Urban Agriculture and Ecosystem Services: Pollination by Native Bee Communities in Berkeley, California

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ABSTRACT

Managing ecosystem services such as pollination are vital to human survival. As a result of recent declines in European honey bee population from CCD, the agricultural industry and researchers are interested in finding alternative means of pollination. Considering the declines in the European honey bee, urban agricultural may have to rely on native bee pollination to meet their pollination needs. Squash, tomato, strawberry and sunflower plants, each having a 3 by 3 foot quadrat, were observed in two urban agriculture sites located in Berkeley, California. Data collected from both sites include; isolation from natural habitat, diversity of pollinators and visitation rates. I hypothesized that the Oxford study site would have higher native bee diversity and visitation rates than the Berkeley Youth Alternative study site, because the Oxford study site was closer to natural habitat. The community statistics gave mixed results for genus richness and evenness. The t-test indicated no significance of visitation rates for each plant type between each site. Results indicated that close proximity to natural habitat had no affect on native bee visitation rates to crops. The three factors expected to contribute to a healthy native bee population are: common floral resources between native and non native habitats, habitat fragmentation and age of gardens. City planners and conservationist should be cognizant of these factors in order to build an urban agricultural site that can provide food and sustain biodiversity.

KEYWORDS

Native bees, urban agriculture, ecosystem services, honey bees, CCD, Berkeley

INTRODUCTION

Bees provide a pollination ecosystem service to many agricultural systems. Ecosystem services, defined as species interacting within their environment and functioning together to sustain life (Costanza et al. 1997), are critical to human survival (Daily 1997). Animal pollinators pollinate one third of the United States' food supply (USFSRMBP 2007), of these, bees are the most abundant and beneficial crop pollinators (Delaplane & Mayer 2000). American farmers rely solely on honey bees (*Apis mellifera*) to pollinate their crops, often importing honey bees specifically for their pollination services (Delaplane & Mayer 2000). Presently, honey bees provide fifteen billion dollars in added agricultural revenue (USDA 2008). However, recent declines in honeybee populations from Colony Collapse Disorder (CCD) have left the agricultural industry and researchers looking for an alternative.

Currently, large-scale agricultural production is declining because of the honey bee's susceptibility to CCD (Winfree et al. 2007). The symptoms associated with CCD are the disappearance of all or the majority of honey bees from the hive, leaving only the live queen, yet no dead honey bees in or near the hive (USDA 2008). Supplementing the honey bee pollination service with a variety of native bee species would provide insurance against future declines in agricultural production wrought by CCD. (Winfree et al. 2007) Native bees, which are unmanaged, are generally more numerous and diverse near natural habitats have been shown to provide pollination services to various crops (Kremen et al. 2002, Klein et al. 2003, Ricketts 2004), and are just as effective at large scale-pollination as the honey bee (Kremen 2004 Kremen et al. 2007, Williams & Kremen 2007).

Studies in agricultural landscapes have shown that native pollinators are more effective when they are close to natural habitats. Ricketts et al. (2004) found that native bee diversity and visitation rates are significantly greater in coffee fields that are near tropical forests than other fields that are further away. Kremen et al. (2004) found that farms that were within a 2.4 km radius of areas with forty percent or more natural habitat were able to rely solely on native bee communities for pollination. Additionally, Ricketts et al. (2008) found strong evidence that increased isolation from natural habitat results in a decline of native bee visitation rates. There are many studies showing the relationship between distance and pollination in commercial agriculture, but not in urban agriculture. Ultimately, there is the potential for native pollinators to play a large role in urban agriculture, but we don't know how effective they will be in this very different landscape – one with presumably less native habitat nearby.

