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Pollinator Sharing Between Mimulus ringens and Coflowering Plant Species in Northeastern Ohio

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Abstract

Competition between plants for pollinators can have serious impacts on plant reproduction; these impacts depend on many factors, such as plant abundance, plant diversity, floral abundance, pollinator abundance, and pollinator preference. The way pollinators move among and between coflowering species can tell us more about how these factors affect competition. In this study, we examine the movement patterns of flower visitors to *Mimulus ringens* and coflowering species in Northeastern Ohio through several types of observations. In addition, we measured the density and diversity of floral units with 20-30 meter transects across each study site. There were six total study sites, including one site where we collected data six times across a one month period. Our results show that *Bombus impatiens*, our most commonly observed pollinator, was the species most likely to make inter-species movements between flowers and that in total, pollinators make movements between separate species about 6% of the time. We observed a wide range of specializations, with several species of pollinators showing a tendency to visit one species of flower over the others. Lastly, the types of quantity and type of flowers at each site affected availability and pollinator preference differed at each site accordingly.

Introduction

Plant reproduction is largely dependent on the actions of pollinators; more specifically, the number of pollinators that choose to visit each plant, the amount of pollen deposited, and the number of visits they make. Each visit to a particular plant allows a chance for pollen receipt and export, increasing the odds of fertilization. Several things can also make pollination more difficult for plants: environmental factors like rainfall and humidity, and a low population of pollinators in the area (Fernandez, 2012). One factor is of particular interest: the potential competition for pollinators between plants. When several plant species flower at the same time and in the same location, pollinators must choose which plants to visit. This can have a positive effect on plants by attracting an abundance of pollinator visits compared to populations that only occur by themselves (Moeller, 2004).

In some cases pollinators move between plant species, but most pollinators largely limit their visits to a particular type of flower (Willmer, 2011). In the case of pollinators sticking to a specific species, we can observe benefits to both the plant and the pollinator as a result of "specialization". Specialist species handle the complex flowers more efficiently than generalists, rapidly becoming highly effective foragers for nectar, pollen, or both (Willmer, 2011). The foraging patterns expressed by pollinators also wield influence over selfing rates, an important consideration when analyzing pollination within a population (Mitchell *et al.*, 2009).

Pollinators can at least occasionally be observed moving between the flowers of different species (Willmer, 2011; Rathcke, 1983; Mitchell *et al.*, 2009), suggesting that not all pollinators specialize in one particular plant species. This raises new questions about how plants may compete with each other for these selective pollinators, and whether the behavior is beneficial to plants and/or pollinators; studies observing bees that moved between *Mimulus* and *Lythrum* showed that bees which made inter-species movements were less effective pollinators (Flanagan, 2009). Competition for pollinators can affect pollen deposition through two mechanisms: pollinator preference (the flowers which a pollinator chooses to visit) and improper pollen transfer (Bell *et al.*, 2005); this study will attempt to gather data on pollinator preference. Namely, we asked: which pollinators switch between different species of flowers and how often? This answer was sought out while also taking the opportunity to document and understand patterns in pollinator behavior.

In order to answer our question, we needed to gather information on the flowering phenology of our locations, including the species flowering, the abundance of flowers, their proximity to each other and to other flowering plants, the time of year, and the time of day. The density of flowers and the changing abundance of these flowers will play a key role in the number of visits from pollinators (Rathcke, 1983). In addition to recording information about the plants, we needed to pay great attention to the pollinators; the most important items being the species of each observed pollinator, the patterns of movement between individual flowers and individual plants, and the total number of visits. The abundance of local pollinator populations are essential in decoding the local pollination web and influences corresponding pollen deposition rates (Mitchell, 2009).

These data sets can provide insight on other questions about specific pollinator behavior, which we will discuss: Which pollinators are most commonly seen in these habitats? Do certain species of pollinators have a preferred species of flower? Does visitation rate/pattern change in a significant way over the day? Which species of plants most commonly co-flower?

Methods

Data was collected between July 29th and August 17th 2016, at locations in Northeastern Ohio where *Mimulus ringens* was flowering near at least two other flowering species. Previous studies conducted by Dr. Randall Mitchell have shown that the period between mid-July and late August is when the greatest number of *Mimulus ringens* are in bloom in northeast Ohio. We conducted recurring studies every week at Bath Nature Preserve, at a specific location called “Garden Bowl West”; this location was ideal due to its abundance of flowering plants and diversity, as well as being close to the University of Akron’s Field Research Station. Other locations included Garden Bowl East (also at Bath Nature Preserve), two sites at Wolf Creek Environmental Center, one site Firestone Park (Cuyahoga National Park), and two sites at the Panzner Wetlands. Complete listings and coordinates for our sites can be found below in Table 1.

