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Wild bumble bees reduce pollination deficits in a crop mostly visited by managed honey bees

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A B S T R A C T

We assessed the pollinator community of two cultivars of highbush blueberry (*Vaccinium corymbosum*, Duke and Bluecrop), and determined the importance of different pollinators to overall crop yield by measuring pollination deficits. The importance of distance to putative wild pollinator habitat (natural field edges) for pollinator abundance within fields and crop yield was also considered. Managed honey bees made 70% of flower visits (85% to Duke, 49% to Bluecrop). Wild bumble bees made half of the visits to Bluecrop. Though bumble bees were observed less frequently as distance from the natural edge increased, there was no effect of distance on levels of crop pollination. Pollination deficits were less pronounced in Duke than Bluecrop, with maximum (hand) pollination leading to a 12% (Duke) to 23% (Bluecrop) increase in yield. Exclusion of pollinators reduced yield by 50–80% compared to ambient pollination. For both cultivars, pollination deficits declined most strongly with either increasing bumble bee visits or increasing total visits (honey bees and bumble bees combined), and in no case were deficit levels significantly reduced by honey bees alone. This study supports a growing body of literature that suggests managed honey bees alone cannot reduce deficits, and that wild pollinators are needed to maximize yields in pollinator-dependent agricultural systems.

1. Introduction

Over one third of the world's crops rely on animal pollinators for some component of yield (Klein et al., 2007). Pollination of global agriculture has been estimated to value $210 billion (Gallai et al., 2009) and is primarily provided by bees (Free, 1993); both wild (Goulson, 2003; Greenleaf and Kremen, 2006; Kremen et al., 2002) and managed (Mader et al., 2010; Potts et al., 2010).

Honey bees (*Apis mellifera* L.), the most common managed pollinators in modern agriculture (Potts et al., 2010), are often used to maximize pollination and yield (Kearns et al., 1998). Globally, managed honey bee populations have increased by 45% over the last 50 years, but this has not been enough to meet the demand imposed by the simultaneous rapid >300% expansion of pollinator-dependent crops (Aizen and Harder, 2009). Existing managed honey bee populations have also been stressed by various factors including parasitic mites and disease (Potts et al., 2010). Given these challenges to managed honey bee pollination, a greater understanding of the contributions of wild pollinators to agriculture is vital. In this paper we investigate the contributions by both managed and wild pollinators to pollination in highbush blueberry (*Vaccinium corymbosum* L.), a pollinator-dependent crop.

Wild pollinators are known to provide pollination services to many crops (Garibaldi et al., 2013; Kremen et al., 2002), and increases in pollinator diversity have been shown to increase crop yields (canola: Morandin and Winston, 2005; coffee: Klein et al., 2003; watermelons: Kremen et al., 2002). Wild pollinators can provide pollination insurance against poor honey bee performance in bad weather (Javorek et al., 2002), and some crops are almost exclusively pollinated by non-*Apis* pollinators because of specialized pollination needs. Tomatoes and peppers, for example, require their anthers to be sonicated to release pollen, so are pollinated by managed bumble bees in greenhouses because bumble bees are adept at sonicating flowers (Buchmann, 1983); this sonication is termed buzz pollination. Highbush blueberry is also buzz pollinated (Free, 1993), and although honey bees will visit flowers to collect nectar, they may not be the most effective pollinators because they cannot sonicate flowers (Javorek et al., 2002). In highbush blueberry, four visits by a honey bee are required to transfer the same amount of pollen as a single visit by a bumble bee (Dogterom et al., 2000). The greater effectiveness of bumble bees at pollen transfer may explain why the abundance of pan-trapped bumble bees is positively correlated with fruit mass in highbush blueberry in our region (Ratti et al., 2008), where the majority of

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highbush blueberry growers in our region hire managed honey bees in order to facilitate pollination of their crop.

Grassy field margins have been shown to enhance the abundance of wild pollinators within agricultural fields (Marshall et al., 2006), most likely by providing nest sites as well as alternative forage when crops are not in bloom. These resources must be close to agricultural fields for wild bees to contribute to crop pollination, as bees are central-place foragers with limited foraging ranges. For example, solitary bees will travel <300 m from their nests to forage (Zurbuchen et al., 2010) whereas bumble bees will travel between 500 m and 1.75 km (Walther-Hellwig and Frankl, 2000). We therefore predict that wild bee abundance may be higher toward the edges of fields (where nest sites and alternative foraging resources are available) than at increasing distances into fields, and that this may translate into differences in yield from edge to center.

Pollen supplementation experiments are often used in wild plants to measure the extent reproductive output are limited by pollen delivery (Knight et al., 2005). A pollination deficit is inferred when pollen-supplemented flowers or plants have higher fruit set, seeds per fruit, or larger fruit than those exposed to ambient pollination conditions. Pollination deficits are well documented in 63% of 482 wild plant species examined (Knight et al., 2005). In contrast, less research has been performed on crop species: 59% of only 17 examined crop species experienced deficits (Mayfield, 1998). In agricultural systems, high pollination deficits equate to lowered yields and can mean substantial economic consequences for the grower, and so crop pollination deficits should be examined more frequently.

