Monitoring Bee Pollination Services on Willamette Valley *Vaccinium* Farms

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Table of Contents

List of Figures

EXECUTIVE SUMMARY

The purpose of this study was to monitor the behavior and population counts of *Bombus* spp. and *Apis mellifera* on *Vaccinium* farms in the Willamette Valley of Oregon. With global pollinator populations declining there is a concern for the reproduction of plants that rely on biotic pollination, most notably food crops. Through this study we obtained a better understanding of the role each genus plays within pollination services.

This research project had two separate studies: first, to monitor behavior through observing the number of *Vaccinium* flowers pollinated per minute per bee, also described as floral handling rate. We observed three *Bombus* and three *Apis* along each transect, following as they moved from flower to flower. The second study was to monitor bee populations in order to establish a comparison between *Apis* and *Bombus* presence. The population survey was an overarching count of the bees, by group, present within 30m and 60m at six local farms. We delineated three main variables that influenced both studies: farm size, farm assessment score, and bloom time.

Behavior or floral handling rate for *Bombus* and *Apis* was proportional across all variables, with *Apis* pollinating an average of 3.52 flowers per minute and *Bombus* pollinating 11.22 flowers per minute. From the population study, we found that *Apis* were more abundant than *Bombus*, although there was no strong correlation between population counts and variables. To compare the overall effectiveness of Apis versus Bombus, we multiplied the average floral handling rate by the average population count of each bee group to determine bee efficiency, which we define as the average number of *Vaccinium* flowers pollinated by bee group per minute. From this, we found that at certain sites *Bombus* were more effective at pollinating *Vaccinium* bushes, even with

lower presence. These sites had the higher habitat assessment scores, which indicate a better site for native pollinator habitat. The implications of our research are that *Bombus* are three times more efficient at pollinating *Vaccinium* flowers than *Apis,* which occurs at farms with better habitat for native bees.

INTRODUCTION

In the last 25 years, scientists have observed sharp declines in global pollinator populations (Pywell et al. 2011). These trends are of great concern because of the ecosystem services provided by pollinators, including an observed reduction in the plant populations that rely on pollinators for reproduction (Potts et al. 2010). Different studies have proposed various causes for the decrease of pollinators. In large part, declines have been attributed to a phenomenon called Colony Collapse Disorder (CCD), in which worker bees abruptly disappear. The causes of CCD are not fully understood but several have been hypothesized, including Israeli Acute Paralysis Virus (Mader, personal communication, 2012), and disrupted navigational senses (Boyle 2007). Disappearing pollinator populations and reduced species diversity have also been attributed to a combination of anthropogenic influences, including habitat loss and fragmentation (Pywell et al. 2011; Pendergrass et al. 2008), increased pesticide use (Pywell et al. 2011; Pendergrass et al. 2008), agricultural intensification (Rao & Stephen 2010), and introduced pathogens. Studies have listed multiple drivers for diminishing populations, with the common theme of multiple factors synergistically impacting pollinators (Potts et al. 2010). Pywell (2011) and Rao & Stephen (2010) agree with this conclusion.

The implications of these declines are especially important in the agricultural sector. Historically, non-native European honeybees (*Apis mellifera)* have been the most commonly used pollinators (Potts et al. 2010; Vaughan et al. 2007), despite the advantages of using native pollinators (Xerces 2007). Domestic honeybee stocks in the United States have declined by almost 59% between 1947 and 2005, making sole reliance on *A. mellifera* an uncertain practice (Potts et al. 2010). These declines make new management practices crucial, by incorporating ways to attract alternative pollinators, especially bumblebees (*Bombus* spp.), to agricultural landscapes (Pendergrass et al. 2008; Vaughan et al. 2007). Ongoing decline of *Bombus* populations has also been documented (Potts et al. 2010), implying that management practices must not only attract alternative pollinators but also provide beneficial habitats and food resources to sustain their populations in the long term (Rao & Stephen 2010). With almost $3 billion dollars in pollination services provided by native bees in 2000 (Vaughan et al. 2007), these species already benefit agricultural production, and the value of these services will only increase with agricultural intensification, and continuing *A. mellifera* population declines.

