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Foraging Preferences of Generalist Megachilidae

Abstract

Subalpine ecosystems are home to hundreds of species of wildflowers, many of which are endemic and very vulnerable to climate change. Megachilidae are a family of primarily solitary bees that are very efficient pollinators, making them crucial components of subalpine ecosystems. Some Megachilidae species are generalists, meaning they visit a wide variety of flower species, but their exact foraging preferences remain poorly understood. Since some flowers are more affected by climate change than others, understanding generalists' flower preferences is necessary in predicting their responses to climate change, and in protecting subalpine ecosystems. In this research project I (1) collected pollen samples from generalist Megachilidae nests and analyzed the pollen composition under a microscope, (2) compared the floral abundance in nests with the floral abundance in intentionally placed transects, (3) analyzed any foraging difference across genera, specifically between *Osmia* and *Hoplitis fulgida*, and finally (4) analyzed the relationship between transects and quadrats to see if transects were sufficient in estimating overall floral abundance at a site. I found that abundance in the field has differing effects on nest abundance depending on the flower species, with some species found in nests at disproportionately higher or lower rates than their transect abundance. This indicates that Megachilidae have foraging preferences, selectively choosing which flowers to collect from, and these preferences seem to be the most pronounced at low species abundance. In particular, flowers such as *Ipomopsis aggregata*, *Eriogonum umbellatum*, and *Lathyrus leucanthus* were found in lower abundances in the nest as compared with other flower species. Additionally, *Linum lewisii* had a significantly larger slope than the average species, indicating a preference for *L. lewisii* as it grew in abundance. I found no significant differences between the foraging preferences of *Osmia* and *Hoplitis*, and the floral abundance described by quadrats vs transects was very consistent, indicating that transects are a good method of estimating general floral abundance at a site.

Introduction

Sub-alpine environments are defined as high-elevation zones just below the treeline, and they are home to hundreds of endemic plant and animal species. Their wide elevation gradient creates a diverse range of temperatures and rainfall that leads to immense biodiversity.¹ However, these delicate ecosystems are easily disrupted by environmental changes, making them particularly vulnerable to climate change.² The Rocky Mountains are home to hundreds of distinct wildflowers, most of which are found exclusively in sub-alpine environments. These wildflowers depend on bees, such as Megachilidae, for pollination.³ Megachilidae are a family of primarily solitary bees that typically nest in wood. They are particularly adept pollinators due to long hairs on the underside of their abdomen that allow for increased pollen collection.⁴ Two particularly important genera of Megachilidae are *Osmia* and *Hoplitis*. For instance, some species from these genera are used to pollinate orchards and other commercial crops, making them some of the most economically important bees in North America.⁵ Because subalpine environments are dependent on Megachilidae for pollination, and are disproportionately affected by climate change, understanding the factors that impact Megachilidae populations is critical in protecting these fragile ecosystems.

Osmia and *Hoplitis* all exclusively depend on floral resources such as pollen and nectar to feed themselves and their offspring.⁶ Because these species fill their nests with pollen to feed their larvae, the number of larvae produced by each bee is dependent on the amount of pollen available to collect.⁷ Furthermore, these three species divide their nests into segmented cells, with each cell corresponding to

¹ Inouye and Wielgolaski, "Phenology of High-Altitude Climates."

² Inouye, "Effects of Climate Change on Alpine Plants and Their Pollinators."

³ Inouye, "Effects of Climate Change on Alpine Plants and Their Pollinators."

⁴ Danforth, Minckley, and Neff, "Chapter 7: The Tools of Trade: Floral Rewards and How Bees Harvest Them."

⁵ Wilson and Carril, *The Bees In Your Backyard; A Guide to North America's Bees*.

⁶ Bain, "Plant Biology and Conservation."

⁷ Forrest and Chisholm, "Direct Benefits and Indirect Costs of Warm Temperatures for High-elevation Populations of a Solitary Bee."

one egg, allowing their nesting rate to be easily quantified.⁸ Studies have shown that Megachilidae generally have larger populations when there are more floral resources⁹. However, the exact relationship between Megachilidae nesting rates and floral availability remains poorly understood, and not all flower species are equally important. For instance, some types of Megachilidae are specialists, meaning that they will only collect pollen from specific flower species¹⁰ and that their nesting rates are solely dependent on the abundance of these particular species. Others are generalists, collecting pollen from a wide variety of species, with nesting rates dependent on general floral resources in the area.¹¹

While the foraging preferences of generalist bumble bees have been extensively studied, the foraging preferences of generalist solitary bees remain largely unknown. Bumble bee preferences vary widely across species. Some bumble bee colonies will specialize when in competitive environments, but different colonies will specialize on different plants, causing the overall species to still act as generalists.¹² Other species of bumble bees develop individual preferences from a young age, but these preferences are flexible and can adapt due to environmental changes.¹³ Understanding the foraging preferences of solitary bees such as Megachilidae is very important for predicting sub-alpine ecosystems' vulnerability to climate change. As some flower species are more impacted by climate change than others, knowledge of flower preferences will be crucial for understanding and predicting Megachilidae's responses to climate change.

In this research project, I (1) collected pollen samples from every cell of generalist bee nests and analyzed them for the most abundant flower species and (2) compared these pollen samples with the relative abundance of each flower species in the field. Disproportionately high abundance of certain species in nests could indicate a foraging preference, with active selection by the bee. I compared any found preferences with existing literature on those plant species to see if there were shared traits across

⁸ Cahill and Forrest, "Colorado Field Protocol for Trap-Nesting Bees."

⁹ Forrest and Chisholm, "Direct Benefits and Indirect Costs of Warm Temperatures for High-elevation Populations of a Solitary Bee."

¹⁰ Wong and Forrest, "The Earlier the Better?"

¹¹ Bain, "Plant Biology and Conservation."

¹² Fontaine, Collin, and Dajoz, "Generalist Foraging of Pollinators."

¹³ Hagbery and Nieh, "Individual Lifetime Pollen and Nectar Foraging Preferences in Bumble Bees."

preferred flower species. Because it is reproductively favorable for bees to collect pollen as efficiently as possible, I hypothesize that preferred flower species will all share traits that allow for easier pollen collection, such as a strong scent or high average pollen collection. Additionally, I (3) evaluated whether bee preferences vary across bee genus by comparing pollen samples between *Osmia* and *Hoplitis* nests. Because these bee genera are both able to coexist in the same areas with the same food sources, I predicted that the two genera would have slightly different preferences, allowing them to specialize and avoid competition amongst each other. Finally, I (4) analyzed the relationship between intentionally placed transects and randomly placed quadrats to see if transects were sufficient in estimating overall floral abundance at a site.

