Supporting Integrated Honey Bee Pollination in Almond Orchards through Increased Forage

Project No.: **15-POLL13-Williams**

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Objectives:

Almond pollination relies on healthy supplies of honeybees. Recent research also suggests that wild bees increase the pollination effectiveness of honey bees through synergistic interactions that cause honey bees to move more frequently between varieties (Brittain et al. 2013). Thus efforts to promote wild and managed bees are important components of a sustainable future for almond production. Beekeepers and researchers have identified lack of diverse nutrient sources as a primary threat to honey bees and wild bees alike. Although almond pollen and nectar are important resources, alternative pollen and nectar sources immediately preceding and following the bloom of almond will likely benefit honey bee health through increased nutritional diversity. These same forage resources can also help bolster wild bee populations. Habitat plantings are increasingly used to boost forage for honey bees and with informed selection of plant species the same flower mixtures designed to support honey bee nutrition can also extend forage resources for wild populations within orchards.

Within this context, several information gaps remain:
1. Data demonstrating the effectiveness of various plant options for support of honey bees and wild bees in the orchard context remain scarce.
2. Honey bee use of currently employed flower mixes has been explored to some degree in central and southern production regions, but little testing has occurred in the northern region, other than with Project Apis m. mixes.
3. There is important unresolved concern of the industry that forage enhancements near orchards might negatively impact almond pollination through competition for pollinators.

In 2016 we had three primary research objectives aimed at addressing the identified information gaps:

1. We assessed the performance of flowering plant mixes including their establishment and bloom timing in northern, central and southern regions of almond production.
2. We quantified honey bee use of the flower plantings in all regions.
3. We quantified potential competition between forage plantings and almond orchards for pollinator visits. Specifically, we measured visitation rates of *Apis mellifera* and wild bees to blooming almond orchards with and without flower enhancements, and measured simultaneous visitation rates to flower mixes in all three regions.

These ongoing projects are supported by the USDA SCRI Project ICP, an NRCS Conservation Innovation Grant and thus productively leverage support. This study also involved effective use of efforts by PAm exploring the ability of flower mixes to provide quality forage for honey bees.

Interpretive Summary:

1. Forage plantings established successfully in all three regions, and provided resources to bees during and after almond bloom without detracting from visitation to the orchard.
2. Both types of forage plantings (wildflower and mustard) provided higher floral abundance than unenhanced controls, with wildflower plots yielding the highest floral resources.
3. Similarly, both forage types received significantly higher honey bee visitation than unenhanced controls, with wildflower plots receiving similar or higher visitation than mustard.
4. Wild bees visited wildflower plots at consistently higher rates than they visited mustard plots, suggesting wildflower plantings may be the better strategy for both bolstering honey bee health and encouraging the phenomenon of improved honey bee pollination in the presence of wild bees.
5. The number of honey bee visits to almond was not significantly affected by the presence of a wildflower planting, and the number of honey bee visits to wildflower plots appeared to drop during almond bloom.

Materials and Methods:

Flower habitat plantings

We worked with industry collaborators in three regions of California's Central Valley (south, central and north) to assess the ability of three different flower mixes to provide floral resources for bees (**Figure 1**). Two of the flower mixes consisted of wildflowers native to California, and the third flower mix was Project Apis mellifera's "Seeds for Bees" mustard mix (**Table 1**). The southern and central wildflower plots were seeded with an early-season mix of six native wildflower species selected for their ability to provide bloom prior to, during and shortly after almond bloom, and the northern wildflower plots were seeded with a mix of twenty native flower species intended to provide nearly year-round forage for bees. Each wildflower or mustard plot was planted adjacent to a mature almond orchard in the fall of 2015. Wildflower mixes in the southern study region were irrigated in the fall to achieve bloom prior to flowering of the almond orchard. Flower-enhanced sites were compared to control sites without naturally-occurring weedy species.

