Canadian Honey Bee Research Gap Analysis

Prepared by Pollinator Partnership Canada

For the Canadian Bee Health Roundtable

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Summary of Findings

This commissioned review and gap analysis of the status of bee health research in Canada presents trends and makes assessments on the current capacity that exists to support a healthy honey bee industry with domestic resources.

Assessments of peer-reviewed and technical literature combined with expert and stakeholder interviews were used to develop a current understanding of research and knowledge capacity in seven key areas of honey bee health in Canada: 1) pesticides; 2) pests, disease, and pathogens; 3) interactions with other bees; 4)genetics and breeding; 5) forage and nutrition; 6) climate change; and 7) best management practices.

Interviews with researchers, beekeepers, farmers, members of industry, and policy makers were used to highlight the current perspective on top priorities in bee health research. This analysis also identified gaps that exist in capacity within Canada.

Items in this report outlined as not receiving sufficient attention, or as gaps, are defined based on a current lack of emphasis or capacity. This designation does not reflect the competency or quality of research and researchers, nor is it intended to suggest an active short fall in funding and government support. This report outlines existing trends and presents basic information to support decision-making.

Gaps and Capacity in Canadian Research

Using interviews with stakeholders and a summary of current or recently completed research in Canada, we developed an assessment of key gap areas of honey bee health research in Canada, and current capacity in each of those gap areas (Table 1). We only included gaps that were identified by at least one Canadian stakeholder.

Table 1 Gaps and capacity in Canadian honey bee health research. Gaps in the table are those that were identified by at least one Canadian respondent; gaps from literature but not discussed by interview respondents generally are not included in this table.

Topic	Subtopic	Gap description	*Priority: low (L), medium (M), high (H)	**Current Capacity: low (L), medium (M), high (H)
Pests, Diseases and Pathogens		Baseline information	H	M
		Longitudinal studies	H	L
		Economic thresholds	H	L
		Regional BMPs	M	L

		Viruses	H	H
		Interactions with other stressors	H	H
		Small hive beetle	H	L
		Emerging pests	M	L
		New control products/techniques for *Varroa* mite	H	H
Forage and Nutrition	Feed and supplement	Supplements as compliments to colony life cycle	M	M
		Supplements as compliments to crops	M	L
		Interactions with stressors	H	L
	Forage	Habitat Creation (support and research)	H	L
		Understanding forage preferences	H	L
Pesticides	Neonicotinoids	Interactions among neonicotinoids and other stressors such as pests, diseases, and other pesticides	M	H
		Tier III field studies on whole colony effects and overwintering	M	L
		Economics of use	L	L
	Other crop pesticides and in-hive pesticides	Treatment thresholds and proper use of in-hive pesticides	H	M
		Build up and impact of crop and in-hive pesticides in colonies	L	L
Interactions with Other Pollinators	Managed pollinators	Synergisms in pollination	M	L
	Wild pollinators	Impacts on food and forage	M	L
		Disease transfer	M	M
Breeding and Genetics	Queens	Local/regional genetics	M	M
	Colony	Local/regional genetics	M	M
		More disease resistant stock	H	H
		Stock security (genetic diversity)	M	M
Climate Change		Crop pollination requirements and important pollinators	L	L
		Managing hives with uncertain weather, variation among years	L	L
Synergies		Interactions among multiple honey bee health stress factors including in-hive and crop pesticides, pests, diseases, colony movement, nutrition etc	H	M
Management		Pesticide exposure prevention	L	L
		Treatment thresholds for pests and diseases	H	M
		Biosecurity	M	L
		Hive and equipment management for reduced disease and pesticide exposure	L	L
		Management of colonies for pollination services	M	L

	More comprehensive guidelines for queen breeding and rearing, including regional considerations	L	M
	Better guidelines for nutritional supplementation and regulation of supplements	M	L
	Extension programs and accessible documents on BMPs for beekeepers	H	M
	Regionally specific guidelines	M	L
	Landscape management for better forage	H	L

***Priority:** Green 'L' indicates low priority where few (1-3 of 23) respondents discussed it as an important gap and/or priority, yellow 'M' indicates medium priority where 4-8 or 23 respondents discussed it as an important gap and/or priority, and red 'H' indicates high priority where at least half of the respondents discussed it as an important gap and/or priority.

****Current Capacity:** Red 'L' indicates there currently is little research in this area (0-2 small-medium projects) in relation to the scope of the issue, yellow 'M' indicates there is an intermediate amount of research (>2 small/medium scale projects, or at least one large multi-regional or national project) in relation to the scope of the issue, and green 'H' indicates there currently is relatively good engagement in that area of research in Canada (>3 small-medium scale projects and/or >1 larger, multi-regional or national studies).

Table 1 highlights areas where respondent consensus indicated that there was a high priority to conduct research in that particular area of honey bee health. A low priority score in the table does not necessarily indicate that individual respondents felt that that area was a low priority for research, but rather that few respondents identified that area as a significant gap or priority. A high priority was identified when at least half the respondents identified an area as either a significant gap in our knowledge and/or a high priority for research in Canada.

Priority Areas: Pests and Disease, Forage and Nutrition, Regional BMPs

Main areas that were particularly noted as priorities and gaps in Canada, as identified by numbers of respondents that discussed that gap or priority, included many aspects of pest and disease control such as treatment thresholds, baseline data, breeding for resistant stock, control of *Varroa* mite and to a lesser extent other pests and diseases, and interactions among pests, diseases and other stress factors such as pesticides. In addition, a better understanding of honey bee nutrition including supplementation and forage enhancement were deemed high priority for honey bee health research. An additional area that was consistently identified as lacking in Canada was development of regional best management practices and extension to beekeepers.

There was a somewhat divergent opinion from a small but significant number of respondents (approximately 4 or 23 respondents) that agriculture, research, and support for bee health in Canada should go in a direction that focuses more on lower inputs and healthy ecosystems (both in terms of crop production and bee management). This group of responders felt that more prescriptive rather than pre-emptive use of pesticides (in-hive and crop) would go a long way towards having healthier honey bee colonies. These respondents strongly felt that fewer pesticides, greater use of IPM, and more focus on healthy ecosystems and a holistic approach to research were crucial. These opinions need not be contrary to opinions that targeted research is necessary, but could be used in conjunction with more targeted research. The idea that perhaps, 'less is more' could be used as a guide for some of our future research into, and support for, more diverse agroecosystems and landscapes, and lower input beekeeping.

Current capacity within Canada also was scored using information on current and recently completed research within Canada. Low capacity indicates that there are few current studies in that priority area in Canada (~0-2 small to medium projects), whereas high capacity indicates that there are greater than ~5 small-medium studies and/or >2 large, national scale projects, or a combination of small-medium and at least one large, national scale project. Medium or high capacity does not indicate that these are areas that should receive less funding in the future, but rather that we are doing a good job of addressing these issues, and we should continue to do so. Conversely, low capacity, especially when associated with a high consensus of priority indicates areas that should receive greater attention in the future.

Areas that currently are doing well in Canada in terms of number and scope of projects include honey bee genomics and markers for resistant stock, and some other aspects of pest and disease control including research into *Varroa* and virus control, and interactions among pests and diseases on honey bee health. Because these also are high priority areas, continued research and funding is advisable.