Methods

Study sites

I collected pollen samples from July 10th through July 25th 2025 at the following sites: Rosy Point, Judd Falls Meadow, Frogs Pond, and Stormy Pass. All of these sites are part of long term bee data sets, and contained between 5-12 ‘trap-nests’ attached to dead tree trunks with 10-20 holes of roughly 6 cm depth drilled in each trap nest. Each hole contained a translucent paper straw of size small, medium, or large placed inside, which allowed bee nests to be removed and inspected.¹⁴

Study system

I primarily sampled nests from two genus of Megachilidae: *Osmia* and *Hoplitis*. Both are solitary, readily nest in “trap-nests,” and build nests with similar segmented structures. *Megachile*, another species of Megachilidae, line their nests with leaves, making the pollen harder to locate, and thus they were only sampled from in rare cases where the nest had been partially destroyed or was uniquely easy to collect from. I collected pollen from every cell of generalist bee nests, which included *Hoplitis fulgida* and some species of *Osmia*. Because different species of *Osmia* are hard to distinguish, I only sampled from the innermost cell of *Osmia* nests, analyzed the sample under the microscope, and returned to collect from the rest of the cells if the bee was generalist.

Bee genus was primarily determined by observing nesting block inhabitants; *Hoplitis fulgida* are distinctly bright green, and *Osmia* are iridescent blue, making both genera very easy to distinguish from other Megachilidae. In cases where the mother was not observed in the nest, it was impossible to know whether the nest belonged to *Hoplitis fulgida* or a generalist species of *Osmia*, and so the genus was marked “Unknown” on data sheets.

Pollen sampling from nests

I collected pollen samples from every cell of completed generalist bee nests in the provided trap-nests. In each cell, I made one small incision towards the back of the pollen ball, avoiding the egg at the front of the pollen, and collected a small amount of pollen on the tip of my knife.¹⁵ I covered incisions with tape to protect the nest once pollen had been collected.¹⁶ Then, I added the pollen to a vial containing fuchsin gel, which stains the pollen pink and allows for easier visualization. These vials were taken back to the lab, where I melted the fuchsin gel onto slides using a hot plate. I analyzed these samples under a microscope, taking photos of all generalist pollen samples for future reference. I used the provided pollen database from Melanie Kanzenel as well as the Southern Rocky Mountain Herbarium pollen collection to identify the flower species present in the samples. Flower species were ranked by abundance from 0-3. A species ranked 0 was not present in the sample, a species ranked 1 was present but was rare, a species

¹⁴ Cahill and Forrest, “Colorado Field Protocol for Trap-Nesting Bees.”

¹⁵ Spear et al., “Asteraceae Pollen Provisions Protect *Osmia* Mason Bees (Hymenoptera: Megachilidae) from Brood Parasitism.”

¹⁶ Wong and Forrest, “The Earlier the Better?”

ranked 2 was fairly abundant, and a species ranked 3 was extremely abundant. These abundances were then compared with collected floral abundance data.

Quantifying Floral Abundance

I generated 15 randomized points at Rosy Point and Judd Falls and placed a 1 meter by 1 meter quadrat at each point. I counted all bee-pollinated flowers in the quadrats once a week for two weeks. Additionally, 5-10 transects of 20 meter length were present at each site, placed and counted either by my mentor Gwen Kirschke or by Jane Ogilvie and Ceci Rigby. These transects were not placed randomly, but instead placed in an attempt to capture as much floral diversity as possible. All bee-pollinated flowers were counted in these transects once a week from early June until early August, providing me with reasonable estimations of plant species abundance even before my quadrats were placed. I generated the relative abundance of each flower species by representing it as a percentage of the total number of flowers counted, and compared this percentage with the ranked abundance from pollen samples. I added up the data separately for the transects and quadrats, which allowed me to compare the species represented in the randomly placed quadrats versus the intentionally placed transects. Because the two were extremely similar, and I had less quadrat data than transect data, I never directly compared quadrat abundance to nest abundance.

Data Analysis

I compared the most abundant flower species at each site each week with the cells finished that week to see if the most abundant flower species were present in the pollen samples. I used the programming language R¹⁷ to analyze my data and see if there was a strong correlation between the flower species in the transects and quadrats and my samples. To do this, I used a cumulative link mixed model¹⁸, which is a type of linear regression, adding in a relationship between flower species and abundance in the transects to see if different flower species impacted nest abundance in differing amounts¹⁹. I also performed a Spearman's rank correlation test to see how closely nest abundance aligned with transect abundance. To analyze the foraging differences between *Osmia* and *Hoplitis fulgida* I used the same Spearman's rank correlation test, as well as an ANOVA. To analyze the correlation between the transects and the quadrats, I used a basic linear regression.

¹⁷ R version 4.5.1 (2025-06-13)

¹⁸ Christenson, "Ordinal-Regression Models for Ordinal Data."

¹⁹ Fox and Weisberg, "An R Companion to Applied Regression."

Results

Throughout the summer, I analyzed 118 pollen samples from 32 different nests, 4 sites, and two different bee genera. This number accounts for every generalist bee nest finished by July 25th at our four sites.

I found that the five flowers with the highest mean abundances in the nest were *Mertensia fusiformis*, *Viola praemorsa*, *Lupinus bakeri*, *Phacelia hastata*, and *Pentaphyloides floribunda* (Figure 1). The flowers found in the highest gross amounts in the nest were Asteraceae species, *Lupinus bakeri*, *Potentilla pulcherimma*, *Phacelia hastata*, and *Pentaphyloides floribunda*. This ranking was calculated by summing all the abundance values given to each species, rather than taking an average.

Conversely, the flowers with the highest mean abundances in the transects were Asteraceae specialists, *Mertensia fusiformis* and *Lupinus bakeri*. While the most abundant species in the nests are generally lined up with the most abundant species in the transects, this relationship was imperfect and had notable exceptions.