Table 1 - Names and coordinates for sites included in this study

Location Name	Coordinates
Garden Bowl West	41.11’3.70 N 81.39’1.99 W
Garden Bowl East	41.11’5.34 N 81.38’53.93 W
Panzner A	41.3’56.72 N 81.36’35.68 W
Panzner C	41.4’1.67 N 81.36’29.46 W
Beaver Pond	41.12’22.04 N 81.41’27.39 W
Firestone Park	41.0’48.53 N 81.30’50.81 W
Wolf Creek East	41.6’53.88 N 81.44’10.74 W
Wolf Creek West	41.6’58.68 N 81.44’17.53 W

Because flowers of *M. ringens* last only a single day (opening before dawn), and are fully pollinated by about noon (Mitchell et al. 2005), each day of surveying began near 8:00 AM, after locating the areas of largest flowering concentration and diversity. To measure flower availability we scored populations along a 20-30 meter transect through the densest area of flowers. We then scored the number of ‘flowering units’ (defined below) within each 1x1 meter square along the transect. One person would then count the number of flowering units for each species within the square and the second person would record each number. Flowering units differed depending on the species; for single flowers, such as *M. ringens*, we would score each individual flower as one unit. We scored species with clustered or compound displays differently; *Asclepias* and *Verbena* flowers were counted by each cluster with a stem. This dataset of floral abundance is labeled below as “Phenology”, and gives us a description of the identity and abundance of the species present at each location.

During this time we would also compile a list of every flowering species within the study area. He compiled each list for every site (we found it beneficial to maintain certain roles for each person to limit the amount of user difference/error in recording certain datasets). This list was recorded to confirm questions about species during analysis and also for future reference when looking for potential sites with specific species.

Beginning at 9:00 AM (after completing the phenology transect) about 9:00 AM we cycled through three different types of data gathering, each with a standard allotment of time for each recording cycle: Pollinator Following (20 min), Walking Survey (10 min), and Plot Observation (15 min). Being careful to write down the exact time range for each dataset, we would split up in order to avoid copying instances. Communicating time limits via voice, we would observe and write down the following observations:

Pollinator Following: The goal here is to assess whether and how often pollinators move between plant species. Each of the 2-3 researchers at the sites spreads out and works independently and identifies a pollinator, writing down its species and the species of plant it is currently on. The researcher then follows this specimen and records the transitions made between individual flowers and plants and species. Special attention is payed to a pollinator that moves between separate species. When the pollinator moves out of sight, the researcher follows the next visitor seen, and repeats the process. At the end of the 20 minute time limit, the current following is ended and the next data set in the cycle is begun.

Walking Survey: The goal here is to assess the abundance of different pollinator species across the site. The walking survey begins with each researcher spreading out from one another - keeping distance between researchers is important for this dataset in order to minimize the chances of recording the same visitors more than once. Each researcher then walks slowly around and throughout the perimeter of the study area, recording each species of pollinator identified on a flower, and the corresponding species of plant it is on. When the 10 minute time limit was reached, the survey was ended and the next data set in the cycle was begun.

Plot Observation: The goal here is to assess the visitation rate experienced by flowers. This data set was collected by having each researcher choose a cluster containing more than two species of flowering plants. The plot is measured and the number of flowers for each species within the plot is recorded. The plot should also be easily distinguished by eye for the observer so that they do not accidentally record pollinator visits that are outside of the plot; furthermore, the plot should not be too large so that the researcher might miss and fail to record a pollinator visit. The researcher then writes down the time and begins recording each visit from a pollinator to each species of plant. When the 15 minute time limit is up, the observation ends and the next data set in the cycle is begun.

Nearest Neighbor: The goal of this quick measurement was to gain an idea of how close plants were growing to one another. We would randomly choose 20-30 M. ringens plants and measure, in meters, the distance to the nearest plant of each coflowering species within 3 meters.

We typically ran through this cycle of three data gathering types three times, ending around 11:30 or noon. Upon finishing, we would consolidate our data sheets, remove anything we brought with us, and plan out the next day. In total, our field work constituted about 82 hours of observation between all the researchers.

Results

Phenology:

Our phenology data was important for understanding and interpreting our visitor data. As previously mentioned, the abundance of flowers and the absence/abundance of certain species dictates what kinds of observations can be made. Being able to look at a sample of the floral diversity and the corresponding population scales is an important piece of understanding all of the data sets on a spatial context. Figure 3.5 shows us the abundance of flowering units for each species at GBW over the course of five different study periods ranging from 7-25 to 8-17, 2016. The same 20-meter transect was used for each measurement. Note that *Lythrum*, although highly observed in our other data, was not present at GBW and *Verbena* is under-represented because it was concentrated in a large patch that did not converge with our main transect line. Figure 3.1 shows us the total number of observed blooms for major species, providing a large picture of species-specific floral density.

The data from our GBW phenology shows us that *M. ringens* populations began seriously declining after our third week of observation, within the first five days of August. *Asclepias* showed a more steady blooming period throughout, with an obvious decline beginning near the middle-end of August around the 18th. Blooming patterns demonstrated by this data are essential when trying to understand the visitor data, because the number of available blooms inevitably affects the number of visits.

Figure 3.0: Abundance of flowering units per plant species across our phenology transect at the Garden Bowl West site from July 22 to August 26/2016.

