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The impact of sown flower strips on plant reproductive success in Southern Sweden varies with landscape context

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ABSTRACT

In agricultural landscapes, sown flower strips can benefit pollinators and pollination of nearby plants, but their impact on pollination in the wider landscape is poorly studied. We evaluated effects on reproductive success of field bean (*Vicia faba*) and woodland strawberry (*Fragaria vesca*) using data from two study systems, both including study sites (1 km radius) with (flower strip sites) or without flower strips (control sites). To assess whether flower strips enhance pollination in the wider landscape, we compared the reproductive success between plants growing in field borders (> 160 m to nearest flower strip) at flower strips sites and control sites. We also tested if flower strips reallocate pollination functions in the landscape. We did this by comparing the reproductive success of plants at flower strip sites, growing adjacent to the flower strips with plants growing in a more distant field border at the same site (> 160 m). Finally, we tested if these potential effects depended on the heterogeneity of the landscape. In field borders without an adjacent flower strip, plant reproductive success was unaffected by the presence of a flower strip at the site, and increased with increasing landscape heterogeneity independently of site type (flower strip vs. control). In contrast, adjacent to the flower strips, reproductive success declined with increasing landscape heterogeneity, resulting in a positive net effect of adjacent flower strips in homogeneous landscapes and a negative effect in heterogeneous landscapes. Our results show that while decreasing landscape heterogeneity may impair pollination in homogeneous landscapes, this can be locally mitigated by sowing flower strips. However, in heterogeneous landscapes, flower strips may instead reduce pollination of adjacent plants.

1. Introduction

Agricultural intensification and concomitant landscape homogenization has affected pollinators negatively partly via loss and deterioration of habitat containing forage plants (Potts et al., 2016; Goulson et al., 2015). Accordingly, one strategy that is used to mitigate pollinator declines is to increase the availability of floral resources (Gill et al., 2016), for example by creating flower strips, i.e. sown patches with pollen- and nectar-rich flowers on arable land (Haaland et al., 2011). Since pollinators promote pollination in a majority of flowering plant species (Ollerton et al., 2011) and cultivated crops (Klein et al., 2007), such strategies may also benefit plants, which often suffer from pollen limitation (Bartomeus et al., 2014; Burd, 1994). By benefitting pollinators, flower strips can increase flower visitation in adjacent crops (Campbell et al., 2017; Feltham et al., 2015) and a few studies have shown locally positive impact of flower strips on crop production (Blaauw and Isaacs, 2014; Carvalheiro et al., 2012; but see Campbell et al., 2017). However, the outcome of such interventions may be highly context-dependent, with consequences depending on how the flower strips affect population sizes and landscape-wide distribution of pollinators and if these changes translate into increased pollination. First, by increasing landscape-wide pollinator abundances (Jönsson et al., 2015), flower strips may increase pollination in the wider landscape. Second, by attracting pollinators from the wider landscape, flower strips could also facilitate the pollination of plants occurring adjacent to the flower strips (cf. Ghazoul, 2006; Kovács-Hostyánszki et al., 2013) or reduce the pollination of plants outside the flower strip because of increased competition for pollinators (cf. Holzschuh et al., 2011; Olsson et al., 2015). Finally, it might be implicitly assumed that benefitting pollinators results in increased pollination. This may, however, not be true if pollination is nevertheless saturated (Burd, 1994), if pollinators benefitting from flower strips are inefficient as

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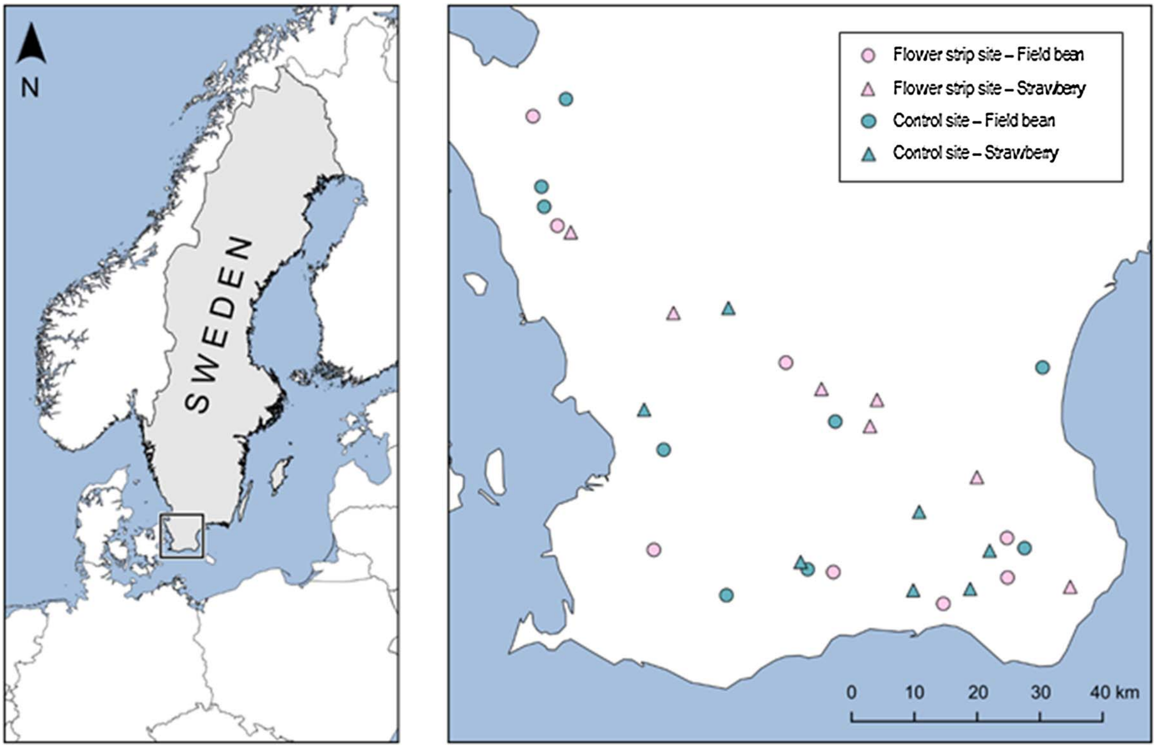

