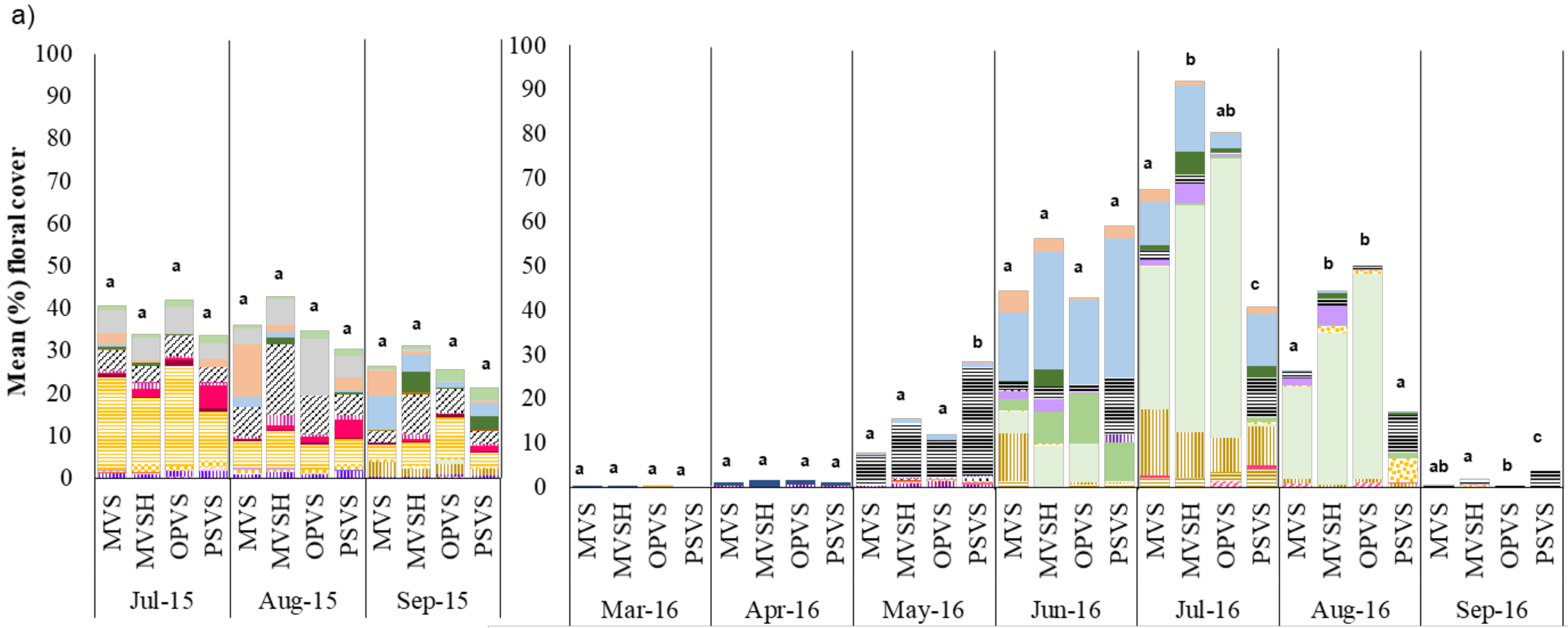
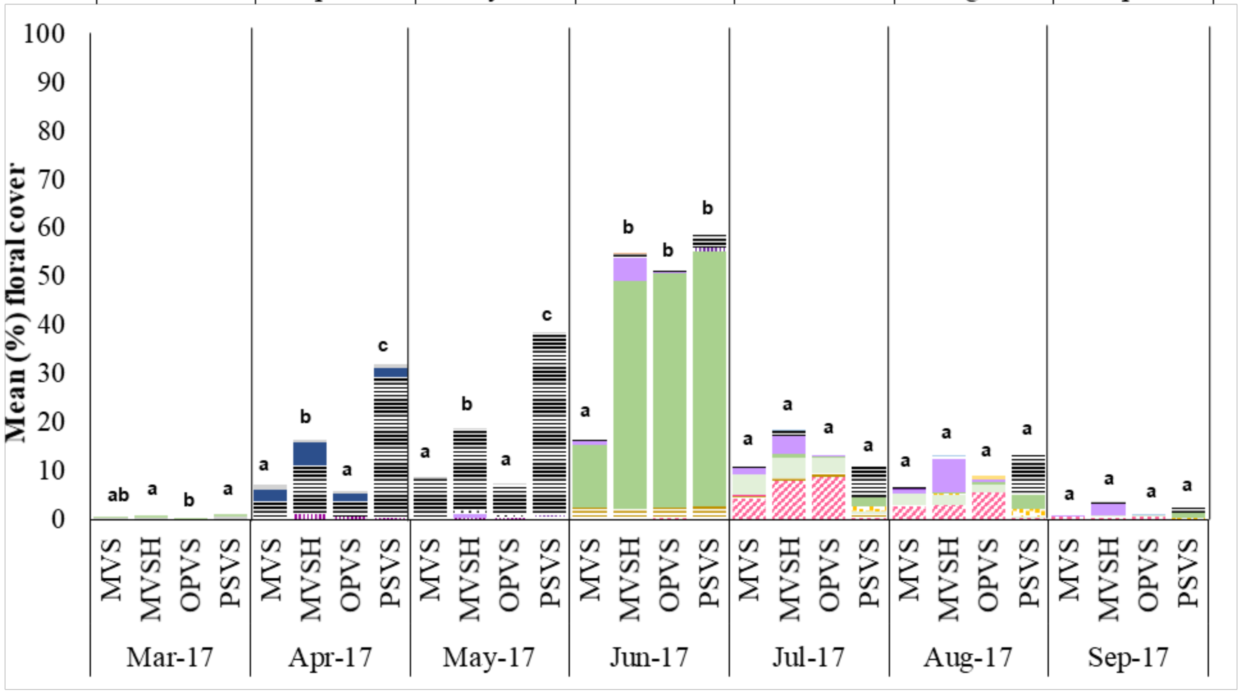
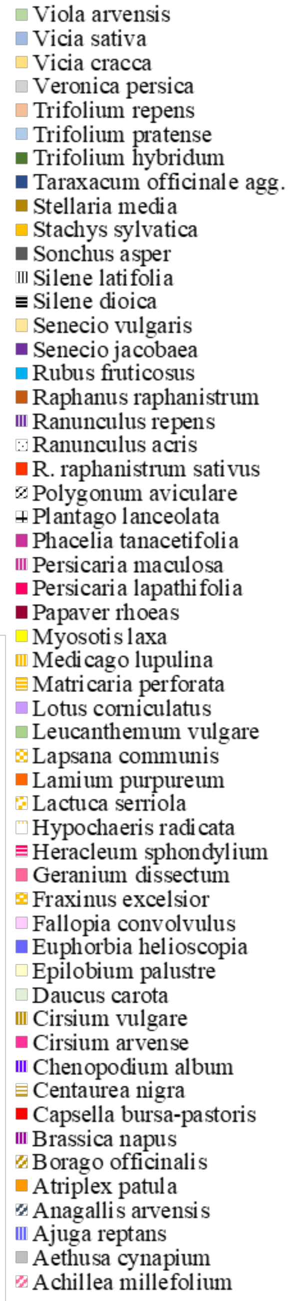
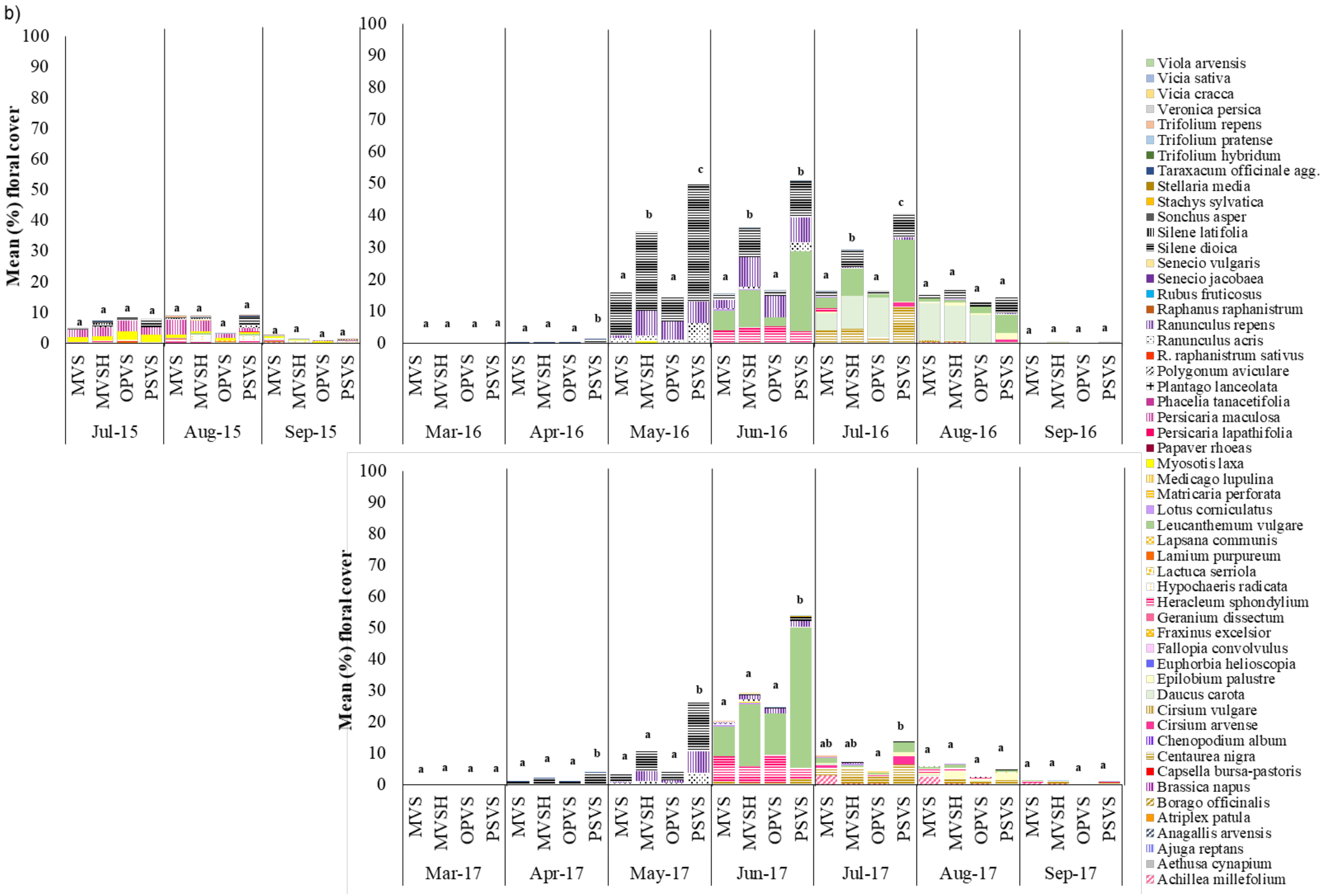


Figure 5-1. The effect of vegetative strip types on mean floral cover in each month of the flowering seasons between July 2015 and September 2017 at sites a) Harper Adams and b) Loddington. Vegetative strip types are depicted as: MVS = Multifunctional strip (20% forbs, 80% grasses), MVSH = Multifunctional strip (50% forbs, 50% grasses & lower sowing rate), PSVS = pollinator support strip (100% forbs) and OPVS = Commercial example of a multifunctional strip (20% forbs, 80% grasses). Percentage cover of each plant species is shown according to the key. Vegetative strips with the same letter are not significantly different (P<0.05).







b)
Mean (%) floral cover
Jul-15
Aug-15
Sep-15
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Sep-16
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Sep-17
MVS
MVSH
OPVS
PSVS
Viola arvensis
Vicia sativa
Vicia cracca
Veronica persica
Trifolium repens
Trifolium pratense
Trifolium hybridum
Taraxacum officinale agg.
Stellaria media
Stachys sylvatica
Sonchus asper
Silene latifolia
Silene dioica
Senecio vulgaris
Senecio jacobaea
Rubus fruticosus
Raphanus raphanistrum
Ranunculus repens
Ranunculus acris
R. raphanistrum sativus
Polygonum aviculare
Plantago lanceolata
Phacelia tanacetifolia
Persicaria maculosa
Persicaria lapathifolia
Papaver rhoeas
Myosotis laxa
Medicago lupulina
Matricaria perforata
Lotus corniculatus
Leucanthemum vulgare
Lapsana communis
Lamium purpureum
Lactuca serriola
Hypochaeris radicata
Heracleum sphondylium
Geranium dissectum
Fraxinus excelsior
Fallopia convolvulus
Euphorbia helioscopia
Epilobium palustre
Daucus carota
Cirsium vulgare
Cirsium arvense
Chenopodium album
Centaurea nigra
Capsella bursa-pastoris
Brassica napus
Borago officinalis
Atriplex patula
Anagallis arvensis
Ajuga reptans
Aethusa cynapium
Achillea millefolium

5-3.1.2 Floral species richness

There was a significant interaction ($F_{4,7}$ = 1.98, P < 0.001), between survey month and vegetative strip type for floral species richness, and again each month was analysed individually (Table 5-2). At both sites floral species richness in all vegetative strips decreased over the three years, between September 2015 and 2017, from an average of 9.1 to 1.9 at Harper Adams, and 2.65 to 0.85 at Loddington. The multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) provided the highest species richness out of all of the vegetative strips at Harper Adams in 71% of the months surveyed and 41% of the months at Loddington, see Table 5-2. In particular, at Harper Adams it was almost always significantly higher than the other vegetative strips from June to September 2017. At Loddington, the species richness was highest in the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) in five of the surveyed months and highest in the multifunctional strip with 20% forbs and 80% grasses (MVS) in six of the surveyed months. Here, the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) was only significantly higher in September 2016, see Table 5-2. In addition, the only time where the pollinator support vegetative strip (PSVS) had the highest species richness was between April & June 2016.

Table 5-2 The effect of vegetative strip type on mean floral species richness at sites a) Harper Adams and b) Loddington. Vegetative strip types are depicted as: MVS = Multifunctional strip (20% forbs, 80% grasses), MVS_H = Multifunctional strip (50% forbs, 50% grasses & lower sowing rate), PSVS = pollinator support strip (100% forbs) and OPVS = Commercial example of multifunctional strip (80% grasses, 20% forbs). Vegetative strips with the same letter are not significantly different (P<0.05). The highest value for mean floral richness of each month is in bold.

Date		**Mean species richness**								**P**	**$F_{4,7}$**
	Site	**MVS**		**MVS_H**		**OPVS**		**PSVS**			
Jul-15	HAU	10.4	ab	**11.0**	**a**	8.6	b	9.8	ab	0.266	1.30
	LODD	**6.0**	**a**	**6.0**	**a**	**6.0**	**a**	3.7	a	0.136	1.98
Aug-15	HAU	9.4	a	**10.8**	**a**	7.0	b	9.0	ab	0.021	2.90
	LODD	**7.2**	**a**	8.0	a	4.2	b	6.2	ab	0.002	4.59
Sep-15	HAU	8.6	a	**10.2**	**a**	9.2	a	8.4	a	0.645	0.70
	LODD	**3.6**	**a**	3.0	ab	1.6	ab	2.4	ab	0.363	1.15
Mar-16	HAU	**0.4**	**a**	**0.4**	**a**	0.2	a	0.0	a	0.726	0.60
	LODD	0.0	a	0.0	a	0.0	a	0.0	a	0.000	0.00
Apr-16	HAU	1.4	a	1.4	a	**1.8**	**a**	1.4	a	0.763	0.60
	LODD	0.2	a	1.0	ab	0.4	a	**1.4**	**b**	0.021	2.89
May-16	HAU	2.2	b	**6.0**	**a**	5.0	a	5.2	a	<0.001	6.90
	LODD	2.8	a	**3.2**	**a**	2.4	a	**3.2**	**a**	<0.001	8.68
Jun-16	HAU	**8.2**	**a**	7.2	a	5.4	b	5.8	b	<0.001	19.90
	LODD	4.2	ab	5.0	a	2.8	b	**4.4**	**ab**	0.0015	4.67
Jul-16	HAU	7.4	a	**8.0**	**a**	6.8	a	6.8	a	<0.001	10.50
	LODD	**5.8**	**a**	5.6	ab	3.0	c	4.0	bc	<0.001	6.94

Aug-16	HAU	**5.4**	**a**	5.0	a	4.6	a	4.2	a	0.012	3.30
	LODD	4.4	a	**4.8**	**a**	2.6	bc	4.0	ab	<0.001	8.07
Sep-16	HAU	0.8	a	**1.4**	**a**	1.0	a	1.0	a	0.012	3.20
	LODD	0.0	b	**0.4**	**a**	0.0	b	0.2	ab	0.101	1.94
Mar-17	HAU	**1.4**	**a**	**1.4**	**a**	0.8	a	1.2	a	0.132	1.80
	LODD	0.0	a	0.0	a	0.0	a	0.0	a	0.000	0.00
Apr-17	HAU	3.0	a	3.4	a	**3.6**	**a**	3.2	a	<0.001	9.80
	LODD	1.2	a	**1.6**	**a**	1.4	a	1.2	a	0.005	3.87
May-17	HAU	2.6	a	**3.4**	**a**	3.0	a	3.0	a	0.041	2.50
	LODD	**2.8**	**a**	2.6	a	2.2	a	2.2	a	<0.001	12.24
Jun-17	HAU	3.6	b	**4.6**	**a**	3.6	b	3.4	b	<0.001	14.30
	LODD	4.8	ab	**5.8**	**a**	3.8	b	5.6	a	<0.001	7.49
Jul-17	HAU	4.2	b	**5.6**	**a**	4.6	ab	4.2	b	<0.001	8.00
	LODD	**4.6**	**a**	3.0	a	3.6	a	4.2	a	0.0207	2.90
Aug-17	HAU	3.0	b	**5.0**	**a**	3.6	b	3.6	b	<0.001	6.90
	LODD	**3.4**	**a**	3.2	a	2.2	a	3.2	a	0.034	2.59
Sep-17	HAU	0.8	a	**3.0**	**c**	1.4	ab	2.4	bc	0.012	3.20
	LODD	**1.2**	**a**	**1.2**	**a**	1.0	a	0.0	b	2.201	0.07

5-3.2 Pollinator visitation

5-3.2.1 Pollinator plant species preferences

At Harper Adams, 23 plant species were visited by pollinators, of these, 17 were visited by Hoverflies, 18 by Other flies, 16 by Beetles, 14 by Solitary bees, 13 by Bumblebees, 8 by Wasps, 7 by Moths and 4 by Butterflies. At Loddington, 18 plant species were visited by pollinators, of these, 14 were visited by Hoverflies, 16 were visited by Other flies, 12 by Bumblebees, 11 by Beetles, 10 by Solitary bees, 6 by Honeybees, 6 by Butterflies, 5 by Wasps and 5 by Moths. At both sites Other flies were the species group that visited the highest number of different plant species.

Results of the analysis for pollinator groups where there were significant differences in number of visits to different plant species are presented in Tables 5-3 and 5-4. Mean species group richness and diversity are presented in these tables and all mean number of visits per plant species for each pollinator group are presented in Figures 5-2 a) and b). At Harper Adams, no significant differences were observed between the visited plant species for Solitary bees, Wasps, Butterflies, Moths or Beetles. Also, at Loddington, no significant differences in number of visits to different plant species were observed for Solitary bees, Bumblebees, Wasps and Moths. Pollinator species groups where significant differences were observed in numbers of visits to different plant species are summarised here.

At Harper Adams, the three plant species that received the most visits from all pollinators, *Daucus carota* (1.28 ± 0.20), *Achillea millefolium* (0.60 ± 0.20) and *Leucanthemum vulgare* (0.99 ± 0.20), see Table 5-3. The three most visited plant species at Loddington included *L. vulgare* (0.97 ± 0.13), but also, *Heracleum sphondylium* (1.17 ± 0.13) and *Centaurea nigra* (0.61 ± 0.13).

Specific plant species were preferred by different pollinator species groups. At Harper Adams, the highest mean number of visits by Bumblebees were observed on *Trifolium pratense* (0.75 ± 0.22), *Lotus corniculatus* (0.15 ± 0.23) and *C. nigra* (0.09 ± 0.24). *L. vulgare* (0.11 ± 1.01), *D. carota* (0.11 ± 1.01), *C. vulgare* (0.08 ± 1.01) *Silene dioica* (0.07 ± 1.02), *C. nigra* (0.06 ± 1.01), *A. millefolium* (0.06 ± 1.01) and all of these plant species received comparably higher numbers of visits by Hoverflies. *D. carota* (0.66 ± 0.71) and *A. millefolium* (0.50 ± 0.71) also received significantly more visits by other flies. Overall *D. carota* (0.33 ± 0.31) had the highest species group richness of pollinator visits with similar numbers for *L. vulgare* (0.12 ± 0.31), *C. nigra* (0.17 ± 0.32) and *A. millefolium* (0.20 ± 0.32). *D. carota* also received highest species group diversity of pollinator visits (0.091 ± 1.64) with similar diversities seen on *L. vulgare* (0.04 ± 1.64), *C. vulgare* (0.04 ± 1.64) and *C. nigra* (0.03 ± 1.64).

At Loddington, the highest mean number of visits by Hoverflies were observed on *H. sphondylium* (0.19 ± 0.58), *C. nigra* (0.11 ± 0.59) and *L. vulgare* (0.10 ± 0.60). The highest number of other flies were also observed on *H. sphondylium* (0.67 ± 0.14) and *L. vulgare* (0.51 ± 0.14), but also *Ranunculus acris* (0.38 ± 0.14). *C.nigra* received the most visits by Butterflies (0.23 ± 1.07), and *L. vulgare* received the most visits by Beetles (0.33 ± 0.51). Overall *H. sphondylium* had the highest species group richness of pollinator visits (0.41 ± 0.22) with similar numbers for *L. vulgare* (0.34 ± 0.22) and *C. nigra* (0.34 ± 0.22). *H. sphondylium* also received the highest species group diversity of pollinator visits (0.10 ± 0.63) with similar diversities seen on *C. nigra* (0.09 ± 0.64) and *L. vulgare* (0.07 ± 0.64).

Table 5-3 Mean pollinator visits to flowering plant species present on the Harper Adams site. * P < 0. 05, ** P < 0.01, *** P < 0.001. Plant species with the same letter are not significantly different (P<0.05). Where the full sequence of letters is given, this indicates that no visits were made to this plant species.

Plant species	**Total pollinators**				**Bumblebees**				**Hoverflies**				**Other flies**				**Species group richness**					**Shannon species group diversity**				
	SE	***z***	***p***		**SE**	***z***	***p***		**SE**	***z***	***p***		**SE**	***z***	***p***		**Mean**	**SE**	***z***	***p***		**Mean**	**SE**	***z***	***p***	
Dactylis glomerata	0.73	-3.51	***	a	910.60	-0.02	0.985	abcdefg	1004.00	-0.02	0.988	abcde	367.30	-0.04	0.971	abcdef	0.002	1.04	-2.26	*	ab	0.000	1009.00	-0.01	0.989	abc
Succisa pratensis	0.73	-3.51	***	a	911.70	-0.02	0.985	abcdefg	1.41	0.03	0.974	abcd	1.23	-0.56	0.578	ab	0.003	0.77	-2.17	*	a	0.001	2.02	0.32	0.752	abc
Ranunculus repens	0.54	-3.51	***	a	911.80	-0.02	0.985	abcdefg	1004.00	-0.02	0.988	abcde	1.23	-0.56	0.578	ab	0.005	0.65	-1.94	0.053	a	0.001	2.02	0.32	0.752	abc
Veronica chamaedrys	0.54	-3.55	***	a	911.60	-0.02	0.985	abcdefg	1.41	0.01	0.990	abc	366.80	-0.04	0.971	abcdef	0.003	0.77	-2.20	*	a	0.000	1008.00	-0.01	0.989	abc
Vicia cracca	0.54	-3.51	***	a	0.54	-3.05	**	ab	1004.00	-0.02	0.988	abcde	367.10	-0.04	0.971	abcdef	0.003	0.77	-2.17	*	a	0.000	1010.00	-0.01	0.989	abc
Cirsium arvense	0.49	-3.40	***	a	911.70	-0.02	0.985	abcdefg	1004.00	-0.02	0.988	abcde	0.84	1.11	0.267	ab	0.006	0.58	-1.67	0.095	a	0.000	1010.00	-0.01	0.989	abc
Jacobaea vulgaris	0.40	-2.94	**	a	1.02	-2.97	0.003	abc	1004.00	-0.02	0.988	abcde	0.82	1.36	0.174	ab	0.008	0.54	-1.39	0.164	a	0.000	1010.00	-0.01	0.989	abc
Hypochaeris radicata	0.36	-2.43	0.015	a	910.30	-0.02	0.986	abcdefg	1.41	0.03	0.976	abcd	0.91	0.46	0.648	ab	0.009	0.51	-1.13	0.261	a	0.001	2.26	0.05	0.960	abc
Heracleum sphondylium	0.30	-1.23	0.220	ab	911.70	-0.02	0.985	abcdefg	1.16	0.99	0.322	a	0.78	1.94	0.052	b	0.136	0.44	-0.13	0.895	ab	0.019	1.76	1.04	0.298	ab
Brassica napus	0.30	-1.06	0.290	ab	0.61	-3.19	**	ab	991.20	-0.02	0.988	abcde	0.78	1.87	0.062	b	0.016	0.43	0.02	0.988	ab	0.004	1.81	0.80	0.423	ab
Trifolium hybridum	2.11	5.42	***	ab	5.58	20.95	***	bcd	6.69	2.55	*	abc	5.03	-12.42	***	ab	0.017	3.44	11.33	***	ab	0.003	9.43	1.41	0.160	abc
Lactuca serriola	0.27	0.11	0.912	ab	912.20	-0.02	0.985	abcdefg	1.03	2.66	**	abcde	0.84	1.11	0.269	ab	0.017	0.40	0.87	0.383	abc	0.001	1.77	0.99	0.323	ab
Trifolium repens	0.24	2.53	*	bc	0.26	2.40	*	cde	1.23	0.58	0.559	a	367.50	-0.04	0.971	abcdef	0.023	0.36	2.17	*	abc	0.003	1008.00	-0.01	0.989	abc
Taraxacum officinale agg.	0.23	4.03	***	c	0.61	-3.27	**	ab	1.16	0.90	0.368	a	0.75	2.81	**	bc	0.038	0.34	3.83	***	cde	0.000	1.75	1.02	0.307	ab
Lotus corniculatus	0.22	5.68	***	c	0.23	5.68	***	fg	1.41	-0.05	0.961	ab	364.40	-0.04	0.970	abcdef	0.066	0.34	3.38	***	bcd	0.004	1.86	0.62	0.536	ab
Silene dioica	0.23	-2.04	*	a	0.32	-3.86	***	a	1.02	2.07	*	a	0.77	-0.54	0.587	a	0.058	0.33	2.23	*	abc	0.002	1.67	1.12	0.263	a
Ranunculus acris	0.21	9.00	***	d	912.10	-0.02	0.985	abcdefg	1.16	0.97	0.334	a	0.79	1.72	0.085	b	0.064	0.34	3.92	***	cde	0.001	1.97	0.40	0.691	abc
Centaurea nigra	0.20	9.60	***	d	0.24	3.46	***	def	1.01	3.53	***	bcde	0.71	5.35	***	e	0.169	0.32	7.00	***	fg	0.034	1.64	2.42	*	bc
Cirsium vulgare	0.20	10.30	***	de	0.23	4.62	***	ef	1.01	3.68	***	e	0.72	4.87	***	de	0.184	0.32	6.93	***	fg	0.037	1.64	2.43	*	bc
Achillea millefolium	0.20	13.26	***	gh	912.40	-0.02	0.985	abcdefg	1.01	3.60	***	cde	0.71	7.08	***	f	0.195	0.32	5.93	***	efg	0.005	1.66	2.01	*	abc
Trifolium pratense	0.20	11.92	***	ef	0.22	6.96	***	g	1.12	0.69	0.491	a	0.80	1.26	0.208	ab	0.272	0.32	5.77	***	def	0.045	1.72	0.99	0.322	a
Leucanthemum vulgare	0.20	12.89	***	fg	1.02	-3.47	***	ab	1.01	3.65	***	de	0.72	4.16	***	cd	0.116	0.31	7.51	***	g	0.016	1.64	2.31	*	bc
Daucus carota	0.20	14.24	***	h	1.02	-4.59	***	a	1.01	3.56	***	cde	0.71	7.00	***	f	0.331	0.31	7.54	***	g	0.091	1.64	2.75	**	c

Table 5-4 Mean pollinator visits to flowering plant species present at the Loddington site. * P < 0. 05, ** P < 0.01, *** P < 0.001. Plant species with the same letter are not significantly different (P<0.05). Where the full sequence of letters is given, this indicates that no visits were made to this plant species.

