Diurnal insect visitation patterns to ‘Hayward’ kiwifruit flowers in New Zealand

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Abstract Different pollinators may vary in their temporal flower-visitation patterns within crops, potentially extending the period pollination may occur. To assess whether this could be the case in kiwifruit, we conducted standardised observational surveys of insects visiting kiwifruit flowers within 31 orchards at three times: 10:00–11:00, 12:00–13:00 and 14:00–15:00 hr. Honey bees (*Apis mellifera*) represented 92% of visitations (n=5474), but temporal abundances were uneven (predicted abundances were lower at 14:00–15:00 hr). Predatory hover flies (*Melangyna*, *Melonostoma*, *Allograpta* spp.) also showed an uneven temporal pattern. There were no significant differences in the temporal abundances for buff-tailed bumble bees (*Bombus terrestris*), rat-tailed hover flies (*Eristalis*, *Helophilus* spp.), March flies (*Dilophis nigrostigma*), flower longhorn beetles (*Zorion guttigerum*) or the native bees (*Leioproctus* and *Lasioglossum* spp.) although, in some cases, low numbers may have masked potential unevenness trends. Variation in diurnal flower-visitation patterns among insects suggests the potential for complementarity between different pollinators.

Keywords kiwifruit pollination, pollinator diversity, wild pollinators, pollinator complementarity, crop pollinators, flower visitation, fly pollination, non-bee pollinators, pollinator activity.

INTRODUCTION

The presence of wild pollinating species in addition to managed honey bees is considered important for increasing yields for many crops (Garibaldi et al. 2013). Differing, and potentially complementary, diurnal activity patterns among different pollinating species may be one factor that improves crop pollination. In Spain, bumble bees (*Bombus* spp.) could be considered

complementary pollinators to honey bees (*Apis mellifera*) in kiwifruit (*Actinidia chinensis* var. *deliciosa*) orchards because they are more likely to visit and pollinate flowers earlier in the morning (Miñarro & Twizell 2015). In New Zealand, over 150 insect species have been recorded visiting kiwifruit flowers (Macfarlane & Ferguson 1983), with honey bees, bumble bees and native

Leioproctus bees (*Leioproctus* spp.) considered the most efficient pollinators (Macfarlane & Ferguson 1983). Elsewhere, non-bee insects such as flies, beetles and butterflies have also been implicated in kiwifruit pollination (Miñarro & Twizell 2015).

Although various insects may contribute to kiwifruit pollination, there is a lack of published data assessing diurnal flower visitation patterns of these various flower-visiting insects in New Zealand orchards. For vegetable seed crops grown in New Zealand, honey bees, other bees and non-bee pollinators can vary in their flower visitation times (Howlett et al. 2013a; Rader et al. 2013). Some of this fluctuation may be because of differences in weather variables such as temperature and light intensity (Howlett 2012; Howlett et al. 2013a) but peak activity within species may also vary depending on crop species. For example, in kiwifruit, peak honey bee foraging activity on flowers in New Zealand orchards has been noted to occur during the late morning (10:00–11:00) (Goodwin & Haine 1995), whereas for pak choi (*Brassica rapa* var. *chinensis*) and onion (*Allium cepa*), abundances tended to peak around 12:00 (Howlett et al. 2013a). The potential for variation in the diurnal activity of different pollinators between crops emphasises the need to further assess such activity for each crop species.

New Zealand 'Hayward' kiwifruit orchards across three regions: Bay of Plenty, Gisborne and Hawke's Bay were surveyed to assess diurnal visitation patterns of flower visiting species (honey bees, bumble bees, native bees and non-bee insects) by comparing their abundances during the day at 10:00–11:00, 12:00–13:00 and 14:00–15:00. Whether or not the presence of wild pollinating species across these times could complement honey bees as pollinators of kiwifruit by being relatively more abundant at different times is then discussed.