Capacity can be improved in pest and disease, forage and nutrition, and longitudinal studies, however, areas that respondents consistently identified as priorities and/or gaps but currently score low on the capacity ranking in Canada include better overall understanding of pests and diseases in Canada, how pests and disease impact honey bee health, and thresholds for treatment. In addition, a number of areas within honey bee nutrition are important areas for increased future research such as in nutritional supplementation and landscape management for better forage. Most importantly, many researchers emphasized the need to have more holistic, long-term studies that assess interactive effects of multiple stress factors on honey bees. While we have relatively good current research capacity in this area, the great scope and complexity of studying interacting factors calls for greater future investment in this area.

Honey bee health is receiving increasing attention and funding in Canada. As such, the strategy going forward should focus on areas that are both high priority, and low in current capacity, while maintaining funding in areas that have high priority and high capacity.

Learnings from Partners and Abroad

Collectively, responses from researchers and other key stakeholders point toward some successful programs in the United States as good models that could be used directly or adapted to Canadian issues. A key reason for this was the similarities between agriculture and honey bee management between Canada and the US. Systems in North America are different enough from those in Europe that successful management strategies and programs might not be applicable. More specifically long-term monitoring efforts that integrate total bee health (nutrition, disease and pest, pesticide exposure) were highlighted as effective approaches that are providing baseline data on a regional scale. Collaborations already exist between Canada and US honey bee research. Suggestions about addressing management issues through the registration of bee hives and pesticide usage plans as required in California were also brought up, but it should be noted that this is the only location in the US with this management system in place. A final point regarding learnings from abroad and paralleling other successful approaches highlights support for developing a scientific reviews of bee health in Canada modeled after the National Academies of Science report on the Status of Pollinators in North America.

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1. Introduction

Honey bees are a vital component of agricultural and economic systems in Canada, as well as globally. Domestically, between $3.15 to $4.39 billion per year are attributed annually to the beekeeping industry resulting from managed pollination services of key crops such as canola, blueberries, and other orchard and field crops. An estimated 80% of crop varieties are dependent on bee pollination, and therefore play a key role in our food systems. The honey industry also has grown significantly with consumer demand for Canadian honey and hive products increasing in Canada and abroad.

Emerging issues in bee health and management are now at the forefront of concerns not only for beekeepers, but also farmers, regulators, and the public. Maintaining vigorous hives that survive the winter and combating established (*Varroa destructor*, *Nosema* spp.) and encroaching pests and pathogens (small hive beetle, *Aethina tumida*) are annual challenges for beekeepers. Hive management for pollination services and honey production has also changed, and will continue to change with environmental and commercial factors as an adaptable beekeeping industry responds. For example, demands for canola pollination in western Canada and blueberry pollination in the eastern Canada are resulting in increased migratory operations. Competing land uses within agriculture and a lack of practical approaches to supporting bee forage impacts nutrition, and is one of the areas we know least about. Together these issues put stresses on bees and beekeepers.

Current bee health issues also have been politicized and polarized through the media, resulting in stakeholder demand for action that might not be sufficiently addressed by science. This has been the case with effects of pesticides on bees and the focus on neonicotinoid pesticides over a holistic approach to a reduction in the use of all chemicals in landscapes that bees frequent. Keeping bees, and keeping bees healthy, is complicated and a process that involves adaptive management and forward thinking. Action on honey bee health issues must be rooted in and guided by science to be effective in supporting policy and management.

The diverse and complex set of drivers and stakeholders in the honey bee realm has created an equally complex distribution of understanding scattered across industry, research institutions, and government. Such a climate opens the potential for duplication of efforts and overlooked opportunities due in part to a lack of a solid communication network between parties, but also due to the inherent complexity of the issues at hand. Summary reviews, and gap and capacity analyses are essential in rebalancing efforts in such scenarios and in providing managers and regulators with tangible targets to address. In this gap analysis we have undertaken the following actions:

1. Assessing the current understanding of honey bee health issues in scientific literature and among experts in Canada,

2. Tabulating recent and ongoing research in Canada,

3. Addressing where there are gaps in our knowledge that our limiting our ability to keep managed honey bees in Canada healthy,

4. Evaluating where our current and future priorities within limited funding resources, and

5. Assessing how we can learn from initiatives and programs in other parts of the world.

The Canadian Bee Health Research Gap Analysis report outlines research capacity and gaps relevant to honey bee health in the following key areas:

1. pests, disease, and pathogens;
2. forage and nutrition;
3. pesticides;
4. interactions with other managed and wild pollinators;
5. genetics and breeding;
6. climate change; and
7. management practices

This report provides an assessment of the current breadth and capacity of research efforts within each category, highlighting strengths and weaknesses within Canada as they pertain to the needs and interests of the Bee Health Roundtable. Recommendations and next steps for filling identified gaps, including a prioritized recommended action are provided in summary and overall conclusions.

2. Review Methodology

We developed this review and assessment of honey bee health capacity and gaps in Canada by reviewing existing literature and through consultation with experts and key stakeholders in honey bee health research and industry. Published literature pertaining to honey bee health issues is voluminous and growing at a rapid pace. Our presentation of references and resources in this report primarily is for the purpose of assessing current research directions and emphasis areas and is not intended to represent a compendium of honey bee health studies. The key focus of this report is to outline active research initiatives in honey bee health and to identify if efforts in Canada are consistent in addressing issues identified as urgent and critical.

We used direct consultations and interviews with key stakeholders in the public and private sectors to acquire information not present in published sources and to aggregate expert opinion in Canada. Scheduled telephone interviews were conducted throughout January to March 2016. Some respondents provided information via written questionnaire. In all cases we have kept responses anonymous.

We asked the following questions of all interviewees:

1. You and/or other experts are active in research on honey bee health (specifically in relation to pesticides, forage and nutrition, pest and diseases, breeding, management, and/or climate change). Could you please elaborate on your specific area of research and your current projects?

2. Do you know of critical research, published and pending, that we should be aware of that could be valuable for informing Canadian honey bee health policy?

3. Within your specific area of expertise, are there gaps that you can identify in research on honey bee health that could limit our ability to create national policies and best management programs for bees?

4. In your opinion, what are the top three issues in honey bee health in Canada?

5. Can you think of areas where research and other activities are currently sufficient to support the policy and action on honey bee health issues in Canada?

6. With respect to management and policy gaps, are there initiatives in the United States or globally that you feel are relevant to supporting and promoting Canadian policy and programs?

We also asked for any additional comments that stakeholders would like to contribute that we did not ask directly. For our analysis of responses Question 1 provided information on current research that is reported in Section 3 of this report. Question 2 provided us with information for our key literature reviews in each topic section of this report (Sections 4 to 10).

3. Current Canadian Research

We tabulated current and recently completed Canadian research on honey bee health (Electronic Supplement 1). This list primarily is based on the 2014 and 2015 CAPA submitted research projects, supplemented by our interviews with 23 individuals from Canada and four from the USA. The research table was used to create an interactive Google map of current honey bee health research in Canada (Figure 1). Location points on the map are based on the location of the PI, or if more than one PI, on the location of the first PI. The Google map has been shared with the Research Working Group and contains an embedded current Canadian honey bee health research table that can be updated as needed.

