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Native bees (Hymenoptera: Apoidea) and berry polycultures: Studying farmers' motivations for diversification and the impact of mass floral resources on pollinator communities

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Native bees (Hymenoptera: Apoidea) and berry polycultures:

Studying farmers' motivations for diversification and the impact of mass floral resources on pollinator communities

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Abstract

Floral resource continuity is an important component in pollinator conservation. Mass blooms early in the season may bolster pollinator communities on sequentially flowering crops by creating a resource pulse in an agricultural landscape. This study seeks to understand if mass flowering crops in polycultural systems can be used to simultaneously conserve pollinators and benefit farmers. To understand if these systems can be used to inform conservation policy, we are also interested in learning why farmers establish polycultures to begin with. A mixed-methods approach was used to address the following research questions: 1) do farmer's motivations for diversification align with the principles of diversity described by agroecological theory? And 2) do early flowering crops (Vaccinium corymbosum) affect the abundance and diversity of native pollinators (Hymenoptera: Apoidea) visiting later season crops (raspberry, Rubus cv.)? A sample of nine Vermont berry farmers were interviewed about the crops they grow, why they chose polycultural systems, and their potential benefits. Ecological data was collected from 14 Vermont berry farms, 8 of which grew blueberry and raspberry crops, and 6 of which only grew raspberry. We found that farmers most commonly reported reasons for diversification that aligned with agroecological principles of diversity. Additionally, we found no significant relationship between pollinator abundance and diversity on sequentially flowering crops between the two farm treatments. We conclude that follow-up studies are necessary to determine if mass flowering crops can be used as a sustainable pollination management practice and whether or not farmers would be interested in adopting this practice.

Keywords bees • pollinators • mass flowering crops • crop diversification • berries

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Introduction

Pollinators are essential for environmental and human health. Successful pollination of plants, the primary producers in the food web, is essential for maintaining entire ecosystem function (Fontaine et al. 2006). Both self-fertile plants and self-incompatible plants benefit from animal pollination; pollinators allow for cross pollination and the development of more resilient gene pools (Cutler et al. 2014). Globally, pollinators are also well recognized for their contribution to human food systems: 75% of staple food crops are dependent on insect pollinators (Klein et al. 2007).

Pollination and native bees

Pollination, however, is considered to be an essential ecosystem service at risk because pollinator population trends are declining across the globe (Klein et al. 2007; Potts et al. 2010). While there are over 4000 species of bees (Hymenoptera: Apoidea) in North America alone (Kremen et al. 2002b), we depend primarily on one, *Apis mellifera*, for the majority of pollination services. The general population trends for *Apis* in the United States, however, are declining, with recent figures showing a change from 5.9 million colonies in 1947, to 2.4 million in 2005 (NRC 2007).

Native bees visit the flowers of many crops and can be considered an insurance policy against the collapse of *Apis* populations (Kremen et al. 2002a; Winfree et al. 2007). Native bee species are more efficient or just as efficient as *Apis* in pollinating blueberry (Cutler et al. 2014; Javorek et al. 2002), cherry (Holzschuh et al. 2012), coffee (Ricketts 2004), raspberry and blackberry (Cane 2005), watermelon (Kremen et al. 2002a; Kremen et al. 2004; Winfree et al. 2007) and many other crops (Garibaldi et al. 2013). Under the right environmental conditions, diverse bee populations are able to provide sufficient crop pollination services, even in intensive land use areas (Winfree et al. 2007). Rather than relying on one bee species, farmers can utilize this 'free' form of pollination provided by diverse species of native bees.

Native pollinator populations are not without their own threats. Seven species of Hawaii's yellow-face bees, *Hylaeus spp.*, received federal recognition of their endangered status, effective October 31, 2016 (USFWS 2016). The rusty patched bumble bee, *Bombus affinis*, which is native to the eastern and Midwestern United States was also added to this list in mid-February (USFWS 2017). Habitat fragmentation is thought to be the greatest driver of pollinator population decline (Potts et al. 2010). Other threats include climate change, land use change, invasive species, spread of diseases, and interactions between one or more of these drivers.

Bees are impacted by landscape and local scale resources. On a landscape scale, bee abundance and species richness will be higher if more high quality habitats surround crop fields (Kennedy et al. 2013). Solitary wild bees, in particular, benefit from having semi-natural habitats surrounding fields (Westphal et al. 2003). Local scale variables include management practices and diversity in fields (Kennedy et al. 2013). Other important variables include nest site, floral availability, and total crop area (Kremen et al. 2004). Farms, which contain mass flowering crops (MFC) and are often the most dependent on the services that pollinators provide, are an important site to consider in terms of native bee conservation.

Pollinators and agroecosystems

Diversified agroecosystems can be both ecologically and economically beneficial, but the temporal impacts of multiple crop flowering periods on pollinators and crop yields are not entirely understood. The *landscape-moderated concentration and dilution hypothesis*, proposed by Tscharntke et al. (2012) suggests that populations may concentrate or dilute due to temporal and spatial landscape changes. The availability of resources may create notable differences in bee population sizes. Westphal et al. (2003) found that mass floral abundance, such as flowering crops, increases pollinator densities. The authors demonstrated that when these resources are available earlier in the season, they promote colony growth, resulting in higher population densities later in the season (2003).

Grab et al. (2017) investigated the density dependent response of bees by looking at the impact of apples, a mass flowering crop, on pollination of co-blooming crops occurring in the same place. They found that the abundance and diversity of bees visiting co-blooming strawberry fields is related to the temporal stage of apple bloom: the resource pulse provided by apple flowering negatively impacted abundance and diversity of pollinators visiting co-blooming strawberry during early and peak bloom but had a positive impact during the late bloom stage (2017). What remains unknown is how mass flowering crops impact crops that bloom in sequence. Based on the findings from Grab et al. (2017) and the pollinator population dynamics described by Westphal et al. (2003), we hypothesize that resource continuity through mass flowering crops have a significant effect on the abundance and diversity of pollinators visiting crops that flower in sequence.

Insect populations can be directly influenced by the manipulation of vegetation diversity, both spatially and temporally (Altieri et al. 2015). One means of enhancing ecological diversity is through multiple cropping agricultural schemes, or polycultures: systems in which multiple crops are planted together. These systems tend to be diversified in both space and time (Altieri et al. 2015). Polycultures, when consciously designed, have the ability to increase pollination services on farms and to also conserve pollinating insects (Gurr et al. 2003; Kremen and Miles 2012). Berry farms, which often contain crops that bloom in sequence, provide a unique case to study the impact of temporal resource trends on native bee populations. Mutual benefits are shared by pollinators and berry crops: highbush blueberry, *Vaccinium corymbosum*, and raspberries, *Rubus* cv., benefit from native bee pollination (Cane 2005; Garibaldi et al. 2013; Tuell et al. 2009), and bees receive nutrient-rich pollen (Free 1993) large quantities of nectar from *Rubus* (Schmidt et al. 1987), and nesting habitats in natural areas that surround agricultural fields (Ricketts et al. 2006).

