Nearby forest habitat increases wild bee diversity in managed blueberry fields

Sergio Vega

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By: Sergio Vega

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Signed by the Final Examining Committee:

___________________________________ Chair
Dr. Alisa Piekny

___________________________________ External Examiner
Dr. James Grant

___________________________________ Examiner
Dr. Grant Brown

___________________________________ Examiner
Dr. Emma Despland

___________________________________ Supervisor
Dr. Jean-Philippe Lessard

Approved by ____
Dr. Robert Weladji, Graduate Program Director

_______________ 2018 ____
Dr. André Roy, Dean of Faculty

ABSTRACT

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Sergio Vega

Global declines in managed honey bee populations have been a major concern for the agricultural sector. Similarly, continued habitat fragmentation and degradation of natural and semi-natural habitats have been identified as a major threat for wild bee communities. In Canada, wild bees and managed honey bees both pollinate blueberries (*Vaccinium* spp.), which is the largest fruit commodity and accounts for a market value of over $250 million per year. I assessed whether the amount of forest land cover surrounding highbush blueberry fields affects the diversity of wild bee pollinators. Specifically, I sampled wild bee communities in 18 blueberry fields during the blooming period in Monteregie, Quebec, Canada. Sampling consisted of placing pan trap triplets and direct observation of flower visitations on blueberry bushes. I also quantified the surface area representing natural, semi-natural, and anthropogenic landscape cover in a radius of 500m, 1000m, and 2000m around each field. Then I related wild bee abundance and richness to forest land cover proportion. The proportion of forest land cover varied along different scales from 0.00% to 50.8% at 500m radius and from 0.17% to 62% at 2000m radius. Wild bee abundance and richness were positively related to the proportion of the forest habitat adjacent to the crop field. Moreover, the strength of these relationships increased with spatial scale. By understanding how the nearby natural habitat benefits wild bee diversity in highbush blueberry fields and, ultimately, pollination services, conservation efforts can focus on land cover features to help halt the decline in bee diversity.

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Nearby forest habitat increases wild bee diversity in managed blueberry fields

Introduction

Insect pollinators, particularly bees, play an important functional role in ecosystems and provide a crucial ecosystem service (Potts et al., 2010). In fact, pollination services provided by bees contribute to the productivity of >75% of the world's crop species (Hanley et al., 2015; Klein et al., 2007). Although many crops are pollinated by managed honey bees (*Apis mellifera* Linnaeus), an increasing number of studies has shown that pollination and yields are often enhanced by wild bees, even in the presence of honey bees (Garibaldi et al., 2011; Hevia et al., 2016). More importantly, as managed honey bees around the world face serious threats from diseases, parasites and pesticides, wild bees represent an important insurance policy for agro-ecosystems.

Wild bee pollinators can contribute to crop pollination in four main ways. First, they can substitute for the services provided by commercially managed pollinators, replacing them either fully or partially (Kremen et al., 2015). Second, they can enhance the services provided by managed pollinators through behaviors that increase the effectiveness of the managed pollinator (Holland et al., 2015). Third, they can provide services to plants that are not efficiently pollinated by a managed pollinator (Moisan-Deserres et al., 2014). Fourth, they can enhance productivity in plants that self-pollinate and for which pollination is consequently rarely managed (Kremen et al., 2015). Therefore, wild bees as well as native and introduced non-managed bees can offer insurance against changes in the abundance of managed honey bees for many crops and, in some cases, are better pollinators than honey bees (Garibaldi et al., 2011).

Marked decreases in populations of honey bees, bumble bees, and other pollinating insects have raised awareness about the importance of pollinator conservation (Tucker et al., 2015). In the past decade, declines in managed bee colonies due to pests, pathogens, and environmental stressors have been linked to the decrease in pollination services in agro-ecosystems (Neumann and Carreck, 2010); possibly something similar is occurring with wild bee communities and their pollination services (Potts et al., 2010). Similarly, it has been recognized that wild bee communities and their pollination services might be declining due to the same factors (Potts et al., 2010), including (i) habitat loss, fragmentation and degradation, (ii) invasive species, (iii) parasites and disease, (iv) exploitation, (v) extinction cascades, and (vi) climate change (Brown and Paxton, 2009). Yet, continued habitat fragmentation and degradation of natural and semi-natural habitats have been identified as a major threat for wild bee communities (Brosi et al., 2008; Burkle et al., 2013; Potts et al., 2010; Ricketts et al., 2008).

Landscape composition and local farm management practices can affect pollinator abundance and richness in agro-ecosystems (Hevia et al., 2016; Kennedy et al., 2013). Natural habitats and semi-natural habitats surrounding agricultural areas, for example, provide pollen, nectar, and nesting sites as well as substrates that contribute to the long-term persistence of wild bee populations (Williams and Kremen, 2007). Similarly, nesting sites that might be provided by natural areas may be unavailable within an intensive crop system, which might limit the foraging range of pollinators and, thus, their abundance and richness (Kennedy et al., 2013; Rogers et al., 2013; Zurbuchen et al., 2010b). Further, wild bees have been shown to make complementary spatial-temporal use of agro-natural landscapes (Pisanty and Mandelik, 2011), and to increase in richness and abundance in orchards surrounded by a forested landscape (Watson et al., 2011). Land conversion from natural to agricultural ecosystems can have negative impact on wild bee communities (Kremen and Williams, 2007). As a consequence of decreasing bee diversity in agro-ecosystems, fruit set, weight, quality and seed number and quality can also decrease (Kremen et al., 2015; Tucker et al., 2015). The conversion of forested natural habitats into agricultural fields is therefore a major threat to wild bees and the pollination services they provide (Knight et al., 2005; Zurbuchen et al., 2010a).

Wild bees show a particularly important and effective role in the pollination of blueberries, which is the largest fruit commodity in Canada and represents a market value of over $250 million (Statistics Canada, 2016). Producers have used honey bees for decades to help pollinate highbush blueberry (*Vaccinium corymbosum* L.) crops, but since the highbush blueberry is native to North America, it has co-evolved with endemic pollinators (Benjamin and Winfree, 2014; De Luca and Vallejo-Marín, 2013; Javorek et al., 2002; Klein et al., 2007). As a result, honey bees are not the most suitable pollinators for these crops (Finnamore and Neary, 1978). Compared to honey bees, wild bees transfer more pollen to a stigma per flower visit and more readily forage during cool, wet spring weather, which is common during late April and May when the highbush blueberry blooms (Isaacs and Kirk, 2010). Wild bees naturally exist in landscapes surrounding farms and freely pollinate crop flowers (Kennedy et al., 2013). Furthermore, their availability and proximity to forest natural habitat patches can promote wild bee diversity and pollination services in agro-ecosystems (Ricketts et al., 2008). However, it is not clear how much of these natural patches of forest, adjacent to crop habitats, are required to support viable wild bee communities.

