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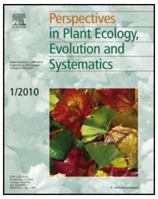

Research article

Does the surrounding matrix influence corridor effectiveness for pollen dispersal in farmland?

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ABSTRACT

Recent decades have seen a shift in agricultural land use from pasture to arable combined with increased use of fertilisers and pesticides. In this quite hostile landscape matrix, pollinator movements between native vegetation remnants may be impeded. Linear landscape elements (LLEs) in farmland can function as biological corridors by facilitating pollinator movements and pollen flow between fragmented plant populations. The type of landscape matrix surrounding LLEs and plant populations, and LLE habitat quality may influence the effectiveness of LLEs as corridors for pollen dispersal through the availability of floral resources and nesting opportunities for pollinators. Using fluorescent dyes as pollen analogues, we investigated dye dispersal patterns between fragmented populations of the rare insect-pollinated *Primula vulgaris* connected by existing LLEs. We examined how dye deposition on *P. vulgaris* and within LLEs (on other co-flowering insect-pollinated species) could be influenced by the surrounding matrix type (pasture, arable field), the recipient population traits of *P. vulgaris* (flowering population size, flower display, flowering plant density and co-flowering floral resources) and by LLE traits (LLE length and co-flowering floral resources). Dye dispersal through corridors was significantly higher when the landscape matrix surrounding *P. vulgaris* recipient populations and LLEs consisted of pastures rather than arable fields (or a mix of both), even after accounting for differences in floral resources. A higher cover and diversity of insect-pollinated plants increased dye deposition when co-flowering within small *P. vulgaris* populations, but led to dye loss within LLEs. Large *P. vulgaris* populations appeared more attractive thereby increasing heterospecific dye deposition in the LLEs. Our study shows that farming practices shifting from pastures to maize arable fields have a negative impact on dye dispersal patterns, and so possibly affect pollen dispersal of *P. vulgaris*, likely through a reduced pollinator service. Corridor effectiveness depends on the type of surrounding matrix, and the abundance of floral resources directly influences dye dispersal patterns. Preserving the remaining pastureland is essential, but restoring rich flowering vegetation at field boundaries and along LLEs may also promote corridor effectiveness for pollen dispersal.

Introduction

The modernisation and intensification of agriculture after World War II in Western Europe have resulted in the loss of native farmland vegetation and landscape elements such as field boundaries, ditches, hedges and tree rows, an increased use of fertilisers and pesticides, drainage and irrigation (Stoate et al., 2001). In intensively used agricultural landscapes, native vegetation is highly fragmented (e.g. Endels et al., 2002), the abundance and diversity of pollinator guilds can be reduced and plant–pollinator interactions disrupted, leading to an overall decline in both quality and quantity of pollination (Kearns et al., 1998; Kiers et al., 2010). The reconnection of isolated populations by corridors, a method becoming popular to restore pollen flow in fragmented landscapes (Gilbert-Norton et al., 2010; Haddad et al., 2011), might be a more feasible strategy for the preservation of plant species in farmland than the restoration of large continuous areas of suitable habitats (Falcy and Estades, 2007). Corridors are narrow landscape elements that are thought to facilitate the movement of animals and diaspores, and subsequent gene exchanges (Rosenberg et al., 1997; Haddad et al., 2003). However, little is still known about which characteristics influencing pollinator movements and behaviour (e.g.

Abbreviations: LLE(s), linear landscape element(s).

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surrounding landscape matrix, abundance of floral resources and vegetation height, LLE length and width) might be needed to enhance pollen flow through corridors (Van Geert et al., 2010; Van Rossum and Triest, 2010, 2012; Haddad et al., 2011; Cranmer et al., 2012).

Land use and management in farmland determine the amount of pesticides and fertilisers applied and soil alteration in the cultivated or grazed parcels, influencing floristic composition, also in LLEs (Kleijn and Verbeek, 2000; Power et al., 2012), and feeding resource and nesting opportunities for pollinators (e.g. Bäckman and Tiainen, 2002; Kells and Goulson, 2003). Intensively used cereal arable fields are usually poor in insect-pollinated plants and nesting sites, and hence can be considered of low habitat quality for pollinators, which occur in lower abundance and diversity (Kells and Goulson, 2003; Pywell et al., 2005; Carvell et al., 2011; Öckinger et al., 2012a). In pastures the amount of nectar or pollen rewards will depend on grazing intensity and forb richness, but can still offer nesting opportunities (Morandin et al., 2007; Sjödin et al., 2008; Power et al., 2012). Besides, the shift from pasture to arable field may alter the functional connectivity of the landscape (Jules and Shahani, 2003; Murphy and Lovett-Doust, 2004; Cranmer et al., 2012; Tscharntke et al., 2012). Inhospitable cereal arable fields may hamper pollinator movements between native plant populations (Osborne and Williams, 2001; Öckinger et al., 2012b). Grazed pastures may be considered as less hostile (no pesticide use), more similar to native grasslands, and so more permeable to pollinators (Ricketts, 2001; Eycott et al., 2012).