Polycultures: benefits to farmers

The benefits of polycultures are both ecological and economic, extending far beyond pollinator support. Ecosystem functions, such as productivity, may be greatly impacted by increases in diversity, especially in agricultural systems composed of few species (Jackson et al. 2007). Additionally, Polycultures perform better in droughts (Altieri et al. 2015), strengthen an agroecosystem's resilience to climate change (Mijatovic et al. 2013), support weed suppression, use soil nutrients better (Altieri et al. 2015; Gurr et al. 2003), and reduce crop vulnerability to pests and disease (Altieri and Letourneau 1982; Altieri et al. 2015; Letourneau et al. 2011; Pretty 2008; Smith et al. 2015). Economically, multi-cropping may provide farmers with greater yields (Letourneau et al., 2011), revenue from biomass (Brandes et al. 2016; Smith et al. 2015), and allow them to achieve maximum per unit area and time output (Hardwood, 1974 as quoted in Altieri et al. (2015)). Agricultural risks are also spread over several crops, limiting impact to a farmer's overall harvest (Navarette et al. 2015).

Research questions and objectives

This study is divided into two parts: 1) interviewing farmers about why they establish polycultures and 2) examining the effects of polycultures on ecosystem function. If mass flowering crops positively impact the abundance and diversity of pollinators on co-blooming crops and crops that bloom in sequence, they can be recognized as an agricultural practice that conserves pollinators through providing them with foraging and shelter while simultaneously increasing crop yields. This mechanism is only able to exist through the diversification of crops on farms. If we are to suggest this practice and consider future policy implications, we must understand why farmers decide to diversify and also if the mechanism functions in nature. In this two-part study, we seek to understand 1) if farmers' motivations for diversification align with the principles of diversity described by agroecological theory and 2) do early flowering crops (e.g. *Vaccinium corymbosum*) affect the abundance and diversity of pollinators visiting later season crops (raspberry, *Rubus* cv.)?

Methods

Semi-structured Interviews

In order to understand farmer decision-making on berry farms, in-depth semi-structured interviews were conducted with nine of the farmers involved in the ecological assessment of this study. We used an interview guide containing both open and close-ended questions (Appendix A). This approach was used, rather than close-ended questions, in order to allow the respondents to freely frame their answers, rather than limiting them to a prepared set of possible responses (Oppenheim 1986; Weisberg and Bowen 1997). Interview topics included the history of crops grown on the farm, reasons for multi-cropping, and the influence of pollinators.

Interview audios were transcribed using HyperTRANSCRIBE v1.5.3. The transcriptions were coded in HyperRESEARCH v3.5 using a grounded theory framework to understand farmer's motivations for diversification as they compare to agroecological principles of diversification. Grounded theory involves constant comparisons of incoming data with preexisting (grounded) theories in order to modify or develop new theories (Corbin and Strauss 1990). In this case, grounded theory was used to inform analyses rather than to generate a theory.

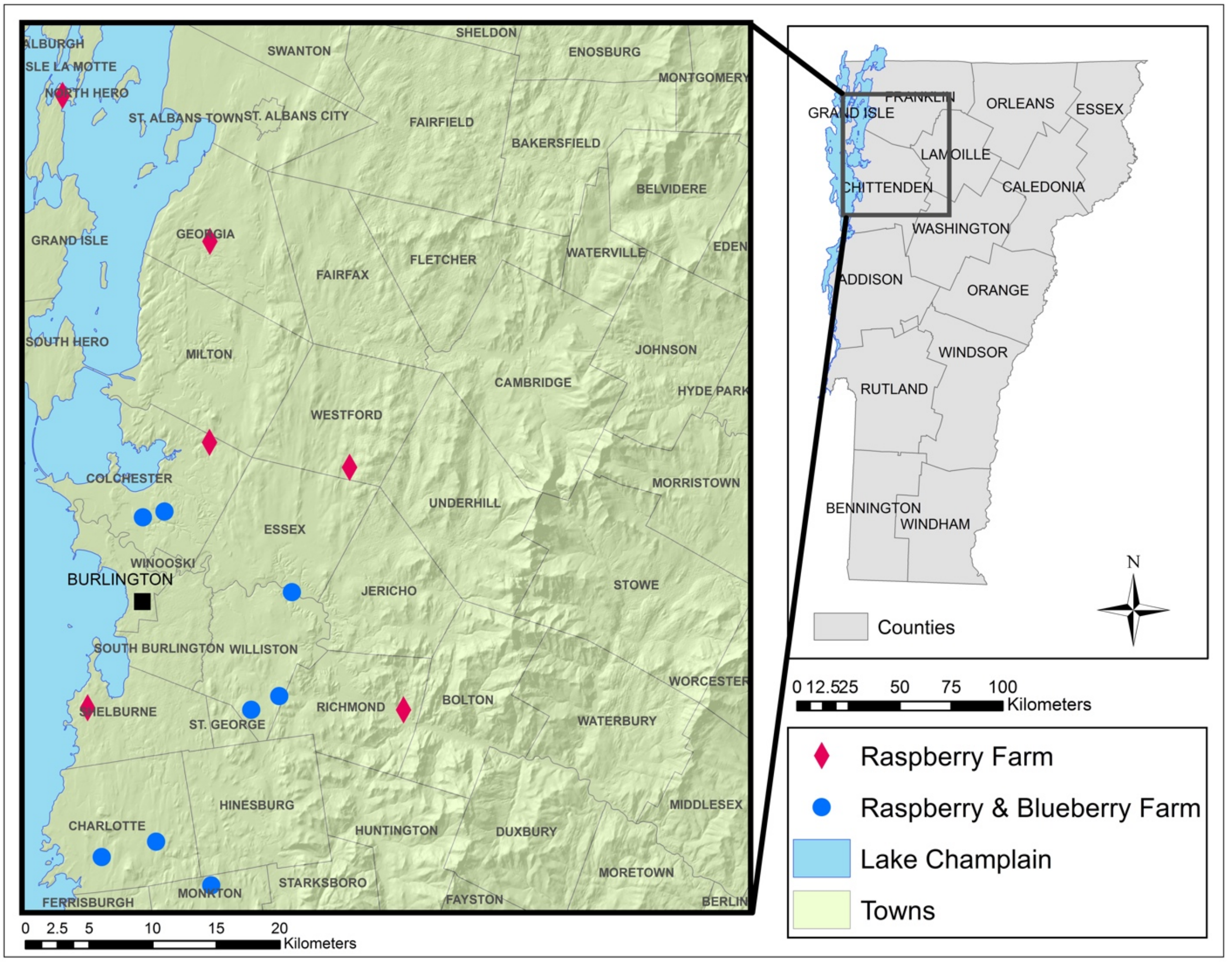
Open-coding was used to establish codes that connote overlap with the preexisting principles of diversity in addition to alternative motivations behind crop diversification. Altieri and Nicholls (2004) cite seven reasons why diversity is of value in agroecosystems, regardless of farm scale. These reasons were synthesized from works by Altieri (1994) and Gliessman (1998), two foundational books in the field of agroecology. The same seven reasons were cited again in Altieri (2005) and used as the fundamental principles of diversity for this study. Each of the principles was given a specific name for ease of use and described as follows (Altieri 1994; Gliessman 1998):

