Pollen fidelity of *Apis mellifera* L. during pollination of *Limnanthes alba* Hartw. ex Benth. ssp. *alba*, Limnanthaceae

By

Ann J. Watkins

A THESIS

submitted to

Oregon State University

Honors College

In partial fulfillment of

the requirements for the

degree of

Honors Baccalaureate of Science in BioHealth Sciences

(Honors Associate)

Presented 23 May 2017

Commencement June 2017

AN ABSTRACT OF THE THESIS OF

Ann J. Watkins for the degree of Honors Baccalaureate of Science in BioHealth Sciences presented on May 23, 2017.
Title: Pollen Fidelity of *Apis mellifera* L. During Pollination of *Limnanthes alba* Hartw. ex Benth. ssp. *alba*, Limnanthaceae

Limnanthes alba, commonly known as meadowfoam is a popular commercial crop because its seed oil is composed of long carbon chains that provide it with high oxidative stability and consequently make it a desirable ingredient in cosmetic products. As a commercial pollinator, the western honey bee, *Apis mellifera*, may be utilized to pollinate monocultures such as *L. alba*. The pollen fidelity of a pollinator with regard to its intended crop determines the efficiency and overall benefit of the pollinator's presence in the field. This research examines pollen fidelity of *A. mellifera* with regard to *L. alba* in a commercial setting. The average *L. alba* proportion of total trapped pollen was determined to be 88.5%. The high fidelity of *A. mellifera* to *L. alba* suggests that it was beneficial to have a supplemental pollinator present, but to definitively determine that a comparative study would need to be performed.

Abstract approved: _____
Dr. Ramesh Sagili

Key Words: *Limnanthes alba*, meadow foam, pollination, pollen fidelity, *Apis mellifera*, honey bee

Corresponding email address: watkiann@oregonstate.edu

Pollen Fidelity of *Apis mellifera* L. During Pollination of *Limnanthes alba* Hartw. ex Benth. ssp. *alba*, Limnanthaceae

By

Ann J. Watkins

A THESIS

submitted to

Oregon State University

Honors College

In partial fulfillment of

the requirements for the

degree of

Honors Baccalaureate of Science in BioHealth Sciences

(Honors Associate)

Presented 23 May 2017

Commencement June 2017

Honors Baccalaureate of Science in BioHealth Sciences project of Ann J. Watkins presented on 23 May 2017.

APPROVED:

_____

Dr. Ramesh Sagili, Mentor, Department of Horticulture

_____

Dr. Michael Burgett, Committee Member, Department of Horticulture

_____

Hannah Lucas, Committee Member, Department of Horticulture

_____

Toni Doolen, Dean, Oregon State University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

_____

Ann J. Watkins, Author

Acknowledgements

The process of writing an undergraduate thesis is arduous, but with the assistance of certain people it was also enlightening and enriching. Dr. Michael Burgett was an endless source of expertise and encouragement from start to finish. Even working from the other side of the planet, he was able to give me thoughtful advice to keep me on track with this project. In addition, he helped me keep my financial costs at a minimal amount with assistance. I cannot thank him enough for his aid in my efforts.

I would also like to thank Hannah Lucas, a faculty research assistant in the Honey Bee lab in the Horticulture Department at Oregon State. She welcomed me to the lab, provided me with all necessary materials, and was willing to listen to my questions and give me advice whenever I asked for it.

I owe thanks to Dr. Ramesh Sagili for offering a Honey Bee Biology class at Oregon State, which served as inspiration for my selection of this topic. Before taking this course, I could not think of a single thesis topic. I found Dr. Sagili's lectures enthralling, and I decided that there must be a number of topics I could investigate for my thesis in the field of entomology. I would also like to thank Dr. Sagili for serving as my thesis mentor.

Mark Johnson graciously allowed me the use of his honey bee colonies during the field portion of this research and I am very thankful to him for trusting me to conduct my research with his hives. In addition, I am thankful to Wayne Keizer for allowing me to collect data on his property with his crop of meadowfoam. Without Wayne and Mark's cooperation I could not have conducted my research.

Finally, I must thank my parents for encouraging me to pursue knowledge and be tenacious in my studies from a young age. Thank you for making me the person I am today.

Introduction

Pollination

Pollination is a process that involves the transfer of pollen (male element) from one flower's anther to the stigma (female element) of the same flower or a different flower of the same species (Sagili 2015). It is a crucial step in the process of sexual reproduction that results in seed production. Flowering plants, or angiosperms, have both male and female parts that allow for sexual reproduction. The stamen of the flower produces pollen, and the pistil of the flower has a sticky end called the stigma. Seeds are produced at the base of the pistil within ovules (Faegri and Van Der Pijl 2013). In order for pollination to take place, pollen must be transferred from an anther to the stigma. This may occur on the same plant, resulting in self-pollination, or from one plant's stamen to another plant's stigma, which is cross-pollination. The latter type of pollination generally results in more successful offspring because the progeny have more genetic variation. Genetic diversity is important for a species' survival because a wide variety of genotypes increases the likelihood of producing phenotypes capable of tolerating environmental or nutritional changes, thereby allowing the species as a whole to adapt. (Tack 2011). This also reduces the occurrence of unfavorable genes, helping the species to strengthen survival of its individuals and the species itself.

Pollination occurs through various mechanisms. Animals and the wind are the most common pollen vectors. Anemophily is pollen distribution by wind (Kyaw 1989). The plants that rely on this type of pollination do not need to produce attractive features for animal pollinators like color or scent, so they can dedicate the majority of energy towards producing as many pollen grains as possible. Anemophilous pollen grains have

evolved to be lightweight and smooth so that it is easy for them to be carried by the wind (Faegri and Van Der Pijl 2013). Zoophily is a type of pollination in which pollination is carried out by animals. There are different types of zoophily, including malacophily, which is slug and snail pollination; ornithophily, or bird pollination; chriopteriphily, or bat pollination; and entomophily, or insect pollination (Meeuse 1972). Zoophilous species have evolved flowers that are attractive to their pollinators, which increases the likelihood of pollinator visits, thereby improving the chances of pollen transfer from flower to flower. Entomophilous plants produce nectar as a food incentive for insects to visiting their flowers (Jahns 1990). Such flowers often utilize bright colors or attractive scents in order to attract pollinators. Insects like bees and butterflies do not purposefully try to pollinate plants, they venture to the flower for food, pollen or nectar, and they inadvertently remove and transfer pollen. When the insects fly to another plant, pollen is deposited on the next plant's stigma, resulting in cross-pollination (Faegri and Van Der Pijl 2013).