The purpose of urban agriculture is to provide healthy food to urban food deserts, to revitalize neighborhoods, and to provide environmental justice and ecosystem health (McClintock 2008). Urban agriculture is the process of utilizing sustainable agricultural techniques in an urban environment in order to produce food, while a food desert is an area in an inner city that lacks food retailers (McClintock 2008). Urban agriculture has been on the rise in many urban areas including Oakland California, where the city council has mandated that thirty percent of all food in Oakland must come from a local source such as urban agriculture by 2015 (Green 2007). As agriculture becomes more prominent in urban settings, the need for pollination services by bees also increases (Green 2007). Considering the losses of honey bees, native bees can be utilized to meet the growing demand for pollination service in urban areas. Incorporating resources for native bees into urban agriculture will promote urban ecosystem health in such ways as providing viable seeds and fruits for insects, birds, and other wildlife (Delaplane & Mayer 2000), while in turn providing urban neighborhoods with sustainable nutritious food. In order to achieve these goals as well as gain further knowledge of how the pollination service works, it is important to understand the relationship between the distance of the native bee habitat from the site of pollination and the rate of pollination in these urban settings.

The purpose of this study is to examine native bee pollination in two urban agricultural sites that differ in their proximity to natural habitat. The two sites under study were the Oxford study site (OXF) and the Berkeley Youth Alternative study site (BYA). The objectives of this study are to 1) calculate native bee diversity for each plant type per site, and 2) compare visitation rates between the two sites for each plant type. I hypothesized that OXF would have higher native bee diversity and visitation rates than the BYA because OXF site was closer to natural habitat. Using distance from natural habitat, diversity of pollinator, and rates of visitation, I hope to further the understanding of the pollination ecological service, by native bees for urban agriculture.

METHODS

Site description

The study assessed two urban agricultural gardens located in Berkeley, California (Fig. 1). The two gardens are: Berkeley Youth Alternative (BYA) Community Garden located at 1260 Bancroft Way, Berkeley, CA and OXF located at Oxford at 1751 Walnut Street, Berkeley CA. OXF is 9000 square feet, while BYA is 25000 square feet. OXF is closer to natural habitat than BYA. Both gardens are functional throughout summer and fall ensuring that that some flowers are always available for pollination, regardless of the season. In each garden I found sufficient quantities of sunflowers, strawberries, squash, and tomatoes for my study.

Figure 1: Location of sites in Berkeley, California**.** A represents Oxford Garden and B represents Berkeley Youth Alternative Garden (BYA).

The length of the beds in OXF was roughly 6 by 4 feet. The length of the beds in the BYA garden was roughly 12 by 4 feet. BYA contains three European honey bee hives. OXF is next to a native bee garden. Both are organic; they do not use pesticides, nor do they use synthetic fertilizers.

Natural habitat classification

I used Google Earth to locate the nearest natural habitat to each garden. In an urban setting, natural habitats were designated as vacant/fallow land or gardens specifically designed for native bee attraction. OXF borders a native bee garden located to the southeast. BYA is located roughly two miles away from the nearest natural habitat.

Bee visitation

To measure bee visitation rates at each garden, I observed a 3 by 3 square foot quadrat of squash, tomato, strawberry and sunflower for three minutes. This size quadrat and observation time worked well in other urban bee studies (Frankie et al. 2009b). The quadrates were set according to where the four plants were spaced in the gardens. Each site was visited at least once a week. A visitation was recorded when the bee touches the pollen produced by the flower. To ensure equal representation among the visitations observed, each quadrat was examined between 7:00 am and 2:00 pm. Each quadrat was observed for 3 minutes at a time. Each visit was conducted under sunny or scattered clouds with temperatures between 21 and 38 degrees Celsius and wind speeds that are less than 4 m s^{-1}.

Data analysis

For my data analysis I compared 3 independent variables with visitation rates. I used R commander (Fox et al. 2009) in R (R Development Core Team 2009) Office Excel 2007, Microsoft Access 2007 for organizing and analyzing my data. To test my hypothesis I used the following independent variables:

1. Distance to native habitat: This has been measured and is a fixed number. OXF was represented by 0 and BYA was represented by 1. This is a binary approach to represent two categories.
2. Bee genera: Each site was given a total number of bee genera. The bee genera are comprised of 8 categories: *Bombus spp., Ceratina sp., Megachile spp., Anthophora sp., Melissodes spp., Peponapis pruinosa, Apis Mellifera,* and Small bee.
3. Plant type: There are 4 plant types categories comprised of: tomatoes, squash, sunflowers and strawberries.

