Renewable Agriculture and Food Systems

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Perceptions of wild bees and farm characteristics associated with the uptake of pollinator-supporting land management practices among Canadian apple growers

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Research Paper

Cite this article: Nalepa RA, Epstein G, Pittman J, Colla SR (2021). Perceptions of wild bees and farm characteristics associated with the uptake of pollinator-supporting land management practices among Canadian apple growers. *Renewable Agriculture and Food Systems* **36**, 334–343. https://doi.org/10.1017/S1742170520000344

Received: 15 January 2020
Revised: 2 May 2020
Accepted: 12 October 2020
First published online: 1 December 2020

Key words:
Apples; Canadian agriculture; perceptions of bees; pollination; pollinator-friendly farming; wild bees

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Abstract

Pollination services are critical for food production. Although domesticated honey bees are important pollinators in agriculture, there is growing interest in supporting naturally occurring wild bees. Diversifying pollination management strategies by encouraging healthy wild bee communities may be especially useful for growers of insect-pollinated crops, such as apples. Although research has identified several land management practices that can enhance local pollinator communities on farms, there are few studies on the factors that influence growers to adopt pollinator-supporting actions on their land. Here, we surveyed 75 Canadian apple growers and used regression models to explore the influence of farm characteristics and perceptions about bees on the likelihood of adopting 15 unique pollinator-supporting practices. We also provide a descriptive analysis of growers' pollination management practices and self-assessed resourcefulness on the ability to improve habitat for wild pollinators on the farm. We found that an increase in three variables: awareness of wild bees, perception of the severity of threats facing wild populations, and the perception of the benefits provided by wild bees is associated with more pollinator-supporting practices on the farm. Overall, growers were less likely to adopt pollinator-friendly practices as the fraction of rented land increased and as the perceived costs of implementing these practices rose. We found 'low-hanging fruit' (i.e., pollinator-supporting practices that could be easily and inexpensively implemented) were adopted by less than one-third of growers and that the majority of those surveyed had little to no knowledge on what actions to take if they wanted to improve their farms for wild bees or where to go for that knowledge. Our results suggest that policies and programs that focus on raising grower awareness of wild bees, increasing grower perception of their benefits, and reducing the perceived costs of implementing pollinator-supporting practices may positively affect their uptake. A deeper understanding of grower perceptions will provide essential insight into how growers may contribute to wild pollinator conservation while potentially increasing agricultural production and reducing vulnerability borne of heavy reliance on managed pollinators.

Introduction

Insect pollination is a vital process that underpins the global agricultural sector, human food security, and the livelihoods that rely on pollinator-dependent crops. Of pollinating insects, managed and wild bees are the most dominant animal pollinators for crops in most areas in the world (Klein *et al.*, 2007; IPBES, 2016).

Globally, the Western honey bee (*Apis mellifera* Linnaeus, 1758) is the most utilized managed pollinator for its economically valuable byproducts, such as honey, generalist behavior that allows for the pollination of many crops types, and its ability to be easily transported and positioned next to target crops (Morse, 1991; Aizen and Harder, 2009; Rucker *et al.*, 2012; Hung *et al.*, 2018). However, experts have been calling for growers to diversify their pollination strategies to include an increased focus on wild bees (Winfree *et al.*, 2007; Isaacs *et al.*, 2017).

Wild bees can be more effective pollinators than honey bees as well as enhance crop yield (Klein *et al.*, 2007; Garibaldi *et al.*, 2013). Supporting wild bee populations may also reduce grower vulnerability due to the risks associated with relying heavily on the honey bee industry. These risks include inevitable local or seasonal shortages due to the increasing demand, pests and diseases, or other unforeseen events that may impact honey bee supplies (US House, 2007; Aizen and Harder, 2009; Garibaldi *et al.*, 2016). Lastly, managed honey bees may be contributing to the decline of wild bees and other biodiversities in places where they are not native,

https://doi.org/10.1017/S1742170520000344 Published online by Cambridge University Press

such as North America, eroding the resilience of the ecosystems that shape, and are shaped by the agricultural systems embedded within them (Fürst *et al*., 2014; Thompson, 2016; Colla and MacIvor, 2017; Mallinger *et al*., 2017; Valido *et al*., 2019).

The recognition of the importance of wild bees is on the rise at a time when some populations are declining due to a combination of climate change, habitat fragmentation and loss, pathogen spillover from managed bees, competition from non-native species, and agrochemical use (IPBES, 2016; Cameron and Sadd 2020). Although agriculture plays a significant role in pollinator declines mainly through habitat loss and degradation, there is significant evidence that land management practices can enhance local native pollinator communities and play a crucial role in bee conservation (Scheper *et al*., 2013; IPBES, 2016). Pollinator-supporting practices on the farm or orchard can range from actions that benefit a diverse array of wild insect pollinators, such as reduced insecticide use, to habitat enhancements that support particular wild bee communities, such as leaving old stems or dead wood standing on the property. Using multiple pollinator-supporting practices can have synergistic effects producing 'stacked' benefits that yield more than the sum of their parts contributing not only to conservation efforts, but to other valuable ecosystem services such as moderating soil temperature and structure or attracting more beneficial insects, among others (Campbell *et al*., 2017; Eastburn *et al*., 2017; Donkersley, 2019).