Table 1. Three seed mixes tested for bee forage; (1) Wildflower mix used in the southern and central sites, (2) mix used in the northern sites, and the PAm mustard mix

Wildflower seed mix (1)		Wildflower seed mix (2)		PAm mustard seed mix	
Common name	**Ann/ Per**	**Common name**	**Ann/ Per**	**Common name**	**Ann/ Per**
Chinese houses	A	Deerweed	P	Brown mustard	A
California poppy	A, P	Fort Miller clarkia	A	Common mustard	A
Fivespot	A	Elegant clarkia	A	White mustard	A
Baby blue eyes	A	Chinese houses	A	Radish	A
Desert bells	A	California poppy	A, P		
Great valley phacelia	A	Gumweed	P		
		Bolander's sunflower	A, P		
		Summer lupine	P		
		Chick lupine	A		
		Arroyo lupine	A		
		Coyote mint	P		
		Baby blue eyes	A		
		California Phacelia	P		
		Desert bells	A		
		Great valley phacelia	A		
		California bee plant	P		
		Desert mallow	P		
		Vinegarweed	A		
		Pin point clover	A		
		Bull clover	A		

In the southern region, near Lost Hills in Kern County, we planted three wildflower plots (each 1.2 acres) at Wonderful Orchards West Valley facility. Our central sites consisted of three wildflower plantings at Ag Pollen LLC (ranging from 0.09 to 0.19 acres in size), and three sites planted with PAm's mustard mix located around the Modesto area. In the northern region, ranging from Yolo county to the Chico area, we planted five wildflower plots (ranging from 0.37 to 0.89 acres), and worked with almond growers to locate two sites planted with PAm's mustard mix. The five mustard plantings were selected to be of similar size and establishment success to the five northern wildflower plots. Control plots were also selected to be of comparable size to the wildflower plots they were tested against.

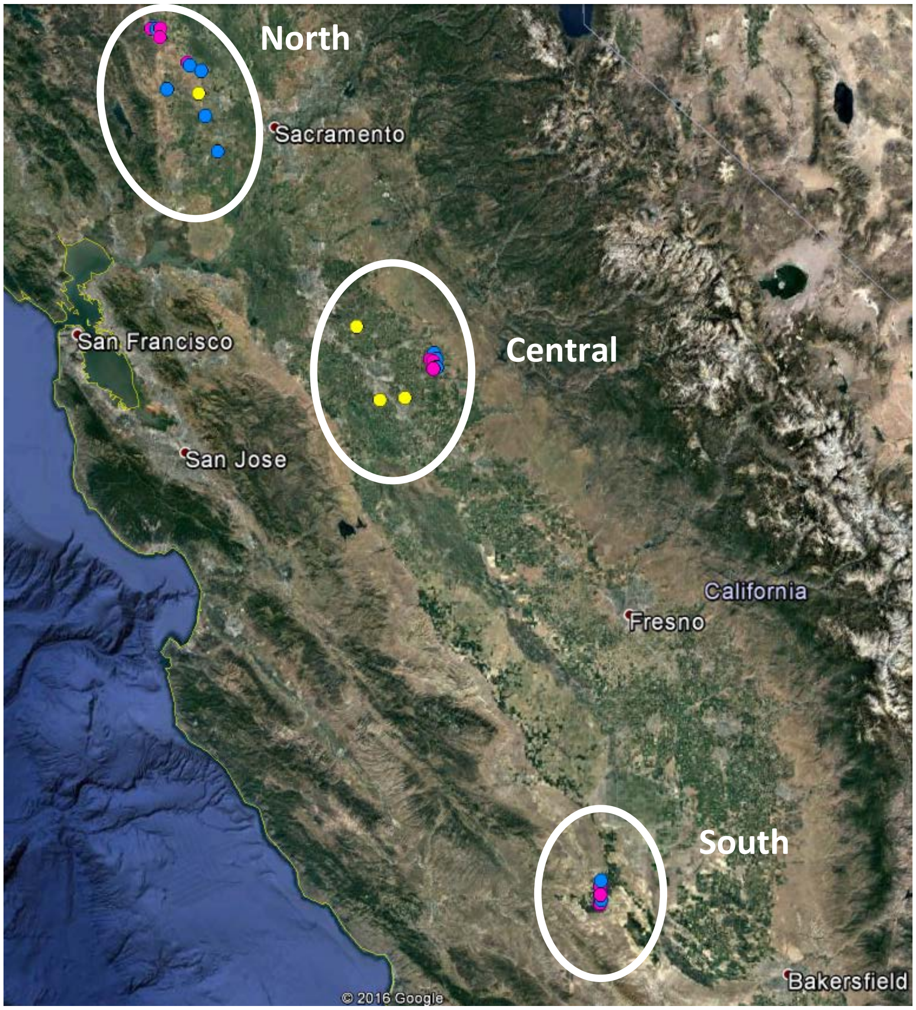

Figure 1. Map of study sites in Northern, Central and Southern regions of California almond production. Unenhanced orchards are depicted in blue; orchards enhanced with wildflower borders are in pink; orchards enhanced with the PAm mustard mix are in yellow.