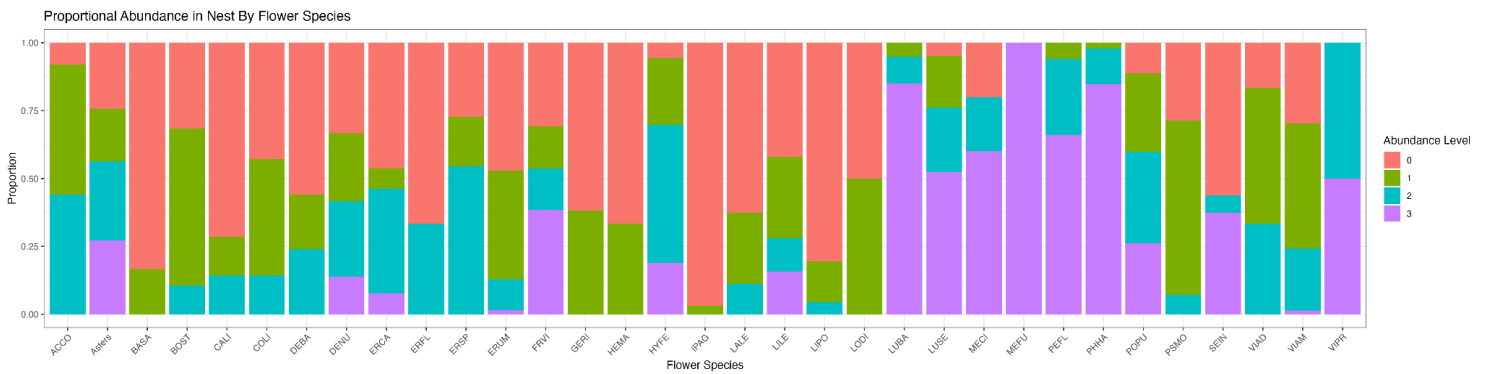


Figure 1: The top flower species are graphed above along the x axis, with the proportion of times that each species was given a particular abundance level on the y axis. This ranking is imperfect because flowers were only ranked zero when they were present in the transects but not the nests, causing flowers that bloomed for short periods of time to seem more abundant. Flowers are labeled by four-letter IDs, where the first two letters are the genus and the second two letters are the species epithet.

Floral Abundance in Nests vs Transects

A Cumulative Link Mixed Model fitted with the Laplace approximation was used to analyze the correlation between floral abundance in the nest and the transects, controlling for random effects of site, nest ID, and week of nest completion. The model found a coefficient of +0.039019 ($p = <2e-16$) (Table 1). This coefficient represents log based growth, meaning that a 1% increase in the transects corresponds to roughly a 3.3% increased chance of that species being ranked in the next highest abundance category. These results indicate that there is a small but statistically significant positive correlation between abundance in the transects and the nest. Therefore, flowers that are more abundant in the transects are more likely to be abundant in the nest (Figure 2).

	Estimate	Std. Error	z-value	Pr(> z) (p-value)
Abundance in transects	0.030356	0.003414	8.891	<2e-16

Table 1: Depicts the outputs of the cumulative link mixed model. The estimated relationship between nest and transect abundance, standard deviation error, z-value, and p-value, are shown above, with most important values bolded.

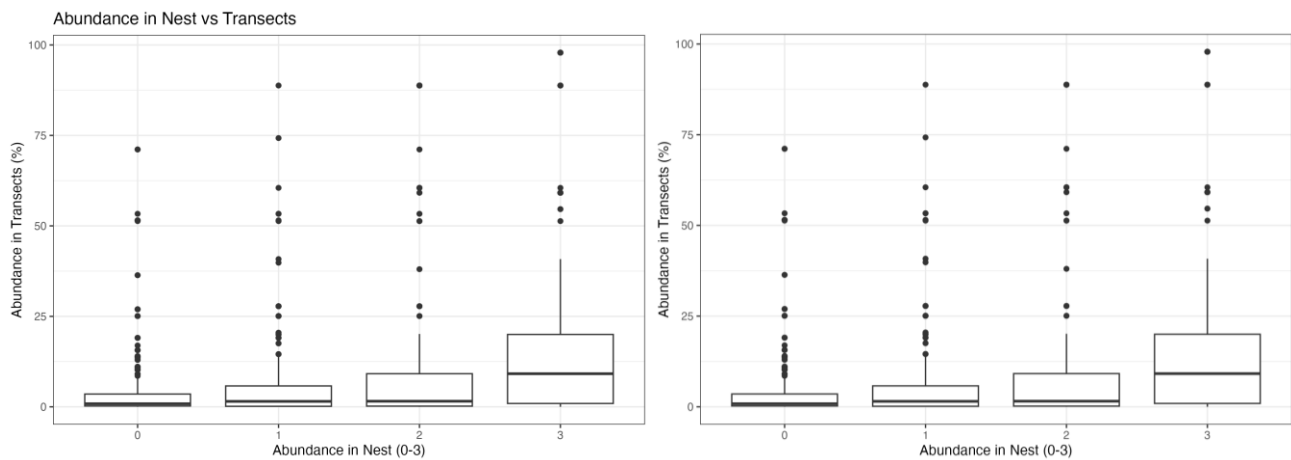


Figure 2: Above figures depict the abundance in the nest on the x axis, with four box plots representing the four abundance categories. Percent abundance in the transects is graphed on the y axis. A jitter was added to the right graph to show the distribution of points. Each point represents a flower species ranked 0-3 in the nest, with many points corresponding to the same flower species.

Random effect:	Intercept:	Variance:
Nest ID and cell #	0.000000	0.00000

Date of transect count	0.002804	0.05296
Site	0.134468	0.36670

Table 2: Impact of the controlled random effects are shown above. Nest ID is responsible for essentially zero variability, while the date of transect count has a small effect. Site has the most variance, but it is still less than one. This means that the vast majority of variability between nest and transect abundance is not due to grouping by random effects.

Additionally, the mean nest abundance of each flower species was calculated and compared with its average abundance in the transects. This value was plotted (Figure 3) and a Spearman's rank correlation test was performed, finding a correlation of 0.477217. These results further solidify that there is a moderate positive correlation between nest and transect abundance.

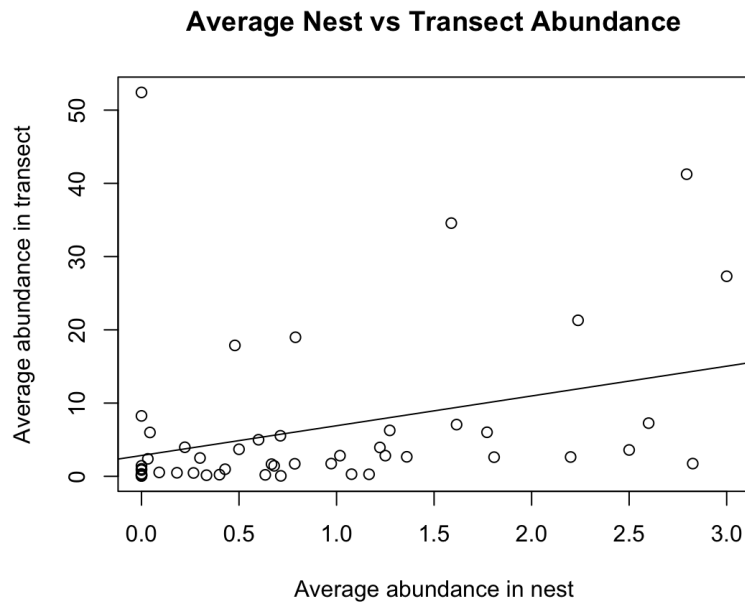


Figure 3: The average nest abundance of each flower species is plotted along the x axis, and the average transect abundance is plotted along the y axis. An abline was added to represent the line of best fit.