Implementing pollinator-supporting land management practices requires grower buy-in, yet few studies have examined how perceptions about wild bees and other factors may influence the uptake of farming practices that support them (see Hanes *et al*., 2015; Gaines-Day and Gratton, 2017; Garbach and Morgan, 2017; Hanes *et al*., 2018; Park *et al*., 2018). These aforementioned studies used grower survey data focusing on fruit growers (blueberry, apple, cherry, and cranberry) in the Midwest and Eastern United States to characterize grower pollination strategies as well as attempt to identify factors that either influence the use of, or willingness to use, pollinator-supporting land management practices. Garbach and Morgan (2017) specifically investigated the influence of one factor (i.e., grower's social network) on the adoption of innovative pollination strategies, two of which can be characterized as land management practices.

This study is the first to survey and characterize the pollination management strategies of Canadian apple growers and their self-reported resourcefulness in farm management for wild bee habitat. We also synthesized and built on the results of recent studies to explore the influence of perception variables and farm characteristics on the likelihood of implementing specific pollinator-supporting actions using regression models. The goals of this research were twofold: (1) to identify areas where technical support and other resources would be best directed to engage growers in native pollinator conservation and (2) help apple growers, and potentially other fruit and vegetable growers, diversify pollination strategies to reduce their reliance on managed pollinators.

Methods

Study system

After blueberries, apples are the second highest valued Canadian fruit crop contributing >$200 million to the national economy and covering over 42,000 acres throughout five provinces (AAFC, 2015). Apple blossoms cannot self-pollinate making animal pollinators critical to the viability of the apple industry. Wild bees such as bumblebees (*Bombus* spp.), mason bees (*Osmia* spp.) and mining bees (*Andrena* spp.) contribute heavily to apple pollination and wild bee abundance and diversity have been shown to increase seed set and fruit set thereby increasing apple production (Matsumoto *et al*., 2009; Mallinger and Gratton, 2015; Martins *et al*., 2015, Blitzer *et al*., 2016; Russo *et al*., 2017).

Honey bees are the dominant pollinator for apple growers, however, despite being only moderately efficient pollinators of apple blossoms (Sapir *et al*., 2017). Beekeepers provide over 15,000 colonies annually to help pollinate Canadian apples and other tree fruit before switching to honey production (Canadian Honey Council, 2018). Other types of bees (e.g., bumblebees) are commercially reared for pollination services but represent the minority when compared with honey bees. Although some apple growers have their own hives or engage in a mutually beneficial arrangement with a beekeeper that does not involve paying for hive rentals, generally apple growers will pay a beekeeper to place one to three hives per acre (~50,000 bees per hive) in their orchard during the spring for apple blossom pollination.

Survey design

In order to support the overall research goals, the main objectives of the survey were to discover the uptake of the unique and overall number of pollinator-supporting practices that Canadian apple growers were already using and the factors that may impact the uptake of these practices. We also hoped to generate a deeper understanding regarding the current pollination management practices of apple growers, how prepared they felt to support wild bees, and how they might utilize networks to help them engage in wild bee conservation on their farm. The data gathered to support the latter objective were descriptive and were not incorporated into the models.

The survey contained 57 questions with response styles including: yes/no, multiple-choice, open-ended, and Likert-style items (Table S1). Questions gathering data intended for the descriptive analysis were focused on: (1) the structure of the growers' agricultural operation (e.g., amount of minimally managed/'natural' area on the farm, farming experience, and apple varieties cultivated), (2) grower pollination management practices (e.g., types, amounts and costs of commercial bees that were rented or purchased) and (3) grower resourcefulness centered on the networks growers used/would use to learn about pollination, improving native bee habitat, and how confident they were if they were to do it on their own.

Model inputs were provided by yes/no questions ascertaining grower use of 15 pollinator-supporting management practices (i.e., dependent variables) and Likert-style questions on perceptions related to wild and managed pollinators (i.e., independent variables). Other predicting variables related to farm characteristics were ascertained through a short answer or yes/no or open-ended survey questions. The variables and overall conceptual model are discussed below in the 'Variables and conceptual model' section. To maximize reliability while assessing perception variables, three to five related Likert-style items with possible responses (*not at all* = 1, *slightly* = 2, *somewhat* = 3, *very much* = 4, *extremely* = 5) were summed to create a Likert scale that represented each variable (see more in the 'Data analysis' section).

Variables and conceptual model

Dependent variables comprised 15 management practices widely accepted to be beneficial to pollinators (Table 1).

https://doi.org/10.1017/S1742170520000344 Published online by Cambridge University Press

We identified seven independent variables including five perception-related variables and two farm characteristic variables (Fig. 1).

Perceived threats to wild bees

Though not pollinator specific, research on pro-environmental behavior on behalf of private landowners in Canada has shown that concern for wildlife and a higher awareness of environmental problems can be motivational factors for engaging in biodiversity-friendly farming or participation in land conservation programs (Banack and Hvenegaard, 2010; Drescher *et al*., 2017). In addition to ascertaining grower knowledge regarding the threats facing wild bees, our 'threats' variable also aimed to gauge the perceived severity of each.

