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Diversity patterns of wild bees in almond orchards and their surrounding landscape

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ABSTRACT

Insect pollination is essential for almond production, and most growers rely exclusively on honeybees for pollination. However, the number of honeybee hives has declined drastically over the last few decades and their efficiency in pollinating almond might be limited. Wild bee communities inhabiting the habitats surrounding almond orchards may provide significant pollination services to almond, but this has yet to be studied. In this preliminary investigation, we looked at spatial diversity patterns of wild bees in almond orchards and their surrounding landscape. The study was conducted in the Judean Foothills, a region with a Mediterranean ecosystem in central Israel, during almond bloom in 2008. We sampled bees and blooming plants in natural habitats, almond orchards, a weedy orchard (where wild flowers had been allowed to grow), and the margin between orchard and natural habitat. The margin and natural habitats had a significantly higher abundance of wild bees compared to the orchard, while the weedy orchard showed intermediate abundances. No significant differences were found among habitats in the number of wild bee genera, but there were significant differences in genera composition between the natural and orchard habitats. Honeybees were the main bee visitor to almond flowers. Nevertheless, the diverse and abundant wild bee community surrounding the orchards warrants further investigation of their role as almond pollinators.

Keywords: almond, biodiversity conservation, ecosystem service, pollination, wild bee

INTRODUCTION

Almond (*Prunus dulcis* Mill.) requires insect pollination to set fruit and has extremely high pollination requirements for commercial production (Lumkin, 2005). Most almond growers rely on rented honeybee (*Apis mellifera* L.) hives as the sole source of pollination (Delaplane and Mayer, 2000). However, reliance on a single pollinator species is generally risky, as crop pollination is vulnerable to species-specific declines due to, for example, parasites and disease (Winfree et al., 2007a). As a case in point, the number of honeybee hives has drastically declined in Israel and abroad in the last few decades due to parasitic mites and other reasons (Committee on the Status of Pollinators in North America, 2007; Efrat et al., 2007). Moreover, the recent emergence of "Colony Collapse Disorder" has caused unprecedented losses of up to 75% of hives in parts of the US and other countries for reasons that are not yet fully understood (Stokstad, 2007).

The risk of relying on honeybees as a sole pollinator is further augmented in almond as it blooms in early spring (end of January to early March in Israel), when weather conditions might reduce honeybee activity and pollination efficiency (Michael and Eisikowitch, 1995). Furthermore, the honeybees' flight pattern runs along, rather than between rows, and may limit cross-pollina-

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tion (the main variety and the pollinizer are usually planted in alternating rows so that cross-pollination requires pollen transfer between rows; Ish-Am, 1996; but see Degrandi-Hoffman et al., 1992). All these problems decrease the pollination efficiency of honeybees on almond. Consequently, in many cases honeybees fail to provide optimal pollination services for almond (Dag et al., 2006), and there is growing concern over the possibility of pollination shortages in the almond industry (Committee on the Status of Pollinators in North America, 2007).

These problems have led to the search for additional pollinators to supplement honeybee pollination in almond orchards. *Osmia cornuta* Lat. (Bosch, 1994; Bosch and Blas, 1994) and *Bombus terrestris* L. (Dag et al., 2006; D. Weil, pers. comm.) have been applied with some success, though their activity declined strongly with distance from the hive. Wild bee communities inhabiting natural habitats that surround almond orchards may provide significant pollination services as some wild bee species have higher pollination efficiency of almond compared to honeybees (Free, 1993, and references therein). Many wild bees, especially large species like bumblebees, are active also during cold and inclement weather, when honeybees are usually not active (Free, 1993, and references therein). Indeed, studies conducted in the Jerusalem Mountains, close to the location of the present study (Judean Foothills), found large, wild bees active during early spring and foraging on almond flowers (Bar-Shay, 1995) and on mint flowers (Shmida and Dukas, 1990). Furthermore, most of the non-*Apis* species are generally considered non-susceptible to many of *A. mellifera*'s parasites and diseases (Winfree et al., 2007a).