Pollinators

Pollinators are the vectors that transfer pollen from anther to stigma. There is a variety of the different types of animal pollinators. Some vertebrates, like bats and hummingbirds, can be effective pollinators. There are bats that feed on nectar of flowers and transfer pollen between flowers of their food source. Bats are unusual pollinators because unlike most insect pollinators, they are nocturnal so they visit flowers that are open at night (Singaravelan 2004). Hummingbirds consume nectar from hundreds of flowers every day and consequently quickly spread pollen. Some insect species are pollinators because their survival relies on foraging pollen and nectar from flowers. Bees

are excellent pollinators because their diet is composed entirely of flower products. Their food foraging efforts, therefore, focus entirely on visiting flowers, inadvertently moving pollen around as they move from flower to flower (Faegri and Van Der Pijl 2011). The protein from pollen is the nourishment that bees provide to their developing offspring, so while the bees are collecting nutrition for their progeny they are also pollinating flowers (Sagili 2015).

Eusocial bees, like the Western honey bee, are particularly effective pollinators because their massive colonies (up to 100,000 individuals per colony in some species) contain large numbers of foragers—bees whose sole job is seeking out and bringing products from their environment into the hive (Faegri and Van Der Pijl 2013). Indeed, *Apis mellifera* is a premiere pollinator of commercial crops around the world. In order to divide the workload of the hive, there are four types of foragers, including water, nectar, pollen, and propolis foragers. These various tasks are allocated to different bees depending on the needs of the colony and their age, in a phenomenon which is called temporal polyethism (Siegel 2013). This division of labor helps maximize the forager's efficiency.

Another versatile pollinator trait that *A. mellifera* shows is polylecty (Eckhardt 2014). Honey bees do not visit only one species of plant. They have a wide variety of possible plant species from which to forage, which means they may pollinate several different kinds of plants. Because of their polylecty, this species has become a part of the commercial pollinating industry. Agriculturists will pay beekeepers to bring their hives to crops during bloom so that the honey bees may pollinate them. *Apis mellifera* may successfully pollinate one species that blooms in the spring, and the colonies can be

moved to a different field that blooms in the summer and pollinate additional crops as well (Eckhardt 2014). In Oregon, honey bees are used commercially for pollination of blueberries, pears, cherries, apples, and many other crops. This variety of foraging sources fulfills the honey bees' need for both nectar and pollen. Despite the fact that *A. mellifera* may pollinate many plant species, individuals tend to exhibit floral fidelity, in which they continue visiting flowers from the same species for the remainder of the foraging trip and potentially the next few days (Sagili 2011). This trait is desirable in a commercial pollinator since it increases pollinator efficiency specifically on the crop intended for pollination.

Commercial Development of *Limnanthes alba*

Limnanthes alba Hartw. ex Benth. ssp. *alba*, family Limnanthaceae, commonly known as white meadowfoam, is a crop that is grown in Oregon's Willamette Valley. Meadowfoam was developed as a commercial crop in the early 1980s at the Oregon State University Agricultural Experiment Station in Corvallis, OR. It is a native species to Northern California and was able to adapt well to the Willamette Valley's similar environment (Savonen 1997). The crop grows in areas of wet grasslands and damp soil.

In 1971 the new crop development project at the Oregon State University Agricultural Experiment Station tested the crop to examine whether it would grow successfully in the Willamette Valley. The crop flourished in the fields, thriving in the damp soil. The crop became popular with farmers because it is a viable cash crop that leaves minimal field residue such as stems and seeds after it has been harvested (Jolliff 1981). The crop may also be part of a double-cropping system, so that it can be grown part of the year while another cash crop may be grown during another season. This crop

is attractive to farmers because it helps diversify their workload and risks. *Limnanthes alba* grew popular and became the crop of local growers in the Willamette Valley who formed a group in 1984 called the Oregon Meadowfoam Growers Association (Sagili 2015).

Meadowfoam seed oil was examined at the Northern Regional Research Laboratory in Illinois and was identified by the USDA as a new industrial raw material that could be useful in the production of many products due to its chemical composition (Jolliff 1981). The seed oil has long chain fatty acids of 20 and 22 carbons, which is longer than most other vegetable oils, which typically have 18 carbon chains. The longer carbon chains in *L. alba*'s seed oil allows it to be stable in higher temperatures, making it commercially desirable as a lubricant (Savonen 1997). The oil's unique property of 98% fatty acids with long carbon chains give high oxidative stability, allowing the oil to be used in many different types of cosmetics and skin care products (Papanikolaw 1999). The oil can be a quality emollient without being greasy, because it is a stable lipid. It is also unlikely to become rancid, so it can be formulated into many different products without concern of spoiling quickly (Papanikolaw 1999). *Limnanthes* seed oil is an important product because it is used to replace sperm whale oil as a lubricant and is widely used in the cosmetics industry. Meadowfoam seed oil is often used in products for hair and skin care, makeup products such as foundation and lipstick, and as a pigment improver in industrial work.

Pollination of *Limnanthes alba*

Since *Limnanthes alba* blooms in late spring, the weather is frequently optimal for *A. mellifera* to forage, thus pollinating the crop (Jahns 1990). Honey bees rarely forage

below 55°F (12°C), but *L. alba*'s flowers do not open below the same temperature (Sagili 2015). This mutually required environmental condition benefits both species. The intermittently sunny and rainy weather of spring means that optimal foraging conditions for *A. mellifera* may change quickly. The presence of commercial hives is insurance for the farmer that there will be a large number of pollinators available to pollinate the crops if a rainy spring day suddenly becomes sunny and warm. This helps maximize overall pollination for *L. alba*. *Apis mellifera* hives are typically placed in *L. alba* fields at *ca*. 10% bloom, so that the honey bees will forage on the target crop. The *L. alba* fields should ideally be at least two miles away from other blooming plants or crops that could compete with meadowfoam as pollen and nectar resources. If they are planted closer, the honey bees may be attracted to other crops, thereby reducing their commercial effectiveness (Sagili 2015). *Limnanthes alba* is polyphilic, so it may be pollinated by a large variety of insects. This common trait among plant species improves the probability of achieving optimal pollination (Ramirez 2003).