In this study we observed and trapped potential pollinators of highbush blueberry and experimentally estimated pollination deficits to investigate the following questions: (1) what are the pollinators of highbush blueberry in our region? (2) is there a pollination deficit in highbush blueberry? and (3) is pollination deficit reduced with increasing pollinator visits? Crop cultivars vary in self- and cross-fertility (Dogterom et al., 2000; Ehlenfeldt, 2001), blooming period (Bożek, 2009), and in the case of highbush blueberry, flower size and shape (Courcelles et al., 2013), all of which have the potential to influence pollinator visit patterns. To account for these differences we chose to study two widely grown cultivars of highbush blueberry: Duke, and Bluecrop. We also consider the importance of distance from the natural field edge for pollinator visits and pollination deficits. Finally we translate deficits into economic values which are useful for stakeholders in industry.

2. Methods

British Columbia (BC) produces 56% of Canada's blueberries (Statistics Canada, 2012) and is one of the top three blueberry producing regions in the world (British Columbia Ministry of Agriculture, 2011), generating $83 million in sales for blueberries in 2010 (Statistics Canada, 2012). Temporally variable factors like weather have been shown to influence the pollinator community and aspects of highbush blueberry yield such as fruit weight (Tuell and Isaacs, 2010), so we conducted our study across two consecutive field seasons in 2011 and 2012, and included fields across the growing region of blueberries in BC. We included 14 fields of cv. Bluecrop and 12 fields of cv. Duke. Duke has a slightly earlier (a few days) but mostly overlapping blooming period with Bluecrop, but berries take less time to ripen (Ehlenfeldt and Martin, 2010). Duke flowers are also larger than Bluecrop flowers (wider and longer corollas), which increases access by relatively short-tongued honey bees to nectar, affecting pollinator visit rates (Courcelles et al., 2013). In general, the blueberry bloom in our study area lasts about three weeks; mid-May to mid-June. The 26 study fields were located within 16 farms in BC's lower mainland; these farms were on average 4.2 km (min 2 km, max 8.3 km) from the nearest farm also included in the study. Ten farms had fields of both cultivars. For each field we determined the "most natural edge" as the one apparently containing the most non-crop forage and, potentially, nesting habitat, as opposed to field edges on farm roads or abutting another cultivar. To determine whether distance from the natural edge affected the pollinator community and measures of crop yield, sampling was conducted along three 100 m long transects parallel to and at three distances from the natural edge (0, 50, and 100 m).

2.1. Pollinator community composition

We assessed the pollinator community both observationally (insects visiting flowers) and with pan traps (passively collecting insects present in the fields) during the approximately three week period of blueberry bloom.

Each 100 m long transect was divided into ten, 10 m intervals. Pollinators were observed on one randomly selected bush within each 10 m interval for 1 min, meaning 10 min of observation per distance and observation date. Only insects that entered the flower legitimately (through the corolla opening) and apparently contacted the stigma were counted as pollinators, and we recorded the total number of flowers visited (visit rate).

Honey bees (*A. mellifera*) and bumble bees (*Bombus* spp.) were identified to species on the wing. Other insects, which can only be identified to species upon close examination, were grouped into mason bees (*Osmia* spp.), flies (almost exclusively Syrphidae), "tiny bees" (mostly *Ceratina* spp., *Halictus confusus* (Smith) or *H. tripartitus* (Cockerell), and *Lasioglossum* (*Dialictus*) spp.), "other bees" (mid-sized species, mostly *Lasioglossum (Lasioglossum* or *Evylaeus)* spp., *Halictus rubicundus* (Christ) or *Andrena* spp.) or wasps. Observations were limited to days in which weather patterns were conducive to pollinator activity (days with full or part sun, temperatures above 13 °C, and non-windy conditions) and alternated among am, midday, and pm. The total number of observation dates differed each year, with 3–4 per field in 2011 and 2–3 in 2012, due to variation in the number of days with weather conducive to pollinator activity.

We used pan traps in 2011 to assess the community of insects available to pollinate blueberry. Nine wooden stakes were placed within each of the three, 100 m transects in each field, with a single stake every 10 m. Stakes were placed among the bushes with the tops embedded within the canopy, and green pans were stapled to the tops. In order to control potential color bias based on pollinator acuity and preference (Vrdoljak and Samways, 2011), we used three pan trap colors (white, yellow, and blue). Pans were filled with soapy water and placed in regular order on top of the green pans within the field to collect flying insects within the blueberry canopy. Pan trapping was conducted twice per field during blueberry bloom (e.g., within the same three weeks period observations were performed), with at least one week between sample collections, in fair weather conditions for a minimum of 7 h in order to capture potential pollinators. One pan of each color (white, yellow, and blue) was collected into a single sample, resulting in three samples per transect. Insects were stored in 75% alcohol for later pinning and identification to species.

2.2. Pollination deficit experiments

To determine if fruit production was limited by pollination, we conducted hand pollination experiments at all fields in both years. Bushes were randomly selected within the 10 intervals in each transect described earlier. Two canes with similar phenology, flower number, and length were selected and designated as either control (open to ambient pollination) or supplemented (open to ambient pollination and supplemented by hand with pollen of the same