Beginning in late January and extending through late March, we used bi-weekly (2x/week) monitoring of the wildflower and mustard plantings to assess the onset of bloom and flower density of each plant species. Floral density was counted using standardized quadrat sampling, and floral area for individual flower species was calculated with flower counts multiplied by flower area as measured using digital calipers.

Monitoring honey bee and wild bee use of flower plantings

On the same days that we assessed flower abundance within each plot, we also walked transects to quantify honey bee and wild bee visitation to each plant species and mix. All visitation data were collected on days that were sunny or brightly overcast, with average winds below 3.5 m/s. Temperature during bee sampling was always at least 15C. Transect length was 50 m for the southern and central wildflower and control plots, and 100 m for the northern sites and all mustard sites. Each transect was sampled for 10 minutes, regardless of transect length. To allow comparison of data collected from transects of different lengths, we report "bees per minute per meter" as our unit of bee visitation. Wild bees visiting flowers were netted, and have been curated and stored at the University of California, Davis for future identification. Honey bees visiting flowers were counted using hand-held click-counters. We calculated bee visitation for each wildflower, mustard, and control plot, and present our findings here in terms of mean bees observed or netted per minute per meter, averaged among sites within a treatment type.

Potential competition between flower plantings and orchards

Here we combine two years of data from Wonderful Orchards West Valley site in the southern region to assess the potential for wildflower plots to compete with crop pollination by drawing bees out of the orchard. Here we planted three wildflower plots and set up three control plots without plantings for comparison (see "flower habitat plantings" section above). A benefit of limiting our study to a single but very large orchard is that we ensured uniform orchard and beekeeping practices in all replicates and treatments. The orchard was planted with almond varieties Monterey and Nonpareil in alternating rows, and was stocked with honey bees prior to bloom at a rate of 4.4 (2015) or 5.0 hives per hectare (2016). Honey bee colonies were generally distributed in groups of 24 colonies that were evenly placed throughout the orchard, with 200-300 meters between groups.

To assess the level of competition between wildflower plantings and orchards for bee visitation, we counted honey bees and wild bees visiting flowers in almond trees adjacent wildflower or control plots on three dates during crop bloom each year (2015-2016). Again we only observed almond trees for bee visitation on sunny or brightly overcast days with winds below 3.5 meters per second and temperatures above 15C. We visually counted the number of bees (honey bee or wild bee) in five trees in the second row of orchard (~ 8 meters into the orchard) and in five trees in the tenth row of the orchard (~ 60 meters in) adjacent to our wildflower plantings or control orchard borders. All sampled trees were Nonpareil. The observer slowly walked around a focal tree for one minute, counting the numbers of bees landing on almond flowers. These counts were repeated early and late in the day, representing an early and late time point within the range bee activity hours on that day. We estimated relative bloom in each tree by counting the number of open flowers in a cubic volume of canopy (0.33 m on a side). Tree size was relatively uniform throughout the orchard (tree crown diameter 5.4-6.2 m, tree height 4.7-6.3 m, n=10). We therefore assumed that the average number of open almond flowers per unit volume was proportional to the total number of open flowers in a tree. Bee and flower counts were averaged across the five trees surveyed per row.

To determine if bee visitation rates to almond flowers differed for trees adjacent wildflower plantings compared to control field borders, honey bee visits per tree (square root transformed) was analyzed with a Generalized Linear Mixed Model with treatment (wildflower or control), year, sample round, orchard row (2 or 10) and time of day (early or late) added as fixed factors. The number of open almond flowers per cube was added as a covariate. Interactions were added to test if the effect of the wildflower plantings differed between rows (treatment × row interaction) or early versus late in the day (treatment × time of day interaction). We also tested the three-way interaction between treatment, row and time of day. To account for the paired design, the replicate pair of wildflower planting and control border nested within year was specified as a random factor. To account for the multiple measures taken from the same sets of trees in the orchard, sample day (1^{st}, 2^{nd} or 3^{rd} sample during almond bloom) was specified as a repeated factor, with the row nested within treatment, replicate and year specified as the subject, and with the covariance structure specified to compound symmetry.