Figure 1: *Limnanthes alba* in a field in Harrisburg, OR. Photo source: Ann Watkins

As *L. alba* grows, it yields 1 to 12 flowers on each stem and between 1 and 10 stems on each plant. The flowers have 10 stamens. There are five stigma within a single pistil and five ovaries, each containing one ovule. Each of these ovaries has the potential to produce one seed. The flowers open during the day and close in the evening in order to be available to pollinators. The flowers continue this flower opening and closing cycle until they are pollinated. In order to avoid self-pollination, *L. alba*'s pollen is available before stigmas in the same flower are receptive. This self-pollination avoidance

mechanism is termed protandry, which promotes cross-pollination, so that the progeny have greater genetic diversity (Sagili 2015).

Figure 2: The *L. alba* field and site of data collection in Harrisburg, OR. Photo source: Ann Watkins

Once open, the *L. alba* flower is viable for pollination for 1 to 4 days. Because *L. alba* pollen is sticky and dense, with an average diameter of 13.5 microns, the wind cannot pollinate this crop (Erdtman 1986). Other crops that are wind pollinated may have much larger diameters, such as barley, which has pollen grains with an average diameter of 35-45 microns (Office of the Gene Technology Regulator 2008). Despite the comparatively small size of *L. alba*'s pollen, it is too heavy for wind pollination. This means that the success of the crop is dependent on zoophily with honey bees as the commercially premiere pollinators. Three colonies per acre is the recommended number to achieve sufficient pollination (Sagili 2015). Honey bee pollination results in an average of 2.5 seeds per flower.

Figure 3: *Apis mellifera* collects pollen from blooming meadowfoam flowers. Photo source: (Sagili 2015)

Objective

The goal of this study was to examine the pollen fidelity of honey bees employed for meadowfoam pollination and determine the cost effectiveness of using honey bees to pollinate meadowfoam.

Methodology

Honey bee colonies and meadowfoam field selection

The Honey Bee Lab in the Horticulture department at Oregon State University provided the contact information of a local beekeeper who had previously collaborated with their research. The collaborating beekeeper agreed to allow data collection to be conducted with his hives and stated that they would be located at a meadowfoam field in Harrisburg, Oregon. He provided contact information for the farmer who owned and

operated the meadowfoam fields, who also agreed to allow research to be done on his property.

Pollen and Bloom Collection

Of the 120 commercial honey bee colonies contracted to pollinate the 90 acre meadowfoam field in May 2016, six hives were selected to be fitted with pollen traps. The selected pollen traps were plastic grates fitted over the entry points to the colonies. The grates were on hinges so they could be down or "on" so that bees would enter through the holes in the grate, or up and "off" so that bees could enter the hive unimpeded. When the pollen traps were engaged, the pollen from pollen foraging bees was removed from their pollen baskets (corbicula) as they passed through the holes on the grate. This pollen removed from their pollen baskets would fall into a collection tray. Pollen collection from these trays commenced at 10% bloom and continued for 19 days. Pollen traps were alternated so that three traps were on and three were off on a given day so that data for each day could be collected without depriving the colonies of pollen. Pollen trap collection occurred at approximately the same time each day, *i.e*., 6 p.m., so that hives were engaged for 24 hours at a time. The pollen was stored for later analysis in plastic screw top containers at -20ºC and labeled with the date and hive number.

Three permanent quadrats (0.25 m^2) were placed in the meadowfoam field at 10% bloom. The quadrats were placed in a row in the interior of the field, centralizing the bloom count so that it was not on the sparser outskirts of the field. The row created an accessible path and minimized the amount of flowers trampled in the field during data collection. The number of blossoms opening daily were counted in the quadrats each day. The new blooms were removed at each counting. These data were used to create a bloom

phenology which illustrates the number of new flowers that were open each day over the course of the experimental period. The life of a *L. alba* flower was calculated to be three days. To create the total bloom availability on a daily basis on day 2 the blooms from day one were added to day 2; on day 3 the blooms from days 1 and 2 were added to the blooms from day 3; on day 4 the blooms from days 2 and 3 were added and the blooms from day 1 were subtracted. This results in a bloom phenology for the entire bloom period based on the available flowers for a three day period. These data are significant to this experiment because they represent the number of flowers that were opening with initial pollen availability (Jahns 1997).

Figure 4: A quadrat in the field of data collection in Harrisburg, OR. Photo source: Ann Watkins

Ambient temperature and humidity were recorded utilizing two Hobo dataloggers (Onset, Bourne, MA). These devices recorded data every hour. In this study, one device

was attached to one of the hives, while the other recorded data in the most central quadrat in the interior of the field. These data were recorded to interpret the data from the pollen collection. Honey bees do not generally forage below 55ºF, so if the air temperature was low, it potentially skewed the pollen collection data (Sagili 2015).

Pollen Analysis

A reference slide of pollen from *L. alba* was developed and used to identify pollen samples collected during the study period by placing pollen grains from the sample flower in deionized water on a microscope slide and viewing the grains under 400x magnification. The pollen pertaining to *L. alba* was identified and quantified from the pollen loads collected. There were three sources of pollen from three hives for each day of data collection since the hives alternated pollen collection days. For a given day the pollen samples from the three colonies were weighed. The smallest mass sample was determined, and equivalent amounts from the other two samples were weighed out, and the three samples, still in corbicular pollen load form, were thoroughly mixed together. A 0.5 gram sample was taken from this mixture and combined with deionized water using a vortex machine to break up the pollen pellets and create a homogenous pollen solution. Then one drop of the solution was placed on a hemocytometer (Figure 5) with a disposable pipette. Using a compound light microscope at 400x magnification the number of *L. alba* and non *L. alba* pollen grains were counted and recorded.