Even with a reduction in *A. mellifera* populations, many scientists have expressed that native bees could compensate lost pollination services (Rao & Stephen 2010). There are over 4,000 species of native bees in North America, with at least 45 species of *Bombus* in the United States alone (Xerces 2007). A single queen founds each nest, and the colonies last one season. One colony can contain anywhere from one- to three-hundred worker bees (Xerces 2007). Bumblebees tend to be ground-nesters, preferring abandoned rodent burros or hives under lodged grasses (Xerces 2007). In the Northwest, the prime pollination season for blueberries (*Vaccinium),* tree fruits and wildflowers, favored by *Bombus*, is early spring and late winter during cold and wet weather. Yet the most pollination occurs in the summer during sunny and warm weather. *Bombus* tend to pollinate in less favorable conditions than honeybees, earlier in the season, while honeybees stay in their hives until weather improves (Tuell & Isaacs 2010). *Bombus* also buzz pollinate, visit more flowers per minute, (Steven et. al 2009) and forage longer each day. During buzz pollination, bees grab onto the anthers of a flower and move their flight muscles very rapidly, forcing the pollen out (Xerces 2007). Buzz pollination is a more efficient method of pollination, hence the importance of bumblebees as *Vaccinium* pollinators.

Because of their importance, creating viable habitats for native bees is an integral aspect of agricultural production. Successful native bee populations require specific habitats consisting of sufficient nesting sites, sequential bloom, and a high ratio of native vegetation to crop plants. Along with nesting habitat, there must also be plentiful foraging space. Characteristics to consider when analyzing this aspect are percent cover of natural vegetation within ½ mile, variety of non-cropped plants (mix of natives is best), percent of vegetation cover (non-crop) that contains forbs or flowering shrubs within ½ mile of site, number of flowering species, and the succession of flowering plants throughout all seasons (Xerces Habitat Assessment 2010). Additional landscape features that are beneficial include hedgerows, windbreaks, riparian buffers, and overall flora diversity (Xerces 2007). There are many specialized bees for specific crops so it is important to address characteristics of superior habitat when analyzing or enhancing a field.

Farm management practices also influence habitat quality. Small farms (0.2-2.8ha) tend to have more nectar resources; limit tilling and pesticide use, and carry high populations of wild bees as a result (Isaacs and Kirk 2010). For larger farms (greater than

2.8ha), fragmentation of crop area may be necessary because natural habitat availability within ½ mile of the farm has a direct influence on pollinator diversity and abundance (Xerces 2007). Ratti et al. (2008) found that native bees stay closer to their habitats, making foraging into smaller fields more probable and convenient than venturing into the middle of a hundred hectare field (Ratti et al., 2008). Conservation or restoration of weedy buffers between fields and roads into pollinator crops is one method, but native bees forage a radius of 500-1000m, so hedgerows solely along borders of fields may not always be enough to attract an even spread of pollinators across all the crops. Our research communicates the importance of native bee habitat while encouraging farmers to implement the best management practices for restoration.

MONITORING QUESTION

In analyzing our study sites, we address two questions:

1. How does *Apis* and *Bombus* pollination efficiency compare during the pollination of *Vaccinium* bushes?
2. Is there a difference between *Apis* and *Bombus* populations at each site and does it relate to availability of native habitat?

To investigate these questions, we monitored bee behavior and population at six sites through implementing the protocol outlined in the Methods section below.

METHODS

Study Areas

The six farms we studied were in the Willamette Valley, in and around the city of Eugene.

Small Farms

Farm A is a family owned and located in Southeast Eugene. *Vaccinium* are managed through conventional farming techniques. The field size is .8 hectares (ha) and is contained within one plot. There are some flowering trees on site, along with clovers and grasses between each row. The neighboring properties are flower farms, including a large field of clover. Farm A rents 6 *Apis* hives.

Farm B is located in North Eugene less than 150m from the Willamette River. The plots are separated into three age groups in a field less than .5 ha: 40, 25, and 10. Farm B has a variety of ornamental flowers and fruit trees, along with 1.6 hectares that are managed with a western pollinator seed mix of clover and grasses to attract bumblebees. It is organic, and their neighbors have 50 *Apis* hives.

