Relative abundance and movement of flower visitors within 'Black Doris' plum orchards in Hawke's Bay, New Zealand

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Abstract The Japanese plum 'Black Doris' (*Prunus salicina*) is a self-infertile early-flowering crop so insufficient cross pollination and lack of pollinators could be factors to explain reported poor fruit set. This project assessed the relative abundance of flower visitors within a plum orchard and their movements among three orchards, as part of a wider study on plum pollination. Insect surveys conducted over three days across one orchard in 2014 identified a total of 479 individual pollinators. Honey bees represented 94.6% of all pollinators observed. To assess pollinator movement across the crop, 140 individual flower visitors were followed over a five-day period in 2014 and again in 2015 across three orchards. Bumble bees moved further within the orchard and visited more trees per minute than foraging honey bees, while silveryeyes visited more than twice as many flowers per minute than any other insect flower visitor.

Keywords plums, honey bees, bumble bees, flies, pollination.

INTRODUCTION

There are two main types of plum, European and Japanese. The 'Black Doris' cultivar is a form of Japanese plum (*Prunus salicina*) that originates from China, where it has been cultivated for thousands of years. It is a self-infertile diploid ($2n = 16$) species. Most cultivars grown today are from selections from Japan, where it is also an ancient crop (Faust & Surányi 1999; Guerra & Rodrigo 2015; Yoshida 1987).

Poor fruit set has been reported in 'Black Doris' orchards in Hawke's Bay, with some growers reporting significantly higher crop loads in orchards where commercial bumble bee colonies were introduced (B. Mackay, pers.

comm.). However, the precise cause and degree of pollen limitation of fruit set has not yet been determined, and poor pollinator performance could be a factor during the short (typically less than two weeks) late winter/early spring flowering period.

Pollinator activity may differ among years because of weather conditions and the timing of flowering due to the effects of winter chilling on bud break. Pollinators, especially European honey bees (*Apis mellifera*), show a preference for other competing flora, which they find more attractive than Japanese plums (Free 1993). Sapir et al. (2007) recommended that an activity rate of

7–8 honey bees/tree/minute is required to ensure a higher rate of fruit set and improved yield in Japanese plums. The resulting fruit yield depends on the number of flower visits: one study reported a requirement of 3–5 honey bee visits to a plum flower to produce a fruit (Benachour & Louadi 2013). It also depends on pollen deposition efficiency. Pollen deposition efficiency is based on the number of compatible pollen grains deposited per visit, but also depends on the correct cross-pollen being deposited, rather than self-pollen.

Other pollinator species may differ from honey bees in both their efficiency and their visitation rate. Observations of pollinator foraging behaviour, rates of stigma contact, and preferences for pollen/nectar sources provide useful information for assessing potentially important pollinators.

To help to determine the key pollinators of 'Black Doris' plums in New Zealand, we assessed the relative abundance of different flower visitors in orchards, and their movements through the orchard while foraging.

MATERIALS AND METHODS

Study sites

This investigation was carried out on three plum orchards located near Hastings, Hawke's Bay. One plum orchard (A) was used for the insect surveys between 10 and 12 September 2014 and three plum orchards (A, B and C) were chosen for the rate of insect movement between flowers and trees over two consecutive years: between 8 and 12 September 2014 and between 2 and 6 September 2015. The orchards all had a stocking rate of eight honey bee hives per hectare for the flowering periods.

In 2014, Bee-Scent™ (a pheromone-based liquid attractant) was applied at 5 litres/ha, as standard practice at Orchard A, to all plum trees on 4 September when 10% of flowers were in bloom and on 10 September when 50% were in bloom. Weather data, including air temperature, were collected using the grower's on-site weather station.