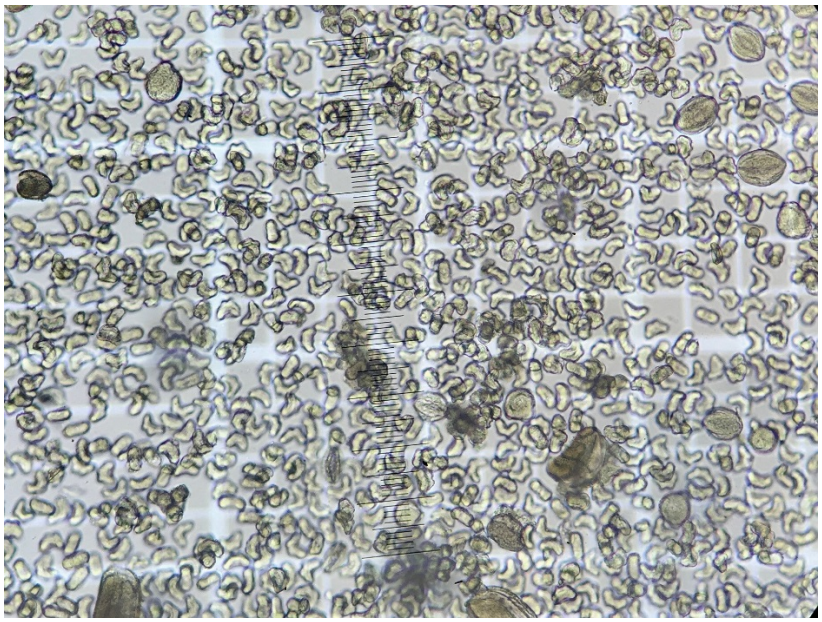

Figure 5: A sample of pollen grains at 400x magnification on a hemocytometer. The translucent crescent-shaped pollen grains are from *L. alba.* Photo source: Ann Watkins

Every pollen grain within the grid of the hemocytometer was counted. From these counts, crop fidelity of those hives was calculated as the proportion of *L. alba* pollen in total collected pollen. The pollen grain counts on the microscope slides were repeated twice and the percentage *L. alba* was averaged. I made the assumption that the three colonies sampled each day for pollen collection were a fair representation of the pollen foraging for the total 120 colonies placed around the field periphery.

Results

Bloom Phenology

Daily bloom counts are shown in Figure 6 as the average of values from all three quadrats. Bloom progression followed a generally bell-shaped curve.

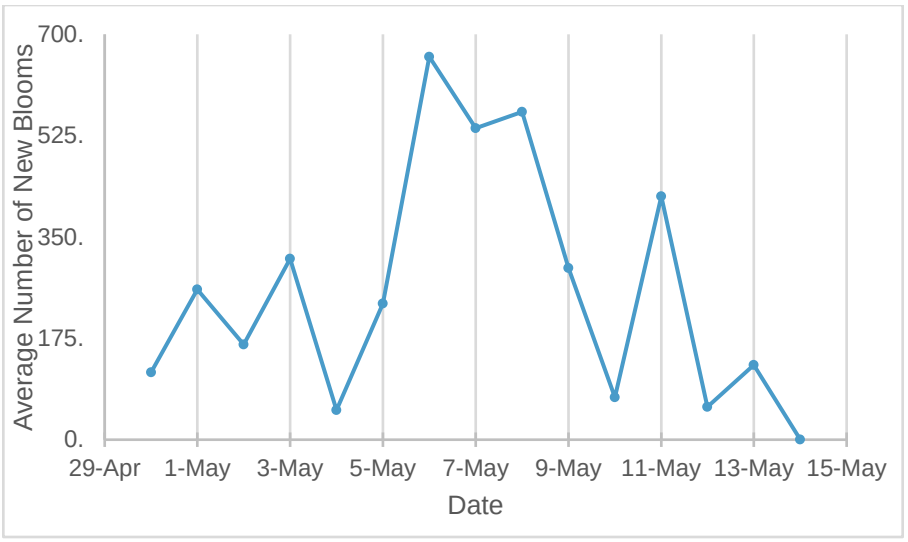

Figure 6: Daily bloom count of *L. alba*. The average number of new blooms per quadrat for each date of data collection.

A bloom phenology was created using these data, showing the total number of flowers that were open each day over the course of the experiment. Figure 7 represents the bloom availability on a daily basis.

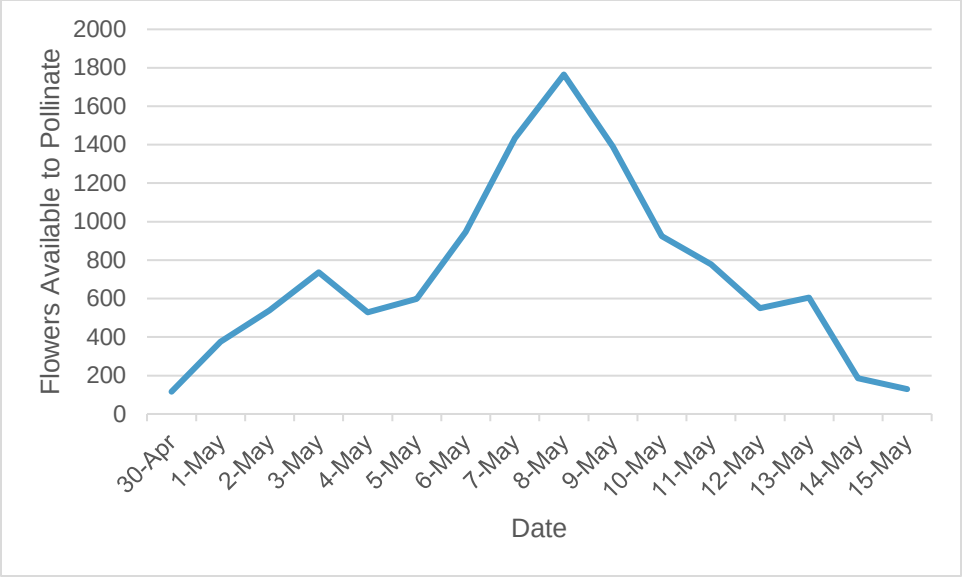

Figure 7: Bloom Phenology of *L. alba*. The number of flowers available for pollination each day, based on the assumption that each flower was open for ~3 days.

