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Managed bumble bees increase flower visitation but not fruit weight in polytunnel strawberry crops

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Abstract

Animal-mediated pollination is essential for the production and quality of fruits and seeds of many crops consumed by humans. However, crop pollination services might be compromised when wild pollinators are scarce. Managed pollinators are commonly used in crops to supplement such services with the assumption that they will enhance crop yield. However, information on the spatiotemporal pollinator-dependence of crops is still limited. We assessed the contribution of commercial bumble bee colonies compared to the available pollinator community on strawberry ('Fortuna' variety) flower visitation and strawberry quality across a landscape gradient of agricultural intensification (i.e. polytunnel berry crop cover). We used colonies of bumble bees in winter and in spring, i.e. when few and most wild pollinators are in their flight period, respectively. The placement of colonies increased visits of bumble bees to strawberry flowers, especially in winter. The use of bumble bee colonies did not affect flower visitation by other insects, mainly honey bees, hoverflies and other Diptera. Flower visitation by both honey bees and wild insects did not vary between seasons and was unrelated to the landscape gradient of berry crop cover. Strawberries were of the highest quality (i.e. weight) when insect-mediated pollination was allowed, and their quality was positively related to wild flower visitors in winter but not in spring. However, increased visits to strawberry flowers by managed bumble bees and honey bees had no effect on strawberry weight. Our results suggest that the pollination services producing high quality strawberry fruits are provided by the flower visitor community present in the study region without the need to use managed bumble bees.

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Introduction

Around 75% of world food crops require or benefit from animal-mediated pollination to increase the production and quality of fruits and seeds (Klein et al. 2007). During the last half century, the area devoted to these crops has disproportionately increased compared with non-dependent crops (Aizen, Garibaldi, Cunningham, & Klein 2008). Several factors can affect the presence of pollinators in crops and compromise the service they provide. For instance, the reduction of natural habitats can decrease wild pollinator abundance and richness in agroecosystems (Williams et al., 2010; Winfree, Bartomeus, & Cariveau 2011) because it decreases the availability of nesting sites and flower resources over time. Furthermore, the temporal variability of wild pol-

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linators, which is due to their life-cycle and their activity depending on temperature, creates periods in which their abundance is low (Pisanty, Klein, & Mandelik 2014; Ellis, Feltham, Park, Hanley, & Goulson 2017). If crops bloom outside of the main pollinator flying phenophase period or for a long period, wild pollinators might not fulfill crop pollination services. For these reasons, many farmers do not solely rely on wild pollinators, but rather managed insect pollinators are used to supplement visitation rates on pollinator-dependent crops regardless of the occurrence of wild pollinators.

Honey bees (*Apis mellifera*) and bumble bees (*Bombus* ssp.) are the most common managed pollinators used worldwide. Honey bees have been historically domesticated for honey production and crop pollination (Aizen & Harder 2009; Garibaldi et al. 2013), being present in many crop systems worldwide (Winfree, Williams, Dushoff, & Kremen 2007). In contrast, bumble bees have been domesticated more recently (i.e. last four decades) mainly to pollinate greenhouse tomato crops (Velthuis & van Doorn 2006). Because bumble bees show higher activity when weather conditions are cool and cloudy and require less management effort compared with honey bees, their use has been extended to many other crops, such as berries and apples. Nowadays, over a million colonies are annually commercialized all over the world (Velthuis & van Doorn 2006).

Contrasting results have been found in relation to the use of managed pollinators and crop yield. In fact, their contribution might depend on the spatiotemporal variability of wild pollinators in crops. For instance, when the services provided by managed pollinators are estimated in a scenario where wild pollinators are absent, an overall positive effect is found (Roldán Serrano & Guerra-Sanz 2006; Albano, Salvado, Duarte, Mexia, & Borges 2009). However, in a scenario where wild pollinators are present, this relationship can vary. On the one hand, if wild pollinator populations are relatively small and do not complete the required pollination services, managed pollinators can make a significant contribution to crop yield as seen in blueberry (Isaacs & Kirk 2010), raspberry (Lye, Jennings, Osborne, & Goulson 2011) and sunflower crops (Pisanty et al. 2014). On the other hand, if wild pollinator populations are large and diverse, managed pollinators may drop back to a secondary role and supplement the pollination services, which in many cases does not translate into an increased crop yield (Holzschuh, Dudenhöffer, & Tscharntke 2012; Garibaldi et al. 2013; Mallinger & Gratton 2015). But even negative effects, for example in raspberry drupelet set, have been found when non-native bumble bees and also honey bees visit flowers quite frequently (Sáez, Morales, Ramos, & Aizen 2014).

In addition, managed pollinators can also spillover into adjacent natural areas (Ishii, Kadoya, Kikuchi, Suda, & Washitani 2008; González-Varo & Vilà 2017). There, they can compete with native pollinators for floral and nesting resources (Inoue, Yokoyama, & Washitani 2008; Ishii et al. 2008), as well as drive parasite spread into native pollinator populations (Colla, Otterstatter, Gegear, & Thomson 2006; Fürst, McMahon, Osborne, Paxton, & Brown 2014). Furthermore, managed pollinators can disrupt plant-pollinator networks and impact the reproductive success of wild plants (Magrach, González-Varo, Boiffier, Vilà, & Bartomeus 2017).

Huelva province in SW Spain is the second largest producer of strawberries (*Fragaria x ananassa*) in the world (~300,000 t per year; Freshuelva 2016). Farmers typically grow strawberries under semi-open polytunnels for a long period; the flowering period spans from November to May. Many farmers rely on managed pollinators (honey bees and/or bumble bees) to aid crop pollination, because studies have shown that strawberry fruit quality is enhanced when insect-pollinated (e.g. Klatt et al. 2014). In general, honey bee hives are used throughout the entire crop flowering period, while bumble bee colonies are mainly used in winter when it is cold. However, in this region wild pollinators are diverse and abundant in the remaining natural habitats, especially in spring (Magrach et al. 2017).

Our goal in this study was to determine whether strawberry quality increases with the use of commercial bumble bee colonies, and the role of the native strawberry flower visitor community. For this purpose, we placed colonies of *Bombus terrestris* in 12 strawberry plots along a landscape gradient of polytunnel berry crop cover. We surveyed strawberry flower visitors when colonies were both absent and present, and evaluated the pollination services provided during winter (early-January to mid-February), a period when major revenues might be compromised by the scarcity of wild pollinators, and in spring (early-March to mid-April), a period when most wild plants bloom and pollinators are very active in adjacent natural habitats. We addressed the following questions: (a) Does the use of bumble bee colonies affect flower visitation rates in strawberries? (b) Are strawberry flower visitors affected by seasonal differences along a landscape gradient? (c) To what extent does strawberry quality rely on insect-mediated pollination? and (d) Does the use of bumble bee colonies and/or the increase of flower visitors enhance strawberry quality?

Materials and methods

Study system

The study was conducted in the Guadalquivir valley, province of Huelva (SW Spain), in 2016. The climate is typically Mediterranean with hot and dry summers and mild winters. Mean annual temperature and precipitation are 18.2 °C and 525 mm, respectively (AEMET 2016). In the study region, berry crops are quite widespread, especially strawberries (~75% of the area devoted to berry crops; Freshuelva 2016), forming an intermingled mosaic with woodland patches composed of a rich entomophilous understorey that mostly blooms in spring.

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