Table 1: Agroecological Principles of Diversity

Principle Name	**Description**
Coexistence	As diversity increases, so do opportunities for coexistence and beneficial interactions between species that can enhance agroecosystem sustainability.
Complementarity	Greater diversity often allows better resource-use efficiency in an agroecosystem. There is better system-level adaptation to habitat heterogeneity, leading to complementarity in crop species needs, diversification of niches, overlap of species niches, and partitioning of resources.
Pest Control	Ecosystems, in which plant species are intermingled, possess an associated resistance to herbivores. As in diverse systems, there is a greater abundance and diversity of natural enemies of pest insects, keeping in check the populations of individual herbivore species.
Microclimate	A diverse crop assemblage can create a diversity of microclimates within the cropping system that can be occupied by a range of noncrop organisms- including beneficial predators, parasites, pollinators, soil fauna, and antagonists – that are important for the entire system.
Conservation	Diversity in the agricultural landscape can contribute to the conservation of biodiversity in surrounding natural ecosystems.
Soil Health	Diversity in the soil performs a variety of ecological services such as nutrient recycling and detoxification of noxious chemicals and regular of plant growth.
Livelihood Stability	Diversity reduces risk for farmers, especially in marginal areas with more unpredictable environmental conditions. If one crop does not do well, income from others can compensate.

Bee Abundance & Diversity Sampling

Figure 1: Study area map depicting the farms sampled and their respective crops



Pollinator abundance and diversity sampling took place on 14 berry farms in 4 counties of Vermont's Champlain Valley (Figure 1) between May 23 and June 30. Farms were visited at least 3 times during each of the crop flowering periods: blueberry (May-June) and raspberry (June). Our experimental design consists of eight farms that grew blueberries (with MFC, mass flowering crop) and raspberries and six farms that grew raspberries without the presence of blueberry (without MFC). The farms contained at least .4 acres of blueberries and or 50 linear ft. of raspberries.

Pollinator sampling only took place on days with favorable conditions: less than 3.0 m/s wind, temperatures above 16° Celsius, and no sampling during a precipitation event. Each farm was sampled at different times for each visit, between 10am and 2pm. Farms had two sampling sites for each crop, located 0 and 50 meters away from the most natural edge. Site conditions, including weed and bloom level[1], percentage of bare ground, row cover, and inter-row conditions[2] were also recorded prior to sampling.

For each sampling date, two 10-minute observations were conducted at both sites for the crop in flower (blueberry or raspberry). At each site, individual foraging bees were surveyed in a 1 m^2 observation area. Bees were identified and recorded based on the following morphospecies: *Apis*, Big *Bombus*, Orange *Bombus*, Small *Bombus*, Small orange *Bombus*, green bees, big black bees, slender black bees, tiny bees, and other bees (Appendix B). In addition to morphospecies, the number of flowers visited per bee was recorded. Only true foraging events were considered as a 'visit': e.g. nectar robbing was not recorded. At the end of the observation, a rough estimate of the number of flowers in bloom in the observation area was also recorded.

In addition to bush observations, 10-minute hand netting samples were completed at each site to assess the diversity that exists at farms. Along a 20 bush transect, research assistants attempted to catch a diverse sample of native bees within the 10-minute timeframe. The 10-minute period was paused during the process of transferring specimen from the net into captive jars. At the end of the collection period, a label containing the site, farm, date, and observer's initials were placed into the jar with the collected specimen. Start time and jar number were

[1] Weed and bloom level recordings were based on a Likert scale of 1-3 (0= used for weeds only, indicating no weeds, 1= sparse open flowers, 2= abundant open flowers, 3= full bloom).
[2] The inter-row options included bare ground, mown vegetation, tall grass, diverse plants, or an herbicide-killed ground cover.

recorded on the data sheet containing site characteristics. After specimens were collected, they were pinned and labeled with a 7-digit identification number and their collection information.

Data Analysis

This study focused on native bee community structure and therefore abundance and specimen data of non-native species (*Apis mellifera* and *Osmia cornifrons*) are excluded from data analysis. All data were tested for normality and then transformed to meet the conditions of normality if necessary for individual analyses. For each farm type (with or without MFC), abundances were standardized to a per-10-minute observation measure. Abundances were normalized using a log+1 transformation and then averaged across farms, within treatments. A one-way analysis of variance (ANOVA) was used in order to compare native bee abundance in the two farm treatments.

Specimens were identified to species and used to analyze native bee species composition and diversity across treatments types (with or without MFC). The Chao Estimator provides a lower boundary of species richness and also accounts for rare species that may not necessarily be represented in smaller samples (Jost 2006). One-way ANOVAs were used to compare estimated and observed species richness across the two treatments. The Jaccard Index of Community Similarity was used to examine the proportion of overlap between native bee species visiting raspberry crops on the two farm types. Statistical analyses were performed using the software R v3.2.2.

Results

Farmer motivations for diversification

Farmer interviews lasted between 12 and 30 minutes, resulting in 2 hours and 32 minutes of audio. While the sample of nine farmers was initially chosen because they grow blueberry and or raspberry crops, all of the farmers grow a diversity of crops. This ranges from a selection of other berries (blackberries, black raspberries, and strawberries were common responses) to diversified vegetable crops and fruit trees. Motivations for crop diversification varied among farmers. Interview analyses yielded a total of 13 codes that describe the reasons these berry farmers cite for multi-cropping (Table 2). The definitions for each code were developed directly from the interview transcriptions.

Farmers provided a variety of reasons to explain why they chose to diversify their farms. For example, rather than paying for crop insurance, one of the farmers reported relying on their other crops to provide an economic buffer. The idea that crop diversity acts as an insurance policy against crop loss (code: farmer protection) was the most frequently reported reason for diversification. One farmer commented:

> If you get hit by, let's say, like a late frost, I mean, that could kill our blueberries, so we would need some sort of back up. Yes, so, you can get crop insurance (which we don't have) …. We just like to have that diversification just in case.