In this study, I assessed forest natural habitat land cover effects on wild bee communities in managed blueberry fields across Monteregie, Quebec, Canada. I hypothesized that bee abundance and richness is related to the proportion of available forest habitat near blueberry fields. Furthermore, I investigated the additional effect, to that of forest, of potentially important variables such as the size of the focal crop habitat (highbush blueberry fields), highbush shrub density, and air temperature.

Methods

Study area

We sampled the bee community at farms in Monteregie (45°23′N 73°06′W), Quebec, Canada (Figure 1). The region is dominated by a range of crops including corn, soybean, and hay as well as smaller quantities of apple orchards, vineyards, and small fruit plantations such as strawberry and blueberry fields (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, 2012). Additionally, it consists of a mix of fragmented coniferous and deciduous forest, semi-natural areas such as grasslands, meadows, hedgerows, marshlands, pastures, and old fields (abandoned fields) (Mitchell et al., 2014). The study was conducted in 18 highbush blueberry (*Vaccinium corymbosum* L.) fields (sites) composed of different cultivars including "Patriot", "Blueray", "Burkley", and "Bluecrop". Each field had a surface area of at least 0.5ha (Appendix A; Supplementary data Table 1). The sites were separated from one another by an average distance of 5km (min. 4.7km and max. 80.9km). We visited each site twice over the course of the blooming season from 23 May 2017 to 9 June 2017.

Measurement of environmental variables

Temporally variable factors such as daily weather affect the level of bee activity in blueberry fields (Isaacs and Kirk, 2010). Sampling took place between 10h and 17h on sunny to partially sunny days, when the air temperature was between a minimum of 13°C and a maximum of 25°C; on an average, the air temperature was 15.9°C. Weather data was collected from Canada's environmental and natural resources website.

Wild bee sampling

I implemented two sampling techniques: visual/observation data collection and pan trap triplet specimen collection. At each site, a quadrant distribution was arranged at 10m intervals, starting from the western middle point of the field moving towards the east, for a total of 10 sampling stations (Figure 2).

Visual data collection

A visual sampling was performed for 5min per sampling station, meaning 50min observation dates per site, for a total of 1800min. Observations were done on blooming sections of blueberry shrubs located within a 2m radius from the pan trap triplets (see pan trap triplet specimen collection). Only bees that entered the flower legitimately (through the corolla opening) and apparently contacted the stigma were recorded. I identified visiting bees on the fly by using a morphotype guide that included photos of the most common bees present at highbush blueberry bloom. Honey bees (*Apis mellifera* L.) and bumble bees (*Bombus* spp.) were identified to species on the fly. Morphos that were not in the photo guide but observed foraging on highbush blueberry flowers and can only be identified upon close examination were net captured, recorded and grouped as Andrena, Halictid green bee, Small black bee, and Metallic black bee.

Pan trap triplet specimen collection

Visual sampling was complemented by using pan traps (Droege et al., 2010). Pan trapping is a standard method for sampling bees (Tucker et al., 2015; Westphal et al., 2008) though it is known to perform poorly for some taxa (Nielsen et al., 2011). For the pan traps, we used 500ml plastic bowls painted with either fluorescent yellow or blue Krylon® paint on the interior surface or left unpainted as opaque white. Each pan trap was filled with 250ml of water and 1 drop of non-fragrant liquid soap (detergent) to break surface tension (Bushmann and Drummond, 2015; Fortel et al., 2014; Moisan-Deserres et al., 2014). The pan traps were placed in every study site and were deployed for 24h for the first round and 48h for the second round. They were set by triplets per station (1 pan trap of each color) in a quadrant at 10m intervals for a total of 10 sampling stations and 30 pan traps per site. The pan traps were placed at ground level, and at the end of each sampling period, each pan was drained of water and the captured specimens were stored in 70% ethanol until pinned.

Bee identification

Bees were identified using taxonomic classification books based on dichotomous keys such as the "Bee Genera of Eastern Canada" (Packer, 2007), "Bees of the World" (Michener, 2000), and "Bumble Bees of North America" (Williams et al., 2014) as well as publicly available online resources (http://www.discoverlife.org/). Identification was validated by personnel from the Centre de recherche et innovation sur les végétaux at Laval University in Quebec and the Entomological Collection Ouellet-Robert (QMOR) at the University of Montreal. The specimens that were not identified to species level were assigned a morpho-species/morphotype status.

Surrounding land cover proportion

Land cover types and their spatial configuration are key elements in ecological studies that consider the impacts of human activities at regional spatial scales (Ricketts et al., 2008). It is important to understand the relationship between spatial heterogeneity and biodiversity in agricultural landscapes (Fahrig et al., 2011). Together, monocultural landscape and natural habitats have particularly high biodiversity potential (Aviron et al., 2005). Thus, incorporating land cover information to study wild bee communities in highbush blueberry fields may provide useful information that could lead to better understand wild bee diversity.

Five land cover types surrounding blueberry fields were identified: (1) Agriculture (Financier Agricole du Quebec, 2016), (2) forest / woodland (4th inventory from Eco-forestry information system of Quebec, 2017), (3) urbanization (Ministry of public security of Quebec, 2016), (4) water bodies (Ministry of energy and natural resources of Quebec, 2014), and (5) abandoned areas / semi-natural areas, considered as the remaining area from the addition of the four previous land cover types, which include spiny shrub vegetation, pasture fields, hydric herbaceous, and shrub vegetation (Benjamin et al., 2005). All data sources were in vector format as shapefiles (Esri and Paper, 1998).

I extracted land cover types within radii of 500m, 1000m, and 2000m from the sampling sites using the buffer and clip tool in ArcGIS (Clermont et al., 2015). Then, I determined the proportional area of these five habitat types within different radii. Radii length were considered based on typical estimated flight ranges of wild bees (Araújo et al., 2004; Fortel et al., 2014; Pasquet et al., 2008; Tucker et al., 2015). All spatial analysis was conducted in ArcGIS10.0 (ESRI, 2011).