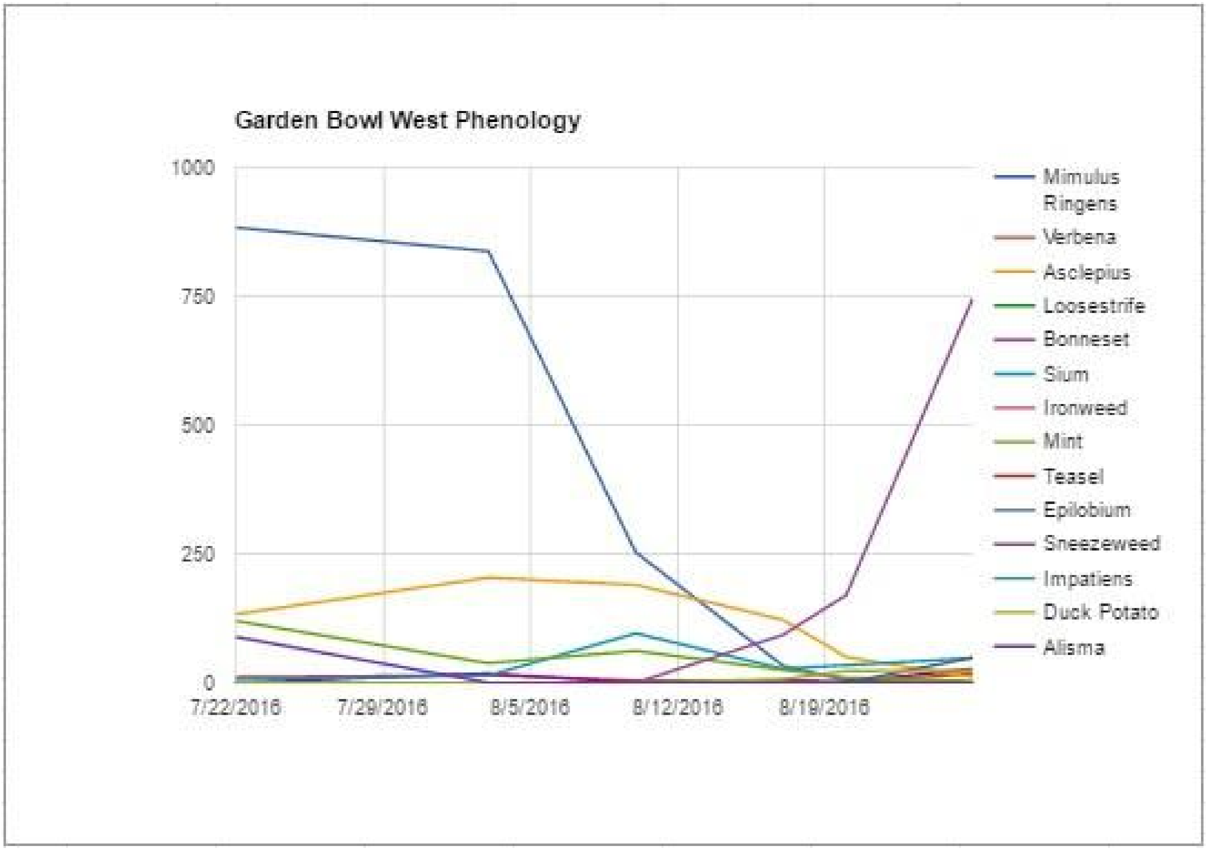


Figure 3.1: Total floral units recorded for each plant species over the course of our observations at Garden Bowl West (Phenology observations; See Figure 3.0). Note the prominence of *M. ringens* and *Asclepias* in comparison with the abundance of visits from our Pollinator Follow and Walking data sets.

Plant Species	**Total Flower Units**
M. ringens	4022
V. hastata	84
A. incarnata	1409
E. maculatum	8
E. perfoliatum	73
S. suave	404
P. virginianum	513
Eplobium sp.	49
H. autumnale	1271
S. latifolia	84
P. sedoides	8
Alisma	178
Grand Total	8103

Visitors and plant species:

Overall we observed 17 different animal taxa visiting flowers during our 82 hours of observation (Figure 3.2a). Across our 6 sites we noted 17 different plant species visited by these animals.

Figure 3.2A: Visitor species observed across all sites. This table serves as a key for understanding the abbreviations used in our data for pollinators. It is sorted by the frequency of sightings in descending order.

Visitor Abbreviation	**Visitor Species**	**Common Name**
Imp	*Bombus impatiens*	Common Eastern Bumble Bee
Carp	*Xylocopa virginica*	Carpenter Bee
HB	*Apis mellifera*	Honey Bee
Gris	*Bombus griseocollis*	Brown-Belted Bumble Bee
Ferv	*Bombus fervidus*	Golden Bumble Bee
Anthophora	*Anthophora terminalis*	Red-Tipped Digger Bee
Hawk	*Hemaris thysbe*	Hummingbird Hawkmoth
Hal	Halictidae sp.	Sweat Bee
Silver	*Epargyreus clarus*	Silver Spotted Skipper
Skip	Hesperiidae sp.	Orange Skipper
Swallowtail	*Papilio troilus* & *Papilo glaucus*	Spicebush Swallowtail & Eastern Tiger Swallowtail
Bi	*Bombus bimaculatus*	Two-Spotted Bumble Bee
Sphex	*Sphex ichneumoneus*	Great Golden Digger Wasp
Cabbage	*Pieris rapae*	Cabbage White
Leafcutter	Megachilidae sp.	Leafcutter Bee
Vag	*Bombus vagans*	Half Black Bumble Bee
Eum	Eumenidae sp.	Potter Wasp

Figure 3.2B: Plant species flowering across all sites. This table serves as a key for understanding the abbreviations and flowering units used in our data for plants.