MATERIALS AND METHODS

Surveys were conducted across 31 'Hayward' orchard blocks with fourteen orchards located in the Bay of Plenty within a 100-km radius of Katikati (37°33'S 175°55'E), eight within 50 km of Gisborne (38° 40'S, 178° 01'E) and nine in

Hawke's Bay within a 50-km radius of Hastings (39° 39' S, 176° 50' E). Twenty-seven orchards were survey in October 2014 across all regions and a further four were surveyed in the Bay of Plenty in October 2015. Six trained staff were employed to survey orchards in 2014 and four staff in 2015. Staff were initially trained in an early-flowering orchard over a two-day period to standardise methodology and all staff surveyed multiple orchards. Each block was surveyed for one hour at three times throughout the day starting at 10:00, 12:00 and 14:00 under fine weather conditions (15–30°C) and average wind speed below 15 km/h (measured using a Silva Windwatch).

Standardised observational surveys were used across all orchard blocks to record flower-visiting insect taxa visiting fully open kiwifruit flowers. Flowers on 'Hayward' female vines were assessed by walking four sets of transects throughout the block, while flowers from four male vines (various varieties) neighbouring the female vine transects were also assessed.

Within-row transects were positioned diagonally and equidistantly across each block, with two transects located in opposing corners and two inside the block. Each 'Hayward' transect was 20 m long and between 1.2 m and 1.4 m in width (determined by the distance between supporting trellis wires) and each transect observed flowers from multiple vines. All orchards contained male vines, evenly spaced throughout orchard blocks. The nearest flowering vine to each 'Hayward' vine transect was chosen to survey. The survey length was 3.6 m (1.8 m on each side of the vine trunk) and the width was 0.4 m.

To standardise counts of flower visitors within each 'Hayward' and male vine transect areas, we estimated flower visitor numbers per 100 flowers. For 'Hayward' transects, flower counts were conducted within three square quadrats (area 0.81 m²) spaced at 5 m, 10 m and 15 m along the transect length and equidistantly placed between the transect width. The number of flower visitors per 100 flowers was then estimated for each transect by using flower visitor count by the estimated number of flowers across each transect area (calculated by the dimensions of each specific transect). For

male vines, flower counts were conducted within two rectangular quadrats of area of 0.36 m² (0.9 m length x 0.4 m wide). Each transect was positioned either side of the vine trunk to incorporate flowers between 0.9 m to 1.8 m from the trunk., that were then counted. As with the Hayward transects, quadrat counts were used to estimate the number of flowers within each male vine transect, from which the estimated number of flowers visitors per 100 flowers could be estimated.

At the beginning of each survey period the ambient temperature (°C) was recorded using a Thermo-Hydro recorder. Light intensity (irradiance) Watts (W)/m² was also measured using a Daystar meter directed toward the sun.

A preliminary assessment of the data indicated that most wild pollinating species were present in very low abundances. For hover flies (Syrphidae), the abundances of the more closely related species were summed together into two broader groupings. These were predatory hover flies (subfamily: Syrphinae) [*Melangyna novaezealandiae*, *Melanostoma fasciatum* and *Allograpta dorsalis*], and rat-tailed hover flies (subfamily: Eristalinae) [*Eristalis tenax*, *Helophilus hochstetteri*, *Helophilus seelandica*]. For Lasioglossum bees, there are two known species present in the North Island, *Lasioglossum sordidum* and *L. cognatum* (Donovan 2007), but it was not possible to distinguish between these visually. Leioproctus bees (*Leioproctus* spp.) were identified to genus-level only.

A nested-model comparison was undertaken to assess whether the diurnal visitation pattern for different flower-visiting taxa was similar across the three survey times. Maximum likelihood fitting of a mixed-effect model was conducted using the R package lme, with and without the effect of time. Region and orchard were considered random effects in the model. Sex of the flower and year were kept as fixed effects in the model. Model fitting was checked using diagnostic plots. Significance of the nested model comparison was then tested against a Chi-square distribution.