Plant species	Total pollinators			Hoverflies			Other flies			Butterflies			Beetles			Species richness			Shannon species group diversity		
	SE	z	p	SE	z	p	SE	z	p	SE	z	p	SE	z	p	SE	z	p	SE	z	p
Daucus carota	6.81	-6.65	<0.001 *** cde	17.09	-2.69	0.007 ** a	8.56	-6.28	<0.001 *** cd	93.40	-0.84	0.402 ab	20.39	1.79	0.073 a	10.08	-4.61	<0.001 *** ab	23.08	-1.24	0.214 a
Rubus fruticosus	1.01	-4.21	<0.001 *** a	978.68	-0.02	0.987 abcde	355.90	-0.05	0.962 abcdefg	4268.00	0.00	0.997 ab	975.18	-0.02	0.987 abcd	1.02	-3.07	0.002 ** a	982.08	-0.02	0.987 abc
Lotus corniculatus	0.40	-5.80	<0.001 *** a	980.42	-0.02	0.987 abcde	1.01	-4.09	<0.001 *** a	4273.00	0.00	0.997 ab	0.71	-0.03	0.980 a	0.54	-3.25	0.001 ** ab	1.54	-1.08	0.280 abc
Hypochaeris radicata	0.72	-4.94	<0.001 *** a	979.32	-0.02	0.987 abcde	356.10	-0.05	0.962 abcdefg	4271.00	0.00	0.997 ab	975.77	-0.02	0.987 abcd	1.02	-3.07	0.002 ** f	982.65	-0.02	0.987 abc
Centaurea nigra	0.13	8.19	<0.001 *** g	0.59	4.86	<0.001 *** d	0.23	-4.43	<0.001 *** ab	1.07	1.79	0.073 b	0.55	2.24	0.025 * a	0.22	8.57	<0.001 *** de	0.64	4.17	<0.001 *** bc
Ranunculus repens	0.14	5.32	<0.001 *** f	0.60	3.52	<0.001 *** abc	0.15	3.88	<0.001 *** e	2822.00	-0.01	0.994 ab	0.57	1.04	0.300 a	0.24	3.18	0.001 ** cde	0.68	1.82	0.069 a
Cirsium arvense	0.16	0.81	0.419 de	0.63	2.77	0.006 ** abc	0.21	-2.29	0.022 * bc	1.16	0.91	0.365 b	0.56	2.59	0.010 ** ab	0.25	2.81	0.005 ** abc	0.73	1.23	0.219 a
Taraxacum officinale agg.	0.25	-4.82	<0.001 *** ab	0.82	-0.01	0.990 a	0.30	-5.00	<0.001 *** ab	4257.00	0.00	0.997 ab	0.71	-0.03	0.979 a	0.31	-0.49	0.621 ab	1.40	-1.02	0.308 ab
Myosotis laxa	1.01	-4.21	<0.001 *** a	977.95	-0.02	0.987 abcde	1.01	-4.08	<0.001 *** a	4265.00	0.00	0.997 ab	974.42	-0.02	0.987 abcd	1.02	-3.08	0.002 ** g	981.35	-0.02	0.987 abc
Heracleum sphondylium	0.13	16.91	<0.001 *** j	0.58	6.22	<0.001 *** e	0.14	13.62	<0.001 *** g	3963.00	-0.01	0.996 ab	0.52	4.79	<0.001 *** c	0.22	10.82	<0.001 *** e	0.63	4.96	<0.001 *** c
Epilobium palustre	0.18	-1.65	0.100 bcd	0.65	2.10	0.036 * abc	0.28	-4.88	<0.001 *** ab	4291.00	0.00	0.997 ab	984.54	-0.02	0.987 abcd	0.24	4.58	<0.001 *** f	0.69	1.97	0.049 * a
Ranunculus acris	0.13	10.80	<0.001 *** hi	0.60	3.82	<0.001 *** cd	0.14	8.99	<0.001 *** f	3417.00	-0.01	0.995 ab	0.52	4.42	<0.001 *** bc	0.22	7.62	<0.001 *** f	0.65	3.14	0.002 ** ab
Leucanthemum vulgare	0.13	11.37	<0.001 *** i	0.60	3.96	<0.001 *** cd	0.14	7.43	<0.001 *** f	1.66	-2.75	0.006 ** a	0.51	6.17	<0.001 *** d	0.22	7.35	<0.001 *** a	0.64	3.30	<0.001 *** ab
Senecio jacobaea	0.59	-5.32	<0.001 *** a	0.91	-0.45	0.654 ab	356.10	-0.05	0.962 abcdefg	1.41	0.00	0.999 ab	975.90	-0.02	0.987 abcd	0.74	-3.32	<0.001 *** bcd	1.40	-1.01	0.311 ab
Silene dioica	0.20	-2.97	<0.001 *** bc	0.76	0.35	0.728 ab	0.23	-3.39	<0.001 *** abc	4271.00	0.00	0.997 ab	1.12	-1.27	0.203 a	0.28	0.75	0.453 abcdefg	1.07	-0.66	0.511 a
Trifolium pratense	217.40	-0.07	0.941 abcdefghij	980.09	-0.02	0.987 abcde	356.50	-0.05	0.962 abcdefg	4274.00	0.00	0.997 ab	976.56	-0.02	0.987 abcd	360.10	-0.04	0.965 ab	983.51	-0.02	0.987 abc
Crepis biennis	0.24	-4.58	<0.001 *** ab	0.82	0.00	0.997 a	0.26	-4.45	<0.001 *** ab	4274.00	0.00	0.997 ab	976.65	-0.02	0.987 abcd	0.37	-2.02	0.043 * abcdefg	0.98	-0.44	0.663 a
Cirsium vulgare	217.40	-0.07	0.941 abcdefghij	980.13	-0.02	0.987 abcde	356.50	-0.05	0.962 abcdefg	4275.00	0.00	0.997 ab	976.61	-0.02	0.987 abcd	360.10	-0.04	0.965 abcdefg	983.54	-0.02	0.987 abc
Vicia cracca	217.60	-0.07	0.941 abcdefghij	980.81	-0.02	0.987 abcde	356.70	-0.05	0.962 abcdefg	4278.00	0.00	0.997 ab	977.34	-0.02	0.987 abcd	360.30	-0.04	0.965 abcdefg	984.24	-0.02	0.987 abc
Trifolium repens	217.60	-0.07	0.941 abcdefghij	980.84	-0.02	0.987 abcde	356.70	-0.05	0.962 abcdefg	4277.00	0.00	0.997 ab	977.32	-0.02	0.987 abcd	360.30	-0.04	0.965 bcde	984.26	-0.02	0.987 abc
Angelica sylvestris	0.14	8.05	<0.001 *** gh	0.61	3.59	<0.001 *** bcd	0.15	7.44	<0.001 *** f	4272.00	0.00	0.997 ab	976.14	-0.02	0.987 abcd	0.27	1.64	0.101 abcd	0.74	1.10	0.273 a
Achillea millefolium	0.15	3.04	0.002 ** ef	0.62	2.81	0.005 ** abc	0.16	2.38	0.017 * de	4198.00	0.00	0.997 ab	0.87	-0.86	0.388 a	0.25	2.76	0.006 ** cde	0.73	1.23	0.218 a

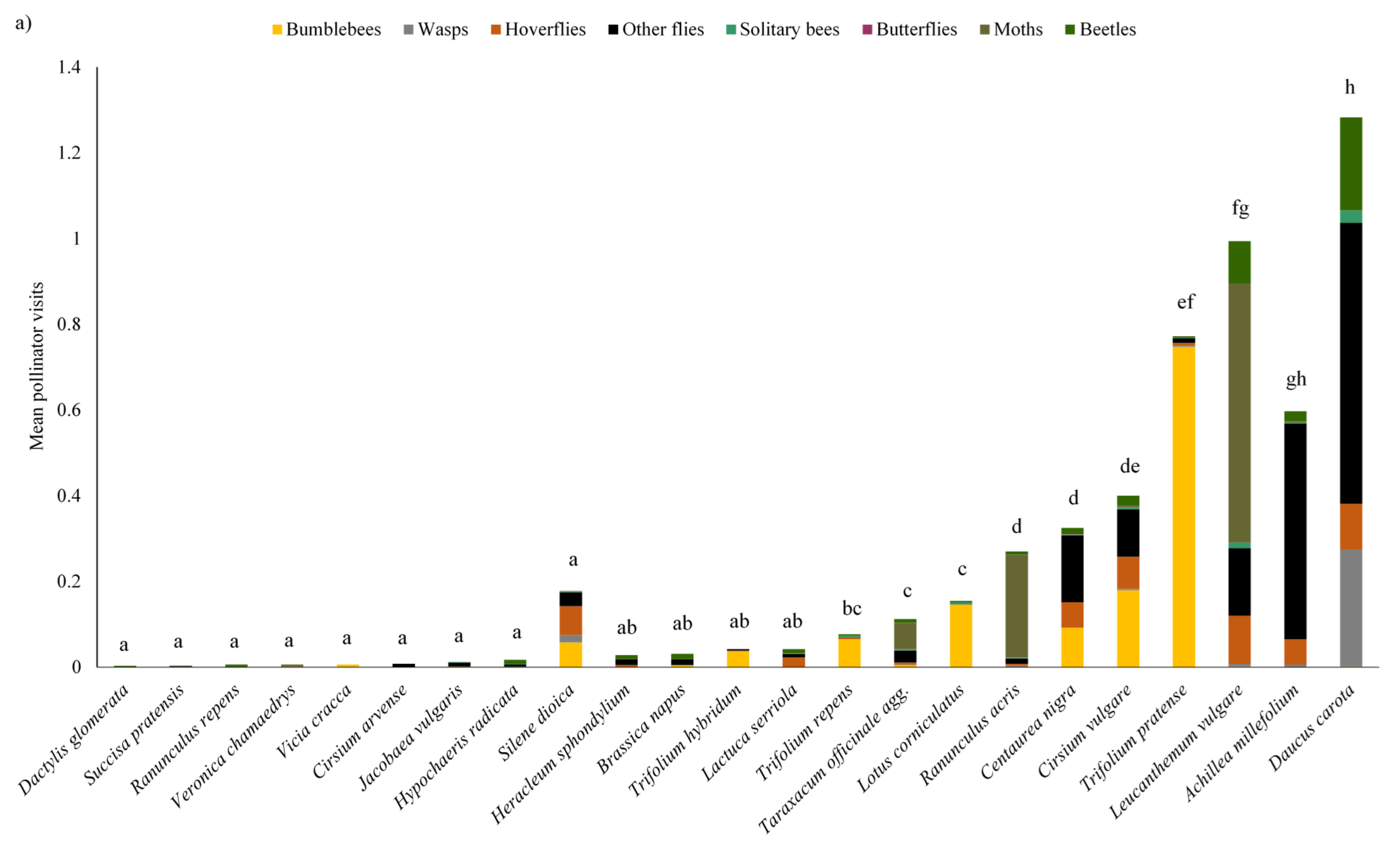
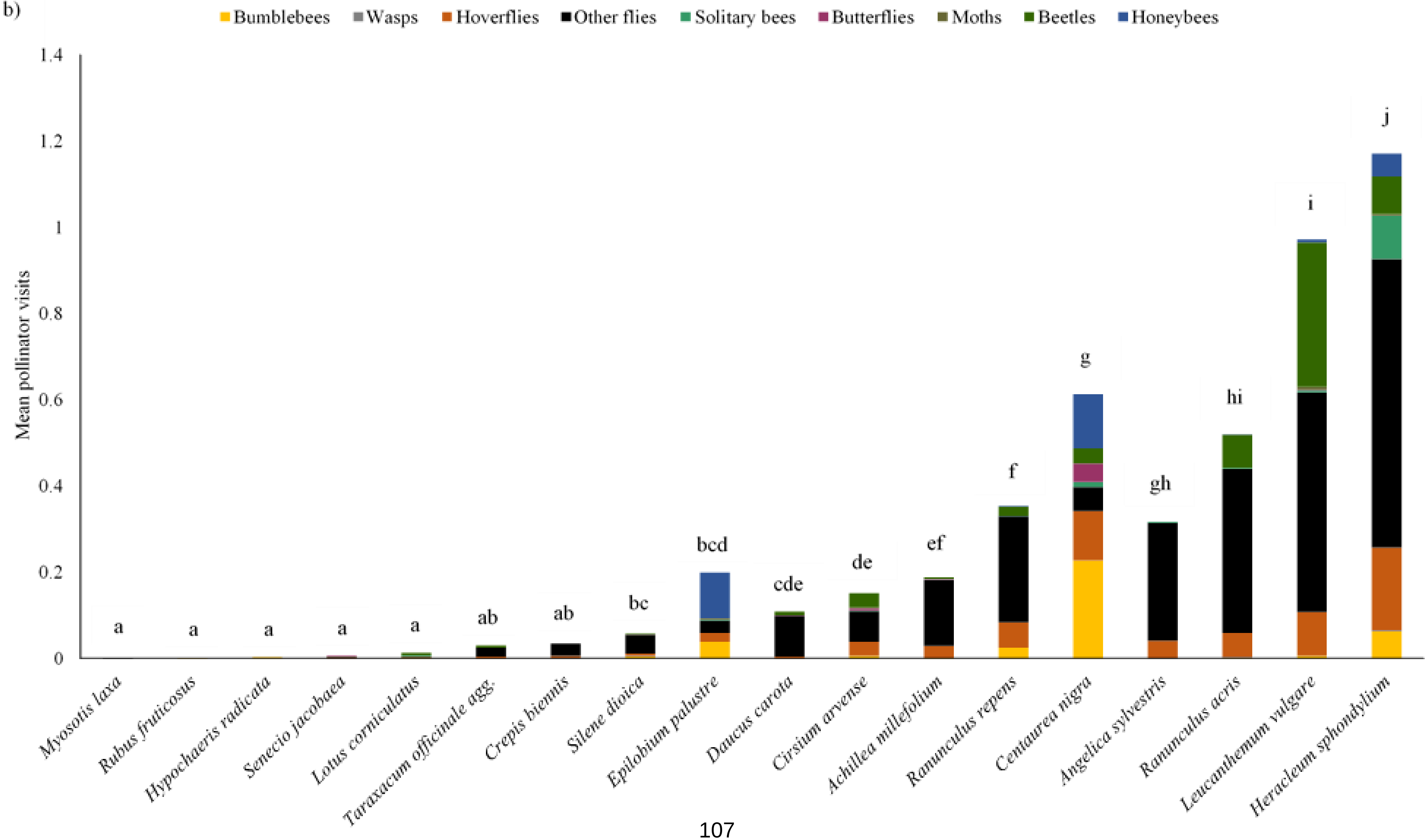


Figure 5-2. Mean pollinator visits to each of the plant species on sites a) Harper Adams and b) Loddington across the flowering season. Plant species with the same letter are not significantly different (P<0.05). Mean insect group visits are colour coded according to the key.

b)



Bumblebees
Wasps
Hoverflies
Other flies
Solitary bees
Butterflies
Moths
Beetles
Honeybees
Mean pollinator visits
1.4
1.2
1
0.8
0.6
0.4
0.2
0
a
a
a
a
a
ab
ab
bc
bcd
cde
de
ef
f
g
gh
hi
i
j
Myosotis laxa
Rubus fruticosus
Hypochaeris radicata
Senecio jacobaea
Lotus corniculatus
Taraxacum officinale agg.
Crepis biennis
Silene dioica
Epilobium palustre
Daucus carota
Cirsium arvense
Achillea millefolium
Ranunculus repens
Centaurea nigra
Angelica sylvestris
Ranunculus acris
Leucanthemum vulgare
Heracleum sphondylium

5-4. Discussion

5-4.1 Floral cover

The provision of the initial floral support in 2015 by the non-sown annuals did not appear to be detrimental to the establishment of the sown species in subsequent years. In addition, they provided a source of floral support whilst the sown perennial species establish. Also, there was considerably lower cover of *D. carota* at both sites in 2017 when compared to 2016. This was likely due to the life-history of *D. carota* as it is a monocarpic perennial, meaning it can complete its growth cycle within two years, but often persists for longer (Grime et al., 2007).

From April/May 2016 we observed differences between the vegetative strips at both sites, but these varied across the flowering seasons. The multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) had consistently higher floral support than the multifunctional vegetative strip with 20% forbs and 80% grasses (MVS). These results demonstrate an increased proportion of forbs in the seed mix can directly increase the amount of floral support that is provided in a multifunctional vegetative strip, even when the mix is sown at a lower rate.

The decrease in floral support in 2017 was slightly smaller for the pollinator support vegetative strip (PSVS) and multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H). In fact, the MVS actually had higher (30-40%) floral cover at Harper Adams in April 2017 and similar cover in May and June 2017 at both sites. This could be explained by the reduced presence of sown grass species in these two vegetative strips, which are likely to be competing with the forbs in the vegetative strip with 20% forbs and 80% grasses (MVS) and the commercial example of a multifunctional strip (OPVS). Also, in June 2017 the MVS_H, OPVS and PSVS all had significantly higher floral cover by 30-40%, than the MVS at Harper Adams, whilst at Loddington only the PSVS had significantly higher cover. The difference between the two sites here is interesting as we would expect the grasses sown in the multifunctional mixes to start to out-compete the forbs, whilst this is what happened at Loddington, it did not happen at Harper Adams. It is likely that the grasses established quicker at Loddington than Harper Adams, due to the increased fertility of the soil (Grime et al., 2007), and this could be the reason for the lower overall floral cover at Loddington. So, at Harper Adams, with a slower establishment of the grasses we may be observing the increased competition with forbs in the MVS and OPVS from *Dactylis glomerata,* as it is classified by Grime et al., (2007) to be competitive, stress tolerant and ruderal. The difference between the MVS and OPVS may arise from the MVS including only four grass species so *D. glomerata* constitutes 20% of the mix whilst the OPVS has five grass species so only 16% *D. glomerata.* Considering this, it may be necessary to decrease the proportion of *D. glomerata* in this seed mix, to help reduce the competition.

The pollinator support vegetative strip (PSVS) provided more floral support than the other vegetative strips in the early flowering season (April/May) in 2016 and 2017, at both sites. A large proportion of this cover (up to 38%) was provided by *Silene dioica.* This is key as *S. dioica* is known to be highly visited by bees (Kirk & Howes, 2012) so it could be a key species to include in seed mixes to provide support for early emerging pollinators. Further research to determine whether an increase in *S. dioica* would lead to increased populations would further support these results.

5-4.2 Floral species richness

The multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) almost consistently provided the highest species richness throughout the three years at Harper Adams. The same pattern was not seen at Loddington, where the MVS_H only had higher species richness in five of the months, but the multifunctional vegetative strip with 20% forbs and 80% grasses (MVS) had the highest in six of the months. As the same species were included in these seed mixes, similar species richness is expected in both of these vegetative strips. The reason we may have seen a difference at Harper Adams, could be due to the increased proportions of forbs in the MVS_H seed mix. With more seeds, the forbs that establish well on sandy loam soils (e.g. *Achillea millefolium, Centaurea nigra* and *Daucus carota*), may have had a better chance at establishment on this site (Grime et al., 2007). This is reflected in the overall higher species richness at Harper Adams than Loddington in all of the vegetative strips.

5-4.3 Pollinator visitation

In total 23 different plant species were visited by pollinators at Harper Adams and 18 at Loddington. At both sites the species that were shown to receive the most visits across the pollinator species groups (*A. millefolium, C. nigra, D. carota, H. sphondylium* and *L. vulgare*) (Figure 2b), all had a large floral display size, showing a positive relationship with this plant trait and visits from pollinators. This is key because a larger floral display size was shown to be preferred by pollinators in Chapter 2 and therefore essential when designing vegetative strip seed mixes to support crop pollination (Chapter 3*)*. The findings from this study also support the argument for using these plant species within vegetative strips when supporting pollinator species.

5-4.3.1 Total pollinator preferences

The species that were shown to receive the most visits across the pollinator species groups (*A. millefolium, C. nigra, D. carota, H. sphondylium* and *L. vulgare*) were all included in the multifunctional vegetative strip with 20% forbs and 80% grasses (MVS) and the multifunctional strip with 50% forbs and 50% grasses (MVS_H) and they established and persisted throughout the three years surveyed. These findings correlate with the study undertaken by Wood et al. (2015) who found these species to be popular with bees and wasps, with the exception of *H. sphondylium*. This is likely because Hoverflies and other flies were not included in this study, and they were the main visitors to this species. These five species may be key when designing perennial vegetative strip seed mixes to support pollinators.

5-4.3.2 Bumblebee preferences

It is known that *Trifolium pratense* is preferred by long-tongued Bumblebees (Carvell et al., 2006) and this is reflected in the observed higher visitation rates that this plant species received when compared to others at Harper Adams. Bumblebees are one of the most effective pollinator groups for *Brassica napus* and *Lycopersicon esculentum* crop pollination (Asada and Ono, 1996; Stanley et al., 2013), so inclusion of *T. pratense* could be essential to support this ecosystem service. All of the vegetative strips at Harper Adams provided comparable floral cover of *T. pratense* in the 2016 flowering season, but very few flowers were observed in 2017 or at all at Loddington. This may indicate that *T. pratense* only provides initial substantial support on sandy loam soils. Whilst studies have been undertaken to increase the persistence of *T. pratense* (e.g. Marshall et al., 2012) it is likely that different, more persisting plant species are required to provide continued support for Bumblebees. Both of the multifunctional vegetative strips (MVS_H and MVS) included *Lotus corniculatus*, which was also shown to be popular amongst bumblebees and this is in accordance with what is already known about their preferences (Kirk and Howes, 2012). Approximately 5% floral cover of *L. corniculatus* was observed in both vegetative strips in 2016 and 2017, showing persisting support by this plant species. However, again, this plant species did not establish at all at Loddington, so *T. pratense* and *L. corniculatus* should potentially be sown with caution on heavy clay soils. *Centaurea nigra,* which was also preferred by bumblebees, showed the same trend in persistence as *L. corniculatus*, but it also received the most visits from Bumblebees at Loddington, therefore if trying to target all soils, this may be a key plant species to include for pollinator support.

It is also worth noting that *Cirsium vulgare*, a non-sown species, received a similar visitation rate to *L. corniculatus* and *C. nigra* at Harper Adams. Unfortunately, this is generally not a favourable plant species with farmers having been classified as injurious under the Weeds Act 1959 and so is usually removed. However, whilst *Cirsium* arvense can cause considerable damage in arable crops (Donald, 1990), *C. vulgare* rarely persists through the crop rotation (Moss, 2016). If it could be managed so that it does not spread into adjacent crops from the field margins, then it could provide another valuable source of floral support.

5-4.3.3 Hoverfly preferences

Of the sown plant species across the two sites, *H. sphondylium, S. dioica, C. nigra, L. vulgare, A. millefolium* and *D. carota* all received comparably higher numbers of visits by hoverflies, indicating a range of preferences by this species group. Whilst some of these species were also preferred by bumblebees, which are usually the main target for vegetative strips for pollinator support, *A.millefolium, D. carota* and *L. vulgare* were not. Whilst providing some pollination services as adults, hoverflies in their larval form are also predators of crop pests (Raymond et al., 2014), so if these preferred plant species were included in seed mixes, an increase in the functionality of the vegetative strips could be seen. *Epilobium palustre*, *C.vulgare* and *Lactuca serriola* were also preferred by hoverflies, but again they are often disliked by farmers and removed.