I then compared them to visitation rates which were continuous.

Community statistics

I examined the community statistics by using three diversity indices to see if there is a difference in diversity and evenness between OXF and BYA. The values will be examined to see if visitation rates for each plant were dominated by some genera over others. To quantify the community statistics three indices were used: the Berger Parker index,$d = \frac{N}{N_{max}}$, where N is the total number of indivudals of all genera and N_{mas} is the number of indivudals in the most common genus. A larger d value means more diveristy in the system. The Simpons's Index, $D = \sum_{i=1}^{S} \frac{n_i(n_i-1)}{N(N-1)}$, where there are S speices and n_i is the number of indivuals of the i^{th} genus and N is the total number of indivuals. I expressed Simpson's index as 1/D so that the index will increase as diveristy increases. Simpon's Index used infromation from each genus, unlike Berger Parket, and so it is more accurate, but very insenstive to the addition of rare speices to the sample. The Shannon index, $H' = -\sum_{i=1}^{S} p_i \ln p_i$, where $p_i$is the proportion of indivudals (from the sample total) of speices i. Using the Shannon index, I calculated the eveness, $E = \frac{H'}{H_{max}}$, where H_{max} is attained when the number of individuals in every speices is equal.

Statistical analysis

I used a Welch Two Sample t-test to compare visition rates at the garden sites per plant type. I used this type of t-test because I had unequal variances in my data. This will tell me if there is a difference between weeks in terms of average visitition between the two study sites for the given plant type.

RESULTS

Community statistics

From late June through July, 2009, I observed 372 bee visits (203 at BYA and 169 at OXF) representing 8 genera. At both BYA and OXF, squash was visited the most by Pepon (P.*pruinosa),* Strawberry was visited the most by Honey (*A.mellifera*), Sunflower was visited the most by Honey (*A. mellifera*), and Tomato was visited the most by Bombu (*Bombus*) (Fig. 2a and Fig. 2b). In comparing diversity indices between the two study sites, I found that BYA had more native bee diversity than OXF when I used the Berger Parker index and the Simpson's index (Table 1). The percent difference between the sites and the Berger Parker index is 9% while the percent difference for the Simpson's index and the sites was 3%. Using the Shannon index for diversity and evenness I found that OXF was more diverse and more even than BYA (Table 1). The difference between the two sites as determined by the Shannon index for diversity and evenness is 1%

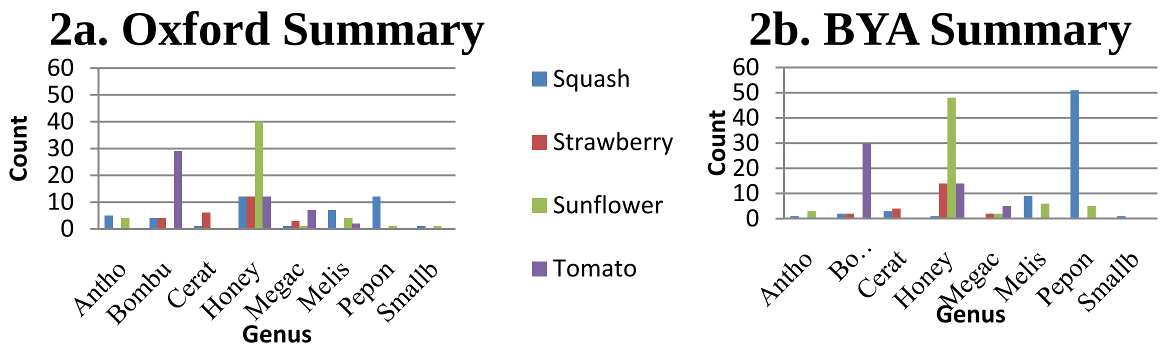

Figure 2a and 2b. Count of Genera by site. This graph shows the number of visits of each genus to the plant type at the Oxford Tract Garden in Berkeley, Ca.