RESULTS

A total of 5934 insects were observed visiting kiwifruit flowers across all surveys. Honey bees

were the most abundant flower visitor seen, representing 92.2% of all insects observed. Their abundances were similarly dominant across all regions (Bay of Plenty 93.0%, *n*=4310; Gisborne 87.0%, *n*=616; Hawke's Bay 92.9%, *n*=548). The next most common taxa were: flower longhorn beetles (*Zorion guttigerum*) 2.22%; predatory hover flies 1.07%; native Lasioglossum bees, 1.05%; buff-tailed bumble bees (*Bombus terrestris*) 0.77%; March flies (*Dilophis nigrostigma*) 0.59%; native Leioproctus bees 0.47%; and rat-tail hover flies 0.42%.

Diurnal visitation patterns

Honey bees and predatory hover flies showed significant differences in their relative visitation to kiwifruit flowers over the three surveyed time periods (Table 1). For these two pollinator groups, the modelled data indicated that abundances on flowers are predicted to be higher at 10:00–11:00 and 12:00–13:00 relative to 14:00–15:00 (Figure 1). No significant differences were found for the other insect groups (Table 1, Figure 1); however, the low counts for some taxa within and across orchards may have hidden trends that may have become more apparent if higher counts across orchards were obtained.

Table 1 Analysis of deviance table testing significance of time effect for each pollinator group on number of visits per 100 kiwifruit flowers. Significance of the nested model comparison was tested against a Chi-square distribution.

Taxonomic grouping	Statistic Chi	Df	p-value
Honey bees	93.7	2	<0.001
Lasioglossum bees	4.9	2	0.086
Leioproctus bees	5.3	2	0.072
Buff-tailed bumble bees	0.8	2	0.670
Predatory hover flies	11.3	2	0.004
Rat-tail hover flies	1.1	2	0.570
March flies	0.8	2	0.670
Flower longhorn beetles	0.1	2	0.970

Figure 1 Predicted means and 95% confidence limits of the number of visits per 100 kiwifruit flowers (females and males) at the three time periods for each of the major pollinator groups. Means and confidence limits are predicted from a mixed effects linear model with region and orchard as fixed effects.

Weather during survey periods

The mean ($\pm$ S.D) temperature across all surveys increased from morning to afternoon (10:00: $21.6^{\circ}\text{C} \pm 2.4$; 12:00: $23.7^{\circ}\text{C} \pm 2.6$; 14:00: $24.2^{\circ}\text{C} \pm 2.4$). Mean light intensity (irradiance) (W/m^2) was highest at 12:00 (10:00: $662.2 \text{ W}/\text{m}^2 \pm 397.1$; 12:00: $766.7 \text{ W}/\text{m}^2 \pm 355.5$; 14:00: $755.3 \text{ W}/\text{m}^2 \pm 383.2$).

DISCUSSION

Honey bees and other flower-visiting insects can vary significantly in their pattern of abundances throughout the day in kiwifruit orchards, although the patterns do not appear to be consistent across all flower-visiting taxa. As some of these flower visiting (or closely related) taxa are considered pollinators of kiwifruit (Macfarlane & Ferguson 1983; Miñarro & Twizell 2015), there may be potential for different pollinating species to provide complementary roles. This result supports the findings of Rader et al. (2013), who found that different pollinating species were likely to provide complementary pollination in *Brassica rapa* because of variation in their diurnal activity patterns.

The dominance of honey bees within the surveyed kiwifruit orchards suggests, however, that wild pollinators are currently contributing minor pollination services, at least during our survey period (10:00 to 15:00 hr). The dominance of honey bees relative to other species is consistent with some New Zealand crops, e.g. avocado (*Persea americana*) (Read et al. 2017) and plum (*Prunus salicina*) (McBrydie et al. 2017) but not others, e.g. onion and pak choi (Howlett et al. 2009). Some wild flower-visiting taxa, such as flower longhorn beetles, and buff-tailed bumble bees remained relatively abundant during the afternoon. In contrast, the numbers of honey bees visiting flowers are typically declining during this period of time. Therefore, it is possible that these taxa have the potential to further complement honey bee pollination if present in substantially increased numbers.