5-4.3.4 Other flies

This species group was seen to visit the highest variety of plant species, 18 out of 23 at Harper Adams, and 16 out of 18 at Loddington. This was expected as there are over 5000 species in this group in the UK (Oldroyd, 1970). It is also consistent with findings from Grass et al. (2016) where 75% of flower visiting insects that were observed consisted of flies (other than hoverflies). *D. carota* and *A. millefolium* received significantly more visits than any other plant species at Harper Adams and so did *H. Sphondylium* at Loddington. This is likely due to their large floral display size, which has been shown to be preferred by flies and other pollinator groups by Møllller & Sorci (1998). Despite this, these three plant species are not regularly included in a single-focus vegetative strip for pollinator support as they are not frequently used by Bumblebees and Honeybees, which tend to be the main target organisms. Flies have a huge potential to contribute to pollination and agricultural production (Ssymank et al., 2008; Inouye et al., 2015), and so it is recommended that these plant species are considered for inclusion in vegetative strips for pollinator support.

5-4.3.5 Species group richness and diversity

Across the two sites *D. carota* and *H. sphondylium* had the highest species group richness of pollinator visits and *A. millefolium, C. nigra, L. vulgare,* had similar scores. These plant species all have a large floral display size and so this trait seems to support the widest range of pollinators as well as receive the highest number of visits by pollinators. This association is further confirmed because the same plant species had the highest species group diversity of pollinator visits, with the exception of *A. millefolium.*

5-4.3.6 Other pollinator groups

It is likely that no significant differences were observed in plant species visits between some of the pollinator groups because there was a very small number of observations of each in the surveys. They were included in the total counts for pollinators and the species richness and diversity measures, so their influence may still be seen here. Interestingly, the widest range of plant species were visited by Solitary Bees (Harper Adams: 14, Loddington: 10) and Beetles (Harper Adams: 16, Loddington: 11), but significant differences were only observed at Loddington for Beetles where significantly more visited *L. vulgare*. If further surveys could be undertaken to increase observation numbers, it may be possible to better understand which plant species they prefer within these vegetative strips.

5-5. Conclusion

This study demonstrates that an increase in the functionality of a vegetative strip can positively affect the support provided for pollinators, depending on the proportion of forbs sown. Whilst the multifunctional vegetative strip with 20% forbs and 80% grasses (MVS) provided less floral resources in the third year of establishment than the single-focus strip (PSVS), the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) provided the most floral support at both sites with the most variety and the most visited plant species by pollinators, despite its lower sowing rate.

The additional floral support that was provided by non-sown annual plant species provided a bonus source of support and should not be removed if possible. Also, a key early flowering plant species to include in vegetative strip seed mixes is *S. dioica* as it persisted throughout the three years and provided substantial floral support in April and May when other floral species had not yet begun to flower. Whilst it did not receive large numbers of pollinator visits at either site, this is likely due to lower pollinator populations in the early flowering season and so only a few individuals would be observed foraging. Early flowering plants have been proven to be essential in supporting Solitary bee and Bumblebee populations as these groups contain numerous species that emerge in April and May (Williams, 2012).

In total, 23 plant species were used by pollinators at Harper Adams and 18 at Loddington, but an overall preference was observed for *Achillea millefolium, Centaurea nigra, Daucus carota, Heracleum sphondylium* and *Leucanthemum vulgare*. It is clear from the results of this study that in order to provide support for a large variety of pollinators, a large variety of flowering plant species should be sown, but a focus should be given to those with a large floral display size. This is key because this plant trait was shown to be preferred by pollinators in Chapter 2 and was therefore essential when designing vegetative strip seed mixes to support crop pollination (Chapter 3*)*.

With insect pollinators benefiting 87 different crops globally (Aizen et al., 2009), providing support to pollination services is of great importance. The findings from this study could begin to inform policy makers and land-owners on how to increase the functionality of vegetative strips and enhance support for pollinators at the same time. It is clear that careful consideration should be taken when selecting plant species for a vegetative strip. The evidence-informed methods developed in Chapter 3 have facilitated the development of seed mixes that provide valuable pollinator support on two distinct sites. It is recommended that further landscape-scale experiments should be undertaken, to test the establishment and persistence of support provided by multifunctional strips in different environmental conditions. These data could help improve understanding of how multifunctional vegetative strips can benefit pollinators in the whole environment and long-term.

Chapter 6. Increasing the functionality of farmland buffer strips – outcomes for water quality protection support

Abstract

In the UK and Europe, farmers are required to maintain a vegetative buffer strip on land adjacent to a watercourse to protect against pollution from pesticides and fertilisers. A key issue effecting the efficacy of these strips is the lack of a specifically prescribed selection of plant species for sown seed mixes. In addition, in order to meet current food production requirements, there is a need to increase vegetative strip functionality. The concern with this is that an increase in functionality could potentially compromise the support provided for water quality protection.

From April 2015, in a three year experiment, on two distinct sites, using seed mixes developed with a standardised, evidence-informed method (Chapter 3), we compared the above and below-ground vegetative support of multifunctional vegetative strips to a single-focus strip for water quality protection. Vegetative cover and plant height were surveyed monthly and root structural density sampled bi-annually.

The sown seed mix and the site location and soil type on which the vegetative strips were established had a significant effect on the resulting plant communities and the support they provided for water quality protection. Where the sown forbs and grasses provided the majority of the vegetative cover, the multifunctional vegetative strip provided comparable support for protection against run-off, erosion and pesticide spray-drift, to the single-focus strip. Also, the functionality of a vegetative strip did not seem to effect root structural density and therefore protection against watercourse sedimentation.

The vegetative support for water quality protection (protecting against run-off, erosion and spray-drift) in multifunctional vegetative strips was found to be comparable to that of a single-focus strip, if the multifunctional seed mix is sown with 20% forbs and 80% grasses and the sown species establish on that site. The findings from this study should encourage land managers to consider increasing the functionality of their vegetative strips, but also consider the soil type and other environmental conditions of their land prior to choosing a seed mix as this can greatly affect the desired plant community that establishes.

In prep: Cresswell, C.J., Wilcox, A., Cunningham, H.M., Randall, N.P. Increasing the functionality of farmland buffer strips – outcomes for water quality protection support. Intended for submission to: Agriculture, Ecosystems and Environment.

6-1 Introduction

Globally, the intensification of agricultural practices is associated with a rise in phosphate, nitrate and pesticide applications which have increased concentrations of these pollutants in ground and surface waters through run-off and erosion (Cartwright et al., 1991; Carpenter et al., 1998; Berka et al., 2001; Thorburn et al., 2003; Almasri and Kaluarachchi, 2004; Smith et al., 2013). A widely-used method to reduce water pollution is the use of vegetative buffer strips, established between a watercourse and the crop (Marshall and Moonen, 2002; Randall et al., 2015). Vegetative strips are a proven, valuable barrier to water pollution in farmland, however their effectiveness can be variable (Muscutt et al., 1993; Davies, 1999; Dorioz et al., 2006; Reichenberger et al., 2007; Lazzaro et al., 2008; Borin et al., 2010; Campo-Bescós et al., 2015).

Under cross-compliance and the countryside stewardship policy, landowners in the United Kingdom and across Europe, must maintain a vegetative buffer strip on land within two metres of the centre of a watercourse (DEFRA, 2018). However, whilst some advice is available, there is no specifically prescribed selection of plant species for these strips (Farming Advice Service, 2018). In a meta-analysis undertaken by Mayer et al. (2007) on different types of buffer strips, vegetation type within the strip did not have an effect on the efficiency of nitrogen removal. However, the effects of specific plant species were not investigated, and this could be essential in the efficacy of a vegetative strip, with regard to pollution mitigation. Plant traits, such as leaf area, floral display size or nectar content, define a plant's ability to support water quality protection and other ecosystem services such as crop pollination and the biological control of crop pests (Kattge et al., 2011; Diaz et al., 2007; Garnier and Navas, 2012). Therefore, the plant species that are established within a buffer strip could have positive or negative effects on its potential to protect water quality, depending on their combination of traits.

As land availability becomes increasingly restricted and food production requirements continue to increase, there is a need to improve the efficacy and functionality of vegetative buffer strips (Robinson and Sutherland, 2002; Godfray et al., 2010; Stutter et al., 2012; Hackett & Lawrence, 2014). The concern with this is that an increase in functionality could potentially compromise the support provided for water quality protection.

To test the potential of a multifunctional vegetative strip a standardised method of seed mix design was developed, that utilises systematically collated evidence on plant traits and used this to produce different perennial seed mixes for multifunctional and single-focus vegetative strips (Chapters 2 and 3).

In this study the following questions are addressed: (i) How does the vegetative support for water quality protection in multifunctional vegetative strips compare with that of a single-focus strip? (ii) How does functionality of a vegetative strip effect root structural density?

6-2 Methods

This study is part of a three year experiment which investigated the effects of eight different vegetative strips on the establishment and persistence of plant communities (Chapter 4) and provision for pollinators (Chapter 5), natural enemies of crop pests and water quality protection. Seven of the vegetative strips were developed using evidence on plant traits that was systematically collated (Chapters 2 and 3), and the last was a commercial example of a multifunctional vegetative strip. A full methodology of all of the vegetative strip seed mixes, study sites, plot management and vegetative surveys can be found in Chapter 4, a summary of those methods is included here as well as any additional methods for this study.

6-2.1 Vegetative strip seed mixes

In this study, two multifunctional and one single-focus UK plant species seed mix designed using methods outlined in Chapter 3, were considered. The multifunctional seed mixes were designed to support pollination, bio-control and water quality protection concurrently, one with 20% forbs and 80% grasses (MVS) and one with 50% forbs and 50% grasses (MVS_H). This was a key comparison as standard practice is to include only 20% forbs, and 80% grasses, mainly to reduce the cost of the seed mix (e.g. Syngenta, 2014; Buglife, 2018; Kings Seeds, 2018; Emorsgate Seeds, 2018), The MVS_H also had a sowing rate of 1g/m^2, due to the higher proportion of forbs and associated increased cost of the seed mix. The single-focus seed mix (WQVS) was designed to support water quality protection only and consisted of 100% grasses. Table 6-1 shows a list of the plant species and their percentage weight contribution in each seed mix.

Table 6-1 Seed mixes, relevant codes, included plant species and their percentage weight contribution. MVS - Multifunctional vegetative strip for all soil types (20% forbs, 80% grasses), MVS_H - Multifunctional vegetative strip for all soil types (50% forbs, 50% grasses & lower sowing rate) and WQVS – Water quality protection vegetative strip.

	Plant species	Percentage weight contribution to the following seed mixes:		
		MVS	MVS_H	WQVS
Forbs	*Achillea millefolium*	2.00	5.00	
	Centaurea nigra	2.00	5.00	
	Daucus carota ssp carota	2.00	5.00	
	Hypochaeris radicata	0.50	1.25	

	Leucanthemum vulgare	2.00	5.00	
	Lotus corniculatus	2.00	5.00	
	Primula vulgaris	1.00	1.50	
	Ranunculus acris	2.00	6.25	
	Silene dioica	2.00	5.00	
	Stachys sylvatica	1.00	2.50	
	Taraxacum officinale agg.	2.00	5.00	
	Trifolium pratense	0.50	1.25	
	Trifolium repens	0.50	1.25	
	Veronica chamaedrys	0.50	1.00	
Grasses	*Agrostis capillaris*	10.00	6.25	10.00
	Alopecurus pratentsis			30.00
	Dactylis glomerata	10.00	6.25	15.00
	Festuca rubra	50.00	31.25	
	Phleum pratense			30.00
	Schedonorus arundinaceus			15.00
	Schedonorus pratensis	10.00	6.25	

6-2.2 Study sites and experimental design

In April 2015, the seed mixes were hand-sown with five replications in a randomised-block design on sandy loam soil at Harper Adams University, Shropshire, England and on heavy clay soil at the Game and Wildlife Conservation Trust Loddington Farm, Leicestershire, England. The MVS and WQVS were sown at 2 g/m^2, and the MVS$_H$ was sown at 1 g/m^2, on 4m by 4m plots with a 1m grass buffer in-between.

6-2.3 Vegetative surveys and root structural density sampling

Between 20th July 2015 and 20th April 2018, percentage vegetative cover (reflecting protection against run-off and erosion) and mean plant height (reflecting protection against pesticide spray-drift) of each plant species was recorded every month. Root structural density (reflecting protection against watercourse sedimentation) was also sampled bi-annually in spring and autumn, using a soil auger 5cm diameter by 30cm depth (Van Walt, Haslemere, Surrey). Five random samples were taken from each plot. Each sample was then divided into six sections, representing 5cm depth classes, which were pulled apart by hand and qualitatively scored from one to five on the density of the root structure present.

6-2.4 Statistical analyses

The evaluation of the effect of vegetative strip type on percentage vegetative cover was expanded from what was shown in Chapter 4 to consider the contribution of sown and non-sown forbs and grasses to the cover. The effect of vegetative strip type on the mean plant community height and root structural density was evaluated using repeated-measures ANOVAs. *Post hoc* tests (LSD) were performed for significant factors in the analyses. All ANOVA assumptions were achieved. Percentage bare ground was arcsine square root transformed to achieve normality. For the analysis, the mean plant height for the whole plant community in each plot was calculated by using the vegetative cover values for each species, as shown in the following formulas:

The weighted mean height of each plant species as a contribution to the total height of the whole plot was calculated using the following equation (1):

$$W_i = H_i \cdot \left(C_i \cdot \frac{100}{C_t} \right) \tag{1}$$

where W_i is the weighted mean height of plant species i; H_i is the mean height of plant species i, C_i is the percentage (%) cover of plant species i and C_t is the total percentage cover in plot t.

Subsequently the mean height for the whole plot was calculated with equation (2):

$$M_t = \frac{\sum_i^n W_i}{100} \tag{2}$$

where M_t is the mean height of plot t and the number of plant species in the plot is n.

The data for percentage bare ground have been analysed and discussed in Chapter 4 to investigate the effects of management, soil type and sowing rates on the establishment and persistence of the resulting plant communities. In this study, these data are evaluated in further detail in reference to provision of water quality protection. In addition, the data on plant height and the vegetative cover provided by sown and non-sown forb and grass species, was analysed. The provision of support for water quality protection was assessed and compared between single-focus and multifunctional vegetative strips.

6-3 Results

At the Harper Adams University site on sandy loam soil, survey month had a significant effect on the differences in percentage bare ground and mean plot height between vegetative strip types. No effect of survey month, on the differences between the vegetative strips, was found at the Loddington site on heavy clay soil, see Table 6-2.

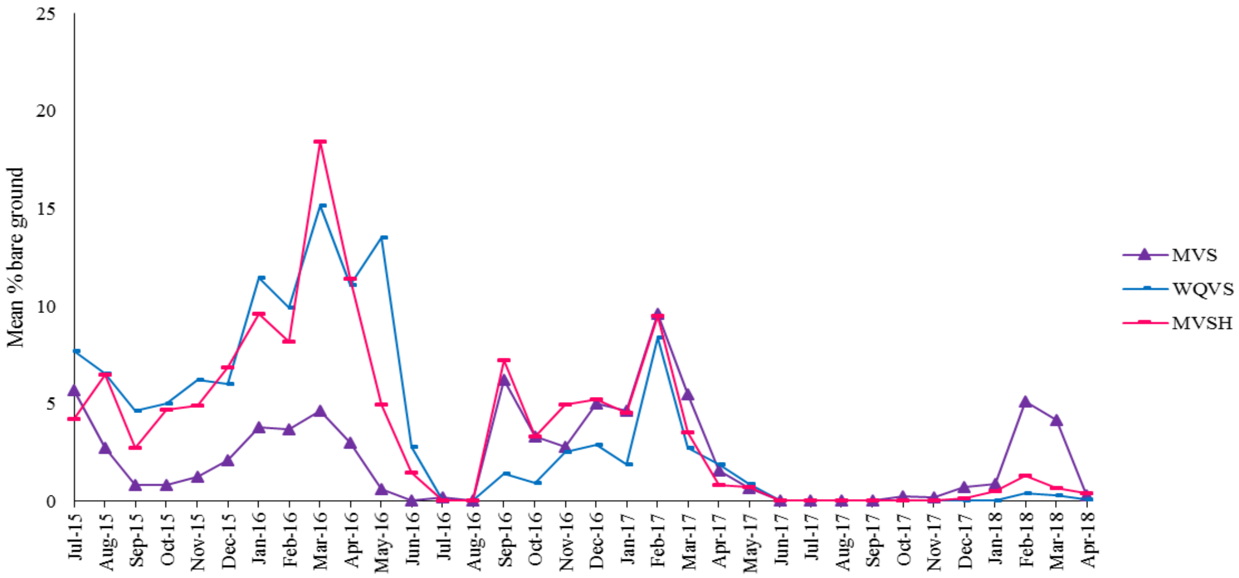
Table 6-2 Repeated measures ANOVAs considering the effect of vegetative strip type on percentage bare ground and mean plot height at Harper Adams (sandy loam soil) and Loddington (heavy clay soil). * P<0.05, ** P<0.01, *** P<0.001. Results on percentage bare ground adapted from Chapter 4.

Element of vegetative cover	Site	Vegetative strip type	Survey month	Vegetative strip type* survey month
Percentage bare ground	Harper Adams	$F_{4,7}$ = 22.581, P<0.001***	$F_{4,33}$ = 95.907, P<0.001***	$F_{4,231}$ = 2.641, P<0.001***
	Loddington	$F_{4,7}$ = 5.176, P<0.001***	$F_{4,32}$ = 95.782, P<0.001***	$F_{4,224}$ = 0.482, P = 1
Mean plot height	Harper Adams	$F_{4,7}$ = 21.38, P<0.001***	$F_{4,33}$ = 574.54, P<0.001***	$F_{4,231}$ = 57, P<0.001***
	Loddington	$F_{4,7}$ = 33.896, P<0.001***	$F_{4,32}$ = 318.625, P<0.001***	$F_{4,224}$ = 1.054, P = 0.297

6-3.1 Percentage bare ground

In Chapter 4 it was highlighted that percentage bare ground decreased over time for all of the vegetative strips in the experiment at both sites, the results for the strips included in the present study can be seen in Figure 6-1. At the Harper Adams site on sandy loam soil, the multifunctional vegetative strip (MVS) initially had significantly lower (P < 0.05) percentage bare ground than the water quality protection strip (WQVS). After this, the amount of bare ground in the two strips became comparatively similar. Interestingly, the multifunctional vegetative strip with 50% forbs and 50% grasses and a lower sowing rate (MVS_H) always had comparably similar bare ground to the water quality protection strip (WQVS) on this site. At the Loddington site on heavy clay soil, the percentage bare ground found in the water quality protection strip (WQVS) was consistently significantly lower (P < 0.001) than both of the multifunctional strips (MVS and the MVS_H), but these differences decreased in magnitude over time as the percentage bare ground in all vegetative strips decreased overall.

a)



b)

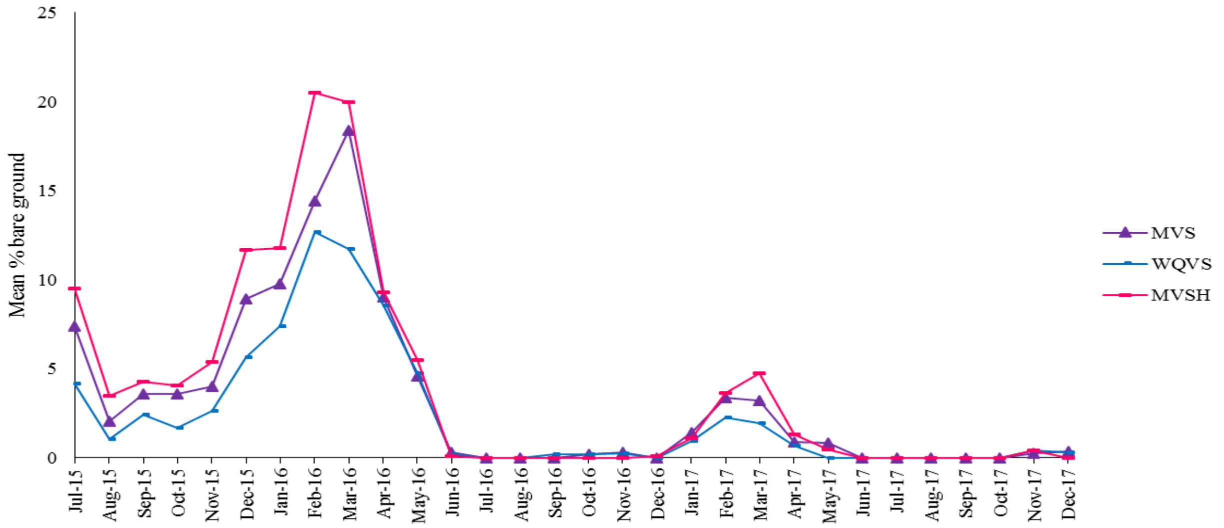


Figure 6-1 Mean percentage bare ground at sites a) Harper Adams University on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as: MVS = Multifunctional strip (20% forbs, 80% grasses), MVS_H = Multifunctional strip (50% forbs, 50% grasses & lower sowing rate) and WQVS = Water quality protection strip. Adapted from Chapter 4.

6-3.2 Percentage vegetative cover provided by sown and non-sown forbs and grasses

Over the three year survey period two different trends at each site were observed. At the Harper Adams site on sandy loam soil, for all treatments the cover provided by sown grasses increased until they provided the dominant form of cover by the end of the survey period, see Figure 6-2. Conversely, at the Loddington site on heavy clay soil the non-sown forbs remained dominant across all treatments throughout the survey period (Figure 6-2). However, in almost all of the surveyed months, at both sites, the multifunctional vegetative strip with 50% forbs and 50% grasses and a lower sowing rate (MVS_H) did have higher proportions of sown forb species than the water quality protection strip with 100% grasses (WQVS) and the multifunctional strip with 20% forbs and 80% grasses (MVS).

a)

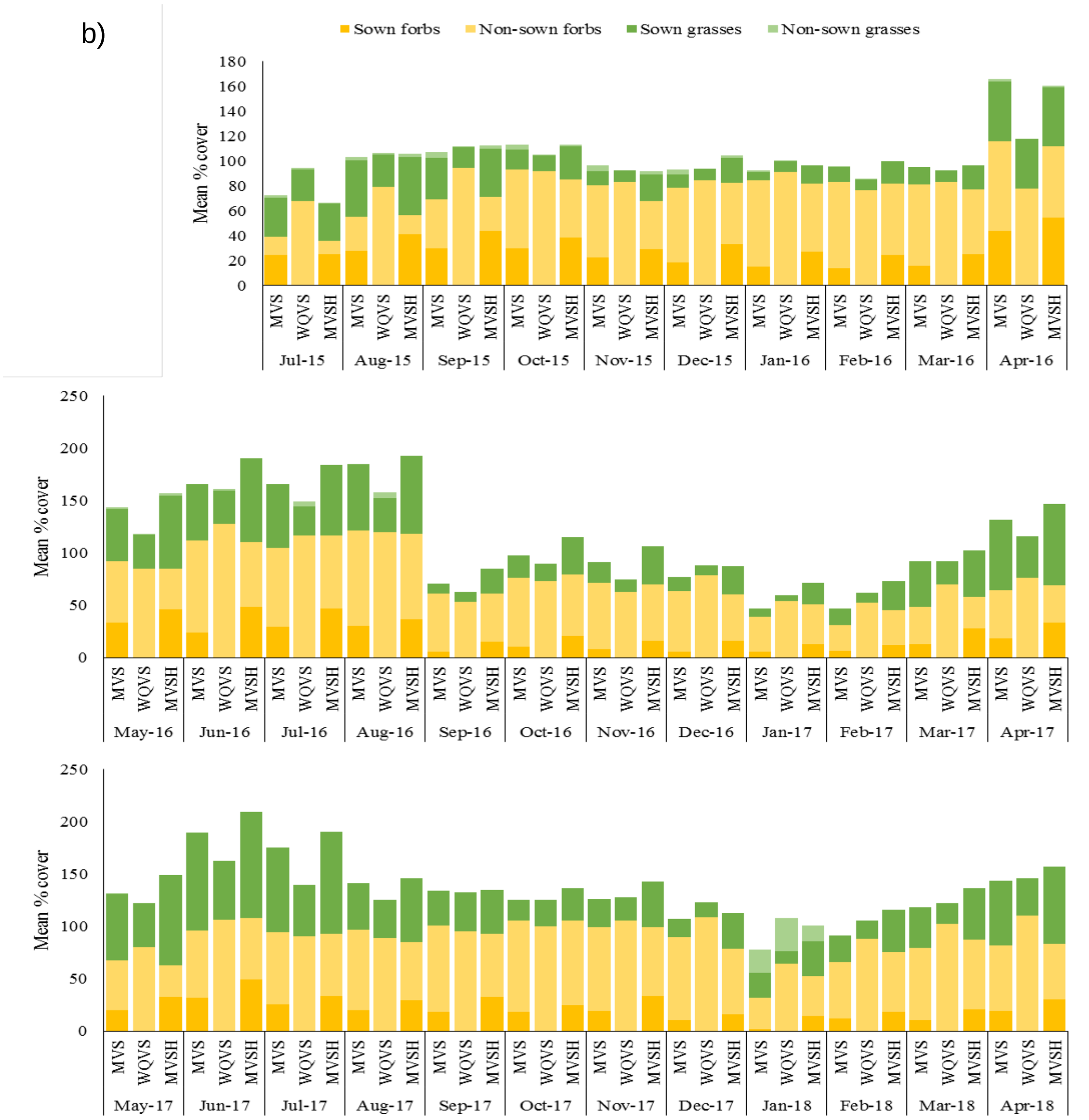


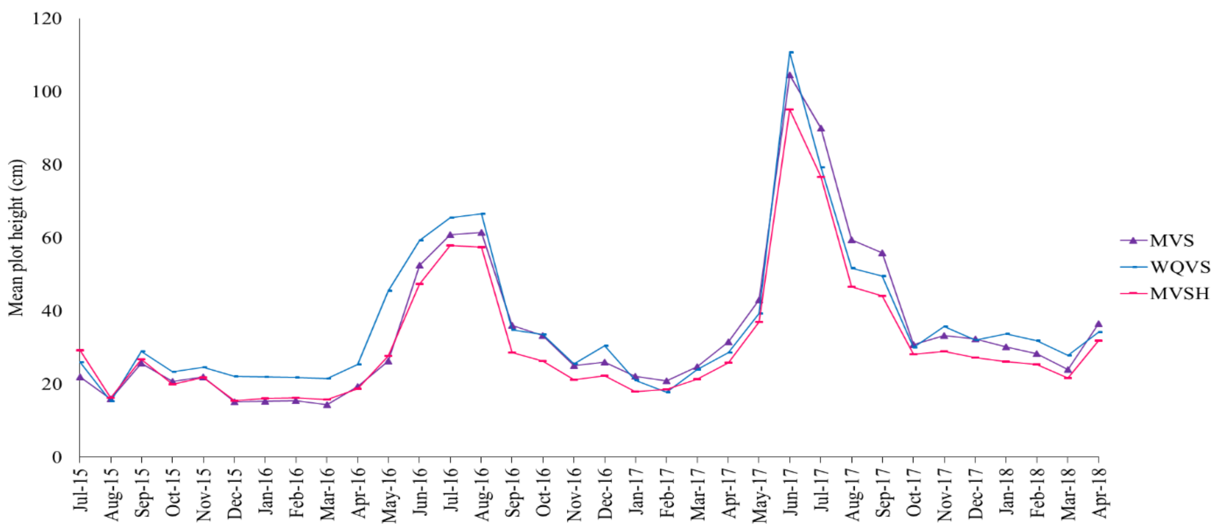
Figure 6-2 Effect of vegetative strip type on percentage cover provided by sown and non-sown forbs and grasses at sites a) Harper Adams on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as: MVS = Multifunctional strip (20% forbs, 80% grasses), MVS_H = Multifunctional strip (50% forbs, 50% grasses & lower sowing rate) and WQVS = Water quality protection strip.

