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Toward a wild pollinator strategy for Canada: expert-recommended solutions and policy levers

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Abstract

Invertebrate pollinators are in trouble: particularly documented are declines among bees and butterflies. Interacting stressors include pesticides, pathogens, habitat loss, nonnative species, and climate change. Many governments have strategies to reduce negative pressures on pollinators, but Canada does not despite widespread public interest in pollinator health. This study serves as a needs assessment for science-based policy solutions for wild pollinator conservation in Canada. We designed a Policy Delphi survey technique to identify solutions that experts deem both desirable and feasible. Our secondary aim was to identify research priorities that would inform the implementation of these solutions. Sixty % of the 83 unique solutions were supported and feasible at a high consensus level (10% were "strongly" supported and "definitely" feasible). General themes included improving the Canadian government's approach in assessing pesticide risk to pollinators, curbing pathogen spillover/spillback between managed and wild pollinators, and reducing the reliance of Canadian agricultural systems on pesticides, among others. We discuss solutions in reference to pollinator conservation policies recommended by the broader scientific community and identify policy levers within the context of Canada's highly decentralized approach to biodiversity conservation/management and a political economy that uses high numbers of managed, mostly nonnative bees for pollination services.

Key words: bee conservation plan, science-based biodiversity

Introduction

Invertebrate pollinators are in trouble: particularly documented among the best studied taxa are bees and butterflies (IPBES 2016; Kopec and Burd 2017; Forister et al. 2019). Pollinator declines are alarming, not only because pollinators possess intrinsic value but they are bellwethers for the integrity of ecological communities (Kevan 1999). Flowering plants have coevolved with pollinators and pollination is essential for almost all of them (Ollerton et al. 2011). Disruptions in this process between plants and pollinators undermine the stability of terrestrial ecosystems and the ecosystem services that are essential for the perseverance of life on earth, including our own species (Aizen et al. 2009). Globally, 70% of the major flowering crop plants that produce our food depend on animal pollination (Klein et al. 2007). Thus, pollinators are vital for food security and are of economic importance; pollination services for food crops are estimated to comprise an annual global market value worth hundreds of billions of USD (IPBES 2016).

Pollinator declines are due to a multitude of converging pressures including disease caused by pathogens (i.e., bacteria, protozoa, mites, viruses, and fungi), habitat loss, pesticides, climate change, and invasive species (Kearns et al. 1998; Potts et al. 2010; Colla 2016). These stressors can also interact, compounding challenges for pollinators (Vanbergen 2013). While there continue to be knowledge gaps about stressors and species-specific conservation assessments, we know enough about the problem and attendant solutions to act with sound conservation policy.

With no international agreements that specifically address what Forister et al. (2019) call the "multicontinental crisis" of pollinator declines, national and subnational governments are adopting their own policies to target pollinator declines (Hall and Steiner 2019). These policies include stand-alone legislation or top-down frameworks that coordinate subnational actions to address pressures on pollinators and sometimes contain measurable targets. Over the last decade, numerous countries have adopted national strategies, plans, or initiatives to specifically protect pollinators, including Belgium, Spain, Norway, the Netherlands, France, Mexico, Ireland, Colombia, Nigeria, and the US. The UK has also issued a strategy that coordinates pollinator conservation actions across England, Scotland, Wales, and N. Ireland, some of which also have their own strategies. To date, at least 32 US states have developed subnational pollinator plans with more plans in development (US EPA OIG 2019).

Canada does not have a strategy nor does it have adequate protective legislation to support pollinator conservation (Tang et al. 2007). At the time of this publication, there are no Canadian provinces or territories with pollinator plans. In 2015, Ontario implemented their Pollinator Health Strategy but it was short-lived despite being strongly supported by the public; the province's ruling party canceled it less than 2 years after it was adopted with nothing to replace it (Nicholls et al. 2020; Officer of the Auditor General Ontario 2020). There is intense interest from the public and civil society for strong leadership and a sweeping coordinated government response to protect Canada's pollinators (Nicholls et al. 2020; van Vierssen Trip et al. 2020; GBC 2021).

If a national pollinator conservation strategy for Canada is imminent, what actions should be prioritized and can barriers to those actions be anticipated? How should it be structured and duties delegated? Though needed to advise policy-makers about potentially successful designs and implementation approaches, there are currently very few empirical studies comparing insect pollinator policies or analyzing the degree to which these policies are evidence based or informed by science (Hall and Steiner 2019; Stack-Whitney and Burt-Singer 2021). The development of a Canadian strategy could be informed by current national frameworks by taking stock of the "lessons learned" and course changes that have come about as a result of interim evaluations, audits, and the couple of analyses of active strategies or action plans that do exist (see Underwood et al. 2017; US EPA OIG 2019; Stack-Whitney and Burt-Singer 2021). However, the political ecology of pollinator decline (and biodiversity loss in general) in Canada differs from other countries in key ways that should inform not only the content of a pollinator strategy but also how it should be implemented if it is to serve as a scientifically sound and sustainable conservation strategy.

First, a conservation strategy needs to centre the health of wild, native pollinator communities. In North America, many national policies, US state plans, and Ontario's defunct provincial plan focus mainly on European honey bee health (Colla and MacIvor 2017; Hall and Steiner 2019). While some actions targeting honey bees and beekeeping can be interpreted as conservation in regions in other continents where the honey bee is native, in North America honey bees were and continue to be imported to pollinate field crops and produce honey. They did not evolve within native flora and fauna and are thus not essential for ecosystem functioning and in many cases less efficient than wild pollinators at pollinating crops and wild plants (Breeze et al. 2011; Garibaldi et al. 2013).

Honey bee health is important, but some have argued that focus on the honey bee in places like North America and Australia where the honey bee is not native has, in essence, provided domestic livestock with plans that the public conflates with species conservation, siphons resources, and monopolizes media attention away from native pollinators, some of which are actually in great peril and others in decline (Nicholls et al. 2020; Ford et al. 2021). Although some actions that help honey bees can also support wild pollinators, broad-scale policies and resources directed toward honey bee management are not necessarily protective of wild pollinators and can, without discernment, actually harm them (Colla and MacIvor 2017; Geldmann and González-Varo 2018; Ford et al. 2021).

The success of a strategy that endorses science-based solutions for native pollinators hinges on the ability of those solutions to be implemented. Canada faces unique challenges enacting robust biodiversity conservation due to a system of governance that is defined by an anomalous degree of decentralized authority exacted by provinces/territories over natural assets and resources (Ray et al. 2021). The Canadian federation's orientation around protecting systems that enable natural resource extraction can result in a conflict of interest within and between jurisdictions (Cairns 1992). There is no evidence of an integrated approach to biodiversity protection that is enacted through a "bewildering" array of policy instruments administered by different levels (federal, provincial/territorial, municipal) of government (Ray et al. 2021). This fragmentation may complicate the ability to coordinate the multiscale, multisector actions needed to achieve national conservation goals (Buxton et al. 2021). Underlying our research is the assumption that overall success implementing science-based solutions depends a great deal on understanding how and where to exact policy levers in existing governance structures.

The goal of our study was to provide, in essence, a needs assessment to support the development and adoption of science-based policy solutions for wild pollinators in Canada. By surveying experts on the desirability and feasibility of conservation actions generated within the study group as well as on research priorities to support native pollinator conservation policy, we aim to identify both opportunities for immediate action and hindrances or knowledge gaps that may impede it. We anticipate that many desired solutions will echo those already supported within the larger scientific community. Relying on the opinions of Canadian-based experts or those with professional reach in Canada, we aim to shed light on important issues germane to conservation in this country including the tension and synergies between managing for commercial bees and wild pollinators and how to reconcile the urgent need for large-scale, coordinated changes in a policy landscape shaped by weak federal leadership.

Methods

The main objectives of this study were to identify and evaluate expert-generated solutions for wild pollinator conservation in Canada that were considered highly desirable and considered feasible to implement according to the surveyed group. Our secondary aim was to identify research priorities that would support these solutions. We designed and administered a Policy Delphi to facilitate experts in the generation of these solutions as well as in an anonymous evaluation of the solutions suggested by their peers.