To avoid inhospitable habitats, pollinators may use LLEs for passing from one patch to another patch of conspecific flowers, but they can also forage on other flowering species within the LLE as well as in the patch of the target species. A high habitat quality in LLEs, i.e. offering enough floral or feeding resources and/or nesting opportunities, might enhance the attractiveness to foraging pollinators, increasing their visitation and movements through the matrix, and hence pollen dispersal (Öckinger and Smith, 2008; Jauker et al., 2009; Van Rossum and Triest, 2012; but see Haddad and Tewksbury, 2005). Similarly, large flowering population size and high plant density of a particular plant species may increase its attractiveness to pollinators (Cresswell and Osborne, 2004; Van Rossum and Triest, 2010; Mayer et al., 2012). However, if foraging on other co-flowering plant species may increase pollinator visitation (facilitation), it may also lead to a change in pollinator foraging preferences, to increased competition for pollinators and to pollen wastage through interspecific pollen deposition (Goulson, 2003; Ghazoul, 2006; Flanagan et al., 2011; Van Rossum et al., 2013).

The study of Van Geert et al. (2010) using fluorescent dye particles as pollen analogues has been the first to show that existing LLEs in an intensive farmland can function as biological corridors facilitating pollinator movements and pollen transfers between fragmented populations of the insect-pollinated *Primula vulgaris*. In Flanders (Belgium) this rare plant species occurs in small, fragmented populations embedded in an agricultural landscape, which traditionally consists of pastures grazed by cattle crossed by many ditches planted with willow tree rows (*Salix* spp.) and hedges (Endels et al., 2002). Maintaining pollen flow, by facilitating pollinator movements through existing corridors connecting those populations, appears as a key element for the long-term persistence of the species (Van Rossum and Triest, 2003; Van Geert et al., 2008, 2010).

Nevertheless, not all *P. vulgaris* populations connected by an LLE showed dye transfers. It has been hypothesised that other factors may affect pollinator service, and so corridor effectiveness, such as habitat quality of the LLEs (e.g. related to floral resources availability), and the surrounding landscape matrix type (pasture versus arable field). The present study aims at testing these hypotheses in a context of changing agricultural land use. Indeed, land use has changed over recent decades shifting from traditional pastures to arable fields mostly used to cultivate maize (*Zea mays*), highly demanding in fertilisers and pesticides (Kleijn and Verbeek, 2000). Using dye deposition as an estimator of pollinator activity between populations of *P. vulgaris*, we investigated whether (i) arable fields represent a more hostile surrounding matrix than pastures for pollinator movements through LLEs; (ii) low quality LLEs (i.e. reduced floral resources) alter the functional connectivity from a pollinator perspective and negatively affect *P. vulgaris* pollen flow; and (iii) recipient population traits of *P. vulgaris* (flowering population size, flower display, flowering plant density, and co-flowering insect-pollinated species richness, diversity and cover) and LLE traits (LLE length and co-flowering insect-pollinated species richness, diversity and cover) may affect dye dispersal patterns, in relation to population attractiveness, facilitation or competition for pollinators. As pollinators may also forage in the LLE during their flight (Schmucki and de Blois, 2009), we examined dye deposition patterns in the LLEs themselves, on other co-flowering insect-pollinated species. The results are discussed in the context of the management of existing LLEs.

Materials and methods

The species

P. vulgaris Huds. (=*P. acaulis* (L.) Hill., Primulaceae) is a diploid, long-lived perennial rosette-forming herb. In Flanders (northern Belgium), at the north-eastern border of its North Atlantic and Mediterranean European distribution, it is a rare and rapidly declining species (Van Landuyt et al., 2006). There, it occurs in moist native vegetation, comprising deciduous forest remnants and linear landscape elements such as ditch banks along forest edges, hedges, and pastures (Endels et al., 2002). Because of its self-incompatibility system (distyly), *P. vulgaris* can be considered as allogamous (Richards, 1997). Flowers appear in early spring (March–April) and are insect-pollinated, mainly by Hymenoptera, usually long-tongued species, such as bumblebee queens and workers (mainly *Bombus hypnorum, B. pasquorum, B. pratorum*, and *B. terrestris sensu lato*), and solitary bees (e.g. *Andrena* spp., *Anthophora plumipes*, and *A. acervorum*), but also by butterflies (e.g. *Gonepteryx rhamni*), moths and Diptera, usually Syrphid flies (e.g. *Rhingia campestris*), and Bombyliidae (e.g. *Bombylius major*) (Van Geert et al., 2010 and references therein).

Study site, populations and linear landscape elements

The study was conducted in the first week of April 2005. The study site, comprising 16 populations of *P. vulgaris*, was located near Donk, Flanders (3°21′ E, 51°13′ N). The populations were located on ditch or tree row banks (grassland vegetation usually dominated by *Arrhenatherum elatius* and *Agrostis* spp.), embedded in an agricultural landscape matrix consisting of a mosaic of pastures (grass-vegetation dominated by *Lolium perenne*) and arable fields (maize, with weed flora systematically destroyed) (Fig. 1, Appendix A). In each population, all flowering individuals were mapped, and the shortest geographical distances between population pairs were measured (at population borders) using GPS coordinates. The geographical (nearest direct) distance between populations ranged from 0.07 to 3.18 km. Flowering population size (N), defined as the number of flowering individuals, ranged from 2 to 86 (Table 1), and remained stable during the experiment. Flowering plant density was estimated as $D = N/\pi \sum r_i^2$, where N is the number of flowering individuals and r_i is the distance (m) from a