Plant Abbreviation	**Plant Species**	**Common Name**	**Flowering Unit**
MR	*Mimulus ringens*	Square-Stem Monkey Flower	*Flower*
MW	*Asclepias incarnata*	Swamp Milkweed	*Inflorescence (umbel)*
V	*Verbena hastata*	Vervain	*Stem*
Mint	*Pycnanthemum virginianum*	Mountain Mint	*Inflorescence*
LS	*Lythrum salicaria*	Purple Loosestrife	Stem
Iron	*Vernonia gigantea*	Ironweed	Inflorescence
SW	*Helenium autumnale*	Sneezeweed	Flower
Smart	*Persicaria* sp.	Smartweed	Stem
Agr	*Agrimonia* sp.	Agrimony	Stem
JP	*Eupatorium maculatum*	Joe Pye Weed	Inflorescence (umbel)
DP	*Sagittaria latifolia*	Duck Potato	Flower
BS	*Eupatorium perfoliatum*	Boneset	Stem
Sium	*Sium suave*	Water Parsnip	Inflorescence
Epil	*Eplobium* sp.	Willow herb	Flower
Teasel	*Dipsacus fullonum*	Teasel	Stem
SC	*Penthorum sedoides*	Stonecrop	Inflorescence
Al	*Alisma subcordatum*	Alisma	Flower

<u>Pollinator Following:</u>

The three species of flower visitor that we observed the most were *Bombus impatiens, Xylocopa virginica,* and *Apis mellifera* (Figure 3.3A); for brevity's sake, we will call these three species our "signature species".

Figure 3.3A: The totals for inter-plant movements made by the seven most frequently observed species of pollinators. For brevity's sake, abbreviations are used for the plant species, and a reference can be found above in Figure 3.2B. The complete table for this information can be found in the Appendix, Figure A.

	Impatiens	Xylocopa	Apis	Fervidus	Anthophora	Hemaris	Grand Total
MR/MR	124	33	30	72	57	37	413
LS/LS	52	42	19	19			135
MW/MW	3	87	17			3	124
V/V	45		75				120
Agr/Agr	2		34				36
JP/JP	14		4				25
SW/SW	3	11					14
MR/MW	1	4				5	10
V/MR	7						7
Teasel/Teasel	3						7
MW/MR		3				4	7
MR/V	5						7
Teasel/MR	1						4
MR/Teasel	1						4
SW/MR	2						2
MW/V		1	1				2
MR/Imp	2						2
Imp/MR	2						2
V/SW	1						1
V/MW		1					1
V/Ludw							1
V/JP							1
Si/Mint							1
Seum/V	1						1
Seum/MW							1
Physo/MW		1					1
MW/LS		1					1
MW/BS							1
MR/SW	1						1
MR/Seum	1						1
MR/Mint	1						1

MR/Agr	1						1
Mint/MR	1						1
Mint/Mint							1
Lyth/V		1					1
Ludw/V							1
LS/MW		1					1
BS/MW							1
Agr/Teasel	1						1
Grand Total	275	186	180	91	57	49	942

Inter-plant moves were very uncommon (Figure 3.3A, Appendix Figure A). Out of a total of 942 total interplant moves across all visitor taxa in ~82 hours of observation, only 6% were between species. The most common inter-plant move type was between *Mimulus ringens* and *Verbena hastata*, with a combined total of 12 observed switches between these two species alone (out of 275 total interplant movements by *B. impatiens*). *Bombus impatiens* also had the largest total on inter-species switches, with a grand total of 28 switches. Carpenter bees (*Xylocopa virginica*) tended to switch between *Mimulus ringens* and *Asclepias incarnata* (Swamp Milkweed) when making inter-species switches. *Apis mellifera* showed a different pattern despite being observed with about the same frequency as *B. impatiens* and *Xylocopa*; the honey bee was only observed switching between species one time, between *Asclepias* and *Verbena*.

Figure 3.3: Total observed transitions between individual plants of the same species (listed in the far left column) made by visitors during the “pollinator following” observations. This table shows the major species only, and the complete table can be found in the Appendix, Figure A.

	Bombus Impatiens	Xylocopa virginica	Apis mellifera	Bombus fervidus	Anthophora terminalis	Hemaris sp.
M. ringens	**124**	**33**	**30**	**72**	**57**	**37**
L. salicaria	**52**	**42**	**19**	**19**		
A. incarnata	**3**	**87**	**17**			**3**
V. hastata	**45**		**75**			
Agrimonia sp.	**2**		**34**			
E. perfoliatum	**14**		**4**			
H. autumnale	**3**	**11**				

Our pollinator following data also showed us which species of flower our pollinators tended to prefer (Figure 3.3). *Bombus impatiens* showed a strong preference for *Mimulus ringens* (124/243 moves were between *Mimulus* plants; Figure 3.3), while *Xylocopa* preferred *Asclepias* and *Apis* preferred *Verbena (Figure 3.3)*. Additionally, *Bombus fervidus*, *Anthophora terminalis*, and the Hawkmoths were all observed less often than the three signature species, but were much more commonly seen visiting *Mimulus ringens* than any other species. These numbers also correspond to the density of specific flowering species at each location. For example, Garden Bowl West (GBW) had no Loosestrife (*Lythrum salicaria*) in flower, while Panzner A & C both had high abundance of *Lythrum*. If *Lythrum* had been present at GBW, it would most likely have been visited frequently.