Awareness of wild bees

In a study on barriers to cranberry grower participation in cost-share programs for pollinator conservation, Gaines-Day and Gratton (2017) found that growers ranked knowledge of pollinator habitat as an important consideration on whether they provide habitat enhancements for pollinators on their property. In our study, we included an 'awareness' variable operationalized as a combination of both grower knowledge and interest in native bees and their habitats.

Perceived benefits of wild bees

Previous research has indicated that fruit growers rank the importance of wild native pollinators to their crops as a contributing factor in whether they choose to manage their land for wild bees (Hanes *et al*., 2015; Gaines-Day and Gratton, 2017) and uncertainty about the effectiveness of non-honey bee pollinators is a barrier to actively managing orchards for wild pollinators (Hanes *et al*., 2015; Park *et al*., 2018). Thus, we aimed to include growers' perceived contribution of wild bees to crop yield as an important component of the 'benefits' variable. As another component to 'benefits', we gauged growers' perception of substitutability; even if growers are certain that wild pollinators contribute to crop yield to some degree, they may not protect or create habitat for them if they think that increasing the number of honey bees will produce the same results. Lastly, we considered that the perceived benefits of wild bees may not be limited to crop pollination services but that growers may consider their presence to be a valuable indicator of general farm health.

Perceived costs to improving farm for wild bees

Economic considerations are of paramount importance when growers decide whether to engage in biodiversity-enhancing measures (Siebert *et al*., 2006). Apart from financial limitations, results from prior research indicate that growers face other practical barriers such as perceived time commitment or other problems that might arise from managing farms for pollinators and other wildlife (e.g., increased pest presence on the farm) (Gaines-Day and Gratton, 2017; Park *et al*., 2018). Among Pennsylvania and New York apple growers, Park *et al*. (2018) found that the majority were willing to make changes to increase the abundance and diversity of bees in their orchards but this willingness was, in part, dependent on the financial resources and effort involved.

Tenure status (land rented or owned)

Owning land as opposed to renting has been positively linked to actions related to environmental stewardship that may partially come from a sense of attachment to the land (Walford, 2002; Ryan *et al*., 2003). Thus we hypothesized that owning land may increase the uptake of pollinator-supporting practices as an expression of stewardship and that, in addition, renting land may further discourage practices that yield only long-term returns on investment.

Farm size

Although there are exceptions (Mann, 2005; Siebert *et al*., 2006), larger farm size has been shown to be correlated with participation in nature conservation and biodiversity enhancing measures (Kazenwadel *et al*., 1998; Drake *et al*., 1999; Pavlis *et al*., 2016). The size of landholdings may affect the real or perceived distribution of benefits and costs of implementing certain management practices for growers; for example, the net costs of taking land out of production may be higher for farmers with smaller overall landholdings (assuming all land can be farmed).

Perceived risks of relying on the honey bee industry for pollination

In a study of apple growers in New York and Pennsylvania, Park *et al*. (2018) found that the majority of survey participants perceived declines in honey bees due to colony collapse disorder to be a threat to successful apple production. In a prior study of blueberry growers in Maine, Hanes *et al*. (2015) revealed similar concerns about the volatility of the honey bee industry; growers were worried about the rising cost of renting honey bees, honey bee health, and the availability of honey bees in the near future. Although overwintering honey bee loss rates vary by province in Canada, honey bees, on average, are being lost at rates higher than can easily be restocked but if, or how, these losses have translated into a trend of price hikes for growers requiring pollination services is not known (CAPA, 2019). Heavy honey bee reliance in fruit growers is at least partly a strategy rooted in risk avoidance (Hanes *et al*., 2015) thus perceived risk associated with failing honey bee health, local shortages, and the potential impact of these factors on hive rental prices may drive interest in alternative pollination management strategies.

Given the recent refusal of many of Alberta's beekeepers to travel to pollinate British Columbia's economically important blueberry crops (Flanagan, 2018; Pynn, 2018), we also asked about concern in finding pollination service providers amenable to the grower's current pesticide practices as a measure of perceived vulnerability to increased sensitivity among apiculturists to the potential impact of agrochemicals on their colonies.

Data collection

We collected the data used in this study through an online survey. The survey was incentivized with a gift card to a Canadian coffee chain to minimize bias by encouraging the participation of growers that were not already keen on pollinators and pollination issues. Grower associations distributed the survey to 602 apple-growing members by email and/or newsletter in four Canadian provinces: Ontario, British Columbia, Nova Scotia, and New Brunswick. All potential survey participants farmed apples on a commercial scale. In Ontario, all growers with over 10 acres of apples (generally accepted as the minimum to grow commercially) are required by the province to join the Ontario Apple Growers Association. Thresholds for association membership may also be related to earnings. For example, the Nova Scotia Tree Fruit Growers' Association currently represents 80% of apple growers in the province and

Table 1. Dependent variables: evidence-based pollinator-supporting farm management practices (IPBES 2016)