Fig. 1. Map showing location of the study sites (1 km radius) in Southern Sweden, with flower strip sites (pink) containing at least one sown flower strip and control sites (turquoise) without any flower strips. At each site, pots with either field bean (circles) or woodland strawberry (triangles), were placed. For clarity, two control sites have been slightly separated (although still overlapping on the map); the distance between the pots in these two sites was 800 m. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

pollinators of the focal plant (Fontaine et al., 2006) or if the presence of a concentrated flower resource close to focal plants increases the risk of interspecific pollen transfer such that pollen donors suffer from pollen loss and pollen receivers from stigma clogging (i.e. pollen from another species prevents pollination by covering the stigma) (Morales and Traveset, 2008). Because most pollen is deposited within a few flower visits (Thomson and Plowright, 1980), increasing interspecific pollen transfer could be expected to mainly reduce the pollination of plants adjacent to the sown flower strip. Hence, in order to make sure that flower strips benefit plant pollination, while avoiding unintended consequences for plant populations or crop production, a spatially explicit understanding of the effect of sown flower strips on pollination is needed.

Because pollinators are mobile organisms utilizing resources across landscapes (Kremen et al., 2007), the impact of flower strips on pollination may depend on landscape context. For example, flower strips can have a strong positive impact on flower visitation by bees near habitats that provide them with nesting opportunities (Campbell et al., 2017). It is also possible that in homogeneous agricultural landscapes, where permanent grasslands and field borders are scarce, pollinating insects are particularly food limited (Persson and Smith, 2013; Dicks et al., 2015). In these landscapes, pollinators commonly respond more strongly to the implementation of agri-environment measures that increase the availability of floral resources (Scheper et al., 2013). Thus, the effects of flower strips on pollination may be exceptionally strong in homogeneous landscapes. However, it is possible that such landscape-dependent impacts differ among plant species primarily pollinated by different groups of pollinators (cf. Fontaine et al., 2006) since some pollinator taxa such as hoverflies seem relatively unaffected by landscape heterogeneity (e.g. Ekroos et al., 2013; Rader et al., 2016).

Given that European agroecosystems are facing an ongoing homogenization (Pe'er et al., 2014), potentially threatening crop and wild flower pollination (Biesmeijer et al., 2006; Bommarco et al., 2012), it is important to understand whether mitigation measures designed to benefit pollinators, such as flower strips, also benefit pollination. In this paper, we tested how flower strips affected the reproductive success of two insect-pollinated plant species over a gradient of landscape heterogeneity. We assessed the effect of flower strips on plant reproduction both at a local scale (i.e. close and distant from flower strips) and at a landscape scale (i.e. in landscapes with or without sown flower strips).

2. Methods

2.1. Study organisms

We used field bean (*Vicia faba*) and woodland strawberry (*Fragaria vesca*), two partially self-compatible species, which benefit from insect pollination (Bartomeus et al., 2014; Free, 1993; Lundgren et al., 2013).

Field bean is a legume with large pods, containing 2–6 ovules (Free, 1993; this study) and producing on average 3 seeds under open pollination (Nayak et al., 2015). The plant is visited mainly by bumblebees and to a lesser extent by honey bees (Bartomeus et al., 2014, Nayak et al., 2015). Flower visitation increases yields (Bartomeus et al., 2014) and has a positive impact on both the number of pods per plant and the proportion developed seeds per pod (Free, 1993; Garratt et al., 2014). We used the proportion of developed seeds as a measure of reproductive success.

Strawberries are aggregated fruits and the true fruits of the strawberry are the achenes, the small nuts (one seed per nut) on the strawberry surface (Free, 1993). Flowers of woodland strawberry are typically visited by dipterans, solitary bees and other (non-*Apis* and non-*Bombus*) hymenopterans (Blažytė-Čereškienė et al., 2012; Lundgren et al., 2013). The number of developed achenes per strawberry increases with insect pollination (Lundgren et al., 2013), and fruit weight increases with the proportion of successfully pollinated pistils (Muola et al., 2017). In cultivated strawberry, increased number of honey bee visits has been found to positively affect pollination up to around 60 visits per flower (Free, 1993). Because the number developed achenes