Overall, *Bombus impatiens* visited the most diverse range of plants (Figure 3.4); *B. impatiens* switched to or from a total of 10 different species, with a grand total of 275 observations making it the most commonly observed species of pollinator as well. *Xylocopa* showed less diversity in flower preference, likely due to its larger size and apparent inability to land on certain smaller species of flowers. *Xylocopa* was observed moving to or from a total of 7 different species, with a heavy preference for larger, thicker-stemmed flowers like *Lythrum* and *Asclepias*.

The Following data also provided insight into the behaviors of pollinator movement among the flowers of a single plant. Our three signature species all had totals over 300 for intra-plant movements, and reflected the same three preferences as the inter-plant movements (*impatiens:Mimulus, Xylocopa:Asclepias, Apis:Verbena*). The intra-plant movement data had larger values, as one would expect, that largely reflected the same pattern as inter-plant observations. *Anthophora terminalis* had 64 total intra-plant movement observations, 62 of which were among the same individual plant belonging to the *Mimulus ringens* species. This supports the notion that *A. terminalis* has a strong tendency to specialize in *Mimulus* harvesting. Many of the observed species of pollinators had too little data to draw significant conclusions, although possible trends can be predicted for certain sites due to an abundance of location-specific data density for certain species which were only observed at a single or two sites.

Figure 3.3 and 3.4 show totals for the inter-plant and intra-plant movements made by visitors, respectively. Note that because some visitors were never observed to move between individuals, there are more plant and animal species in Figure 3.4 (within plant movements) than in Figure 3.3 (between plant movements). Both tables show us that *Bombus impatiens, Apis mellifera, and Xylocopa virginica* were the three most observed species of visitors by a large margin, and this can be asserted at all research sites by looking at site-specific tables in the Appendix, Figures B and C. Figures 3.3 and 3.4 also show us that *Anthophora terminalis, Hemaris thysbe,* and *Bombus fervidus* were the next three most frequently observed species, but by a smaller margin than the first three. Sweat bees, belonging to the family *Halictidae*, were also observed quite frequently, but when comparing data sheets between observers there is a clear absence of *Halictidae* tracking from several observers, indicating observer bias.

Figure 3.4: This table shows totals for all of the moves between flowers on an individual plant during the “pollinator following” observations. Plant species with totals <40 are excluded for the sake of brevity, but those movements are included in the Grand Total for each pollinator species.

	MR	MW	LS	V	JP	SW	Grand Total
B. Impatiens	116	3	113	93	47	35	413
Xylocopa	70	224	67	8		11	392
Apis	31	84	36	102	10		301
B. Fervidus	113		11				124
Hemaris	39	17					56
Anthophora	62	2			2		66
Epargyreus	15	2	24				41
Halictidae	22				10		32
Griseocollis	2	7			14		23
Pieris			6	17			23
Bimaculatus	12	5					17
Papilio	2	7					14
Sphex		10					10
Megachilidae	2			2			4
Hesperiidae				2			2
B. Vagans					1		1
Eumenidae					1		1
Grand Total	486	367	271	231	85	46	1556

Based on the following data, sites differed strongly in both the species of plants present, and the number of movements observed by different visitors (Figure 3.5 and 3.6). Our following data (Fig 3.5), in addition to our phenology data, gives an indication of what plants co-flower with *Mimulus ringens*. Each site had differing abundances of certain plants; for example, both Panzner Wetland sites showcased high populations of *Lythrum* while sites at Garden Bowl had no *Lythrum* at all. These differences are reflected in the pollinator data, as seen in Figure 3.3, which shows the number of intra-plant movements for each species within a location. Garden Bowl West had the most diversity of plants in which pollinators took interest; Garden Bowl East and both Wolf Creek sites had the least diversity.

Figure 3.5: Number of intra-plant (floral) movements for each plant species at our 8 study sites (summed over visitor species) during the “pollinator following” observations. Note the absence or abundance of certain plant species between sites.

	GB W	Panzner C	GBE	Panzner A	Firestone	Wolf Creek 1	Beaver Pond	Wolf Creek 2	Grand Total
Mimulus	251	29	99	6	33	9	54	5	486
Asclepias	202	13	106	24		22			367
Lythrum		192		79					271
Verbena	103			56	30	41	1		231
Eupatorium perfol.	9	1			59			16	85
Persicaria	77								77
Pycnanthemum	3				9				12
Physocarpus	8								8
Agrimonia							7		7
Dipsacus							5		5
Lythrum				4					4
Impatiens		2							2
Sium			1						1
Grand Total	653	237	206	169	131	72	67	21	1556
N Plant Species	8	5	3	5	4	3	4	2	

In summary there were substantial differences among locations in the plant and pollinator communities. Our main location, Garden Bowl West, had abundant flowering, moderate plant diversity, and moderate pollinator diversity (Figure 3.6). The data from this location will be analyzed independently further in the results. Other locations had plant populations that were too small or had a lower range of plant diversity that negatively affected the data. Beaver Pond was an exception to this: despite large diversity of plants and a large population, very few pollinators were observed in comparison. We speculate this was due to the weather, which was overcast and about 8 degrees cooler than our averages on other days; the observation time was mid-August (8-12) and we do not believe this impacted the plant populations, as the number of flowers was healthy. The differences in pollinator sightings per location can be seen below in Figure 3.6.