Delphi technique

The Delphi technique is a primary research method that gathers and distills expert opinions on a complex topic through a structured group communication process (Hasson et al. 2000). A common administration of a Delphi is characterized by a series of survey iterations with controlled feedback via the principal investigator to find points of consensus and/or dissensus among participants on the given subject using a statistical estimator of group opinion

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(Dalkey 1969). The Delphi technique is especially useful where absolute or quantitative answers are elusive and/or the goal is to develop a deeper understanding of an issue and identify potential solutions (Mitroff and Turoff 1975). The anonymity of the process is considered a strength of the method since it allows the participants to share their ideas without fear of judgment and can mitigate the influence of unequal power dynamics (Dalkey and Rourke 1972; Frewer et al. 2011). A Delphi technique is also practical in that it costs little and allows for the inclusion of geographically dispersed participants, the latter an important consideration given the national scope of the project.

Several Delphi subtypes have been applied to ecology and conservation problems (Mukherjee et al. 2015). One of these subtypes, Policy Delphi, focuses on generating or assessing implemented solutions to complex socioecological challenges (Mukherjee et al. 2015). Delphis applied to generate solutions to such challenges have been pioneered in the fields of protected areas management in regard to climate change adaptation options in Ontario, Canada (Lemieux and Scott 2011), as well as agricultural policy to reduce phosphorus loading in the Lake Erie Basin (Lee 2019).

Participants

The optimal number of Delphi participants is between 10 and 50 (Turoff 1970). We selected 32 participants with the capability of offering diverse expert viewpoints on the topic of pollinators and/or issues closely related to pollinator health using "cascade" methodology. Otherwise known as snowball sampling, this methodology relies on personal researcher contacts or members of an existing professional network to recommend other possible participants and seems to lessen attrition in subsequent Delphi rounds (Frewer et al. 2011), a noted liability with Delphi research in general (Fletcher and Marchildon 2014). Participants represented deep professional experience in one or more of the following areas: genetics, citizen/community science, pollinator health and diseases, genomics, landscape ecology, at-risk pollinator conservation, taxonomy, pollination ecology, agro-ecology, land management, and toxicology. In addition to professional expertise, geographic, sociocultural, and organizational diversity was highly prioritized in the panel selection process. The majority of participants were focused primarily on pollinator research (basic or applied) or policy where pollinator health was a relevant aspect of their work. Most had posts in academia or the government (federal or provincial) with a smaller subset based in nonprofit organizations or industry with reach in both the US and Canada. Whatever their professional locus, many participants contributed to pollinator science and conservation in multiple ways spanning policy advocacy, program design/delivery and outreach.

Survey design, implementation, and data analysis

We gathered data in two distinct rounds of online surveys that conformed to the standards of the Canadian Tri-Council Research Ethics guidelines and were approved by York University's Ethics Review Board. Surveys were designed and implemented through Survey Monkey. Round Two was administered in two parts given the sheer amount of unique solutions generated in Round One that subsequently needed to be synthesized and evaluated by participants. In total, three surveys were emailed to the participants between November 2019 and January 2021. Participants provided written, informed consent and ongoing consent prior to completing each survey. Respondents were given approximately 3 weeks to complete the survey and were provided with two email reminders.

Round One

The first round of the Delphi process traditionally begins with an open-ended questionnaire as the wellspring of content on a specific topic (Custer et al. 1999). We organized our survey around five stressors widely accepted to be contributing to pollinator declines globally including pesticides, habitat loss/fragmentation, pathogens, nonnative species, and climate change (IPBES 2016; Dicks et al. 2021). For each stressor, we asked each of the participants to list up to three policies, regulations, or financial tools as well as up to three programs/initiatives that, if adopted, might contribute to reducing stress on Canada's wild pollinators. We clarified that entries could include improvements on existing government, nongovernmental organization, or industry programs/initiatives or suggestions for new ones. For each stressor category, we also asked participants to identify up to three pressing research gaps that, if addressed, may contribute to reducing the stress of that particular stressor on Canada's native pollinators. The maximum potential contribution of each participant in Round One was 45 entries but we informed participants that they could skip any stressor category or question depending on their self-assessed expertise.

We performed a thematic analysis to organize unique suggestions and to synthesize closely related suggestions. We used NVIVO 12 to perform a hybrid of deductive and inductive coding to establish broader categories. The inductive coding process was driven by grounded theory that prompts the investigator to use the data itself to generate codes (Boyatzis 1998). This approach is especially useful in exploratory concepts where innovative ideas might be expected (Fletcher and Marchildon 2014). On the other hand, deductive coding is characterized by using pre-established concepts drawn from literature or theory (Crabtree and Miller 1999). In our analysis, deductive coding was also a useful approach since we expected particular themes to come up in the data given the amount of existing pollinator conservation plans, burgeoning literature, and comprehensive treatment of global pollinator decline in reports issued by international organizations (see IPBES 2016). For example, supporting "agricultural best management practices" was expected to be a frequently suggested solution to reduce stress on pollinators in the category of habitat loss based on current literature and broadly sanctioned recommendations.

When analyzing entries in Round One, suggestions for policy, regulation and financial tools were merged and coded together with program/initiative suggestions because there was not enough distinction between these in terms of the responses. Very few respondents referred to specific existing programs and often conflated policies and programming or regulation and programming (e.g., "programs to mandate use of native plants in restoration and habitat creation"). The confusion was understandable, especially in the conflation between programs and financial tools since programs are often created or tasked to deliver financial incentives (e.g., Ontario's Species at Risk Farm Incentive Program).

In preparation for Round Two, climate change was dropped as a stressor category. Other than broad policy suggestions to mitigate warming such as "reduce fossil fuel use", suggestions for solutions that related the issue specifically to pollinators (outside of the context of research) were lacking. However, participant-identified research gaps were retained and coded into themes (S2).

After coding, we synthesized entries into condensed statements for participants to evaluate in Round Two. We generally synthesized prioritizing the specific over the general; to use the previous example, we expected most, if not all, participants to "support agricultural best management practices". In this case, we retained suggestions that mentioned the mechanism of support or type of practice (e.g., agricultural extension) and omitted the vague, less descriptive statement. However, we kept general statements that were unique and inductively coded (i.e., not theory driven). For example, the solution "support native seed stock" was passed onto Round Two noting to participants that the type of "support" was not qualified. Participant-identified research gaps were not passed to Round Two for participant evaluation.

Round Two

In the second round, we distributed the synthesized solutions to participants to perform a guided, anonymous evaluation process using Likert scales. Thirty-five synthesized solutions for the pesticides stressor category were distributed first followed by a second survey with solutions for habitat loss (19), pathogens (18), and nonnative species (11) (Supplementary Material 1).

We asked participants to rate the desirability for the solutions on a four-point scale using descriptors from "Strongly Support" to "Strongly Oppose" as well as their opinion on the solution's feasibility from "Definitely Feasible" to "Definitely Infeasible" (Turoff 1970; Lee 2019). Feasibility was qualified to mean any barrier that may affect the likelihood of adoption or implementation including, but not limited to, resource limitations, technological challenges, political willpower, critical knowledge gaps, and other hurdles. No neutral option was provided to avoid participants defaulting to neutral out of indecisiveness or in the case they did not have enough information (in which case they should skip it) (de Loë 1995). We prompted participants to provide qualitative justifications for their support and feasibility ratings for at least three of their choices per stressor category to gather context and illuminate the thought processes underlying participant choices. Participants were instructed to prioritize commenting on statements that were of high priority and/or those the participant felt strongly about (for or against). As with Round One, we invited participants to skip any statements that they felt insufficiently informed to evaluate.

We analyzed the data as described in Table 1 to find the solutions that reached a level of consensus (high–low) and if there was a consensus, where the point of agreement was found on the respective rating scales for support and feasibility. A common approach used to analyze ratings generated by the Delphi technique uses descriptive statistics of central tendency, the spread of distribution, and the level of dispersion (standard deviation and interquartile range) (Hasson et al. 2000). We adopted an analysis developed by de Loë (1995) that is more sensitive and especially illuminating in the cases where the group exhibits polarity (i.e., split opinion) on a particular idea (Table 1).

If considering responses from two contiguous categories moved the consensus up a level or levels (e.g., from medium to high, or low to medium or high), the consensus was recorded as spanning two points on the scale. For example, as shown in Table 2, if a solution was found to be "Somewhat Feasible" at a low consensus level and considering the contiguous "Definitely Feasible" responses moved the consensus level to high, the solution was recorded as high consensus and the point of consensus recorded as "Definitely Feasible to Somewhat Feasible" (DF-SF).