Practice	Description
Integrated pest management (**IPM**)	Integration of cultural, biological, physical, and chemical tactics to reduce pest populations to tolerable levels while minimizing health, economic, and environmental risk
Leave areas intentionally **undisturbed**	Leaving areas such as marginal and unused lands unmanaged can provide habitat and forage for pollinators, especially through the fall season
Maintain **hedgerow**s	Demarcating boundaries with closely spaced trees or shrubs can provide nectar, pollen sources, and habitat for some bee species
Delay mowing until after bloom time	Mowing techniques and timing can affect available food resources and habitat for pollinators. Although the optimal mowing practice will ultimately depend on the site, delaying mowing until after bloom is a general approach that can provide additional forage
Keep **uncultivated** field **margins**	Buffering fields and orchards with natural spaces can provide habitat and forage for pollinators
Leave **weeds to flower**	Flowering weeds can provide additional nutrition and forage for pollinators
Leave **dead wood**/shrubs standing	Dead wood with bored channels and other hollow spaces can provide habitat for cavity-nesting bees
Plant **flowering trees**/ **shrubs** other than crops	Providing forage other than crops can provide additional nutritional benefits and/or continual nourishment throughout the seasons depending on the bloom time
Keep a vegetable or herb **garden** (or potted garden)	Personal gardens can provide additional and diverse forage for pollinators; staggered bloom times can provide continual nourishment throughout the seasons
Leave **old stems** standing on property	Narrow cavities such as those in old raspberry stems can provide habitat for cavity-nesting bees
Plant **wildflowers**	Wildflowers can provide additional forage for pollinators and continual nourishment throughout the seasons depending on the bloom time
Break up orchards or fields with different types of **habitat**	Varying habitat between orchard or crop rows or between crop types can provide nesting sites and other resources for pollinators close to field crops
Building **nesting sites** (**bee box** or other types of nests)	Proactively creating habitat through building bee boxes and/or creating favorable ground conditions can help cavity-nesting or ground-nesting wild bees
Intercrop	Planting flowering crops in between row crops helps to discourage weeds and can provide forage for pollinators
Farm **organic**ally	Farming using environmentally and animal friendly methods (as governed by organic standards and regulations of Canada) can reduce stress on wild native pollinator populations

Bolded text reflects variable codes in Table 2.

Fig. 1. Conceptual model showing independent variables, survey questions operationalizing them, and their hypothesized influence on the dependent variable.

requires that a grower earn minimum annual gross revenue of $10,000 from the production of tree fruit to join.

Although a sizable industry, Quebec growers were not included in the survey due to resource and time constraints. The Ontario Apple Growers sent members multiple email reminders to complete the survey while the associations in the other provinces sent either one reminder or no reminder.

Data analysis

Survey data were analyzed using Stata version 11.2. Descriptive information regarding the structure of the growers' agricultural operation, pollination management practices, and grower resourcefulness (see the 'Survey design' section) was summarized according to raw numbers and percentages. For the models, principal component factor analysis was used to construct indices

https://doi.org/10.1017/S1742170520000344 Published online by Cambridge University Press

using the conceptual model and Likert-style item responses related to grower perceptions (Tables S3–S7).

A variety of approaches have been proposed to determine the number of factors to retain using eigenvalues, scree-tests, or variance-based thresholds (Costello and Osborne, 2005). All five perception variables we hypothesized to influence the uptake of pollinator-supporting practices resulted in a single factor solution using Kaiser's criterion. We summed individual Likert-style item scores (1–5) for each retained factor/variable to create a new variable that could be measured on a Likert scale. For example, for the variable measuring grower awareness of wild bees, respondents could earn a score from 5 to 25 based on their answers to the five questions that assess grower knowledge of, and interest in, wild bees on their farms. A score of 5 would indicate the grower had no awareness of wild bees and their habitats and a score of 25 would suggest the grower was extremely aware.

To explore the relationships between the variables and the 15 separate pollinator-supporting practices (binary, yes/no data), we used logistic regressions using maximum-likelihood estimation (Table S9). Poisson regression was used to explore the relationship between the factors and the number of pollinator-supporting practices adopted by an individual grower (Table S10).

Summary statistics for all variables used in the models as well as regression coefficients, standard errors, scalar model statistics, and model fit statistics can be found in Tables S3–10. The samples vary slightly across models due to missing data. Since errors were likely to be correlated within the province, we used clustered standard errors to correct for bias.

Results

A total of 75 growers responded to the survey (13% response rate) including 47 growers (63%) located in Ontario. Growers from British Columbia, Nova Scotia, and New Brunswick represented 21, 11 and 5% of the sample, respectively.

Structure of operations, pollination management and pollinator-supporting practices

The average farming experience of the sample population was 30 years and ranged from 2 to 62 years. The average number of years of experience growing apples was 27 years, ranging between 2 and 60 years. Responding growers cultivated 12 different varieties of apples on average ranging from 1 to 42 distinct types. The average acreage farmed by the sample population was 184 acres (a combination of owned and rented land) with a range from one to 4000 acres and a median of 68.5 acres. The average amount of farmed land that could be described as 'natural' land or 'minimally managed' was 17% across respondents. On average, an estimated 29% of the land within a 1 km buffer around the farm was described this way.