Statistical analysis: Influence of forest land cover on wild bee communities

General linear models were performed for each radius to test if wild bee abundance and richness was influenced by the surrounding natural habitat. To analyze the data, I proceeded as follows: First, I tested the hypothesis that wild bee abundance and richness is related to the proportion of forest habitat adjacent to the field of study. For this, I fitted two simple models — one correlating the proportion of forest land cover and bee abundance and the other correlating the proportion of forest land cover and bee richness. Then, I considered that other land cover features might play a role in bee abundance and richness. Therefore, I tested the effects of i) Abandoned fields, which could represent potential sources of foraging and nesting sites between forests (Hevia et al., 2016); and ii) Highbush blueberry field size and shrub density — larger fields or higher shrub density may represent more resources and, therefore, result in more species and bee abundance, and iii) air temperature; I included this factor for two reasons: a) because ectothermic organisms (like wild bees) respond to environmental temperature by being more or less active and a given temperature during the sampling day in the focal field may affect the presence or absence of bees and, b) because this variable allowed testing of the potential effect of the latitudinal trend that the sampling sites followed, even though it is minimum. I reported R^2 values as a measure of goodness of fit and used Akaike's information criteria (AIC) to determine if the additional effect of a given variable would represent a better model different from that of forest. The AIC identifies parameters (independent variables) that explain the variation in a response variable (i.e. relative goodness of fit) based on the relative amount of information that is lost in the model (Zuur et al., 2007). For the analysis, I pooled data from the visual sampling technique and pan traps of all 18 fields. Honey bees were not considered for any statistical analysis. The statitical analyses were carried out in SYSTAT v.12.

Results

Bee community related to surrounding land cover

I tested the hypothesis that wild bee abundance and richness is related to the proportion of available forest habitat near highbush blueberry fields. As expected, bee abundance was positively correlated with forest in each radius. Forest accounted for between 34.5% and 48.4% of the variance in bee abundance among the different radii. As for bee richness, forest accounted for 13.1% and 25.4% at 1000m and 2000m radii respectively, but only 1% at the 500m radius (Figure 5).

Model selection indicated that the additional effect of other variables, to that of forest, on bee abundance was important only for air temperature at 1000m radius plots (Forest + T°: AICcWt = 0.57 *vs.* Forest: AICcWt = 0.25) (Table. 2). Forest remained as the most important factor accounting for bee abundance variance at 2000m and 500m radii. Regarding bee richness, only the additional effect of abandoned fields was identified as important at 500m radius plots (Forest + AbF: AICcWt = 0.51 *vs.* Forest: AICcWt = 0.30). At 1000m and 2000m, forest remained the most important factor explaining the variance of richness among plots (Table. 2).

Bee community

In total, I found 17 different species/morphospecies, corresponding to 11 genera (Table 1). 74 bees were captured with pan traps whereas 952 corresponded to observations of bees visiting flowers at the experimental blueberry shrubs. *Bombus* spp. and *Apis mellifera* were present in every sampled site with an abundance of 437 and 298, respectively. *Nomada* spp., *Colletes* spp., and *Ceratina* spp. were the least present, with an abundance of 4, 2, and 2, respectively; these groups were captured at sites with higher surrounding forest land cover habitat.

Bee communities in the sampled highbush blueberry fields were dominated by *Bombus* spp. and *Apis mellifera,* which were the most abundant flower-visiting bees. *Bombus* spp. was the most abundant pollinator group and was represented by five distinguishable species: *B. impatiens* was the most abundant species, being recorded at all sites and comprising over 85% of all sampled bees; *B. ternarius* followed with 13%, and *B. bimaculatus*, *B. terricola*, and *B. perplexus* with less than 1% of the individuals observed (Figure 4).

The abundance of other pollinators such as *Andrena* spp. and *Lasioglossum* spp. represented 16% and 3% of the total bee community abundance, respectively. Halictid green bees, small black bees, and metallic black bees represented together over 6%. *Osmia* spp. and *Augochlorella* spp. were found in smaller quantities, representing just under 2% of all bees across sampling sites.

Surrounding land cover

The analyses of land cover proportion concerning 500m, 1000m, and 2000m radii showed that average land cover proportion varied among scales (Figure 3). Forest habitat, mainly composed of deciduous forests, did not show drastic land cover changes, remaining between 18% and 27% as radius increased. Abandoned fields, mostly composed of scrubland, meadows, and pastures, decreased from 40% to 31%, as radius increased. Agriculture habitat, primarily composed of corn, soy, and wheat, showed an average of 39% cover throughout the three radii, as opposed to urbanization (residential, commercial, roads, and greenhouses) and water bodies, which remained below 2.5% throughout the three radii.

Post hoc analysis

Supplementary analysis was conducted to test the effect of agriculture on bee diversity (Appendix A; Supplementary data, Figure 1). The model showed that bee abundance correlated negatively to agriculture land cover proportion. Agriculture accounted for 35% and 34% at 1000m and 2000m radii, respectively, but only 16% at 500m radius. Regarding bee richness, agriculture had a negative effect at 1000m and 2000m accounting for 25% and 30% respectively and 8% at 500m radius

Discussion

Influence of forest land cover on wild bee communities

The results are consistent with my hypothesis — higher values of wild bee abundance and richness were associated with a larger proportion of forest land cover. This conclusion, in general, holds for the different radii I assessed: 500m, 1000m, and 2000m radii, suggesting that the proportion of forest patches surrounding blueberry fields is, in fact, an important driver of bee abundance and richness for this crop. Moreover, the proportion of forested natural habitat explained more variation in wild bee abundance and richness at the 2000m radius than at smaller radii.

The lack of forest habitat surrounding highbush blueberry fields has a negative effect on wild bee presence. On average, forested habitats consisted of less than 28% of the land cover within a 2000m radius across the sampled sites. These findings are consistent with previous studies where the presence of forest habitat is an important factor for some wild bees (Diaz-Forero et al., 2011). It has been demonstrated that wild bee abundance and species richness in apple orchards were positivelly correlated with the proportion of forest land cover at 1000m and 2000m radii plots (Watson et al., 2011). Similarly, the abundance of *Bombus vosnesenskii* in cherry tomato fields was observed to increase with the proportion of natural habitat (chaparral, riparian, oak, or mixed-oak) at 2300m radius plots (Greenleaf and Kremen, 2006). Also, recent studies in different fruit commodities, including blueberries in Monteregie, Quebec (See Martins et al., 2018), indicate that both wild bee abundance and richness were highest in crop fields when diverse and abundant nesting and floral resources were available in the surrounding landscape (Kennedy et al., 2013; Martins et al., 2018). Thus, greater forest proportion has a positive effect on wild bee diversity, particularly for bee abundance.

The high bee abundance associated with the presence of high proportion of forest cover is relevant from the pollination service perspective and therefore to blueberry production. This means that blueberry fields with a higher proportion of adjacent forested area are visited by a higher abundance of wild bees, potentially because the forested habitat functions as a source for these pollinators. Previous studies have shown that natural habitats provide food and nesting resources that contribute to the long-term persistence of wild bee populations (Williams and Kremen, 2007). Although to partially confirm the benefit of this pattern, it would be necessary to assess whether blueberry production also increases in fields with more adjacent forest. Unfortunately, in this study, data on yield was available only for a small number of farms. Nevertheless, there is sufficient evidence showing that the production of different types of crops generally increases either with the proportion of natural habitat (Kremen et al., 2004) or with wild bee abundance (Greenleaf et al., 2007; Morandin and Winston, 2005). As bee abundance increases so does pollen deposition by bees (Kremen et al., 2004). Pollen deposition is a proxy for pollination service (Kearns & Inouye 1993; Willmer et al, 2017) and is the most direct measure influencing fruit production (Kremen et al., 2004). Therefore, the positive pattern between bee abundance and forest land cover proportion suggest that fields with higher proportion of surrounding forest should have higher yield. Similarly, bee richness was related to forest proportion to one extent.