Farm D is located 35 miles east of Eugene and is certified organic. The field is .8 ha and contains about 1,500 plants. Farm D also grows other crops and has an orchard along with flowers, including *Helianthus annus* and *Lavandula*. The farm has 2 hives of *Apis* and a nest of *Osmia*.

Large Farms

Farm C is a 50-year-old farm located in Northwest Eugene. They are certified organic by Oregon Tilth and the USDA. The farm contains 4,400 high-bush *Vaccinium* plants. These are split into 4 plots depending on age and field size ranging from 4 to 5 ha. The plots are separated into three age groups: 50 years old, 25 year old, and 15 years old. *Vaccinium* is the only crop on the farm and the remainder of the property is 45 acres of unmanaged hay and pasture. The properties nearby grow *Vinus vinifera* and *Vaccinium*. Farm C does not own *Apis* hives, but a nearby farm has 27 hives.

Farm E is located just east of Eugene and has been cultivating *Vaccinium* for 60 years. The farm has been managed organically for the past 17 years and has also managed Farm D in the same manner for around 6 years. They have 4 *Apis* hives that are maintained year-round. The farm has 80 other crop varieties that provide nectar sources to bees throughout the 2.2 ha site. They also interplant other plants between the rows.

Farm F is located east of the Eugene-Springfield area. This 2.8 ha farm has over 6,000 *Vaccinum* plants. The farm does not use herbicides or pesticides; they use fertilizers and fabric for weed control. The farm has 5 *Apis* hives. There are many flowering plants on the property, including *Rhododendrons* and fruit trees.

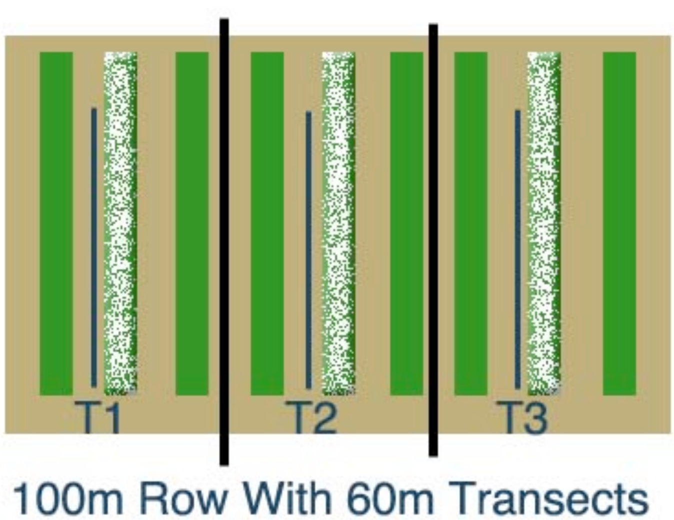
Field Methods

In our pollinator studies we visited six farms. Three are within small parameters (< 1 hectare) and the other three are within the large parameters (> 1 hectare). Transects at the large farms were 60m and 30m at the small farms. The surveys were only conducted when the outside temperature was above 15^{o} C, weather was partly cloudy to sunny, and the flowers were blooming. Surveys were not conducted when wind speed exceeded 5.6 mph, a measurement determined by Envirometer or the Beaufort wind scale.

The team mapped and established all transects before we began our studies. We determined transect location by employing a systematic sampling design; we divided the field into equal sections, randomly chose a row, and then followed the pattern in the other sections of the site. We flagged the beginning and end of each surveyed row with temporary markers to ensure that we visited the same transects when monitoring. Transects were greater than 8 meters apart to avoid double counting of pollinators. Teams of four researchers completed the monitoring surveys, and team was split into sub teams of two. Each sub team focused on either the pollinator population or behavior assessment surveys. One researcher would verbally monitor and identify the bees, and the other would record the observation. For the pollinator identification survey this meant determining the species category and count.