Results and Discussion:

Flower habitat plantings

Average floral area varied by treatment (wildflower, mustard, and control) and changed over the season (**Figure 2**). Although almond bloom times varied among sites, the ranges of crop bloom dates were similar between the three regions. Wildflower plots in the southern region provided substantial bloom starting 3-4 weeks prior to almond bloom, showing the potential for these plantings to provide resources to migrating honey bee colonies placed in orchards prior to crop pollination. These southern wildflower plots reached their peak bloom concurrently with crop bloom, while north and central native wildflowers and mustard flowers both reached their peak bloom after the end of almond bloom (**Figure 2**). This may partly result from differences in sowing date and irrigation. Wildflower plots in the south and central region were seeded in early October while northern wildflower sites were seeded a month later. Southern wildflower sites were irrigated after sowing and through December, while all other wildflower sites received only natural rainfall. Planting date and irrigation regimes varied among landowners using the PAm mustard mix.

Wildflower plantings in the central region provided floral resources for approximately the same duration as the mustard plantings, although they flowered longer than mustard in the north (**Figure 2**). This is partially explained by the fact that the southern wildflower mix of species were restricted to springtime-blooming species, whereas the wildflower mix used in the northern sites was specifically designed to last all year (these plots will continue to be monitored through October, and will continue to produce flowers through early fall). Mustard sites were mowed by landowners after they stopped blooming.

Although there were some differences in overall floral resource abundance between the three regions, some patterns were consistent statewide. Wildflower plots had between 20 and 43 times higher floral area than control plots, and mustard plots had between 5 and 16 times higher floral area than controls. Wildflower plots had 3 to 4 times higher average floral area than mustard plots.