Results

Survey results shed light on the most desirable and feasible actions within each stressor category to help protect native pollinators in Canada. We present high consensus solutions that are either "Strongly Supported" (SS) or supported (SS-WS) as well as select feasibility rating justifications to provide a deeper understanding around perceived challenges in implementing some of those solutions in a Canadian context. We also present research gaps that, if addressed, will contribute to reducing the stress on Canada's native pollinators according to Delphi participants. The response rate for Round One was 84%. In Round Two, the response rate was 59% (evaluating pesticide solutions) and 38% (evaluating pathogens, habitat loss, and nonnative species).

Overall solutions results

The consensus level and point-of-consensus matrices for the 83 total native pollinator conservation solutions are shown in Tables 3*a* (support) and 3*b* (feasibility). Overall, participants showed a high consensus of support for the vast majority (90%) of the solutions presented by their peers (Table 3*a*).

Almost half of the solutions reached a high consensus level of support by combining "Strongly Support" and "Weakly Support" categories (45.8%) and 42.2% were rated "Strongly Support" at a high consensus level (Table 3*a*). Overall, no solutions were "Weakly Opposed" or "Strongly Opposed" at any consensus level. Despite high support, participants were generally less optimistic about the feasibility of implementing solutions. Participants perceived 48.2% of the solutions to be

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Table 1. Delphi analysis methods, Round Two (adapted from Lee 2019).

Unit of analysis	Definition	Categories
Consensus	Measure of the degree to which the panel agreed on the desirability or feasibility of a proposed solution	**High**: 70% of ratings in one category or 80% in two contiguous categories **Medium**: 60% of ratings in one category or 70% in two contiguous categories **Low**: 50% of ratings in one category or 60% in two contiguous categories **None**: <60% of ratings in two contiguous categories **Ambiguous**: Consensus split among categories
Point of consensus	Indicates where the consensus opinion fell on the support rating scale (if any consensus existed)	• **Strongly Support (SS)** • **Strongly Support-Weakly Support (SS-WS)** • **Weakly Support (WS)** • **Weakly Support-Weakly Oppose (WS-WO)** • **Weakly Oppose (WO)** • **Strongly Oppose-Weakly Oppose (SO-WO)** • **Strongly Oppose (SO)**
	Indicates where the consensus opinion fell on the feasibility rating scale (if any consensus existed)	• **Definitely Feasible (DF)** • **Definitely Feasible-Somewhat Feasible (DF-SF)** • **Somewhat Feasible (SF)** • **Somewhat Feasible-Somewhat Infeasible (SF-SI)** • **Somewhat Infeasible (SI)** • **Definitely Infeasible-Somewhat Infeasible (DI-SI)** • **Definitely Infeasible (DI)**
Polarity	Variance of the distribution	Strong $\geq$ 1.5 Weak $\geq$ 1.2 and < 1.5 None < 1.2

Table 2. Example solution: Solution (S23): "Develop a national Integrated Pest Management Program".

	Strongly Support	Weakly Support	Weakly Oppose	Strongly Oppose	Consensus level	Point of consensus
Support:						
Responses	13	2	2	0	High	Strongly Supported (SS)
% w/opinion	76.4%	11.8%	11.8%	0%		
	Definitely Feasible	Somewhat Feasible	Somewhat Infeasible	Definitely Infeasible	Consensus level	Point of consensus
Feasibility:						
Responses	6	9	2	0	High	Feasible (DF-SF)
% w/opinion	35.3%	52.9%	11.8%	0%		

Table 3a. Consensus and support point-of-consensus matrix for 83 native pollinator conservation solutions.

	Strongly Support	SS-WS	Weakly Support	WS-WO	Weakly Oppose	WO-SO	Strongly Oppose	Ambiguous	None	Total
Consensus										
High	42.2%	45.8%	2.4%	0.0%	0.0%	0.0%	0.0%			90.4%
Med	0.0%	3.6%	0.0%	0.0%	0.0%	0.0%	0.0%			3.6%
Low	0.0%	0.0%	0.0%	2.4%	0.0%	0.0%	0.0%			2.4%
Ambiguous								2.4%		2.4%
None									1.2%	1.2%
Total	42.2%	49.4%	2.4%	2.4%	0.0%	0.0%	0.0%	2.4%	1.2%	100.0%

feasible (DF-SF) at a high consensus level and less than 10% considered to be "Definitely Feasible" (Table 3*b*). There was almost no polarization among participants. Participants were weakly polarized on the feasibility of the solution, "Require labeling of produce with names of pesticides used" (and borderline weakly polarized in their support).

Despite experts generally having less optimism in the feasibility of the solutions than their support for them, about

Table 3b. Consensus and feasibility point-of-consensus matrix for 83 native pollinator conservation solutions.

	Definitely Feasible	DF-SF	Somewhat Feasible	SF-SI	Somewhat Infeasible	SI-DI	Definitely Infeasible	Ambiguous	None	Total
Consensus										
High	9.7%	48.2%	3.6%	3.6%	1.2%	0.0%	0.0%			66.3%
Med	0.0%	14.5%	2.4%	3.6%	0.0%	0.0%	0.0%			20.5%
Low	0.0%	1.2%	1.2%	2.4%	0.0%	0.0%	0.0%			4.8%
Ambiguous								7.2%		7.2.%
None									1.2%	1.2%
Total	9.7%	63.9%	7.2%	9.6%	1.2%	0.0%	0.0%	7.2%	1.2%	100.0%

half were still considered to be supported (i.e., high consensus at the point of WS or spanning SS-WS) and feasible (high consensus at the point of SF or spanning DF-SF) (Fig. 1). A smaller subset (~10%) of solutions reached a high consensus level for "Strongly Support" and "Definitely Feasible" (Fig. 1). Approximately one-quarter of the solutions were supported but reached a low or medium consensus in terms of feasibility, or their feasibility was in question (i.e., the point of consensus spanned the categories of SF-SI) (Fig. 1). Another approximately 11% of the solutions were either ambiguous or reached no consensus for either support or feasibility. The remainder (labeled "Other" in Fig. 1) consisted of solutions that were a combination of medium consensus support and feasibility, or those that had questionable support (WS-SO).

The reader can assume any feasibility ratings discussed from this point on to have reached high consensus unless stated otherwise.

Results for individual stressors

Pesticides

Almost 90% of the 35 participant-rated solutions to ameliorate the negative impacts of pesticides on native pollinators were "Strongly Supported" (SS) or supported (SS-WS) (Fig. 2). The average response rate was 87% across solutions. Participants provided 290 justifications for their rankings; eight was the average number of justifications provided per solution and the range was 4–18. We grouped the strongly supported solutions ($n = 22$) into three general themes: (1) reduce access to pesticides (namely through regulation); (2) reduce the reliance of agricultural systems on pesticides; and (3) improve the Canadian government's approach in assessing the risk of pesticides to nonhoney bee pollinators.

Strongly supported solutions that would reduce access to pesticides can be separated into those that would moderate or prevent pesticides from being acquired for cosmetic purposes and pesticides that would be used in an agricultural setting. Participants agreed that these measures were "Definitely Feasible", reasoning that since cosmetic pesticide bans were already in place in several provinces throughout Canada, there was precedence. The perceived feasibility of further regulations that reduce access to pesticides for the agricultural industry was less certain; participants cited pressure from interest groups, entrenched ways of farming, and the complexities involved with trying to establish thresholds at which pesticide use is economically justified (Table 4).

Overall, solutions to reduce the reliance of agricultural systems on pesticides (e.g., crop insurance, cost-shared agri-environment schemes) were strongly supported as well as feasible (DF-SF) (Fig. 2). "Definitely Feasible" solutions were related to increasing agricultural extension to support technology transfer and Integrated Pest Management (IPM) practices on the farm (i.e., a combination of biological, physical, cultural, mechanical and/or behavioural pest control methods in lieu of agrochemicals). Increasing access to seeds untreated with pesticides was also perceived to be "Definitely Feasible". Cited barriers to implementing solutions were related to labour costs for increased personnel as well as concerns that chemical companies that sell pesticides (and own large seed companies) have filled gaps in current agricultural extension models and exert considerable influence over grower choices.

Actions to improve the Canadian government's ability and approach in assessing the risk of pesticides to nonhoney bee pollinators prior to pesticide approval were, for the most part, strongly supported and feasible (e.g., mandatory testing of new pesticides on multiple pollinator species, the development of new tests for novel routes of exposure for pesticides under consideration for regulatory approval). Strongly supported solutions that reached only medium consensus for feasibility included applying the precautionary principle in the approval of new pesticides and solutions that, if implemented, would serve to provide data to help regulators perform cyclical re-evaluations of approved pesticides on pollinators at a landscape scale (Table 4).