6-3.3 Mean plant community height

At both sites the mean plant community height of all the vegetative strip types was highest during the Spring/Summer periods, see Figure 6-3. At the Harper Adams site on sandy loam soil the water quality vegetative strip (WQVS) initially had significantly higher ($P < 0.05$) mean plant community height than both the multifunctional vegetative strips (MVS and MVS_H). After December 2016 no differences were observed between the WQVS and the MVS, but the WQVS continued to occasionally have significantly higher plant community height than the multifunctional strip with 50% forbs and 50% grasses (MVS_H), in particular in Autumn 2016. Also, the MVS plant community height was significantly higher (P <0.05) than the MVS_H in some of the autumn and winter months in the second and third year of establishment and in April 2017.

At the Loddington (heavy clay soil) site the water quality protection strip (WQVS) had consistently significantly higher ($P < 0.001$, $F_{4,7} = 33.58$) plant community height than the multifunctional vegetative strip (MVS), and both of these strips had consistently significantly higher (P <0.05) plant community height than the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H).

a)



b)

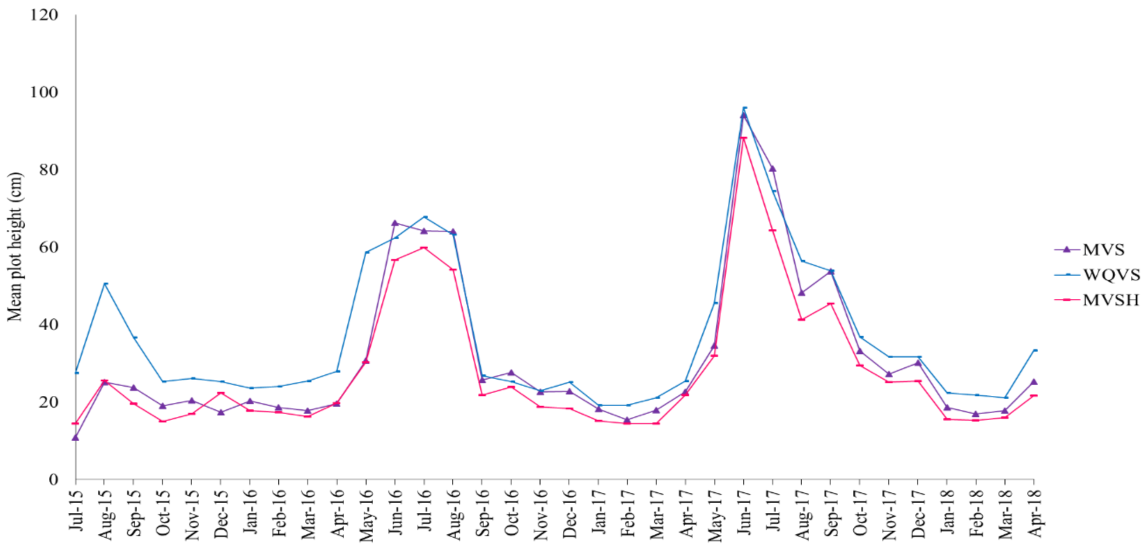


Figure 6-3 Effect of vegetative strip type on mean plant community height at sites a) Harper Adams on sandy loam soil and b) Loddington on heavy clay soil. Vegetative strip types are depicted as: MVS = Multifunctional strip (20% forbs, 80% grasses), MVS_H = Multifunctional strip (50% forbs, 50% grasses & lower sowing rate) and WQVS = Water quality protection strip.

6-3.4 Root structural density

No significant effect of vegetative strip type on average root structural density score was found at either site at any depth, see Table 6-3. This showed that vegetative strip type had no effect on root structural density up to a depth of 30cm.

Table 6-3 Repeated measures ANOVAs considering the effect of vegetative strip type on root structural density up to a depth of 30cm.

		Depth (cm)						
Site	df	0-5	5-10	10-15	15-20	20-25	25-30	Whole sample (0-30)
Harper Adams	4,7	F = 0.62, P = 0.736	F = 0.79, P = 0.598	F = 0.52, P = 0.815	F = 0.51, P = 0.823	F = 1.21, P = 0.305	F = 1.02, P = 0.420	F = 0.823, P = 0.57
Loddington	4,7	F = 3.90, P = 0.0502	F = 0.74, P = 0.392	F = 0.40, P = 0.528	F = 0.004, P = 0.948	F = 0.57, P = 0.453	F = 0.24, P = 0.626	F = 0.104, P = 0.747

6-4 Discussion

The sown seed mix and the site location and soil type on which a vegetative strip is established can have a significant effect on the resulting plant communities and the support they provide for water quality protection. In this study, the effects of vegetative strip type on percentage bare ground and plant community height varied between the two sites. Also, drastically different trends were observed between the sites in the proportions of sown and non-sown forbs and grasses that contributed to the vegetative cover in each strip. Whilst the sown forbs and grasses provided the majority of cover at the Harper Adams site, the non-sown forbs and sown grasses provided the majority of cover at the Loddington site, see Figure 6-2. This means that the measured support for water quality protection at the Harper Adams site can be attributed to the sown seed mixes, but, there wasn’t such a clear relationship at the Loddington site.

At Harper Adams, the multifunctional vegetative strip (MVS) provided an initial significant enhancement of support for protection against run-off and erosion (lower percentage bare ground), and then became comparably similar to the water quality protection strip (WQVS). In contrast, at Loddington significantly less support for protection against run-off and erosion in the MVS and the multifunctional strip with 50% forbs and 50% grasses (MVS_H), than in the WQVS was consistently observed. At the Loddington the vast majority of cover was provided by non-sown forbs, namely *Rumex obtusifolius,* for the majority of the survey period. So, the lower cover of the established sown plants at this site is the likely cause of this decreased support, and not the lack of ability of the selected plants to provide the required support, as we can see that, when established at Harper Adams, they did support protection against run-off.

This same pattern was observed when comparing support for protection against pesticide spray-drift (plant community height) between the two sites. At the Harper Adams site on sandy loam soil the multifunctional strip (MVS) initially had a lower plant community height than the water quality protection strip (WQVS), but then was not significantly different from the WQVS after December 2016. At Loddington, the water quality protection strip (WQVS) almost always had a higher mean plant community height than both of the multifunctional strips (MVS and MVS_H). Research demonstrates the direct effect of hedgerows on protection against spray-drift (Lazzaro et al., 2008), whereas vegetative strips are usually studied in terms of run-off and erosion. These results could demonstrate the potential of vegetative strips to buffer against spray-drift, but further research into the effects of the structure of this vegetation would increase our understanding of the efficacy of each strip (Hewitt, 2000).

This is essential evidence when considering what to sow on different soil types and sites. There was a clear difference in the provision of support by all vegetative strips to protect against run-off, erosion and pesticide spray-drift between these two sites. When developing seed mixes for heavy clay soils, it may be wise to only consider a few plant species that are extremely robust and known to establish well on that particular site. Sowing larger quantities of fewer plant species may give more favourable plant community establishment results.

When increasing the functionality of a vegetative strip to support several ecosystem services the trade-offs that may be made must be carefully considered. The multifunctional vegetative strip designed in Chapter 3, aims to support pollinators and natural enemies of crop pests, whilst protecting water quality. At both sites the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) had consistently less protection against run-off and erosion (higher percentage bare ground) and pesticide spray-drift (lower plant community height) than the water quality protection strip (WQVS). However, in almost all of the surveyed months, at both sites, the MVS_H did have higher proportions of sown forb species than the WQVS and the multifunctional vegetative strip sown with 20% forbs and 80% grasses (MVS). Also, in Chapter 5 the MVS_H provided the most floral support with the most variety, and it contained the highest amount of plant species that were preferred by the pollinators. This is key, because though this seed mix may provide the best support for pollinators, it seems to provide less support for water quality protection than the WQVS and MVS. It is likely that the MVS, which provides some benefits to pollinators (Chapter 5), but better support for water quality protection than the MVS_H, could be the most appropriate multifunctional option.

As no effect of vegetative strip type was observed on root structural density, sowing a more multifunctional seed mix may not adversely affect the ability of a vegetative strip to protect against watercourse sedimentation (Burylo et al., 2012; Chau and Chu, 2017).

6-5 Conclusions

The vegetative support for water quality protection (protecting against run-off, erosion and spray-drift) in multifunctional vegetative strips can be comparable to that of a single-focus strip, if the multifunctional seed mix is sown with 20% forbs and 80% grasses and the sown species establish on that site. Also, the functionality of a vegetative strip does not seem to effect root structural density and therefore protection against watercourse sedimentation.

It is clear that careful consideration should be given when establishing a multifunctional vegetative strip, to ensure that all the targeted ecosystem services are supported. However, as water quality protection is of primary concern for vegetative strips established alongside farmland watercourses, it is recommended that the multifunctional vegetative strip with 20% forbs and 80% grasses mix could be used in sandy loam soils to increase the functionality of vegetative buffer strips whilst still providing support for protection against water pollution. The findings from this study should encourage land managers to consider increasing the functionality of their vegetative strips, but also consider the soil type of their land prior to choosing a seed mix as this can greatly affect the desired plant community that establishes.

Chapter 7. Increasing the functionality of farmland vegetative strips – benefits for crop pest natural enemies

Abstract

Increasing food production requirements and restrictions on land availability have driven a need to increase the functionality of vegetative strips, to support multiple ecosystem services. This increase in functionality could also help to meet the habitat requirements of the taxonomically diverse species that act as natural enemies of crop pests.

The effect of vegetative strip functionality on plant diversity and natural enemy abundances were evaluated using in-field plots, sown on two soil types, with multifunctional and single-focus vegetative strips.

The multifunctional vegetative strips almost always had the highest plant diversity on both soil types. Whilst the multifunctional mix with 50% forbs provided significantly higher diversity than the multifunctional mix with only 20% forbs, on sandy loam soil, it did not on heavy clay. A positive correlation with the proportion of grasses sown and Araneae abundances was observed, as well as a positive correlation with proportion of forbs sown and Carabidae abundances.

The results from this study demonstrate the essential support that forb plant species could provide to natural enemies as well as the increased plant diversity from a multifunctional vegetative strip. In addition, they demonstrate the effect of soil type and site location on plant diversities found in vegetative strips. The results provide an initial insight into the effect of vegetative strip functionality on the provision of support for the biological control of crop pests. These findings could begin to inform policy makers and land managers on the importance of increasing the diversity and functionality of vegetative strips to increase support for ecosystem services within farmland.

In prep: Cresswell, C.J., Wilcox, A., Cunningham, H.M., Randall, N.P. Increasing the functionality of farmland vegetative strips – benefits for crop pest natural enemies. Intended for submission to: Ecological Entomology.

7-1 Introduction

Farmland vegetative strips are used globally to support biodiversity and ecosystem services such as pollination, biological control of crop pests and water quality protection (Pfiffner and Wyss, 2004; Reichenberger et al., 2007; Lye et al., 2009; Haaland et al., 2011; Tschumi et al., 2016). In particular, the most widely-used type of vegetative strip for the support of insect natural enemies of crop pests is the 'beetle bank', originally created in England by the Game and Wildlife Trust in collaboration with the University of Southampton (Game and Wildlife Conservation Trust, 2018). In the United Kingdom, these are commonly sown with various grass species, mainly tussock types such as *Dactylis glomerata* and *Phleum pratense* (e.g. Emorsgate Seeds, 2018; Game and Wildlife Conservation Trust, 2018), which satisfy the AB3: Beetle banks option in the government countryside stewardship schemes (Natural England, 2018). However, supporting the taxonomic diversity of natural enemies commands a variety of habitat requirements, in particular, a variety of plant species with key traits. For example, floral resources with large floral displays, and/or high nectar availability and content, support aerial natural enemies such as parasitoid wasps and hoverflies (Møller & Sorci, 1998; Bianchi and Wackers, 2008), as seen in Chapter 3. Also, more functionally diverse and heterogeneous plant communities are known to support a higher diversity of parasitoids and hoverflies, and a higher species richness and abundance of key surface active natural enemies such as carabid beetles (Wardle and van der Putten, 2002; Ramsden et al., 2013; Balzan, et al., 2015; Rouabah, A., et al., 2015).

As insect natural enemies are so taxonomically diverse, their prey species preferences can differ significantly, and when targeting a specific crop pest, not all predators will provide effective control (Lefebvre et al., 2017; Bannerman et al., 2018; Yang et al., 2018). Whilst some generalist species exist, supporting a more diverse population of natural enemies, with specific and generalist preferences, can provide the most effective pest control (Gontijo et al., 2015; Dib et al., 2016).

Often, vegetative strips have been successfully designed to support single ecosystem services or species groups, such as the previously discussed beetle bank, but also wildflower strips for pollinators (Lye et al., 2009; Haaland, et al., 2011; Feltham et al., 2015) and grassy strips for water quality protection (Davies, 1999; Dorioz et al., 2006; Reichenberger et al., 2007; Campo-Bescós et al., 2015). There is a distinct need for a more functionally diverse vegetative strip to meet the habitat requirements of a variety of natural enemy species (Balzan, et al., 2015; Rouabah, A., et al., 2015). In addition, increasing food production requirements and restrictions on land availability require a more multifunctional vegetative strip that supports these ecosystem services concurrently (Godfray et al., 2010; Stutter et al., 2012; Hackett and Lawrence, 2014).

In 2015, a method of plant species selection for vegetative strips to support multiple ecosystem services was developed (Chapter 3). Systematically collated evidence on plant traits was used, as these define how a plant species may support an ecosystem service (Chapter 2). In particular, three main ecosystem services were to be supported by one vegetative strip – pollination, bio-control and water quality protection. To investigate the ecosystem service support provided by the designed seed mixes, a large in-field experiment at two distinct sites was established. Between 2015 and 2018 vegetative cover was surveyed monthly, and surface active natural enemy abundances were sampled in Summer 2016.

In this study the following questions are addressed: (i) How does the diversity of vegetative support for natural enemies in multifunctional vegetative strips compare with that of single-focus strips? (ii) How does functionality of a vegetative strip effect the abundance of surface active natural enemies?

7-2 Materials and Methods

This study is part of a three-year experiment which investigated the effects of eight different vegetative strips on the establishment and persistence of plant communities (Chapter 4) and provision for pollinators (Chapter 5), natural enemies of crop pests and water quality protection (Chapter 6). Seven of the vegetative strips were developed using evidence on plant traits that was systematically collated (Chapters 2 and 3), and the last was a commercial example of a multifunctional vegetative strip. A full methodology of all the vegetative strip seed mixes, study sites, plot management and vegetative surveys can be found in Chapter 4, a summary of those methods is included here, as well as the additional methods used in this experiment.

7-2.1 Vegetative strip seed mixes

Seed mixes of UK plant species were designed using a plant species ranking methodology that was developed using systematically collated evidence on plant traits (Chapters 2 and 3).

Two versions of a multifunctional seed mix were designed, one with 20% forbs and 80% grasses (MVS) and one with 50% forbs and 50% grasses (with a lower sowing rate of 1g/m^2 due to the increased proportion of forbs) (MVS_H), to investigate the effect of different proportions of forbs on the support provided. Also, a single-focus grass only mix for water quality protection (WQVS) was designed. This mix included grasses that are also typically found in a beetle bank seed mix (Emorsgate seeds, 2018), so it acted as a typical example of this vegetative strip type. Lastly, a single-focus forb only mix for pollinator support (PSVS) was developed. To compare the designed seed mixes to a commercially available perennial seed mix, a multifunctional mix from Syngenta’s

Operation Pollinator programme, was also included in the study (OPVS). A list of plant species included in the seed mixes can be found in Table 7-1.

Table 7-1 Seed mixes, relevant codes, included plant species and their percentage weight contribution to each seed mix type. MVS - Multifunctional vegetative strip for all soil types (20% forbs, 80% grasses), MVS_H - Multifunctional vegetative strip for all soil types (50% forbs, 50% grasses & lower sowing rate), PSVS – Pollination support, WQVS – Water quality protection and OPVS – Operation Pollinator (commercially available multifunctional example).

	Plant species	Percentage weight contribution to the following seed mixes:				
		MVS	MVS_H	PSVS	WQVS	OPVS
Forbs	*Achillea millefolium*	2.00	5.00			2.00
	Centaurea nigra	2.00	5.00	12.50		1.00
	Daucus carota ssp carota	2.00	5.00			3.00
	Galium album					2.00
	Heracleum sphondylium			4.00		
	Hypochaeris radicata	0.50	1.25	0.25		
	Leontodon hispidus			12.00		
	Leucanthemum vulgare	2.00	5.00	12.50		2.00
	Lotus corniculatus	2.00	5.00			
	Primula vulgaris	1.00	1.50	2.00		
	Ranunculus acris	2.00	6.25	12.25		2.00
	Silene dioica	2.00	5.00	12.00		2.00
	Stachys sylvatica	1.00	2.50			2.00
	Taraxacum officinale agg.	2.00	5.00	10.00		
	Trifolium pratense	0.50	1.25	10.00		1.00
	Trifolium repens	0.50	1.25	10.00		
	Veronica chamaedrys	0.50	1.00	2.50		

	Vicia cracca					2.00
Grasses	*Agrostis capillaris*	10.00	6.25		10.00	
	Alopecurus pratentsis				30.00	
	Dactylis glomerata	10.00	6.25		15.00	10.00
	Festuca rubra	50.00	31.25			30.00
	Phleum pratense				30.00	10.00
	Schedonorus arundinaceus				15.00	10.00
	Schedonorus pratensis	10.00	6.25			20.00

7-2.2 Study sites and experimental design

In April 2015 the seed mixes were hand-sown with five replications in a randomised-block design on sandy-loam soil at Harper Adams University, Shropshire, England and on heavy clay soil at the Game and Wildlife Conservation Trust Loddington Farm, Leicestershire, England. The multifunctional vegetative strip with 20% forbs and 80% grasses (MVS), water quality protection strip (WQVS) and commercial example of a multifunctional strip (OPVS) were sown at 2 g/m^2 and the multifunctional strip with 50% forbs and 50% grasses (MVS$_H$) and pollinator support vegetative strip (PSVS) at 1 g/m^2 (due to the increased forb proportions), on small (4m by 4m) plots with a 1m grass buffer in-between. In addition, three replications of each treatment were sown in a randomised-block design on larger in-field plots (8m by 31m) at Loddington Farm. These were managed the same as the small plots as detailed in Chapter 4 but were not hand-weeded after sowing in 2015.

7-2.3 Crop pest natural enemy surveys

In summer 2016, pitfall traps were set to capture surface active natural enemies in the large in-field plots at Loddington farm. Each pitfall trap was set up as seen in Figure 7-1. Five traps were set one metre apart along a transect in the centre of each vegetative strip. The traps remained in the same position for the duration of the experiment. In each sampling month from 22nd June to 22nd September the traps were set at midday, left for 24 hours and collected the following day. Samples were collected and stored in 70% methylated spirits at approximately 5℃. All specimens within the samples were sorted to order or family and put into size categories: small (<7mm), medium (7-12mm) and large (>12mm).

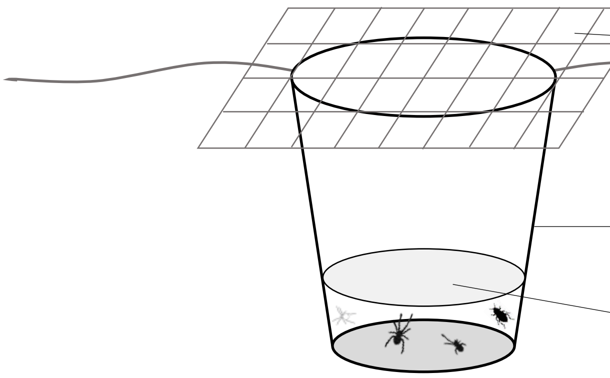


Figure 7-1 Pitfall trap setup in-field. The small mammal and amphibian guard consisted of 15mm^2 wire mesh. Preservative consisted of 50ml 70% methylated spirits.

7-2.4 Statistical analyses

All analyses were conducted in R version 3.5.0. We evaluated the effect of vegetative strip type on percentage vegetative cover diversity and natural enemy abundances with repeated measures ANOVAs. *Post hoc* tests (LSD) were performed for significant factors in the analyses. All ANOVA assumptions were achieved. Natural enemy abundances were Log_{10} transformed to achieve normality.

Plant species diversity of vegetative cover was calculated with the Shannon diversity index using the following equation:

$$Shannon\ diversity\ Index\ (H) = -\sum_{i=1}^{s} p_i \ln p_i$$

where *p* is the proportion (n/N) of individuals of one particular species found (n) divided by the total vegetative cover found (N) and s is the number of species.

7-3 Results

7-3.1 Effect of vegetative strip type on plant species diversity of vegetative cover

In the small plot experiments a total of 80 plant species were found at the Harper Adams site on sandy loam soil and 78 at the Loddington site on heavy clay soil. Sampling month affected the differences in plant diversity between the vegetative strips (Table 7-2), and so each month was analysed separately, see Additional File 7-1 for the detailed analysis.

Table 7-2 Repeated measures ANOVA considering the effect of vegetative strip type on plant diversity.

		Harper Adams		Loddington	
Variable	df	F	P	F	P
Vegetative strip type	4,7	148.06	<0.001	102.581	<0.001
Sampling month	4,33	105.75	<0.001	40.598	<0.001
Vegetative strip type * Sampling month	4,231	2.791	<0.001	2.016	<0.001

Throughout the 36 months surveyed, on both sites, the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) almost always (at Harper Adams: 72% of months, at Loddington: 94% of months) had the highest plant diversity. Also, both multifunctional strips (MVS_H and MVS) frequently (Harper Adams: MVS – 56%, MVS_H - 92% of months, Loddington: MVS – 58%, MVS_H – 61% of months) had significantly higher ($P<0.05$) plant diversity than the grass only strip (WQVS), see Figure 7-2. As expected, the grass only strip often had the lowest plant diversity. Also, the multifunctional vegetative strips (MVS and MVS_H) almost always had higher plant diversity than the vegetative strip for pollinators (PSVS), which was sown with forbs only. At Harper Adams, the multifunctional mix with 20% forbs and 80% grasses (MVS) and MVS_H frequently (MVS – 47% of months and MVS_H – 89%) had significantly higher ($P<0.05$) diversity than the PSVS. Whilst at Loddington, there were fewer months where the MVS (11%) and the MVS_H (22%) had significantly lower diversity than the PSVS.

At Loddington, plant diversity in the MVS_H was never significantly different from the MVS, but it was significantly higher ($P<0.05$) at Harper Adams in 69% of the months.

During 2016, at Harper Adams, the vegetative strip for pollinators (PSVS), sown only with forbs, had significantly higher ($P<0.05$) plant diversity than the grass only strip (WQVS) in 75% of the months, but after this the two vegetative strips had surprisingly similar plant diversities. A different trend was observed on the heavy clay soil where the forb only strip (PSVS) had significantly higher ($P<0.05$) plant diversity than the grass only strip (WQVS) in the majority of months (86%).