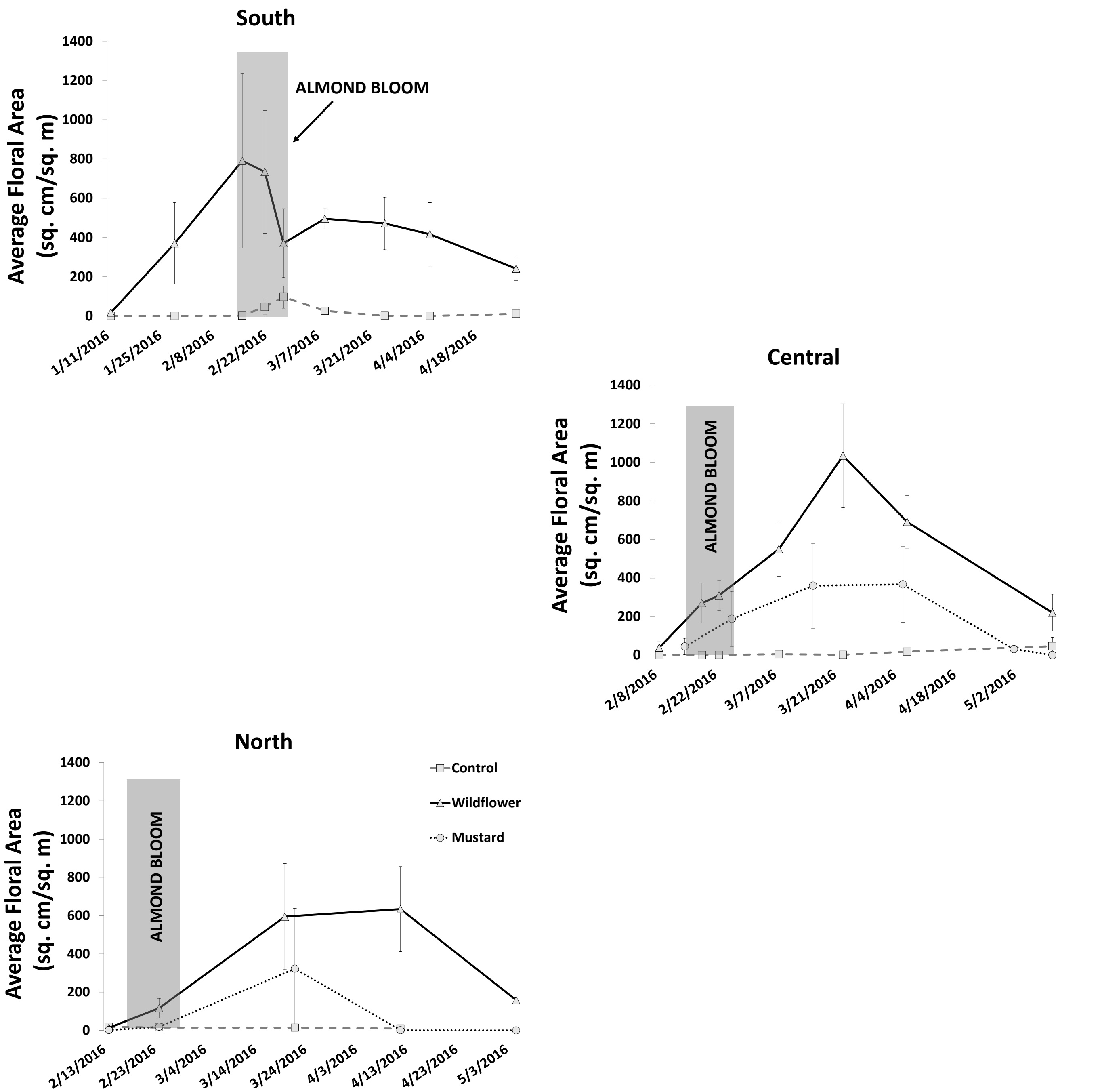

Figure 2. Floral resources in wildflower and mustard forage plots and unenhanced control orchard borders. Each point is the average (± s.e.) among sites within a treatment type. Almond bloom is represented by a grey box, and is specific to our sites in that region. Floral area for wildflower and mustard plantings included only flower species that were intentionally seeded, while in control plots all naturally occurring flowers were counted.

Monitoring honey bee and wild bee use of flower plantings

Across all regions, honey bees visited wildflower plots 23 to 87 times more frequently than control plots in the same region, and they visited mustard plots 10 to 40 times more frequently than controls (**Figure 3**). In northern sites, honey bees visited wildflower and mustard plantings with similar frequency while they were both blooming, although visitation to wildflower plots continued long past the end of mustard bloom. In the central region, honey bee visitation to wildflower plots was more frequent than visitation to mustard until late in the season. Honey bee visitation to all flower-enhanced plots peaked after almond bloom had ended. In the northern and central regions, this can be partly explained by the fact that floral area in those regions also peaked post-almond bloom. In the southern region, however, the peak bloom of the wildflower plots occurred at the same time as the almond bloom. There are two spikes in honey bee visitation to these wildflower plots: one before and one after almond bloom, with a distinct drop in visitation to wildflowers during the bloom (**Figure 3**). This suggests that honey bees preferentially chose to visit almond bloom over wildflowers during that time.