Participants submitted a total of 61 research priorities. We categorized these into seven themes (S2). The three most popular themes included the need to include more species of pollinators routinely in pesticide risk assessments in the context of regulatory approvals and cyclical re-evaluations, developing more ecological pest control approaches and further characterizing routes of pesticide exposure pollinators (Table 5).

Pathogens

Most of the 18 participant-rated solutions meant to address the threat of pathogens to native pollinators reached a high consensus level of support, but in general, were not as strongly supported as those in the pesticides category

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Fig. 1. Combined support and feasibility results as percentage of 83 wild pollinator conservation solutions.

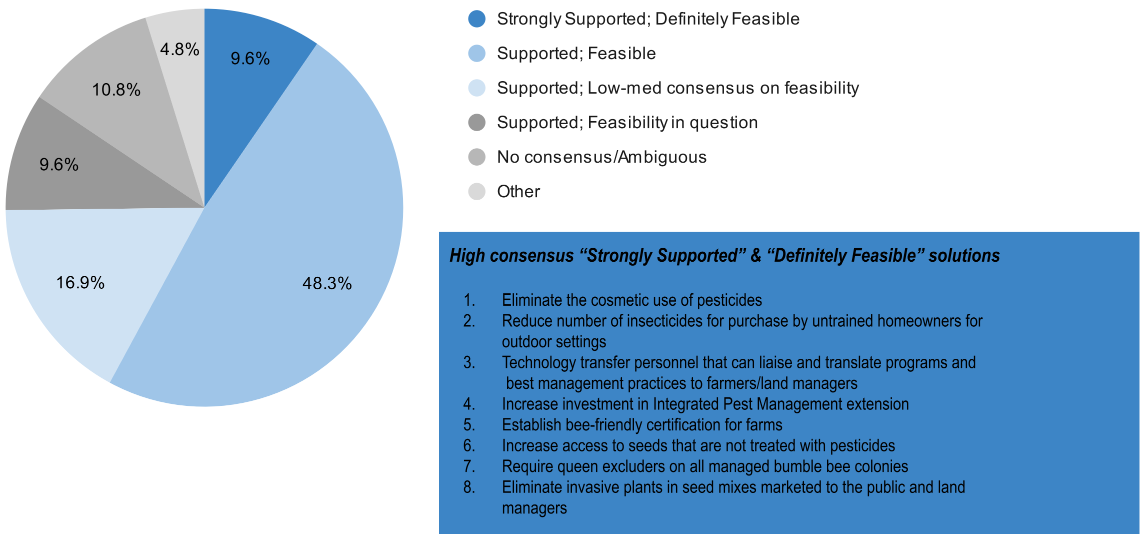
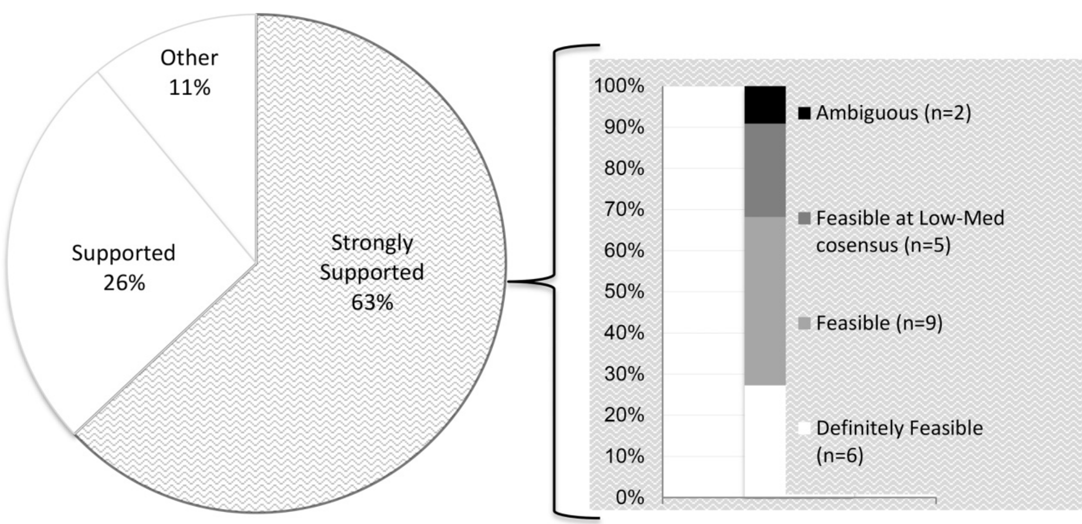


Fig. 2. Distribution of feasibility ratings of strongly supported solutions for reducing the negative impacts of pesticides on wild pollinators ($n = 22$).



(Fig. 3). The average response rate was 84% across solutions. Participants provided 40 justifications for their rankings; 6 was the average number of justifications provided per solution and the range was 2–8. Since there were only four strongly supported solutions at high consensus out of 18, we present the feasibility ratings distribution of all supported solutions ($n = 15$) (Fig. 3). We grouped these supported solutions into two general themes: (1) reduce pathogens in managed pollinators and (2) limit the spillover and spillback of pathogens transmitted between managed and wild pollinators.

Solutions intended to reduce pathogens in managed pollinators focused on new or stricter measures that ensure that managed bees are adequately tested and tracked. Most of these supported solutions referred to the common eastern bumble bee (*Bombus impatiens*) or were nonspecific as to the type(s) of bees. An example of the former included the need to establish a "clean stock program" to track the movement and quantity of independently tested pathogen-free bumble bees. A few supported solutions were specific to the beekeeping industry and included establishing "Mandatory courses/tests for beekeepers on how to properly control for pests, parasites or diseases" and "Restrict distance that honey bee hives may be transported". Four of the solutions grouped into this theme were high or medium consensus for feasibility and the remaining four were of questionable feasibility (i.e., low, medium, or high consensus with SF-SI as the point of consensus). Feasibility concerns were related to the cost (and who would incur it) as well as the personnel involved in implementation, especially for those measures related to honey bees given the sheer scale of the industry (Table 6).

All of the solutions to reduce the spillover and spillback of pathogens between managed and wild pollinators explicitly stated or implied regulation to prevent managed bees

Table 4. Select feasibility rating justifications for pesticide solutions by theme.

Reduce access to pesticides
Solution (S4): Restrict the use of pesticides only to when there is an evidence of need
Feasibility: Ambiguous
"Economic thresholds are not always well researched, in part because of cutbacks in government ag research (companies don't necessarily have an interest in this unless they recognize that their product won't last without conjoint IPM implementation). Provincial ministries of ag have cut back on the infrastructure for advising farmers on economic thresholds (IPM staff, phone alert systems, extension bulletins and up to date web sites, etc). Farmers don't necessarily have the skill to properly scout and assess and won't necessarily pay for private scouting services. Many of these services have collapsed financially"
"This is a good plan. However it requires some on the ground research and extension work for every crop to develop the necessary threshold information. If threshold information is reliable, growers will use it for sure. BUT [sic] you have to have reactive tools available"
"Growers love seed applications because they are done at the point of production rather than on the farm, they tend to pose less risk to applicators, and they are super easy to use. Such applications are usually systemic. If pesticides are sprayed in reaction to a pest, there are many other problems associated with that methodology, some of which are environmental and some relate to human health"
Reduce reliance of agricultural systems on pesticides
Solution (S16): Adopt targeted crop insurance programs
Feasibility: DF-SF
"This approach is excellent as it provides the safety net for producers that might allow them to have the confidence not to use prophylactic pesticide applications. This has been shown to work on a local scale in parts of Italy, and works well.
"In an era of climate change and unpredictable markets, insurance that provides real time relief to producers is critical. Again if all the money we currently wasted on unfair subsidies to meat, dairy, egg and corn producers was diverted to a robust insurance program, this would be feasible
Improve the Canadian government's approach in assessing pesticide risk to pollinators
Solution (S21): National pesticide use survey for all crops every 3 years
Feasibility: Med. consensus DF-SF
"I am not sure if this would be feasible in the long term. Lots of new chemicals come and go, and changing governments may not see this as a priority down the road"
"Definitely implementation challenges. Pieces of this have been done in the past (through things like FEMS) but the questions weren't well designed. Nobody really wants to pay for this as part of the Census of Agriculture. Ontario has been doing it every 5 years, but the survey isn't well designed. Survey design is critical"
Solution (S13): Apply the precautionary principle in the approval of new pesticides
Feasibility: Med. consensus DF-SF
"It is going to make registering new pesticides in Canada very cost prohibitive, putting our agricultural sector at great disadvantage if the U.S. does not follow suit (and it won't). Companies will just not bother registering their products in Canada. This is already happening in the biological control sector"
"The issue is that the federal Pest Control Products Act (PCPA) does not translate the language of precaution from the preamble to the operational logistics of data collection and approval processes. So this requires a major rewrite of the bill, the regulations and the regulatory protocols"

Table 5. Top participant-identified research gaps on pesticides and wild pollinators.