Flower Preferences

In order to determine whether Megachilidae had a preference for some flower species over others, I performed a Cumulative Link Mixed Model fitted with the Laplace approximation, adding in an interaction between abundance in the transects and flower species. I then summarized and performed an

ANOVA on this model. This interaction told me the intercept and slope of each flower species, allowing me to see which flower species started at lower or higher nest abundance, and which grew in abundance more quickly. This model controlled for transect abundance. As some species were rare and only had a few data points, the model would not converge with all flower species included, so I only included flower species with more than seven non-zero data points for nest abundance. Additionally, I only included species that were present at two or more sites. The following species were included in my model: *Delphinium barbeyi* (DEBA), *Eriogonum umbellatum* (ERUM), *Fragaria virginiana* (FRVI), *Hydrophyllum fendleri* (HYFE), *Ipomopsis aggregata* (IPAG), *Lathyrus leucanthus* (LALE), *Linum lewisii* (LILE), *Lupinus bakeri* (LUBA), *Pentaphyloides floribunda* (PEFL), *Phacelia hastata* (PHHA), *Potentilla pulcherimma* (POPU), and *Vicia americana* (VIAM). I also grouped together all species of the family Asteraceae in my analysis (Asters), as the pollen of Asteraceae species looks very similar and is hard to distinguish.

The results of this model indicate that not only does transect abundance influence nest abundance ($p = 5.632e-10$), but the particular flower species also impacts nest abundance ($p < 2.2e-16$). Furthermore, there is a statistically significant relationship between transect abundance and flower species ($p = 0.0002147$), meaning that flower species still influence nest abundance even after controlling for abundance in the field. From these results, it can be concluded that abundance in the field has differing effects on nest abundance depending on the flower species, with some species found in nests at disproportionately higher or lower rates than their transect abundance.

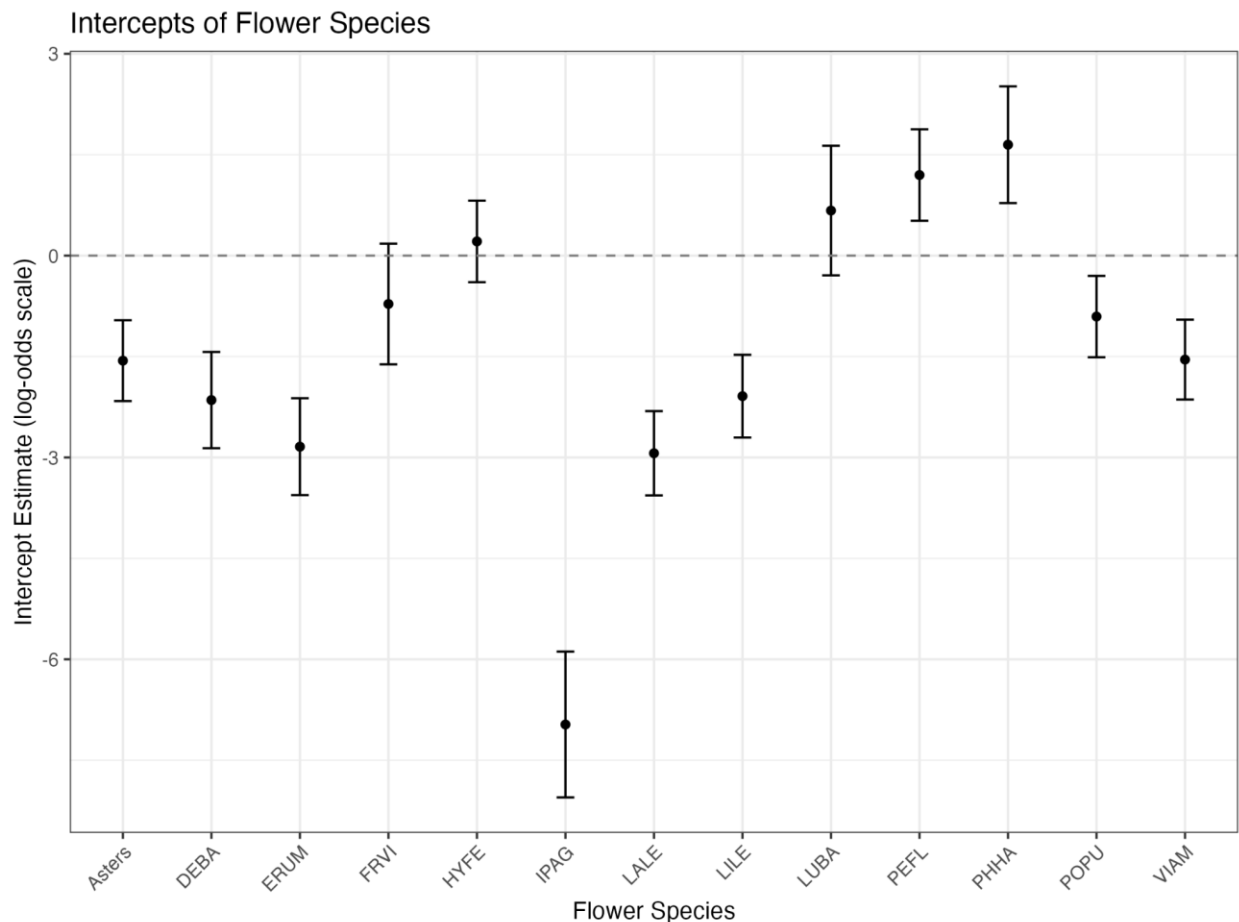


Figure 4: Flower species are plotted along the x axis, with their estimated intercept plotted along the y axis. The gray dashed line represents an intercept of zero. Error bars were added to each point, and any species whose error bars cross the dotted line are not statistically significant.

The model also calculated estimated intercepts for each flower species (Figure 4). While it may not intuitively make sense for an intercept to be less than zero, as there can't be negative numbers of flowers, negative intercepts represent a lower starting abundance in the nest. If all 13 plotted flowers had the same starting abundance in the field, the value of their intercept would represent how abundant they are expected to be in the nest compared to the other flowers. The flower with the lowest intercept was *Ipomopsis aggregata* (scarlet gilia), with an intercept of -6.9694 ($p = 1.27\text{e-}10$). *Asteraceae* species, *Delphinium barbeyi*, *Eriogonum umbellatum*, *Lathyrus leucanthus*, *Linum lewisii*, and *Vicia americana* all also had statistically significant negative intercepts (Table 3). Interestingly, no flowers had statistically significant positive intercepts.