Many of the farmers agreed that having a diversity of crops allowed them to have years where certain crops do not perform as well:

> If you're only growing four crops and you have a bad year in 1 of those 4 crops then it's hard to make up the difference, but if you're growing 40 or 50 different crops, then the risk management of your economic vitality is much easier... And so for that reason I think it's valuable to be diverse too.

Farmer protection was cited in 8 other instances. Farmers also frequently explained that they diversify in order to appeal to customers. One farmer reflected that her crops were chosen because they are attractive to people who want to pick berries:

> I grow raspberries, 3 different varieties of raspberries and black raspberries and I, I do have some strawberries but I think I'm gonna give up on those, I'm not as good with those. And blackberries. And the reason I grow these varieties is because we're trying to do pick-your-own and those are the types of berries that people, um, tend to like to pick.

These farmers believed that their diverse crop assemblages attracted customers for various reasons. For example, another farmer reflected that his various crops inspire customers to return:

> I believe that I don't need to be a big farm, I just need to be a small farm and have most of my customers... are here several times a year, for different things. They come pick berries, they see the trees, they come back and get a tree, they find out I'm growing pumpkins, they come back and pick a pumpkin. And while they're here, and each time they stop, they might pick up some maple syrup, or.... kids get married here or they have birthday parties.

"Appeals to customers" was the second most frequent code that appeared in the interview transcriptions. This code differs from "draws specific customers" because of one farmer's experience. She commented, "It's nice to have different types of berries and attract different people, you know, and that's nice, 'cause it's amazing, the personalities of, like, blueberry people- are different than, like, raspberry people". She continued to say that "raspberry people are more intense" and "the black raspberry people are really nice". This farmer sees value in her diversity because she can use the various crops she plants in order to attract customers with specific characteristics.

One of the farmers has an educational mission and uses his polycultural farm to support that mission. When asked why he decided to diversify instead of specializing in one crop he said,

> So our goal was to serve our educational mission and to provide, primarily, vegetables to the restaurant and, um, to tell a story at the restaurant and to our educational audiences, that there's a seasonality to vegetables. You shouldn't be getting tomatoes in January. And strawberries, you know, don't grow year round: they fruit and flower primarily in June. And, so, to tell that story, well, you want to have, you know, a diversity of vegetables through the season.

In this case, he uses the seasonality of his diverse crops to educate visitors and customers that come to the farm and restaurant.

Other farmers discussed that they diversified in order to obtain longer growing seasons. At the time of her interview in October, one farmer commented "It does help out, I think, having [a] diverse number of crops, instead of just having one. It does bring me through the season. It starts in June and goes until… I was still picking raspberries two weeks ago in the high tunnel". A polyculture allows this farmer to continue producing fruit into the fall months. The berry farmers we interviewed were not only interested in season extension for the benefit of their economic livelihood. In her interview, one farmer discussed the benefit that this practice has on pollinators:

> If I want to have the pollinators there, it's nice to have a lot of different flowering crops at different times of year. And even when, like, I do some brunching broccoli, and I don't get it right in time, it flowers…. So I used to just, like, cut back the flowers. And one year I noticed there were bees throughout [the crop] and it was really late so I was like, "ahh, they have nothing else, this is for them" So I would just let it go and I wouldn't cut the flowers back or anything. So there's, I think, just a benefit in diversity not only in, like, your financial, you know, kind of portfolio, but like, your bees and pollinators too…

In this case, mutual benefits are shared between the farmer and the pollinators: the pollinators receive diverse foraging sources and the farmer benefits from their pollination services.

Table 2: Farmer-reported reasons for diversifying

Code	Definition	Frequency
Appeals to customers	Customers are attracted to farms that have a wide variety of crops to pick and or purchase.	8
Beneficial insects	Diverse agroecosystems support populations of pollinators and beneficial insects.	3
Draws specific customers	Farmers may expand certain crops to attract a specific customer base.	1
Education	Having a diverse assemblage of crops and cultivars allows farmers to educate their customers.	4
Experimentation	Some farmers diversify to try out new or different crops.	3
Farmer protection	Diversity allows farmers to have good and bad years within specific crops. Multi-cropping acts as an insurance policy against crop loss.	10
Income	Increasing crop diversity provides farmers with a means of expanding their income.	1
Intrinsic value	There is an intrinsic benefit to having diversity within an agroecosystem.	1
Maintenance	Diversification to include crops that require less maintenance reduces allocation of labor resources.	1
Personal interest	Farmers have a personal commitment to creating and maintain on-farm diversity.	1
Personal spending	A farmer who supplements their diet with the crops they grow may reduce personal spending on produce.	1
Pollination	A diverse agroecosystem receives better pollination services.	4
Season extension	Diversity allows farmers to extend their crop growing season.	6