Research gap themes: pesticides	Example/s
Expanding assessments to include more species ($n = 16$)	"Expanding species assessed in impact studies and regulatory frameworks beyond honey bees and a few eusocial species of native bees"
Alternatives ($n = 12$)	"Increased research into biological control methods, crop rotation and mechanical control methods could reduce the need for pesticides"
Routes/parameters of exposure ($n = 8$)	"What is the coefficient of transference between soil-borne pesticide residues and ground-nesting bees?" "Differences between foliar vs. systemic pesticide use"

from interacting with wild bees and sharing flower resources. Examples included regulating greenhouses to prevent the escape of managed bumble bees into the wild, banning honey bees from public lands, and regulating the proximity of managed bees to protected lands. Four solutions in this theme were rated feasible, two feasible at a medium or low consensus, and one was of questionable feasibility (i.e., medium consensus with SF-SI point of consensus) (Table 6). Cited feasibility challenges were related to limited ability or will to enforce regulations. Citing import restrictions in the province

Fig. 3. Distribution of feasibility ratings of supported and strongly supported solutions for reducing the threat of pathogens on wild pollinators ($n = 15$).

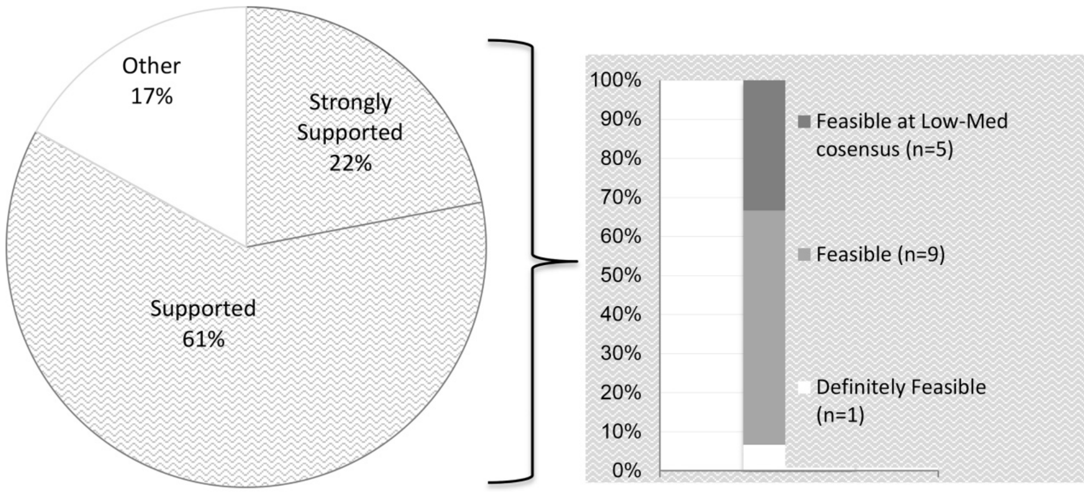


Table 6. Select feasibility rating justifications for pathogen solutions by theme.

Reduce pathogens in managed pollinators
Solution (S37): Establish clean stock program that tracks the movement and quantity of independently tested pathogen-free bumble bees Feasibility: DF-SF "This seems desirable and realistic to achieve. I am sure there would be pushback from the commercial bumblebee producers, but it would remove elements of doubt about whether or not colonies going to glasshouses or field pollination sites are "clean" when they are put in place. A key question would be which parasites and pathogens to include. Would this be limited to Nosema, Crithidia, Apicystis, Spherolaeria and mites, or would this also include viral infections?" "Traceability of the movement of any livestock (bees included) is a practice that should be in place; allowing movement of independently tested "clean" bees would be even better. Cost and enforcement will present challenges. Who pays for the independent testing and movement certificates? The supplier? The grower?"
Solution (Q43): Require screening and health certificate before any movement of managed honey bees Feasibility: SF-SI "This seems realistic for inter province/territory movement, but would likely be too cumbersome to operate within a province or territory due to the numbers of operators moving honey bees. The costs in terms of time and personnel would be very high to run, regulate and enforce such a program"
Reduce pathogen spillover and spillback between managed and wild pollinators
Solution (S45): Only allow the use of commercial bees (honey bees excepted) within their native range Feasibility: DF-SF "Definitely feasible as we currently do not allow import of bumblebee colonies into Newfoundland and Labrador as *B. impatiens* is not native here. It has presented some challenges convincing cranberry and blueberry growers that our native pollinators are doing the job. Have also encountered a few greenhouse growers seeking advice on pollination options" "This is feasible, but would require their native ranges to be defined. Would recent expansions of *Bombus impatiens* be considered nonnative expansions (I would suggest yes, but this might not prevent them widening their area of occupation in southern British Columbia and Alberta). This would certainly require commercial production of a western bumblebee species, and possibly other managed solitary bees to be developed"
Solution (S47): Ban honey bees from public lands Feasibility: Low consensus DF-SF "You can potentially prevent the physical colonies being placed in some public lands (but e.g., Ontario Crown Lands, anyone can go in and hunt or remove materials, so why legislatively wouldn't you be allowed to put colonies there?) but if you put the physical hives within a few km of the public lands, the bees will still visit. I've heard of beekeepers putting their hives on the edge of the public area on a neighbouring property so their bees can go and forage on the public land"
Solution (S42): Regulate greenhouses to make sure they are adhering to best practices and are designed to prevent pathogen spillover Feasibility: Med. consensus SF-SI "Generally they are encouraged already; who is going to enforce?"

of Newfoundland and Labrador (NL) as precedence, confining the use of managed bees (other than honey bees) to native ranges was considered a feasible solution but participants mentioned challenges associated with defining native (versus acclimated) ranges, which bees should be included, and how to provide growers with viable options for crops that benefit greatly from the use of nonnative bees in the and Western and Prairie provinces as well as NL (Table 6).

Participants submitted a total of 39 research priorities that we categorized into six themes (S2). Top research priorities included characterizing the magnitude of "spillover" and "spillback" and the need for lab and field studies on how transfer occurs, the frequency of transference for different pathogens and parasites and which species are affected (Table 7). Participants also prioritized research into the effects of pathogens for different species in various environments (i.e., rural, urban, agricultural and under varying exposure and honey bee hive densities). Within this theme, participants noted the important distinction between pathogen transference and the ability of pathogens to cause disease. Participants also pointed out that more research is needed to establish background pathogen loads for wild pollinators (Table 7).

Habitat loss

All but one of the solutions that participants rated to address the threat of habitat loss to native pollinators reached a high consensus level of support, five of them strongly supported (Fig. 4). The average response rate was 78% across solutions. Participants provided 75 justifications for their rankings; 4 was the average number of justifications provided per solution and the range was 1–8. Of the strongly supported and supported solutions ($n = 18$), participants rated almost all to be feasible at a high consensus yet none to be "Definitely Feasible" (Fig. 4). We grouped supported solutions into two closely related themes: (1) expand and protect pollinator habitat; and (2) ensure the quality of expanded habitat. The former includes suggested mechanisms that encourage habitat creation or protection and their success largely depends on the latter, which includes solutions that support these efforts upstream such as increasing the availability and access to native plants and seeds. As one participant stated, "The more native plants the better, but we need to have the stock in place, and it needs to be locally sourced, and we need to have people who know what should be planted where, etc… the infrastructure is not in place".

Supported solutions geared toward expanding or protecting pollinator habitat were strongly focused on private land such as incentivizing growers to maintain naturalized spaces on noncropped areas. Supported solutions that could be applied to public land as well included adopting green roof policies, which include forage for pollinators, supporting initiatives that protect and/or expand habitat with focus on habitat connectivity and requiring pollinator habitat on land controlled by various levels of government. Most concerns related to feasibility came up in relation to proposed mechanisms to financially incentivize private property owners to incorporate pollinator-friendly habitat on their land. For example, although several tax breaks schemes were suggested (and supported), participants mentioned challenges related to their design and raised doubts as to their financial viability (Table 8).