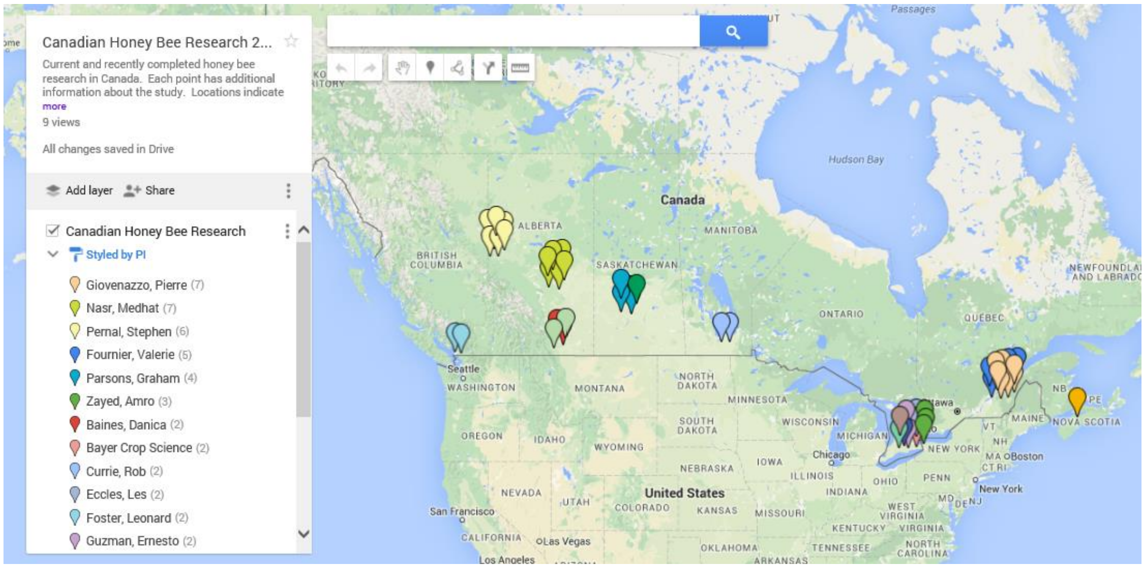

Figure 1. Screen shot of an interactive map of current Canadian honey bee research. Each point contains embedded information for the project from the data table. For the purpose of viewing research projects, when multiple points are in the same location they have been moved slightly so that each can be seen at the Canada-scale view.

3. Overview of Stakeholder Responses

We contacted approximately 50 stakeholders from January - March 2016, representing Canadian (and 7 US) government and university honey bee researchers as well as industry stakeholders and researchers. Of the 50 we contacted, we were able to complete interviews with 23 Canadian and 4 US stakeholders (Appendix 1).

Answers to questions 3-6 were categorized as far as possible in order to create pie charts of responses (Figures 2-5). Pie charts were developed from a quantification of aggregated responses. If two or more respondents provided a similar answer (i.e., it could be grouped in the same category), that answer was given a category in the pie chart. Answers that were only given by one respondent are grouped in the 'other' category. Each response was scored into a category or as 'other'. Some respondents were scored twice in one category if they gave distinct, separate answers that fell in the same category (within the limits of not giving any one respondent more than 3-4 responses for any one question). We did not include data from outside of Canada in our analysis of responses and only included their responses in discussions of the topics. While grouping responses to open ended questions cannot result in perfect categorization, trends and commonalities can be identified.

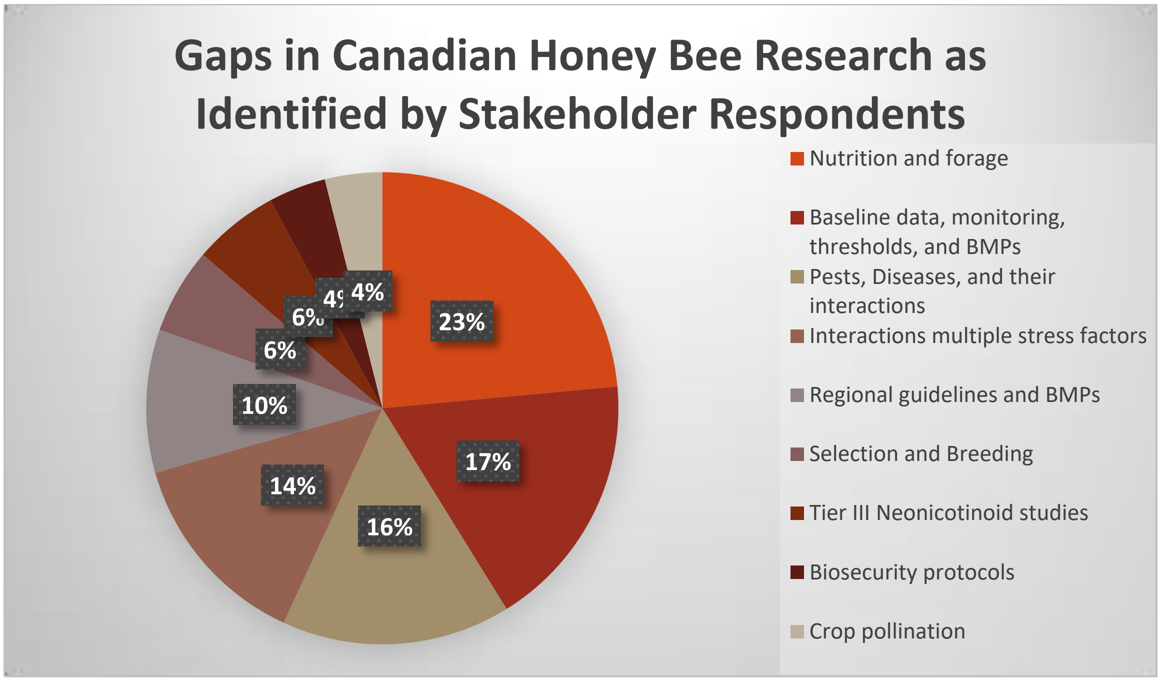

Figure 2. Results of question 3 to Canadian honey bee health experts.