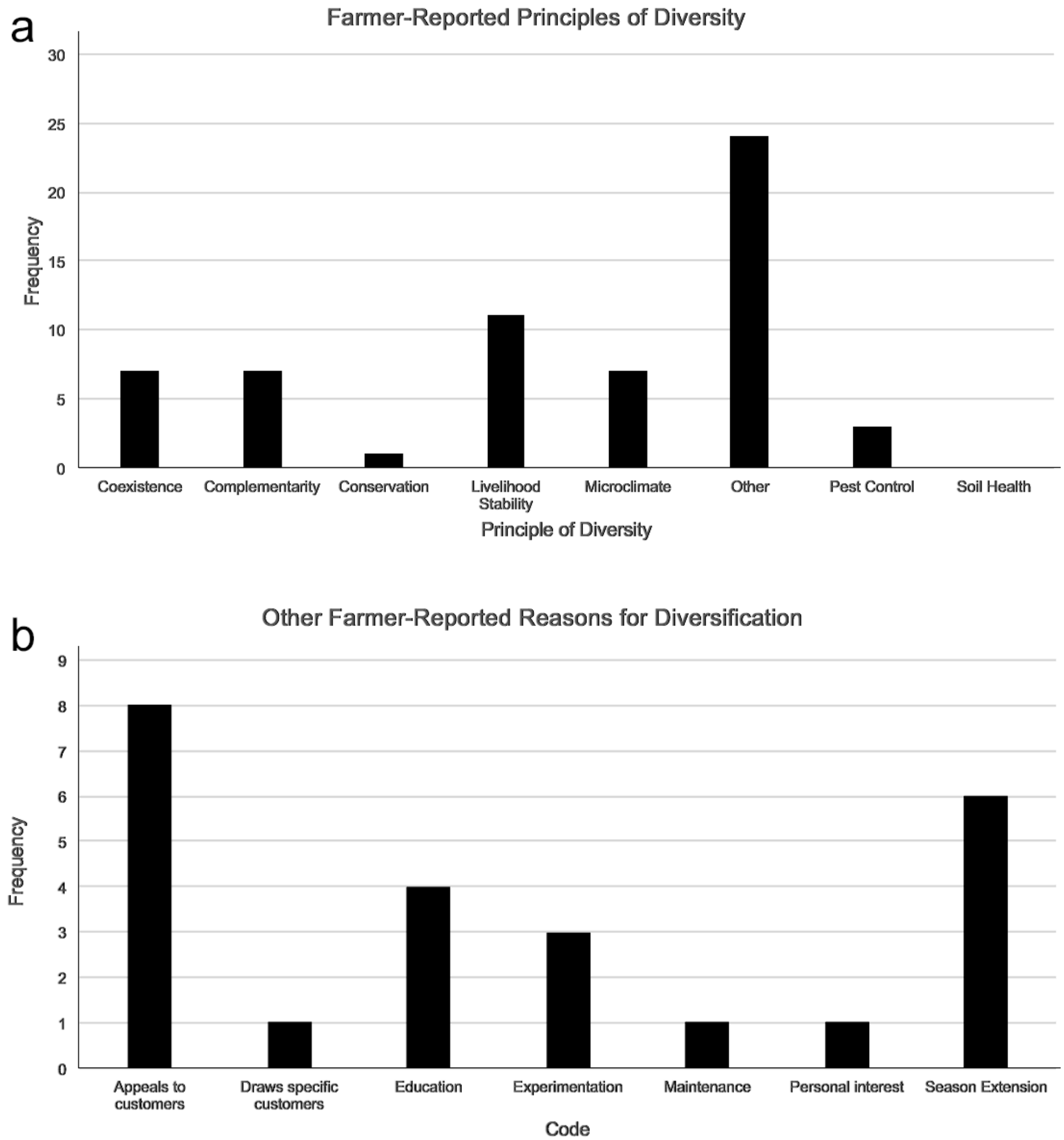
Of the thirteen motivations for diversification described in interviews with berry farms, six overlap with the principles of diversity listed by Altieri and Nicholls (2004) (Table 3). Some of the principles of diversity are broad in their scope, which allows codes to fall into multiple categories. Pollination, for example, overlaps with three principles (Coexistence, Complementarity, and Microclimate). This is because pollinators provide beneficial interactions between species through their provisioning of an ecosystem service (Coexistence), receive resources from flowering crops (Complementarity), and can use agroecosystems as nesting sites (Microclimate). The only principle of diversity that did not overlap with any codes is the Soil Health principle, because no farmers mentioned soil health as a reason for diversification.

Table 3: Agroecological principles of diversity and overlapping codes

Principle of Diversity	**Overlapping Codes**
Coexistence	Pollination, Beneficial insects
Complementarity	Pollination, Beneficial insects,
Pest Control	Beneficial insects
Microclimate	Pollination, Beneficial insects
Conservation	Intrinsic value
Soil Health	
Livelihood Stability	Farmer protection, Personal spending, Income

In Figure 2a, we list the principles of diversity and the frequency at which they were reported in interview analyses. The ‘other’ category refers to the seven codes that do not overlap with the principles; the frequency of these codes are depicted in Figure 2b. The most commonly reported principle of diversity was Livelihood stability, which came up 11 times in the interviews (Figure 2a). The Coexistence, Complementarity, and Microclimate principles were each reported 7 times. In total, the principles of diversity can be used in 36 instances to explain why farmers diversify. Reasoning that does not overlap with these principles occurs 24 times. Of these other reasons, the most common responses included “appeals to customers”, “season extension”, and “education” (Figure 2b).

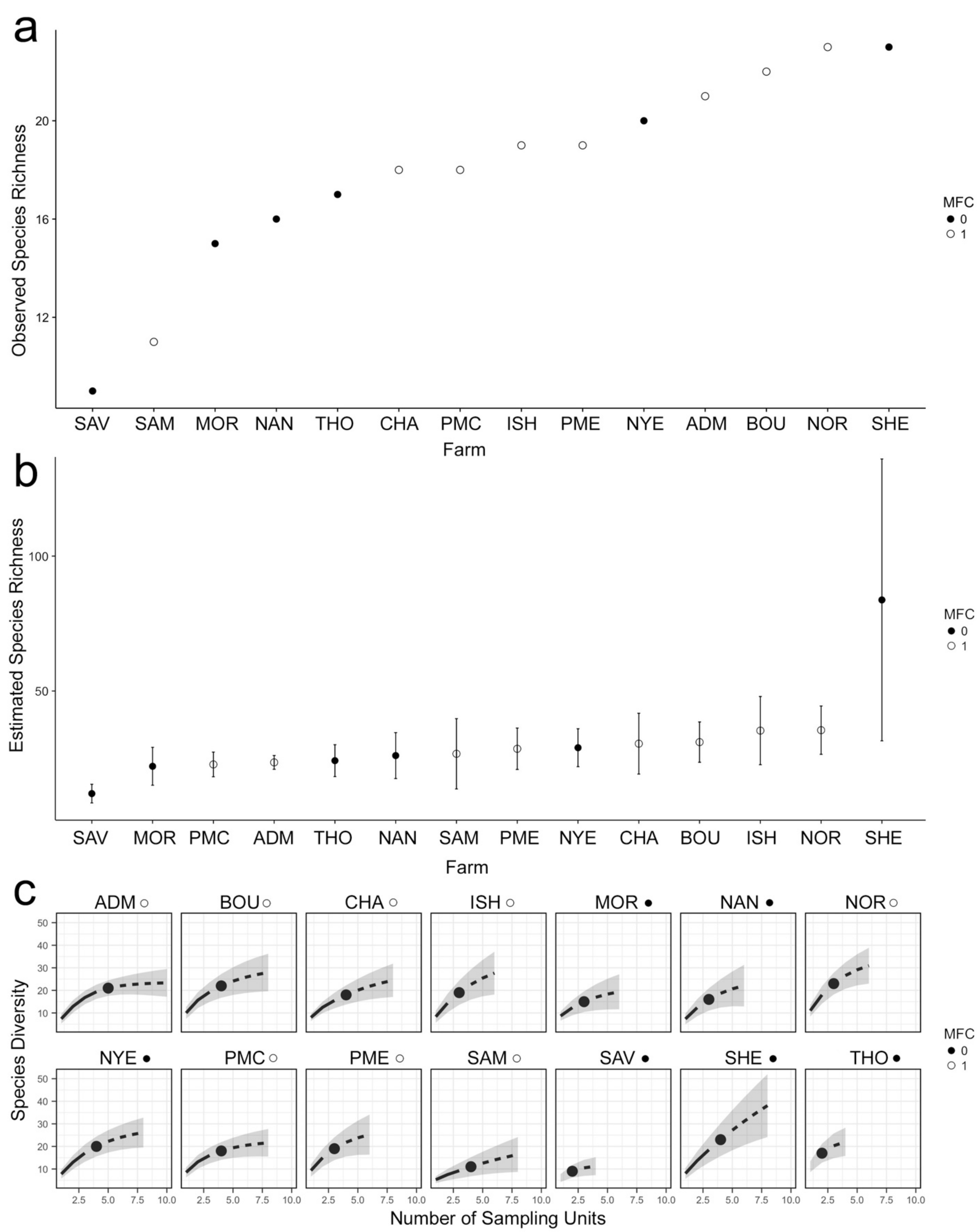
Figure 2: Frequency of farmer-reported principles of diversity and other reason for diversification