Bee richness also increased with the proportion of forested habitats surrounding blueberry fields at 1000m and 2000m radii. This result is meaningful for at least two main reasons. First, it supports the view that current trends in habitat loss are a major threat to wild bee diversity (Potts et al., 2010; Tucker et al., 2015). Studies showed that bee richness is low in arable landscapes due to the increased distance between the interior of agricultural settings and peripheral bee habitats, along with the lack of floral resources once bloom season is over (Kennedy et al., 2013; Mandelik et al., 2016; Martins et al., 2015). Additionally, forest habitats may provide favorable nesting conditions for a number of bee-nesting guilds, e.g., ground-, cavity-, and twig-nesting (Mandelik et al., 2016). Second, decreasing the diversity of wild bees not only exposes these pollinators as a group, but it puts at risk the flowering plants that depend on them for completing their life history. It is well known that many plants species have co-evolved with specific pollinators (Cappellari et al., 2013). This is particularly relevant for plants like highbush blueberry that co-evolved with bumble bees, which are arguably the most efficient pollinators of this species. Indeed here, we saw

5 species of bumble bee pollinating the blueberries. Therefore, the presence of forest habitats insures that several species of bumble bees are available to provide pollination services. Similarly, agriculture land cover proportion effect was assessed.

The negative effect of agriculture land cover proportion on bee diversity was evident mainly at 1000m and 2000m radii. Both, bee abundance and bee richness decreased as the proportion of agriculture increased. The results are in agreement with previous studies where it has been demonstrated that agricultural intensification decreases bee pollinator communities (Kennedy et al., 2013; Martins et al., 2017; McKechnie et al., 2017). Hence, the conversion of natural habitats into monoculture proves to affect wild bee diversity probably due to the loss of nesting and foraging habitat. According to Carré, et al., (2009), it may not lead to the extinction of all bees in agro-ecosystems, but instead may change its community with an increase in the most resilient bee species and loss of the more vulnerable species (Carré et al., 2009). Similar to what was observed for forest land cover proportion, agriculture land cover effect was significant at 1000m and 2000m radii; it is possible that at 500m radius the relation between land cover proportion and bee diversity does not correspond well with foraging distances for some bee species (Kremen et al., 2004). Indeed, it has been exposed that bee diversity of solitary wild bees has a positive correlation with the percentage of seminatural habitats at small scales up to 750m, whereas larger-social bees, e.g. bumble bees, do not respond to landscape context at these scales, but rather at larger scales >2000m (Steffan-Dewenter et al., 2002; Walther-Hellwig and Frankl, 2000). Most of the bee community sampled are members of larger-social bees, therefore, the adverse effect that agriculture has on wild bee diversity is evident at larger scales. Likewise, other independent variables were considered in terms of its influence on bee diversity.

The inclusion of potentially important variables measured in the fields revealed that abandoned fields and mean temperature had an additional positive effect on wild bee diversity. Abandoned fields proved to have an effect along with forest cover only at 500m radius for bee richness, being a significant one (variance increased 14.5%). Martins et al., (2018) suggest that hedgerows and meadows habitats surrounding apple orchards, raspberry and blueberry fields, in the region of Monteregie, provide nesting and floral resources for wild bee communities within 850m radius, making it crucial for the survival of bee species in arable landscapes, as agriculture fields and forests generally have low floral richness (Martins et al., 2018; Mandelik et al., 2016).

However, in my study, its effect was isolated to some degree; it did not show a general trend in the models. Then, it is possible that different radii are suitable for analysing different variables' effects, or bee groups that have different foraging ranges (Greenleaf et al., 2007). Similarly, the additional effect of temperature on wild bee diversity was only detected at 1000m radius for bee abundance, yet the effect was significant (variance increased 7.4%). Martins et al. (2018) observed a similar effect of temperature on wild bee abundance in the same study region. However, the effect reported was observed at 580m radius, and suggest that warmer temperatures represent a condition favorable for bee pollinators. Likewise, the detected effect might be linked to the sampling design; not every site was sampled at the same time of day and under the same conditions. Thus, homogenizing the time for sampling among sites may help to confirm or reject my observations. Therefore, the interpretations regarding the positive effect of abandoned fields and temperature should be taken cautiously.

Bee community: observations vs pan traps

Most observed visits were made by *Bombus* spp. (42.59%), *Apis mellifera* (29.04%), Andrena (16.18%), and other bees (12.19%). In contrast, pan trapping collected a different insect community and surprisingly lower quantities of bees, with a total of 74 individuals that were mainly members of *Lasioglossum* spp. and *Andrena* spp. genera. Although pan traps are useful to assess a wider insect community, active pollinators that are possibly providing services to the crop itself can be assessed through direct observations (Isaacs and Kirk, 2010). Pan traps can also under-sample bee species richness when floral resources are abundant (Baum and Wallen, 2011); yet, they remain as an effective sampling technique when flowers are scarce or when targeting particular species that are easily trapped (Roulston et al., 2007). It suggests that using a netting method directly on the flowers is useful when bee communities are more diverse.

Bumble bees are the most important pollinators of highbush blueberry shrubs in the experimental fields. *Bombus* spp. is arguably the most efficient pollinator in these types of habitat due to its co-evolution with *Vaccinium* spp and its sonification pollination behavior (Buchmann, 1983; Cane et al., 1985). It was evident that *B. impatiens* was the most prosperous bumble bee species, whereas others, such as *B. perplexus*, *B. terricola*, and *B. bimaculatus*, were not that conspicuous. The high presence of *B. impatiens* could be caused by growers placing bumble bee colonies to provide adequate pollination requirements for certain fruit crops. However, none of the growers reported using pollination services provided by bumble bee colonies during the sampling period. The high abundance of *B. impatiens* compared to the rest of the sampled bees raised the question whether there is a strong competition between bee species that could be causing displacement. Different studies have demonstrated that the most important factor influencing nectar-foraging rates in wild bees is the forager body size (Araújo et al., 2004; Cutler et al., 2015). For example, according to Ings *et al.* (2006), a commercial bumble bee (*Bombus terrestris dalmatinus*) colony, which is consistently larger than native foragers (*Bombus terrestris audax*) with a large number of superior nectar foragers, will have a greater impact on local nectar resources than a native colony (Ings et al., 2006). For upcoming research, it is advised addressing this possible interaction. Nevertheless, bumble bees demonstrated to be the most abundant and important pollinators at the sampled higbush blueberry fields. Likewise, there were other bee groups that played an important role as bio-indicators.