There are over 17,000 described bee species worldwide (Michener, 2007), many of which visit crops and contribute to agricultural production (reviewed by Klein et al., 2007). Animal pollination, provided mainly by bees, accounts for 35% of global food production (Klein et al., 2007). Some studies have found wild bees to be more efficient pollinators than honeybees under favorable environmental conditions, e.g., close to patches of natural habitat (Kevan et al., 1990; Kremen et al., 2002). Wild bee community composition and abundance are greatly affected by land-use characteristics on a local (orchard/field) and landscape scale (Ricketts et al., 2008). While many researchers have found that loss of natural habitat adversely affects wild bee populations (e.g., Steffan-Dewenter et al., 2001; Klein et al., 2003; Kremen et al., 2004; Ricketts et al., 2004), some have found that certain forms of human disturbance increase the number of wild pollinator species and their abundance (Westphal et al., 2003; Winfree et al., 2007b). Investigating the distribution of wild pollinators across habitats in agro-natural landscapes is an essential first step in evaluating their potential as crop pollinators.

Israel is considered a global hot-spot of bee diversity due to its exceptionally high environmental heterogeneity (Dafni and O'Toole, 1994; Michener, 2007; but see Roll et al., 2009). However, the contribution of wild bees to crop pollination has received very limited attention. Some studies have looked into the role of *Xylocopa* as a greenhouse pollinator (Shmida et al., 2005; Sadeh et al., 2007), but the potential pollination services provided by species-rich wild bee communities to agriculture have never been studied in Israel. In this preliminary study, we looked into diversity patterns of wild bees in almond orchards and their surrounding landscape during almond bloom to establish their potential role as almond pollinators. We asked: (1) Are wild bees present in almond orchards during the blooming period in early spring? If so, (2) do wild bees visit almond flowers? What is the proportion of wild bees vs. commercial bees (honeybees and bumblebees) as visitors, hence potential pollinators, of almond flowers? (3) Are wild bees affected by local (orchard) and landscape-scale land-use practices?

METHODS

Study system

The research was conducted in the Judean Foothills, a region with a Mediterranean ecosystem in central Israel where almond production is a growing commodity (Birger, 2003). We worked in two sites that were approximately 14 km apart: Kfar Menachem, an almond orchard occupying ca. 160 ha with 2- to 6-year-old trees, and Netiv Halamed Hey, an almond orchard occupying ca. 56 ha with trees of mixed age (2–24 years). At both sites, we sampled trees of 5 years and older. Both sites share a similar planting design and variety composition (two rows of the main variety, mainly Um Al Fahem, alternating with rows of pollenizers, mainly 53′, 54′, and M.D.). In the Kfar Menachem orchard, both honeybee and bumblebee hives were present (the use of *Bombus terrestris* to improve almond pollination was under investigation during the course of the present study, see Dag et al., 2006; D. Weil, pers. comm.), whereas in the Netiv Halamed Hey orchard, only honeybee hives were present. Honeybee hive densities were similar across sites (ca. 3–4 honeybee hives/ha); bumblebee hive density was 20 hives/ha. The Netiv Halamed Hey orchard has a higher proportion of natural habitat in its surroundings than the Kfar Menachem orchard (ca. 50% compared to less than 32% natural habitat within a 2000-m radius around the respective sites; based on 2005–2006 satellite images and calculated using ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, CA)). To prevent soil erosion, part of the orchard at Kfar Menachem was not mowed and wild annuals were allowed to grow. We termed this section "weedy orchard".

We classified four habitat types: natural habitat—open fields with a low density of shrubs and trees and a diversity of wild flowers; edge—the margin between the orchard and the surrounding natural habitat (the almond tree lines at the border of the orchard); orchard—within the orchard; weedy orchard—the part of Kfar Menachem's orchard that contained wild flowers. We marked fourteen 50-m transects: four transects in each of the natural, edge, and orchard habitats (two in each site) and two in the weedy orchard. Transects in the natural and orchard habitats were at least 100 m away from an orchard edge. Transects were at least 100 m apart, and at least 100 m away from a honeybee or a bumblebee hive. The orchard transects were perpendicular to the tree rows and therefore included both Um Al Fahem and pollenizer trees.