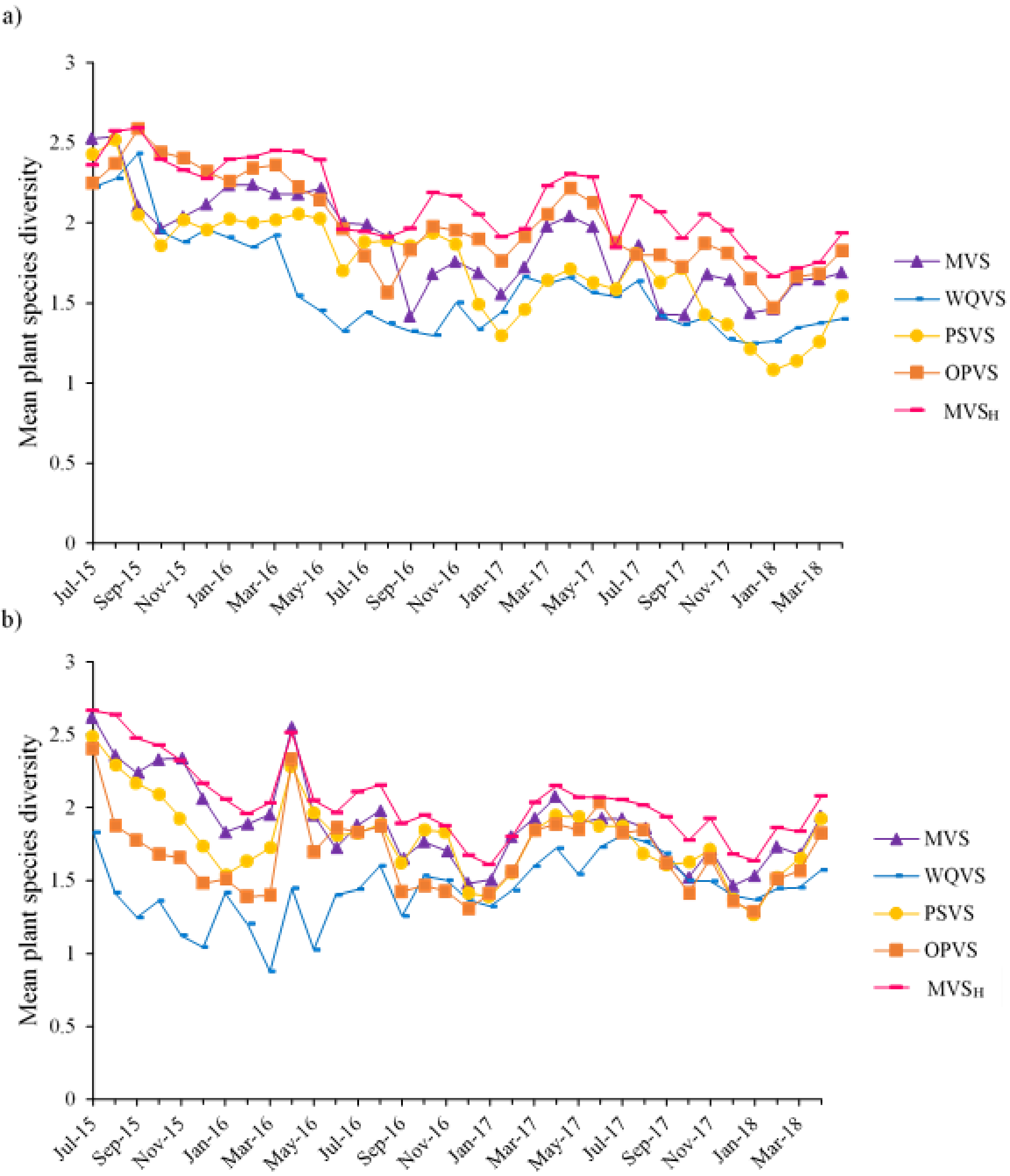


Figure 7-2 Effect of vegetative strip type on plant diversity of percentage cover at sites a) Harper Adams (sandy loam soil) and b) Loddington (heavy clay soil). MVS = Multifunctional vegetative strip (80% grasses, 20% forbs), WQVS = water quality protection strip (100% grasses), PSVS = pollinator support strip (100% forbs), OPVS = Commercial example of multifunctional strip (80% grasses, 20% forbs) and MVS_H = multifunctional strip with 50% forbs and 50% grasses.

7-3.2 Effect of vegetative strip type on natural enemy abundances

A total of 3,502 natural enemies were collected from the pitfall traps, of which 48% were Araneae, 44% Carabidae and 8% Staphylinidae. There was an effect of vegetative strip type on the differences in abundances between the species groups, and these differences did not change between sampling months, see Table 7-3.

Table 7-3 Repeated measures ANOVA considering the effect of vegetative strip type on abundances of Araneae, Carabidae and Staphylinidae.

		Araneae		Carabidae		Staphylinidae	
Variable	df	F	P	F	P	F	P
Vegetative strip type	2,7	4.44	<0.0001	4.72	<0.0001	2.85	0.0064
Sampling month	2,3	21.53	<0.0001	8.98	<0.0001	18.24	<0.0001
Vegetative strip type * Sampling month	2,21	1.39	0.1152	1.486	0.0772	1.579	0.0502

For each natural enemy species group there was no significant difference in mean abundance (P>0.05) between the multifunctional vegetative strip (MVS) and the grass only vegetative strip (WQVS), see Figure 7-3. Also, both strips had similar abundances of the small (<7mm), medium (7-12mm) and large species (>12mm) within each group. Apart from the MVS, all other seed mixes that contained forb species (MVS_H, PSVS and OPVS) had significantly higher (P<0.05) Carabidae abundances than the grass only vegetative strip (WQVS). In fact, the highest Carabidae abundance was found in the strip that was sown only with forbs for pollinator support (PSVS). In contrast, all seed mixes sown with at least 80% grasses (MVS, WQVS and OPVS) had significantly higher Araneae abundances, in particular the OPVS had significantly more than the PSVS and MVS_H (the multifunctional mix with 50% forbs). The main contributors to change in Araneae and Caribidae abundances were the medium-sized (7-12mm) natural enemies, however, in the Staphylinidae the small (<7mm) natural enemies controlled the variation.

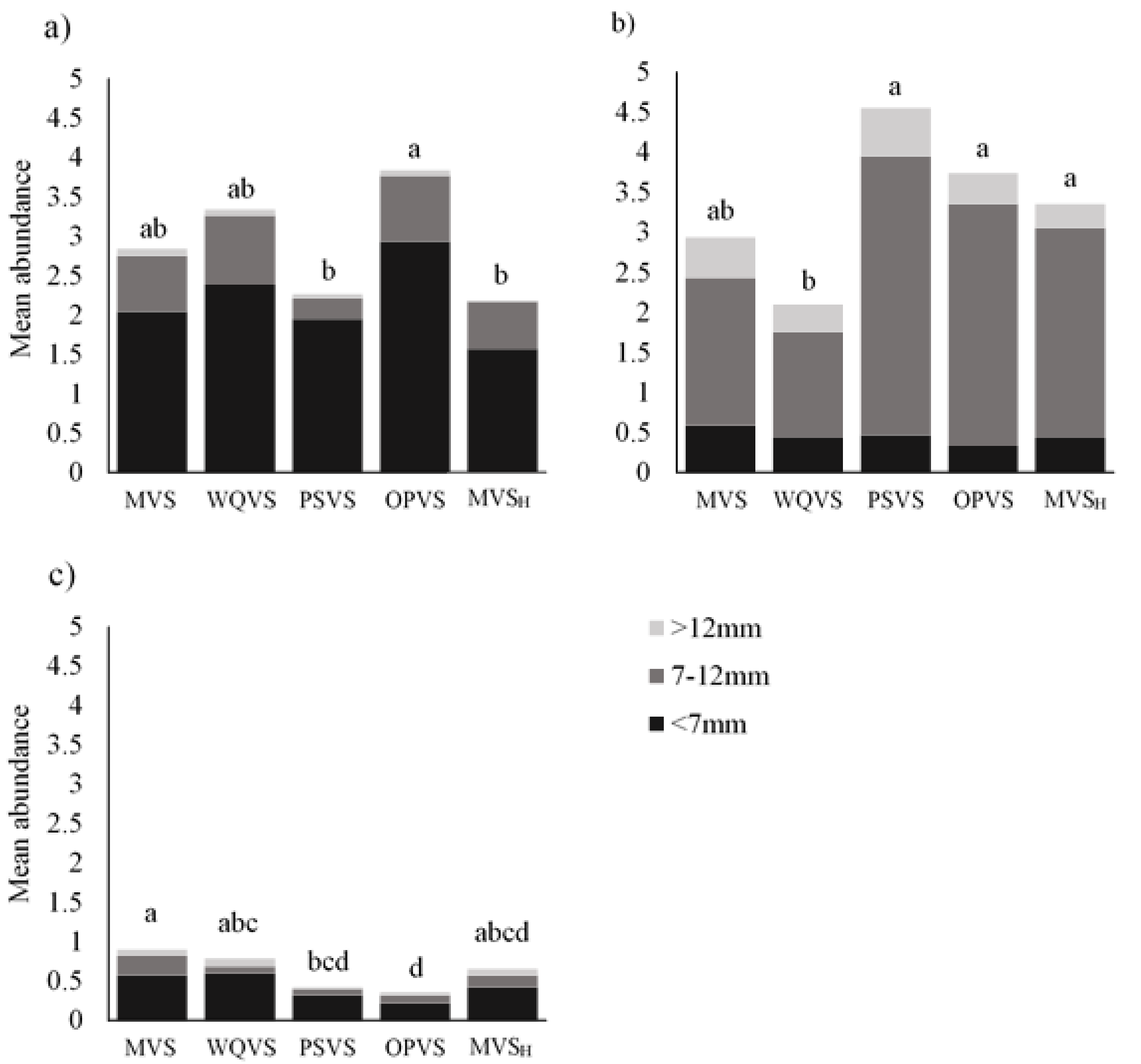


Figure 7-3 Effect of vegetative strip type on mean abundances of a) Araneae, b) Carabidae and c) Staphylinidae. Individuals are grouped into size categories; small (<7mm), medium (7-12mm) and large (>12mm). Vegetative strip types are depicted as: MVS = Multifunctional vegetative strip (80% grasses, 20% forbs), WQVS = water quality protection strip (100% grasses), PSVS = pollinator support strip (100% forbs), OPVS = commercial example of multifunctional strip (80% grasses, 20% forbs) and MVS_H = multifunctional strip with 50% forbs and 50% grasses. Vegetative strips with the same letter are not significantly different (P<0.05).

7-4 Discussion

A vegetative strip must be functionally diverse to support the taxonomically diverse species that act as natural enemies of crop pests (Balzan, et al., 2015; Rouabah, et al., 2015). Here it is demonstrated that single-focus vegetative strips that target just one ecosystem service or species group, such as pollination, water quality protection or terrestrial predatory beetles, provide less plant diversity. The multifunctional vegetative strips in this study (MVS and MVS_H) almost always had the highest vegetative diversity, when compared to the single-focus strips and even the commercial example of a multifunctional mix (OPVS). This demonstrated that the method of vegetative strip design in Chapter 3 produced multifunctional vegetative strips that could have an increased capability to support natural enemies over single-focus strips, and it could potentially provide an enhanced alternative to commercially available mixes.

Soil type and site location was found to potentially affect the establishment of a diverse vegetative strip as was been demonstrated in Chapter 4. Whilst not significantly different to the multifunctional mix with 20% forbs and 80% grasses (MVS) on the Loddington site with heavy clay soil, the multifunctional mix with 50% forbs and 50% grasses (MVS_H) had significantly higher diversity on the Harper Adams site on sandy loam soil in the majority of months (69%), see Figure 7-2. This demonstrates that sowing a higher proportion of forbs could increase the plant diversity in a multifunctional mix on sandy loam soil, but not on heavy clay. This is likely because forb species tend to prefer lower-fertility (Grime et al., 2007), free-draining soils and sandy loam soils tend to possess these qualities whilst heavy soils do not. Interestingly, at Harper Adams, the vegetative strip sown only with forbs (PSVS), had similar plant diversity to the vegetative strip sown with only grasses (WQVS), but then almost always had significantly higher diversity at Loddington. These differences emphasise the need for structured, evidence-informed methods of plant species selection, especially when trying to establish a functionally diverse vegetative strip on different sites with different soil types.

A positive correlation with the proportion of grasses sown and Araneae abundances was observed (Figure 7-2a), as well as a positive correlation with proportion of forbs sown and Carabidae abundances (Figure 7-2b). The higher Araneae abundances may be due to the grass species sown. All of the vegetative strips that were sown with higher proportions of grasses (MVS, WQVS and OPVS), included 10/15% *Dactylis glomerata* which is known to support higher abundances of Araneae species (Collins et al., 2003). The higher Carabidae abundances found in vegetative strips with increased forb proportions could be due to the increased plant diversity that these forbs bring to the vegetative strip (see Figure 7-2), as plant functional diversity can increase Carabidae species richness and abundance (Rouabah et al., 2015). Whilst the commonly used grass only beetle banks target predatory beetles (Emorsgate Seeds, 2018; Natural England, 2018), they seem to lack the forb species that are required to increase functional diversity and support a range of natural enemy species. There is a clear trade-off between the types of habitat that are required by the different groups of predators. Both Araneae species and Carabidae species are key predators that contribute to the control of insect crop pests, as described by Boys et al. (2016). Therefore, both must be supported in a vegetative strip designed to provide bio-control services.

The results from this study demonstrate the essential support that forb plant species could provide to natural enemies. The inclusion of a mixture of grasses and forbs in a vegetative strip seed mix introduces the increased plant diversity that is preferred by surface active natural enemies, the grass cover preferred by Araneae species and the floral resources for aerial natural enemies. These include hoverflies and parasitoid wasps, which also can help control crop pests (Ramsden et al., 2013; Raymond et al., 2014; Balzan et al., 2016). In Chapter 5 insect floral visitation surveys were conducted on the small plots at both sites in this experiment. In that study a range of floral resource preferences by Hoverflies were found, including *Heracleum sphondylium, Silene dioica, Centaurea nigra, Leucanthemum vulgare, Achillea millefolium* and *Daucus carota*. In addition, out of 201 observed visits made by wasps (including parasitic wasps), 87% were to *D. carota*. All of these plant species were included in the multifunctional vegetative strip seed mixes (MVS and MVS_H) designed in Chapter 3 due to their favourable plant traits that support each of the target ecosystem services, see Table 7-1. The results from both studies correlate with studies undertaken by Gontijo et al. (2013) and Diaz et al. (2012), where wildflowers were found to support natural enemies which, in-turn, suppressed crop pest populations.

Further research into plant traits that are favourable for surface active invertebrates would help to better inform plant species selection for their support. Current literature indicates the specific plant species trait preferences of aerial natural enemies (see Chapter 2), but for plant traits that support carabids and other natural enemies are less clear, only that more functionally diverse plant communities increase abundance (Rouabah et al., 2015). Also, whilst the conclusions from this study indicate that the designed multifunctional vegetative strips may provide increased support for natural enemies, further sampling is required to determine whether these findings are replicated across the life of the vegetative strips and on other soil types and field sites. The results from this study provide an initial insight into the effect of vegetative strip functionality on the provision of support for natural enemies of crop pests. These findings could inform policy makers and land managers on the importance of increasing the diversity and functionality of vegetative strips to increase support for ecosystem services within farmland. Further research on the persistence and potential variation in support provided by multifunctional vegetative strips at a landscape-scale, compared to current single focus strips, is recommended. The next step to gain further insight into the effectiveness of this support in providing pest control would be to sample crop pest abundances and predation rates in adjacent crops.

Chapter 8. General discussion

The widely-used vegetative strip sown in farmland field margins has provided valuable support for water quality protection, pollination and bio-control individually (Pfiffner and Wyss, 2004; Reichenberger et al., 2007; Lye et al., 2009; Haaland et al., 2011), but increasing land restrictions and food production requirements, command an increase in their functionality. As there currently is no prescribed or evidence-informed method of plant species selection for vegetative strips, though some advice is available (Farming Advice Service, 2018), this study set out to develop and test a method of multifunctional vegetative strip design.

The main objectives of the study were:

1. Develop a structured, evidence-informed method of multifunctional vegetative strip design, using plant traits, which can be applied across temperate climate zones. Particularly targeting support for ecosystem services including pollination, biological control of insect crop pests (bio-control) and water quality protection.
2. Using vegetative strip seed mixes designed through the evidence-informed method and existing farmland buffer strips, investigate the establishment and persistence of different vegetative strip types under differing environmental conditions.
3. Compare and contrast support for pollinators (for pollination), natural enemies of insect crop pests (for bio-control) and water quality protection provided by multifunctional vegetative strips to single-focus strips.
4. Provide advice and recommendations to land managers, advisors and policy makers on increasing the functionality of vegetative strips.

8.1 Multifunctional vegetative strip design

When developing the method of vegetative strip design, the systematic map of plant traits, in Chapter 2, identified a large bias in the research towards plant traits linked with pollination. This was likely due to the highly dependent, mutualistic relationship between pollinators and flowering plants and current pollinator declines driving research to understand this relationship further (Hector and Bagchi, 2007; Potts et al., 2010; Nicolson and Wright, 2017). Despite this, a large number of plant traits were identified in total and the evidence collated in the systematic map was sufficient to be used in the development of a vegetative strip design method in Chapter 3. Further research into the plant traits that support bio-control, in particular, could strengthen this method of vegetative strip design. Specifically, the traits discovered to support bio-control (e.g. floral display size and nectar availability) were only linked with aerial natural enemies such as parasitoid wasps and hoverflies (Møller & Sorci, 1998; Bianchi and Wackers, 2008), and no articles were found linking specific plant traits to surface active predator groups such Carabids, see the systematic map database from Chapter 2.2 in Additional File 2-5. de Bello et al. (2010) and Perović et al. (2018) also found little evidence to this effect, but de Bello et al. (2010) did identify some of the same plant traits, for example leaf area for water quality protection and nectar content for pollination. However, de Bello et al. (2010) did not find evidence of floral display size supporting pollination and bio-control, which was a key trait identified in this map, in fact only 7 plant traits were identified by de Bello et al. (2010) to support pollinators, whereas 40 were identified by the systematic map in Chapter 2. This difference is likely because whilst de Bello et al. (2010) used some key terms, their list was not extensive and their searches were not of a systematic nature, potentially missing key literature.

One important finding from the systematic map was the cross-over between plant traits studied for natural enemy and pollinator support as floral display size, floral nectar and flower colour were linked to both. This was advantageous when developing a multifunctional vegetative strip in which numerous invertebrate species groups were targeted. Lastly, the majority of traits that had been linked to supporting water quality protection were related to plant roots (78%), which demonstrated an overwhelming focus on belowground traits for the support of this service, and this finding is emulated in de Bello et al. (2010).

In Chapter 3, the findings on plant traits were reviewed and utilised. Table 3-1 provided an essential summary of the plant traits that were identified by the systematic map and their key aspects. Importantly, findings were the same from articles that investigated the same plant trait, for example the articles that studied floral display size all identified that pollinators preferred a larger display. In addition, information was gathered on eight different plant community characteristics and environmental factors that are essential to multifunctional vegetative strip establishment (Table 3-2). Perennial UK plant species were then ranked using these traits and characteristics (Table 3-3) for inclusion in multifunctional and single-focus seed mixes.

A key caveat to the seed mix design method was the lack of presence or absence information on some of the identified plant traits in individual UK plant species. For example, the research identified traits including fibrous root depth or length and percentage fine roots, to aid water quality protection, but only information on the overall root system was available (e.g in Grime et al. 2007). Fortunately, the traits discovered were indicative of an adventitious root system, so this overall trait could be included in the design method instead, see the plant trait database in Additional File 3-1. In other cases, there was incomplete data on traits for some plant species, which potentially impacted its ranking. Further primary research to fill in these gaps in the plant trait database would be advised to strengthen the vegetative strip design method.

The design method developed in Chapter 3 focussed on exactly what is required of individual plants, and of plant communities, to support three ecosystem services in farmland, namely pollination, bio-control and water quality protection. Whilst this method is extremely transparent, structured and evidence-informed, the field experiments in Chapters 4 – 7, tested the potential of the vegetative strip seed mixes to establish and persist, and support the target ecosystem services.

The literature review in Chapter 1 highlighted the need for multifunctional vegetative strips and a structured, evidence informed and repeatable method of seed mix design. The method outlined in Chapter 3 is a novel approach to plant species selection for vegetative strips, which has not been previously undertaken and it offers a theoretical framework for plant species selection which can be tested experimentally. It can be used to develop seed mixes that can be reliably prescribed by government policy, to encourage farmers to increase the functionality of their vegetative strips.

8-2 Establishment and persistence of a multifunctional vegetative strip

Chapter 4 demonstrated that vegetative strip establishment is highly dependent on the seed mix sown, management undertaken, soil type, soil seed bank and environmental conditions. Numerous species of forbs, sown to provide floral support, require less fertile soils (Grime et al., 2007; Syngenta, 2014; Kings Seeds, 2018; Emorsgate Seeds, 2018). Due to this, they often do not establish as effectively on more fertile soils. Sandy and loam soils tend to be less fertile and free-draining, whereas heavy clay soils tend to be much more fertile and are often slow-draining. In the surveys of existing buffer strips and the sown strips designed using the method outlined in Chapter 3, significant effects of sown seed mix and soil type was observed up to 70 years of age, on forb species richness and proportion of cover. In addition, in the field experiment, seed mix type effected the proportion of sown species and bare ground across the first three years of establishment.

The combined evidence from the surveys of existing buffers and designed vegetative strips suggested that, overall, the vegetative strips on sandy or sandy loam soils had higher species richness, proportion of forb cover and proportion of sown species cover. Also, on clay soils, in the early establishment years, species richness in the vegetative strips was reduced, but if sown with a pollinator mix (including forb species), species richness increased over the subsequent 10-15 years. So, whilst establishment of a more diverse buffer strip on sandy loam soils may be more successful in the early years, there is still scope for their establishment on clay soils long-term. Also, targeting a seed mix towards a specific soil type did not aid sown species establishment, and the multifunctional vegetative strip designed for most soil types (MVS) actually provided the highest percentage cover of sown species. Therefore, when selecting plant species for a vegetative strip seed mix, robust species that meet the criteria for plant community characteristics and environmental factors set out in Table 3-2 in Chapter 3, should be used. This could also make plant species selection for seed mixes for different soil types, far more straight forward, rather than a complex system targeting plant species to a specific soil type.

The competitive nature of grasses and their management are extremely influential in the establishment of a botanically diverse vegetative strip. Species richness of a strip tends to decrease over time as grasses begin to outcompete less-competitive wildflowers and this is often exacerbated in conditions of high soil fertility (Huusela-Veistola and Vasarainen, 2000; Grime et al., 2007; Noordijk et al., 2011; Tscharntke et al., 2011). An increase in proportions of grass species over time was observed in all of the designed vegetative strips, but, despite this, forb proportions did still persist.

The multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) demonstrated the most successful establishment and persistence of the desired plant communities. It consistently provided high proportions of forbs and sown species and plant species richness and had similar percentage bare ground to the other vegetative strips.

The surveys of existing buffer strips provided an initial insight into the effects of age, management and seed mix type on plant communities within buffer strips across three broad soil types. It was clear from the findings in Chapter 4 that using the structured and evidence-informed method of vegetative strip design affected the initial establishment and overall resulting plant communities of the strips. In particular, the inclusion of the plant characteristics and environmental factors criteria (Table 3-2) which ensured only species that were pre-dispositioned to establish in a variety of environmental conditions were included in the seed mixes. In addition, the management of a vegetative strip, especially of grasses, was found to be vital for the long-term persistence of a diverse plant community.

8-3 Vegetative strip support for pollinators, water quality protection and natural enemies of insect crop pests

The findings in Chapter 4 demonstrated that the method of vegetative strip design developed in Chapter 3 could produce vegetative strips where the majority of the sown plant species and the desired plant communities establish and persist, at least over the first three years. But, do these plant communities provide support for the target ecosystem services and is the support in multifunctional vegetative strips equivalent to that provided by single-focus strips? Firstly, the most important thing to remember here is that though the multifunctional vegetative strips are targeting three ecosystem services (pollination, bio-control and water quality protection), they are designed to be sown adjacent to watercourses (as buffer strips) and so this is a key service that must be supported. In essence, the multifunctional vegetative strips need to sustain or improve the support that buffer strips provide for water quality protection and increase their functionality to provide support for pollination and bio-control concurrently.

Considering the performance of the multifunctional and single-focus vegetative strips over the three years at each site, Table 8-1 gives a summary of the support provided for each target ecosystem service and the mechanism of that support. This is highly simplified compared to what is presented in Chapters 5-7 but provides an overall summary of the findings and conclusions in each chapter, to understand how the strips differ from each other. The key considerations that should be made when using this table are that it is not the whole picture, but a summary for ease of comparison, and the evidence from each relevant chapter should be considered alongside it. Also, performance of the strips varied in some cases between the sites. This was almost certainly because at Loddington the vegetative cover was dominated by non-sown forb species. Therefore, when considering the support provided on this site, whilst some sown forbs and grasses established, the non-sown forbs may have been the main source of support.

Chapters 5 and 7 showed the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) to provide slightly better support for pollinators to the single-focus strip (PSVS) for this service, and the most support for natural enemies in terms of plant diversity and floral support. The multifunctional strip with 20% forbs and 80% grasses (MVS) was second best to the MVS_H in this respect, however, Chapter 6 showed the MVS to provide marginally better support for water quality protection against run-off, erosion and spray-drift. The term ‘marginally’ is key here as the differences in support were indeed very small. In fact, the MVS_H had a three-year average of 3.7% bare ground at Harper Adams and 3.9% at Loddington, whilst the MVS had 2.4% at Harper Adams and 3.4% at Loddington. The percentage of bare ground did fluctuate throughout the year and the multifunctional strip with 20% forbs and 80% grasses (MVS) did have the lowest percentage of bare ground in year 1, but after this there were no huge differences between the multifunctional strips and the single-focus strip for water quality protection (WQVS). The same marginal differences can be found in the three-year averages for plant community height, with the exception of the multifunctional strip with 50% forbs and 50% grasses (MVS_H) at Harper Adams, which only had an average height of 16.3cm, whilst the MVS and WQVS had a height of 34.6cm and 36.5cm respectively. In addition, there was no difference found in the root structural densities between the vegetative strips, potentially indicating no detrimental effect on support for watercourse sedimentation from including forbs in a vegetative buffer strip. It may be that, the multifunctional vegetative strip with 50% forbs and 50% grasses (MVS_H) could provide support for all three ecosystem services, with enhanced support for pollinators and natural enemies.

If we are to consider the multifunctional strips (MVS and MVS_H) developed and tested in this study against the current, single-focus, grassy strip that is often sown alongside watercourses for water quality protection only (Table 8-1), there is great potential to increase its functionality. Also this study demonstrated that using a structured, evidence-informed method of plant species selection, such as the one outlined in Chapter 3, can produce vegetative strips that provide support for multiple ecosystem services. Chapter 1 highlighted the need for a multifunctional vegetative strip and an evidence-informed, repeatable method of plant species selection for strips. This study has provided such a method in Chapter 3, but also demonstrated in Chapters 4-7, the potential of this method to increase the functionality, establishment, persistence and efficacy of vegetative strips.