Supported solutions that were focused on the quality of habitat included supporting regional seed libraries and seed exchanges to enhance local ecotypes, subsidizing the development of native seed stock, adopting a policy to reduce allelopathic grass density in seed mixes for revegetating rights-of-way, and supporting more native plant nurseries/producers. These solutions were all considered feasible but participants' justifications indicated that their adoption largely depends on public education and inciting demand for native products (Table 8).

Participants submitted a total of 42 research priorities that we categorized into eight themes (S2). The most mentioned knowledge gaps included the need for more monitoring not only to characterize ranges and habitat but also to establish baselines against which to measure pollinators' response to land-use alteration, habitat fragmentation, and conservation interventions (Table 9). Participants also cited as top priorities the need for a deeper understanding of pollinator requirements and how land use impacts pollinator biology, declines, and pollination effectiveness (Table 9).

Nonnative species

Participants supported almost all (10/11) of the proposed solutions to reduce the threat of nonnative species to wild pollinators. Four were considered to be strongly supported and the remainder were supported (SS-WS; $n = 5$) or weakly supported ($n = 1$). The average response rate was 72% across solutions. Participants provided 110 justifications for their rankings; 4 was the average number of justifications provided per solution and the range was 1–7. We grouped supported solutions into three general themes: (1) generalized, high-level actions to halt the entry or spread of potentially invasive species; (2) removal and prevention of invasive plant species; and (3) policies that reduce potential competition of wild pollinators (specifically bees) with nonnative bees.

Of the supported solutions, seven were high consensus DF-SF, "Definitely Feasible", or "Somewhat Feasible" and the remainder were either medium consensus for feasibility, ambiguous, or the feasibility of the solution was in question (SF-SI). Participants justified their feasibility ratings for some broad level actions (e.g., more and better surveillance and monitoring at points of entry, support for early response to invasive species) by stating they would be fairly easy to implement but there were several comments indicating that participants were not deeply educated on the topic or the comments did not provide any substantive justification. The main impediments identified had to do with a perceived severe lack of capacity (e.g., financial, technical, personnel) to be able to effectively apply up-and-coming methods such as scanning incoming biotic material and using eDNA databases to monitor for potentially invasive species (Table 10). As one participant stated, "You need to know where and when to test, and for what".

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Table 7. Top participant-identified research gaps on pathogens and wild pollinators.

Research gap themes: pathogens	Example/s
Characterizing pathogen "spillover" and "spillback" between managed and native pollinators ($n = 14$)	"Characterizing and understanding the complexity and extent of pathogen transmission networks in the field. Key questions are whether pathogen transfer occurs primarily from managed pollinators to wild species (spillover), vice versa (spill-back), or significantly in both directions"
	"How can floral resources mitigate or contribute to pathogen spread?"
Effects/ability of pathogens to cause disease ($n = 7$)	"Establishing the importance of different pathogens on a wider range of pollinator taxa. Many studies use molecular approaches to detect presence and/or prevalence of pathogens, but this is not the same as establishing infection has occurred or indeed the extent of impacts of infections"
Determine (background) pathogen load in native pollinators ($n = 5$)	"Determining the number of pathogens infecting wild pollinator species and the extent to which these overlap with pathogens already characterized as infecting managed honey bees or bumble bees"

Fig. 4. Distribution of feasibility ratings of strongly supported and supported solutions for reducing the threat of habitat loss to wild pollinators ($n = 18$).

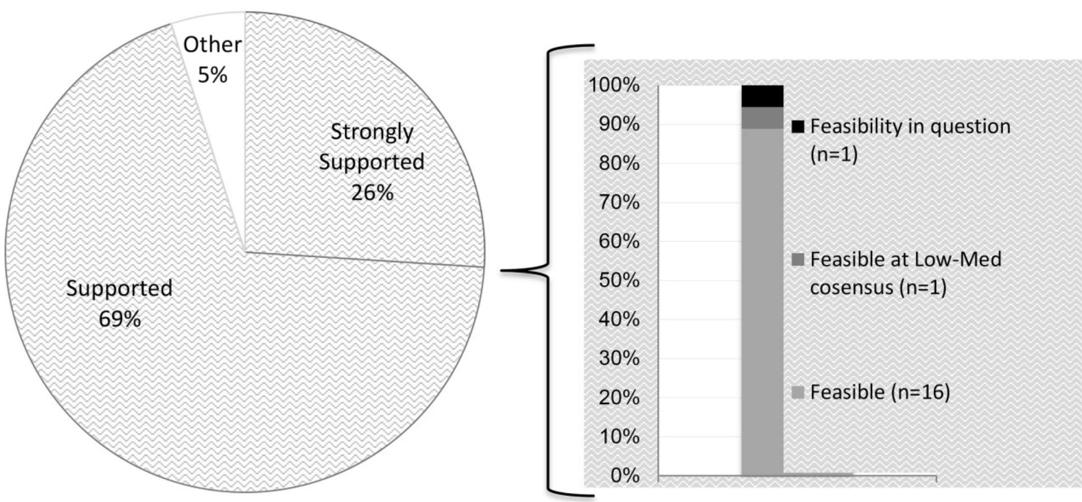

Table 8. Select feasibility rating justifications for habitat loss solutions by theme.

Expand and protect pollinator habitat
Solution (S56): Tax break to homeowners that plant pollinator-friendly alternatives to turfgrass
Feasibility: Med. consensus SF-SI
"Do you mean property tax break? Hard to implement when municipalities are so strapped for cash…our options to reduce municipal property taxes are limited unless the provinces change how municipalities are funded"
"This is certainly desirable, but may come with challenges from homeowners associations because of worries that things look "messy". May also need to specify that "x% of the lawn needs to be pollinator friendly"
Ensure quality of expanded habitat
Solution (S59): Support more native plant nurseries/producers
Feasibility: DF-SF
"…Bigger landscape contractors are used to the ease of buying from big companies for certain prices. Will take consumer demand and price comparisons to make this more feasible"

On the theme of removing nonnative invasive species and restoring ecosystems, cited challenges were related to justifying the cost, especially if the species in question were already "embedded in the landscape". In this case, support and feasibility were closely tied in that the problem was considered so widespread that it was uneconomical to address (especially for municipalities) and as a result, considered intractable and too "hopeless" to be a priority (Table 10).

Only two solutions addressed potential effects of nonnative bees on wild pollinators and only one was supported

Table 9. Top participant-identified research gaps on habitat loss and wild pollinators.

Research gap themes: habitat loss	Example/s
Baseline data and monitoring (n = 10)	"Native pollinator communities are not benchmarked in many landscapes. This gap makes it difficult to interpret the impact of habitat alteration/fragmentation"
	"No comparative data for population sizes for different functional trait groups, more extensive studies are needed"
Requirements (n = 8)	"An increased focus on understanding nesting requirements/preferences for native pollinators, particularly those that are common in agricultural systems. This also needs to include overwintering sites. Without appropriate places to construct nests, it doesn't matter how many flowers there are!"
	"Need to know how much habitat pollinators actually require in a landscape"
Land-use effects on pollinators (n = 6)	"The scale at which fragmentation affects bee biology"
	"Disentangling the relative influence of habitat loss and fragmentation on bee population (declines) and pollination effectiveness"

Table 10. Select feasibility rating justifications for nonnative species solutions by theme.

Generalized, high-level actions to halt the entry or spread of potentially invasive species
Solution (S79): Increase surveillance using all available technology (Note: Example given was environmental barcoding) Feasibility: Med. consensus SF-SI "Is good in theory to do more monitoring. e.g., CFIA is doing some, and community scientists and researchers are keeping their eyes open for new or different looking things, but it's not as if we have the financial, technical, or HQP to frequently test e.g., every possible border crossing, every new shipment of materials, etc. eDNA is doing great things, but you need to have the barcodes in the database to match your unknown with…"
Removal and prevention of invasive plant species
Solution (S77): Subsidize invasive plant removal and restoration Feasibility: DF-SF "Feasibility depends strongly on the type of plant and the extent to which it has become embedded in the landscape. Many very widely spread species of plant are invasives [sic] from Europe that would be uneconomical to try and eliminate as they are widely established across the whole of/or large parts of the country. More recent invasions by plants might be more realistically controlled in this way"
Policies that reduce potential competition of wild pollinators (specifically bees) with nonnative bees
Solution (S81): Label or certify wild-pollinated crops Feasibility: DF-SF "Too difficult to inspect and certify, unless based strictly on distance of farm from commercial nonnative bee operations"

by the group. The supported solution "Label or certify wild-pollinated crops" was rated feasible but participants pointed out that verification would be a challenge. To ensure that farms were not benefitting from managed bees on neighbouring lands, they must be located a certain distance from other farms that used managed pollinators (Table 10).