Table 1. Summary of diversity indices for BYA and OXF. The Bold numbers correspond to a higher diversity. For all indices, the greater the number the more diverse the system is.

	Berger-parker Index	Simpson's Index	Shannon Index	Evenness
BYA	**2.64**	**3.95**	1.57	0.76
OXF	2.22	3.74	**1.61**	**0.78**

Visitation statistics

There was no significant difference in visitation by native bees between the two gardens for squash (Welch Two Sample t-test with df = 33, t = 1.33, P = 0.19), tomatoes (Welch Two Sample t-test with df = 36, t = -0.38, P = 0.71), sunflower (Welch Two Sample t-test with df = 28, t = 0.37, P = 0.72), and strawberries (Welch Two Sample t-test with df = 8.6, t = 0.84, P = 0.42).

DISCUSSION

To test the hypothesis that urban gardens closer to natural habitat will have higher native bee diversity and visitation rates, I compared native bee visitation rates to four plants, squash, strawberry, sunflower and tomato, at two gardens BYA and OXF. To test my hypothesis I used diversity indices and t-tests.

Contrary to the hypothesis that OXF would have higher native bee diversity and visitation rates because it is closer to natural habitat. The diversity indices from OXF and BYA did not produce consistent results which may be a result of how each diversity index is calculated. Both the Berger-Parker index and the Simpsons index indicated that BYA is more diverse than OXF. The Shannon index contradicted this finding, instead resulted in OXF as more diverse than BYA. The mixed diversity and evenness results would be a result of study sites sharing the same number of genera. The three diversity indices may vary because of the abundance of one genus or the different sample sizes collected (Wolda 1983, Caruso et al 2007). The Shannon index increases through additional unique genera, or greater species evenness (Wolda 1983). When comparing the evenness of Fig. 2a and Fig. 2b, OXF displayed more evenness than BYA because the Pepon numbers are closer in magnitude to the other genera counts. Overall the number of each genus that visited each plant type was more even in the Fig. 2a than in Fig. 2b. The difference in the Shannon index can be attributed to OXF having a small sample size of 169, versus BYA having a sample size of 206. The Berger-Parker index and the Simpsons index both indicated that BYA was more diverse. A reason for the differences in indices could be that both weigh heavily towards the most abundant genera in the sample while being less sensitive to species richness (Caruso et al 2006, Walda 1983). Although BYA and OXF have the same number of genera, BYA had higher numbers of a few genera than OXF. The mixed results from the diversity indices indicated that both study sites showed no difference in their diversity or evenness.

Contrary to the hypothesis that OXF would have higher native bee diversity and visitation rates because is closer to natural habitat; I found no strong association between distance from natural habitat and native bee visitation and diversity. The diversity indices gave mixed diversity results and the t-test showed no significance between the visitation rates at each site for each plant type. My findings indicate that BYA is no different from OXF in terms of native bee visitation or diversity. The lack of significance in my data suggests that native bee visitation and diversity is not governed by distance from natural habitat alone. Indeed, studies have shown that natural habitat is one of many governing factors for native bee visitation and diversity in a garden (Williams & Kremen 2007, Winfree et al 2008). I suggest four possible reasons as to why proximity to natural habitat may not be the primary governing factor for native bee visitation rates and diversity in urban agriculture.

Floral resources at the study sites may have been complementary between natural and unnatural habitats (Williams & Kremen 2007, Winfree et al 2008). Studies have shown that females nesting in organic farms were buffered to isolation effects by switching to floral resources growing at the farm site when seminatural habitat was too distant (Williams & Kremen 2007). The buffering to isolation effects could explain why distance from natural habitat was not significant in BYA and OXF. Although BYA did not have natural habitat in close proximity, the females may have been able to feed off of floral resources already existing in BYA or around the residential area. Winfree et al (2008) showed that gardens with sufficient weedy or floral resources year around could mimic the utility of natural resources for native bees. Although BYA does not have any natural habitat in close proximity, there was plenty of bee attracting plants in the neighboring residential area (Frankie et al. 2009a and Frankie et al. 2009b) which could have sustained the bee population found at BYA.