While we cannot say whether these flowers are preferred or repulsive overall, we can compare them to each other. We know that at the same starting abundances, bees prefer to collect pollen from species with larger intercepts, and are less likely to collect pollen from species with smaller intercepts. These intercepts suggest a hierarchy of flower species, with bees selectively choosing which flower species to visit regardless of their overall abundance.

Flower Species	Intercept	Interaction Slope	Total Slope
Baseline	0	-0.238 ($p = 0.116798$)	NA
Asters	-1.5612 ($p = 0.009360$ **)	0.2658 ($p = 0.079943$)	0.0278
DEBA	-2.1473 ($p = 0.002678$ **)	0.1743 ($p = 0.467204$)	-0.0637
ERUM	-2.8397 ($p = 8.02\text{e-}05$ ***)	0.301 ($p = 0.072831$)	0.063
FRVI	-0.7186 ($p = 0.422985$)	0.4192 ($p = 0.014134$ *)	0.1812
HYFE	0.2113 ($p = 0.727358$)	0.3605 ($p = 0.029070$ *)	0.1225
IPAG	-6.9694 ($p = 1.27\text{e-}10$ ***)	0.4915 ($p = 0.029854$ *)	0.2535
LALE	-2.9374 ($p = 2.73\text{e-}06$ ***)	0.2516 ($p = 0.098472$)	0.0136
LILE	-2.0888 ($p = 0.000681$ ***)	0.488 ($p = 0.002764$ **)	0.25

LUBA	0.6701 (p = 0.486547)	0.3091 (p = 0.046236 *)	0.0711
PEFL	1.1980 (p = 0.078088)	0.2576 (p = 0.099098)	0.0196
PHHA	1.6488 (p = 0.057417)	0.6497 (p = 0.109276)	0.4117
POPU	-0.9056 (p = 0.134217)	0.3801 (p = 0.015840 *)	0.1421
VIAM	-1.5454 (p = 0.009223 **)	0.2831 (p = 0.094867)	0.0451

Table 3: Each species, its intercept, interaction slope, and total slope is shown above, with statistically significant results highlighted yellow. The interaction slope was given by the model, and the total slope was calculated by adding the negative baseline slope to the interaction slopes. Because adding two numbers involves adding their std. Error, only *Linum lewisii* is still statistically significant.

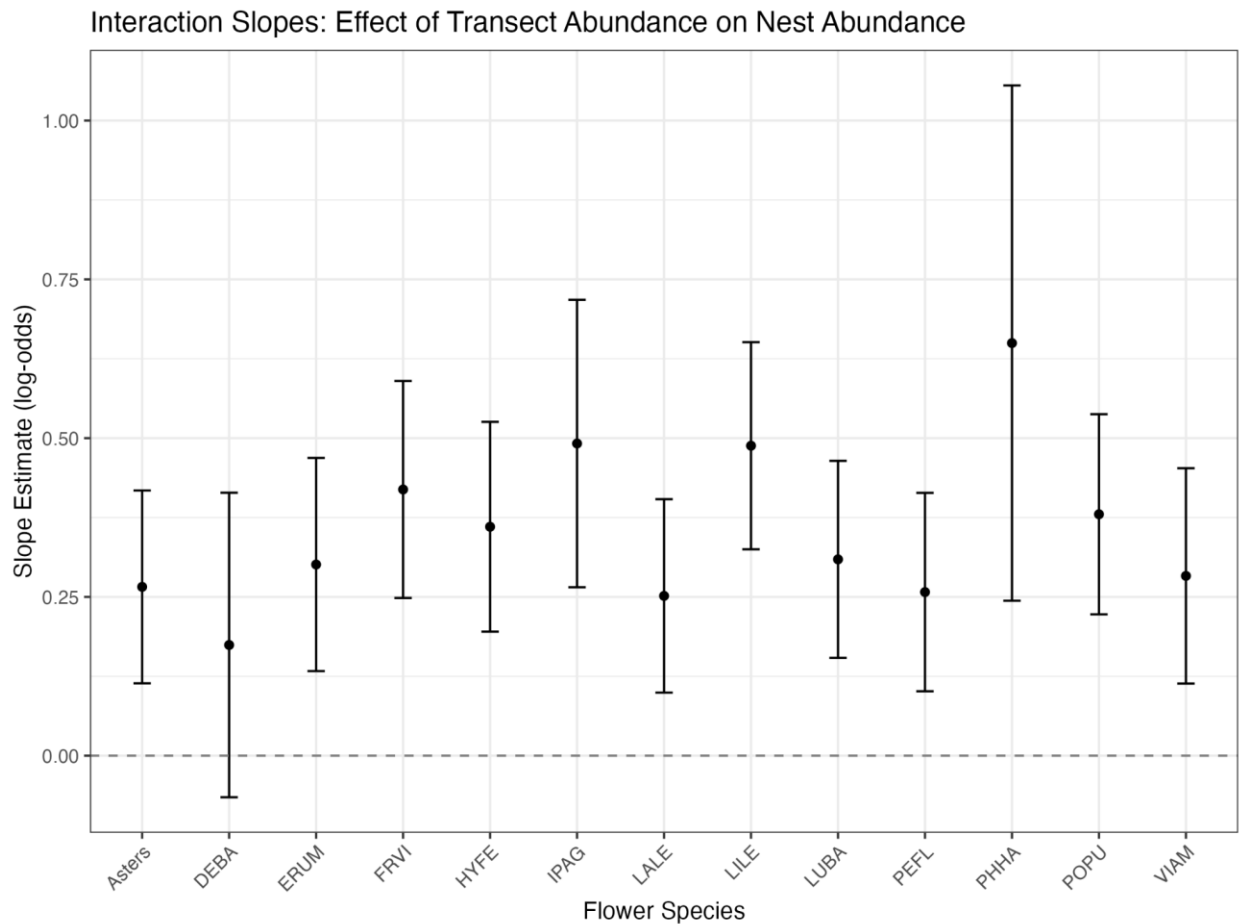


Figure 5: The interaction slopes of each flower species are plotted above, with added error bars. Again, any error bars that cross dotted line are not statistically significant. The dashed line represents a slope of

0, which would mean that abundance in the field has no impact on nest abundance. All flowers have positive slopes, as they increase in nest abundance as transect abundance increases. Flowers with larger slopes grow faster in abundance in the nest as their abundance increases in transects.

