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Late-season mass-flowering red clover increases bumble bee queen and male densities

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ABSTRACT

Spatiotemporal resource continuity promotes persistence of mobile animal populations. Current agricultural landscapes are poor in flowers resources for bumble bees. Available forage crops are predominantly early-season mass-flowering crops (MFC). It has been suggested, but not tested, that scarcity of late-season flower resources are limiting bumble bee populations. We examined whether addition of late-season flowering red clover affected worker, queen and male bumble bee densities. Bumble bees were surveyed in flower-rich uncultivated field borders across 24 landscapes (radius 2 km) with or without a clover field in the centre, varying in semi-natural grassland (SNG) and early MFC availability. Clover fields had over ten times higher worker densities compared to field borders, suggesting red clover as favoured forage. Five times more queens and 71% more males were found in landscapes with clover fields compared to control landscapes, despite these fields constituting less than 0.2% of the landscape area. Both MFC and SNG increased the density of males, but only in the presence of clover fields. Our results suggest that late-flowering red clover positively affects bumble bee reproduction, likely by increasing temporal resource continuity. Interventions such as flower strips can thus have mitigating effects if they release population regulation by late-season resource bottle-necks.

1. Introduction

Insect pollinators have been declining for decades in many agricultural areas of the world (Bartomeus et al., 2013; Biesmeijer et al., 2006; Bommarco et al., 2012; Dupont et al., 2011). The most important cause of these declines is probably large-scale agricultural intensification in agricultural landscapes. This intensification has resulted in loss of semi-natural habitat and increased use of agrochemicals, leading to loss of nesting and foraging resources for pollinators and toxic effects of insecticides (Brittain et al., 2010; Carvell et al., 2006b; Kremen et al., 2002; Rundlöf et al., 2008; Williams et al., 2010). In the northern temperate regions, bumble bees are frequent visitors of wild plants and important native pollinators of crops (Bommarco et al., 2012; Steffan-Dewenter et al., 2002; Winfree et al., 2008). Together with other wild bees, bumble bees can provide pollination insurance and complementation (Garibaldi et al., 2013) in times of honey bee deficit (Breeze et al., 2011) and decline (Winfree et al., 2008). We need to identify the causes of the decline of bumble bees and, based on that understanding, develop efficient interventions that enhance bumble bee densities in the landscape.

The distribution of resources over time and space is an important factor influencing the dynamics of animal populations. For a bumble bee colony, a continuous and readily available supply of food is crucial for successful establishment, growth and finally production of sexuals (males and queens) (Westphal et al., 2009; Williams et al., 2012). Bumble bees have a strongly male-biased sex allocation, partly explained by a more than three times higher cost to produce queens compared to males (Beekman and Van Stratum, 1998; Bourke, 1997). Flower availabilities during colony foundation in early spring, and colony reproduction in mid to late summer have been suggested as important resource bottle-necks in current landscapes (Fitzpatrick et al., 2007; Pelletier and McNeil, 2003). Especially the availability of early-season flower resources has often been studied in relation to bumble bee population regulation. For instance, mass-flowering oilseed rape (*Brassica napus* L.) in early spring has been shown to contribute to early colony growth and colony size in three bumble bee species, but did not

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result in higher reproductive success (Carvell et al., 2011; Herrmann et al., 2007; Westphal et al., 2003, 2009; Williams et al., 2012). The promotion of populations is, however, most prominent for species that are able to exploit ephemeral and scattered but very rewarding flower resources (Walther-Hellwig and Frankl, 2000; Westphal et al., 2006). The lack of influence on reproductive success has been suggested to be caused by a deficiency of forage resources in late season (Westphal et al., 2009; Williams et al., 2012), but this hypothesis has not been tested.

Agricultural landscapes dominated by arable crops have lost many wild plants (Persson and Smith, 2013). In temperate Europe, large areas of oilseed rape can provide abundant forage resources early in the season, while fewer crops flowering in late summer are cultivated. Lack of flower resources in this period, when bumble bee colonies are large and resource-demanding, is possibly limiting bumble bee population growth.

Red clover (*Trifolium pratense* L.) is a late-flowering crop that is cultivated in monocultures for seed intended for animal fodder production in grass-clover leys. The cultivated area of red clover seed production has decreased dramatically; in Sweden by 90% during the last 70 years, down to just over 2000 ha today (Bommarco et al., 2012). The same trend has been reported from the UK (Carvell et al., 2006b), Belgium, and the Netherlands (Kleijn and Raemakers, 2008). Red clover is one of the most favoured plants for bumble bee pollen and nectar foraging in summer (Carvell et al., 2006a; Goulson et al., 2005; Kleijn and Raemakers, 2008), but the relative portion of red clover pollen collected by bumble bees is today considerably lower compared to before the 1950s (Kleijn and Raemakers, 2008). The occurrence of remaining monocultures of red clover in some landscapes allows us to test whether this resource affects bumble bee density.