Participants submitted a total of 29 research priorities that we categorized into six themes (S2). Participants interpreted nonnative species to be plants or managed pollinators that were not native to the region where they are being used. The most popular theme was the need for research on how nonnative bees impacted native bees through pathogen spread and/or resource competition (Table 11). Top themes also involved understanding the impacts of nonnative species on the composition of and interactions between local species of plants and pollinators (e.g., plant–pollinator networks) and how to potentially prevent nonnative/invasive species from establishing in areas where they are not native (Table 11).

Discussion and next steps

Through the research presented here, we have identified solutions to counteract ongoing wild pollinator decline in Canada that are both highly desired by experts and considered feasible to implement. We have also identified knowledge gaps that, if addressed, will help inform and implement some of those supported conservation solutions. We found that overall, our selected group of expert participants supported the solutions suggested by their colleagues but the group was less certain about the feasibility of those solutions. They were also more divergent from one another in their feasibility rankings as compared with their support ranking. Still, almost 60% of the 83 solutions were supported and feasible at a high consensus. Since discussing each solution in detail is not possible here, we will discuss solutions that closely align with policies endorsed by the broader scientific community and are supported and considered feasible to implement by survey participants. For science-based recommendations,

Table 11. Top participant-identified research gaps on nonnative species and wild pollinators.

Research gap themes: nonnative species	Example/s
Effects of nonnative bees on native bees through competition and disease introduction ($n = 8$)	"Research on interaction (competition) between managed bees (honey bees primarily but also other managed bees such as nonnative bumbles or leafcutters) on native bees in agricultural landscape"
Characterizing plant–pollinator networks ($n = 4$)	"Research/info on benefits of native plants and reduction of nonnatives/invasives to native bee populations… And in urban environments this research can help educate on benefit of native plantings and inform municipal policy for municipal lands"
	"Understanding the frequency and extent of impacts of nonnative plant species on plant–pollinator visitation and pollination networks. Invasive plants can restructure native networks by offering super abundant floral rewards and monopolizing attention from flower visiting species"
Prevention ($n = 4$)	"How to keep queens and males inside the managed bumble bee colonies and not allow them to escape"
	"Keep out the nonnative species? Some areas will have these interactions due to climate change and southernly species moving north"

we rely on the policy forum: "Ten Policies for Pollinators" by Dicks et al. (2016) as key authors of the first global thematic assessment from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on the state of knowledge about pollinators and pollination, which is the most extensive and comprehensive assessment on the topic to date (IPBES 2016). The 10 policies listed are those that the authors think governments should adopt to protect pollinators and secure pollination services and were chosen in part due to their potential for successful adoption (Dicks et al. 2016).

By its nature, the quality of information gathered through the Delphi method is limited, in part, by the knowledge and experience of the participants (Frewer et al. 2011). Since our goal was to put forward solutions that were rooted in science, we chose participants that could primarily be identified as scientists engaged in basic and applied research. Depending on their professional vantage point and experience, participants' varying degrees of understanding related to the design and implementation of policy may limit the value of assessments. For example, a participant may support a peer's solution from a scientific perspective but disagree with the mechanism suggested to achieve it. Limitations may be compounded by the fact that depth of knowledge can forego breadth (de Loë 1995), a trade-off that may bear on participants' ability when evaluating policy on diverse topics from land management to animal health. The diverse geographical representation of participants can also complicate interpretations of what is possible. For example, using economic thresholds as a requirement for accessing certain pesticides may be desirable but more difficult to establish for crops typical to particular provinces or because a standing policy using a different method has already been established (e.g., Quebec vs. Ontario). We recognize that what experts think of as desirable and possible can differ greatly from what practitioners or policy-makers think can be achieved—especially those in politicized environments with their own resource limitations. To maximize the usefulness of the data generated in this Delphi, we recommend that it is combined with other approaches that invite practitioners and decision-makers in relevant government agencies and departments as well as other stakeholders to evaluate the highly desired solutions for feasibility and work to remove barriers to implementation. In the case of rightsholders in Canada, these science-supported solutions can be evaluated in conjunction with other ways of knowing and adapted to serve or cocreate further pollinator conservation efforts.

On the topic of pesticides and the threat they pose to pollinator health, suggestions from Delphi participants are aligned with recommendations posed by Dicks et al. (2016) including the focus on raising regulatory standards to ensure that risk assessments consider sublethal and indirect effects to a range of pollinator species, not just the honey bee. Health Canada's Pest Management Regulatory Agency (PMRA) is responsible for performing risk assessments on pesticides prior to their authorization and periodically re-evaluates the impacts of approved pesticides to see if the risk of continued use is acceptable. Participants were optimistic that assessments could be bettered through PMRA procedural changes aimed at raising the quality of industry submissions, and almost half of the identified research priorities were related to work that would inform comprehensive risk assessment protocols for nonhoney bee pollinating species. Upon the cyclical re-evaluation of approved pesticides, supported solutions that could aid in realistic field and landscape level studies (e.g., national pesticide use surveys) face feasibility challenges in terms of the logistics, value-for-money considerations and privacy concerns linked to the collection of georeferenced data.

The agricultural sector is by far the largest user of pesticides in Canada, yet participants were also concerned with the use of pesticides for cosmetic purposes mainly herbicides for turf and turf industries which include, inter alia, golf courses, sports fields, sod farms, residential and commercial lawns, and cemeteries. Access to nationally approved pesticides can be restricted or banned at the provincial level or municipal level (in the case of cosmetic pesticide use only) as long as there is not a provincial ban that disallows municipalities from adopting more restrictive measures. Jurisdictions often take divergent approaches that can be broadly or narrowly scoped (e.g., applying to residential lawn care only). About half of Canadian provinces/territories have cosmetic bans and all make exceptions or conditional exceptions for certain uses including for golf courses, plant nurseries or for reasons related to public health and safety (Bachand and Gue 2011). Through the enactment of cosmetic bans and their exceptions for industry, provincial governments engage in what Millington and Wilson (2016) refer to as "environmental managerialist" decision-making which attempts to simultaneously promote the often incompatible dual mandate of economic growth and environmental sustainability. Aside from fulfilling one mandate at the expense of the other, a result of this approach is that certain industries can be favoured over others and foster a perceived arbitrariness of exemptions (Millington and Wilson 2016; Taylor 2022). In general, Delphi participants are strongly supportive of cosmetic pesticide bans enacted uniformly across the federation and exemptions for industry eliminated. We would add to this discussion that municipalities should retain their ability to regulate more restrictively if they wish; predating provincial bans, the anticosmetic pesticides momentum started with municipal bylaws and the local policy innovation demonstrated during this movement was considered remarkable under federalism and remains example of what is possible to achieve from the ground up (Pralle 2006).

Overall, Delphi participants were strongly supportive of measures that encourage a paradigm shift to more sustainable farming methods with reduced pesticide inputs. Under this general theme, Dicks et al.'s (2016) "Top Ten Policies for Pollinators" recommends the adoption of IPM as a widely supported organizing principle to guide pesticide use (Lemay 2019). Delphi participants demonstrated strong support for IPM principles and practices but voiced concerns consistent with other criticisms that have been directed at IPM. These criticisms include that IPM has strayed in concept and practice from the ecological roots upon which it was founded decades ago and that the "quasi-infinite" definitions and emergent interpretations cause unnecessary confusion at best, and render the term meaningless at worst (Peterson et al. 2010; Deguine et al. 2021). As one participant commented, "I think IPM has so many different definitions, I'm afraid this would get watered down, which is why I weakly oppose it". Despite the goal of IPM to relegate agrochemical use to the last possible resort, plant health programs still largely revolve around chemical control (Deguine et al. 2021). Canada is no exception; where IPM was once well conceived and supported, infrastructure has largely been dismantled and more narrowly scoped programs centre mainly on ushering the registration of lower risk pesticides (MacRae et al. 2012; MacRae 2021).

Delphi participants also agree that it is highly desirable and definitely feasible to reinvigorate IPM extension services that have largely been replaced with mass communications that target growers and other stakeholders with synthesized knowledge rather than field-level advice (Dixon et al. 2014; Lemay 2019). Extension would provide more education, training, on-site visits and technical advice so growers have the skills and knowledge to implement IPM strategies and respond effectively to specific pest activity and trends. In-person interaction with rural landowners is more likely to inspire behavioural changes and innovation on the farm as opposed to one-way forms of communication (e.g., "fact sheets", web-based information, recorded phone messages) (Milburn et al. 2010).