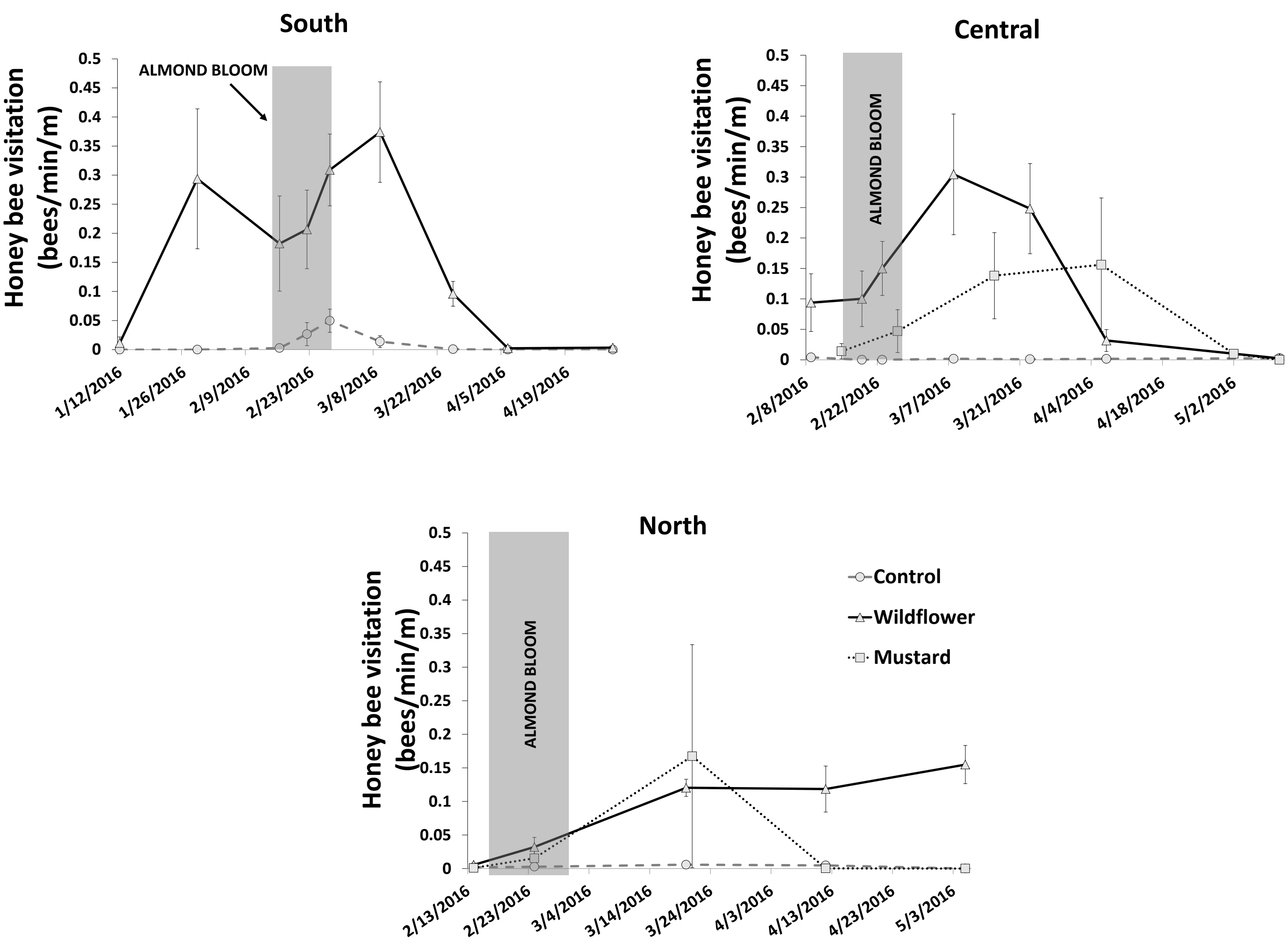

Figure 3. Honey bee visitation to wildflower and mustard forage plots compared to unenhanced control orchard borders. Each point is the average (± s.e.) among sites within a treatment type. Almond bloom is represented by a grey box, and is specific to our sites in that region

Across all regions, wild bees visited wildflower plantings at 6 to 31 times the rate they visited control plots (**Figure 4**). Wild bees showed little to no preference for mustard plots over control plots. Wild bees also exhibited a distinct preference for wildflowers over mustard flowers. Wild bees visited wildflower plots 76 times more frequently than mustard plots in the north, and 10 times more frequently in the central region (**Figure 4**). Additionally, wild bees were netted at about twice the rate at northern wildflower plots than at either the southern or central wildflower plots. Wildflower plots in the northern region did not appear to provide more floral resources per square meter than southern and central wildflower plantings; in fact, average floral area of wildflower plots in the northern region was the lowest overall compared to the central and southern regions (**Figure 2**). One possible reason for the high rate of wild bee visitations in the northern sites is that most of these sites were planted near relatively undisturbed natural riparian and grassland habitat, where wild bees tend to occur naturally. Thus, wildflower plantings may be a strategy for supporting honey bees while encouraging the phenomenon of improved honey bee pollination of almond in the presence of wild bees, and this strategy may be most effective where orchards tend to be smaller scale and closer to remnant natural habitat.

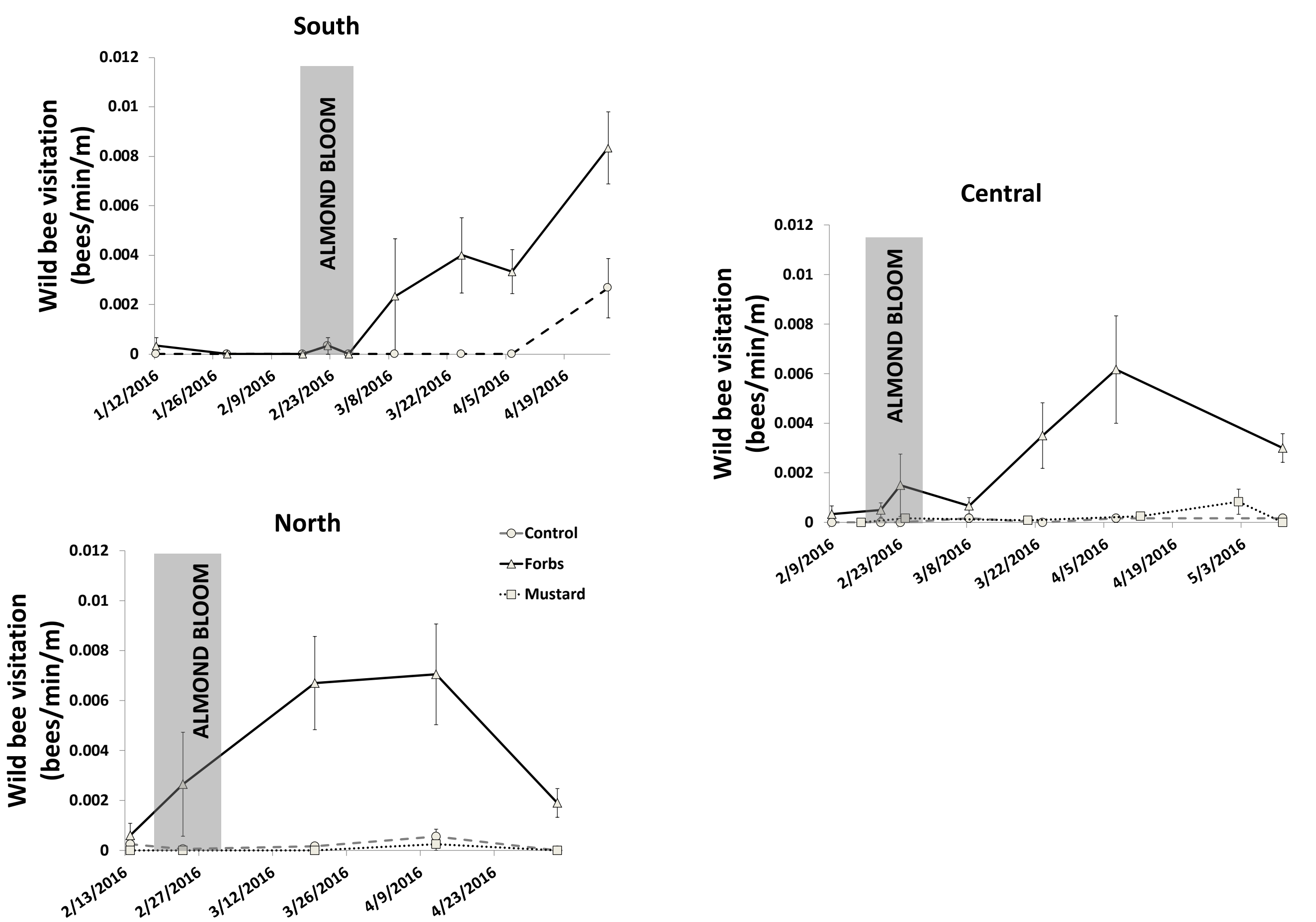

Figure 4. Wild bee visitation rates to wildflower and mustard forage plots compared to unenhanced control orchard borders. Each point is the average (± s.e.) among sites within a treatment type. Almond bloom is represented by a grey box, and is specific to our sites in that region.

Potential competition between flower plantings and orchards

We recorded 6,428 honey bees and 2 wild bees visiting almond flowers in a total of 12 hours of observations at the three southern sites.

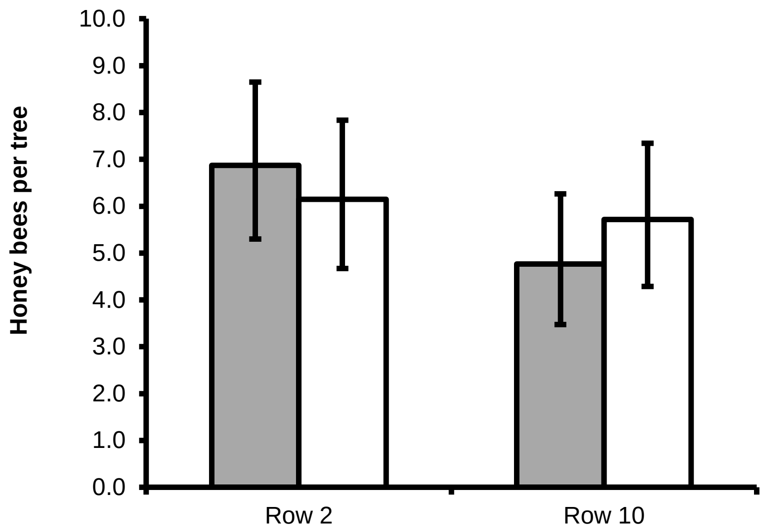

Figure 5. Honey bees per tree in the outer (row 2) and interior (row 10) of the almond orchard next to wildflower plantings (grey bars) or control borders (white bars). Values are back-transformed least square means with 95 percent confidence intervals.

There does not appear to be any evidence of competition for bees between the wildflower plantings and the crop: the number of honey bee visits to almond was not significantly affected by the presence of a wildflower planting, nor did the effect of the wildflower plantings differ between rows (no treatment × row interaction) or between early or late in the day (no treatment × time of day interaction; **Figure 5**). There was also no significant three-way interaction between treatment, row and the time of day (**Table 2**). Honey bee visits to almond trees were higher in 2015 compared to 2016, higher early in the crop bloom compared to later and positively affected by the number of open almond flowers per tree. Honey bee visits tended to be higher at the outer part of the orchard (row 2) compared to in the interior (row 10). Honey bee visits did not differ significantly early versus late in the day.

Together these results suggest forage plantings hold large potential for bolstering honey bee health without the risk of competing for pollinators with crop bloom. Wildflower plantings may be the optimal strategy for both supporting honey bees and encouraging the phenomenon of improved honey bee pollination in the presence of wild bees. Further research is needed to demonstrate the benefits of forage provision on hive health and to investigate the potential for wildflower plantings to improve crop pollination through increased presence of wild bees in the orchard.

Table 2. Test statistics and estimates for the analysis of honey bee visitation to almond. Estimates are back transformed means (95 percent confidence intervals within parentheses) with the exception for the covariate 'flowers', where the numbers indicate the slope and its standard error on the original scale. Significant results are indicated in bold and marginally significant are indicated in italics. See text for further explanation of variables tested.

Variable	F_{df}	p	Factor	Estimate
year	**$321.25_{2,}$**	**<0.0001**	2015	11.7 (10.0-13.5)
			2016	2.0 (1.4-2.8)
sample round	**$13.18_{2,}$**	**<0.0001**	early	7.1 (5.8-8.5)
			mid	6.3 (5.2-7.7)
			late	4.3 (3.3-5.4)
flowers	**$140.20_{1,}$**	**<0.0001**	**-**	0.06 (0.005)
treatment (t)	$0.06_{1, 6.83}$	0.82	wildflower	5.8 (4.6-7.0)
			control	5.9 (4.8-7.2)
row (r)	*$4.17_{1, 9.95}$*	*0.07*	2	6.5 (5.2-7.9)
			10	5.2 (4.1-6.5)
time of day (td)	$0.57_{1, 127}$	0.45	early	6.0 (4.8-7.4)
			late	5.7 (4.5-7.0)
t×r	$1.77_{1, 5.91}$	0.23		
t×td	$0.84_{1, 126}$	0.36		
t×r×td	$0.28_{2, 124}$	0.76		

Research Effort Recent Publications:

None.

References Cited:

None.