Table 8-1 Summary of support provided for each target ecosystem service in the multifunctional and single-focus vegetative strips. Each performance is rated Best, Good or worst. Where a performance is rated as 'Good', it was comparably similar to the other strips. Vegetative strip types are depicted as: MVS =

		Ecosystem service and mechanism of support:					
		Pollination	**Bio-control**		**Water quality protection**		
Vegetative strip type	Site	Floral support for pollinators	Floral support for aerial natural enemies	Vegetative diversity for surface active natural enemies	Ground cover to protect against run-off and erosion	Plant community height to protect against spray-drift	Root structural density to protect against sedimentation
MVS	Harper Adams	Good	Good	Good	**Best**	Good	Good
	Loddington	Good	Good	Good	Good	Good	Good
MVS_H	Harper Adams	**Best**	**Best**	**Best**	Good	Good	Good
	Loddington	**Best**	**Best**	**Best**	Good	Good	Good
WQVS	Harper Adams	Worst	Worst	Worst	Good	**Best**	Good
	Loddington	Worst	Worst	Worst	**Best**	**Best**	Good
PSVS	Harper Adams	Good	Good	Good	Good	Worst	Good
	Loddington	Good	Good	Good	Worst	Worst	Good
OPVS	Harper Adams	Good	Good	Good	Worst	Good	Good
	Loddington	Good	Good	Good	Good	Good	Good

8-4 Limitations of the study and further research

Some limitations to the study are recognised which provide a basis for further research. One key limitation was the lack of evidence discovered in Chapter 2 for plant traits that support surface active natural enemies for the biological control of crop pests. Whilst plant traits were identified for aerial natural enemies such as hoverflies and parasitoid wasps (e.g. Møller & Sorci, 1998; Bianchi and Wackers, 2008), no traits were found for predators such as Carabid beetles or predatory spiders. This was also the case in de Bello et al., (2010) and Perović et al. (2018), where only floral traits were identified for hoverflies and parasitoid wasps. Further primary research in this area could further inform the method of vegetative strip design and potentially enhance the support provided for this ecosystem service.

The information in the plant trait database in Chapter 2 is limited to the available data on UK plant species traits. Whilst 68 different plant traits were discovered, just 6 could be used when ranking UK plant species. However, 17 of these traits related to a fibrous root system for water quality protection, so this overall trait for roots could be used. Further primary research to catalogue the presence or absence of the identified traits in UK plant species could further inform the developed method of vegetative strip design. In addition, further searches to capture new literature published since the systematic map searches were undertaken, could provide further evidence on plant traits that support the target ecosystem services.

The community weighted mean (CWM) for plant height could be estimated due to the average height measurements that were made in the monthly surveys during the field experiment. This could be used to compare support for water quality protection against pesticide spray-drift. However, whilst floral cover was surveyed, a similar measure for floral display size could not be feasibly gathered within the restrictions of the project. To calculate a CWM for floral display size the average number of flowers for each plant species needed to be counted or estimated for each plot in each survey. This was not possible within the time constraints of the project whilst keeping the surveys standardised using one researcher. With a larger team of surveyors this could be measured and potentially provide further insight into the presence of this key trait in the plots.

Whilst existing buffer strips were surveyed of ages up to 70 years, the developed vegetative strips that were the main focus of the study could only be monitored for the first three years of growth in this study. Further, long-term, landscape-scale studies of the designed vegetative strips, on different soil types and locations, could be extremely valuable to understand how these strips persist after the first 3 years, in different environmental conditions within the whole environment. In addition, further tests to understand the effects on crop yield through supporting pollination services and the control of crop pests by natural enemies, and on water quality through protection against run-off, erosion, spray-drift and sedimentation, could help justify the cost of the seed mixes and management investment to land managers. Also, whilst the single-focus strip for water quality protection (WQVS) performed best overall in support for protection against run-off, erosion and spray-drift, it is not clear whether the differences between the WQVS and the multifunctional strips (MVS and MVS_H) have a significant detrimental effect on water quality. They all showed similar potential for protecting against watercourse sedimentation and the multifunctional strip with 20% forbs and 80% grasses (MVS) even had more support at Harper Adams for protection against run-off and erosion. Literature demonstrates that the type of vegetation within a vegetative strip should not affect its efficiency of nitrogen removal (Mayer et al., 2007), so there could be potential for the multifunctional mixes to provide adequate support for water quality protection.

8-5 Implications for policy and management

European Common Agricultural Policy does not currently stipulate that vegetative strips, alongside farmland watercourses, need to be sown with anything but a standard grass seed mix (European Commission, 2018). However, there is need for policy to change and specifically encourage land managers to increase the functionality of their vegetative strips, to benefit agricultural production and biodiversity concurrently. The method of vegetative strip design developed and tested in this study is a clear, constructed method that could be used and continuously updated to provide evidence-informed plant species selections for these strips. Incentives such as those proposed in the Results Based Agri-environment Payment Scheme (RBAPS) pilot study (Natural England, 2017), could be used to encourage farmers to sow multifunctional seed mixes, but also manage them effectively to establish the desired plant community. While the farmer receives a monetary incentive to increase the functionality of their vegetative strips, they could also reap the benefits in increased crop yields, if encouraged to manage them effectively.

The findings from this study demonstrate the importance in considering the soil type and potential seed bank of a field margin prior to sowing a vegetative strip. Any history of the site should be gathered, such as: susceptibility to support high populations of competitive non-sown plant species, and the wildflowers that normally establish on the site. This can be investigated by farming advisors using brief surveys of the local area and other established vegetative strips on the farm, prior to sowing.

Whilst this study was undertaken with UK plant species, the method of vegetative strip design can be applied across temperate climate zones. This study used databases of British species, but there is an international plant trait database (TRY) created by Kattge et al. (2011) which can be used to access information gathered from numerous plant trait databases across the world.

The unrelenting, exponentially increasing global human population will continue to place more and more pressures on agricultural production and wildlife habitats (Godfray et al., 2010; UN Population Division, 2018). With regulating ecosystem services playing such an important role in agricultural production (Aizen et al., 2009; Zavaleta et al., 2010; Blitzer et al., 2016), a balance between support for agriculture and wildlife must be struck, otherwise we could continue to see huge losses in both (Kremen et al., 2002; Carvell, 2004; Biesmeijer et al., 2006; Brown and Paxton 2009; Williams and Osborne 2009; Winfree et al., 2009; Garratt et al., 2013; Stanley et al., 2013; Rusch et al., 2016). Increasing the functionality of vegetative strips in farmland field margins could support improved crop yield, protect water quality and provide support for biodiversity at the same time. The method of vegetative strip design developed in this project is an important step towards evidence-informed plant species selection, and it has been proven to produce vegetative strips that can establish and provide support for their target ecosystem services within the first three years. The proposed further research could strengthen the developed method of vegetative strip design and further support the findings from this study. With the proposed further research, these multifunctional strips have the potential to be part of the solution to alleviate the mounting pressures on agriculture and wildlife and even enhance agricultural production and the environment.

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References

Aizen, M.A., Garibaldi, L.A., Cunningham, S.A., Klein, A.M., 2009. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of botany.

Albon, S., Turner, K., Watson, B., Anger, A., Baker, J., Bateman, I., Bentley, S., Blyth, N., Bowles-Newark, N., Brown, C., Brown, I., 2014. UK National Ecosystem Assessment follow-on: Synthesis of key findings. UNEP-WCMC, LWEC, UK.

Almasri, M.N., Kaluarachchi, J.J., 2004. Assessment and management of long-term nitrate pollution of ground water in agriculture-dominated watersheds. Journal of Hydrology 295, 225-245.

Ashman, T.L., Swetz, J., Shivitz, S., 2000. Understanding the basis of pollinator selectivity in sexually dimorphic Fragaria virginiana. Oikos. 90, 347-356.

Aviron, S., Herzog, F., Klaus, I., Luka, H., Schupbach, L., Jeanneret, P., 2006. Effects of Swiss agri-environmental measures on arthropod biodiversity in arable landscapes. Aspects of Applied Biology. 81, 101.

Balzan, M.V., Bocci, G., Moonen, A.C., 2016. Landscape complexity and field margin vegetation diversity enhance natural enemies and reduce herbivory by Lepidoptera pests on tomato crop. Biological Control. 61, 141-154.

Bannerman, J.A., McCornack, B.P., Ragsdale, D.W., Koper, N., Costamagna, A.C., 2018. Predators and alate immigration influence the season-long dynamics of soybean aphid (Hemiptera: Aphididae). Biological Control. 117, 87-98.

Barrio, M., Teixido, AL., 2015. Sex-dependent selection on flower size in a large-flowered Mediterranean species: an experimental approach with Cistus ladanifer. Plant Systems Evolution. 301, 113-24.

Bass, C., Denholm, I., Williamson, M.S., Nauen, R., 2015. The global status of insect resistance to neonicotinoid insecticides. Pesticide biochemistry and physiology. 121, 78-87.

Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. Conservation Biology. 29, 1006-16.

Batáry, P., Holzschuh, A., Orci, K.M., Samu, F., Tscharntke, T., 2012. Responses of plant, insect and spider biodiversity to local and landscape scale management intensity in cereal crops and grasslands. Agriculture, Ecosystems & Environment. 146, 130-136.

Baude, M., Kunin, W.E., Boatman, N.D., Conyers, S., Davies, N., Gillespie, M.A.K., Morton, R.D., Smart, S.M., Memmott, J., 2016. Historical nectar assessment reveals the fall and rise of floral resources in Britain. Nature. 530, 85-88.

Bauer, D.M., Sue Wing, I., 2016. The macroeconomic cost of catastrophic pollinator declines. Ecological Economics 126, 1-13.

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology and Evolution. 18, 182-188.

Berka, C., Schreier, H., Hall, K., 2001. Linking Water Quality with Agricultural Intensification in a Rural Watershed. Water, Air, and Soil Pollution. 127, 389-401.

Bianchi, F., Wackers, F.L., 2008. Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids. Biological Control. 46, 400-408.

Biddinger, D.J., Rajotte, E.G., 2015. Integrated pest and pollinator management - adding a new dimension to an accepted paradigm. Current Opinions Insect Science. 10, 204-209.

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J., 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science. 313, 351-354.

Biological Records Centre, 2018. Online Atlas of the British and Irish flora. http://www.brc.ac.uk/plantatlas/index.php?q=title_page (accessed 19.01.18).

Blitzer, E.J., Gibbs, J., Park, M.G., Danforth, B.N., 2016. Pollination services for apple are dependent on diverse wild bee communities. Agriculture, Ecosystems & Environment. 221, 1-7.

Blowers, C.J., Cunningham, H.M., Wilcox, A., Randall, N.P., 2017. What specific plant traits provide ecosystem services such as pollinator support, bio-control and water quality protection? A systematic map protocol. Environmental Evidence. 6, 3.

Bommarco, R., Kleijn, D., Potts, S.G., 2013. Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology and Evolution. 28, 230-8.

Borin, M., Passoni, M., Thiene, M., Tempesta, T., 2010. Multiple functions of buffer strips in farming areas. European journal of agronomy. 32, 103-111.

Boys, E., 2016. Encyclopaedia of pests and natural enemies in field crops. AHDB Agriculture & horticulture development board.

Brittain, C.A., Vighi, M., Bommarco, R., Settele, J., Potts, S.G., 2010. Impacts of a pesticide on pollinator species richness at different spatial scales. Basic and Applied Ecology. 11, 106-115.

Brown, M.J., Paxton, R.J., 2009. The conservation of bees: a global perspective. Apidologie. 40, 410-416.

Brunet, J., Thairu, M.W., Henss, J.M., Link, R.I., Kluever, J.A., 2015. The Effects of Flower, Floral Display, and Reward Sizes on Bumblebee Foraging Behavior When Pollen Is the Reward and Plants Are Dichogamous. International Journal of Plant Sciences. 176, 811-819.

Büchi, R., 2002. Mortality of pollen beetle (Meligethes spp.) larvae due to predators and parasitoids in rape fields and the effect of conservation strips. Agriculture, Ecosystems & Environment. 90, 255-263.

Buglife, 2018. Cereal field margins. https://www.buglife.org.uk/advice-and-publications/advice-on-managing-bap-habitats/cereal-field-margins (accessed 15.03.18).

Burylo, M., Dutoit, T., Rey, F., 2014. Species Traits as Practical Tools for Ecological Restoration of Marly Eroded Lands. Restoration Ecology. 22, 633-640.

Burylo, M., Rey, F., Mathys, N., Dutoit, T., 2012a. Plant root traits affecting the resistance of soils to concentrated flow erosion. Earth Surf. Proc. Land. 37, 1463-1470.

Burylo, M., Rey, F., Bochet, E., Dutoit, T., 2012b. Plant functional traits and species ability for sediment retention during concentrated flow erosion. Plant Soil. 353, 135-144.

Campbell, A.J., Wilby, A., Sutton, P., Wäckers, F., 2017. Getting More Power from Your Flowers: Multi-Functional Flower Strips Enhance Pollinators and Pest Control Agents in Apple Orchards. Insects. 8, 101.

Campbell, D.R., Bischoff, M., Lord, J.M. and Robertson, A.W., 2010. Flower colour influences insect visitation in alpine New Zealand. Ecology. 91, 2638-2649.

Campo-Bescós, M.A., Muñoz-Carpena, R., Kiker, G.A., Bodah, B.W., Ullman, J.L., 2015. Watering or buffering? Runoff and sediment pollution control from furrow irrigated fields in arid environments. Agriculture, Ecosystems & Environment 205, 90-101.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological applications. 8, 559-568.

Carreck, N., Williams, I., 1997. Observations on two commercial flower mixtures as food sources for beneficial insects in the UK. The Journal of Agricultural Science. 128, 397-403.

Carreck, N., Williams, I., 2002. Food for insect pollinators on farmland: insect visits to flowers of annual seed mixtures. Journal of Insect Conservation. 6, 13-23.

Cartwright, N., Clark, L., Bird, P., 1991. The Impact of Agriculture on Water Quality. Outlook on Agriculture. 20, 145-152.

Carvell, C., 2002. Habitat use and conservation of bumblebees (Bombus spp.) under different grassland management regimes. Biological Conservation. 103, 33-49.

Carvell, C., Meek, W.R., Pywell, R.F., Nowakowski, M., 2004. The response of foraging bumblebees to successional change in newly created arable field margins. Biological Conservation. 118, 327-339.

Centre for Ecology and Hydrology, 2008a. Countryside Survey: UK Results from 2007: Chapter 8 – Rivers, Streams and Standing waters. http://www.countrysidesurvey.org.uk/sites/default/files/CS-UK-Results2007-Chapter08.pdf (accessed 24.06.18)

Centre for Ecology and Hydrology, 2008b. Countryside Survey: UK Results from 2007: Chapter 2 – The National Picture. http://www.countrysidesurvey.org.uk/sites/default/files/CS-UK-Results2007-Chapter02.pdf (accessed 24.06.18)

Centre for Ecology and Hydrology, 2018. Sustainable Intensification research Platform Dynamic Landscape Typology Tool. https://eip.ceh.ac.uk/apps/sustainable-intensification/info/ (accessed 15.03.18)

Chang, G.C., Rutledge, C.E., Biggam, R.C., Eigenbrode, S.D., 2004. Arthropod diversity in peas with normal or reduced waxy bloom. Journal of Insect Science. 4, 18.

Chang, G.R., 2018. Persistent organochlorine pesticides in aquatic environments and fishes in Taiwan and their risk assessment. Environmental Science and Pollution Research. 25, 7699-7708.

Chau, N.L., Chu, L.M., 2017. Fern cover and the importance of plant traits in reducing erosion on steep soil slopes. Catena. 151, 98-106.

Cole, L.J., Brocklehurst, S., Robertson, D., Harrison, W., McCracken, D.I., 2015. Riparian buffer strips: their role in the conservation of insect pollinators in intensive grassland systems. Agriculture, Ecosystems & Environment. 211, 207-220.

Collaboration for Environmental Evidence, 2010. Guidelines for Systematic Review in Environmental Management. Version 4.0. http.//www.environmentalevidence.org/Authors.htm. (accessed 23.02.15)

Collaboration for Environmental Evidence, 2013. Guidelines for Systematic Review in Environmental Management. Version 4.2. http://www.environmentalevidence.org/wp-content/uploads/2017/01/Review-guidelines-version-4.2-final-update.pdf. (accessed 25.04.17)

Collaboration for Environmental Evidence, 2018. Guidelines and Standards for Evidence Synthesis in Environmental Management. Version 5.0 http://www.environmentalevidence.org/information-for-authors (accessed 15.03.18)

Collins, K.L., Boatman, N.D., Wilcox, A., Holland, J.M., 2003. Effects of different grass treatments used to create overwintering habitat for predatory arthropods on arable farmland. Agriculture, Ecosystems & Environment. 96, 59-67.

Conner, J., Rush, S., 1996. Effects of flower size and number on pollinator visitation to wild radish, Raphanus raphanistrum. Oecologia. 105, 509.

Cresswell, C.J., Cunningham, H.M., Wilcox, A., Randall, N.P., 2018. What specific plant traits support ecosystem services such as pollination, bio-control and water quality protection in temperate climate? A systematic map. Environmental Evidence. 7, 2.

Critchley, C., Mole, A., Towers, J., Collins, A.L., 2013. Assessing the potential value of riparian buffer strips for biodiversity. Aspects of Applied Biology. 118, 101-108.

Critchley, C.N.R., Fowbert, J.A., Sherwood, A.J., Pywell, R.F., 2006. Vegetation development of sown grass margins in arable fields under a countrywide agri-environment scheme. Biological Conservation. 132, 1-11.

Cuevas, N., Martins, M. and Costa, P.M., 2018. Risk assessment of pesticides in estuaries: a review addressing the persistence of an old problem in complex environments. Ecotoxicology. 1-11.

Cunningham, S.A., Le Feuvre, D., 2013. Significant yield benefits from honeybee pollination of faba bean (Vicia faba) assessed at field scale. Field Crops Research. 149, 269-275.

Dabrowski, J.M., Peall, S.K.C., Reinecke, A.J., Liess, M., Schulz, R., 2002. Runoff-related pesticide input into the Lourens River, South Africa: basic data for exposure assessment and risk mitigation at the catchment scale. Water, air, and soil pollution. 135, 265-283.

Daniels, S., Witters, N., Beliën, T., Vrancken, K., Vangronsveld, J., Van Passel, S., 2017. Monetary valuation of natural predators for biological pest control in pear production. Ecological economics. 134, 160-173.

Davies, D.B., 2000. The nitrate issue in England and Wales. Soil Use Manage. 16, 142-144.

Davies, D.H.K., 1999. A brief review of the potential benefits of buffer zones as field margins in UK agriculture. Aspects of Applied Biology. 54, 61-70.

de Bello, F., Lavorel, S., Díaz, S., Harrington, R., Cornelissen, J.H., Bardgett, R.D., Berg, M.P., Cipriotti, P., Feld, C.K., Hering, D., da Silva, P.M., 2010. Towards an assessment of multiple ecosystem processes and services via functional traits. Biodiversity and Conservation. 19, 2873-2893.

De Palma, A., Kuhlmann, M., Bugter, R., Ferrier, S., Hoskins, A.J., Potts, S.G., Roberts, S.P.M., Schweiger, O., Purvis, A., 2017. Dimensions of biodiversity loss: Spatial mismatch in land-use impacts on species, functional and phylogenetic diversity of European bees. Diversity and Distributions. 23, 1435-1446.

Department for Environment, Food and Rural Affairs, 2014. The new Common Agricultural Policy schemes in England: August 2014. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/345073/cap-reform-august-2014-update.pdf. (accessed 19.01.18)

Department for Environment, Food and Rural Affairs, 2018. Cross-compliance 2018 guide. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/668684/Cross_Compliance_2018_guide_v1.0.pdf (accessed 20.04.18)

Díaz, M.F., Ramírez, A., Poveda, K., 2012. Efficiency of different egg parasitoids and increased floral diversity for the biological control of noctuid pests. Biological control. 60, 182-191.

Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., Robson, T.M., 2007. Incorporating plant functional diversity effects in ecosystem service assessments. Proceedings of the National Academy of Sciences. 104, 20684-9.

Dib, H., Sauphanor, B., Capowiez, Y., 2016. Effect of management strategies on arthropod communities in the colonies of rosy apple aphid, Dysaphis plantaginea Passerini (Hemiptera: Aphididae) in south-eastern France. Agriculture, Ecosystems & Environment. 216, 203-206.

Donald, P.F., Green, R.F., Heath, M.F., 2001. Agricultural intensification and the collapse of Europe’s farmland bird populations. Proceedings Royal Society B. 268, 25-29.

Dorioz, J.M., Wang, D., Poulenard, J., Trevisan, D., 2006. The effect of grass buffer strips on phosphorus dynamics—a critical review and synthesis as a basis for application in agricultural landscapes in France. Agriculture, Ecosystems & Environment. 117, 4-21.

Dow AgroSciences Ltd, 2014. Safety Data Sheet: PASTOR PRO Herbicide. http://uk.dowagro.com/wp-content/uploads/PASTOR-PRO-SDS.pdf (accessed 24.06.18)

Ecostac, 2009. Optimising Ecosystem Services in Terms of Agronomy and Conservation. http://www.lancaster.ac.uk/lec/sites/ecostac/seed_selection.php (accessed 25.04.17)

Ehrlich, P.R., Ehrlich, A.H., 2013. Can a collapse of global civilization be avoided? Proceedings Royal Society B. 280, 20122845.

Elle, E., Carney, R. 2003. Reproductive assurance varies with flower size in Collinsia parviflora (Scrophulariaceae). American Journal of Botany. 90, 888-896.

Emorsgate Seeds, 2018. ESG4 – Tussock grass mixture. https://wildseed.co.uk/mixtures/view/49 (accessed 26.07.18)

Emorsgate Seeds, 2018. Farmland Stewardship Mixtures. https://wildseed.co.uk/mixtures/category/farmland-stewardship-mixtures (accessed 15.03.18)

ESRI, 2011. ArcGIS Desktop: Release 10.4.1 Redlands, CA: Environmental Systems Research Institute.

European commission, 2016a. Environment – Introduction to the new EU Water Framework Directive. http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm. (accessed 29.03.16)

European commission, 2016b. Environment – The Habitats Directive. http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm. (accessed 29.03.16)

European commission, 2016c. Agriculture and biodiversity. http://ec.europa.eu/agriculture/envir/biodiv/index_en.htm. (accessed 29.03.16)

European commission, 2016d. Agriculture and Water. http://ec.europa.eu/agriculture/envir/water/index_en.htm. (accessed 29.03.16)

European commission, 2016e. Agriculture and Pesticides. http://ec.europa.eu/agriculture/envir/pesticides/index_en.htm. (accessed 29.03.16)

European commission, 2016f. Soil and agriculture http://ec.europa.eu/agriculture/envir/pesticides/index_en.htm. (accessed 29.03.16)

European commission, 2019. CAP at a glance. https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en (accessed 02.01.2019).

Ewald, J.A., Aebischer, N.J., Richardson, S.M., Grice, P.V., Cooke, A.I., 2010. The effect of agri-environment schemes on grey partridges at the farm level in England. Agriculture, ecosystems & environment. 138, 55-63.

Farming Advice Service, 2018. Buffer strips for ecological focus areas (EFA) under Greening requirements. http://farmingadviceservice.org.uk/events/assets/Uploads/Posters/FASField-marginposterissued.pdf (accessed 20.04.18)

Feltham, H., Park, K., Minderman, J., Goulson, D., 2015. Experimental evidence that wildflower strips increase pollinator visits to crops. Ecology and evolution. 5, 3523-3530.

Fiedler, A.K., Landis, D.A., Wratten, S.D., 2008. Maximizing ecosystem services from conservation biological control: The role of habitat management. Biological Control. 45, 254-271.

Firbank, L.G., Elliott, J., Drake, B., Cao, Y., Gooday, R., 2013. Evidence of sustainable intensification among British farms. Agriculture, Ecosystems & Environment. 173, 58-65.

Fitter, A.H., Peat, H.J., 1994. The Ecological Flora Database. Journal of Ecology. 82, 415-425.

Flowerdew, J.R., 1997. Mammal biodiversity in agricultural habitats. In: Kirkwood RC, editor. Biodiversity and conservation in agriculture: proceedings of an international symposium organised by the British Crop Protection Council. 25-40.

Food and Agriculture Organisation of the United Nations, 2018. http://www.fao.org/faostat/en/#data/EL (accessed 23.02.18)

Fournier, E., Loreau, M., 2001. Respective roles of recent hedges and forest patch remnants in the maintenance of ground-beetle (Coleoptera: Carabidae) diversity in an agricultural landscape. Landscape ecology. 16, 17-32.

Galen, C., 1996. Rates of Floral Evolution: Adaptation to Bumblebee Pollination in an Alpine Wildflower, Polemonium viscosum. Evolution. 50, 120-125.

Game and Wildlife Conservation Trust, 2018. Farming – Beetle Banks. https://www.gwct.org.uk/farming/advice/sustainable-farming/beetle-banks/ (accessed 12.08.18)

Garbuzov, M., Ratnieks, F.L.W., 2015. Using the British National Collection of Asters to Compare the Attractiveness of 228 Varieties to Flower-Visiting Insects. Environmental Entomology. 44, 638-46.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., 2013. Sustainable intensification in agriculture: premises and policies. Science. 341, 33-4.

Garnett, T., Godfray, C., 2012. Sustainable intensification in agriculture. Navigating a course through competing food system priorities. Food Climate Research Network and the Oxford Martin Programme on the Future of Food, University of Oxford, UK, p.51.

Garnier, E., Navas, M.L., 2012. A trait-based approach to comparative functional plant ecology: concepts, methods and applications for agroecology. A review. Agronomy for Sustainable Development. 32, 365-99.

Garratt, M.P.D., Breeze, T.D., Jenner, N., Polce, C., Biesmeijer, J.C., Potts, S.G., 2014. Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. Agriculture, Ecosystems & Environment 184, 34-40.

Garratt, M.P.D., Truslove, C., Coston, D., Evans, R., Moss, E., Dodson, C., Jenner, N., Biesmeijer, J., Potts, S., 2013. Pollination deficits in UK apple orchards. Journal of Pollination Ecology. 12, 9-14.