Additionally, I looked at interaction slopes between flower species (Figure 5, Table 3). These slopes represent how fast flower abundance in the nest was growing compared to abundance in transects, as an interaction of the total growth. While these interaction slopes cannot be compared to the average slope, and therefore overall preferences cannot be distinguished, they can be compared to each other. *Phacelia hastata* had the largest slope, but this was not statistically significant. Interestingly enough, *Ipomopsis aggregata* had the largest statistically significant slope, despite having the lowest intercept (Table 3). This is likely due to the fact that starting at such a low intercept forced the model to give *Ipomopsis aggregata* a steeper slope, and that the flower was never extremely abundant in the field. This slope likely describes the relationship at low abundances, but as *Ipomopsis aggregata* was never given a ranked abundance of over one in the nest, it's unlikely that its abundance would continue to increase faster than other flowers. Overall, these slopes are hard to interpret and may not say much about actual bee foraging behavior.

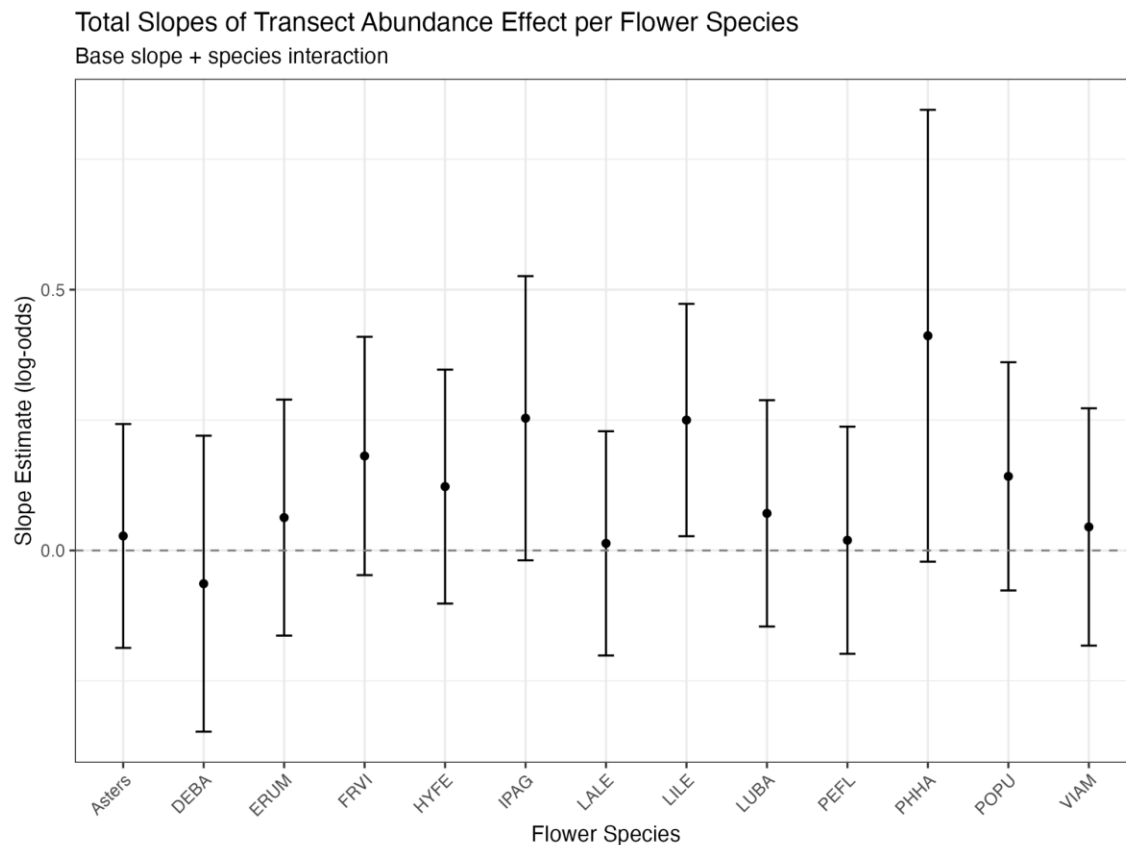


Figure 6: Flower species are plotted along the x axis, and their total slopes are given on the y axis. Total slope was calculated by adding the baseline slope to each flower species' slope. Positive slopes indicate a faster slope than the average flower species, whereas negative slopes indicate slower growth than the average flower species. Above, only *Linum lewisii* has a statistically significant positive slope.

Finally, I compared the total slopes of flower species. Because adding together two numbers involves adding their errors, the std. error is much larger in this case (Figure 6), and only *Linum lewisii* had a significant result. This positive relationship means that as *Linum lewisii* increases in abundance in the transects, it increases in abundance in the nest at a faster rate than the average flower species. This suggests that bees prefer to collect from *Linum lewisii*, especially as it grows in abundance.

Osmia vs *Hoplitis fulgida*

In order to determine whether different bee species had significantly different preferences, I compared nest abundance in *Hoplitis fulgida* vs *Osmia* nests at Rosy Point, the only site where I collected from both *Osmia* and *Hoplitis* nests. Reducing my analysis to this site allowed me to automatically control for floral abundance in the area, so I only had to compare nest abundances. I calculated the mean abundance of each flower species in *Hoplitis* nests vs *Osmia* nests and performed a Spearman's rank correlation test. The data received a correlation of 0.8632973, meaning that it was highly correlated.