Transects were walked at 3 meters per minute. We did not stop the timer to record a large grouping of pollinators; we slowed down in high-populated areas and quickened in lower populated areas. If we did not finish transects within 10 or 20 minutes, we stopped and estimated how many meters we covered. The same transects were used for both surveys, with a 15 minute interval between each survey to allow pollinators to return to their normal behavior. The behavior assessment involved identifying the species and number of flowers visited. This was done by observing an individual pollinator visiting *Vaccinium* flowers and counting the number pollinated in one-minute observation periods. We attempted to observe three *Bombus* and three *Apis* along each transect. We recorded the start and end time to normalize our results and gage distance.

To determine if we surveyed the left or right side of the bushes, we flipped a coin. If rows were longer than 60 meters, we stopped at 60m regardless (Figure x).



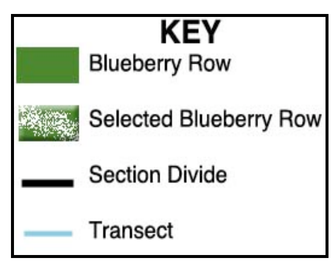


Figure 1: The placement of a 60m transect within a 100m row

If rows were shorter than 75 meters, we wrapped over to the same side of the next row, while walking in the opposite direction.

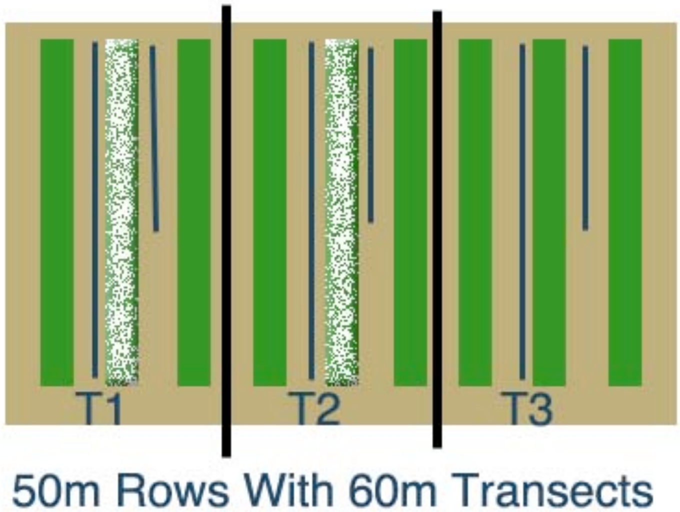


Figure 2: The placement of 60m transects with a 50m row.

Analysis

We analyzed 3 variables in the results: farm size, bloom time of *Vaccinium* bushes, and farm assessment scores. The farms assessment scores are based on Xerces Society's Pollinator Habitat Assessment Form. Scores are determined by analyzing available healthy pollinator habitat from three main categories: nesting habitat, foraging resources, and landscape features. Although this is not the intended use of the assessment guide, we indirectly used it to relate habitat quality to native bee presence.

The behavior assessment was a qualitative observation of the number of flowers pollinated by each bee species, *Apis* and *Bombus*, within the same transects. We termed this assessment floral handling rate. When calculating floral handling rate and population count averages we combined data across all bloom times and transects to then compare against the independent variables. When analyzing the behavior and population surveys against bloom time, we pooled data across all farms and transects. Analyzing the farm assessment scores was the only time we kept the individual farm data separate.

By multiplying the average floral handling rate per minute and the average population count of each bee group, we were able to compare the average number of flowers pollinated within transects during one minute by bee groups. We termed this 'bee efficiency'. Knowing the bee efficiency rate per minute for *Apis* and *Bombus*, we can extrapolate it to the variables of farm assessment score, bloom time, and farm size to see if there is any correlation to *Bombus* pollination rates.

RESULTS

Behavior Survey

Farm Size

Bombus on average pollinated about 3 times as many flowers as *Apis*. Farm size did not play a significant role in the behavior of the two bee groups.