Nomada spp. bees were captured by the pan traps in only four sites out of 18, suggesting that these habitats where they were captured might be in better ecological conditions for specialist bees. The presence of certain bee groups like *Nomada* spp., which are known as cleptoparasitic bees, is negatively impacted when habitat disturbance affects the nesting sites of their host species (Cane, 2001). Therefore, these bees are bio-indicators of high-quality nesting habitats, as they cannot sustain without the adequate host nests (Sheffield et al., 2013). Sheffield *et al.* (2013) state that areas characterized as low human disturbance, such as abandoned fields and woodlands, contain a higher richness of cleptoparasitic bee species than those with higher levels of disturbance. Thus, *Nomada* spp. are important bio-indicators of non-disturbed forest habitats.

Landscape management and conservation

The results demonstrated that forest land cover is an important driver of bee abundance and richness. Supporting pollination services and food security is imperative to develop landscape management strategies that would benefit both natural habitats like forests and semi-natural settings like agriculture (Kennedy et al., 2013). Similarly, abandoned field land cover represents, on average, 31% of the surface in a 2000m radius; this land cover could be strategically used for conservation purposes by restoring forests, which, in turn, could continue providing free pollination services to farmland or even increase it. Therefore, strategical landscape management that favors reforestation could benefit bee diversity in agro-ecosystem settings.

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Table 1. Total bee abundance combining two sampling techniques: a) Pan trap sampling and b) Visuals, in highbush blueberry fields in Monteregie, Quebec.

Pollinator/ morphospecies	**Pan traps**	**Visuals**	**Abundance**	**%**
Andrena	14	152	166	16.2
Apis	5	293	298	29.5
Augochlorella	4	0	4	0.38
Halictid green	0	12	12	1.16
Bombus impatiens	0	374	374	36.4
Bombus ternarius	0	57	57	5.5
Bombus bimaculatus	0	4	4	0.38
Bombus terricola	0	1	1	0.09
Bombus perplexus	0	1	1	0.09
Colletes	2	0	2	0.19
Ceratina	2	0	2	0.19
Lasioglossum	32	0	32	3.1
Small black bee	0	50	50	4.8
Nomada	4	0	4	0.38
Osmia	6	0	14	0.5
Metallic black bee	0	8	8	0.6
Sphecodes	5	0	5	0.4
Total	74	952	1026	100

Visuals indicate that bees were observed making legitimate visits to blueberry flowers.

Table 2.

Linear regression models regarding the effect of forest proportion on bee abundance and bee species richness at 500m, 1000m, and 2000m. Adjusted R^2 values, Akaike information criterion corrected for small samples (AICc), AIC weights (AICcWt), and P-value are presented for each regression model.

Bee Abundance					
Radius	**Model**	**Adj. R^2**	**AICc**	**AICcWt**	**P-value**
500m	Forest	0.34513	185.01	0.38	0.160
	Forest + AbF	0.05896	187.30	0.12	0.247
	Forest + T°	0.11833	186.13	0.22	0.152
	Forest + Shrub density	0.10264	186.45	0.19	0.173
	Forest + Field size	0.02931	187.86	0.09	0.312
1000m	Forest	0.47601	175.66	0.25	0.001
	Forest + AbF	0.40988	178.90	0.05	0.007
	Forest + T°	0.55032	174.01	0.57	0.000
	Forest + Shrub density	0.44062	177.94	0.08	0.005
	Forest + Field size	0.40617	179.02	0.05	0.007
2000m	Forest	0.48478	175.35	0.44	0.001
	Forest + AbF	0.41904	178.62	0.08	0.006
	Forest + T°	0.48909	176.31	0.27	0.002
	Forest + Shrub density	0.44478	177.81	0.13	0.004
	Forest + Field size	0.41609	178.71	0.08	0.006
Bee Richness					
500m	Forest	0.01090	102.74	0.25	0.680
	Forest + AbF	0.15576	101.00	0.59	0.109
	Forest + T°	- 0.11	105.93	0.05	0.857
	Forest + Shrub density	- 0.10	105.77	0.05	0.803
	Forest + Field size	- 0.10	105.87	0.05	0.836
1000m	Forest	0.13153	100.40	0.35	0.139
	Forest + AbF	0.15769	100.96	0.27	0.107
	Forest + T°	0.14976	101.13	0.24	0.115
	Forest + Shrub density	0.02207	103.64	0.07	0.330
	Forest + Field size	0.02365	103.61	0.07	0.326
2000m	Forest	0.25397	97.66	0.4	0.032
	Forest + AbF	0.21480	99.69	0.14	0.063
	Forest + T°	0.27841	98.17	0.31	0.033
	Forest + Shrub density	0.15628	100.99	0.08	0.109
	Forest + Field size	0.16000	100.91	0.08	0.105