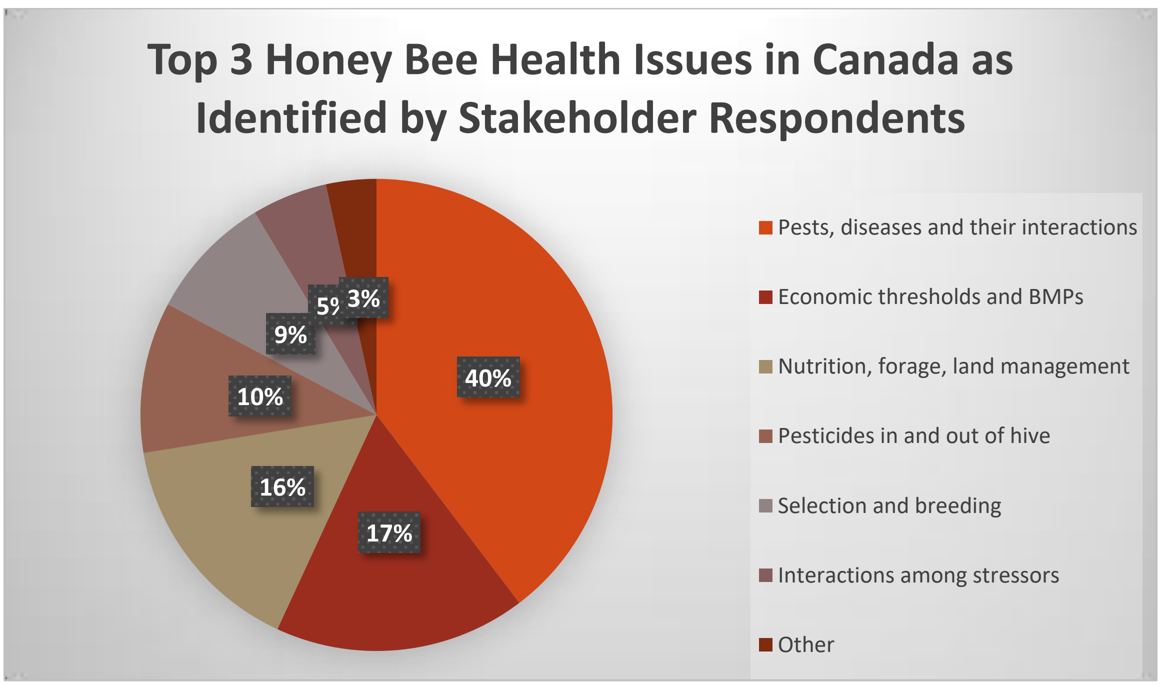

Figure 3. Results of question 4 to Canadian honey bee health experts.

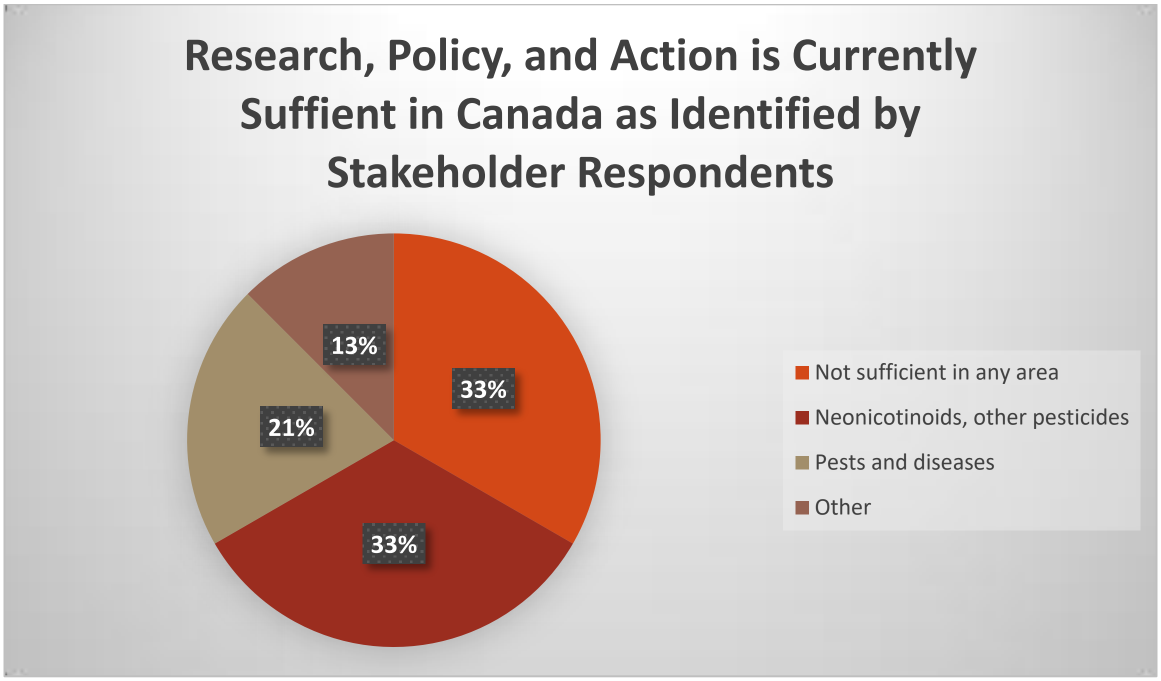

Figure 4. Results of question 5 to Canadian honey bee health experts.

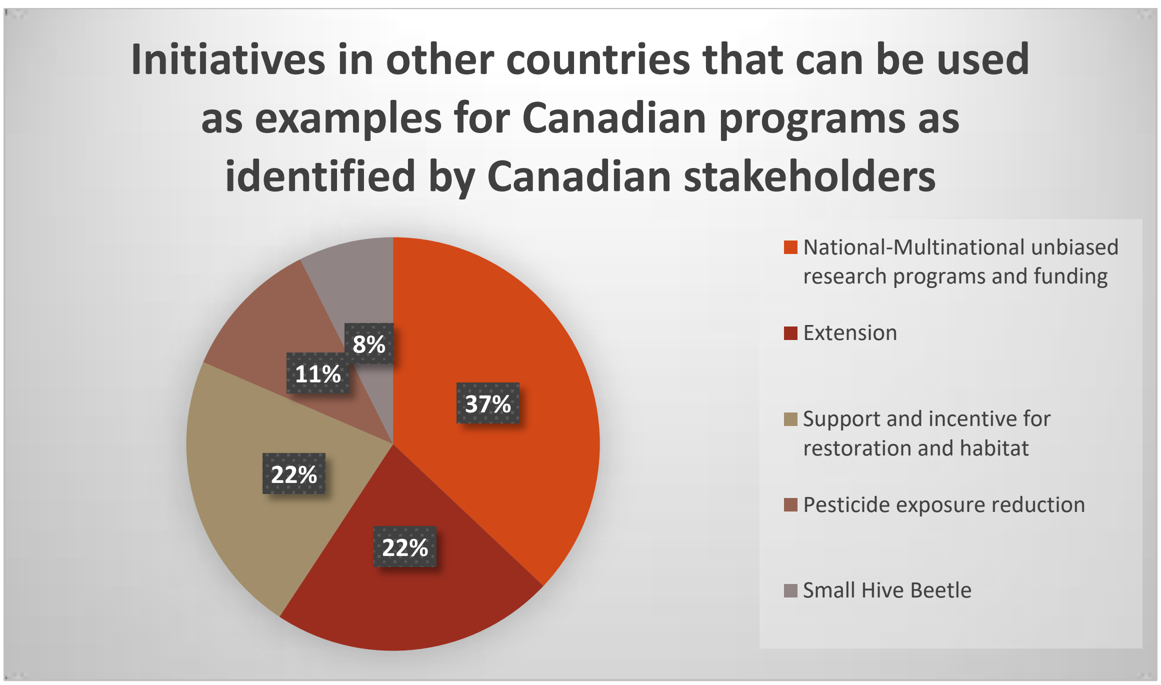

Figure 5. Results of question 6 to Canadian honey bee health experts.