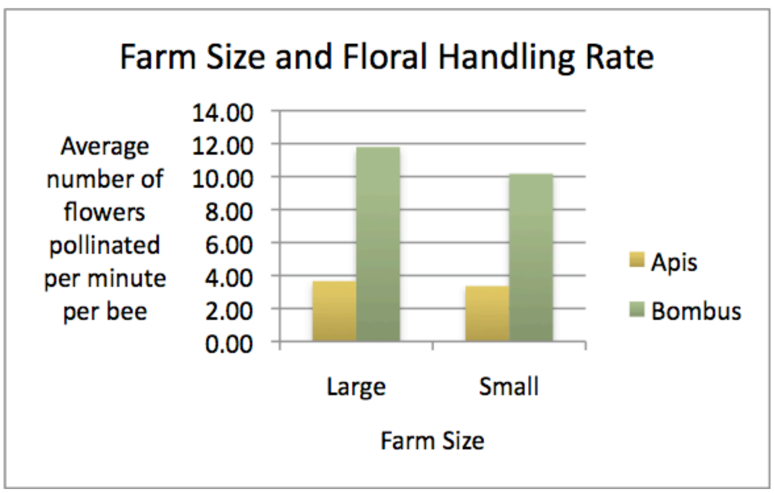


Figure 3: **Average Vaccinium flowers pollinated per minute per bee by farm size, across all boom windows.**

Bloom Time

Bloom time is an important factor influencing the number of flowers pollinated for both bee groups. Early bloom had the highest rates of flowers pollinated, at 13.5 for *Bombus* and 4.6 for *Apis.* These numbers gradually declined through mid bloom and into late bloom, in which *Apis* pollinated 2.5 flowers and *Bombus* pollinated 6.9 flowers per minute.

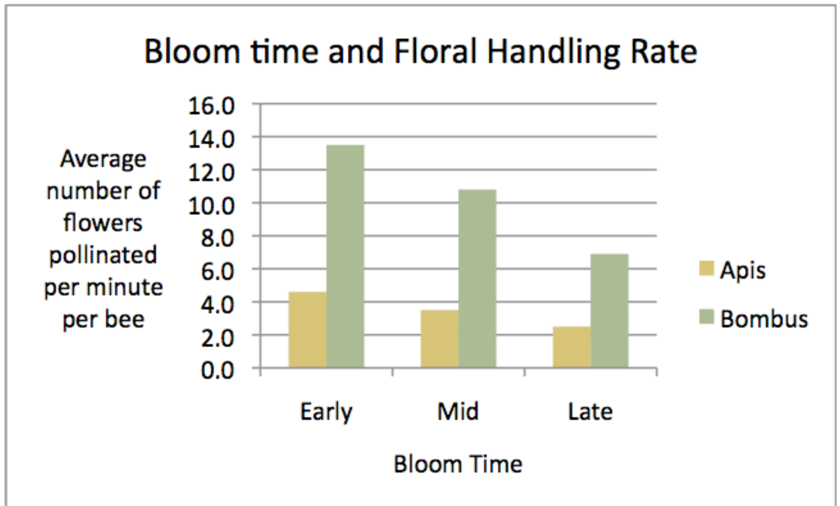


Figure 4: Average Vaccinium flowers pollinated per minute per bee by bloom time, across all farms

Bee Efficiency

The overall average floral handling rate (AFHR) from all surveys was 3.52 flowers pollinated per minute per bee for *Apis* and 11.22 for *Bombus*. We extrapolated these averages to all bees within their group because their floral handling rates were similar across all variables. However, the population counts varied by variable, so we used the floral handling rate averages to scale the population counts to come up with 'bee efficiency'.

Bee efficiency is the average number of *Vaccinium* flowers pollinated by bee group per minute per transect. To determine bee efficiency, we multiplied the average floral handling rate per minute by average population count of each bee group.

The bee counts varied by variable, so we multiplied the AFHR by the bee counts to scale each bee efficiency graph.