In this study, we used information from whole landscape surveys of bumble bee worker, queen and male densities in flower-rich uncultivated linear habitat elements within 24 circular 2 km radius landscapes. Thirteen of the landscapes had a 4–16 ha red clover monoculture for seed production in the centre, which was also surveyed for bumble bees. This design allowed us to investigate the impact of spatiotemporal flower resource availability on the density of foraging bumble bee workers. We could also assess the densities of queens and males and use these as proxies for reproductive success within a year. We were particularly interested in assessing the potential benefit of adding a late-season mass-flowering resource to a landscape. Based on the study design, we tested the following hypotheses;

(1) Red clover seed fields are favoured as foraging habitats over flower-rich semi-natural vegetation in linear elements. This is particularly true for workers because they forage for the entire colony and thus need high yielding resources. The attraction is also expected to be stronger for workers of species shown to be good at utilising larger areas of other mass-flowering resources.
(2) Clover fields attract workers. Because of this the density of workers in linear elements will, during the flowering period of red clover, be lower in landscapes with, as compared to landscapes without red clover seed cultivation.
(3) The addition of late-season flower resources promotes production of sexuals (males and queens), by increasing resource continuity in landscapes. In particular, we hypothesise that densities of queens and males in linear elements are higher in landscapes with red clover seed cultivation, compared to in landscapes without this late-season flower resource. This effect will be particularly pronounced in landscapes which also have a high availability of early-season flower resources.

2. Methods

2.1. Study design and landscape context

The study was conducted in 2008 in the province of Skåne, a region of approximately 100 km × 100 km in southernmost Sweden (Fig. 1). The province is dominated by agriculture and contains a range of landscape types; from regions of simple and intensively managed crop dominated landscapes to regions of more complex landscapes that also include extensively managed grasslands and forest (Persson et al., 2010). In the study region, we selected 24 independent (⩾4 km apart) circular landscapes, radius 2 km (Fig. 1). The 2 km landscape radius was selected because bumble bees are expected to have potential foraging ranges around this scale (Greenleaf et al., 2007) and react to the landscape context at this or even larger radii for some species (Westphal et al., 2006). Landscapes were selected along gradients of varying proportions of semi-natural grasslands (SNG) and of mass-flowering crops (MFC). Thirteen of the landscapes contained a field for red clover seed production (mean size: 8.2 ha, range: 4–16 ha). In the remaining 11 landscapes, no red clover seed production occurred within the 2 km radius.

Digital land use data from the Integrated Administration and Control System (IACS), a yearly updated database on farmland in Sweden, was used in ArcGIS 9.2 (ESRI, Redlands, CA) to characterise the landscapes. The selected landscapes were all dominated by agricultural land (55.5–94.3%) but varied in the proportions of SNG (0–16.4%) and MFC (0.9–15.5%). The SNG in the region consists of permanent grasslands traditionally used for grazing, and more rarely for making hay. These grasslands often contain a low density of flowers, but are important nesting habitat for bumble bees (Öckinger and Smith, 2007). The MFC included oilseed rape, turnip rape (*Brassica rapa* L. ssp. *oleifera*), oilseed radish

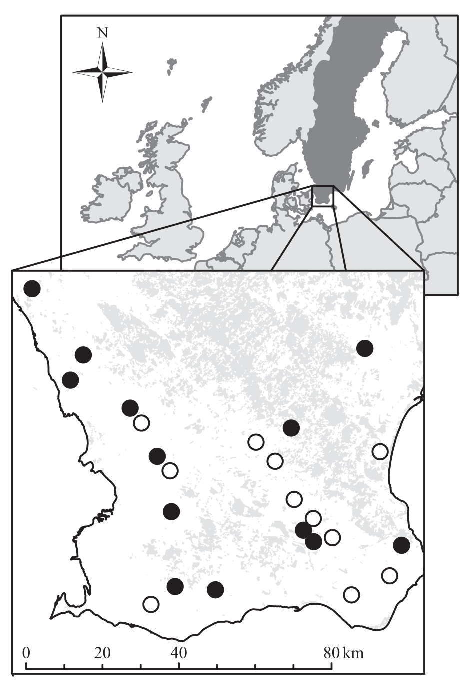

Fig. 1. Location of the study region in the southernmost part of Sweden and of selected landscapes with (filled circles) and without (open circles) red clover seed cultivation. Circles represent landscapes with a 2 km radius and grey areas in the lower map are forest.