Here we discuss general trends in responses and overall implications for gaps, priorities, and areas where action is deemed most important. Within each section topic (pests, diseases, and pathogens, forage and nutrition, pesticides, interactions with other pollinators, genetics and breeding, climate change, and management) we discuss in detail responses that fall within those topics.

Question 3 addressed where there are gaps in research that limit our ability to create policy to support honey bee health in Canada; question 4 addressed what our top priorities should be for research in Canada. Gaps in our knowledge (Q3) and the top three honey bee health issues in Canada, resulted in the most answers and the most varied answers. However, there were some strong trends in responses and the two questions provided complementary information. The top three answers (in terms of number of respondents in each category) for both questions were similar (Figures 2 and 3); 1. pests, diseases, and their interactions; 2. Nutrition, forage, and land management; and 3. treatment thresholds, baseline data, and best management practices. Breeding and genetics, pesticides (in and out of the hive), and interactions among all stressors were other topics that frequently were stated as lacking in research and of high priority.

It is somewhat artificial to divide topics into categories, yet useful for identifying gaps and setting priorities. Some of the main interactions between categories, which should be kept in mind is that interactions among pest and disease stressors are also impacted by other stressors such as pesticides used within hives and on crops. These multi-category interactions were identified by some respondents as important areas of future research. In addition, many categories are not studied in isolation. For example, breeding for hygienic and otherwise resistant stock, nutrition, baseline data, and treatment thresholds and BMPs are related to control of pests and diseases in colonies. As far as possible, we note interactions but keep responses within categories to aid identification of gaps and priorities.

Within the pests and diseases response category, *Varroa* mite control and tools were the most commonly discussed gap in our knowledge and priority for research. Other pests and diseases discussed were *Nosema* spp., viruses and their impact on honey bee health, and the threat of small hive beetle.

Honey bee nutrition, forage, and better land management was identified as one of the top three most prominent gaps and priorities in Canada. Respondents often cited nutrition as one of the possible drivers for poor health in colonies, including susceptibility to pests and diseases. However, it was frequently stated that there has been little recent research on this topic and we in Canada are far behind in our understanding of honey bee nutritional needs compared to our understanding of the nutritional needs for other agricultural organisms such as cattle or poultry. The topic of nutrition also intersected with landscape issues in Canadian agriculture with many respondents stressing that there was little research in Canada into benefits of more diverse agroecosystems, or support for creation of healthy and diverse agroecosystems. There are some studies in Canada addressing supplemental nutrition, mainly pre- and pro-biotics, and only one study on agroecosystem management for honey or other bees. More direct research into agroecosystems is needed.

Another common response theme from this question was our lack of baseline understanding of impacts of many diseases on honey bee health, particularly viruses, economic treatment thresholds for many pests and diseases, and national and regional best management practices.

There is a current, large-scale project addressing baseline information on honey bee health across Canada which will help aid in our understanding of diseases, health, treatment thresholds and BMPs

Intersecting a number of honey bee health topics, breeding and stock security also was a common concern. Methods to better select resistant queens, the geographic origin of queens(most often from other countries), lack of genetic variation, and lack of understanding of regional needs in traits were all discussed. The large-scale 'omics projects will go far towards better selection methods for more disease resistant colonies.

While not as common as the above topics, a few respondents stressed the need for a more holistic approach to research and management of honey bee (and pollinator) health issues. The common theme from these respondents was that we need more examination of what constitutes a healthy ecosystem for bees, how to implement that, and greater support for habitat preservation and restoration initiatives.

Identified areas where research, policy, and action is sufficient in Canada (Q5) resulted in much fewer answers from each respondent, and in many cases, respondents were unable to think of any areas where this was the case (33% of responses). However, that in itself provides consensus that research is needed in many areas. When an area of sufficiency was provided, the most common answer was that we have sufficient data on effects of neonicotinoids, yet action and policy sometimes were identified as lacking. Also, non-neonicotinoid pesticide toxicity, action, and policy were said by many to be relatively robust within Canada. Others identified where in some cases there was sufficient research, policy, and action into specific pests and diseases such as *Varroa destructor*, American foul brood, tracheal mites, and *Nosema* spp.

Finally, the question on initiatives in other parts of the world that Canada could draw on (Q6) provided some strong consensus among respondents. Many answered that honey bee health in Canada would be well-served by having more, large, national, and international-scale programs that were better funded as is the case in the US and EU. Reponses to this question also included general statements that there is a need for non-industry (non-biased) research and more non-profit national initiatives that support bee health issues. Co-ordination with other countries in research and monitoring was stated as important. Two other answers that were very common among respondents (almost 50% of responses) were the great need in Canada for more federal or other support for landscape level agroecosystem management, and greater emphasis on extension and tech-transfer activities, both of which are move extensive and well-funded in the US and EU.

4. Pests, Diseases, and Pathogens

4.1 Chapter Highlights

- There is an identified need for baseline and longitudinal studies to gauge the current status of bee health.

- There are continued challenges when dealing with *Varroa* mite.
- Regional issues with small hive beetle (*Aethina tumida*), and greater biosecurity issues are also a key concern in terms of limited capacity.
- Viruses (their interactions, spread, and treatment) are not receiving sufficient attention.

4.2 Background

Honey bee health is challenged by bacterial, fungal, protozoan, and viral disease; parasitic mites; and other insect pests. Factors affecting honey bee health are numerous, however, *Varroa* mites have been the primary health concern for beekeepers, researchers, and government health officials since their arrival in Canada in the 1980s. Many bee pests and diseases are commonplace and their treatment is part of regular hive management. *Varroa destructor* is present in honey bee colonies in all parts of Canada with the exception of isolated regions such as parts of Newfoundland. Key strategies in managing *Varroa destructor* focus on treatment as the prevention of spread and eradication are highly unlikely.

4.3 Documents and open scientific reviews

Resources outlining honey bee pests and diseases most commonly exist in the form of published documents (books and manuals) that are periodically updated as well as and technical notes or bulletins put out by Provincial Ministries and beekeeping organizations. Information on treatments, best management practices, and prevention is most accessible to beekeepers through the outreach and extension resources mentioned above, as well as through product information sheets put out by manufsacturers. Few end-users of this information make use of peer-reviewed scientific publications as the nature and specificity of these items is not in a format that allows for easy decision making in the field. Honey Bee Diseases and Pests third edition updated and edited in 2013 is cited and documented as a consistent resource for general background, diagnosis, and treatment of pests and diseases in Canada. The recently completed Honey Bee Best Management Practices: Canadian Industry Gap Analysis and Harmonization also provides a thorough and practical review of resources available for monitoring, control, and treatment of bee diseases and pests (Eccles et al. 2015). A more recent document by Eccles et al. is being completed at the time of this report. Regionally specific bee health documents include web resources provided by the Province of Ontario and Alberta, as well as CAPA and in some cases local beekeeping organizations.

Ontario:http://www.omafra.gov.on.ca/english/food/inspection/bees/intro-bee-pests.htm

Alberta:http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/prm13239/$FILE/2014-recommendations.pdf

4.4 Interviews with Canadian Researchers and Stakeholders

We interviewed 12 stakeholders who identified their area of research as either directly or indirectly related to pests and disease. The majority of researchers are actively working in *Varroa* mite management and treatment, either developing new miticidies or new and alternative treatments to *Varroa* mite. Another significant category of research is the investigation of how synergisms between pesticides, fungicides, and nutrition affect resilience to *Varroa* mite and other pathogens and pests.