The recorded bloom period lasted from 4/30/16 until 5/15/16, with 24.9% of the total number of counted flowers had opened by 5/5, 45.4% had opened by 5/7, and 72.6% had opened by 5/9.

Temperature

Two Hobo temperature devices were utilized in this experiment. One device recorded temperature outside of Hive 1, while the other device recorded the temperature in quadrat 1 in the field (Figure 8). The data shown are the temperatures recorded from sunrise to sunset during the dates of data collection.

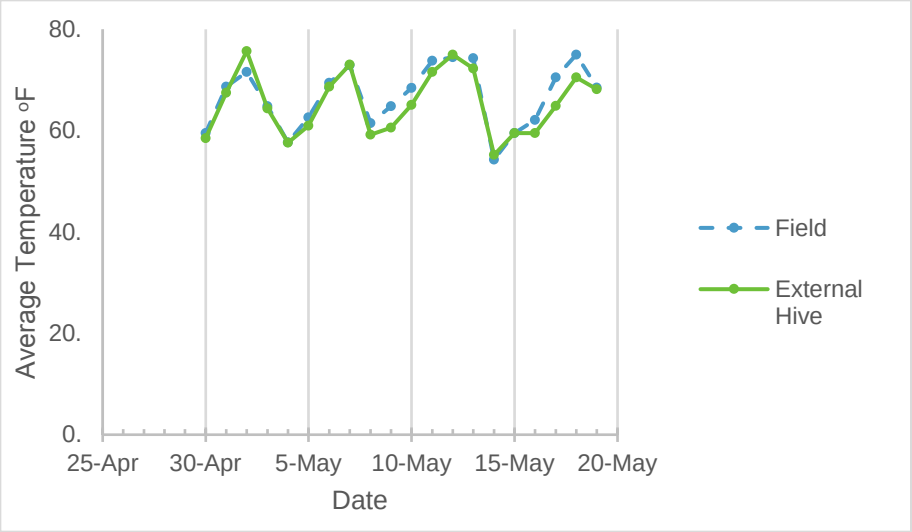

Figure 8: **Average Temperature in Field vs. Average Temperature from External Hive Per Day.** The field series represents the average temperature for each 24 hour period recorded in the field, while the external hive series represents the average temperature recorded by the hives.

Table 1: Duration of Flight Window. This report shows the number of hours each day that the temperature was greater than 55°F and the sun was out, describing the flight window in which *A. mellifera* was able to forage pollen.

Date	Hours
30-Apr	12
1-May	13
2-May	13
3-May	12
4-May	12
5-May	13
6-May	13
7-May	13
8-May	11
9-May	11
10-May	12
11-May	13
12-May	13
13-May	13
14-May	8
15-May	12
16-May	13
17-May	13
18-May	13
19-May	12

Table 1 is an expression of the flight window of time where *A. mellifera* was able to fly and forage with access to the *Limnanthes alba* bloom. The data presented in Table 1 are calculated from the number of hours the daily temperature was ≥ 12°C (55°F).

To better understand the foraging "window" (hours where the field temperature is above several temperature thresholds, the total number of hours above 12°C (55°F), 15.6°C (60°F), 18.3°C (65°F), and 21.1°C (70°F) were determined and are shown in Table 2.

Table 2: Examination of variety of temperature thresholds and their durations. This table includes the amount of hours spent at temperatures in the field and outside of the hive.

Temperature	External Hive (hours)	In Field (hours)
>12°C (55°F)	251	248
>15.6°C (60°F)	195	191
>18.3°C (65°F)	159	161
>21.1°C (70°F)	111	122

The weather during this data collection period was analyzed to determine if the dates of data collection varied from the average weather on the same dates in years past. A ten year history of weather was used to determine the average weather on specific days. All comparative temperature and precipitation data points were reported by a

weather reporting station in Harrisburg, OR. During the bloom period the mean temperature for each day was higher than usual, which was conducive to *A. mellifera* foraging and pollinating *L. alba.*

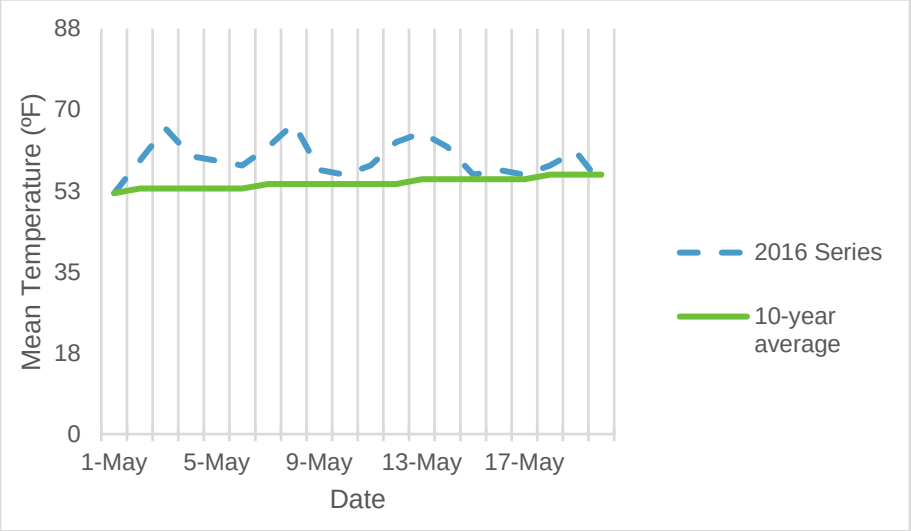

Figure 9: **Daily Mean Temperature.** Mean temperature measured each day during the period of data collection. The 2016 series represents the temperatures during the period of data collection compared to the long term average temperature over the course of 10 years, as reported by Weather Underground (The Weather Company 2017).

In addition, the maximum temperatures for each day was typically higher than the average maximum temperature. During the period of data collection in 2016, the average maximum temperature was 72°C, while in the previous 10 years the average maximum temperature during that same time period was 66°C. The overall warmer weather meant pollination was more likely to occur for longer periods of time.

