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Do sown flower strips boost wild pollinator abundance and pollination services in a spring-flowering crop? A case study from UK cider apple orchards

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ABSTRACT

Flower strips are widely recommended as a tool to boost insect pollinators and yield in pollinator-dependent crops. Using UK cider apple orchards (*Malus domestica* Borkhausen) as a model system, we assessed whether flower strips increased pollination services in orchards. Pollinator communities (visual observation) and pollination services (fruit set) were assessed at increasing distance from surrounding semi-natural habitats (0–200 m) in eight orchards. In four orchards, perennial flower strips had been established and bloomed in the year before the main experiment. In a separate experiment, insect visits to apple flowers were observed to investigate possible functional mechanisms underpinning pollinator efficacy.

The visit rate of wild insects to apple flowers (non-*Apis* bees and flies), but not that of honeybees (*Apis mellifera* L.), increased by 40% in flower strip orchards compared to control orchards, particularly in areas close to semi-natural habitat (<100 m). Wild insect visitation was also positively related to dandelion (*Taraxacum* species) abundance in orchards. Fruit set in orchards was positively related to wild insect richness, and andrenid bee (*Andrena* species) visitation, but neither richness nor andrenid bee visit rate responded positively to flower strips. Wild bees (andrenid bees and bumblebees (*Bombus* species)) contacted apple stigma (95 and 100% of visits) more often than honeybees (81%), but only bumblebees moved frequently between different tree rows, an important trait for transfer of compatible pollen in apples.

Our results demonstrate that flower strips enhanced overall wild insect abundance but not pollination services in cider orchards. Positive effects of ground flora on wild insect abundance in orchards suggest that flower mixtures or orchard management could be optimised for andrenid bees, the single most important pollinator taxa, by increasing the availability of early-flowering plants in orchards. Equally, wild insect richness was highest in areas close to semi-natural habitats. Therefore, whilst flower strips can boost abundance of the existing species pool, only large scale preservation of (semi-) natural habitat will maintain pollinator diversity in apple orchards.

1. Introduction

Around 75% of global food crops are to some degree dependent on animal pollination (Klein et al., 2007), with insects being the most important pollinators in both natural and agricultural settings (Kearns et al., 1998). Yet, pollinators are under threat because of several interrelated factors associated with the intensification of agricultural practices (*e.g.* removal or fragmentation of natural- or semi-natural habitats, agrochemical usage) (Biesmeijer et al., 2006; Park et al., 2015; Potts et al., 2010). Historically, many pollinator-dependent crops have been supplemented with domesticated hives of the European honeybee, *Apis mellifera* Linnaeus (Hymenoptera: Apidae), during crop bloom to ensure adequate pollination (Garibaldi et al., 2009). However, in addition to concerns about over-reliance on a single species for global crop pollination services (Breeze et al., 2014), there is a

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growing body of evidence that the contribution of wild pollinators (*e.g.* non-*Apis* bees, flies), may be equal to, or even surpass that of honeybees (Garibaldi et al., 2013). As such, there is growing interest in the development of management practices that integrate the needs of wild pollinators into productive landscapes (Bommarco et al., 2013; Dicks et al., 2013; Kleijn et al., 2015).

To persist in agricultural habitats, wild pollinators must be able to find suitable nesting sites (if a central-place forager), and collect sufficient food (pollen and nectar) to feed their offspring (Kremen et al., 2004). Changes in agricultural practice that alter the availability of these resources will indirectly affect fitness and population size of wild pollinators (Carvell et al., 2007; Roulston and Goodell, 2011). For example, Marini et al. (2012) found wild bee abundance in apple orchards was higher in landscapes dominated by semi-natural habitats (*e.g.* forest, grassland) compared to orchards in landscapes dominated by apple. They attributed this to semi-natural habitats providing pollinators with a better supply of floral resources, in terms of both temporal availability and abundance, than commercially managed orchards, particularly in periods outside of tree blossom.

Although the role of semi-natural habitats in supporting pollinator communities is clear (Carvalheiro et al., 2010), many farms exist in landscapes already dominated by intensive agriculture (Morandin and Kremen, 2013). As an alternative, the restoration of habitat within farms could enable farmers to enhance existing species pools and pollination services (Kremen et al., 2004; Martins et al., 2015). Research effort into within-farm habitat restoration for pollinators has focused on the use of flowering strips, which are typically sown in the marginal areas adjacent to the crop (*e.g.* headlands, field margins) (Wratten et al., 2012), although the maintenance of existing non-crop flora and the restoration of hedgerows or riparian scrubland habitats have also been investigated (Carvalheiro et al., 2012; Klein et al., 2012; Morandin and Kremen, 2013; Rosa García and Miñarro, 2014; Sardiñas and Kremen, 2015; Saunders et al., 2013).