The effectiveness of the various flower-visiting taxa as pollinators and whether their visitation patterns could influence yield were not examined in the current study. However, studies on the floral biology of ‘Hayward’ kiwifruit highlight the need for the delivery of many viable pollen grains (>2000 grains) to maximise fruit size (Hii 2004 and references within). The delivery of adequate pollen to achieve fruit size of export marketable quality may be achieved through multiple insect visits (Goodwin & Haine 1995), potentially delivered across multiple days (Goodwin & Ten Houten 1989), as the stigma remains receptive for up to 4

days (Gonzalez et al. 1995). The presence of wild pollinating species that complement honey bees through their different diurnal flower visitation patterns could add to kiwifruit pollination, particularly by delivering additional pollen to stigmas beyond the period of peak honey bee diurnal activity.

The variation in activity patterns among different pollinating species throughout the day may be at least partly due to differences in responses to weather variability. Buff-tailed bumble bees and certain fly species, for example, will readily forage under cooler temperatures and lower light conditions compared with honey bees (Howlett et al. 2013a), and this behaviour may explain the earlier morning visitation of bumble bees to kiwifruit flowers compared with honey bees in Spanish orchards (Miñarro & Twizell 2015). However, in this study, the variation in diurnal weather (temperature and light intensity were, on average, lower in morning surveys) across orchards did not clearly match with the higher morning abundance of honey bees, suggesting other factors may be more influential in their activity patterns. Goodwin (1995) suggested that the peak morning activity of honey bees in kiwifruit orchards matches peak pollen availability. Moreover, in New Zealand, there appears to be inconsistency in the diurnal activity of honey bees among crops. For example, in brassica fields, honey bee activity was observed to peak around midday (Rader et al. 2013), while in flowering carrot (*Daucus carota*) fields, peak activity was observed in the afternoon (Howlett et al. 2015). These variations in pollinator diurnal activity among crops demonstrate an inability to attribute any of our measured variables as overarching factors that can be used to predict pollinator diurnal activity patterns across crops.

Because of the scarcity of many wild flower-visiting species, the diurnal activity of only a small number of taxa were able to be assessed in the current study. Moreover, several of the species were pooled into broader taxonomic categories (e.g. the hover flies) because of the low number of individuals within species. The broader categorisation of species may, therefore, have masked species-specific trends. However, it was still

possible to detect variation in the diurnal activity between some categorised pollinator taxa that could potentially influence pollen delivery patterns to flowers.

These findings point to the overall dominant role that honey bees provide as insect pollinators of kiwifruit in New Zealand (at least during the limited periods of the current surveys). Elsewhere, other flower-visiting species can represent a much higher proportion of flower visitors. For example, many flies visit kiwifruit orchards in India (approximately 20% of all visitors were reportedly syrphid flies) (Sharma et al. 2013), while in Spain, 57% of kiwifruit flower visitors were species other than honey bees (Miñarro & Twizell 2015). The reasons why the abundances of non-honey bee flower visitors were low in New Zealand orchards were not explored. Factors known to positively influence their occurrence within various crops include close proximity to native bushland, and the proximity of suitable nesting or rearing sites (Bailey et al. 2014). It remains unknown how these variables might influence the occurrence and abundance of non-honey bee flower visitors in New Zealand kiwifruit orchards. However, there may be potential to increase abundances by focusing on practices to promote wild pollinators such as through the establishment of supporting habitat (Howlett et al. 2013b) or through management of specific species in addition to honey bees (Donovan et al. 2010; Howlett 2012).

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