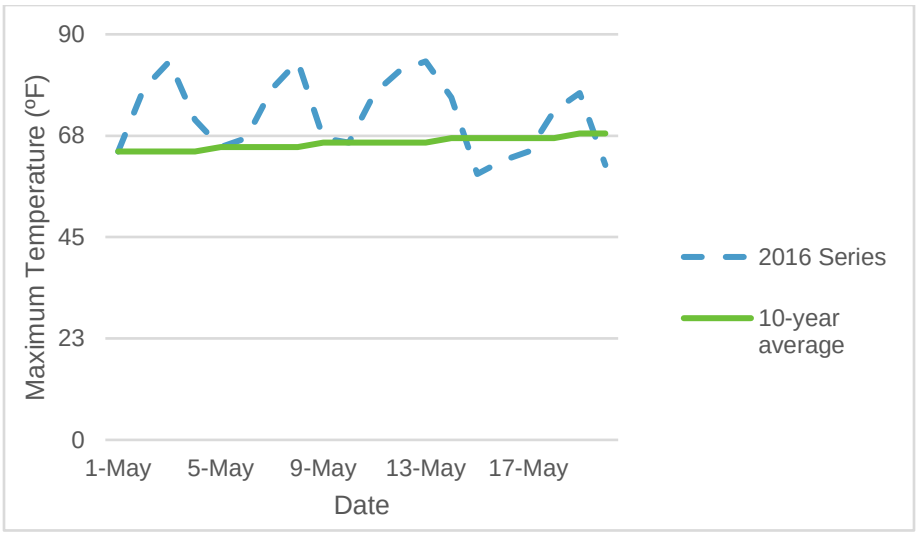

Figure 10: **Maximum temperature measured each day for data collection.** The 2016 series represents the data during collection and the average series represents the 10-year averages over time as reported by Weather Underground (The Weather Company 2017).

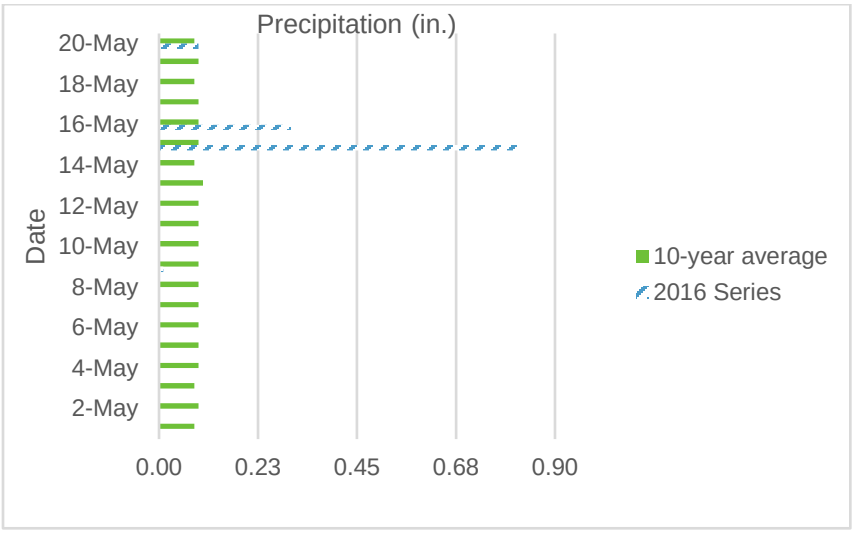

Figure 11: Average precipitation measured each day for data collection. The 2016 series represents the data during collection and the average series represents the 10-year averages over time as reported by Weather Underground (The Weather Company 2017).

Pollen Sample Analysis

Figure 12 illustrates the crop fidelity of *A. mellifera* with regard to *L. alba* during the course of the experimental period. These data represent the averaged two counts of pollen on microscope slides. Overall the honey bees expressed a high fidelity towards the target crop (meadowfoam), with colony pollen foraging averaging 88.5% on *L. alba.*

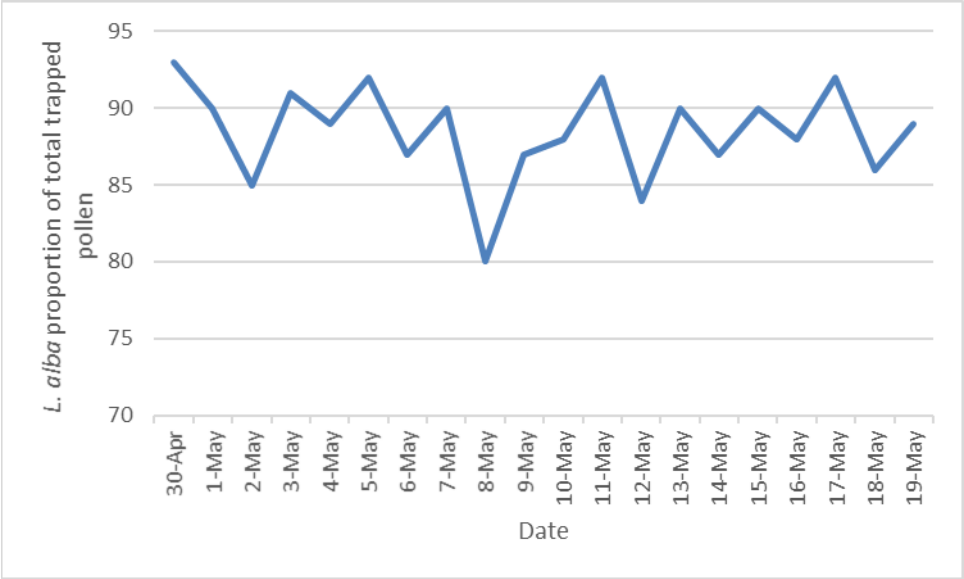

Figure 12: Pollen Fidelity of *L. alba* examined each day of data collection. This data shows the *L. alba* proportion of total trapped pollen for the duration of the experiment.