The vast majority (78%) of respondents rented honey bees on a seasonal basis and 12% purchased their own honey bees. Eighteen percent of respondents also collected and sold honey. Just under half of the sample (40%) had a resident beekeeper that kept hives on the grower's land for mutual exchange of services. Some growers also used alternative managed bees with 9% of respondents purchasing bumblebees and 12% using another type of commercially available managed bee such as mason bees. Growers using honey bees paid an average price of $71 (CAD) per hive. Only 4% of respondents reported that honey bee prices had raised suddenly for them in the course of the last 10 years; most (72%) have experienced a gradual price increase and 24% reported that prices have held steady. Honey bees appear to be a relatively inelastic good; the mean price at which demand for hives would decrease was $124 (CAD), nearly double the current average cost.

Integrated pest management was the most common practice (99%) and given the lack of variation among survey participants, this dependent variable was dropped from the subsequent analysis. Only 6% of respondents engaged in organic farming making it the least used practice overall. The remaining 14 practices appear to have been adopted by at least one in five growers although notably, planting wildflowers, breaking up orchards with different types of habitats, building bee boxes or other nesting sites, and intercropping were practiced by less than one-third of the respondents. The surveyed Canadian apple growers used between two and 14 pollinator-friendly practices with seven practices being the average (Table 2).

Self-reported resourcefulness on pollinator-supporting actions and pollination management

Nearly 40% of responding survey participants listed their beekeeper or a beekeeping organization as their most trusted source for information on pollination management in general. In response to the statement: 'I am knowledgeable about what actions to take if I wanted to improve wild native bee habitat on my farm', 66% of responding growers reported having no knowledge or only slight knowledge. Approximately a quarter of the remaining respondents were only somewhat knowledgeable about what to do if they wanted to improve their farm for wild bees. Just over half (52%) said they had no or only slight knowledge about where to go to get more information to help them manage their land better for wild pollinators if they wanted to. When asked to provide up to three answers for: 'Where would you go to if you wanted to know more about improving habitat for wild native pollinators on your farm?', 20% of respondents referred to beekeepers, beekeeper associations, or materials about beekeeping and 45% mentioned the government (almost exclusively provincial). The internet (i.e., 'web', 'Google search') was also a popular answer (50%) but it wasn't clear in most cases if growers would target certain websites directly or perform a general search. Eighteen percent mentioned grower associations/organizations and only four growers mentioned specifically that they would consult neighbors or friends.

Variables influencing pollinator-supporting land management practices

We found statistically significant positive associations between the use of pollinator-supporting practices on the farm and three of the perception variables: grower awareness, threats to wild bees, and benefits of wild bees to the farm (Fig. 2, panels A–C, respectively). Although increased scores on each of these variables resulted in a larger number of adopted pollinator-supporting practices, the awareness variable appears to have the greatest impact. Indeed, growers with higher general levels of interest in wild bees and knowledge of their activities on their properties were more likely to adopt eight of the 14 practices for which estimates were available, and adopt a larger number of best practices overall (Fig. 2, panel A). Changes in the awareness variable appeared to contribute to the adoption of an additional six practices, while changes in the threats variable or benefits variable

https://doi.org/10.1017/S1742170520000344 Published online by Cambridge University Press

Table 2. Summary of statistical analysis

Practice	Variable							Frequency
	Awareness	Threats	Benefits	Costs	Risks	Farm size	Rented land	
IPM	n/a	n/a	n/a	n/a	n/a	n/a	n/a	98.6%
Undisturbed								75.3%
Hedgerow								69.1%
Delay mowing								67.1%
Uncultivated margins								66.7%
Weeds to flower								58.9%
Deadwood								58.3%
Flowering trees/shrubs								56.9%
Garden								56.2%
Old stems								46.2%
Wildflowers								30.7%
Habitat								26.9%
Bee box/nesting sites								23.6%
Intercrop								21.1%
Organic								5.6%
Sum positive	8	2	6	1	3	1	2	
Sum negative	0	3	1	3	1	2	4	
Total # practices								7.71 (average)

This table summarizes the results from 16 models examining the impacts of variables on the likelihood of adopting 15 distinct management practices or the total number of practices. A gray box indicates that the variable had a positive, statistically significant association ($P < 0.10$) and a black box indicates a statistically negative association ($P < 0.10$). A white box indicates no association. The value 'n/a' indicates any variable dropped from the analysis due to a lack of variation among survey participants. 'Sum' boxes present a count of logistic models in which the column variable had a statistically significant positive or negative association with adoption. The frequency column reports the percentage of respondents adopting each practice and the average number of practices adopted is listed last. See Table 1 for practice descriptions.

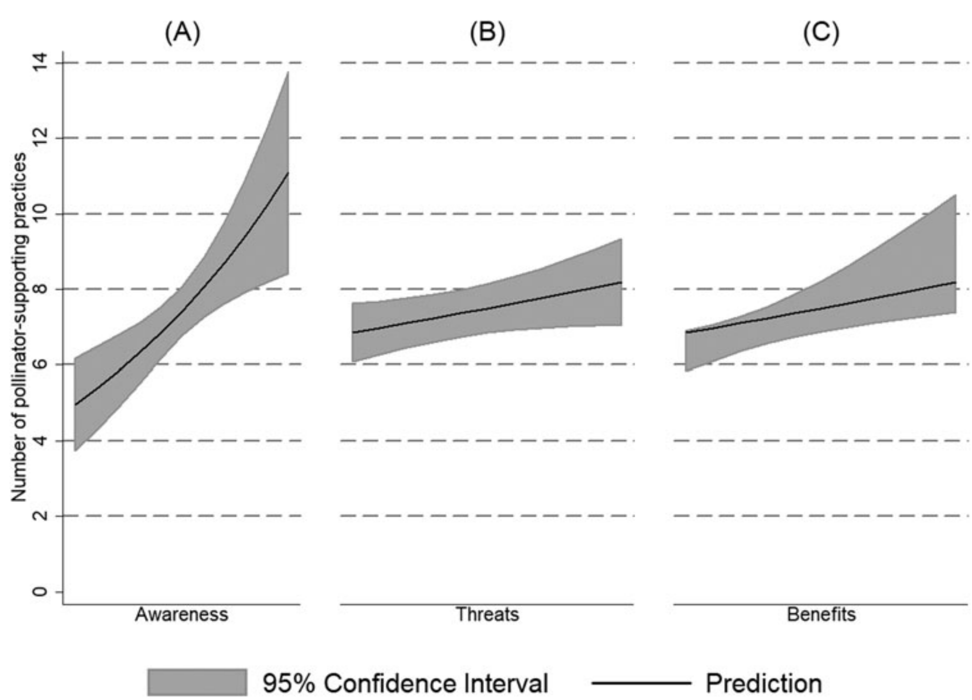

Fig. 2. The number of pollinator-supporting land management practices adopted by growers (y-axis) by scores on perception indices (x-axis). Other values held at their respective sample means.

https://doi.org/10.1017/S1742170520000344 Published online by Cambridge University Press

resulted in the adoption of one additional practice and three, respectively (Fig. 2, panels A–C). Overall, growers were less likely to adopt specific pollinator-supporting practices as the fraction of rented land increased and as the perceived costs of implementing these practices rose (Table 2).

With the notable exception of the awareness variable, the direction of statistically significant coefficients varied across unique management practices. For example, increasing grower awareness had a uniformly positive impact on the likelihood of adopting eight unique pollinator-supporting land management practices (Fig. 3, panel A). However, an increased score on the perceived threats variable increased the likelihood of adopting some practices and decreased the likelihood of adopting others; growers were more likely to plant wildflowers or plant flowering trees and shrubs other than crops but less likely to plant a garden, leave old stems standing in the field, or use organic farming practices (Fig. 3, panel B). In another example, growers more concerned with the time, money, and other problems associated with the uptake pollinator-supporting practices (i.e., cost variable) were less likely to plant wildflowers, create bee boxes or nesting sites, or to delay mowing until after bloom times. They were, however, more likely to leave old stems remaining on their property (Fig. 3, panel C). Respondents were invited to qualify any concerns around other problems that may arise if they were to better manage their land for native bees (Table S1, Q40). Growers mentioned a variety of obstacles ranging from a fear of bees or attracting other insects and foraging animals that would, in turn, require management. Changes in the fraction of rented land also yielded mixed trends. As growers increased their fraction of rented land, they were more likely to leave dead wood standing or create bee boxes or nesting sites but less likely to plant a garden or cultivate flowering trees and shrubs other than crops (Fig. 3, panel D).

Discussion

Our results suggest that there are important socio-cultural components driving the adoption of pollinator conservation management practices. Our findings that the overall likelihood of adopting pollinator conservation practices declines with an increase in the perceived costs of implementing these practices and rises with an increase of the perceived benefits of wild bees empirically corroborated results from past researchthat questionined fruit growers about their pollinator-friendly practices and barriers to conservation action (see Gaines-Day and Gratton, 2017; Park *et al*., 2018). The increase in the number of overall practices with the increase of perceived benefits is also consistent with past research showing blueberry growers take more conservation actions if they rank wild bees as 'important' or 'very important' to the blueberry industry in general (Hanes *et al*., 2015).

The positive relationship between our grower 'awareness' variable and the number of pollinator-supporting practices also agrees with findings that established knowledge of pollinator habitat to be an influencing factor on whether cranberry growers provided habitat enhancements on their property (see Gaines-Day and Gratton, 2017). In fact, our results suggest that awareness may be one of the most important factors in terms of encouraging sheer numbers of pollinator-supporting practices on the farm. Growers who considered threats facing wild bees to be high also appear to adopt more pollinator-supporting practices when compared to the average. This suggests that research documenting a positive impact of increased awareness of environmental problems on pro-environmental land management (see Banack and Hvenegaard, 2010; Drescher *et al*., 2017) may be extended to pollinator-supporting farming specifically.

The varying trends for individual management practices likely implicate cost–benefit evaluations that may be complex and unique to the grower's business model and/or physical features of the farm. The logic behind some trends may be reasonably surmised. For example, growers with a high fraction of rented land may be less likely to plant flowering trees and shrubs other than crops due to a reluctance to make investments that yield returns over a long time horizon. It is also logical that as growers' concern about the time and money involved increases, they would be less likely to build bee boxes, create nesting sites, or plant wildflowers. Interpreting other trends is more speculative. For example, growers scoring highly on the cost variable were less likely to delay mowing until after bloom times. This could be related to the potential of delayed mowing to attract pests to the property. It is unclear why growers with a higher fraction of rented land appear more likely to build nesting sites, including bee boxes. Further research is needed on the factors that motivate specific practices to shed light on the complex thought process that goes into decision-making on the ground.

Before making recommendations beyond calling for more empirical research about what motivates growers to engage in certain practices, it is important to note the limitations of our study. First, omitting Quebec's apple growers and the small sample size could impact the generalizability of our results. Secondly, due to the sampling of respondents at one point in time, it is possible that decisions to adopt, and experience with, pollinator-supporting practices might enhance the knowledge of respondents and influence perceptions of the benefits and costs of adopting them. For instance, certain practices such as leaving old stems as habitat might require growers to invest in developing a better understanding of the nesting activities of certain species of wild bees on their properties, while adopters might perceive greater benefits from wild bees due to their experience and/or confirmation bias. Nonetheless, this exploratory study provides potentially important insights for stakeholders interested in promoting pollinator diversification strategies and pollinator-supporting behavior on apple orchards.

Our results suggest that programs, policies and outreach targeting growers should be focused on two main areas. First, emphasis should be placed on educating growers about wild bees, the threats they face, and the benefits they provide to both the ecosystems that support their farm as a whole and to their apple production.

Secondly, opportunities exist to target 'low-hanging fruit', i.e., pollinator-supporting land management practices that are currently adopted by less than one-third of responding growers. Many growers already engage in practices, such as keeping hedgerows, that help them manage more pressing issues than pollinators (e.g., soil quality) and provide multiple benefits (Zhang *et al*., 2018). Some of the practices more infrequently implemented by the growers that we sampled are likely the result of more complex cost–benefit analyses in which managing for pollinators is also not likely a major consideration in the decision-making process (e.g., organic farming, intercropping) and increasing the uptake of these practices may also have to address systemic factors that influence these choices. However, creating nesting sites and planting wildflowers are relatively straightforward and simple ways to support pollinators but as shown in Table 2, are infrequently utilized compared to many other practices (24 and 31% of respondents, respectively). The relatively low level of adoption

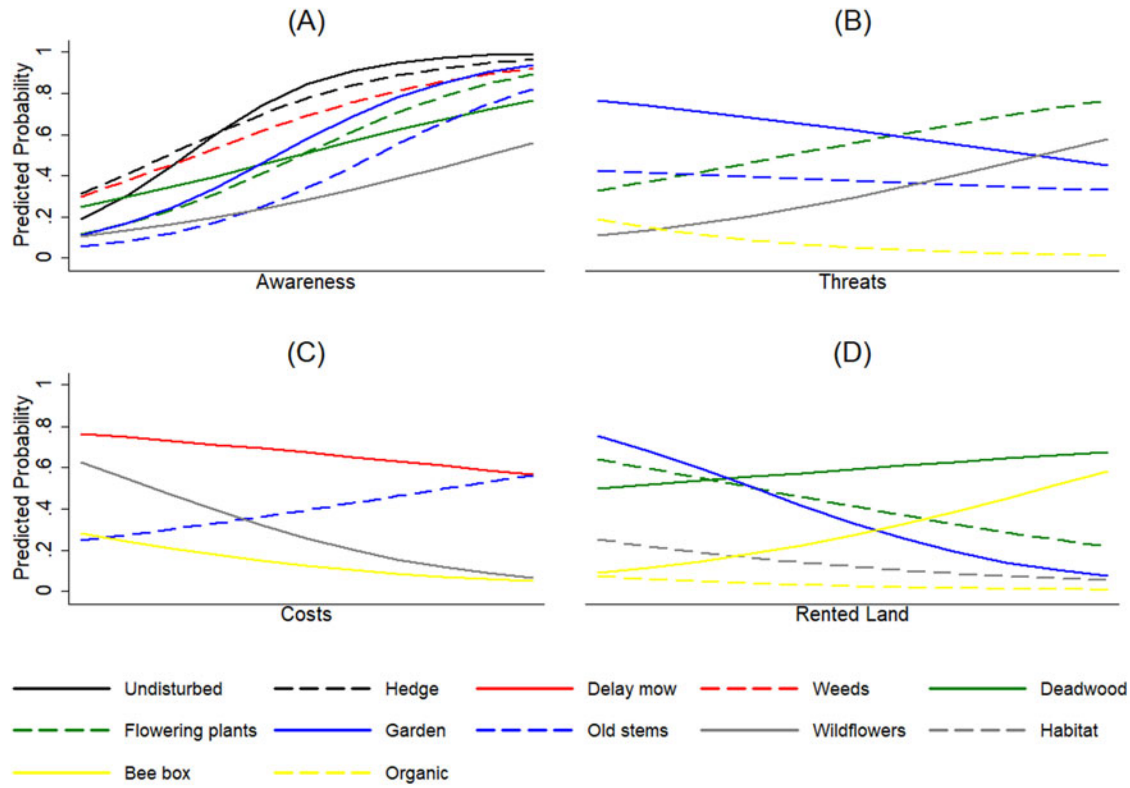

Fig. 3. The predicted probability of adopting pollinator-supporting land management practices for select variables (*y*-axis) by scores on perception indices or fraction of rented land (*x*-axis). Only statistically significant coefficients are shown. Other values are held at respective sample means. See Table S9 for results across all independent variables.

of these practices is similar to results from Hanes *et al.* (2015) that found 22% of responding blueberry growers built nesting boxes and only 14% planted wildflowers. Our results suggest that increasing the uptake of these particular practices could be positively affected by increasing awareness, grower perception of the benefits of wild bees and/or addressing perceived costs to implementation. Educating growers about the threats impacting wild bees may also be useful since growers scoring higher on this index were more likely to plant wildflowers and flowering shrubs and trees other than crops.

Although incentives or subsidies for practices that focus on wild pollinator health should be encouraged (built into existing federal programs that support biodiversity-friendly practices in Canadian agriculture, such as the Habitat Stewardship Program and the Species at Risk Partnerships on Agricultural Lands, for example), given that the majority of responding growers had very little or no knowledge about actions to take or where to get information to improve wild bee habitat, growers may not be able to accurately evaluate the true opportunity costs involved with both simple actions (e.g., creating nesting sites) or more complex ones that may help or harm pollinators unbeknownst to the growers (e.g., delayed mowing). Similarly, other barriers to action may be based on a lack of or incorrect information. For example, in response to a question prompting growers to list other problems that may arise if they were to better manage their land for wild bees, several respondents mentioned fears such as bee 'swarms' or having workers stung even though many wild native bees do not sting and/or are not aggressive and none swarm (Michener, 2000; Danforth *et al.*, 2019). Working with growers to efface these knowledge barriers (in addition to emphasizing the benefits of wild pollinators) may change how growers evaluate the resources they are willing to invest in certain pollinator-supporting practices.

There are avenues that could be leveraged to raise grower awareness of, and appreciation for, native pollinators and the actions that support them. In turn, growers would be equipped to engage in cost–benefit analyses with more complete information. For example, even though extension services in Canada have moved away from providing in-person interaction with growers over the last couple of decades (Milburn *et al.*, 2010), they could still play a role.

First, publishing open access information about the positive contributions of native pollinators and tying benefits to recommendations for other ecological 'best practices' that address issues of larger concern to growers may be useful. Secondly, well-crafted and straightforward educational materials such as factsheets and web-based information may positively impact the knowledge mobilization and implementation of pollinator-supporting land management practices; indeed, research has shown that access to clear guidelines is one of the most important factors in influencing growers to actively manage orchards for wild native bees (Park *et al.*, 2018). Canadian provincial agricultural ministries can do much better in this area; for example in Ontario, the provincial Ministry of Agriculture, Food and Rural Affairs website contains only one page dedicated to pollinator health and has no staff with wild bee expertise. The webpage (http://www.omafra.gov.on.ca/english/pollinator/info-crops.htm) is almost exclusively focused on pesticides with some general bullet points on habitat enhancements. There are no links to further information or more detailed guidelines to aid a grower wanting to diversify

https://doi.org/10.1017/S1742170520000344 Published online by Cambridge University Press

their pollination strategies in a way that is right for their business. This is a missed opportunity, given almost half of responding growers mentioned they would seek out government resources for information if they wanted to know more about how to improve wild bee habitat on their farm.

Online or factsheet-type resources may only go so far; however, other research has suggested that 'one-way' educational materials are less likely to change grower behavior than a mutual exchange of information such as in-person training or discussions (Milburn *et al.*, 2010). Research extension or outreach activities could focus on interactive bee surveys, bee identification and tracking along with educational opportunities like walk-throughs to point out possible wild bee foraging resources and nesting sites on the property. Helping growers monitor bees on the farm could also encourage conservation actions by reducing the uncertainty related to the contribution of wild pollinators to their crops (Hanes *et al.*, 2015, 2018). Canadian universities should also consider adopting extension programs similar to those in the USA, where researchers can dedicate time to knowledge transfer.

This study demonstrates the importance of grower education in encouraging pollinator-supporting actions on the farm. This education encompasses fostering awareness about wild bees, the benefits they offer, the threats facing them, and access to information that will help growers create habitat in inexpensive and easy ways. Increasing awareness seems to be especially important as it leads to an adoption of the most number of pollinator-supporting practices thus providing 'stacked' ecosystem services for the grower. Open questions remain about how our results may apply to other growers that could benefit significantly from an increased presence of wild pollinators. In addition to socio-economic and socio-cultural factors, a deeper understanding of grower perceptions of wild bees will provide essential insight into how to help to promote pollinator diversification strategies to meet the goals of increased biodiversity, ensured food security, and reduced grower vulnerability borne of heavy reliance on managed pollinators.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170520000344.

Acknowledgement. This research was funded by the Weston Family Foundation.

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