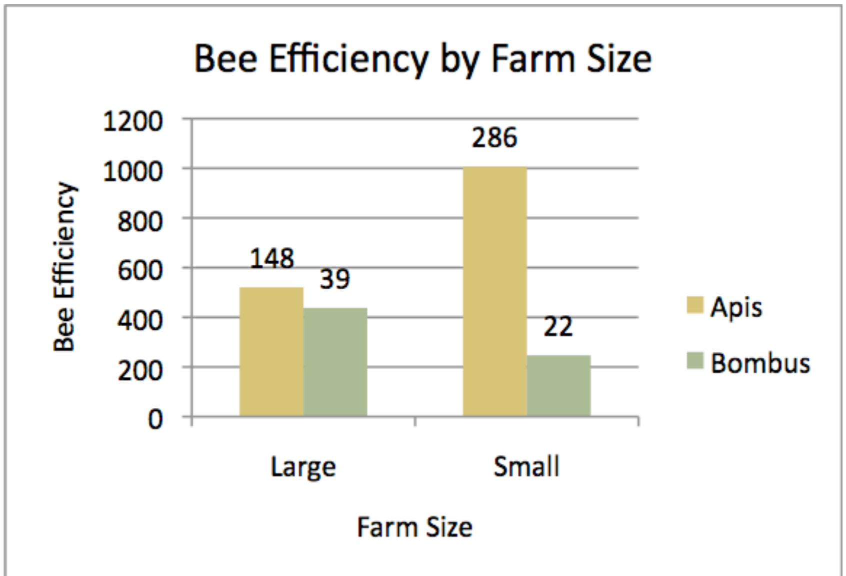


Figure 5: **Average number of *Vaccinium* pollinated per minute, per transect according to farm size.**

Within the bee efficiency graphs, the y-axis equals bee efficiency, the x-axis is the independent variable, and the numbers atop each column represent population count. By scaling and labeling the graphs this way we are able to compare the counts of each bee group to their associated efficiency, across all variables.

Pollinator Identification Survey

Apis and *Bombus* Counts by Farm A=*Apis* B=*Bombus*

	Farm A		Farm B		Farm C		Farm D		Farm E		Farm F	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Total	451	31	289	3	414	27	118	32	275	103	199	104
Average	150.3	10.3	96.3	1	138	9	39.3	10.7	91.7	34.3	66.3	34.7

Table 1: **a summary of our data collection. Listed are total and average population counts per individual farms across all monitoring windows.**

Farm Size

In order to get better coverage across the large farms transects were twice the length of the small farms requiring twice the monitoring time. In order to compare the large to the small farms we divided their *Apis* and *Bombus* counts by 2. The large farms contained ½ the count of *Apis* but 1.7 times the *Bombus* count in relation to the small farms. These counts are represented on top of each corresponding column. Although both farms contained more *Apis* the large farms had a smaller difference in population counts, allowing *Bombus* to pollinate nearly as efficiently as *Apis*. The small farms had 13 times more *Apis* than *Bombus* and this spread was too great for *Bombus* to make up the difference in pollination efficiency.

Bloom Time

Bloom time is a significant factor for the population surveys. Early bloom period for *Vaccinium* yielded the highest average counts for both *Apis* and *Bombus*. There is a substantial difference in the numbers of *Apis* throughout bloom time, starting at 369 counts in early bloom and declining to 41counts during late bloom. *Bombus* were less abundant

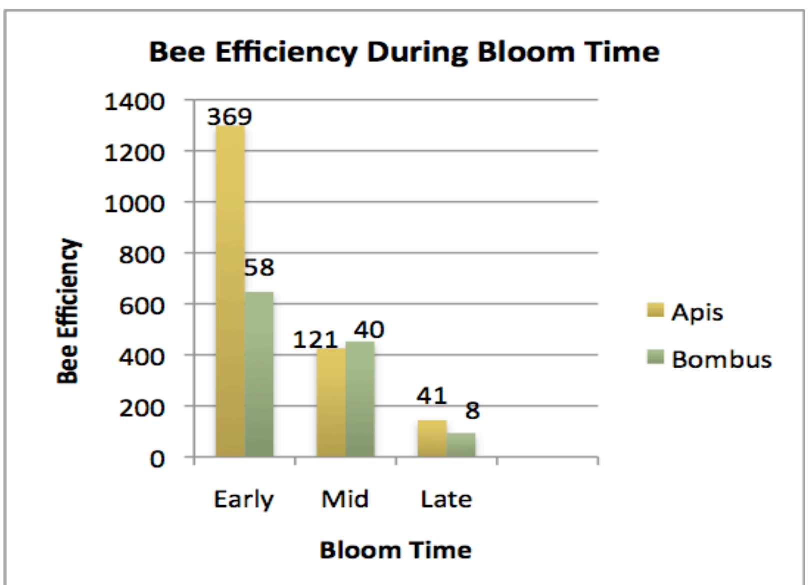


Figure 6: Bee efficiency during bloom time, across all farms

than *Apis* during each bloom period but their count followed the same pattern as the *Apis*, just at a smaller scale from 58 early bloom counts to 8 late bloom counts. During mid bloom *Apis* was 3 times more abundant than *Bombus* but after scaling the graph by AFHR, we see that *Bombus* were actually more efficient. Although bloom windows were similar across all sites, farm assessment scores varied.