Although a federal IPM program including extension activities would require resources, much of the required network of grower organizations, provincial minor use pesticide coordinators, and researchers already exist and could be broadened to include regional IPM expertise to liaise with a (ideally larger) group of provincial IPM extension specialists to set priorities and devise knowledge mobilization strategies (MacRae et al. 2012). Current policy and programmatic federal–provincial scaffolding can be leveraged (e.g., Canadian Agricultural Partnership, Pesticide Management Centre) to provide coordination and funding.

According to IPBES (2016), the science documenting the passing of pathogens between and among managed bees and wild pollinators is "established" and Dicks et al. (2016) stress the adoption of policies that address the risks involved with moving managed pollinators around the world. In Canada, the honey bee is by far the most used managed pollinator but managed bumble bees are a growing industry with inadequate oversight in which *B. impatiens* (native to Canada east of Manitoba) are used in many regions where they are not native to pollinate greenhouse crops and, to a lesser extent, field crops. Escaped or improperly disposed *B. impatiens* have now established nonnative populations in the wild in these regions, which poses a great risk to surrounding native bee communities (Palmier and Sheffield 2019). Solitary bees are also reared to pollinate various crops and include the nonnative alfalfa leafcutting bee and the blue orchard mason bee.

Honey bees are subjects of Canadian Food Inspection Agency (CFIA) regulations. Other commercial bees are either reared within Canada or imported (sometimes directly to an end user through the mail) without any required screening. Voluntary Farm-Level Biosecurity Standards exist for the most commonly used managed bees and serve as guidance for producers and end users, but it is ultimately up to the issuing company to ensure that their pollinators are not diseased. In the case of the commercial bumble bee industry, there is low level of transparency regarding where bees are being shipped, and what kind of screening they underwent prior to leaving the facilities. As of now, there is limited or no tracking on any managed bees, so there is often no chain of accountability or way to trace their physical path to study the impact of any outbreak.

The IPBES report (IPBES 2016) states that the risk of harm to pollinators could be reduced by "better regulation of their trade and use". Our study participants support establishing a "clean stock" program that tracks the movement and quantity of independently tested pathogen-free bumble bees. Delphi participants also consider this solution feasible; groundwork for a program has already been laid. The *Bombus* task force of the North American Pollinator Partnership Campaign has established a clear foundation for the development of a clean stock certification program for commercial bumble bees that recommends protocols for bumble bee screening, and the Colla Native Pollinator Research Lab at York

University, Toronto, has submitted commissioned work to Environment and Climate Change Canada that situates a clean stock program for bumble bees within the Canadian policy landscape (MacPhail et al. 2022; Strange et al. 2022).

Most of the supported and feasible actions according to participants inferred or explicitly referred to more regulation (e.g., tracking commercial bee movements, the requirement of queen excluders on all managed bumble bee colonies and requirements for proper disposal of those colonies). Bee keeping is regulated under provincial Bee Acts or Animal Health Acts and refers almost exclusively to honey bees. These Acts could be amended or expanded to strengthen regulations or codify some of the federal Farm-Level Biosecurity Standard best practices related to the management, disease reporting, transporting and record-keeping for all managed bees, not just honey bees. Federal body coordination would most likely be required to standardize and oversee tracking efforts due to the sheer scale of honey bee movements.

In reference to creating and restoring wild pollinator habitat, Dicks et al.'s (2016) top pollinator policies include "Conserve and restore "green infrastructure" (a network of habitats that pollinators can move between) in agricultural and urban landscapes". Participants strongly supported (and rated feasible) solutions that were in service of creating habitat networks including taking advantage of already established infrastructure corridors such as roads, train tracks and hydro lines as well as deliberately focusing on habitat connectivity between biodiversity "hotspots" when expanding or choosing pollinator habitat to protect. Since these solutions involve access to land managed under various tenure arrangements, creating habitat networks will involve leveraging existing partnerships amongst land trusts, conservation organizations, Indigenous groups, industry, community and landowner groups, and government as well as forging new relationships. Ray et al. (2021) fault a myopic approach to development and natural resource extraction in Canada that exacerbates threats to biodiversity posed by habitat loss. Development proceeds one project at a time, on a sector by sector basis and tacitly accepts the loss of wildlife habitat as something of a foregone conclusion (McCune et al. 2019; Olive 2019). While not addressing root causes as to why quality habitat might be fragmented or degraded in the first place under the current system of governance, participants' focus on building networks inherently considers pollinator habitat at a landscape scale. This holistic approach could partially offset the cumulative effects of connected habitat lost as a casualty of the federal and provincial governments' development planning and permitting processes.

In this study, participants generated more unique solutions for habitat loss that would fall under municipal jurisdictions and play out in urban or residential areas as opposed to agricultural lands or protected areas (e.g., municipal bylaws that reduce mowing). Save providing grants for community habitat projects, federal involvement would be limited. However, actions taken at the municipal level can support Canada as a signatory to the United Nations Convention on Biological Diversity (CBD) and the attendant Strategic Plan for Biodiversity 2011–2020 and its Aichi Targets. Strategic Goal 1 calls for "mainstreaming" biodiversity, which involves embedding biodiversity considerations into policies and planning across all sectors and levels of society (CBD 2018). Canada has received a relatively low score on "mainstreaming" biodiversity when compared with other CBD signatory countries (Whitehorn et al. 2019); en masse implementation of supported and feasible municipal actions such as requiring native plant species in development and infill work and green roof policies that include forage for pollinators can model ways in which development and biodiversity protection can be integrated and shown not to be mutually exclusive goals.

Solutions related to ensuring habitat quality within restored or conserved habitat networks mirror solutions that intend to reduce the threat of nonnative species to wild pollinators. Generally speaking, participants want to adopt solutions that promote habitats with native plant species and discourage those that do not. This may include nonnative species that are not necessarily invasive (i.e., managing to reproduce and persist in new areas at high population densities) but may affect plant–pollinator networks to the detriment of wild pollinators all the same. Eradicating species that negatively affect pollinators can be expensive and is seldomly successful so action steps that reduce their impact as well as preventing new invasions are paramount (Mack et al. 2000). Participants strongly support (and deem feasible) general solutions that focus on pre-entry control as well as actions that would correct oversights that are antithetical to the goal of stopping the spread of invasive species. For example, seed mixes widely marketed to the public, such as wildflower mixes, often predominantly contain potentially invasive species and are a key pathway of new invasive plants into Canada (Brooks 2007; Tilley and Pickett 2017; ISCBC 2019). Participants endorse supporting native plant nurseries/producers that help ensure that the supply and demand of native seed stock evolves in tandem. The participants did not specify exactly how the native plant industry should be supported but all levels of government can play a role either through existing legislation (e.g., Seeds Act R.S.C., 1985, c. S-8), new strategies (see US National Strategy for Rehabilitation and Restoration), and procurement policies that would stimulate and help stabilize the developing market for native seeds and plants (Mock et al. 2016).

Lastly, Dicks et al. (2016) cite considerable knowledge gaps regarding the status of pollinators and recommend as a top policy priority the establishment of long-term, widespread monitoring. Participants cite the need for baseline data on pollinators as the most popular research theme to inform actions to restore/create habitat and reduce habitat loss. Indeed, monitoring is a common thread that weaves throughout participants' suggestions for solutions and research needs across stressor categories. The execution of the vast majority of suggested research endeavours and supported actions are predicated on knowing more about where pollinators are in the first place (to design interventions) and to track changes over time (to refine and evaluate those interventions). There is no government program in Canada charged with the routine, widespread monitoring of wild pollinator populations or pollination services, and few studies exist that repeat sampling at the same locations using the same method. Monitoring is predominantly undertaken by nongovernmental organizations, research institutions, or large researcher networks that frequently have species or location-specific project goals, do not necessarily create or share standardized data in any one place, may use different sampling methods from one another, and do not systematically repeat their efforts. An important government undertaking would be a nationally spearheaded monitoring program that is targeted, well coordinated, and sustained. The objective would be to detect trends at different geographic scales and in priority areas by providing comprehensive data sets conducive to rigorous statistical analyses (Woodard et al. 2020).

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RN conceived and designed the study. RN collected, analyzed, and interpreted the data. RN and/or SRC drafted and revised the manuscript. SRC acquired the funding for this study.

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The authors declare that there are no competing interests

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Supplementary material

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