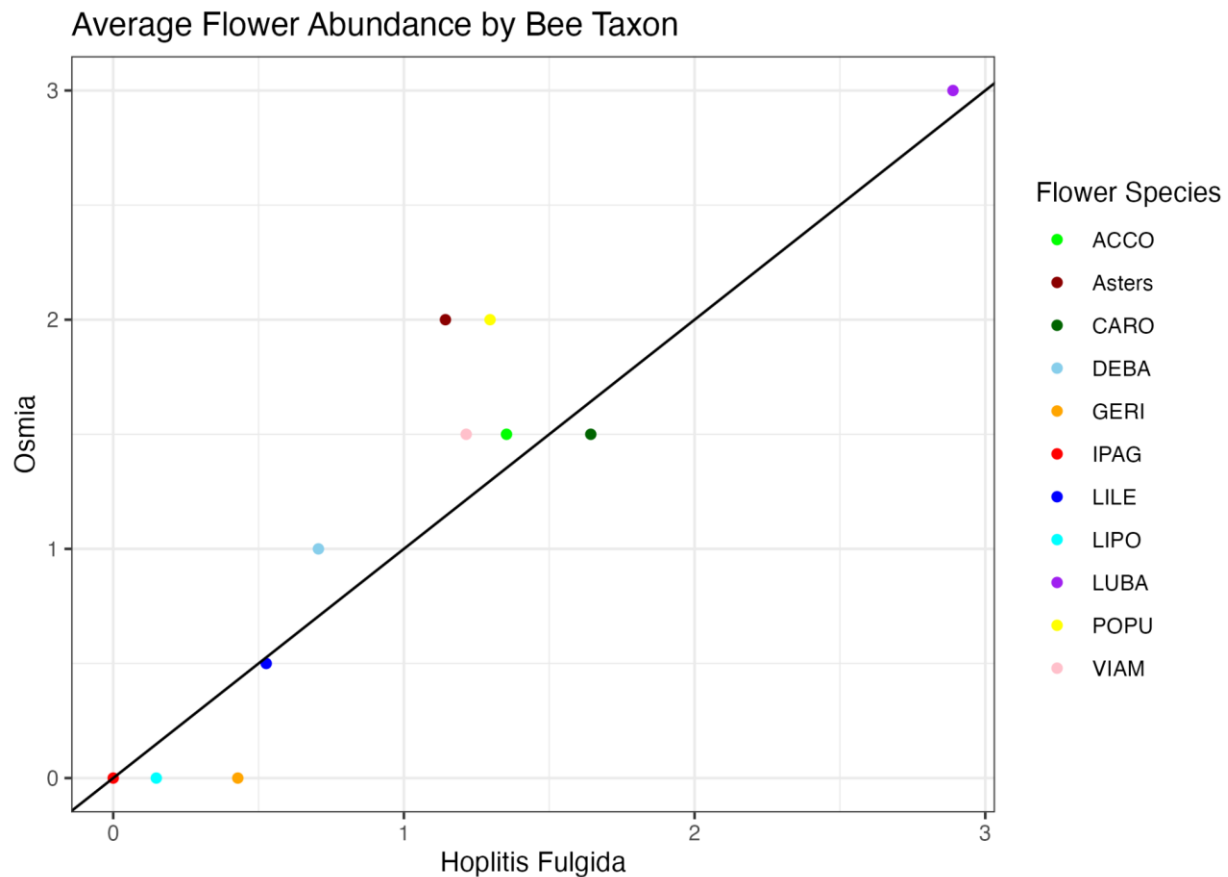


Figure 7: Average nest abundance by flower species in *Hoplitis fulgida* nests is plotted along the x axis, and average abundance in *Osmia* nests is plotted along the y axis. An abline was added and points were

color coded by flower species to allow for easy visualization of outliers. Dots above the line were more abundant in Osmia nests, and dots below the line were more abundant in Hoplitis fulgida nests.

I also ran an ANOVA to test the relationship between bee taxon and flower species. While the relationship between flower species and its abundance in the nest was statistically significant ($p < 2e-16$), both the relationship between bee taxon and abundance in the nest ($p = 0.270$) and the interaction between bee species and flower species ($p = 0.879$) were not significant. These findings suggest that there is little difference between the preferences of *Hoplitis fulgida* and *Osmia*. While many flower species were found in similar abundances in both *Osmia* and *Hoplitis* nests, there were notable outliers; both Asteraceae species and *Potentilla pulcherrima* were more abundant in *Osmia* nests. (Figure 7). While these were not shown to be statistically significant, the sample size was relatively small, and further research could reveal preferences.

Intentionally placed transects vs randomly generated quadrats

As the transects were placed intentionally to try to capture as much floral variation as possible, and the quadrats were placed randomly, another question of this project was how closely the floral abundance across the two lined up. Floral abundance was calculated by adding up all of the times each flower species was counted at a particular site and week and dividing that number by the total number of flowers counted. These abundances were then compared across transects and quadrats (Figure 8), and a Spearman's correlation test was performed to test the correlation between the values. The data received a fit of 0.7041859. A value of 1 indicates a perfect fit, so 0.7 indicates a strong but not perfect correlation between floral abundance in transects vs quadrats. Then, a basic linear regression was used to fit a linear model to the dataset. The calculated slope was 0.93411 ($p < 2e-16$), indicating a relationship close to 1:1. Furthermore, $R^2 = 0.9755$ ($p < 2.2e-16$), meaning that 97% of the variation in quadrat abundance can be explained by transect abundance. This is an extremely strong correlation, and indicates that the floral abundance represented by the two is very similar.

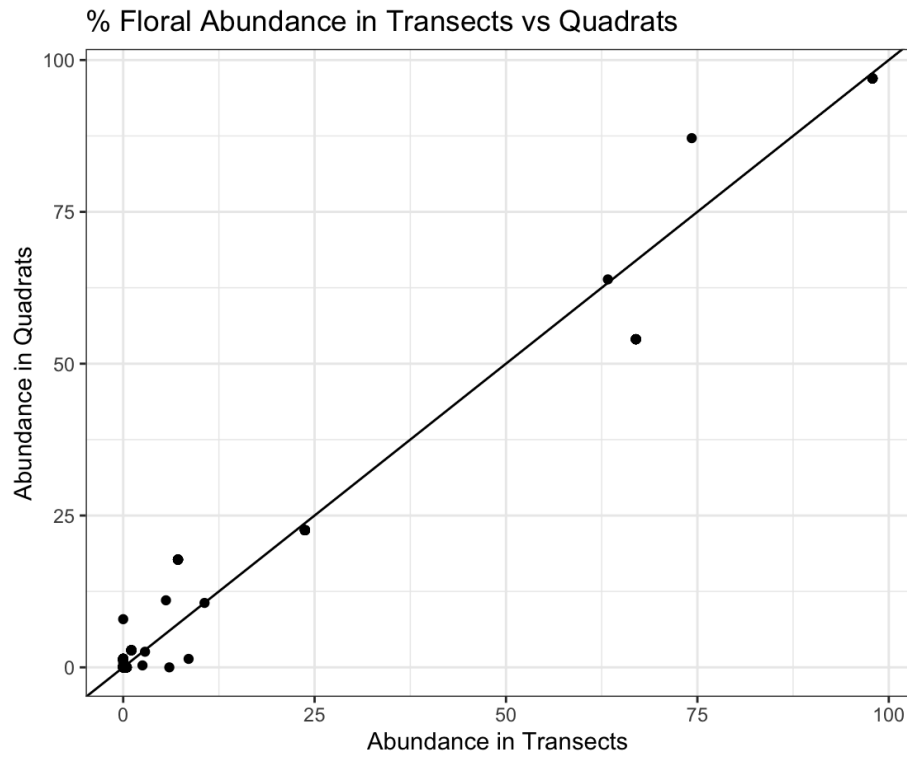


Figure 8: The calculated floral abundance was plotted, with the abundance in transects on the x axis and abundance in quadrats on the y axis. Each dot represents a flower species counted. A line of best fit was added for visualization purposes.