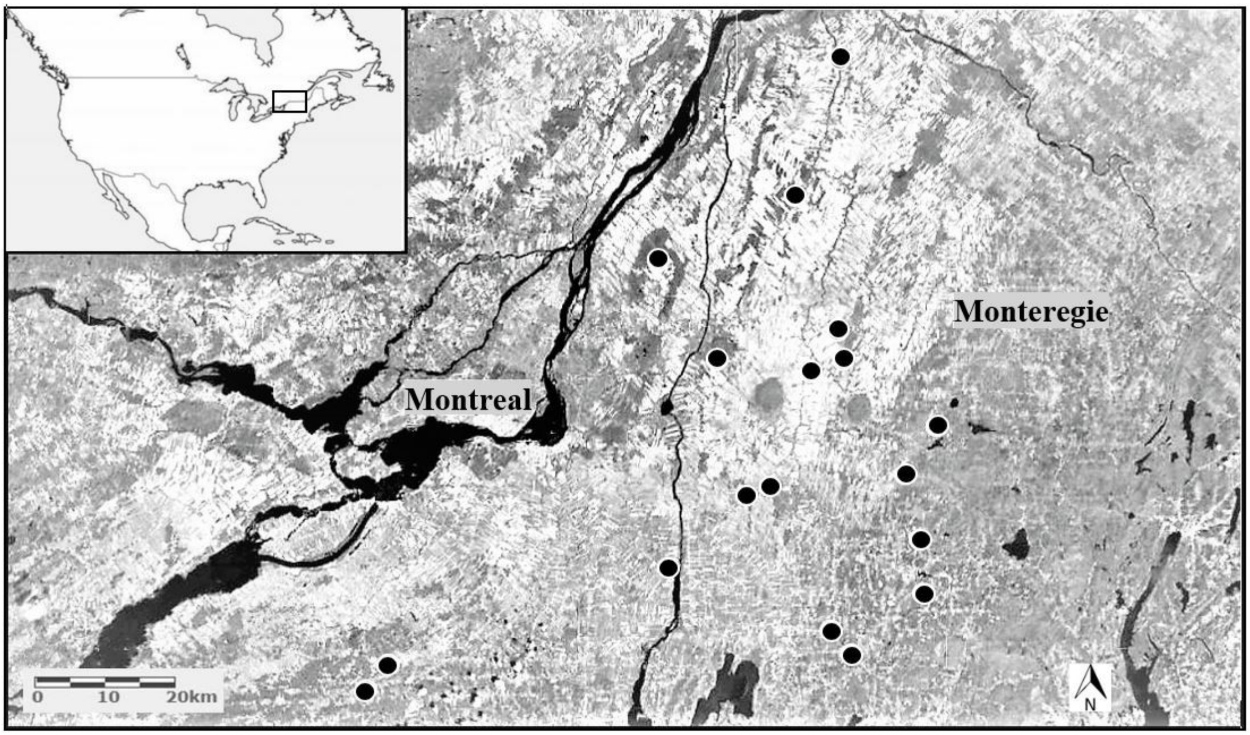

Figure 1. Distribution of blueberry fields sampled in Monteregie region in Quebec, Canada.

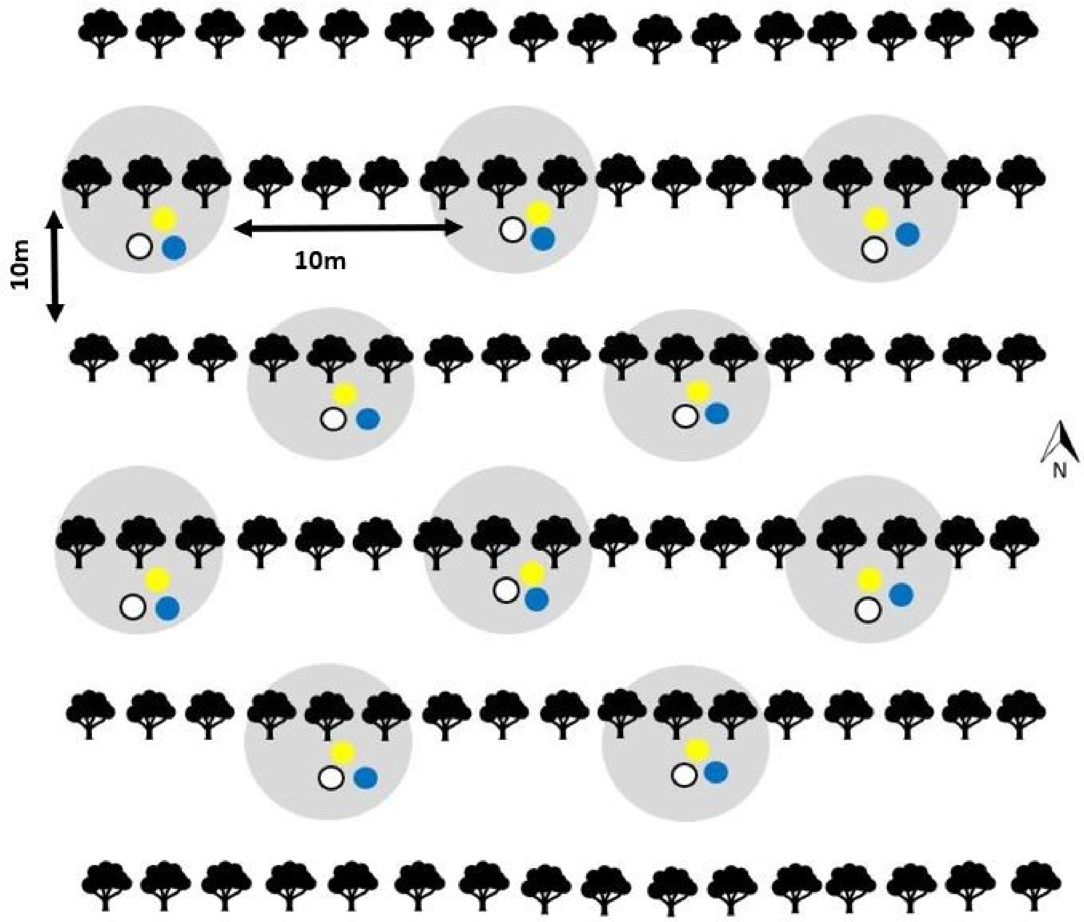

Figure 2. Schematic representation of sampling distribution at a highbush blueberry field, showing pan trap triplet arrangement as well as interval distance per treatment (10m).