High dispersion of natural habitat fragments throughout my study sites may have improved native bee visitation and diversity (Holzschuh et al. 2008, Frankie et al. 2009a). Organic gardens can support higher pollinator diversity if there are fallow strips of land located within the garden (Holzschuh et al 2008). OXF is closer to natural habitat, but most land in the garden is either covered with crops or has groundcover/mulch. Mulching and crop cover makes it difficult to for bees to nest. BYA has fallow strips of land that allow for nesting habitat. Fallow land may provide the year round nesting but it may not provide enough floral resources to sustain a diverse native bee population. However the floral resources needed to sustain a year round population could be found in urban residential gardens (Frankie et al. 2009a). These residential gardens could also provide more nesting habitat for the native bees (Frankie et al. 2009a, Frankie et al 2009b).

The variability in the age of the study sites may also be a factor in visitation rates (Frankie et al. 2009b, Pawelek et al. 2009). Older gardens tend to have more biodiversity Studies have shown that older gardens tend to have more established native bee populations (Frankie et al 2009b, Pawelek et al 2009). BYA is 17 years old while OXF is only 6 years old. OXF is not as old however; it is located close to natural habitat.

The lack of significance may result from small sample sizes for I was unable to detect the true effects of natural habitat distance to the study sites (Williams et al. 2001, Winfree et al

2008). While this may have been true for the smaller data sets such as tomato, the more extensive squash date set also showed no significance between site and visitation rates. This indicates that the sites showed no difference in visitation rates.

CONCLUSION AND MANAGEMENT RRECOMMENDATIONS

In contrast to similar studies of crop pollination by native bees, in my two study sites the close proximity to natural habitat did not affect native bee visitation rates to crops. I expect that there is no difference in native bee visitation rates or diversity between the two study sites because of the effects of common floral resources between natural and non native habitat, habitat fragmentation and the age of the gardens. These factors may explain why native bees are abundant and diverse, even in areas with low proportion of natural habitat

Limitations

Limitations primarily consist of time constraints, and number of samples. Due to time constraints tomato and sunflower had a smaller amount of visitation samples compared to squash and strawberry. Not being able to sample more tomato and sunflower samples could have caused the lack of significance in visitation rates between BYA and OXF. Lack of time and resources prohibited me from collecting plant specimens in and around each study sites. Having knowledge of neighboring floral resources would help in supporting the isolation buffering idea. However, Frankie et al. 2009a and Frankie et al. 2009b provided data that indicated sufficient floral resources to support a health native bee community in Berkeley California.

Future directions

My study has provided many areas of inquiry for future research into native bee ecology and the pollination service. I have identified two factors in addition to proximity to natural habitat that might affect native bee visitation and diversity that should be explicitly examined in future studies. The first factor to consider is the amount of fallow land that is near the study sites. Second, studies should record the amount of floral resources that are not food crops. To make a more robust comparison between visitation rates and diversity more sites could be added that vary in distance from each other. I also suggest three questions for further inquiry. First, how do different varieties of floral resources influence the amount of visitation to food crops?

Second, what affect does fallow land have on the amount of visitation to food crops? Third, is there more native bee visitation and diversity on food crops located in urban areas versus areas near conventional farms? These questions will grant greater insight into native bee ecology and urban ecology.

Native bees can be used to supplement the pollination service that is primarily provided by the European honey bee (Frankie et al 2009b) which are currently declining from CCD. In urban areas, native bees may be able to compensate for this loss and also provide higher biodiversity. Providing the necessary habitat for native bee populations in urban areas can improve food quantity and quality in cities that rely on urban agriculture (McClintock 2008, Frankie et al 2009a). Nevertheless, my study indicates that close proximity to natural habitat is not the only requirement for native bee attraction. By incorporating common floral resources between native and non native habitat, and habitat fragmentation one could expect native bees to be found in urban agricultural.

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