Some limited work is being conducted on viruses, although the emphasis is lower than on other areas of bee health. This current research specifically deformed wing virus (DWV) and Israeli acute paralysis virus (IAPV). Respondents identified a key need to better understand the risks associated with viruses, as well as a general gap in understanding the status quo of virus load in managed colonies. The development of a baseline for pest and pathogen loads in Canadian colonies were noted as areas for growth.

Concerns mentioned very consistently by those interviewed included limitation in treatment options for *Varroa* and *Nosema* spp. Limitations are driven by a generally narrow spectrum of products available (as compared to some products in the US for *Varroa* treatment), a lack of alternative products, resistance (both in the case of *Varroa* and *Nosema*), and in particular a lack of products that can be used to treat *Varroa* during critical hive phases such as honey production. Options are almost completely lacking for what beekeepers can use during this time.

Biosecurity issues relating to the introduction of new pests, diseases, and pathogens into Canada from outside of our borders, and the movement and spread of pest, diseases, and pathogens regionally, have been mentioned as significant issues and areas for concern. Some regions/provinces have monitoring programs (i.e., Alberta and Ontario), but inspection rates are considered too low to detect emerging pathogens. Synergies and communication between groups and levels of regulation is also an issue. Threats posed by small hive beetle were noted many times as a concern in terms of a lack of control and prevention strategies.

4.5 Gaps Identified by Literature Review and Interviews

Table 2 Gaps in pest, disease, and pathogen research globally and in Canada as identified in review papers and through interviews with stakeholders. The list is meant to be a general list and while we tried to be comprehensive it is not necessarily an exhaustive list of gaps.

Gap	Identified by
lack of longitudinal data on pests, disease, and pathogens that would allow for and understanding of "normal bee health" as a baseline.	Stakeholder interview
lack of alternatives for *Varroa* mite treatment.	Stakeholder interview
lack of treatments that can be used in conjunction with honey flow.	Stakeholder interview
lack of treatment options for *Nosema ceranea*.	Stakeholder interview

general lack of understanding of viruses and their impact on bee health.	Stakeholder interview
lack of consistent monitoring and biosecurity networks for the prevention of small hive beetle spread.	Stakeholder interview

4.6 Current Canadian Research and Capacity

Research (see Electronic Supplement 1 and the Interactive map of Canadian research) specifically into pest and disease is being conducted at a number of research facilities across Canada (PI in brackets) including:

Varroa

- Chemical attractants and repellents for *Varroa* mite, pests and diseases (PI Shutler).
- Effects of miticides and agricultural pesticides on *Varroa destructor*, and on the health and behaviour of honey bee pests and diseases, pesticides (PI Guzman).
- Management of *Varroa* mites and viruses (PI Parsons).
- Interaction of clothianidin with *Varroa destructor* and deformed wing virus and their effect on the health of brood and adult honey bees (PI Guzman).
- Developing alternative tools for an IPM for *Varroa* and *Nosema* pests and diseases, pesticides (PI Nasr).
- Genomic selection of *Varroa* sensitive hygiene in honeybees (PI Giovenazzo).
- Copper device at hive entrance: an alternative way to control *Varroa destructor* (PI Fournier).
- Developing alternatives treatments (chemical and cultural) for *Varroa* mite (PI Bayer).
- *Varroa* gate tests in Canada (PI Bayer).
- *Varroa* resistance as part of the 'omics study (PI Foster)

Management to improve health

- Addressing Saskatchewan's Winter and Pest Challenges (PI Parsons).
- Saskatchewan beekeepers adapting technology to meet their needs: hive health, colony mortality and productivity (PI Parsons).
- Next generation IPM for beekeeping (PI Foster).

New Treatments for pathogens

- Developing biosecurity field management practices for bee viral and *Nosema* spp. diseases in Alberta (PI Nasr).
- Development of designer drugs for bee viruses' treatment (PI Nasr).
- Prebiotics: a new tool for bee health (PI Giovenazzo).

Resistance

- Honey bee stock evaluation, reproduction and genetic selection for resistance (PI Giovenazzo).

Viruses

- Pathogen spillover of viruses in native bumble bees (PI Currie).
- Impact and control of viruses associated with honey bee comb (PI Currie).

Pests – non-*Varroa*

- The Small hive beetle (*Aethina tumida* Murray, Coleoptera : Nitidulidae) : surveillance and control (PI Giovenazzo).

Monitoring and surveillance

- National Survey Health of Bee Pollinators in Canadian Agriculture (PI Pernal).
- Honey Bee Health Surveillance in Canada Sentinel hive monitoring (PI Bayer).

4.7 Outstanding Gaps in Canadian Research

A review of relevant literature, manuals, and interviews with stakeholders have identified the following gaps in research relating pest and disease management:

- Nation and regional longitudinal studies that will develop a baseline.
- Alternatives and enhancements in *Varroa* mite treatment, especially those that can be used during honey production and harvest.
- Understanding a full range of viruses and their impact on bee health.
- Biosecurity networks for the prevention of small hive beetle spread, as well as other diseases and pathogens.

4.8 Conclusions and Recommendations

Accessibility to and awareness of resources and current information on managing pests and disease is not limited in Canada, however, a more regionalized and locally responsive approach could be developed. In particular, locally specific information may be lacking where there are smaller audiences (Atlantic Canada for example). General deficiencies in pest and disease management are centered on a lack of alternatives and advances in treatment options, especially where resistance can be an issue. This is true of *Varroa* and *Nosema* as it was pointed out that the available options are limited, and perhaps declining in effectiveness. Developing treatment options that allow interventions throughout the hive management cycle is also a key recommendation as many beekeepers encounter challenges with treating for pests during honey production. Research is actively addressing these points, but should also be encouraged to be ahead of pests, pathogens and disease.

5. Forage and Nutrition

5.1 Chapter Highlights

- Innovation in supplements and feeds is stagnant and are focused on the average colony.

- There is a stated need for supplements and feeds to enhance deficits in alternative parts of colony development.
- There is a lack of transparency in supplement ingredients, as well as a lack of standards, and general regulation – additional rigour in this system would benefit overall honey bee nutrition.
- Little is known about the nutritional value of field-based forage.
- There is a desire to develop complementary plantings or synthetic supplements to support honey bees during crop pollination, however, a basic understanding of the nutritional value of pollen and nectar is needed.

5.2 Background

Honey bees have high, specific, and changing nutritional demands as they progress through their life cycle and as the colony matures and moves through the seasons. Having "well fed" bees is mentioned as a key factor in colony growth, honey production, disease and pest resistance, pollination service provisioning, and overall resilience to pesticides and other environmental factors. However, there has been less specific research into how complete nutrition can be maintained and promoted, especially with planted or natural forage and in conjunction with crop pollination services.

Beekeepers can, and do, provide managed honey bee hives with either *supplements* that aim to enhance or supplement their current foraged diet or they can be provided with *substitutes* intended to provide the full range of protein, lipids, and nutrients required. Of course, bees can also forage in natural areas, on crops, or cover crops. Pollination service contracts provide pollen and nectar sources for bees, but these are not necessarily what is needed or ideal for colony health.