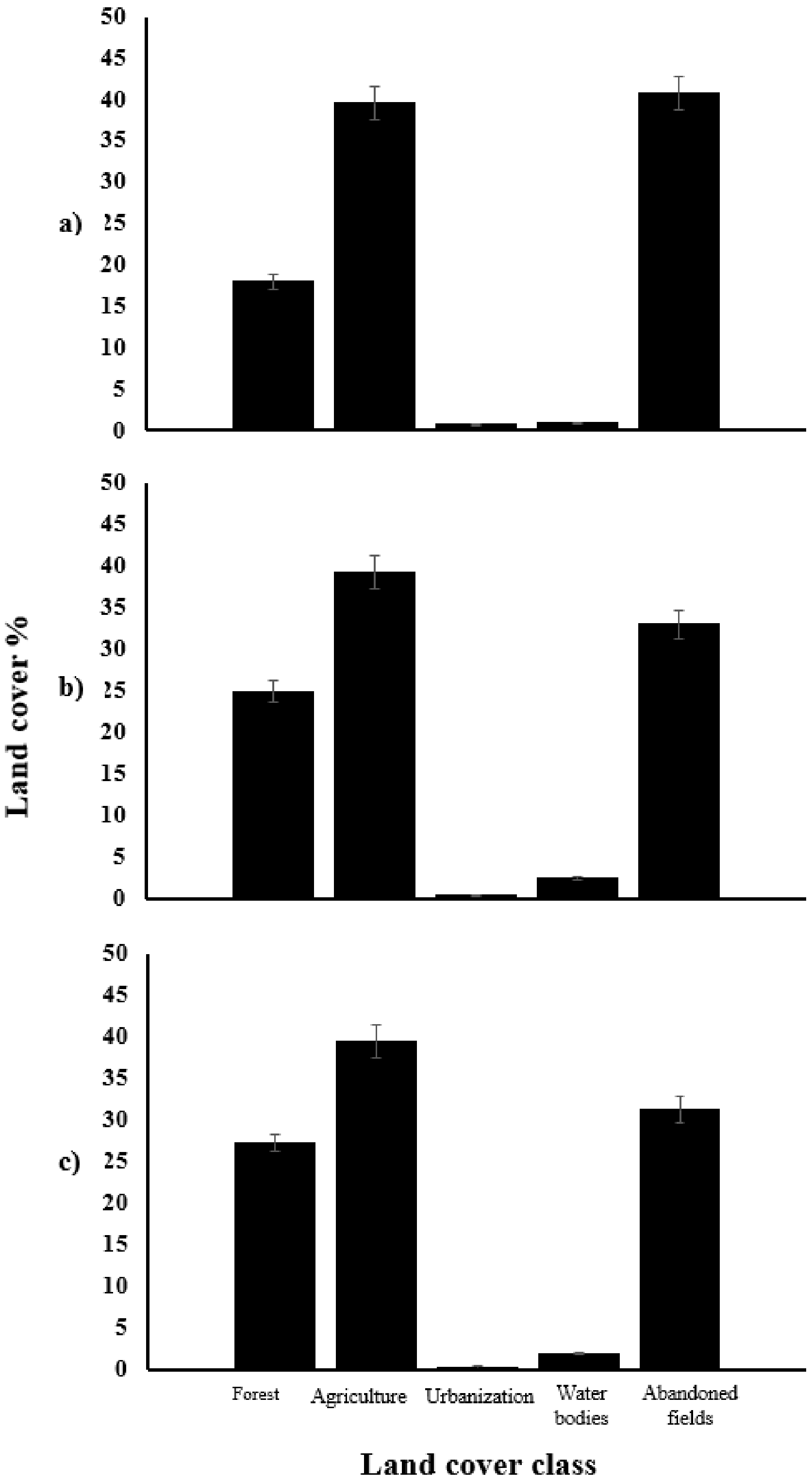

Figure 3. Average proportion of landcover types within a) 500m, b) 1000m, and c) 2000m radii across sampled fields.

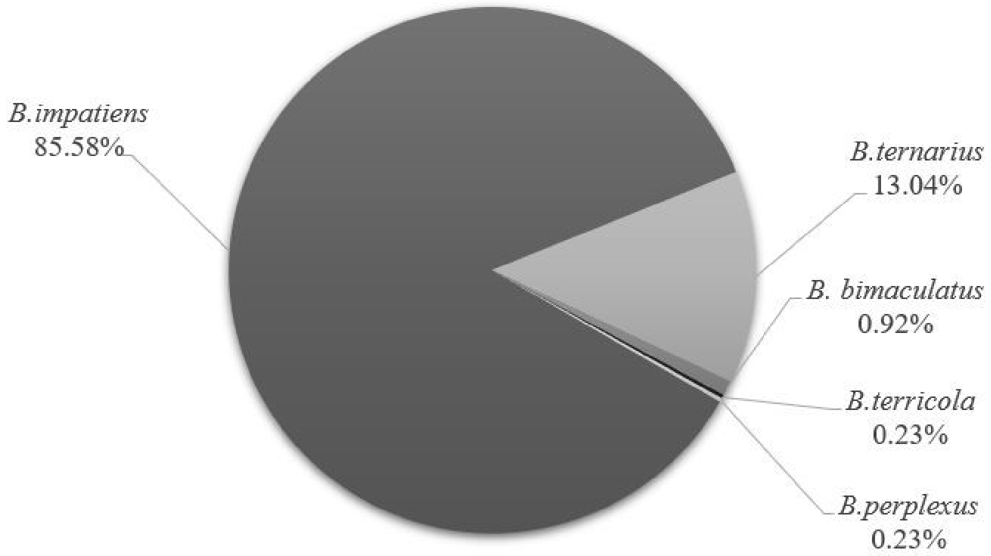

Figure 4. Proportion of *Bombus* spp. occurrence across all sampled fields during the bloom period.