Farm Assessment Score

Farm scores ranged from 61-98 with a max of 165. Average *Bombus* counts across all monitoring windows fluctuated between 1 and 35 across all farms with no direct relationship to farm assessment scores. The farm with the highest score also had the highest bumblebee count. Although there was no apparent connection with *Bombus*, there is a trend of decreasing *Apis* counts as the scores increase.

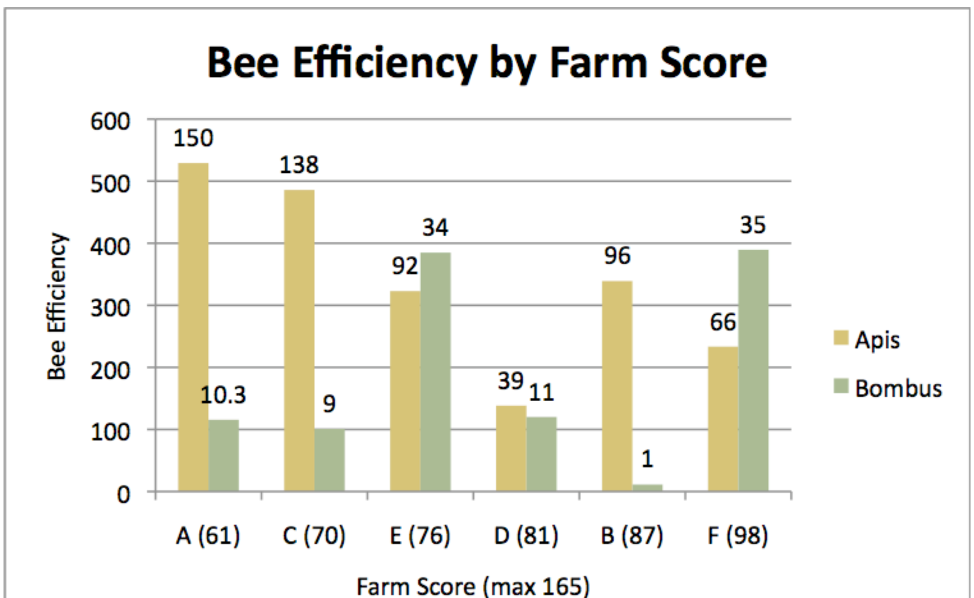


Figure 7: Bee efficiency by Farm score, across all bloom times

However, *Bombus'* efficiency for the 4 farms with the highest score was competitive against *Apis*, with the exception of the anomaly with farm B. Xerces recommends a post-implementation score of at least 100 and an improvement of at least 40 points. The farms we monitored were all relatively in the same score range with no extremely low or high scores.

DISCUSSION

In our surveys we were able to address the comparison of efficiency between *Apis* and *Bombus* during pollination of *Vaccinium* bushes along with the influence available habitat has on the number of bees present at farms. The behavior assessment analyzed the relationships between these questions and the variables we observed in our studies. We looked at the role of native bumblebees in pollination by observing their counts, average floral handling rate (AFHR) of both species, and how available habitat influenced these factors. Based on the Xerces farm assessment, nearby foraging resources were equal for large and small farms, so no group should have skewed results. Walther-Hellwig and Franklin (2000) state that *Bombus*' flight range is 1-2km while *Apis* are known to travel up to 4-5km. With this information we expect to see more *Bombus* at smaller farms and equal if not more *Apis* at the larger farms. However, Figure 2 shows large farms have half the *Apis* count and double the *Bombus* count. The reduction in *Bombus* pollination rates at small farms may be attributable to preference of sourcing pollen from surrounding vegetation. We propose that once *Bombus* is in a large field it may stay there until foraging is complete, whereas in a smaller field *Bombus* may switch between *Vaccinium* flowers and other sources. Again, this does not necessarily mean there were fewer *Bombus* present, perhaps just that they preferred other sources of pollen at the small farms. Future studies could be conducted to determine the plant preferences of *Bombus* during pollination.