Figure 3.6: Intra-plant (floral) movements observed for each species of pollinator at each of the 8 study locations (summed across plant species) during the “pollinator following” observations. The observation

density is easily distinguished between GBW (where multiple studies were conducted and we had large data sets), locations where we had moderate success and medium-sized data sets (Panzner locations and Garden Bowl East), and locations where we had data sets on the smaller end with limited success (Wolf creek locations and the Beaver Pond).

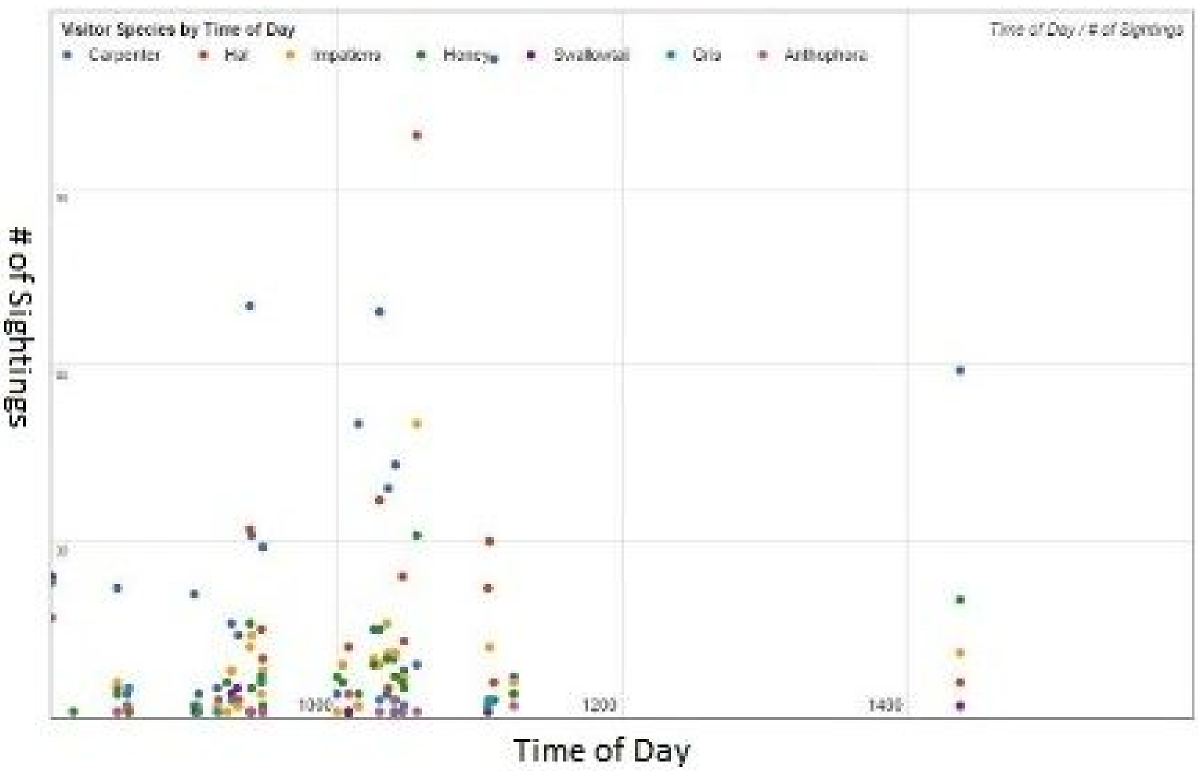
	GBW	Panzner C	GBE	Panzner A	Firestone	Wolf Creek East	Beaver Pond	Wolf Creek West	Grand Total
Impatiens	176	123	14	35	52	9	4		413
Carpenter	165	69	102	34		22			392
Honey	130	21	47	49		41	7	6	301
Fervidus	98		5	11	10				124
Hawk	49		3		4				56
Anthophora	5				9		49	3	66
Silver		24	15	2					41
Hal			10	3	8			11	32
Gris	9				14				23
Cabbage				34	17				51
Bimaculatus	17								17
Pearl					16				16
Swallowtail				7			7		14
Sphex			10						10
Leafcutter	4								4
Skip				2					2
Vag					1				1
Eum								1	1
Grand Total	653	237	206	169	131	72	67	21	1556
N visitor species	9	4	7	10	9	3	4	4	

<u>Walking Survey</u>:

The data from the walking survey (Figure C & Figure D1-2, Appendix) told a story very similar to the pollinator following data. The data shows us that Xylocopa was much more common on Asclepias, with a total of 589 observed visits compared to M. ringens, with only 44 observed visits. B. impatiens was more evenly spread among plant species, with 47 observations on M. ringens, 42 on Lythrum, 24 on Asclepias, and a seemingly surprising first place winner with 62 on Verbena; the prominence of Verbena in this data is deceptive only when comparing it to our phenology because there was a very large population of Verbena at Garden Bowl West that was not present on the transect, thus it did not appear in the phenology for GBW but was well included in the walking surveys.

The data also shows us that peak activity is between the hours of 9:00 AM and 11:00 AM, as demonstrated by the graph in Figure 3.7. This corresponds with our research timing and Figure 3.7 gives an illustration of the visitor activity we saw throughout a typical observation period.

Figure 3.7: This graph shows a plotting of the number of total sightings for several common species of visitors as they correspond to the time of day the observation was made During the "walking survey" observations.



Due to time constraints and an excess of data, we did not analyze the Plot Observation data nor did we report the data from each location's plant species "In Flower" list or Nearest Neighbor measurements.