5.3 Documents and open scientific reviews

Complete and complied scientific documents outlining honeybee nutrition are generally dated. This is the case globally, not just in Canada. Industry research is active in the development and production of commercial diets and supplements, but it should be noted that bee feed products make up a minor component of most commercial markets, and therefore receive much more limited attention. Furthermore, beekeepers often have their own ways of delivering supplements, merging technical advising and adaptive management in the field.

Within Canada resources outlining bee nutrition include Beekeeping in Western Canada published in 1998 and fact sheets from BC, Ontario, Alberta and Quebec that provide basic outlines of diet and supplements for bees. Current published research on field based forage and the nutritional value of crops is fundamentally lacking. Some limited fact sheets exist regarding habitat on farms for honey bees, but these resources only outline plant species that should attract honey bees, or ones for which there is evidence of honey bee use or an understanding of nutritional value.

Classic and foundational references on bee nutrition, including the protein, lipid, and carbohydrate composition of some pollens include:

Table 3 Documents on nutrition and supplements for honey bees.

Resource	Date published	Focus
Barker, R. J. 1977. Some carbohydrates found in pollen and pollen substitutes are toxic to honey bees. Journal of nutrition 107:1859-1862.	1977	pollen
Dietz, A. 1975. Nutrition of the adult honey bee. In the hive and the honey bee, chapter v. Dadant & Sons, Hamilton, Ill.	1975	bee
Haydak, M. H. 1970. Honey bee nutrition. Annual review of entomology 15:143-156.	1970	bee
Johansson, T. S. K., and M. P. Johansson. 1976. Feeding sugar to bees. Bee world 57(4) :137-142.	1976	supplements
Johansson, T. S. K., and M. P. Johansson. 1977. Feeding sugar to bees. Bee world 58(1):11-18.	1977	supplements
Johansson, T. S. K., and M. P. Johansson. 1977. Feeding sugar to bees. Bee world 58(2) :49¬52.	1977	supplements
Johansson, T. S. K., and M. P. Johansson. 1977. Feeding sugar to bees. Bee world 58(2) :49¬52.	1977	supplements
Johansson, T. S. K and m. P. Johansson. 1977. Feeding honey bees pollen and pollen substitutes. Bee world 58(3) :105-118.	1977	supplements
Standifer, l. N W. F. McCaughey, F. E. Todd, and a. R. Kemmerer. 1960. Relative availability of various proteins to the honey bee. Annals of the entomological society of America 53(5):618-625.	1960	pollen
Standifer, l. N F. E. Moeller, N. M. Kauffeld, and others. 1978. Supplemental feeding of honey bee colonies. U. S. Department of agriculture, agriculture information bulletin 413, 9 p.	1978	supplements
Nicolson SW, Thornburg RW. 2007. Nectar chemistry. In Nectaries and Nectar. Edited by Nicolson SW, Nepi M, Pacini E. Springer;:215-264.	2007	nectar
Roulston TH, Cane JH. 2000.Pollen nutritional content and digestibility for animals. Plant Syst Evol 2000, 222:187-209.	2000	pollen
Baker HG, Baker I. 1979. Sugar ratios in nectars. Phytochem Bull V 1979, 23:43-45.	1979	nectar

5.4 Interviews with Canadian Researchers and Stakeholders

Nutrition and supplementation of honey bees was discussed by approximately half of respondents as a major gap in our research and/or one of the top priorities for research in honey bee health. Continued research into diets and supplements exists, but innovation and alternatives are not being developed. The majority of this work focuses on developing products that are high in protein content to support colony growth and brood development. Emerging research into forage preferences and use of common crops or flowers is growing but presently at a very rudimentary stage, especially when compared to work from the United States and Europe.

5.5 Gaps Identified In Literature Review and Through Interviews

Table 4 Gaps in honey bee nutrition and supplemental feeding research globally and in Canada as identified in review papers and through interviews with stakeholders. The list is meant to be a general list and while we tried to be comprehensive it is not necessarily an exhaustive list of gaps.

Gap	Identified by
Understanding the nutritional composition of common crops, cover crops, forage plants, and wildflowers/weeds that are used by honey bees.	Stakeholder Interview
Development and testing of forage seed mixes for use on marginal or managed land near agriculture. Understanding what plant species are preferred and used by honey bees and which provide the best nutritional value.	Stakeholder Interview
Understanding the variability of pollen and nectar value based on growing conditions/site/management.	Stakeholder Interview
Developing complementary supplements or feeds for crop-specific scenarios.	Stakeholder Interview
Developing guidelines for the use of supplements and feeds to complement deficits that occur throughout the colony life cycle and in specific pollination scenarios.	Stakeholder Interview
Developing complementary forage planting recommendations for crop-specific scenarios.	Stakeholder Interview
Developing cost-benefit models to encourage the use of forage or other on-farm management techniques to support honey bee nutrition.	Stakeholder Interview

5.6 Current Canadian Research and Capacity

Few researchers and stakeholders are actively pursuing innovations in supplements or bee diets. It appears that innovation in synthetic/commercial diets is not considered a priority and from the production perspective the current set of available set of feeds and supplements is viewed as sufficient at least from an industry perspective. The composition and structure of feeds and supplements is, however, not clear. Often these diets are proprietary, with ingredients and components not being listed our outlined. There is certainly concern that honey bee feed and supplements are static and innovation in this area is not being driven by true demand and needs of honey bees. There is an interest in developing an understanding of forage-based nutritional support but no specific research studies have been completed. Active research into bee nutrition and forage includes new investigations into prebiotics and probiotics as well as some studies of forage and crop scenarios. Six studies are currently focusing on bee nutrition and forage and can be found in in the supplemental research table. A general summary of the topics under study includes:

- Using prebiotics to maximize bee health nutrition and resistance to disease and pathogens (PI Giovenazzo).

- Understand how probiotics can improve hive health alone or in combination with other nutritional supplements (PI Baines).
- Measuring the effectiveness of bee attractive areas (biodiversity and abundance) near and on farms and on golf courses to develop an understanding of preferences and potential planting guidelines (PI Syngenta).
- Testing preference and use of common cover crops by honey bees for potential on-farm seeding and forage support (PI Wojcik).
- Developing optimal seed mixes and land management practices for blueberry pollination aiming to look at crop ratios, habitat planting, and the use of riparian areas and other non-productive areas to support bee forage (PI Syngenta).
- General honey bee nutrition studies in the east that aim to understand field and supplement food sources (PI Cutler).

5.7 Outstanding Gaps in Canadian Research

The role that natural or planted forage can play in honey bee nutrition is a significant gap highlighted by many key experts, even those that do not indicate their area of expertise as nutrition. Areas where more investigation and research are needed include:

- Understanding the nutritional composition of common crops, cover crops, forage plants, and wildflowers/weeds that are used by honey bees.
- Development and testing of forage seed mixes for use on marginal or managed land near agriculture.
- Understanding the variability of pollen and nectar value based on growing conditions/site/management.
- Developing complementary supplements or feeds for crop-specific scenarios.
- Further development of supplements and feeds and an increase in transparency for ingredients.
- Developing guidelines for the use of supplements and feeds to complement deficits that occur throughout the colony life cycle and in specific pollination scenarios.
- Developing complementary forage planting recommendations for crop-specific scenarios.
- Developing cost-benefit models to encourage the use of forage or other on-farm management techniques to support honey bee nutrition.