Insect surveys

Insect counts were conducted by three people over periods of approximately ten minutes by walking around 17 trees in a row at three time periods: between 1000–1100 h, 1200–1300 h and 1400–1500 h in Orchard A. The surveys were conducted at three locations within the orchard, in a line from two opposing corners i.e. geographic direction N-S and E-W, and in the centre. Stopwatches were used to note the exact time of survey for each period and the number of trees observed was recorded. Surveys were conducted on three days: 10, 11 and 12 September 2014, so there were 27 insect counts in total representing approximately 270 minutes of observation time.

Rate of movement between flowers and trees

Pollinator movement among flowers and trees was collected from Orchards A, B, and C in two consecutive years; between 8 and 12 September 2014 and between 2 and 6 September 2015. Data were collected at varying times of the day, between 0924–1535 h and the recording period varied in each case as recording ceased once the pollinator was lost or a maximum 15 minutes observation time was reached. Four people collected data, which was documented using audio recorders while following the flower-visiting insect or bird (*Zosterops lateralis*; silvereye). Observers walked through the orchard until a flower visitor was located. The flower visitor was then followed, until it moved too far out of range for accurate observation (i.e. inability to distinguish movement between flowers). The information recorded for each observation included: time of day, date, the orchard block, insect species followed, flower visiting behaviour (defined below), and an estimate of distance travelled between trees. Verbal codes were used to annotate the flower visiting behaviour, including movements between flowers, movement between inflorescences and movement between trees. The mean number of flowers visited per minute of foraging, the mean number of trees visited per minute of foraging, and the mean distance (m) travelled per minute of foraging were then calculated.

Pollinators were classified into one of four groups (honey bees, bumble bees, flies and silvereyes) for analysis because of low sample sizes for many individual species. One-way ANOVAs were conducted to test for differences among pollinator groups for each variable assessed multiple comparisons were conducted using Student's t-tests with an initial $\alpha=0.05$ corrected using the Bonferroni method to 0.0083.

RESULTS

Insect surveys

A total of 479 individual pollinators were observed over the three survey days in Orchard A. European honey bees were the most abundant ($n=454$), followed by the buff-tailed bumble bee (*Bombus terrestris*) ($n=10$), with the remaining pollinators comprising flies; Calliphoridae ($n=5$), Syrphidae ($n=9$) and Bibionidae ($n=1$). Honey bees represented 94.6% of all pollinators observed over the three days.

The highest number of honey bees (40.7%, $n=185$) were observed on the first day, when the attractant Bee-Scent™ was applied. Fewer honey bees (24.1%, $n=109$) were observed on the second day. Numbers increased on the third day (35.2%, $n=160$) compared to the second day but did not reach the same level as the first day. This equates to a rate of less than one honey bee/tree/minute. There was no trend in honey bee or any other pollinator numbers and activity due to time of day, temperature or location in the orchard. Over the three days, the temperature ranged from: 12.3 to 15.3°C at 1000–1100 h; 12.7–15.4°C at 1200–1300 h; and 14.3–15.5°C at 1400–1500 h. The temperature progressively increased during each day and from one day to the next.

Rate of movement between flowers and trees

Observations were made of the movements of 83 honey bees with a mean ($\pm$ SEM) observation duration of 209 ± 31 s, 30 bumble bees (108 ± 24 s observation duration), 14 flies (218 ± 52 s observation duration), and three silvereyes (86 ± 19 s observation duration), for the eight days of data collection (three days in 2014 and five in 2015). There were significant differences

among pollinator groups for the numbers of flowers visited per minute ($P<0.001$, $F=23.39$), the numbers of trees visited ($P=0.0012$, $F=5.59$), and the distance travelled ($P=0.001$, $F=5.75$). Silvereyes visited more than twice as many flowers as bumble bees and honey bees, while flies visited the fewest flowers per minute of foraging (Figure 1A). Bumble bees visited significantly more trees per minute (Figure 1B), and travelled further (Figure 1C), than honey bees, but because of small sample sizes, other apparent differences between pollinator groups were not statistically significant using the conservative Bonferroni correction method.