Discussion

Megachilidae forage selectively and show preferences for some flower species over others. Even after controlling for abundance in transects, flower species were found in highly varying abundance levels in the nest. In particular, flowers such as *Ipomopsis aggregata*, *Delphinium barbeyi*, *Eriogonum umbellatum*, *Lathyrus leucanthus*, *Linum lewisii*, *Vicia americana*, and the Asteraceae family were found in lower initial abundances in the nest than other flower species. However, as these species grew in abundance in the field, the rate at which they grew in abundance in the nest was not significantly different from other flower species. In some cases, such as *Ipomopsis aggregata*, their slopes were even significantly larger than other species. These results suggest that at low floral abundances, Megachilidae are more selective with which species they choose to collect pollen from, but that at higher abundances, these preferences matter less.

One species, *Linum lewisii*, was shown to have a steeper slope than the average flower species. Therefore, as *Linum lewisii* grows in abundance in the field, it grows in abundance in the nest at faster rates than other flower species, indicating a preference for *Linum lewisii* over other flowers, even at higher floral abundance.

There are a few possible reasons why some flower species could be more valuable to Megachilidae than others. One potential reason is competition from other bee species. For instance, some species of *Osmia*, solely collect pollen from Asteraceae specialists²⁰, while other *Osmia* species only collect pollen from *Lathyrus leucanthus* and *Vicia americana*.²¹ Additionally, *Delphinium barbeyi* is heavily visited by the specialist bumble bee species *Bombus appositus*.²² All four of these flower types are found at lower initial abundances in the nest. A reasonable explanation for this phenomenon is that at low abundances, these flower species are dominated by specialists, and generalists choose to collect pollen from flowers with fewer competitors. However, as they grow in abundance, there is less competition, and generalist bees collect with less specificity. While this is a plausible explanation, not all of the species with negative intercepts are visited by specialists, so competition cannot be the sole explanation of this behavior.

Another possible explanation could be the average amount of pollen production. *Linum lewisii*, for instance, has a particularly high average pollen production. A previous summer, REU student Kevin Flores calculated the average number and weight of anthers of different flower species in order to represent the amount of pollen produced on average by a species.²³ *L. lewisii* had an average anther weight of 7.286 mg, significantly heavier on average than all but three other relevant species, all of which I had insufficient data to analyze during this project. As collecting pollen provisions efficiently is crucial for maintaining a high nesting rate, it would make sense for Megachilidae to preferentially visit flowers where pollen is particularly abundant or easy to collect. While the rest of the species analyzed here do not follow this pattern, they also do not have very sizable anther weight differences. Hopefully future projects will elaborate on the role of pollen production in floral preferences.

²⁰ Spear et al., "Asteraceae Pollen Provisions Protect *Osmia* Mason Bees (Hymenoptera: Megachilidae) from Brood Parasitism."

²¹ Wong and Forrest, "The Earlier the Better?"

²² Graham and Jones, "Resource Partitioning and Per-Flower Foraging Efficiency in Two Bumble Bee Species."

²³ Flores and Bain, *Variation of Pollen Mass Across Species, Habitat Types, and Time*.

Morphological properties of the flower most certainly also play a role in bee selection. *Ipomopsis aggregata* was the species most strongly selected against, and it is generally known that most bees do not collect from *I. aggregata* at high rates. This species has long tubular flowers, making its morphology particularly well-suited for hummingbirds and long-tongued bumble bees.²⁴ However, the average Megachilidae bee likely cannot collect much pollen from these flowers. While the *I. aggregata* may pose a particularly well understood morphological disadvantage to Megachilidae, this same phenomenon could be at play for other species as well. As mentioned previously, collecting pollen efficiently is biologically favored for Megachilidae, and thus visiting flowers that are easier to collect from would have a reproductive advantage.

Finally, Megachilidae could visit flowers preferentially based on olfactory cues and volatiles. *Osmia* bees have been shown to detect nectar in flowers due to olfactory cues,²⁵ though the role of these cues in collecting pollen has not been studied. Furthermore, volatiles released from plants are critical in attracting insect pollinators such as bees, especially early in the season when flowers are harder to locate.²⁶ The role of volatiles on pollination has not been studied in Megachilidae, but certainly plays a crucial role in locating and collecting from flower species.

One other, perhaps less exciting explanation for the apparent aversion for certain flower species could be miscounting during analysis. If certain species were fairly uncommon in the nest, they could have been undercounted, leading to negative intercepts. Future research will certainly have to be done to solidify these findings, as well as investigate the role of pollen production, volatiles, and interspecies competition on Megachilidae foraging behavior.

Species Specific Preferences

Due to small sample size, it was very difficult to accurately predict any difference in foraging preferences between *Osmia* and *Hoplitis fulgida*. While some flowers appeared to have been collected more by one species than the other, these differences were not statistically significant. Overall, both *Osmia* and *Hoplitis* genera collect pollen from similar flower species without dramatic differences. Though there may be small preferences between the two, further research must be conducted. Additionally, as different species of *Osmia* are hard to identify, I lumped together all *Osmia* generalists. Some *Osmia* species may be more specialized, but it wasn't possible to analyze their preferences in this project.

Transect vs Quadrat Abundance

There was shown to be a very strong correlation between floral abundance in the intentionally placed transects vs the randomly placed quadrats, with 97.6% of the floral abundance in the quadrats also being described by the transect abundance. This close relationship indicates that transects were very accurate in predicting general floral abundance despite being intentionally placed. Furthermore, adding more quadrats did not dramatically increase our understanding of the general floral abundance of the area,

²⁴ Mayfield, "Exploring the 'Most Effective Pollinator Principle' with Complex Flowers."

²⁵ Howell and Alarcón, "Osmia Bees (Hymenoptera)."

²⁶ Metcalf and Kogan, "Plant Volatiles as Insect Attractants."

a positive for future research, as placing quadrats is both time consuming and somewhat disruptive to the landscape.

Conclusion

This study investigated the flower preferences of generalist Megachilidae by analyzing pollen samples taken from completed bee nests and comparing pollen abundances with transect abundance. It was found that Megachilidae do have foraging preferences and active selection, and do not simply forage for the most abundant researchers. As some flowers are more vulnerable to climate change than others, understanding these preferences is crucial for protecting Megachilidae and subalpine environments from climate change. Furthermore, understanding which biological factors are responsible for these preferences, such as competition, volatiles, or pollen composition, will help us to more efficiently predict their preferences and further insulate them from the changing climate.

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