5.8 Conclusions and Recommendations

Capacity in bee forage and nutrition ranks low compared to other aspects of bee health in Canada. Consensus from interviews indicates that our understanding for natural and field based forage for honey bees is limited. Basic data is needed to understand the nutritional value of crops and wild flowers so that management strategies can be developed that target deficits. The role of natural landscapes and seeded areas in bee forage and nutrition is very much unknown throughout Canada. While more data on honey bee use and association with natural and planted forage exists in other countries (US, Europe, Australia) there is still a general deficit in understanding how to manage bee nutrition with forage planting and supplemental feeding for crop-specific scenarios. A key recommendation is filling the gap in forage and nutrition with an emphasis on regionally specific approaches. A unique opportunity exists in Canada for forage research given its' limited status; new programs can be developed from the ground up to successfully address regional issues.

6. Pesticides

6.1 Chapter Highlights

- Neonicotinoid use and effect on bees remains controversial in Canada and globally.
- Tier I and II studies show effects such as brood development and foraging behavior, but usually at application rates higher than what would be encountered in the field.
- Tier III studies show no effects on honey bees of neonicotinoid seed treatments but these studies suffer from inherent problems of low replication and/or lack of control over exposure rates.
- Canadian stakeholders mainly indicated that there were satisfactory levels of research into neonicotinoids, and that they likely are not a major driver of colony losses.
- Gaps exist on effects of neonicotinoids on honey bees, some currently are being examined within Canada.
- Conventional classes of crop pesticides can be harmful to bees but risk is low with current label restrictions.
- In-hive pesticides may be overused and/or misused and may be causing added stress to bee health.
- Priorities for future research should focus on interactions among stressors, including pesticides, rather than studies on effects of neonicotinoids in isolation.

6.2 Background

One of the contributors to honey bee colony loss and poor health is thought to be agricultural land use intensification and resultant exposure to crop insecticides (Vanbergen et al. 2013, Williams et al. 2015, Calatayud-Vernich et al. 2016). Levels of toxicity to honey bees of most current and past insecticides are well-established, and mitigation measures commensurate with toxicity are imposed to reduce impacts on honey and other bees.

However, a new class of insecticides, neonicotinoids are the fastest growing group of pesticides, and currently are considered the most important class of insecticides, making up over 80% of the global market (Jeschke et al. 2011). At their introduction in the early 1990's, they were seen as a good alternative to organophosphates, due to high selectivity to invertebrates over vertebrates, their systemic nature which allows them to be taken up by plant tissue, and that they can be applied in small quantities as seed treatments (Jeschke and Nauen 2008). Because they mainly are used as systemic pesticides, they can be present in all parts of the plant including pollen and nectar, and therefore mitigation measures used for traditionally applied insecticides, such as restricting application to when the crop is not in bloom, cannot be used. In this chapter we focus on past and current research on neonicotinoids, other crop pesticides, and in-hive pesticides used to control honey bee pests and diseases.

6.3 Neonicotinoids

6.3.1 Background

Neonicotinoids were first used commercially in the early 1990s and are now the most widely used insecticide in the world, with approximately 140 registered uses (Jeschke et al. 2011). Neonicotinoids act selectively on the insect central nervous system and there is no known cross-resistance to the older insecticide classes that they have largely replaced including pyrethroids, chlorinated hydrocarbons, organophosphates, and carbamates (Jeschke and Nauen 2008).

Neonicotinoids can be used by soil applications, foliar sprays, or seed treatments. The primary concern comes from the use of the three main neonicotinoids, in the N-nitroguanidine group, imidacloprid, clothianidin, and thiamethoxam. They have been shown to be highly toxic to honey bees and other bees in laboratory tests (Iwasa et al. 2004, Bailey et al. 2005, Scott-Dupree et al. 2009, Wu et al. 2015). When used as seed treatments, exposure and risk cannot be mitigated like it can with foliar applications. Depending on factors such as the crop, climatic conditions, and rate applied to seeds, neonicotinoids are expressed in varying amounts in pollen and nectar.

While the issue of neonicotinoids has been extremely contentious, the intense focus on this class of pesticide has had the benefit of stimulating a huge amount of recent research into the effects of neonicotinoids on bees (Lundin et al. 2015). Yet, despite the great amount of attention that has been paid to neonicotinoids and the number of lab, semi-field, and to a lesser extent, field studies now available, much controversy remains in stakeholder opinion and policy.

6.3.2 Documents and open scientific reviews

Key documents and recent reviews (2011-2016) are summarized in Table 5. There are a number of current, comprehensive reviews, and we briefly summarize some of the major reviews and their conclusions.

Table 5 Recent reviews documents and scientific publications on effects of neonicotinoids on honey bees (2011-2016)

Methods	Results	Conclusions	Reference
Meta-analysis of fourteen studies of the effects of imidacloprid on honey bees under laboratory and semi-field conditions. Lethal and sublethal effects. Created dose-response relationship of field-realistic doses. Statistical power tests of field studies.	Field-realistic doses, in nectar and pollen of seed treated plants, virtually no effect on adult honey bee mortality laboratory and semi-field conditions under either acute or chronic dosing. Field-realistic doses cause sublehtal effects to adult honey bee performance up to 20%. Field trials had too low power to detect effects.	Suggests the presence of trace dietary neonicotinoids is not, in itself, the cause of catastrophic mortality, such as is associated with CCD. But, given current gaps in research (how sublethal lab findings translate to the field, field trial lack of power, realistic bee foraging exposure, synergy of stressors) not currently possible to assess impact of neonicotinoids on the health and fitness of honey bees in the field.	Cresswell 2011
Review of environmental neonicotinoid residue levels in plants, bees and bee products, effects with special attention for sublethal effects, usefulness for evaluation of neonicotinoids of an already existing risk assessment scheme for systemic compounds.	Residues below acute and chronic effect levels in nectar and pollen (but lack of reliable data). Many lethal and sublethal effects in lab studies but none in field studies at realistic levels.	Residues in pollen and nectar low but not enough data for high confidence, and levels may accumulate with continued use. Need more testing on field-realistic concentrations at relevant exposure and durations, and continue side-effect evaluation over winter and the next year in spring.	Blacquire et al. 2012
Literature review of neonicotinoid use, economics, persistence, accumulation, transfer to other environments, toxicity across taxa and pollinators, nectar and pollen residues	Use as seed treatment has reduced IPM, little evidence economic benefit, long half life in soil, soil yearly accumulation expected, mean max seed dressing in nectar: 1.9 ± 0.5 ppb, pollen: 6.1 ± 2.0 ppb. Higher concentrations from foliar application. Strong evidence of sublethal effects.	Loss of IPM significant. Accumulation a serious threat. LC_{50}s and concentrations in nectar and pollen unlikely to have immediate impact on honey bees. