# Implementation of Nesting Blocks for Supplemental Farm Pollination in Contra Costa County 2016

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## ABSTRACT

There is a pressing need to lessen our agricultural dependence on declining European honey bee populations by increasing the biodiversity of other pollinators. This study focuses on the agriculturally productive state of California that contains over 1,400 species of native bees. Native bee declines are also increasingly common as a result of a combination of factors including conventional agricultural practices and habitat conversion. This study aimed to attract wood nesting bees from the Megachilidae family that are known crop pollinators through the implemented of 48 man-made nesting blocks on four different farm sites in Contra Costa county California between late May and November of 2016. To estimate pollinator nesting I manipulated the hole sizes within each block, the placement of the blocks inside or outside of crops, and placed the blocks in farms with a presence or absence of natural habitat. The blocks mainly attracted three species of bees and three species of wasps and their peak nesting time was during the months of June and July. The nesting of the some of these species were significantly related to nesting block hole size. The placement of the nesting blocks (in verse outside crops) and the presence of native habitat did not have a significant relationship with nesting, which may have resulted from the relatively small sample size resulting from data collection occurring in the last year of California's five year drought. Future research is also needed to look at bee trends during the spring months of February to May.

## KEYWORDS

Native bees, Megachilidae, California agriculture, pollinator biodiversity, bee nesting seasonality

# INTRODUCTION

The rapid rate of human population growth has put great strain on global agricultural practice (Bailes 2015). Not only is there an increasing gap between the Earth's capability of providing food and human consumption needs, there is also an increasing misunderstanding of how food is produced, as people distance themselves from direct agricultural practices (Janssen 2016). Of the approximately 1,400 crops grown worldwide, over 80 percent require animal pollination to produce yield (Morse and Calderone 2000). The European honeybee (*Apis mellifera*) in North America provides approximately $14.8 billion worth of annual pollination services (Morse and Calderone 2000). The extensive recent decline of the honeybee, resulting from Colony Collapse Disorder, pesticide use, and other factors (Winfree et al. 2007) has exposed the precarious nature of agriculture's economic dependence on this single pollinator. There is a need for alternate modes of pollination to increase our global food security.

Native bees appear able to sufficiently pollinate numerous crops, but population numbers and pollination ability are reduced by intense agricultural practices and natural habitat destruction, including fragmentation and degradation of original environments for commercial farming and development of human living areas (Kremen et al. 2001, 2007). Wood nesting mason bees, or *Osmia* spp. (Hymenoptera, Megachilidae) are some of the most versatile and desirable native crop pollinators of fruits and nuts. They could considerably contribute to decreased dependency on honeybees (Klein et al. 2012). Large insect numbers can be released in the field for crop pollination, and life cycles of many species can be timed to crop bloom periods (Torchino 1976). Females have high pollination efficiency, visiting each tree enough to ensure adequate pollination (Bosch and Blas 1993). Unfortunately, because Megachilids nest in pre-existing cavities, conversion of habitat to conventional agriculture has greatly altered the availability and variety of their nesting resources (Potts et al. 2005). Increasing nesting resources near agricultural setting is vital to supporting native bee pollinators.

Nesting sites of bees from the Megachilidae family are crucial indicators of pollinator community presence and composition, and recent studies on pollinator habitat improvement show promising nesting numbers. Increasing floral abundance and diversity restore population levels (Hopwood 2008); further, farms located near strips of natural habitat in otherwise isolated environments experience substantially greater visitations of native pollinators (Klein et al. 2012).

Importantly, *Osmia* spp. freely accept man-made nesting materials (Torchino 1976), meaning their populations are sustained on orchards with the introduction of artificial nesting blocks, which provide viable habitats. Although it is known that bees can flies miles a day, this study found that spatial placement of nesting block within crops is also important, as bees apparently favoring nesting sites close to crop perimeters. In Utah, *Osmia* spp. released in orchards favored nesting sites within the crops the first year, and subsequently shifted preference to sites along crop perimeters (Torchio 1980). In Torchio (1980) nesting blocks were not placed at distances further than five feet from crops, leaving unresolved the issue of the effect of placement at further distances. When given the option, *Osmia lignaria* strongly favored holes of wider diameters (Tepedino and Torchino 1989) than *Osmia cornuta* (Bosch and Blas 1994). Depending on what species an orchard is trying to attract and sustain, it is important to provide nesting cavities of the correct size. To maximize nesting in specific farms further research must be conducted on block placement and structure.

Another important factor affecting nesting success is the occupancy of blocks by other species, especially parasitic bees and wasps (Eickwort 1975). Recently, farmers have shown concern that man-made nesting blocks are attracting unwanted species (MacIvor and Packer 2015). In one Canadian study, nesting blocks were heavily occupied by parasitic mites and wasps, with wasp larvae outnumbering bee larvae (MacIvor and Packer 2015). Further, mites commonly parasitize bumble bee nests in Northern California (Otterstatter and Whidden 2004), so *Osmia* spp. may be infested as well. Although this data from Utah, Canada and other regions suggest that mites and wasps may be involved in *Osmia* spp. parasitism in our region, on-site confirmation is required. Overall, knowledge of *Osmia* spp. nesting requirements remains incomplete, limiting the ability to develop optimal man-made habitats supporting Megachilidae populations for farm pollination in California.

The goal of this project was to increase farmer knowledge on maximizing *Osmia* spp. colonization of artificial nesting blocks and to improve crop pollination by manipulating the block placement, hole diameter, and determination of bee and parasite nesting interactions. The study took place on farms in Brentwood, California and addresses the following research questions: (a) What species will nest in these blocks and during what months? (b) Will hole diameter within nesting blocks influence bee and parasite nesting? And (c) How will nesting block placement influence bee and parasite nesting if the blocks are placed in crops or outside of crops or if the blocks are placed in areas with adjacent natural habitat versus areas without adjacent natural habitat?

I hypothesized that bee and parasite nesting density would be higher in blocks placed inside the crops verses those that are placed outside of crops. Furthermore, I also expected the presence of adjacent natural habitat to be positively correlated with the amount of bee and parasite nesting, as block placement near native plant areas could boost nesting by providing other food sources.

I also hypothesized that greater nesting density will occur in larger holes ($5/16^{th}$ of an inch) if *O. lignaria* are the predominant bee species, and in smaller holes ($3/16^{th}$ of an inch) if *O.cornuta* are predominant. Finally, I hypothesized that *O. lignaria* and *O. cornuta* will be the predominant nesters in our study, and that parasites will mostly consist of wasps and mites.

# METHODS

## Farm Characteristics

This experiment was conducted on four farms in the city of Brentwood, located in Contra Costa County, California. Each experiment was conducted on two different sections of each farm; six blocks were placed in each section, for a total of 12 blocks per farm. The farms of Frog Hollow, Brookside, Dwelley, and Wolfe, were used as testing sites (Table 1). The experiment occurred from May 2016 to December 2016.

**Table 1. Farm Descriptions.** This shows each farm's acreage, nesting block location site, surrounding natural habitat, farming type, and other notes. In the future this table will be updated when the exact GPS coordinates of each block are determined and the exact amount of surrounding natural habitat is calculated through ArcGIS.

| Farm | Acreage | Block site locations | Surrounding natural habitat | Farming type | Other |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Dwelley Farm (Figure 1) | 50 acres | The first set of blocks was placed in plum trees near eight vitex shrubs (Chaste trees). The second set of blocks was placed in a row of plums adjacent to a field of ollalieberries. | Natural habitat within the farm was implemented by the Urban bee lab. | Conventional | Family owned and running since 1921, owned by Farmer Patrick Johnson |
| Brookside Farm (Figure 2) | 10 acres | The first set of blocks were placed along the creek and the second set of blocks were placed in a orchard of persimmons and apple pears. | The property is bordered by a creek (30 ft from his property) and natural habitat.There are native wildflowers in the area, such as lupins and poppies. | Organic | Run by farmer Welling Tom |
| Wolfe Farm (Figure 3) | 20 acres | The first set was placed along the natural creek habitat and the second set was placed in a section of plums. | Creek runs through the farm for 2,000 feet, lots of natural woody vegetation. Has a variety of seasonally blooming wildflower. | Conventional | Run by farmer Peter Wolfe |
| Frog Hollow Farm (Figure 4) | 140 acres | The first set is located in an orchard of cherry trees and the second set are in an orchard of plums. | The Urban Bee lab implemented a 300 foot stretch of Vitex trees. The surrounding area has little natural habitat. | Organic | Run by farmer Al Courchesne and has been working the Urban Bee lab for four years |

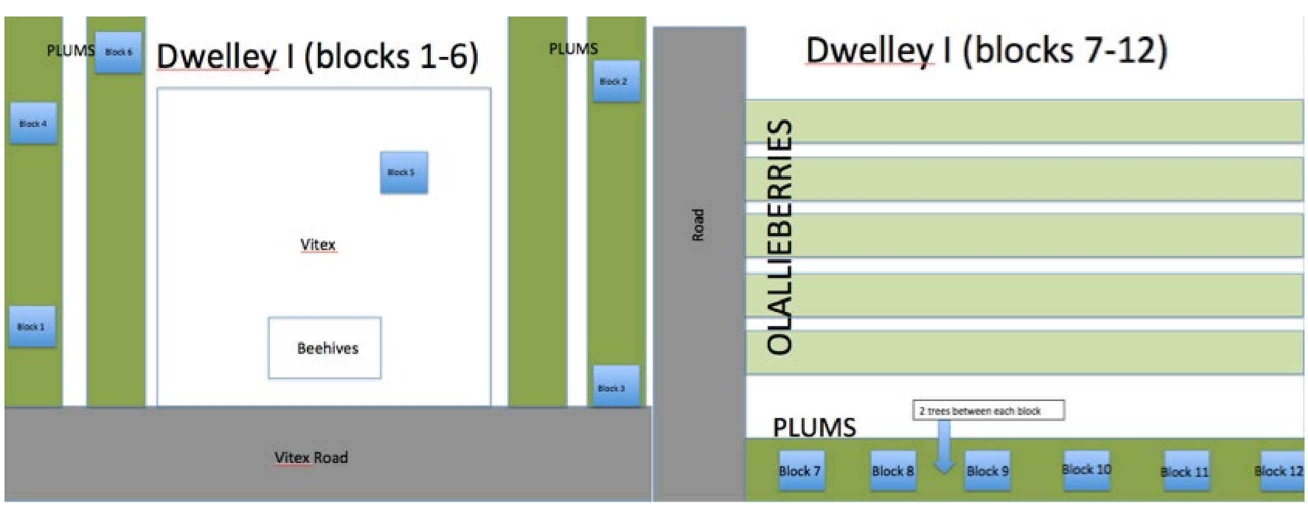


**Figure 1. Map of Dwelley.** All twelve blocks were placed inside crops.

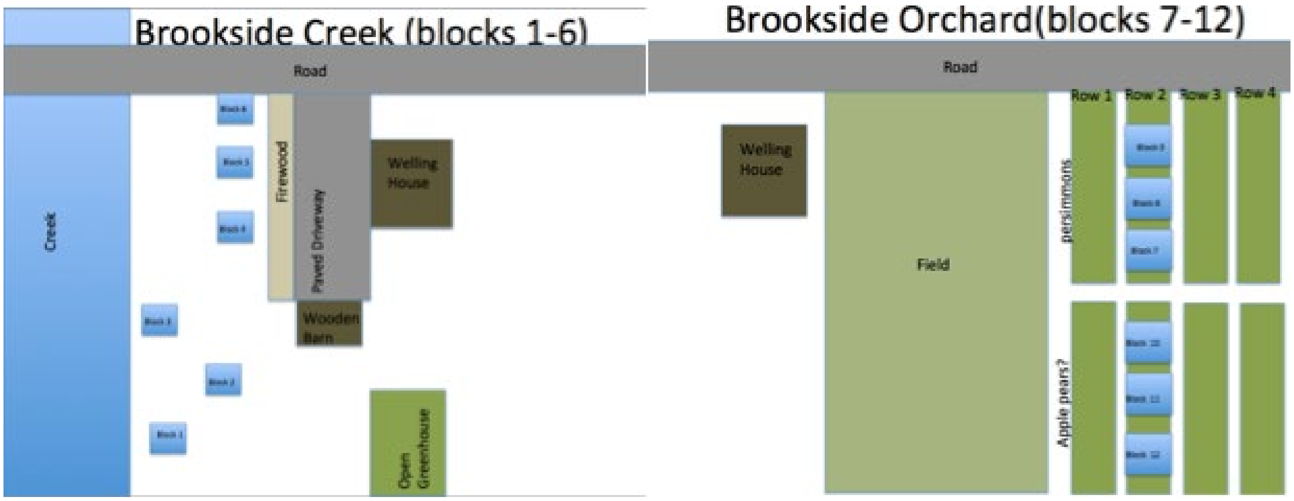



**Figure 2. Map of Brookside.** Blocks 1-6 were placed in natural habitat and blocks 7-12 were placed in crops.

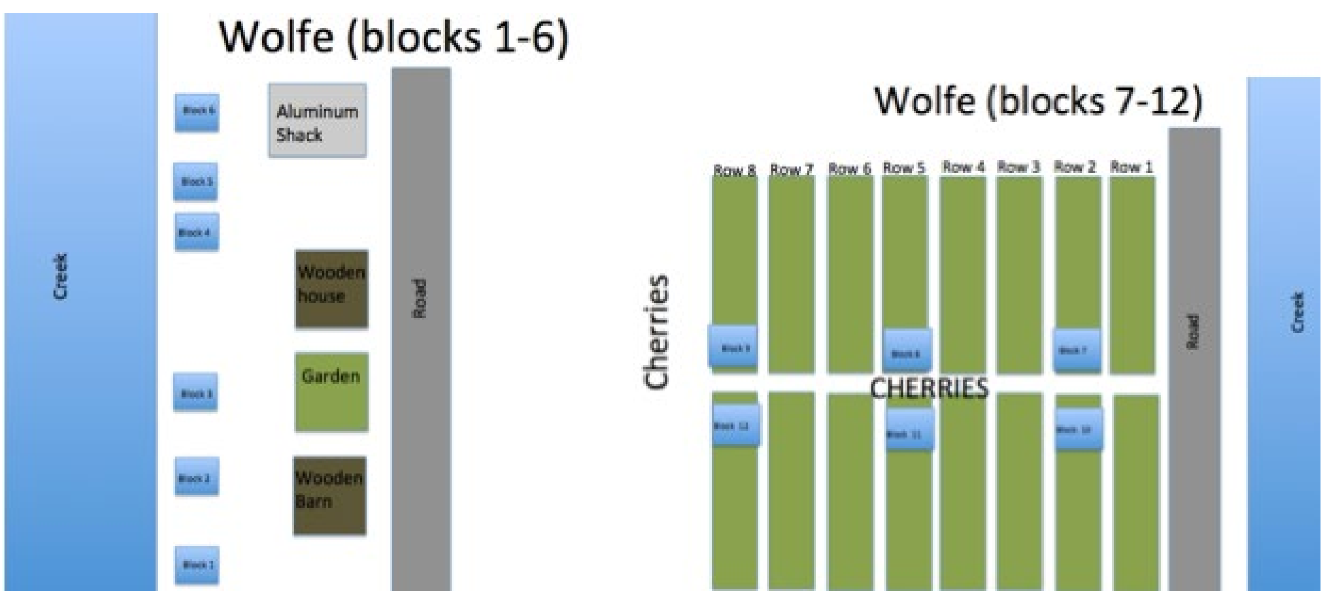



**Figure 3. Map of Wolfe.** Blocks 1-6 were placed in natural habitat and blocks 7-12 were placed in crops.

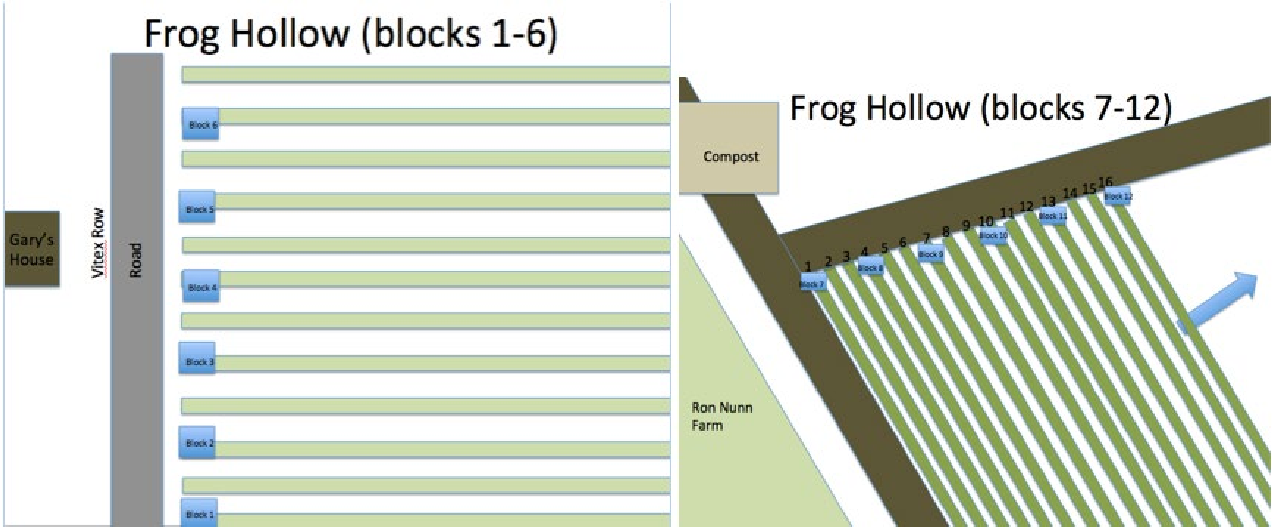



**Figure 4. Map of Frog Hollow.** All twelve blocks were placed in crops.

### Block Design

Each man-made nesting block was composed of 12 individual redwood sub-blocks. There was one drilled hole per sub-block. To determine if there was a bee preference, holes of three different sizes were drilled into each nesting block. The sub-blocks were randomly placed, so the different sized holes were randomly distributed. The drill bit creates a hole that is 5 inches in depth. One-third of the holes have a diameter of 5/16$^{ths}$ of an inch, one-third 4/16$^{ths}$ of an inch, and the last third 3/16$^{ths}$ of an inch (Artz et al. 2013). All 12 sub-blocks were stacked to form 3 rows and 4 columns. When stacked together each man-made nesting block has a total length of 6 inches, a height of 3 inches, and a width of 4 inches. The 12 sub-blocks were held together with masking tape (Figure 5).

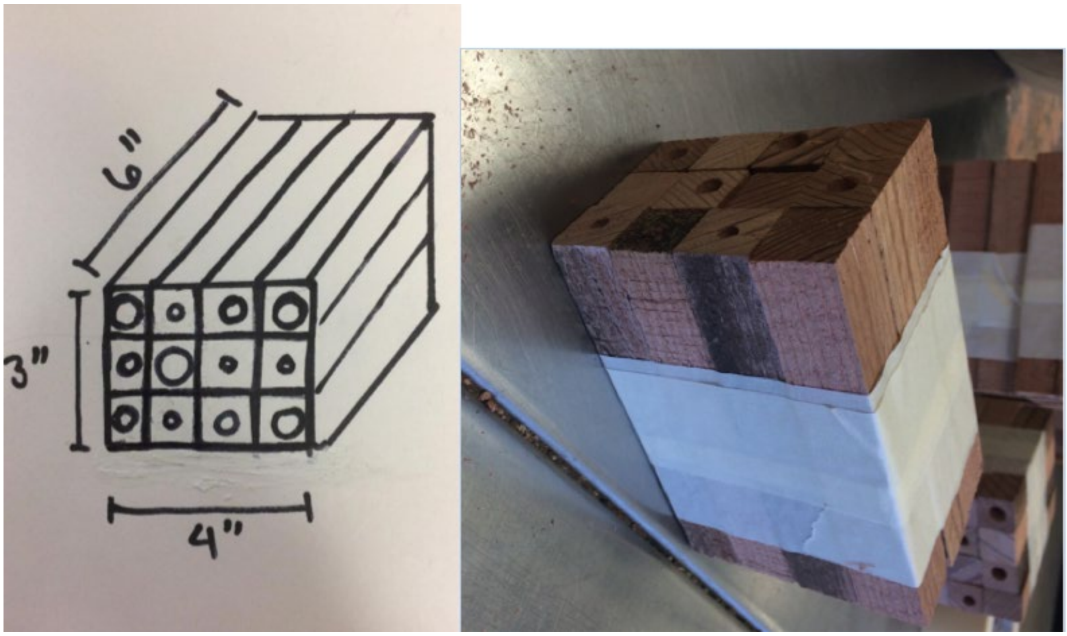



**Figure 5. Diagram and Picture of Nesting Blocks.** Each block consists of 12 sub-blocks for a total dimension of 3x4x6". They are stacked and taped together. There are 3 different randomly distributed sized holes in each block, 1 hole for each sub-block (4 holes of each size per block).

The total of 48 blocks (12 blocks on each farm) was placed out on the farms, on May 13th 2016. Each block was wrapped in polyester string and hung on tree branches so that they were in the shade for the majority of the day. Each block was also labeled in sharpie with the farm name and numbered from 1 to 12 (Figure 6). Placement of the block was recorded through both an approximate hand drawn map (Figures 1-4) and GPS coordinates by dropping a pin on the exact locations with an iPhone mapping system.

Although each farm is a different size, contains different crops, and is adjacent to areas with different amounts of floral resources, some patterns of nesting block placement can be studied 1) nesting block placement at the edge of crops versus outside of the crops and 2) the vicinity of block placement to different amounts of floral abundance. After discussing with farmers, we chose locations on each farm that would not interfere with their activities, such as the collection of fruits and spraying of pesticides.

**Figure 6: Block Implementation Picture.** The blocks are tied with polyester string to branches, so that they are in the shade for the majority of the day. Each block is labeled with the farm name and a number (1-12).

## Data Collection Methods

## Nesting Block Monitoring

To monitor the nesting blocks, the farmer and his workers checked each block throughout the week to ensure that they were still hanging. I also visited the farms once every three weeks to make observations and maintain the blocks. While we recorded the number of holes used and the size of the holes nested in, the occupant insect species based on the nest appearance could not be recorded without rearing. We recorded these discrete data points on a standardized data table.

Whenever sub-blocks were nested in, we replaced the occupied sub-block with a new, empty sub-block of the same hole size. We removed and reared out the occupied blocks, by taping a vial to the openings, and then placed them in a protected, shaded area on each farm. When the bee or parasite hatched in the vial, it could then be pinned and identified. The blocks were left up until November of 2016, when most of the summer bees finished nesting.

**Insect Rearing and Identification**

Once reared out of the vials I pinned the insects and dissected their nests in lab. When the insects died I removed them from their rearing vials and placed them in a humidifying chamber for three days. I then pinned them in insect boxes where the lab taxonomist, Professor Robbin Thorp from UC Davis, identified them.

**Data Analysis Methods**

To gain a broader idea of potential relationships throughout my data, I graphed overall nesting over the seven month period (May-November) and hole size (5/16ths, 4/16ths, and 3/16ths). These analyses were further stratified by location (Dwelley, Frog Hollow, Brookside, or Wolfe), block placement (in or outside of the orchard), and species.

Once I identified my species, I created a generalized linear mixed regression model through R studio using the lme4 package. This model took into account my fixed variables (hole size, placement inside or outside of crops, presense of natural habitat) and random variables (site and block number), so I could better evaluate how bees and other insects chose to nest based hole size, block placement, and presence of natural habitat.

## RESULTS

**General Trends**

From the data gathered from the hatched sub-blocks I found that overall bee nesting abundance in the blocks across all four farms peaked in July and then decreased until December (Figure 7). Approximately 82.6% of nesting occurred in the months of May, June, and July. A total of 51 sub-blocks hatched out. On average each female laid 3.96 larvae that successfully hatched out per sub-block with a range of 1 to 10. The most nesting occurred in hole size 3/16ths and the least nesting occurred in hole size 5/16ths. There were a total of 41 females chose to lay their larvae/eggs in sub-blocks with the $3/16^{th}$ hole size, 7 females laid their larvae/eggs in sub-blocks of hole size $4/16^{th}$, and 2 females laid their larvae/eggs in sub-blocks with a $5/16^{th}$ hole size.

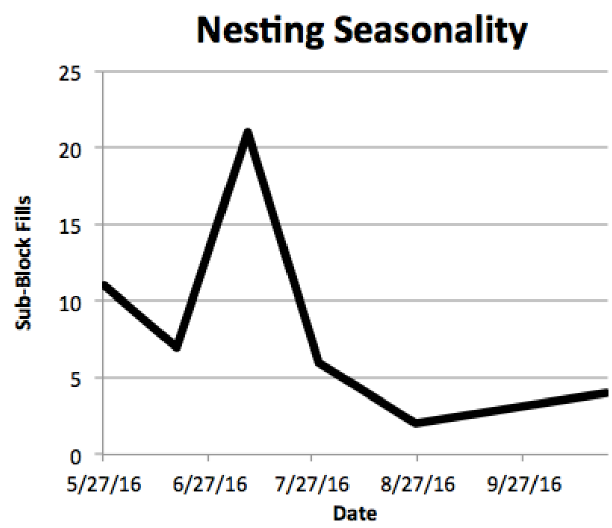



**Figure 7. Overall Nesting Abundance.** Bee nesting peaked from the months of June to July of 2016.

There did not appear to be a significant difference in nesting abundance in different between organic and conventional farms (Figure 8). The farm with the most nest fills (28) was Dwelley, a conventional farm and the farm with the second highest number of fills (14) was Frog Hollow, an organic farm. The farm with the third highest amount of fills (9) was Brookside, an organic farm and the farm with the least amount of fills (1) was Wolfe, a conventional farm.

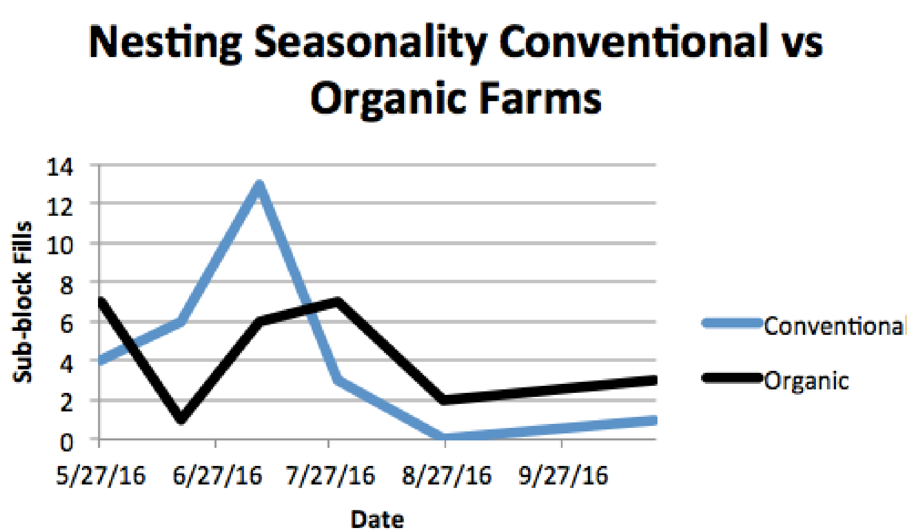



**Figure 8. Nesting Abundance Conventional vs Organic Farms.** Conventional farms sub-block fills peaked in June, while organic farms sub-block fills peaked in July.

When broken down by farm there were differences in nesting abundance between each individual farm (Figure 9). Dwelley had the most nesting in July as well with a peak of 12 sub-fills, Frog Hollow had the most nesting in July with a peak of 6 sub-block fills, Brookside had the most nesting in July with a peak of 4 sub-block fills, and Wolfe had the most nesting in May with a peak of 1 sub-block fill.

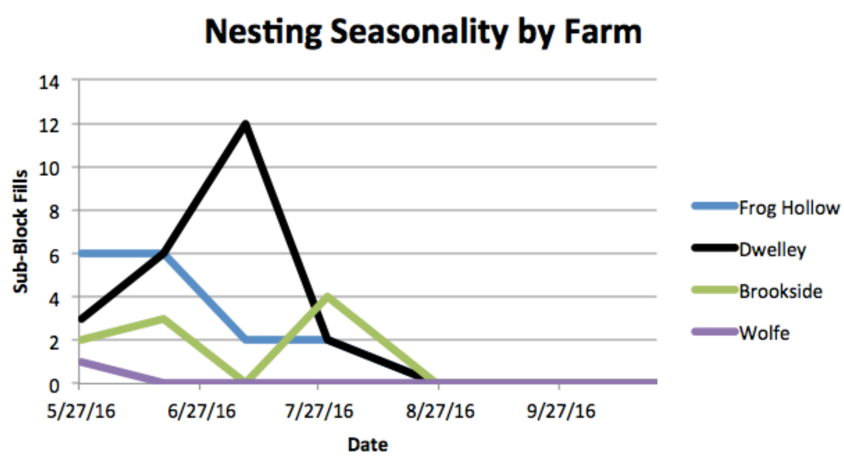



**Figure 9. Nesting Abundance On Each Farm Site.** Each farm site had nesting peaks in July of 2016.

## Species Identification

Professor Robbin Thorp identified a total of 8 different species that hatched from my sub-blocks. There were 3 species of bees from 2 different genera. There were 3 species of wasps identified from 3 genera. The number of species on each farms ranged from 1 to 3 with a median of 1.76. The most common bees and wasps were Megachilidae *Ashmeadiella californica,* Megachilidae *Megachile rotundata, Megachilidae Megachile angelarum,* and Vespidae *Eumeninae*. The most infrequent species were a species of spider and flies. Dwelley and Frog Hollow had the most Megachilidae *Ashmeadiella califronica* and Vespidae *Eumeninae*. Brookside farm had the most Megachilidae *Megachile rotundata* and *Megachilidae Megachile angelarum* (Table 2). I did not observe any direct parasitism of bee larvae in my nesting blocks.

For the total number of offspring that hatched from the sub-blocks, Vespidae *Eumeninae* were the highest with a total of 135 individuals, then Megachilidae *Ashmeadiella califronica* with 48 individuals, and then Megachilidae *Megachile rotundata* with 10 and Megachilidae *Megachile angelarum* with 4 individuals. On average each sub-block with Megachilidae *Ashmeadiella* hatched 4 offspring with a range of 1 to 9. On average each sub-block with Megachilidae *Megachile rotundata* hatched 5 offspring with a range of 4 to 6. On average each sub-block with *Megachilidae Megachile angelarum* hatched 4 offspring (range NA). On average each sub-block with Vespidae *Eumeninae* hatched 5.9 offspring with a range of 2 to 10.

**Table 2. Species Dissection Table**. The trap nesting bees and parasites found on the four different farm sites, the number of sub-block nests created at each site.

| Species | #Nests Frog Hollow | # Nests Wolfe | # Nests Dwelley | #Nests Brookside | Total | Total Offspring Hatched |
|---|---|---|---|---|---|---|
| Megachilidae *Ashmeadiella californica* | 6 | 1 | 8 | 1 | 16 | 48 |
| Megachilidae *Megachile rotundata* | 0 | 0 | 0 | 2 | 2 | 10 |
| *Megachilidae Megachile angelarum* | 0 | 0 | 0 | 1 | 1 | 4 |
| Vespidae *Eumeninae* | 10 | 0 | 14 | 3 | 27 | 135 |
| Strip Winged Wasp | 0 | 0 | 0 | 2 | 2 | 7 |
| Large Wasp | 0 | 0 | 0 | 1 | 1 | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fly | 0 | 0 | 1 | 0 | 1 | 1 |
| Spider | 0 | 0 | 1 | 0 | 1 | 1 |

The number of Megachilidae *Megachile rotundata* nesting peaked in May and June, while the nesting of Megachilidae *Megachile angelarum* peaked in July. Megachilidae *Ashmeadiella californica* nesting peaked in May and July, while Vespidae *Eumeninae* nesting peaked in July (Table 3).

**Table 3. May-December 2016. This shows the number of sub-block fills of the hatched blocks of four relevant specimen.** Highlighted are the months where nesting occurred.

| | May | June | July | August | September | October |
|---|---|---|---|---|---|---|
| Megachilidae *Megachile rotundata* | 1 | 1 | 0 | 0 | 0 | 0 |
| Megachilidae *Megachile angelarum* | 0 | 0 | 1 | 0 | 0 | 0 |
| Megachilidae *Ashmeadiella californica* | 7 | 1 | 7 | 1 | 0 | 0 |
| Vespidae *Eumeninae* | 7 | 3 | 18 | 1 | 0 | 0 |

Species Megachilidae *Ashmeadiella californica,* Megachilidae *Megachile angelarum,* and Vespidae *Eumeninae* had the highest nesting abundance in the 3/16ths hole size. Megachilidae *Megachile rotundata* nesting was split evenly between the 3/16ths and 4/16ths hole size, but had very low abundance (Figure 10). Five different total species nested in hole size 3/16ths and 3 different species nested in hole size 4/16ths. One spider and one wasp species were the only specimen found nesting in the 5/16ths hole size.

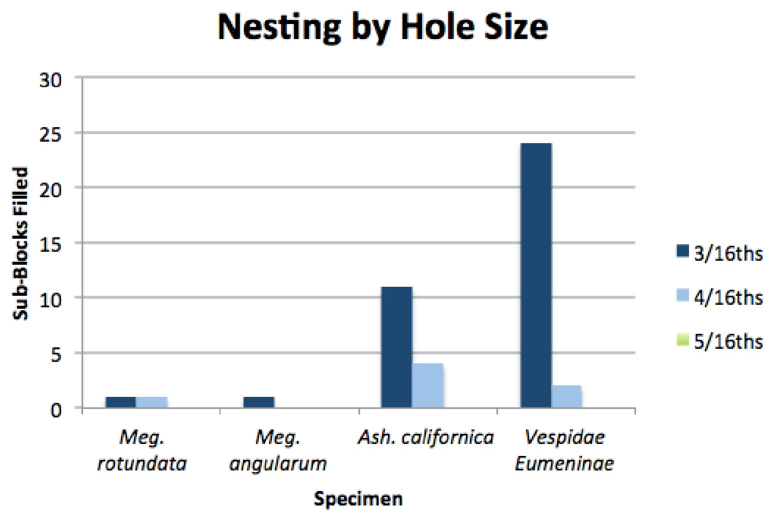
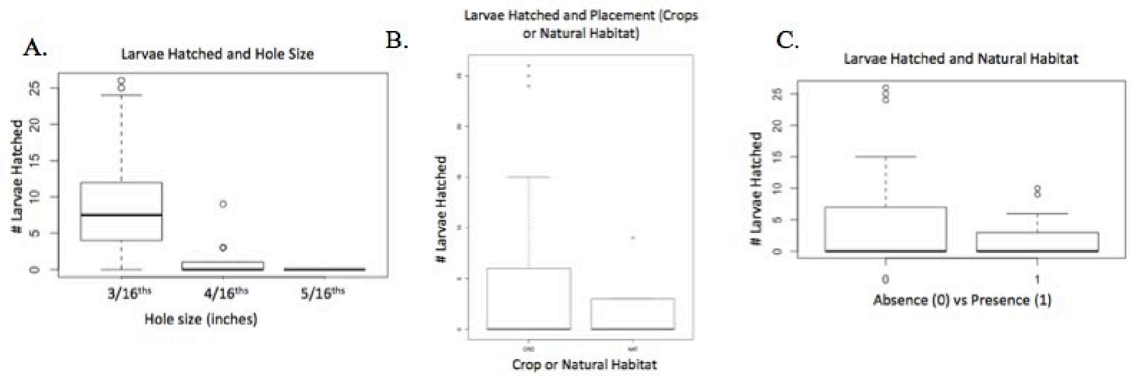



**Figure 10. Nesting by Hole Size and Species**. *Meg. angularum, Ash. californica,* and Vespidae Eumeninae had the most nesting in 3/16ths hole size, while *Meg. rotundata* seems split between the 3/16ths and 4/16ths hole size.

### Mixed Linear Effects Regression Model

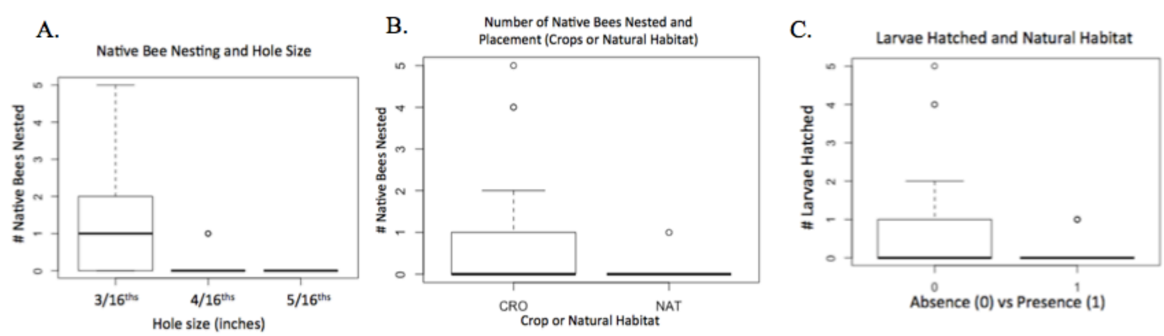
In running four mixed linear effects regression models I found that each had 48 degrees of freedom overall. The test on the number of larvae nested had an overall significance, p<2e-16, the native bee nesting model had an overall significance as well, p=.000189. For *A. californica* the model had an overall significance, p =.01403 and the Vespidae *Eumeninae* model had an overall significant, p= .00163. I could not create a viable model for both M. *rotundata nesting, and M. angelarum* nesting because of their small sample sizes (n<6). For each of the four tests the only significant variable was hole size, while both the variables of block placement and the presence of natural habitat did not have a significant value.

In the first test between the number of larvae laid and the independent variables, the only significant variable was hole size (P < 0.0001). The median number of larvae laid in a hole size of 3/16ths was 7, while the medians for both 4/16ths and 5/16ths were 0 (Figure 11, Graph A). Both placement of the blocks (inside or outside the crops) and the presence of natural habitat did not have a significant relationship with the number of larvae laid (p > 0.05, Figure 11, Graph B and C). The second test tested at the native bee nesting relationship to the independent variables. There was a significant relationship between native bee nesting occurrences and hole size ( p < 0.0001). The median number of native bee nesting in 3/16ths was 1, while the median number nesting in 4/16ths and 5/16ths was 0 (Figure 12, Graph A). Both placement of the blocks (inside the crops or outside) and the presence of natural habitat were not significant in determining the number of native bee nests ($p > 0.05$, Figure 12, Graphs B and C).




| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| (Intercept) | 9.5149 | 0.7299 | 13.036 | <2e-16 | *** |
| HOLE | -2.3655 | 0.2210 | -10.702 | <2e-16 | *** |
| CROPS_NATURALNAT | -0.6805 | 0.4403 | -1.545 | 0.122 | |
| NATIVE_HABITAT | -0.5374 | 0.3706 | -1.450 | 0.147 | |

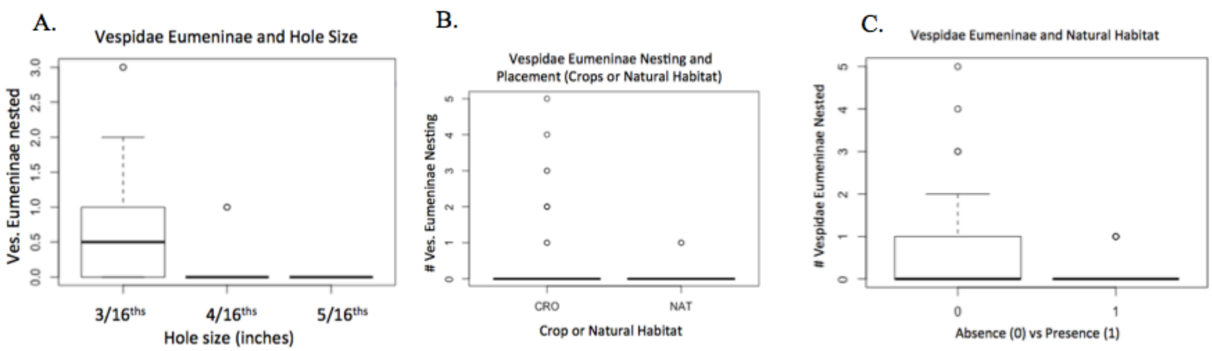
**Figure 11: Number of Larvae Hatched and Hole Size, Block Placement (Crop or Natural Habitat), Natural Habitat.** The numbers indicate that a significant relationship exists between Larvae hatched and hole size (A), while both the placement of the blocks and the surrounding natural habitat does not appear significant (B and C).




| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| (Intercept) | 6.1289 | 1.6414 | 3.734 | 0.000189 | *** |
| HOLE | -1.9933 | 0.4869 | -4.094 | 4.24e-05 | *** |
| CROPS_NATURALNAT | -1.1905 | 1.1533 | -1.032 | 0.301948 | |
| NATIVE_HABITAT | -0.2028 | 0.8302 | -0.244 | 0.807043 | |

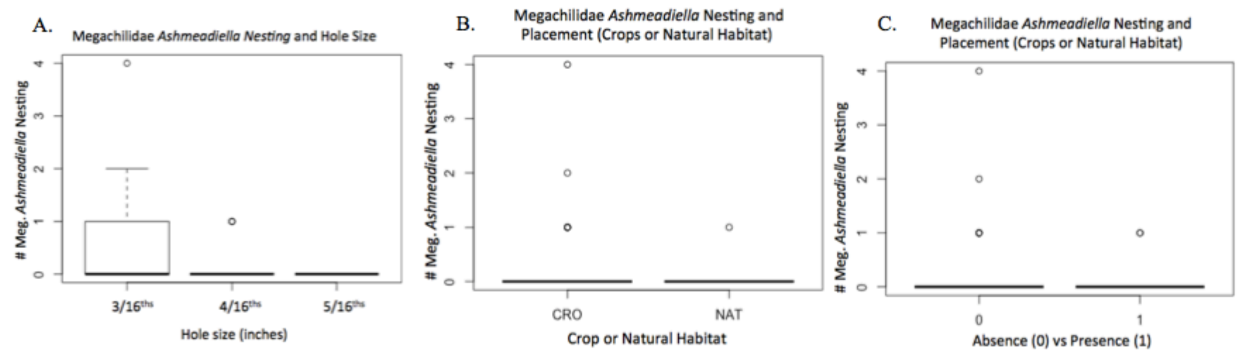
**Figure 12: Number of Native Bees Nested and Hole Size, Block Placement (Crop or Natural Habitat), Natural Habitat.** The numbers indicate that a significant relationship exists between native bees nested and hole size (A), while both the placement of the blocks and the surrounding natural habitat does not appear significant (B and C).

Although Vespidae *Eumeninae* and Megachilidae *Ashmeadiella californica had sufficient hatching rate to run tests,* there were not enough data points for both Megachilidae *Megachile angelarum* and Megachilidae *Megachile with their* low sample size of n >6. For Vespidae *Eumeninae*, the only significant variable was hole size (p = 0.0012). The median value of the nesting in hole sizes of 3/16ths was 0.5, while the medians of 4/16ths and 5/16ths were both 0 (Figure 13, Graph A). Both placement of the blocks (inside or outside the crops) and the presence of natural habitat were not significant in determining the number of nesting of these wasps (p > 0.05, Figure 13, Graph B and C). For Megachilidae *Ashmeadiella californica* nesting I found a significant relationship between occurrence and hole size (p = 0.014). The median values of nesting for 3/16ths, 4/16ths, and 5/16ths was 0 (Figure 14, Graph A). Placement of the blocks (inside or outside the crops) and the presence of natural habitat were not significant in determining the number of larvae laid was not significant (p > 0.05, Figure 14, Graph B and C).




| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| (Intercept) | 6.7961 | 2.1574 | 3.150 | 0.00163 | ** |
| HOLE | -2.2228 | 0.6867 | -3.237 | 0.00121 | ** |
| CROPS_NATURALNAT | 0.9808 | 1.2247 | 0.801 | 0.42322 | |
| NATIVE_HABITAT | -1.6275 | 1.0351 | -1.572 | 0.11589 | |

**Figure 13: Number of Vespidae *Eumeninae* nested and Hole Size, Block Placement (Crop or Natural Habitat), Natural Habitat.** The numbers indicate that a significant relationship exists between native bees nested and hole size (A), while both the placement of the blocks and the surrounding natural habitat does not appear significant (B and C).




| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| (Intercept) | 4.5909 | 1.8689 | 2.456 | 0.01403 | * |
| HOLE | -1.6527 | 0.5622 | -2.940 | 0.00328 | ** |
| CROPS_NATURALNAT | 0.3464 | 1.5099 | 0.229 | 0.81854 | |
| NATIVE_HABITAT | -1.3383 | 1.1398 | -1.174 | 0.24034 | |

**Figure 14: Megachilidae *Ashmeadiella californica* nested and Hole Size, Block Placement (Crop or Natural Habitat), Natural Habitat.** The numbers indicate that a significant relationship exists between native bees nested and hole size (A), while both the placement of the blocks and the surrounding natural habitat does not appear significant (B and C).

## DISCUSSION

As agriculture's main pollinator, the honey bee, continues to decline, scientists are looking to supplement their pollination capabilities with native bees. This study was conducted to better understand how California farmers could increase this form of native pollination, through manipulating man-made nesting block design and placement. I hypothesized that the majority of native bees would be from the genus *Osmia* and that different species would have different hole size preferences. I expected more nesting to occur on farms that were organic and surrounded by native habitat, in comparison to those that were conventional and not surrounded by native habitat. I also thought that block placement in or outside the crops would affect nesting numbers. Although there were significant numbers of both native and non-native species nesting in the blocks with nesting hole size preferences, block placement and nearby native habitat were not significant. No significant trend was detected between convention and organic farm nesting.

Continued monitoring of nesting bees during non-drought years through UC Berkeley's Urban Bee Lab will increase knowledge to help farmers better attract supplement pollinators to their crops in Contra Costa County.

**Species and Nesting Seasonality**

There was a clear seasonality in nesting times, where overall bee nesting peaked in early summer between the months of June and July, indicating an optimal time for the farmer to place his/her blocks out to maximize pollination by certain species that are known to pollinate a particular crop on their farm (Table 4).

The main pollinator found, Megachilidae *Ashmeadiella californica* (16 total sub block fills) were particularly common on the organic farm Froghollow (7 fills) and on the conventional farm Dwelley (7 fills). While the literature indicates that these are great pollinators of legumes, melons, cactus, and compositae (Michener C.D. 1939, Rozen J. and Eickwort G. 1997), the nesting blocks where these A. *california* fills were found on these two farms were within orchards of stone fruits (plums and cherries). Future research could be done to look at pollen samples on this species of bee to see if they could be potential pollinators of these crops as well.

The majority of the nesting occurrences came from the Vespidae *Eumeninae* with 29 total sub-block fills. Although not a pollinator, it is often used as a pest controller that eats caterpillar eggs and beetle larvae (Judd 2017). Their long tubular nests are composed of individual cells, delineated by mud caps and provisioned with their paralyzed prey (Brockmann 1980). While the different types of pests in agricultural towns are constantly changing and evolving, the latest Contra Costa County pest report of 2015, found that the second most common invasive pest was the Japanese beetle (Contra Costa County Dep. of Ag. 2015). While traps are left out in farms to kill off the pest, perhaps the implementation of these nesting blocks during their peaking nesting season of the May through August, could better control their agriculturally damaging populations.

In trying to answer the question of the seasonality of different wood nesting bees and wasps, the time restraints and conditions of the study environment must be considered. Data was collected for only eight months, which missed the crucial spring months of February through

May. These months are the main nesting time of *Osmia* spp., which are known pollinators of many crops like cherries and plums (Bosch et al. 2008). Furthermore, as data was collected during the five-year drought in California, nesting patterns could change with more rainfall.

**Table 4. Reported Literature Species Seasonality and Crop Pollination.** This table compares the nesting times I observed from each species and the nesting seasonality reported in the literature. Furthermore, the crop each species pollinates is listed, so that farms know the optimal time to place out their nesting blocks to attract pollinators for a particular crop.

| Species | What They Pollinate | Nesting Season from Data | Nesting Season from Literature |
|---|---|---|---|
| Megachilidae *Ashmeadiella californica* | Legumes, melons, cactus, and compositae<br><br>(Michener C.D. 1939, Rozen J. and Eickwort G. 1997) | May-August (peak in July) | May-August<br><br>(Michener C.D. 1939) |
| Megachilidae<br><br>*Megachile rotundata* | Alfalfa, canola, berries<br><br>(Abbott et al. 2008, Kemp W.J. et al. 2004) | May and June | Late Spring to Early Summer<br><br>(Pitts-Singer T. and Cane J. 2011) |
| Megachilidae<br><br>*Megachile* angelarum | Alfalfa, cherries<br><br>(Barthell J.F. et al. 1998) | July | May-October<br><br>(Sheffield C.S. et al. 2011) |
| Vespidae Eumeninae | No pollination- eat crop pests like caterpillar eggs and beetle larvae (Judd T.M. and Fasnacht M.P. 2017) | May- August (peaked in July) | May-August<br><br>(Carpenter J.M. and Cumming J.M. 1985) |

## Hole Size

The most nesting occurred in the 3/16ths hole size, Vespidae *Eumeninae (24 fills),* Megachilidae *Megachile angelarum (2 fills)*, Megachilidae *Ashmeadiella californica (11 fills),* and Megachilidae *Megachile rotundata* (2 fills). The second most nesting occurred in the 4/16ths hole size, Megachilidae *Ashmeadiella californica (4 fills),* Vespidae *Eumeninae (3 fills), and* Megachilidae *Megachile rotundata (2 fills)*. The only insects found in the larger hole size of

5/16ths were spiders and larger wasps. While there is lots of literature on the different *Osmia* spp. preferences for different hole sizes, literature does not point to a particular hole size preference for the bees that I found. Some studies in the tropics did find that Vespidae *Eumeninae*, had a significant preference to hole sizes of 4/16ths (Coville R.E. and Griswold C. 1983). This actually contradicted with my data, which showed these wasps having a singificatnt preference for the smaller 3/16ths hole size. Perhaps this difference can be attributed to the different environments in which these studies were conducted. From my data it be could advised to not use this larger hole size, as I found it attracted insects that were not useful for agricultural production and instead use the smaller hole sizes to better pollinator attractors.

Only 3 different hole sizes were tested which probably excluded certain important bee species from nesting, like *Xylocopa spp and Osmia* spp. For example, Apidae *Xylocopa* spp. (carpenter bees) require hole sizes of approximately 10 mm in diameter. Apidae *Xylocopa* spp. have the potential to become commercial tomato pollinators (Hogendoorn et al. 2000). In future studies I could create a larger variety of hole sizes to account for this. In addition, the sampling windows was outside of the *Osmia* nesting season in the spring time, but our lab's past data shows that they prefer the 4/16ths hole size (Gordon Frankie, personal communication). Literature shows that different speices can have different prefences, for example *Osmia lignaria* prefer a larger hole size of 4/16ths and 5/16ths (Tepedino and Torchino 1989), while *Osmia cornuta* prefer the smaller hole sizes of 3/16ths and 4/16ths (Bosh and Blas 1994). Thus with more time to collecting data during these spring months, more information could be gathered on the different species present on each farm and their corresponding hole size preference.

**Block Placement: Within the farm and presence of natural habitat**

The linear mixed effects model did not find any direct correlation with block placement (inside or outside of crops) and with the presence of natural habitat. While a loss of natural habitat by agricultural conversion usually means a decrease in foraging and breeding habitat (Fishcher and Lindenmayer 2007), there is also evidence that many bee species can survive with small fragments of habitat, as bees often fly up to three or four miles a day to gather food (Aguilar et al. 2007). This suggests that bee could be less disturbed by anthropogenic fragmentation as some think, as long as some pollen and nectar sources are preserved and available throughout the year (Kremen 2009). This seems to align with the lack of significance between bee nesting and placement of blocks inside and outside of crops and the presence of natural habitat. As long as there was some food source within their flying range, they could survive on farms with limited amounts of adjacent natural habitat and thus in blocks placed anywhere around the farm.

Although I chose to turn my data measurements into binary values, if I had more time I could of calculated floral abundance with GIS data. It was hard to determine the relationship of nesting bees without calculating the floral abundance at the times in which the blocks were placed on the sites. It could also be useful to create an inventory with common native bees in the area to determine if the nests are capturing a full variety of species. This inventory would require monitoring the main areas primary to the study and including past literature (Frankie et al. 2005).

**Conventional verse Organic Farms**

I did not find a significant difference in nesting between organic and conventional farms. This was of interest as recent studies have shown that certain native bees like *Meg. Rotundata* and *Bombus impatiens*, their internal navigational systems are not as affected by indirect contact with pesticides (from pollinating crops sprayed with pesticides), as honey bees (Bailey et al. 2005). Perhaps this begins to explain why there were not significant differences in native bee nesting between conventional and organic farms throughout my data set. While probably not beneficial to a native bee, it is thought that pesticides may be more easily broken down inside native bees in comparison to honey bees due to their different biology (Scott-Dupree 2009). Furthermore, the lack of nesting differences between conventional and organic farms could of occurred due to a combination of other factors, such as the amount of natural habitat around each farm and also due to the limited times and number of sites in this study.

**Parasitoids**

Direct parasitoids of bee larvae through the forms of certain wasps and mites were expected to be common in these nesting blocks (MacIvor et al. 2015 , Goka et al. 2000), but I was surprised to find none. Both of these previous studies found that in both Canada and Japan so many wasps and parasitoids directly harmed bee larvae that the blocks were rendered inadequate habitats for farm pollinators. Furthermore, in the Canadian study over 3/4ths of the nesting fills were from non-pollinating native wasps. This was similar to the data collected through this study, as the majority of nesting occurred from wasps, which could of acted as indirect competition. While I tried to account for this by removing nested sub-blocks and replacing them with empty sub-blocks, I am unsure if the nesting of the wasps affected the nesting of the native bees. Furthermore, in future studies where the blocks would be left out in the spring months, there could be more attraction of parasitoids to *Osmia* spp. larvae. Further studies need to see if these blocks are larger attractors of non-pollinators, like wasps, than bees.

**Limitations & Future Directions**

With the push for more research on nesting blocks, there are ways in which my research questions could be expanded to improve future experiments. I would increase the number of sites on which I set out my blocks and the number of blocks per farm. This would allow my blocks to cover more area and for a larger number of bees and wasps and other parasites to nest. The study would also be extended to include the spring months of February through May to attract the *Osmia* genus, which is a known pollinator of California orchard crops, particularly cherries and plums (Bosch et al. 2008). Furthermore, this experiment was collected during a drought year, so data from non-drought years could have different nesting patterns and different species.

By both increasing the number of blocks and by collecting for a longer period of time, I would hopefully have a larger total number of observations so that my mixed effects linear regression model will be more robust and indicate relationships between specific species and other factors like block placement and the presence of natural habitat. For example, for both Megachilidae *Megachile angelarum* and Megachilidae *Megachile rotundata,* I did not have enough collections to run them through my model. A larger number of future observations could help better under understand these species nesting patterns and preferences.

Also, with more funding, different block materials could be tested, as well as different hole sizes. An expansion of the experiment is currently happening through the UC Berkeley Urban Bee Lab in Contra Costa County on twelve different farm sites.

**Broader Implications**

Currently the global agriculture system is in a paradoxical bind, where farmers depend on bees to produce yield, while simultaneously needing to degrade pollinator habitat and livelihood with enhanced technologies to increase their profit margins. The dependence on the honey bee is frightening as many fear that its collapse will negatively impact our already strained global food system (Stokstad 2007). As a result of this dependence, farmers are forced to spend millions of dollars purchasing and transporting honey bees to maintain their current levels of production, and they could instead be investing in maintaining pollinators biodiversity. Native bees are capable and sometimes even more efficient pollinators of crops (Winfree et al. 2007, Ricketts 2004). This capability and efficiency suggests that native bees could be a great supplementary pollination source to honey bees if provided with enough habitat and sufficient food and shelter (Kremen et al. 2004). Through the implementation of man-made nesting blocks, habitat is provided in these altered landscapes so that wood nesting bees could potentially aid in the pollination of crops. Thus, increasing pollinator diversity through increasing their native bee habitat could better insure the resiliency of our agricultural system, preventing both economic and ecological losses.

## ACKNOWLEDGEMENTS

I would also like to thank everyone in the Urban Bee Lab, especially Professor Gordon Frankie and the lab manager Sara Leon Guerero. Also thank you to all of the undergraduates who helped me collect my data including Ginger Haight, Christopher Jadallah, and Ingrid Feng. Thank you to the entire ESPM 175 team, particularly to my thesis mentor Tina Mendez who helped me throughout the entire process, editing my drafts and helping analyze my results and to Dylan Chapple who helped create a linear model for my data. Working and participating in this lab for the past two years has defined my college experience and what I hope to achieve in the future. Thank you to Professor Robin Thorpe whose bee and wasp identification skills are invaluable. Also, thank you to CNR's Sponsored Projects for Undergraduate Students funding.

Without the financial support I received through this sponsorship my experiment may not have proceeded. And lastly, thank you to my parents and brother who support me in all that I do.

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