Gevao, B., Semple, K.T., Jones, K.C., 2000. Bound pesticide residues in soils: a review. Environmental Pollution. 108, 3-14.

Godfray, H.C., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. Science. 327, 812-8.

Gontijo, L.M., Beers, E.H., Snyder, W.E., 2013. Flowers promote aphid suppression in apple orchards. Biological Control. 66, 8-15.

Gontijo, L.M., Beers, E.H., Snyder, W.E., 2015. Complementary suppression of aphids by predators and parasitoids. Biological Control. 90, 83-91.

Gould, I.J., Quinton, J.N., Weigelt, A., De Deyn, G.B., Bardgett, R.D., 2016. Plant diversity and root traits benefit physical properties key to soil function in grasslands. Ecology Letters. 19, 1140-9.

Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Info. Libr. J. 26, 91-108.

Greaves, M.P., Marshall, E.J.P., 1987. Field margins: definitions and statistics. In: Way JM, Greig-Smith PJ, editors. Field Margins. Surrey: British Crop Protection Council. p. 3-10.

Green, M.B., LeBaron, H.M., Moberg, W.K., 1990. Managing resistance to agrochemicals. From fundamental research to practical strategies: American Chemical Society.

Grime, J.P., Hodgson, J.G., Hunt, R., 2007. Comparative plant ecology: a functional approach to common British species. Springer.

Gurr, G., Wratten, S., Barbosa, P., 2010. Success in conservation biological control of arthropods Biological control: Measures of success. Springer. 105-132.

Haaland, C., Naisbit, R.E., Bersier, L.F., 2011. Sown wildflower strips for insect conservation: a review. Insect Conservation and Diversity. 4, 60-80.

Hackett, M., Lawrence, A., 2014. Multifunctional role of field margins in arable farming. European Crop Protection Association, Cambridge Environmental Assessments, ADAS UK Ltd. http://www.ecpa.eu/files/attachments/Field%20Margins%20Arable%20Farming_V02.pdf (accessed 23.02.15)

Haddaway, N.R., Brown, C., Eales, J., Eggers, S., Josefsson, J., Kronvang, B., Randall, N.P., Uusi-Kämppä, J., 2018. The multifunctional roles of vegetated strips around and within agricultural fields. Environmental Evidence. 7, 14.

Haddaway, N.R., Styles, D., Pullin, A.S., 2014. Evidence on the environmental impacts of farm land abandonment in high altitude/mountain regions: a systematic map. Environmental Evidence. 3, 17.

Haukos, D.A., Johnson, L.A., Smith, L.M., McMurry, S.T., 2016. Effectiveness of vegetation buffers surrounding playa wetlands at contaminant and sediment amelioration. Journal of environmental management. 181, 552-562.

Hector, A., Bagchi, R., 2007. Biodiversity and ecosystem multifunctionality. Nature. 448, 188-90.

Herrera, C.M., 1993. Selection on floral morphology and environmental determinants of fecundity in a hawk moth-pollinated violet. Ecol. Monogr. 63, 251-275.

Hewitt, A.J., 2000. Spray drift: impact of requirements to protect the environment. Crop Protection. 19, 623-627.

Holzschuh, A., Dudenhöffer, J.-H., Tscharntke, T., 2012. Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. Biological Conservation. 153, 101-107.

Huusela-Veistola, E. and Vasarainen, A., 2000. Plant succession in perennial grass strips and effects on the diversity of leafhoppers (Homoptera, Auchenorrhyncha). Agriculture, ecosystems & environment. 80, 101-112.

Jersáková, J., Jürgens, A., Šmilauer, P., Johnson, S.D., Johnson, M., 2012. The evolution of floral mimicry: identifying traits that visually attract pollinators. Functional Ecology. 26, 1381.

Johnson, S.D., Dafni, A., 1998. Response of bee-flies to the shape and pattern of model flowers: implications for floral evolution in a Mediterranean herb. Functional Ecology. 12, 289-297.

Jonsson, M., Wratten, S.D., Landis, D.A., Gurr, G.M., 2008. Recent advances in conservation biological control of arthropods by arthropods. Biological Control. 45, 172-175.

Kattge, J., Diaz, S., Lavorel, S., Prentice, I.C., Leadley, P., Bönisch, G., Garnier, E., Westoby, M., Reich, P.B., Wright, I.J., Cornelissen, J.H.C., 2011. TRY–a global database of plant traits. Global Change Biology. 17, 2905-2935.

Kevan, P.G., Phillips, T.P., 2001. The economic impacts of pollinator declines: an approach to assessing the consequences. Conservation Ecology. 5, 8.

Kings Seeds, 2018. Field & Hedgerow Mixture. https://www.kingsseeds.com/Products/Wild-Flowers/Wildflower-Mix/Field-Hedgerow-Mixture (accessed 15.03.18)

Kirk, W.D., Howes, F.N., 2012. Plants for bees: a guide to the plants that benefit the bees of the British Isles. IBRA.

Kleijn, D., Baquero, R.A., Clough, Y., Díaz, M., De Esteban, J., Fernández, F., Gabriel, D., Herzog, F., Holzschuh, A., Jöhl, R., Knop, E., Kruess, A., Marshall, E.J.P., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M., Yela, J.L., 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecology Letters. 9, 243-254.

Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proc R Soc B. 274, 303-13.

Koethe, S., Bossems, J., Dyer, A.G., Lunau, K., 2016. Colour is more than hue: preferences for compiled colour traits in the stingless bees Melipona mondury and M. quadrifasciata. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology. 202, 615-27.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World map of the Köppen-Geiger climate classification updated. Meteorology Zoology. 15, 259-263.

Kremen, C., Williams, N.M., Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. Proceedings National Academy of Science. 99, 16812-16816.

Kudo, G., Ishii, H.S., Hirabayashi, Y., Ida, T.Y., 2007. A test of the effect of floral color change on pollination effectiveness using artificial inflorescences visited by bumblebees. Oecologia. 154, 119-128.

Kuivila, K.M., Foe, C.G., 1995. Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco Estuary, California. Environmental, Toxicological Chemistry. 14, 1141-1150.

Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review Entomology. 45, 175-201.

Laskey, B.C., Wakefield, R.C., 1978. Competitive effects of several grass species and weeds on the establishment of birdsfoot trefoil. Agronomy Journal. 70, 146-148.

Lavorel, S., Garnier, É., 2002. Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. Functional ecology. 16, 545-556.

Lavorel, S., Storkey, J., Bardgett, R.D., de Bello, F., Berg, M.P., Le Roux, X., Moretti, M., Mulder, C., Pakeman, R.J., Diaz, S., Harrington, R., 2013. A novel framework for linking functional diversity of plants with other trophic levels for the quantification of ecosystem services. J. Veg. Sci. 24, 942-948.

Lazzaro, L., Otto, S., Zanin, G., 2008. Role of hedgerows in intercepting spray drift: evaluation and modelling of the effects. Agriculture, Ecosystems & Environment. 123, 317-327.

Le Féon, V., Schermann-Legionnet, A., Delettre, Y., Aviron, S., Billeter, R., Bugter, R., Hendrickx, F. and Burel, F., 2010. Intensification of agriculture, landscape composition and wild bee communities: a large scale study in four European countries. Agriculture, Ecosystems & Environment. 137, 143-150.

Lefebvre, M., Franck, P., Olivares, J., Ricard, J.-M., Mandrin, J.-F., Lavigne, C., 2017. Spider predation on rosy apple aphid in conventional, organic and insecticide-free orchards and its impact on aphid populations. Biological Control. 104, 57-65.

Li, X., Xiao, Q., Niu, J., Dymond, S., van Doorn, N.S., Yu, X., et al., 2016. Process-based rainfall interception by small trees in Northern China: The effect of rainfall traits and crown structure characteristics. Agricultural & Forest Meteorology. 218, 65-73.

Losey, J.E., Vaughan, M., 2006. The economic value of ecological services provided by insects. Bioscience. 56, 311-323.

Lye, G., Park, K., Osborne, J., Holland, J., Goulson, D., 2009. Assessing the value of Rural Stewardship schemes for providing foraging resources and nesting habitat for bumblebee queens (Hymenoptera: Apidae). Biological Conservation. 142, 2023-2032.

Mansion-Vaquié, A., Ferrante, M., Cook, S.M., Pell, J.K., Lövei, G.L., 2017. Manipulating field margins to increase predation intensity in fields of winter wheat (Triticum aestivum). Journal of Applied Entomology. 141, 600-611.

Marshall, E., Moonen, A., 2002. Field margins in northern Europe: their functions and interactions with agriculture. Agriculture, Ecosystems & Environment. 89, 5-21.

Marshall, E., West, T., Kleijn, D., 2006. Impacts of an agri-environment field margin prescription on the flora and fauna of arable farmland in different landscapes. Agriculture, Ecosystems & Environment. 113, 36-44.

Martins, K.T., Gonzalez, A., Lechowicz, M.J., 2015. Pollination services are mediated by bee functional diversity and landscape context. Agriculture, Ecosystems & Environment. 200, 12-20.

Mayer, P.M., Reynolds, S.K., McCutchen, M.D., Canfield, T.J., 2007. Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality. 36, 1172-1180.

Meyer, B., Jauker, F., Steffan-Dewenter, I., 2009. Contrasting resource-dependent responses of hoverfly richness and density to landscape structure. Basic and Applied Ecology. 10, 178-186.

Michigan State University, 2014. Arthropod pesticide resistance database. http://www.pesticideresistance.com. (accessed 23.1116)

Møller, A.P., Sorci, G., 1998. Insect preference for symmetrical artificial flowers. Oecologia. 114, 37-42.

Motten, A.F., 1983. Reproduction of Erythronium umbilicatum (Liliaceae): pollination success and pollinator effectiveness. Oecologia. 59, 351-359.

Mu, J., Li, G., Niklas, K.J., Sun, S., 2011. Difference in floral traits, pollination, and reproductive success between white and blue flowers of Gentiana leucomelaena (Gentianaceae) in an alpine meadow. Arctic, Antarctic, and Alpine Research. 43, 410-416.

Muscutt, A., Harris, G., Bailey, S., Davies, D., 1993. Buffer zones to improve water quality: a review of their potential use in UK agriculture. Agriculture, Ecosystems & Environment. 45, 59-77.

Myrick, S., Norton, G.W., Selvaraj, K.N., Natarajan, K., Muniappan, R., 2014. Economic impact of classical biological control of papaya mealybug in India. Crop Protection. 56, 82-86.

Natural England, 2017. Results-Based Agri-environment Payment Scheme (RBAPS) pilot study in England. https://www.gov.uk/government/publications/results-based-agri-environment-payment-scheme-rbaps-pilot-study-in-england (accessed 20.04.18)

Natural England, 2018. Countryside stewardship grants: AB3: Beetle banks. https://www.gov.uk/countryside-stewardship-grants/beetle-banks-ab3. (accessed 26.07.18)

Nicolson, S.W., Wright, G.A., 2017. Plant–pollinator interactions and threats to pollination: perspectives from the flower to the landscape. Functional Ecology. 31, 22-5.

Noordijk, J., Musters, C.J.M., van Dijk, J. and de Snoo, G.R., 2011. Vegetation development in sown field margins and on adjacent ditch banks. Plant ecology. 212, 157-167.

Nowakowski, M., Pywell, R.F., 2016. Habitat creation and management for pollinators. Wallingford, UK: Centre for Ecology & Hydrology. ISBN:978-1-906698-57-7.

Ohashi, K.A.Z.U.H.A.R.U., Yahara, T.E.T.S.U.K.A.Z.U., 2001. Behavioural responses of pollinators to variation in floral display size and their influences on the evolution of floral traits. Cognitive ecology of pollination. Cambridge University Press, Cambridge. 274-296.

Olson, D.M., Wäckers, F.L., 2007. Management of field margins to maximize multiple ecological services. Journal of Applied Ecology. 44, 13-21.

Perović, D.J., Gámez-Virués, S., Landis, D.A., Wäckers, F., Gurr, G.M., Wratten, S.D., You, M.S., Desneux, N., 2018. Managing biological control services through multi-trophic trait interactions: review and guidelines for implementation at local and landscape scales. Biological Reviews. 93, 306-321.

Pfiffner, L., Wyss, E., 2004. Use of sown wildflower strips to enhance natural enemies of agricultural pests, in: Gurr, G., Wratten, S.D., Altieri, M.A. (Eds.), Ecological engineering for pest management: advances in habitat manipulation for arthropods. CABI Publishing, Oxford, pp. 165-186.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., Kunin, W.E., 2010. Global pollinator declines: trends, impacts and drivers. Trends in ecology & evolution. 25, 345-353.

Pullin, A.S., Knight, T.M., 2001. Effectiveness in conservation practice: Pointers from medicine and public health. Conservation Biology. 15, 50-54.

Pywell, R., Warman, E., Hulmes, L., Hulmes, S., Nuttall, P., Sparks, T., Critchley, C., Sherwood, A., 2006. Effectiveness of new agri-environment schemes in providing foraging resources for bumblebees in intensively farmed landscapes. Biological Conservation. 129, 192-206.

Ramsden, M., Menéndez, R., Leather, S., Wäckers, F., 2013.The enhancement of conservation biological control through targeted landscape management. Aspects of Applied Biology. 118, 119-126.

Ramsden, M., Menéndez, R., Leather, S., Wäckers, F., 2013.The enhancement of conservation biological control through targeted landscape management. Aspects of Applied Biology. 118, 119-126.

Rand, T.A., Tscharntke, T., 2007. Contrasting effects of natural habitat loss on generalist and specialist aphid natural enemies. Oikos. 116, 1353-1362.

Randall, N.P., Donnison, L.M., Lewis, P.J., James, K.L., 2015. How effective are on-farm mitigation measures for delivering an improved water environment? A systematic map. Environmental Evidence 4, 18.

Randall, N.P., James, K.L., 2012. The effectiveness of integrated farm management, organic farming and agri-environment schemes for conserving biodiversity in temperate Europe - A systematic map. Environmental Evidence. 1, 4.

Raymond, L., Sarthou, J.P., Plantegenest, M., Gauffre, B., Ladet, S. and Vialatte, A., 2014. Immature hoverflies overwinter in cultivated fields and may significantly control aphid populations in autumn. Agriculture, ecosystems & environment. 185, 99-105.

Read, J., Fletcher, T.D., Wevill, T., Deletic, A., 2010. Plant Traits that Enhance Pollutant Removal from Stormwater in Biofiltration Systems. International Journal of Phytoremediation. 12, 34-53.

Reichenberger, S., Bach, M., Skitschak, A., Frede, H.G., 2007. Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; a review. The Science of the total environment. 384, 1–35.

Reverte, S., Retana, J., Gomez, J.M., Bosch, J., 2016. Pollinators show flower colour preferences but flowers with similar colours do not attract similar pollinators. Annals of Botany. 118, 249-57.

Robinson, R.A., Sutherland, W.J., 2002. Post-war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology. 39, 157-176.

Rocha-Filho, L.C., Rinaldi, I.M.P., 2011. Crab spiders (Araneae: Thomisidae) in flowering plants in a Brazilian" Cerrado" ecosystem. Brazilian Journal of Biology. 71, 359-364.

Rouabah, A., Villerd, J., Amiaud, B., Plantureux, S. and Lasserre-Joulin, F., 2015. Response of carabid beetles diversity and size distribution to the vegetation structure within differently managed field margins. Agriculture, Ecosystems and Environment. 200, 21-32.

Rusch, A., Chaplin-Kramer, R., Gardiner, M.M., Hawro, V., Holland, J., Landis, D., Thies, C., Tscharntke, T., Weisser, W.W., Winqvist, C., Woltz, M., 2016. Agricultural landscape simplification reduces natural pest control: A quantitative synthesis. Agriculture, Ecosystems & Environment. 221, 198-204.

Sánchez-Lafuente, A.M., Guitian, J., Medrano, M., Herrera, C.M., Rey, P.J., Cerda, X., 2005. Plant traits, environmental factors, and pollinator visitation in winter-flowering Helleborus foetidus (Ranunculaceae). Annals of Botany. 96, 845-852.

Sánchez-Lafuente, A.M., Parra, R., 2009. Implications of a long-term, pollinator-mediated selection on floral traits in a generalist herb. Annals of Botany. 104, 689-701.

Schmidt, K., Filep, R., Orosz-Kovacs, Z., Farkas, A., 2015. Patterns of nectar and pollen presentation influence the attractiveness of four raspberry and blackberry cultivars to pollinators. Journal of Horticultural Science & Biotechnology. 90, 47-56.

Shang, Y., Venail, J., Mackay, S., Bailey, P.C., Schwinn, K.E., Jameson, P.E., Martin, C.R., Davies, K.M., 2011. The molecular basis for venation patterning of pigmentation and its effect on pollinator attraction in flowers of Antirrhinum. New Phytology. 189, 602-615.

Shykoff, J.A., Bucheli, E., 1995. Pollinator visitation patterns, floral rewards and the probability of transmission of Microbotryum violaceum, a venereal disease of plants. Journal of Ecology. 83, 189-198.

Smith, A.P., Western, A.W., Hannah, M.C., 2013. Linking water quality trends with land use intensification in dairy farming catchments. Journal of Hydrology. 476, 1-12.

Smith, R.F., van den Bosch, R., 1967. Integrated control. In: Pest Control: Biological, Physical and Selected Chemical Methods. Academic Press, New York. p. 295-340

Sotherton, N.W., Self, M.J., 2000. Changes in plant and arthropod diversity on lowland farmland: an overview. In: Aebischer NJ, Evans AD, Grice PV, Vickery JA, editors. The Ecology and Conservation of Lowland Farmland Birds. p. 26-35.

Sparks, T.C., Nauen, R., 2015. IRAC: Mode of action classification and insecticide resistance management. Pesticide biochemistry and physiology. 121, 122-128.

Stanley, D.A., Gunning, D., Stout, J.C., 2013. Pollinators and pollination of oilseed rape crops (Brassica napus L.) in Ireland: ecological and economic incentives for pollinator conservation. Journal of Insect Conservation. 17, 1181-1189.

Stevens, A., Milne, R., 1997. The effectiveness revolution and public health. In: Scalley G, editor. Progress in Public Health. London: Royal Society for Medicine Press. p. 197-225.

Stutter, M.I., Chardon, W.J., Kronvang, B., 2012. Riparian Buffer Strips as a Multifunctional Management Tool in Agricultural Landscapes. Journal of Environmental Quality. 41, 297-303.

Sullivan, W.M., Jiang, Z.C., Hull, R.J., 2000. Root morphology and its relationship with nitrate uptake in Kentucky bluegrass. Crop Science. 40, 765-772.

Syngenta, 2014. Growers Guidelines Operation Pollinator: Multifunctional Landscapes.

Tang, W., Zhang, H., Zhang, W., Shan, B., Zhu, X., Song, Z., 2015. Dynamics of heavy metals and phosphorus in the pore water of estuarine sediments following agricultural intensification in Chao Lake Valley. Environmental Science Pollution Research. 22, 7948-53.

Thorburn, P.J., Biggs, J.S., Weier, K.L., Keating, B.A., 2003. Nitrate in groundwaters of intensive agricultural areas in coastal Northeastern Australia. Agriculture, Ecosystems & Environment. 94, 49-58.

Tilman, D., Reich, P.B., Knops, J.M., 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature. 441, 629-32.

Tittonell, P., 2014. Ecological intensification of agriculture—sustainable by nature. Current Opinion in Environmental Sustainability. 8, 53-61.

Totland, O., 2004. No evidence for a role of pollinator discrimination in causing selection on flower size through female reproduction. Oikos. 106, 558-564.

Tscharntke, T., Batáry, P. and Dormann, C.F., 2011. Set-aside management: How do succession, sowing patterns and landscape context affect biodiversity? Agriculture, ecosystems & environment. 143, 37-44.

Tschumi, M., Albrecht, M., Bärtschi, C., Collatz, J., Entling, M.H., Jacot, K., 2016. Perennial, species-rich wildflower strips enhance pest control and crop yield. Agriculture, Ecosystems & Environment. 220, 97-103.

United Nations, Department of Economic and Social Affairs, Population Division, 2018. World population prospects, the 2017 Revision. http://esa.un.org/unpd/wpp/DataQuery/ (accessed on 19.01.18)

Vickery, J.A., Bradbury, R.B., Henderson, I.G., Eaton, M.A., Grice, P.V., 2004. The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. Biological conservation. 119, 19-39.

Violle, C., Jiang, L., 2009. Towards a trait-based quantification of species niche. Journal of Plant Ecology. *2*, 87-93.

Violle, C., Navas, M.L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I., Garnier, E., 2007. Let the concept of trait be functional! Oikos. 116, 882-892.

Vollhardt, I.M.G., Bianchi, F.J.J.A., Wäckers, F.L., Thies, C., Tscharntke, T., 2010. Nectar vs. honeydew feeding by aphid parasitoids: does it pay to have a discriminating palate? Entomologia experimentalis et applicata. 137, 1-10.

Vought, L.B.M., Pinay, G., Fuglsang, A., Ruffinoni, C., 1995. Structure and function of buffer strips from a water quality perspective in agricultural landscapes. Landscape and urban planning. 31, 323-331.

Wardle, D.A. and Van der Putten, W.H., 2002. Biodiversity, ecosystem functioning and above-ground-below-ground linkages. Biodiversity and ecosystem functioning: Synthesis and perspectives. 155-168.

Watson, R., Albon, S., Aspinall, R., Austen, M., Bardgett, B., Bateman, I., Berry, P., Bird, W., Bradbury, R., Brown, C., Bullock, J., 2011. UK National Ecosystem Assessment: understanding nature's value to society. Synthesis of key findings. UNEP-WCMC, Cambridge.

Wentworth, J., 2008. Invasive non-native species. POST – Parliamentary office of science and technology. http://www.parliament.uk/documents/post/postpn303.pdf (accessed 01.11.16)

Whalon, M.E., Mota-Sanchez, D., Hollingworth, R.M., 2008. Analysis of global pesticide resistance in arthropods. In: Whalon ME, Mota-Sanchez D, Hollingworth RM, editors. Global Pesticide Resistance in Arthropods. CABI International. p. 5-31.

Wheater, C., Bell, J. and Cook, P., 2011. Practical Field Ecology: A Project Guide. John Wiley and Sons.

Williams, P.H., Osborne, J.L., 2009. Bumblebee vulnerability and conservation world-wide. Apidologie. 40, 367-387.

Winfree, R., Aguilar, R., Vázquez, D.P., LeBuhn, G., Aizen, M.A., 2009. A meta-analysis of bees' responses to anthropogenic disturbance. Ecology. 90, 2068-2076.

Wood, C.M., Smart, S.M., Bunce, R.G., Norton, L.R., Maskell, L.C., Howard, D.C., Scott, W.A. and Henrys, P.A., 2017. Long-term vegetation monitoring in Great Britain–the Countryside Survey 1978–2007 and beyond. Earth System Science Data. 9, 445.

Wood, T.J., Holland, J.M., Goulson, D., 2015a. Pollinator-friendly management does not increase the diversity of farmland bees and wasps. Biological Conservation. 187, 120-126.

Wood, T.J., Holland, J.M., Hughes, W.O., Goulson, D., 2015b. Targeted agri-environment schemes significantly improve the population size of common farmland bumblebee species. Molecular ecology. 24, 1668-1680.

Woodcock, B., Savage, J., Bullock, J., Nowakowski, M., Orr, R., Tallowin, J., Pywell, R., 2014. Enhancing floral resources for pollinators in productive agricultural grasslands. Biological Conservation. 171, 44-51.

Woodcock, B.A., Westbury, D.B., Tscheulin, T., Harrison-Cripps, J., Harris, S.J., Ramsey, A.J., Brown, V.K., Potts, S.G., 2008. Effects of seed mixture and management on beetle assemblages of arable field margins. Agriculture, Ecosystems & Environment. 125, 246-254.

Yang, L., Zeng, Y., Xu, L., Liu, B., Zhang, Q., Lu, Y., 2018. Change in ladybeetle abundance and biological control of wheat aphids over time in agricultural landscape. Agriculture, Ecosystems & Environment. 255, 102-110.

Zavaleta, E.S., Pasari, J.R., Hulvey, K.B., Tilman, G.D., 2010. Sustaining multiple ecosystem functions in grassland communities requires higher biodiversity. Proceedings of the National Academy of Sciences. 107, 1443-1446.

Additional files

Additional files 2-1, 2-4, 4-2, 4-3 and 7-1 are electronic databases and can be found either attached electronically on the online thesis or on the CD disk attached. All other additional files are enclosed below in chronological order.

Additional file 2-2. Searches conducted to find articles published after November 2014

The list of databases searched by Find it @ Harper was checked and cross-referenced with those that were searched in original searches in November 2014. Ethos and Web of Science were searched separately as they were no longer searched by this database searcher.

Water quality protection

Search string:

(plant* AND trait*) AND ("water quality" OR (agri* AND pollut*) OR filtration OR pollut* OR runoff OR (water AND erosion) OR (water AND nitrate*) OR (water AND pollut*) OR (water AND retention) OR (water AND sediment) OR "run off" OR (pollut* AND prevent*) OR (water AND pesticide* AND protect*) OR (water AND phosphate*))

Searches:

Web of science (all databases): 762 (10.1.17) imported, duplicates auto-removed (10.1.17) leaving 760 refs.

Find it @ harper: 1515 (11.1.17), 1127 imported, duplicates auto-removed (11.1.17) leaving 1012 refs. Title exclusion: 22 included (12.1.17)

EThOS: 0 (11.1.17)

All databases: 1772, duplicates auto-removed (11.1.17) leaving 1476 refs, duplicates manually removed (11.1.17) leaving 1142 refs.

Title exclusion: 36 included, 16 excluded on language, 1090 excluded on non-relevance (12.1.17).

Abstract exclusion: 16 included, 20 excluded on non-relevance (17.1.17).

Pollinators

Search string:

(plant* AND trait*) AND (apid* OR apoidea* OR bee OR bees OR bumblebee* OR butterfl* OR hoverfl* OR lepidoptera* OR pollinator* OR (pollinator* AND support) OR syrphid*)

Searches:

Web of science (all databases): 935 (10.1.17), imported, duplicates auto-removed (10.1.17) leaving 919 refs.