Bee and vegetation sampling

Bees were sampled in early March 2008 when standardized weather conditions were met (clear days, wind velocity <2.5 m/s, temperature >18 ºC). Almond trees were in full bloom or close to it. As each sampling technique might have biases, we combined: (1) netting—conducted for 20 min in the morning (0800–1200 h) and 20 min in the afternoon (1230–1600 h) while walking slowly along the transect, surveying 1 m on each side and recording the plant from which the bee was collected, and (2) pan traps—blue, yellow, and white plastic bowls filled with soapy water placed along the transect for 7 h, from morning till afternoon (bees attracted to the pans were caught in the soapy water). We used nine bowls per transect (three of each color), approximately 6 m apart. In each of the natural, edge, and orchard habitats, we conducted two pan trap samplings in two transects, and a single pan trap sampling in the other two transects. In the weedy orchard habitat one transect was sampled once, and the other transect was sampled twice using pan traps. Because the abundance of honeybees in the orchards was usually high (>15 bees per tree/min) and their netting is extremely time consuming, we netted them only in two of the orchard transects and used these figures to estimate their abundance in the other orchard transects. We expected honeybee abundance to be similar across orchard transects as they had similar hive densities and distance to the hives. Collected bees were identified to the genus level. Morpho-species within genera were of similar body size. We recorded the diversity and abundance (number of flowers) of blooming plants in five 1-m radius circles placed 12 m apart along each transect. We recorded only fresh flowers that were likely to be attractive and rewarding for bees, i.e., with petals attached and fresh, corollas open, anthers fresh and with pollen, etc.

Data analysis

Differences between habitats and sites in bee abundance and genus richness (no. of genera, based on netting and pan trap data) were analyzed using ANOVA and LSD post hoc tests. We used redundancy analysis (RDA) to explore differences in genus composition between habitats and sites (Canoco for Windows 4.5, Microcomputer Power, Ithaca, NY). Significance of ordination axes was tested by Monte Carlo permutation (unrestricted; 4999 permutations; Leps and Smilauer, 2003). Genera with only one specimen were omitted from this analysis. The weedy orchard transects were excluded from the RDA analysis as they were confined with site (found in only one site). Analysis of bee visits to almond flowers was based on netting data.

RESULTS

A total of 180 wild bees of 10 genera was sampled. The dominant genera were *Lasioglossum* (79 specimens) and *Andrena* (75 specimens). Significant differences were found between habitats in mean wild bee abundance per transect ($F_{3,10} = 4.41$, $p = 0.03$), with significantly fewer wild bees sampled in the orchard compared to the edge and natural habitats (orchard–edge: $p = 0.02$; orchard–natural: $p = 0.008$) (Fig. 1). The weedy orchard transects had an intermediate number of wild bees, which was not significantly different from the other three habitat types. The edge and natural habitats had similar abundances of wild bees. We found a marginally significant difference in wild bee abundance between sites ($F_{1,6} = 4.76$, $p = 0.07$), with significantly higher wild bee abundance in the edge habitat in Netiv Halamed Hey compared to Kfar Menachem ($p = 0.016$) (Fig. 2).

No significant differences were found between sites or habitats in the number of wild bee genera (sites: $F_{1,6} = 0.1$, $p = 0.76$; habitats: $F_{2,6} = 2.19$, $p = 0.19$). However, genera composition was significantly different between the natural and the orchard habitats (Fig. 3; F = 4.68, $p = 0.02$; Eigenvalue of the first axis: 0.319, second axis: 0.407). *Andrena*, *Eucera*, *Nomada*, and *Anthophora* were closely associated with natural habitats, *Colletes* was associated with orchards, and *Lasioglossum* was associated with both natural and orchard habitats. There were no significant differences in bee composition between the edge and orchard habitats or between the two study sites.