Such flower-rich habitats, if designed effectively, provide pollinators with a greater diversity of pollen and nectar resources, and can increase the availability of nest sites for wild pollinators in crop fields (Carreck and Williams 2002; Pywell et al., 2005; Russo et al., 2013). However, arbitrarily chosen flowering vegetation or naturally regenerated vegetation may be ineffective in supporting key groups of beneficial insects (Campbell et al., 2012; Olson and Wäckers, 2007) and may also generate negative effects, such as increased pest problems (Wäckers et al., 2007; Winkler et al., 2010). For example, incompatibilities between insect feeding structures and floral morphologies, or insufficient temporal overlap between flowering period and insect foraging periods, may limit transfer of fitness benefits to pollinators (Campbell et al., 2012; Junker et al., 2013; Russo et al., 2013). Furthermore, plantings at the crop edge may concentrate ambient populations of beneficial insects at field edges and exacerbate pollinator declines in field centres (Kohler et al., 2008; Morandin and Kremen, 2013). Therefore, establishment of flower-rich areas directly within crop fields may be a more effective means of increasing pollinator visits to crop flowers in large fields, either through facilitative co-pollination (Carvalheiro et al., 2012), or improved reproductive success of pollinators in crop fields and surrounding habitats (Blaauw and Isaacs, 2014).

Here, we explore the effects of sown flower strips introduced directly between tree rows in UK cider apple orchards (*Malus domestica* Borkhausen) on pollinator visitation and pollination services. Cider apple orchards are an ideal candidate for such interventions, as apple is regarded as 'greatly dependent' on pollinators for fruit set (Klein et al., 2007), and fruit quality (Garratt et al., 2014), and the semi-permanent nature of orchards allows populations to build across seasons (Shackelford et al., 2013; Simon et al., 2010). We also investigate the relative contribution of insects to pollination services in cider apple orchards using insect-exclusion and hand pollination experiments, and identify potential behavioural mechanisms that underpin pollination efficiency of different insect taxa. Specifically, we ask 1) whether perennial flower strips introduced directly into orchards increase pollinator abundance and richness during apple blossom along a gradient of isolation from semi-natural habitat, 2) how do changes in pollinator communities (visitor abundance, richness) affect pollination services, and 3) do differences in foraging behaviour among pollinator taxa underpin differences in pollination efficacy?

2. Materials and methods

2.1. Study site details and experimental design

The experiment took place in 2013 during a single growing season in eight cider apple orchards located in Herefordshire, south-west England (52°05′–52°12′ N and 2°47′– 2°56′ W). All orchards were of similar size, age, crop and sward management practices and separated from each other by a minimum distance of 500 m (Table S1; Fig. S1, Supplementary Materials). This distance was considered greater than the average foraging range of most solitary and eusocial bee species found in the study region (Gathmann and Tscharntke, 2002; Zurbuchen et al., 2010). Flower strips had been previously established in four orchards (='flower strip orchards'), with the remaining four orchards left unmanipulated (='control orchards').

2.2. Flower strips

Flower strip orchards were sown with targeted flower mixtures of up to 25 wildflower species in April 2011 (Table S2, Supplementary Materials). Flower mixtures included Fabaceae species attractive to eusocial bee species and commonly included in UK agri-environment schemes (Defra, 2013), as well as other plant families (Apiaceae) with short or 'open' corollas to attract short-tongued insects (*e.g.* solitary bees, hoverflies and parasitoid wasps) (Campbell et al., 2012). Flower strips were divided in three pairs that were randomly distributed among orchard rows and covered a total area of 0.05 ha per orchard. Flower strips bloomed sporadically in the first year following establishment (2011), but flowered consistently in 2012 from early June until August when they were cut to prepare orchards for mechanical fruit harvest. During this period (June–August 2012), insect visitation to flower strips in orchards was recorded on six separate occasions using similar methods (walked transects) to those described below for observations of insect visitors to apple flowers in 2013.

2.3. Pollinator sampling

For observations of insects visiting apple blossom in 2013, approximately two weeks prior to the onset of blossom, we marked out four to five plots in study orchards, with each plot consisting of fifteen healthy trees in the same row. To look at effects of flower strips on pollinators in context to the wider landscape, plots in orchards were marked out at 0, 50, 100, 150, and in the four largest orchards, 200 m from an adjacent area of semi-natural habitat (*e.g.* woodland, grassland or mature hedgerow) (Fig. S2, Supplementary Materials). Plots in flower strip orchards bisected flower strips to ensure distance to the nearest flower strip was never more than the maximum distance to semi-natural habitat (range = 8–175 m).

Observations of insect visitation took place in May 2013 during peak bloom in orchards. A single observation consisted of continuously walking alongside trees of a plot for ten minutes. During this period, all insects observed visiting apple flowers