Find it @ Harper: 1819 (11.1.17), 1163 imported, duplicates auto-removed (11.1.17) leaving 1028 refs.

EThOS: 0 (11.1.17)

All databases: 1947, duplicates auto-removed (11.1.17) leaving 1519 refs, duplicates manually removed (11.1.17) leaving 1142 refs.

Title exclusion: 128 included, 5 excluded on language, 1009 excluded on non-relevance (16.1.17).

Abstract exclusion: 37 included, 91 excluded on non-relevance (19.1.17).

<u>Bio-control</u>

Search string:

(plant* AND trait*) AND (“hoverfly larvae” OR “lady beetle*” OR “pirate bug*” OR “syrphid larvae” OR anthocorid OR beetle* OR (beneficial AND arthropod*) OR (beneficial AND insect*) OR (beneficial AND invertebrate*) OR (beneficial AND organism*) OR coccinellidae OR coleoptera* OR hymenoptera OR ladybird* OR ladybug* OR (natural AND enem*) OR spider* OR “biological control*” OR (insect* AND pest* AND control*) OR lacewing* OR neuroptera*)

Searches:

Web of science (all databases): 1492 imported (11.1.17), duplicates auto-removed (10.1.17) leaving 1486 refs.

Find it @ Harper: 2154 (11.1.17), 1590 imported, duplicates auto-removed (11.1.17) leaving 1417 refs.

EThOS: 0 (11.1.17)

All databases: 2903, duplicates auto-removed (11.1.17) leaving 2368 refs, duplicates manually removed (11.1.17) leaving 1854 refs.

Title exclusion: 116 included, 6 excluded on language, 1732 excluded on non-relevance (17.1.17).

Abstract exclusion: 3 included and 7 included but not relevant to bio-control, 53 excluded as already sorted through pollinator support section, 48 excluded on non-relevance.

Additional file 2-3 Sources searched by Harper Adams University Library Database ('Findit@Harper')

ABC CLIO

Academy of Management

ADIS International Limited

Administrative Science Quarterly

Advanstar Communications

Alexander Street Press

Allen Press Publishing Services

American Bar Association

American Association for the Advancement of Science

American Counseling Association

American Economic Association

American Institute of Physics

American Management Association International

American Meteorological Society

American Psychiatric Publishing

American Psychological Association

American Society of Civil Engineers

American Statistical Association

American Theological Library Association

Annual Reviews Inc.

Asian Network for Scientific Information

ACM - Association for Computing Machinery

ACP Publishing PTY Limited

Associated Press DBA Press Association

B.C. Decker Inc.

Baker & Taylor

BASE

Bentham Science Publishers Ltd.

Berghahn Books

Biblical Archaeology Society

BioOne

Blackwell Publishing

Bloomberg (BusinessWeek)

Books 24x7

Brill Academic Publishers

British Library

British Psychological Society

BSI Online

Business Monitor International

Business Source Complete

CAB Abstracts

Cambridge University Press / Books

Cambridge University Press / Journals

Canadian Medical Association

Chinese University Press

Columbia University Press

Credo Reference

Datamonitor Plc

Dawson E-books

Ebrary

EBSCOhost Database Subscriptions

Edinburgh University Press

Editions Rodopi BV

EDP Sciences

Elsevier journal metadata

Emerald Group Publishing Limited

Ethos

Expert Reviews

Food Science Source

Forbes Inc.

Future Science Ltd.

Georg Thieme Verlag Stuttgart

Greenfile

Guilford Publications Inc. / Journals

Guilford Publications Inc. / Books

Harvard Business Publishing

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Haymarket Media

Henry Stewart Publications LLP

H.W. Wilson Company

Hindawi Publishing Corporation

Human Kinetics Publishers, Inc.

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Martinus Nijhoff

Medknow Publications

Mergent

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Remedica Medical Education & Publishing

Research India Publications

Rittenhouse Books

Rogers Publishing

Royal Society

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Scientific Research Publishing

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SLACK Incorporated

Springer Science & Business Media B.V. / Books

Springer Science & Business Media B.V. / Journals

Statistics Canada

Taylor & Francis Informa

Thieme Medical Publishing Inc.

Thomas Telford Ltd

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University of Alabama Press

University of Calgary Press

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University of Nebraska Press

University of North Carolina Press

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University of Queensland Press

University of Toronto Press

University of Wisconsin Press

US News & World Report

VSP International Science Publishers

Web of Knowledge

Wiley Online Library

World Bank Publications

World Book, Inc.

World Scientific Publishing Company

Additional file 2-6. References for the 56 studies included in the systematic map database.

Alves Venancio DdF, Viccini LF, Luizi-Ponzo AP, Prezoto F. Flower-Visiting Insects and Phenology of Lippia alba (Lamiales: Verbenaceae)…. Environmental Entomology. 2016;45(3):685-93.

Anderson B, Pauw A, Cole WW, Barrett SCH. Pollination, mating and reproductive fitness in a plant population with bimodal floral-tube length. Journal of Evolutionary Biology. 2016;29(8):1631-42.

Anderson, I. A., & Busch, J. W. (2006). Relaxed pollinator-mediated selection weakens floral integration in self-compatible taxa of Leavenworthia (Brassicaceae).

Andersson, S., & Dobson, H. E. M. (2003). Behavioral foraging responses by the butterfly Heliconius melpomene to Lantana camara floral scent. Journal of Chemical Ecology, 29(10), 2303-2318.

Antiqueira P, Romero G. Floral asymmetry and predation risk modify pollinator behavior, but only predation risk decreases plant fitness. Oecologia. 2016;181(2):475-85.

Armbruster, W. S., Antonsen, L., & Pelabon, C. (2005). Phenotypic selection on Dalechampia blossoms: Honest signaling affects pollination success.

Ashman, T.-L., Swetz, J., & Shivitz, S. (2000). Understanding the Basis of Pollinator Selectivity in Sexually Dimorphic Fragaria virginiana, 347.

Barrio M, Teixido AL. Sex-dependent selection on flower size in a large-flowered Mediterranean species: an experimental approach with Cistus ladanifer. Plant Systematics and Evolution. 2015;301(1):113-24.

Bianchi, F., & Wackers, F. L. (2008). Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids. Biological Control, 46(3), 400-408.

Bjorkman, C., & Ahrne, K. (2005). Influence of leaf trichome density on the efficiency of two polyphagous insect predators.

Brunet J, Thairu MW, Henss JM, Link RI, Kluever JA. The Effects of Flower, Floral Display, and Reward Sizes on Bumblebee Foraging Behavior When Pollen Is the Reward and Plants Are Dichogamous. International Journal of Plant Sciences. 2015;176(9):811-9.

Brunet, J. (2009). Pollinators of the Rocky Mountain columbine: temporal variation, functional groups and associations with floral traits: Oxford University Press, 2009-06.

Burylo, M., Dutoit, T., & Rey, F. (2014). Species Traits as Practical Tools for Ecological Restoration of Marly Eroded Lands. Restoration Ecology, 22(5), 633-640.

Burylo, M., Rey, F., Bochet, E., & Dutoit, T. (2012). Plant functional traits and species ability for sediment retention during concentrated flow erosion: Springer, 2012.

Burylo, M., Rey, F., Mathys, N., & Dutoit, T. (2012). Plant root traits affecting the resistance of soils to concentrated flow erosion. EARTH SURFACE PROCESSES AND LANDFORMS, 37(14), 1463-1470.

Campbell DR, Juergens A, Johnson SD. Reproductive isolation between Zaluzianskya species: the influence of volatiles and flower orientation on hawkmoth foraging choices. New Phytologist. 2016;210(1):333-42.

Campbell, D. R., Bischoff, M., Lord, J. M., & Robertson, A. W. (2010). Flower color influences insect visitation in alpine New Zealand.

Chau NL, Chu LM. Fern cover and the importance of plant traits in reducing erosion on steep soil slopes. Catena. 2017;151:98-106.

Conner, J., & Rush, S. (1996). Effects of flower size and number on pollinator visitation to wild radish, Raphanus raphanistrum. Oecologia, 105(4), 509.

Deyto, R. C., & Cervancio, C. R. P. U. L. B. C. L. I. o. B. S. (2009). Floral biology and pollination of ampalaya (Momordica charantia L.). Philippine Agricultural Scientist (Philippines) / Formerly The Philippine Agriculturist.

Duffy KJ, Johnson SD. Staminal hairs enhance fecundity in the pollen-rewarding self-incompatible lily Bulbine abyssinica. Botanical Journal of the Linnean Society. 2015;177(3):481-90.

Elle, E., & Carney, R. (2003). Reproductive assurance varies with flower size in Collinsia parviflora (Scrophulariaceae). 90(6), 888-896.

Galen, C. (1996). Rates of Floral Evolution: Adaptation to Bumblebee Pollination in an Alpine Wildflower, Polemonium viscosum, 120.

Garbuzov M, Ratnieks FLW. Using the British National Collection of Asters to Compare the Attractiveness of 228 Varieties to Flower-Visiting Insects. Environmental Entomology. 2015;44(3):638-46.

Gary C. Chang, C. E. R., Russell C. Biggam, and Sanford D. Eigenbrode. (2004). Arthropod diversity in peas with normal or reduced waxy bloom: University of Arizona Library.

Gould IJ, Quinton JN, Weigelt A, De Deyn GB, Bardgett RD. Plant diversity and root traits benefit physical properties key to soil function in grasslands. Ecology Letters. 2016;19(9):1140-9.

Herrera CM. Selection on floral morphology and environmental determinants of fecundity in a hawk moth-pollinated violet. Ecological monographs. 1993 Feb 1;63(3):251-75.

Irwin, R. E., & Adler, L. S. (2006). Correlations among Traits Associated with Herbivore Resistance and Pollination: Implications for Pollination and Nectar Robbing in a Distylous Plant, 64.

Jersáková, J., Jürgens, A., Šmilauer, P., Johnson, S. D., & Johnson, M. (2012). The evolution of floral mimicry: identifying traits that visually attract pollinators. Functional Ecology, 26(6), 1381.

Johnson, & Dafni. (1998). Response of bee-flies to the shape and pattern of model flowers: implications for floral evolution in a Mediterranean herb. Functional Ecology, 12(2), 289-297. doi: 10.1046/j.1365-2435.1998.00175.x

Koethe S, Bossems J, Dyer AG, Lunau K. Colour is more than hue… Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology. 2016;202(9/10):615-27.

Kudo, G., Ishii, H. S., Hirabayashi, Y., & Ida, T. Y. (2007). A Test of the Effect of Floral Color Change on Pollination Effectiveness Using Artificial Inflorescences Visited by Bumblebees, 119.

Kumano-Nomura, Y., & Yamaoka, R. (2009). Beetle visitations, and associations with quantitative variation of attractants in floral odors of Homalomena propinqua (Araceae).

Larue A-AC, Raguso RA, Junker RR. Experimental manipulation of floral scent bouquets restructures flower-visitor interactions in the field. Journal of Animal Ecology. 2016;85(2):396-408.

Lele, L., Zuojun, L., Guozhen, D., & Zhigang, Z. (2012). Floral traits, pollinator assemblages, and phenotypic selection at different flowering time for Trollius ranunculoides. Biodiversity Science(3), 317.

Li X, Xiao Q, Niu J, Dymond S, van Doorn NS, Yu X, et al. Process-based rainfall interception by small trees in Northern China: The effect of rainfall traits and crown structure characteristics. Agricultural & Forest Meteorology. 2016;218:65-73.

Mant, J., Peakall, R., Schiestl, F. P., & Williams, C. F. (2005). DOES SELECTION ON FLORAL ODOR PROMOTE DIFFERENTIATION AMONG POPULATIONS AND SPECIES OF THE SEXUALLY DECEPTIVE ORCHID GENUS OPHRYS? Evolution, 59(7), 1449-1463.

Møller, A.P. and Sorci, G., 1998. Insect preference for symmetrical artificial flowers. Oecologia, 114(1), pp.37-42.

Motten, A. F. (1983). Reproduction of Erythronium umbilicatum (Liliaceae): Pollination Success and Pollinator Effectiveness, 351.

Mu, J, et al. (2011). Difference in Floral Traits, Pollination, and Reproductive Success between White and Blue Flowers of Gentiana Ieucomelaena (Gentianaceae) in an Alpine Meadow. Arctic, Antarctic & Alpine Research, 43(3), 410.

Ohashi, K. A. Z. U. H. A. R. U., and T. E. T. S. U. K. A. Z. U. Yahara. . (2004). Behavioural responses of pollinators to variation in floral display size and their influences on the evolution of floral traits. Cognitive Ecology of Pollination, 274.

Papiorek S, Junker RR, Alves-dos-Santos I, Melo GAR, Amaral-Neto LP, Sazima M, et al. Bees, birds and yellow flowers: pollinator-dependent convergent evolution of UV patterns. Plant Biology. 2016;18(1):46-55.

Read, J., Fletcher, T. D., Wevill, T., & Deletic, A. (2010). Plant Traits that Enhance Pollutant Removal from Stormwater in Biofiltration Systems. International Journal of Phytoremediation, 12(1), 34-53.

Renoult, J. P., Thomann, M., Schaefer, H. M., & Cheptou, P. (2013). Selection on quantitative colour variation in Centaurea cyanus: the role of the pollinator's visual system. Journal of Evolutionary Biology, 26(11), 2415-2427.

Reverte S, Retana J, Gomez JM, Bosch J. Pollinators show flower colour preferences but flowers with similar colours do not attract similar pollinators. Annals of Botany. 2016;118(2):249-57.

"Rocha-Filho, L.C. and Rinaldi, I.M.P., 2011. Crab spiders (Araneae: Thomisidae) in flowering plants in a Brazilian"" Cerrado"" ecosystem. Brazilian Journal of Biology, 71(2), pp.359-364."

Rouabah, A., et al. (2015). Response of carabid beetles diversity and size distribution to the vegetation structure within differently managed field margins. Agriculture, Ecosystems and Environment, 200, 21-32.

Sánchez-Lafuente, A. M., & Parra, R. (2009). Implications of a long-term, pollinator-mediated selection on floral traits in a generalist herb: Oxford University Press, 2009-09.

Sanchez-Lafuente, A.M., Guitian, J., Medrano, M., Herrera, C.M., Rey, P.J. and Cerda, X., 2005. Plant traits, environmental factors, and pollinator visitation in winter-flowering Helleborus foetidus (Ranunculaceae). Annals of Botany, 96(5), pp.845-852.

Schmidt K, Filep R, Orosz-Kovacs Z, Farkas A. Patterns of nectar and pollen presentation influence the attractiveness of four raspberry and blackberry cultivars to pollinators. Journal of Horticultural Science & Biotechnology. 2015;90(1):47-56.

Shang, Y. J., et al. (2011). The molecular basis for venation patterning of pigmentation and its effect on pollinator attraction in flowers of Antirrhinum. New Phytologist, 189(2), 602-615.

Shykoff, J. A., & Bucheli, E. (1995). Pollinator visitation patterns, floral rewards and the probability of transmission of Microbotryum violaceum, a venereal disease of plants. Journal of Ecology (Oxford), 83(2), 189-198

Sullivan, W. M., Jiang, Z. C., & Hull, R. J. (2000). Root morphology and its relationship with nitrate uptake in Kentucky bluegrass. Crop Science, 40(3), 765-772.

Totland, O. (2004). No evidence for a role of pollinator discrimination in causing selection on flower size through female reproduction. Oikos, 106(3), 558-564.

Vollhardt, I. M. G., Bianchi, F. J. J. A., Wäckers, F. L., Thies, C., & Tscharntke, T. (2010). Nectar vs. honeydew feeding by aphid parasitoids: does it pay to have a discriminating palate? Entomologia Experimentalis et Applicata, 137(1), 1-10

Wilsey, B. J., & Polley, H. W. (2006). Aboveground productivity and root–shoot allocation differ between native and introduced grass species. Oecologia, 150(2), 300-309. doi: 10.1007/s00442-006-0515-z

Additional file 3-2. References for Table 1 - Data extracted from the systematic map showing the important aspects for the chosen plant traits.

Ashman, T.L., Swetz, J., Shivitz, S., 2000. Understanding the basis of pollinator selectivity in sexually dimorphic Fragaria virginiana. Oikos. 90, 347-356.

Barrio, M., Teixido, AL., 2015. Sex-dependent selection on flower size in a large-flowered Mediterranean species: an experimental approach with Cistus ladanifer. Plant Syst. Evol. 301, 113-24.

Bianchi, F., Wackers, F.L., 2008. Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids. Biol. Control. 46, 400-408.

Brunet, J., Thairu, M.W., Henss, J.M., Link, R.I., Kluever, J.A., 2015. The Effects of Flower, Floral Display, and Reward Sizes on Bumblebee Foraging Behavior When Pollen Is the Reward and Plants Are Dichogamous. International Journal of Plant Sciences. 176, 811-819.

Burylo, M., Rey, F., Mathys, N., Dutoit, T., 2012a. Plant root traits affecting the resistance of soils to concentrated flow erosion. Earth Surf. Proc. Land. 37, 1463-1470.

Burylo, M., Rey, F., Bochet, E., Dutoit, T., 2012b. Plant functional traits and species ability for sediment retention during concentrated flow erosion. Plant Soil. 353, 135-144.

Burylo, M., Dutoit, T., Rey, F., 2014. Species Traits as Practical Tools for Ecological Restoration of Marly Eroded Lands. Restoration Ecol. 22, 633-640.

Campbell, D.R., Bischoff, M., Lord, J.M. and Robertson, A.W., 2010. Flower colour influences insect visitation in alpine New Zealand. Ecology. 91, 2638-2649.

Chang, G.C., Rutledge, C.E., Biggam, R.C., Eigenbrode, S.D., 2004. Arthropod diversity in peas with normal or reduced waxy bloom. J. Insect Sci. 4, 18.

Chau, N.L., Chu, L.M., 2017. Fern cover and the importance of plant traits in reducing erosion on steep soil slopes. Catena. 151, 98-106.

Conner, J., Rush, S., 1996. Effects of flower size and number on pollinator visitation to wild radish, Raphanus raphanistrum. Oecologia. 105, 509.

Elle, E., and Carney, R. 2003. Reproductive assurance varies with flower size in Collinsia parviflora (Scrophulariaceae). 90, 888-896.

Galen, C., 1996. Rates of Floral Evolution: Adaptation to Bumblebee Pollination in an Alpine Wildflower, Polemonium viscosum. Evolution. 50, 120-125.

Garbuzov, M., Ratnieks, F.L.W., 2015. Using the British National Collection of Asters to Compare the Attractiveness of 228 Varieties to Flower-Visiting Insects. Environ Entomol. 44 638-46.

Gould, I.J., Quinton, J.N., Weigelt, A., De Deyn, G.B., Bardgett, R.D., 2016. Plant diversity and root traits benefit physical properties key to soil function in grasslands. Ecology Letters. 19, 1140-9.

Herrera, C.M., 1993. Selection on floral morphology and environmental determinants of fecundity in a hawk moth-pollinated violet. Ecol. Monogr. 63, 251-275.

Jersáková, J., Jürgens, A., Šmilauer, P., Johnson, S.D., Johnson, M., 2012. The evolution of floral mimicry: identifying traits that visually attract pollinators. Funct. Ecol. 26, 1381.

Johnson, S.D., Dafni, A., 1998. Response of bee-flies to the shape and pattern of model flowers: implications for floral evolution in a Mediterranean herb. Funct. Ecol. 12, 289-297.

Koethe, S., Bossems, J., Dyer, A.G., Lunau, K., 2016. Colour is more than hue: preferences for compiled colour traits in the stingless bees Melipona mondury and M.

quadrifasciata. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology. 202, 615-27.

Kudo, G., Ishii, H.S., Hirabayashi, Y., Ida, T.Y., 2007. A test of the effect of floral color change on pollination effectiveness using artificial inflorescences visited by bumblebees. Oecologia. 154, 119-128.

Li, X., Xiao, Q., Niu, J., Dymond, S., van Doorn, N.S., Yu, X., et al., 2016. Process-based rainfall interception by small trees in Northern China: The effect of rainfall traits and crown structure characteristics. Agricultural & Forest Meteorology. 218, 65-73.

Møller, A.P., Sorci, G., 1998. Insect preference for symmetrical artificial flowers. Oecologia. 114, 37-42.

Motten, A.F., 1983. Reproduction of Erythronium umbilicatum (Liliaceae): pollination success and pollinator effectiveness. Oecologia. 59, 351-359.

Mu, J., Li, G., Niklas, K.J., Sun, S., 2011. Difference in floral traits, pollination, and reproductive success between white and blue flowers of Gentiana leucomelaena (Gentianaceae) in an alpine meadow. Arct. Antarc. Alp. Res. 43, 410-416.

Ohashi, K.A.Z.U.H.A.R.U., Yahara, T.E.T.S.U.K.A.Z.U., 2001. Behavioural responses of pollinators to variation in floral display size and their influences on the evolution of floral traits. Cognitive ecology of pollination. Cambridge University Press, Cambridge. 274-296.

Read, J., Fletcher, T.D., Wevill, T., Deletic, A., 2010. Plant Traits that Enhance Pollutant Removal from Stormwater in Biofiltration Systems. Int. J. Phytoremediation. 12, 34-53.

Reverte, S., Retana, J., Gomez, J.M., Bosch, J., 2016. Pollinators show flower colour preferences but flowers with similar colours do not attract similar pollinators. Annals of Botany. 118, 249-57.

Rocha-Filho, L.C., Rinaldi, I.M.P., 2011. Crab spiders (Araneae: Thomisidae) in flowering plants in a Brazilian" Cerrado" ecosystem. Braz. J. Biol. 71, 359-364.

Sánchez-Lafuente, A.M., Guitian, J., Medrano, M., Herrera, C.M., Rey, P.J., Cerda, X., 2005. Plant traits, environmental factors, and pollinator visitation in winter-flowering Helleborus foetidus (Ranunculaceae). Annal. Bot. 96, 845-852.

Sánchez-Lafuente, A.M., Parra, R., 2009. Implications of a long-term, pollinator-mediated selection on floral traits in a generalist herb. Annal. Bot. 104, 689-701.

Schmidt, K., Filep, R., Orosz-Kovacs, Z., Farkas, A., 2015. Patterns of nectar and pollen presentation influence the attractiveness of four raspberry and blackberry cultivars to pollinators. Journal of Horticultural Science & Biotechnology. 90, 47-56.

Shang, Y., Venail, J., Mackay, S., Bailey, P.C., Schwinn, K.E., Jameson, P.E., Martin, C.R., Davies, K.M., 2011. The molecular basis for venation patterning of pigmentation and its effect on pollinator attraction in flowers of Antirrhinum. New Phytol. 189, 602-615.

Shykoff, J.A., Bucheli, E., 1995. Pollinator visitation patterns, floral rewards and the probability of transmission of Microbotryum violaceum, a venereal disease of plants. J. Ecol. 83, 189-198.

Sullivan, W.M., Jiang, Z.C., Hull, R.J., 2000. Root morphology and its relationship with nitrate uptake in Kentucky bluegrass. Crop Sci. 40, 765-772.

Totland, O., 2004. No evidence for a role of pollinator discrimination in causing selection on flower size through female reproduction. Oikos. 106, 558-564.

Vollhardt, I.M.G., Bianchi, F.J.J.A., Wäckers, F.L., Thies, C., Tscharntke, T., 2010. Nectar vs. honeydew feeding by aphid parasitoids: does it pay to have a discriminating palate? Entomol. Exp. Appl. 137, 1-10.

Additional file 4-1. Buffer strip questionnaire

Please answer the questions below to the best of your knowledge.

If you have more than one buffer strip on your farm and the answers would be different for each one, please fill out a questionnaire for each.

<table>
<tr><th></th><th>Question</th><th colspan="7">Answers</th></tr>
<tr><td>1</td><td>What is the location of the buffer strip on your farm?</td><td colspan="7"></td></tr>
<tr><td>2</td><td>What kind of waterbody is it adjacent to? Please circle appropriate.</td><td>River</td><td>Stream</td><td>Ditch</td><td>Lake</td><td>Pond</td><td colspan="2">Other:</td></tr>
<tr><td>3</td><td>What predominant soil type is it on? If it is a combination of soil types please circle all that are appropriate.</td><td colspan="2">Sand</td><td colspan="3">Loam</td><td colspan="2">Clay</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">What was the buffer strip sown with or was it left to natural regeneration? Please circle the appropriate option and provide as much detail of the plant species sown as possible.</td><td colspan="2">Pollinator mix</td><td colspan="2">Grass mix</td><td colspan="2">Natural regeneration</td><td>Other:</td></tr>
<tr><td colspan="7">Details:</td></tr>
<tr><td>5</td><td>When was the buffer strip established?</td><td colspan="7"></td></tr>
<tr><td>6</td><td>When was the buffer strip last sown or left to natural regeneration?</td><td colspan="7"></td></tr>
<tr><td rowspan="3">7</td><td rowspan="3">What kind of management has been undertaken and when? (weeding, cutting, spraying etc.) Please circle all appropriate.</td><td>Weeding</td><td colspan="2">Within the first year</td><td>1st to 2nd year</td><td colspan="2">2nd to 3rd year</td><td>3rd to 4th year</td></tr>
<tr><td>Cutting</td><td colspan="2">Within the first year</td><td>1st to 2nd year</td><td colspan="2">2nd to 3rd year</td><td>3rd to 4th year</td></tr>
<tr><td>Other:</td><td colspan="2">Within the first year</td><td>1st to 2nd year</td><td colspan="2">2nd to 3rd year</td><td>3rd to 4th year</td></tr>
<tr><td>8</td><td>What is the approximate width of the buffer strip in meters? Please circle appropriate category.</td><td>0 – 2</td><td>2 - 4</td><td>4 - 6</td><td>6 - 8</td><td>8 - 10</td><td>10 - 12</td><td>Other:</td></tr>
<tr><td>9</td><td>What is the approximate length of the buffer strip?</td><td colspan="7"></td></tr>
<tr><td>10</td><td>Any other useful observations that you may have?</td><td colspan="7"></td></tr>
</table>