Statistical Significance

A linear regression was created to examine the level of pollen fidelity of *A. mellifera* to *L. alba* throughout the bloom (Figure 13). The results showed an almost straight line with a β value of -0.0632. This value's proximity to zero indicated that the data from the first date of collection on 4/30/2016 to the last date of collection on 5/19/16 was not

significantly different. This calculation indicated that *A. mellifera* did in fact maintain a high level of fidelity to *L. alba* throughout the time frame of the bloom. The small R^2 value is due to the variability of the *L. alba* proportion of total trapped pollen.

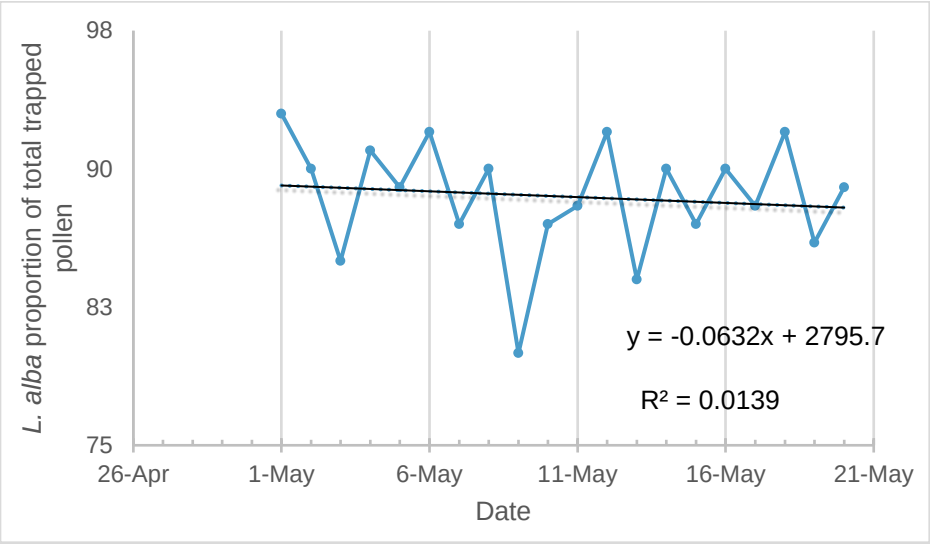

Figure 13: **Linear regression of pollen fidelity for *L. alba.*** The small β value supports the hypothesis that there was not a statistically significant difference between data from the beginning to the end of the period of data collection.

Discussion

The weather for the period of data collection was exceptional in that it was warmer than the previous 10 year average. The number of bees foraging is proportional to the ambient temperature, i.e., an increasing temperature results in a larger proportional of the foraging worker bees to fly (Sagili 2015). Because the majority of days were warm temperatures with minimal precipitation, *A. mellifera* had many hours to pollinate *L. alba*. This could

have increased the overall pollination and seed yield of *L. alba*, but that cannot be determined without a comparative study in which no supplemental pollinator is utilized.

Supplemental Pollinator Significance

Managed commercial pollinators like *A. mellifera* are important because they can supplement the high pollination demands of agricultural monocultures which create bloom densities that overwhelm indigenous pollinator populations. Well-maintained and healthy colonies can exponentially increase the pollination in commercial crops and allow farmers to optimize crop yield. Additionally, pollinators increase genetic diversity by increasing levels of cross pollination over self-pollination. The higher biodiversity increases the adaptability and survival of the crop population (Govindaraj 2015).

Commercial Significance

Farmers that rent colonies for pollination anticipate that the colonies will exhibit high fidelity to their crops. In the United States, honey bee pollination is estimated to be worth $15 billion (Sagili 2011). In this particular examination, *A. mellifera*'s average of 88.5% fidelity to *L. alba* indicates that the farmer made a wise decision in opting to have the colonies placed in the field. The honey bees concentrated on the intended crop and as a result pollination levels and plant reproduction were likely higher than they would have been if the crop had been pollinated solely by wild bees. Since the farmer's goal in growing *L. alba* was harvesting the seeds for oil, the result of increased pollination yielding more seeds made his investment in renting the hives worth his time and money. Since *A. mellifera* is a polylectic species and may collect pollen from a variety of plant species, this pollinator may be utilized by agriculturists for other crops to increase pollination and ultimately increased reproductive success in target crops.

Comparisons

Although no previous data were available specifically observing *A. mellifera*'s pollen fidelity to *L. alba,* there have been research projects examining the fidelity of a pollinator with regard to a monoculture. In a monoculture analysis of pollen fidelity of *Byrsonima chrysophylla* (murici pitanga) the examined pollinator, *Centris caxiensis*, (a solitary bee species) showed 98.41% fidelity to the crop (Ribeiro 2008). In a study in which the fidelity of bumble bee pollinators was examined with regard to *Gentiana parryi* (Parry's Gentian) the colonies were 78% faithful to the intended crop (Ogilvie 2016). The approximate average of fidelity from these numbers, 88.2%, comes close to the fidelity of *A. mellifera* displayed in *L. alba, (*88.5%).

Determining Cost Effectiveness

In this study, the actual crop yield of *L. alba* was 1120.8 kg/ha. The price the farmer received for the seed was $0.70 per pound, or $1.54 per kilogram. The gross profit was $1729.74 per hectare, and $63,000 for the entire field. The farmer paid $50 per hive and reported that there were no other service fees as he performed all other operations himself, including cleaning the seed and delivering it. With 120 hives employed for pollination, the total cost of the pollination was $6,000, which accounted for 9.5% of the farmer's farm-gate value of the crop. The high fidelity of *A. mellifera* to *L. alba* suggests that the supplemental pollinator was beneficial to the farmer's crop and financial yields, but a more definitive statement cannot be made without a comparative study to examine the growth of *L. alba* without a supplemental pollinator.

Citations:

Erdtman G. Pollen Morphology and Plant Taxonomy. Stockholm, Sweden: Almqvist & Wiksell; 1986.

Faegri K, Van Der Pijl L. Principles of Pollination Ecology. Burlington: Elsevier Science; 2013.