Discussion

This study provides insight into the behaviors of local pollinators operating in specific habitats. It also provides a picture of the co-flowering species that inhabit these places, and in the case of Garden Bowl West, provided a five week analysis of blooming periods for multiple species. Together, these data sets gave us a complete picture of several populations over the course of the study period at a given location. We observed several unique behaviors and also noticed patterns that were common across different groups of species, such as pollinators preferring certain types of flowers and others expressing a more common ability to switch between different species.

Some baseline conclusions can be made about our question about inter-species switches made by potential pollinators during visits. For a start, the data shows us that *Bombus impatiens* is the most likely species to make visits to multiple flowering species during a pollination run; we speculate that this may be due to the utility of the versatile body size of *B. impatiens.* The *B. impatiens* workers we observed were smaller than the Carpenter Bees which were occasionally seen struggling with smaller flowers (Personal Observation). This moderate size allows *B. impatiens* to utilize the larger flowers, which may require a longer reach to obtain nectar, but also allow it to access the nectar in smaller flowers like *Verbena* and smaller flower of *M. ringens.*

Inter-species movements by visitors were uncommon; 57 transitions between species were observed during following surveys, a mere 6% of the 942 movements tracked. Certain species made more inter-species movements (*B. impatiens, A. terminalis*) while other species made very few in comparison *(X. virginica).* Given the objectively selected floral diversity of our research sites, we may be able to attribute the frequency of inter-species movements to the surplus of choices; questions for future studies would be: "Do pollinators make inter-species movements more commonly when there are large populations of different plants available? How does the proximity between flowers of different species influence pollinator movement?"

The size of the pollinator is another area of interest. When looking at three different species *(B. impatiens, X. virginica, and A. terminalis*) the size difference is one of the first differences noted. *Impatiens* had a moderate size compared to the tiny body of *A. terminalis* and the large body of *X. virginica* (terminalis is about the size of a honeybee; impatiens is about twice the size of a honeybee; xylocopa is about four times the size of a honey bee). Xylocopa v*irginica* made many fewer inter-species switches compared to *B. impatiens* and *A*. *terminalis*, suggesting that the large body size may negatively affect their ability to harvest nectar from certain species, whereas *A. terminalis* and *B. impatiens* expressed their flexibility through a more diverse selection of flowers. Future studies may consider taking average sizes for each species of flower and pollinator and then linking the two with their data to explore this relationship.

Given the far-reaching goals of this study and the rather short period of time in which we attempted to complete them, it is obvious where some detail was lost. A lot of time was spent scouting for potential sites during the critical blooming period which ends up being a sacrifice of potential study time during the blooming period. In the future, the known sites are now marked and provide a solid base of study sites that can be added on to for more diversity and a larger sample size. Each of these locations had specific traits that must be considered when analyzing data, and thus do not provide a holistic picture on their own, but rather produce the most value when analyzed collectively. Having more study sites and visiting them each as often as possible would produce the most benefit for creating an accurate picture of these populations.

As more and more was learned from analyzing the data we managed to collect, new goals and more specific questions become easier to visualize. The recurring study of Garden Bowl West provided the most complete picture of our populations of interest. If a recurring study could be replicated at each of the study sites, it would provide a massive increase in data and picture completeness, as well as multiply the time required for data retrieval. With more assistance, perhaps a few more research assistants with good training, this could be managed and it would increase the value and insight of the study exponentially. Additionally, less time spent scouting for potential sites could mean more time spent at one or several sites collecting data.

The phenology data turned out to be more valuable during analysis than predicted, and in future studies I would consider developing a better system for performing random phenology measurements. Observer bias played a large role in selecting the sites for measurement, which although ended up providing the best picture of flower density, also ended up missing key species such as in the case at GBW where *Verbena* was severely underrepresented in phenology. Also, a standard number of 1x1m plots should be chosen universally for all sites, as the differing number of plots made data construction seem uneven.

All three of the data sets (Pollinator Following, Walking Surveys, Plot Observation) produced good data; the Pollinator Follow data set was the most informative and we predicted this when entering the study. Once the Plot Observation data has been analyzed, a re-analysis of the usefulness for each of these data sets should be performed and the time spent on each one during future studies might be reconsidered accordingly.

New sets of data considerations may also be made in the future, such as more specific notes on weather patterns (such as in the peculiar case at Beaver Pond which may have been due to weather), temperature and humidity recordings, and nectar crop measurements. Additional detailed logging of elements such as these will help us grasp an even fuller picture of what kinds of factors may be affecting pollinator selection of flowers.

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Appendix

Figure A: This table shows total inter-plant movements made by visitors during the Pollinator Following studies. Visitor species with totals of zero are excluded.