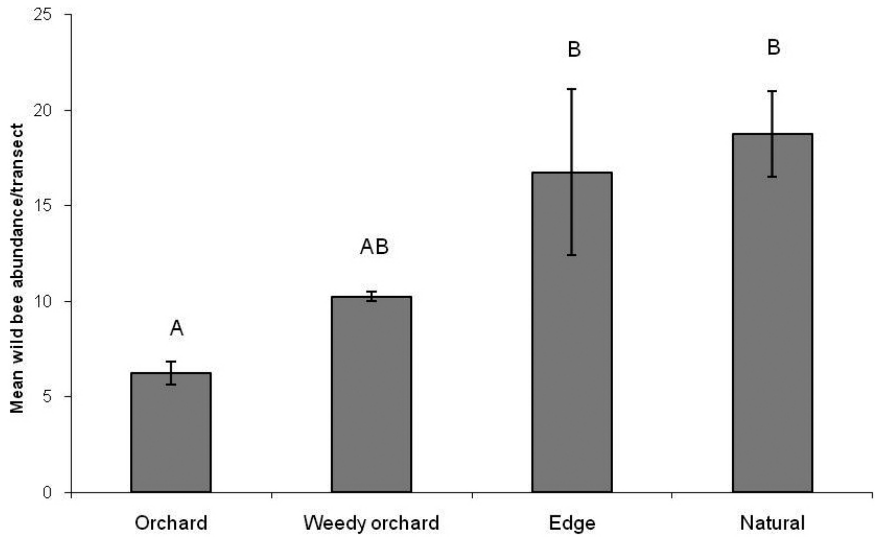

Fig. 1. Differences between habitats in mean wild bee abundance per transect ± standard error (combined data from the two study sites).

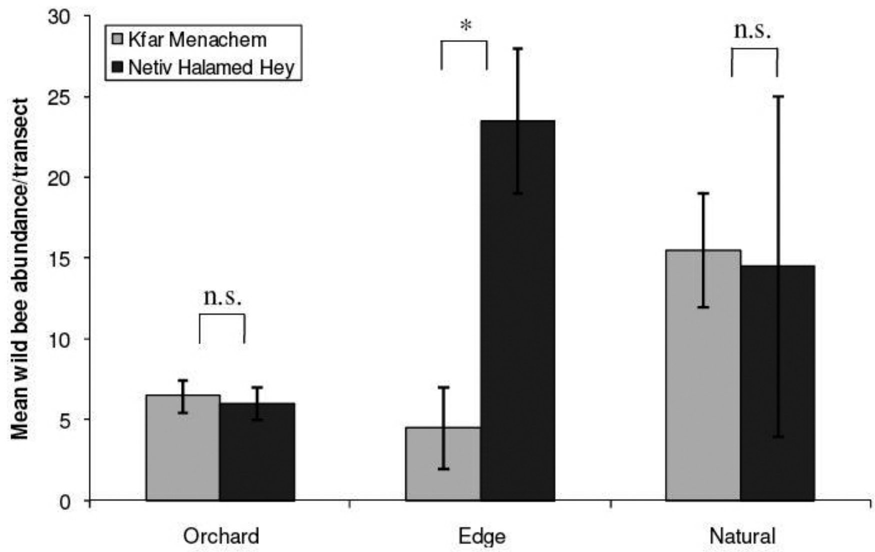

Fig. 2. Differences between sites in mean wild bee abundance per transect ± standard error across habitats. n.s. $p > 0.05$; $*p < 0.05$.

Ninety-five percent of bee visits to almond flowers were done by honeybees. Some flies and wasps were also observed in low numbers, but they were not sampled. Honeybees were mostly restricted to almond flowers (97% of honeybees sampled were from almond flowers) while wild bees used a broader floral set. Umbelliferae flowers (mainly *Ainsworthia trachycarpa* Boiss.) were a major floral resource for wild bees (ca. 32% of wild bees netted; Fig. 4). Approximately 17% of the wild bees were netted on almond flowers, and 5 to 12% of the wild bees were netted on each of the other five major plant families (see Fig. 4). Plants from which bees were collected included *Asphodelus ramosus* Miller, *Biscutella didyma* L., *Crepis* spp., *Foeniculum vulgare* Miller, *Medicago* spp., Salvia spp., *Sarcopoterium spinosum* (L.) Spach, *Sinapis arvensis* L., *Thrincia tuberosa* (L.) DC., and *Trifolium* spp. Bumblebees were not sampled on any transect.