DISCUSSION

European honey bees were the dominant flower visitors, with low numbers of other species. The orchards all had honey-bee hives, which is likely to have driven the relatively high abundance of this species on flowers. However, the observed activity of less than one honey bee/tree/minute is beneath the recommended activity rate of seven honey bees/tree/minute that Sapir et al. (2007) proposed for improved fruit set and fruit yield. This result suggests that further research into improving pollination for this crop is warranted.

This high relative abundance of honey bees, compared with other flower visitors, does not necessarily imply relative importance, as pollinator species can vary in the amount of compatible pollen they deposit on flowers in each visit. An important determinant of the efficiency in depositing compatible pollen is the probability that each individual crosses from a polliniser cultivar to the main fruiting cultivar within a foraging trip. This can be approximated by assessing the movement of individuals through orchards.

Pollinators were placed into broad groups because of the low abundance of flower visitors: we were not able to analyse pollinator movements by species. This may hide some inter-specific variability in performance, especially for flies. Although these experiments are time consuming, further trials replicating these methods will help to build sufficient sample sizes for individual

Figure 1 Mean number of flowers visited (A), mean number of trees visited (B) and mean distance travelled (C) per minute of foraging, for each of four pollinator groups in three plum orchards in Hawke's Bay over consecutive days (8–12 September 2014 and 2–7 September 2015). Error bars indicate standard error of the mean (SEM). Lower case letters indicate significant differences (Bonferroni-corrected $\alpha=0.0083$) between pollinator groups from multiple pairwise Student's *t*-tests.

species in subsequent years. Further work would also allow for species-level analysis to be conducted as has been achieved for other crops (Rader et al. 2009; Howlett et al. 2013).

Despite the lack of species-level resolution for the flies, there were significant differences in movement patterns of the pollinator groups. Bumble bees and honey bees visited flowers at a similar rate, but bumble bees moved over further distances and between trees more frequently. This could not be explained as an artefact of observation durations, as bumblebees (and silvereyes), were observed for shorter periods than flies or honey bees mostly due to their tendency to fly long distances within the orchard rapidly. The ability of bumble bees to deliver least as much pollen to stigmas as honey bees has been demonstrated in other crops in New Zealand (Rader et al. 2009; Howlett et al. 2011; Howlett et al. 2017). If this holds true for plums then bumble bees are likely to contribute an equivalent amount to pollination as honey bees even at lower densities. Studies to quantify the relationship between bumble bee visits to flowers and bumble-bee colony densities could lead to recommendations on bumble-bee colony stocking rates.

These findings also point to the potential benefits of increasing the abundance of diverse flower visitors, as even flies showed similar movement rates to honey bees between trees. In New Zealand, calliphorid and syrphid flies are known to be effective pollinators of other crops (Rader et al. 2009; Howlett 2012). Moreover, calliphorids will forage under cool, low light conditions that are not preferred by honey bees (Howlett et al. 2013), and are active throughout all seasons of the year (Howlett et al. 2016). Increased abundance of all these flower visitor species will increase pollen transfer in the orchard and thus increase the likelihood of high cross pollination rates. An assessment of the amounts of compatible pollen deposited by these different species will allow a comparison of their effectiveness as pollinators.

Silveryeyes visited flowers at a much higher rate than other visitors, and although relatively rare, they may make a significant contribution to pollination of 'Black Doris' in the orchards they visit. Silveryeyes

can be important pollinators, including of native plants (Pattamore & Wilcove 2012). This study was focused on insect pollinators, and the methods used were not appropriate for assessing pollination by birds. The methods used in the current study would have reduced the apparent effectiveness of bird flower visitors, as observers were likely to have disturbed their behaviour. The high flower visitation rate and fast movement of silvereyes through the orchard suggests they could be important pollinators if they are abundant, regular visitors in the orchards. Being warm-blooded vertebrates, they could make a significant contribution during inclement weather. Further study is required to assess the potential contribution of these birds to the pollination of 'Black Doris' and other crops.

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