Native bee abundance and diversity

In total, we collected 932 individual bee specimens belonging to 14 genera and 69 native bee species across the 14 farms. The most common genus was *Bombus*, with 292 specimens captured. *Bombus, Andrena,* and *Ceratina* comprised 77.4% of all specimens collected and were the three most common genera across both crop and farm types. The single most abundant species collected was *Ceratina calcarata*, with 109 individuals. The next-most abundant species were *Bombus bimaculatus*, with 90 individuals, and *Bombus impatiens*, with 80 individuals. Farms with MFC had a native bee community made up of 66 individual species. Forty-four of these species were collected on blueberry crops and 52 were collected on raspberries. Using the Jaccard Index of Community Similarity, we found that 26.9% of observed species are shared between blueberry and raspberry crops on the 8 farms with MFC.

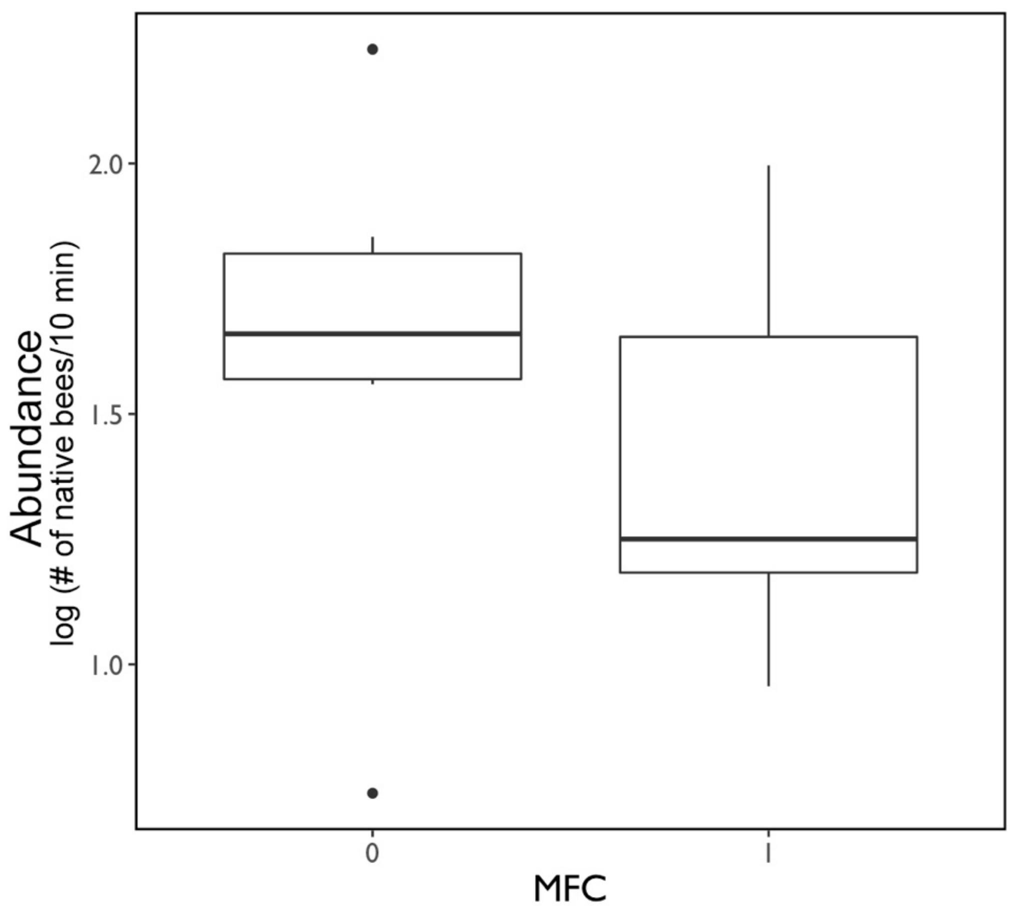
Figure 3: Species richness (observed and estimated) across farm and farm types



Forty-one native bee species were collected across farms without MFC. The Jaccard Index revealed that native bee communities visiting raspberry on farms with and without MFC are 64.1% similar. Observed species richness on raspberry crops varied across farms and farm types (Figure 3a,c).