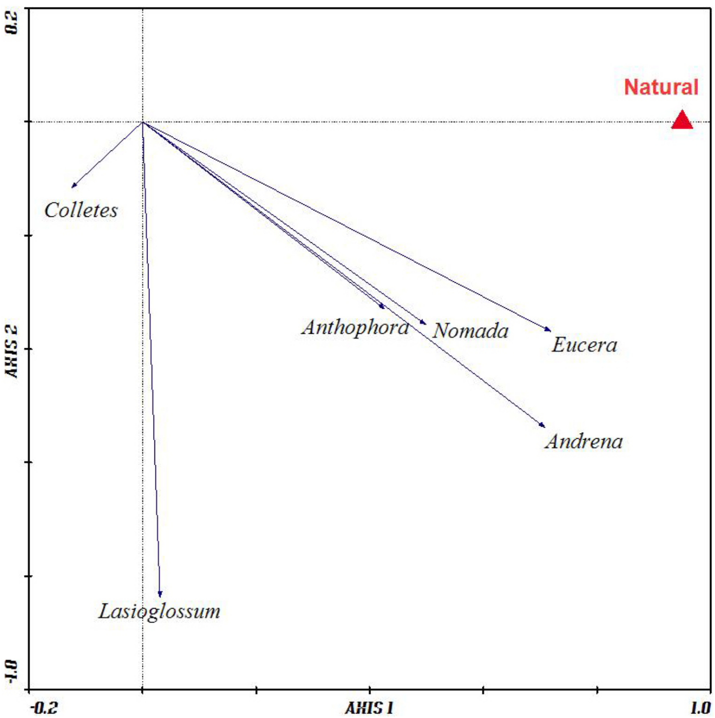

Fig. 3. RDA on wild bee genera across natural, orchard and edge transects (combined data from the two study sites). Genera with a single specimen as well as the two weedy orchard transects were omitted.

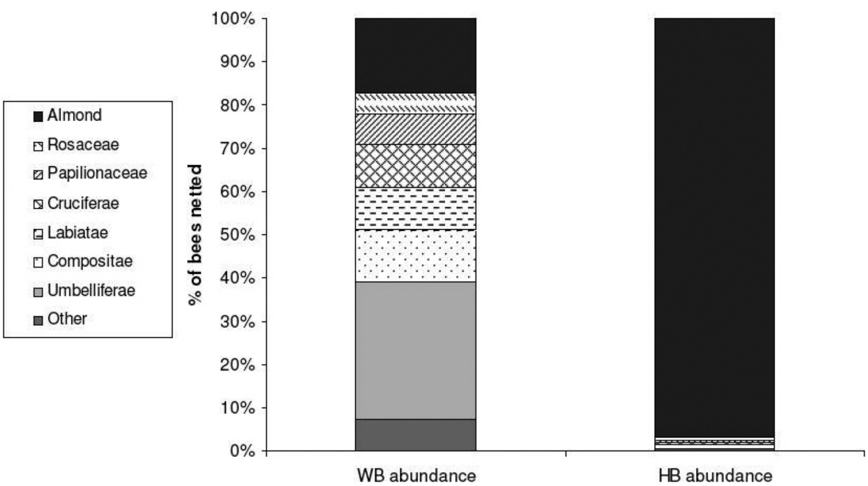

Fig. 4. Percentage of honeybees (HB) and wild bees (WB) netted on major plant families and almond flowers (shown here separately from other Rosaceae; combined data from the two study sites). *HB abundance on almond flowers in orchards was extrapolated from a limited sampling (see details in Methods).

DISCUSSION

We found a diverse and abundant wild bee community in natural habitats surrounding almond orchards during the early spring bloom of almonds. Since this early spring bloom may be a major limitation for honeybee pollination (Dag et al., 2006), this finding supports further investigation into the contribution of wild bees to almond pollination. Though wild bees alone are unlikely to fill the high pollination requirements of almond (Klein et al., 2008), they might be an important supplement to honeybees.