Govindaraj M, Vetriventhan M, Srinivasan M. Importance of Genetic Diversity Assessment in Crop Plants and Its Recent Advances: An Overview of Its Analytical Perspectives Rogozin IB, editor. Genetics Research International. 2015 [accessed 2017 Feb 13];2015:1–14. https://www.hindawi.com/journals/gri/2015/431487/

Jahns TR. Pollination biology and pollinator alternatives in mermaid meadowfoam (*Limnanthes alba* Hartw. ex Benth.). ScholarsArchive@OSU. 1990 Jul 31 [accessed 2016 Nov 12]. http://ir.library.oregonstate.edu/xmlui/handle/1957/37404

Jolliff GD, Calhoun W, Crane J. Meadowfoam (*Limnanthes alba*): Its research and development as a potential new oilseed crop for the Willamette Valley of Oregon. Agricultural Experiment Station. 1981 Nov [accessed 2017 Jan 17]. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/15811/StationBulletin648.pdf?sequence=1

Kyaw TPU, Hotton C. Optimum Pollen and Female Receptor Size for Anemophily. American Journal of Botany. 1989 [accessed 2017 Feb 13];76(3):445–453. http://www.jstor.org.ezproxy.proxy.library.oregonstate.edu/stable/pdf/2444615.pdf

Meeuse ADJ. Angiosperm phylogeny, floral morphology and pollination ecology. Acta Biotheoretica. 1972 [accessed 2017 Jan 10];21(3-4):145–166. http://download.springer.com.ezproxy.proxy.library.oregonstate.edu/static/pdf/955/art%253A10.1007%252FBF01557177.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1007%2FBF01557177&token2=exp=1492467943~acl=%2Fstatic%2Fpdf%2F955%2Fart%25253A10.1007%25252FBF01557177.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1007%252FBF01557177*~hmac=a4c7f26faa2c6b8a8e38083428a21dfbb3a2c4be22f43c775f7b3a85ae8e8379

Ogilvie JE, Thomson JD. Site fidelity by bees drives pollination facilitation in sequentially blooming plant species. Ecology. 2016 [accessed 2017 Jan 10];97(6):1442–1451. http://onlinelibrary.wiley.com.ezproxy.proxy.library.oregonstate.edu/doi/10.1890/15-0903.1/abstract;jsessionid=A737D9384494284E91B0E80A5B000DE1.f01t03

Office of the Gene Technology Regulator, Department of Health and Ageing. The Biology of *Hordeum vulgare* L. (barley). Austrian Government. 2008 Apr 1 [accessed 2017 Jun 2]. http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/Content/barley-3/$FILE/biology-barley08.pdf

Papanikolaw J. Meadowfoam Seed Oil Enjoys A Rapidly Growing Market. Chemical Market Reporter. [accessed 2016 Nov 14];256(11):22. http://bi.galegroup.com.ezproxy.proxy.library.oregonstate.edu/global/article/GALE|A55780981/4e6089bf334c646e9b7f34c51035f6ab?u=s8405248

Ramirez N. Floral Specialization and Pollination: A Quantitative Analysis and Comparison of the Leppik and the Faegri and van der Pijl Classification Systems. Taxon. 2003 [accessed 2017 Feb 13];52(4):687–700. http://www.jstor.org.ezproxy.proxy.library.oregonstate.edu/stable/3647344?sid=primo&origin=crossref&seq=1#page_scan_tab_contents

Ribeiro EKMD, Rêgo MMC, Machado ICS. Cargas polínicas de abelhas polinizadoras de Byrsonima chrysophylla Kunth. (Malpighiaceae): fidelidade e fontes alternativas de recursos florais. Acta Botanica Brasilica. 2008 [accessed 2017 Feb 13];22(1):165–171. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0102-33062008000100017&lng=pt&nrm=iso&tlng=pt.

Sagili RR, Burgett DM. Evaluating Honey Bee Colonies for Pollination: A Guide for Commercial Growers and Beekeepers. PNW 623. 2011 Jan. Pacific Northwest Extension Publication. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/pnw623.pdf

Sagili R, Kling J, Breece C. Pollination and Seed Set in Meadowfoam. OSU Extension Catalog. 2015 Jun [accessed 2016 Nov 15]. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em8666_0.pdf

Savonen C. Thar She Grows. Oregon's Agricultural Progress Online. Fall 1997 [accessed 2017 Apr 9]. http://oregonprogress.oregonstate.edu/fall-1997/thar-she-grows

Siegel AJ, Fondrk MK, Amdam GV, Page RE. In-hive patterns of temporal polyethism in strains of honey bees (*Apis mellifera*) with distinct genetic backgrounds. Behavioral Ecology and Sociobiology. 2013 [accessed 2017 Jan 13];67(10):1623–1632. http://search.library.oregonstate.edu/primo_library/libweb/action/display.do?frbrVersion=11&tabs=viewOnlineTab&ct=display&fn=search&doc=TN_springer_jour10.1007%2fs00265-013-1573-y&indx=1&recIds=TN_springer_jour10.1007%2fs00265-013-1573-

y&recIdxs=0&elementId=0&renderMode=poppedOut&displayMode=full&frbrVersion=11&frbg=&&dscnt=0&scp.scps=scope%3A%28OSU%29%2Cscope%3A%28P%29%2Cscope%3A%28E-OSU%29%2Cprimo_central_multiple_fe&tb=t&mode=Basic&vid=OSU&srt=rank&tab=default_tab&dum=true&vl(freeText0)=temporal%20polyethism&dstmp=1492464694001

Singaravelan N, Marimuthu G. Nectar Feeding and Pollen Carrying from *Ceiba pentandra* by Pteropodid Bats. Journal of Mammology. 2004 [accessed 2016 Nov 14];85(1):1–7. http://www.jstor.org.ezproxy.proxy.library.oregonstate.edu/stable/pdf/1383968.pdf

Tack AJM, Roslin T. The relative importance of host-plant genetic diversity in structuring the associated herbivore community. Ecology. 2011 [accessed 2016 Dec 10];92(8):1594–1604. http://www.jstor.org.ezproxy.proxy.library.oregonstate.edu/stable/pdf/23034885.pdf

The Weather Company. Weather Underground. Weather in Harrisburg, OR. [accessed 2017 April 10]; https://www.wunderground.com/cgibin/findweather/getForecast?query=harrisburg%2C+oregon