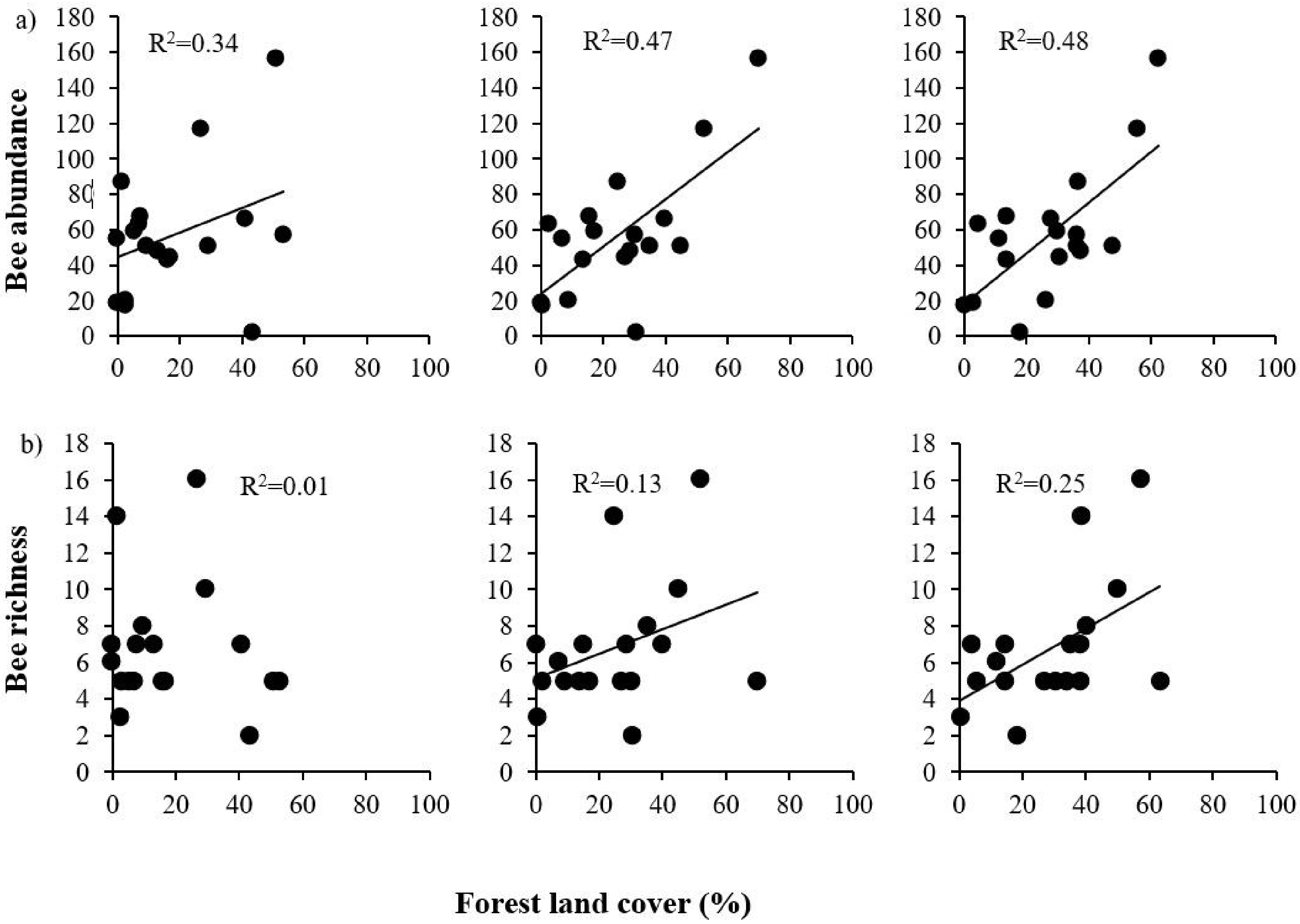

Figure 5. Observed relationships of wild bee abundance (a) and richness (b), as a function of the proportion of forest land cover habitat at 500m, 1000m, and 2000m radii (from left to right) at the sampled highbush blueberry fields in Monteregie, Canada.

Appendix A. Supplementary data

Table 1.
Geographic coordinates of 18 field sites where wild bees were collected in commercial highbush blueberry fields, in Monteregie, Canada.

Field Name	Geographic coordinates (DD)	Field Area (ha)	Shrub density
Charbonneau	45.681094N; 73.2964W	1.25	3600
Bleuesime	45.216417N; 73.260533W	0.8	1200
Sylvie Remillard	45.023469N; 73.929875W	3.1	5000
Alain Menard	45.079583N; 72.879433W	2	4000
Bleuets du ridge	45.113644N; 72.920956W	0.8	6500
La colline au bleuets	45.173981N; 72.716811W	1.2	1700
Les delisles	45.25435N; 72.73265W	2.5	4300
Bleuetiere_du_boise	45.356933N; 72.75925W	2.2	4000
Bleuetiere giard	45.428633N; 72.69825W	1	5000
Joualbleu	45.7829N; 73.00185W	3	3000
Machabee	45.057933N; 73.887733W	14	9000
Aux dames bleuets	45.98725N; 72.895217W	0.5	2250
Bleu ciel	45.573067N; 72.906933W	2	4200
Ferme equinoxe	45.527908N; 72.897864W	2.3	3700
Reve Bleu	45.508433N; 72.963283W	7	12500
Domaine du flanc sud	45.532483N; 73.169617W	3	5700
Jutras	45.325639N; 73.09513W	10	8000
Sur le Champs	45.331317N; 73.063272W	3	3000

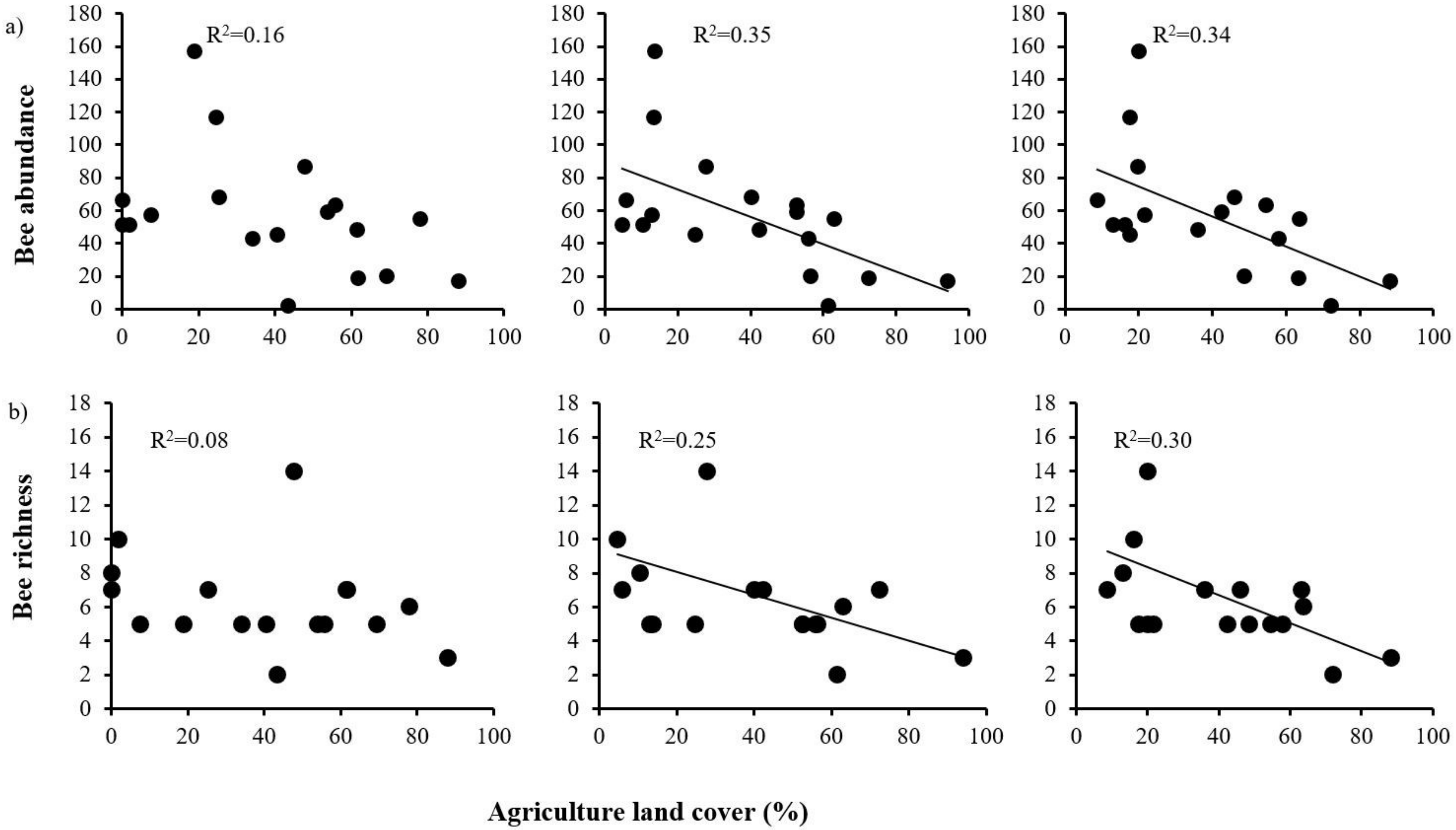

Figure 1. Observed relationships of wild bee abundance (a) and richness (b), as a function of the proportion of agriculture land cover habitat at 500m, 1000m, and 2000m radii (from left to right) at the sampled highbush blueberry fields in Monteregie, Canada.