Wild bees foraged mainly on wild flowers and contributed little to total bee visits on almond flowers. However, all our samplings were done on relatively warm, clear, and calm days (18.5 to 34 ºC; wind velocity mostly <1.8 m/s), which are optimal or close to optimal for honeybee activity. Indeed, honeybee activity was generally high (>15 bees per tree/min), and under these conditions, honeybees contributed the vast majority of the bee visits to almond. Under less favorable weather conditions (cold, windy, and cloudy days), which are common during the almond blooming period, honeybee activity may be greatly diminished (Dag et al., 2006), while some of the early spring wild bees may be active (O'Toole and Raw, 2004). Bar-shay (1995) found a much greater contribution of wild bees (mainly of the genus *Anthophora*) to total pollinator visits to *Amygdalus communis* L. flowers compared to our findings (up to 30% vs. less than 5%, respectively). These differences might be, among other causes, due to differences in weather conditions in the course of the study, as Bar-shay's study lasted throughout the almond blooming period. A prolonged sampling throughout the almond blooming period might reveal a greater contribution of wild bees to almond pollination in our study system. Indeed, weather conditions during the almond blooming period are a main limiting factor in almond production in Israel (Ish-Am, 1996).

The natural and orchard habitats were distinctly different in the abundance and composition of wild bees. The margin between these two habitats had intermediate bee composition (not significantly different from the natural or the orchard habitats) but high wild bee abundances, as was found in the natural habitat. Thus, while wild bees are active in almond orchards, they are mostly restricted to their periphery. Natural habitats may provide floral resources and nesting sites for bees, and thus support a more diverse and abundant wild bee community in adjacent habitats (Steffan-Dewenter et al., 2001; Ricketts et al., 2008). The fact that wild bees were caught in orchards but mostly in pan traps and not on almond flowers may further indicate the role of surrounding natural habitats in providing wild bees with foraging resources. Noteworthy, *Lasioglossum*, the most abundant genus in the orchards, was associated with both natural and agricultural habitats.

Natural habitats had a positive effect on wild bee communities at the landscape scale as well, as evident by the marginally higher wild bee abundance in Netiv Halamed Hey, where the proportion of natural habitat in the surrounding landscape was higher. However, this marginal landscape effect was restricted to the edge of the orchard. Thus local-scale configuration (edge vs. inside orchards) seems to have an overriding effect on wild bee abundance (but not composition) compared to landscape context. This might be the result of the highly fragmented landscape in the region, providing resources for wild bees across natural and semi-natural habitats (Winfree et al., 2007b). These conclusions must be made with caution, as the temporal and spatial scope and the number of sites studied were limited.

The occurrence of wild flowers within orchards had some positive (albeit non-significant) effect on wild bee abundance. Thus, managing for wild flowers within orchards might be a way of enhancing wild pollinators' activity within those orchards (though their foraging preferences, especially preference for almond vs. wild flowers, remain to be studied). Honeybees foraged almost exclusively on almond flowers, and therefore the potential risk of decreased almond pollination due to competing bloom seems rather low in this ecosystem (but other studies did find a negative effect of competing bloom on almond pollination; see DeGrandi-Hoffman et al., 1992, and Free, 1993). Eisikowitch and Lupo (1989) found that only Cruciferae flowers compete with almond flowers for honeybee pollination services, but in our system Cruciferae were a negligible foraging source for honeybees (0.65% of the honeybees were sampled on these flowers). Bumblebees were not found in natural habitats. This may further support the notion of the limited role of competing bloom in attracting pollinators and decreasing pollination of almond in this ecosystem.

Based on this preliminary study we conclude that the wild bee fauna found in the study region in natural habitats may provide significant supplementary pollination services to almond, especially in orchards surrounded by natural habitats and close to the orchard–natural habitat margin. These findings need to be further explored on a wider set of study sites, especially the effect of surrounding landscape and the potential contribution of wild bees to almond pollination during suboptimal (cold, windy, and cloudy) weather conditions.

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