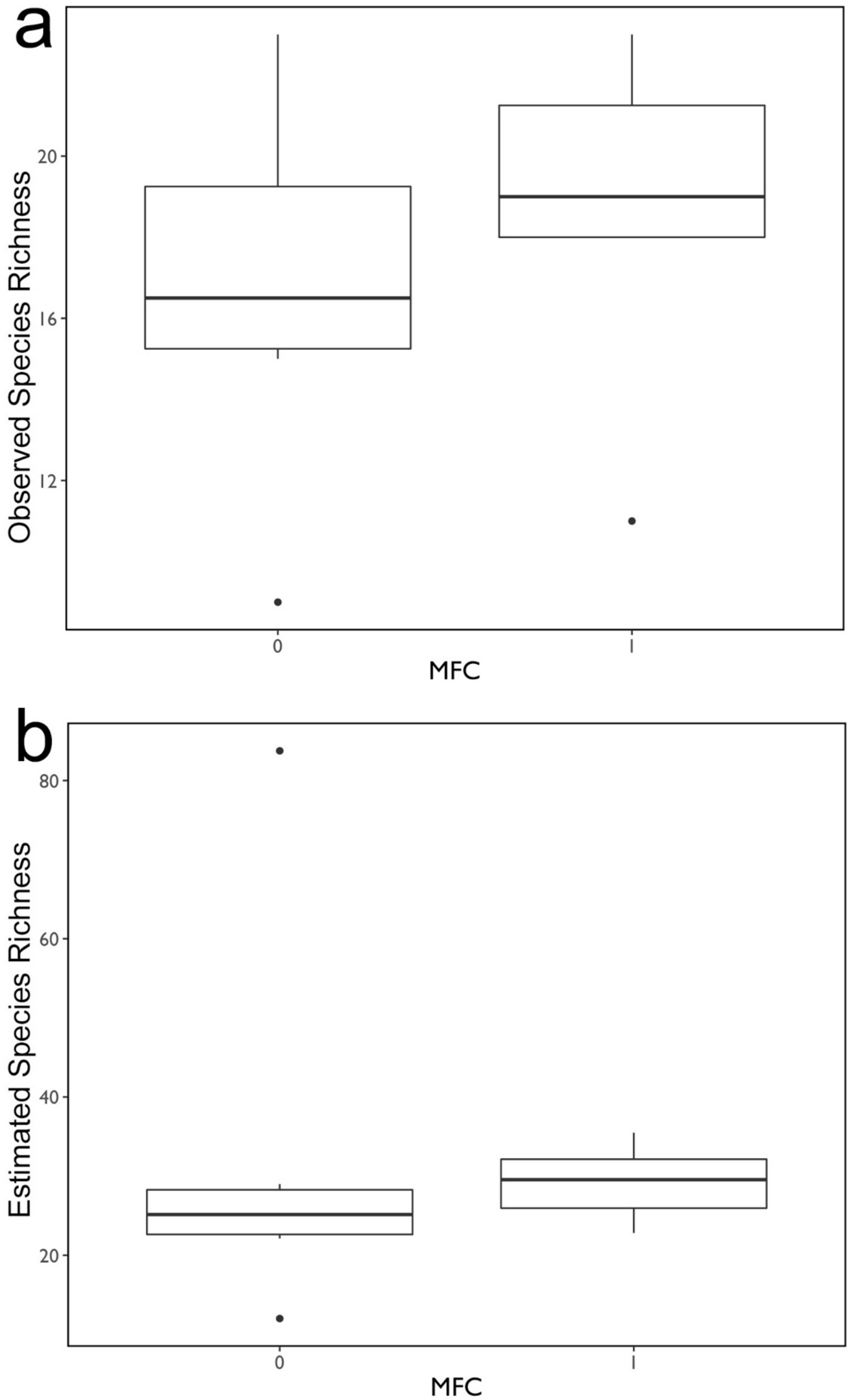
On average, farms without MFC tended to have a higher abundance of native bees than farms with MFC. A one-way ANOVA indicated, however, that there is no significant difference in native bee abundance between the two farm types ($F_{(1,12)}$= 0.875, p= 0.368) (Figure 4).

Figure 4: Abundance of native bees visiting raspberry crops between farm types, where 0= farms without MFC, 1= farms with MFC



A one-way ANOVA was used to test for a relationship between observed native bee diversity on raspberry and presence of MFC (Figure 5a). We found that there is no significant relationship between native bee species and MFC presence ($F_{(1,12)}$= 0.964, *p*= 0.346) when using observed species richness as a metric. The Chao Estimator predicted that the lower boundary of species richness for farms with and without MFC were 29.3 and 31.2, respectively (Figure 5b). A one-way ANOVA revealed no significant relationship between native bee diversity and farm treatment type when using species richness values based on the Chao Estimator ($F_{(1,12)}$= 2.602, *p*= 0.133).

Figure 5: Native bee species richness between two farm types, where 0= farms without MFC, 1= farms with MFC



Discussion

Motivations for Diversification

The farmers in this study valued diversity for the ecological functions it provides on their farms, but the reasons farmers tended to diversify were practical, rather than purely ecological. These findings suggest that this sample of farmers largely decided to establish polycultures in order to achieve specific, demonstrable goals. This is comparable to a study by McKenzie et al. (2013), which found that farmers were interested in agri-environmental schemes when they are able to yield observable benefits. However, a survey conducted by Ryan et al. (2003) instead found contradictory results, showing that farmers had more intrinsic motivations when it came to adopting on-farm conservation practices. Their results also showed that a motivation for farmers was wanted to be perceived as good stewards of their land (2003).

The conclusions from these studies contain many implications for policies that focus on farmer adoption of conservation practices that benefit pollinators. Increasing farm diversity is one means of supporting pollinator populations, as illustrated by Kennedy et al. (2013), who found that farms with diverse crops and organic management have the most abundant and diverse native bee populations, while simple (monocultural) conventional farms have the least richness and abundance. Farmers who share similar values to those in the study by Ryan et al. (2003) may be encouraged to expand their crop diversity simply for the intrinsic benefit of diversity and the themes represented in agroecology's Conservation Principle. Jackson et al. (2007) found that farmers are more likely to respond to private uses and values of diversity, rather than "'external' benefits of conservation that accrue to the wider society". Farmers that prefer to adopt practices with demonstrable results may be more motivated by policies that speak to the Complementarity and Livelihood Stability principles.

Farmers most commonly reported the Livelihood Stability Principle as a motivation for diversification. This suggests that farmers are concerned about their economic vitality. Polycultures promote farmer economic sustainability by spreading the risks across multiple crops (Navarette et al. 2015). Diversification of crops in time also supports income security by stabilizing income throughout the entire year and or growing season (Navarette et al. 2015; Pretty 2008). Policies that target conservation with measurable economic impact may be more widely accepted than those that focus solely on ecological benefits of diversification. The wide range of responses by farmers suggest that adoption of practices may be more likely when backed by multiple motivations (McKenzie et al. 2013; Ryan et al. 2003). For example, farmers may be more interested in diversifying if it supports their income security and improves ecological function.

Sequentially Flowering Crops & Pollinators

While research has been conducted on facilitation and competition caused by co-flowering crops, the impact of mass flowering crops on the pollination of sequentially flowering crops is unknown (Grab et al. 2017). In this study we examined farms growing blueberry and/or raspberry crops in order to understand if mass flowering crops cause a temporal spillover of pollinator communities onto later-flowering crops. We found that the presence of blueberry as a mass flowering crop did not significantly impact the abundance or diversity of native bee species visiting raspberry crops later in the season.

Multiple factors may be involved in explaining why there was no significant impact on pollinator communities between farm treatment types. Ranging behavior is one consideration: large-bodied bees, such as bumblebees, can forage much farther than smaller bees (Greenleaf et al. 2007). Although some bee species may be pollinators of both blueberry and raspberry crops, if the crops were not proximal enough, some short-ranged species may not have access to both resources. The 14 farms sampled in this study are also situated in a variety of landscape types; the proportion of natural upland habitat may significantly impact the presence of bee communities (Kremen et al. 2004). The percentage of natural habitat, availability of nest sites, and presence of other foraging resources are other variables that impact abundance and diversity of pollinators and may explain some of the variation in the data set (Westphal et al. 2003).