As noted in the results, pollination services decreased after early bloom for all sites. We believe this is due to the decline of available flowers as *Vaccinium* fruits had begun to form. AFHR of *Bombus* surpassed *Apis* during the entire observation period by a factor of 3. Even though AFHR decreased, *Bombus* efficiency was still 300% higher than *Apis*.

When comparing farm score and bee efficiency, there are trends connecting this qualitative ranking to pollinator presence. A higher score signifies better available habitat. Even though none of the sites had extremely low or high scores, the presence and effectiveness of *Apis* had a relative decline as the score increased. With the exception of Farm B, *Bombus* effectiveness increased and surpassed *Apis* in the higher range of scores, even though *Bombus* counts were fewer than *Apis.* The absence of *Bombus* at Farm B could be due to an abundance of *Trifolium* cover crop and *Rhododendrons*. Although the surrounding foraging habitat attracted *Bombus* to the farm, preference could have attracted *Bombus* to the other sources of pollen and nectar, creating competition between floras. The use of the Xerces assessment was a novel application, as it was not intended for this purpose, but rather to give farmers a qualitative estimate of their farms available pollinator habitat. The relationship between farm size and pollinator efficiency is also notable, as *Bombus* had higher rates of efficiency at the large sites. This is exemplary as *Bombus* has a shorter flight range when compared to *Apis*. This variation could be attributed to larger numbers of flowers available for pollination, but more research would be needed to establish this as a determining factor.

While higher numbers of *Apis* were observed at each farm, we wanted to distinguish if the higher AFHR rates for *Bombus* increased overall efficiency and to further research the role native pollinators. Bloom time of *Vaccinium* bushes altered the overall presence of both species along with their floral handling rate. Both declined, but bee efficiency of *Bombus* exceeded *Apis* during Mid-Bloom, notable because of the reduced count *Bombus* count. This could be attributed to many factors, with a large change in temperature being a possible contributor. While *Bombus* had a slight decline, we believe the ability to withstand lower temperatures made this drop in mid bloom pollination rates less severe. Stephen and Rao determine this is due to the ability of *Bombus* to continue pollination in poor weather (2010). However, many factors could have influenced efficiency, including the higher overall AFHR of *Bombus.*

While an overall trend of higher *Apis* AFHR has been observed, it is notable that *Bombus* AFHR are on average 66% higher than honeybees, and their sample population proportion is 14.7%. This can be attributed to a variety of factors, including the ones mentioned in this discussion and the presence of *Apis* hives at the sites. We can conclude that if Bombus populations increased, then a rise in *Vaccinium* pollination rates would also occur. More research is needed to fully comprehend the relationship between the pollination services provided by *Apis* and *Bombus.* We recommended further research into the role of individual species of native *Bombus,* and the proportion of pollination services each species provides for different flora (Stephen and Rao, 2010). We would also further research both species to see if a higher proportion of *Bombus* yields higher efficiency for *Vaccinium* and other agricultural crops, and if the presence of managed *Apis* hives influence the amount of *Bombus.*

RECOMMENDED MANAGEMENT PRACTICES

There are various management methods to take into account that will promote visitation and establishment of pollinators. According to Xerces, the best management practices include no tilling (2007); if the farm decides that tilling is necessary, we recommend Keyline Subsoil Plowing since it will not disturb bees that nest in the soil the way traditional plowing will (citation). Limited use of pesticides is also important for pollinator success, but if used, it is best to spray at night when pollinators are not foraging.

Other considered management practices are cover crop selection and crop rotation. It is important to attract a diversity of pollinators with the inclusion of an array of plant species preferred by pollinators. The establishment and conservation of habitat within and around the area is also essential for pollinator success, due to the limited flight range of native pollinators and the biological need for nesting and foraging habitat. There was been extensive research on pollinator habitat, and

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