	Impatiens	Carpenter	Honey	Fervidus	Terminalis	Hawk	Anthophora	Swallowtail	Hal	Leafcutter	Silver	Gris	East	Bimaculatus	Grand Total
MR/MR	124	33	30	72	57	37	20	4	14	10	7	1		4	413
LS/LS	52	42	19	19							3				135
MW/MW	3	87	17			3		5			1	2	6		124
V/V	45		75												120
Agr/Agr	2		34												36
JP/JP	14		4						2			5			25
SW/SW	3	11													14
MR/MW	1	4				5									10
V/MR	7														7
Teasel/Teasel	3							4							7
MW/MR		3				4									7
MR/V	5									1					7
Teasel/MR	1							3							4
MR/Teasel	1							3							4
SW/MR	2														2

MW/V		1	1												2
MR/Imp	2														2
Imp/MR	2														2
V/SW	1														1
V/MW		1													1
V/Ludw															1
V/JP										1					1
Si/Mint									1						1
Seum/V	1														1
Seum/MW									1						1
Physo/MW		1													1
MW/LS		1													1
MW/BS													1		1
MR/SW	1														1
MR/Seum	1														1
MR/Mint	1														1
MR/Agr	1														1
Mint/MR	1														1
Mint/Mint									1						1
LS/V		1													1
Ludw/V															1
LS/MW		1													1
BS/MW													1		1
Agr/Teasel	1														1
Grand Total	275	186	180	91	57	49	20	19	19	12	11	8	8	4	942

Figure B: Total number of sightings for each species of visitor at each of the six study sites during Pollinator Following studies.

	GBW	Panzner C	GBE	Panzner A	Firestone	Wolf Creek 1	Beaver Pond	Wolf Creek 2	Grand Total
Impatiens	176	123	14	35	52	9	4	0	413
Carpenter	165	69	102	34		22			392
Honey	130	21	47	49		41	7	6	301
Fervidus	98		5	11	10				124
Hawk	49		3		4		0		56
Terminalis	2				9		42		53
Silver		24	15	2					41
Hal	0		10	3	8			11	32
Gris	9				14				23
Cabbage				6	17				23
Bimaculatus	17								17
Pearl					16				16
White				14					14
Swallowtail				7			7		14
Anthophora	3	0					7	3	13
Sphex			10						10
East				6					6
Leafcutter	4								4
Skip				2					2
Vag					1				1
Eum								1	1
Grand Total	653	237	206	169	131	72	67	21	1556

Figure C: Number of sightings for each species of visitor at all six of our study sites during the Walking Survey studies.

	GBW	GBE	Panzner A	Panzner C	Firestone	Beaver Pond	Wolf Creek West	Wolf Creek East	Grand Total
Carpenter	363	217	22	36		3		25	666
Hal	86	25	129	17	52	16	26		351
Impatiens	98	18	57	34	23	3		2	235

Honey	78	19	43	15		6	6	9		176
Swallowtail	6	2			13	1	2			24
Gris	15				8					23
Anthophora	7		1	2		6	1			17
Silver	1	1	3	5	3	1	1			15
Fervidus	7	6	1		1					15
Terminalis	6		2		2	2				12
Cabbage			6	5	1					12
Pearl		4	5				1			10
Hawk	6					1				7
YellowJack	4			1						5
Bi	2		1			2				5
Sphex	4									4
rusty	1									1
Leafcutter	1									1
Carter				1						1
									0	0
Grand Total	685	292	270	116	103	41	37	36	0	1580

Figure D-1: Number of observations for each species of visitor as they correspond to the time of day during Walking Surveys. Continued in Figure D-2, the numbers from which are included in the Grand Total Column.

	Carpenter	**Hal**	**Impatiens**	**Honey**	**Swallowtail**	**Gris**	**Anthophora**	**Silver**	**Grand Total**
1437	59	6	11	20	2				102
1124	7	4	6	4			2	1	25
1110	112	6	3	3					128
1107		30	12		3	3	1		49
1106		22	3		1	2		2	32
1056	9	99	50	31			1		199
1047	8	13	7	5	2	2			40
1046		24		6	1		1		33
1041	43	3	11	7	1	1	3		69

1040	10	1	7	3			0	2	24
1036	39	5	11				6		62
1035	4		16	10					31
1030	69	37	9	15		3	1	1	140
1026	15		10	9					34
1015	50	2	2	4				1	61
1008	1	12	1	0	1		6		23
1004	9	6	9	6				1	32
1000	4		1	7					12
948	29	10	8	2	1		1		55
947	6	15	4	7				2	37
940	31		14	5	1	1			53
939	70	32	12	16	1		3	1	141
931	14	3	2						20
930			2		5		1		8
926	16	8	8		4	3		1	40
923			1	6					8
917		3	1					1	5
916	5		2			1			8
903	4		2			1			10
901		2			1			1	4
900	21		1	2					24
854	5	1	1	1		5			13
853	4	2	2	2			2	1	16
846	22	5	6	4		1	1		40
815				1					2
Grand Total	666	351	235	176	24	23	17	15	1580

Figure D-2: Continuation of Figure D-1.

	Fervidus	**Cabbage**	**Pearl**	**Hawk**	**YellowJack**	**Bi**	**Sphex**	**rusty**	**Leafcutter**	**Grand Total**
1437			2	2						102

1124		1								25
1110	2		2							128
1107										49
1106	1	1								32
1056	1	3	5							199
1047	1			1				1		40
1046			1							33
1041										69
1040		1								24
1036										62
1035				1						31
1030	1			1	2		1			140
1026										34
1015	2									61
1008						2				23
1004					1					32
1000										12
948	1				2		1			55
947		3								37
940									1	53
939	3					1	2			141
931	1									20
930										8
926										40
923				1						8
917										5
916										8
903				1		2				10
901										4
900										24
854										13
853		3								16
846	1									40

815	1									2 0
Grand Total	15	12	10	7	5	5	4	1	1	1580