Phenology of flowering crops may play a role in explaining why abundance data trended in the opposite direction expected. On farms with MFC, blueberry may be the first crop to bloom, resulting in a resource pulse that draws pollinators (Westphal et al. 2003). On farms without an early flowering MFC, raspberry may provide this first resource pulse. As a result, pollinators in the surrounding landscape would react by concentrating on this mass foraging source.

Floral resource continuity can be considered a common ground between pollinator ecology and farmer motivations for diversification. While some bees experience their entire adult stage during the period of a single crop bloom, temporal continuity of foraging resources is necessary to support the life cycles of long-lived bees (Corbet et al. 1992). Polycultural farms that contain crops that bloom in sequence are therefore important for their provisioning of floral resources throughout the life cycles of both long-lived social and solitary bees. This extension of a farm's blooming period also benefits farmers. Season extension was one of the top three motivations for diversification reported by our sample of farmers (Figure 2b); One farmer explained that it allows her to yield fruit from "very late June, early July, until the first hard frost". In these scenarios, farm work is also spread throughout the year instead of being concentrated into one short season (Navarette et al. 2015).

Limitations

The sample of farmers for this study may have biased responses and perceptions about pollinators because of their involvement with the second portion of this study. This sample therefore cannot be generalized to reflect the opinions of berry farmers in the Northeast. A larger, randomly selected sample of farmers could be interviewed with the same guide in order to provide a more generalizable understanding of the motivations of berry farmers for diversification and how they might overlap with agroecological principles. Since this was the first year sampling on raspberry, we do not know if this was a normal or abnormal year for pollinators visiting raspberry crops. Sampling over multiple field seasons would provide a more accurate representation of the hypothesized ecological mechanism. Additionally, there are many local and landscape factors that could impact the abundance and diversity on pollinators on the farm scale (Westphal et al. 2003). These factors could not be included in analyses due to time restrictions, but should be considered for incorporation in future studies.

Conclusions and Next Steps

Farmer decision-making, especially as it relates to agrobiodiversity, is complex, even when focusing on specifically on crop selection (Brush 2004). In this study, farmers proved to be most strongly motivated by diversification as it relates to livelihood stability, by providing them with a sort of insurance against crop losses. While mass flowering crops may not significantly impact the abundance and diversity of pollinators on sequentially blooming crops, resource continuity is important in ensuring proper health and successful reproduction of native bee populations (Schellhorn et al. 2015). Season extension through the establishment of polycultures may provide long-term benefits to both farmers and the pollinator communities they rely on. Repeat studies over multiple field seasons are needed to determine if mass flowering crops do impact pollinator composition on sequentially-flowering crops and the conservation value of these systems. Additional interviews focused on farmer perceptions of their resources may provide additional insight into the willingness of farmers to incorporate conservation practices into their agroecosystems.

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Appendix A

Motivations for diversification: Interview guide

Farmer Name	Farm	Date	Time	Location	Organic?

Section 1 – Farm Crops

1. What berries do you grow and why these berries?
2. What, if any, other crops do you grow?
3. Do you grow any flowers or maintain wildflower patches on your farm?

Section 2 – Cropping History

4. What crops did you start with on the farm?
5. Why did you choose to diversify instead of specializing in a single crop?
6. Why/how have your crops changed over time?
7. Do you believe that you benefit from diversifying? How?

Section 3 – Pollinators (if not discussed in the previous questions)

8. Do you have any honeybee hives?
9. What other pollinators do your crops depend on?
10. Do you find pollinators to be important to your annual production? How?
11. Do you plant any crops or flowers on your farm specifically for pollinators?

Appendix B

Morphospecies identifications

Morphospecies	**Associated Species**	**Visits Blueberry**	**Visits Raspberry**
Apis	*Apis mellifera*	X	X
Big *Bombus* (Caste: queen)	*Bombus bimaculatus*	X	X
	B. borealis	X	X
	B. griseocolis	X	X
	B. impatiens	X	X
	B. perplexus	X	X
	B. terricola	X	X
	B. vagans	X	X
Big Orange *Bombus* (Caste: queen)	*Bombus ternarius*	X	X
	B. rufocinctus		X
Small *Bombus*	Same species as Big *Bombus*, but of the worker caste.		
Small Orange *Bombus*	Same species as Big Orange *Bombus*, but of the worker caste.		
Big Black	*Andrena carlini*	X	X
	A. commoda		X
	A. crataegi		X
	A. dunningi	X	
	A. milwaukeensis	X	X
	A. nivalis	X	X
	A. regularis		X
	A. vicina	X	X
	Osmia bucephala	X	
	O. cornifrons		X
Slender Black	*Andrena bradleyi*	X	
	A. carolina	X	X
	A. commoda ♂		X
	A. crataegi ♂		X
	A. cressonii	X	X
	A. forbesii		X
	A. hippotes		X
	A. imitatrix		X
	A. nasonii	X	
	A. nivalis ♂		X
	A. rufosignata	X	X
	A. rugosa	X	X
	A. spiraeana		X
	A. thaspii		X
	A. vicina ♂		X
	A. wilkella	X	X
	Halictus ligatus		X
	H. rubicundus	X	X

	Lasoglossum acuminatum		X
	L. coriaceum		X
	L. paraforbesii	X	X
	L. truncatum	X	
	Osmia atriventris	X	
	O. pumila	X	
Tiny Black	*Andrena platyparia* ♂		X
	Halictus confusus	X	X
	Hoplitis producta		X
	Hylaeus affinis		X
	H. affinis ♂		X
	H. mesillae		X
	H. modestus		X
	Lasioglossum admirandum		X
	L. cressonii	X	X
	L. ephilatum	X	X
	L. foxii		X
	L. imitatum		X
	L. hitchensi	X	
	L. linectulum	X	X
	L. macoupinense		X
	L. pilosum	X	X
	L. quebecense	X	
	L. tegulare	X	X
	L. versatum	X	X
	L. viridatum		X
Ceratina	*Ceratina calcarata*	X	X
	C. calcarata ♂	X	X
	C. dupla	X	X
	C. mikmaqi	X	X
	C. mikmaqi ♂		X
Green	*Agapostemon sericeus*	X	X
	A. virescens		X
	Augchlorella aurata	X	X
	Augochlora pura	X	X
	Augochloropsis metallica		X
Other	*Nomada articulata*		X
	Nomada imbricata		X
	Xylocopa virginica	X	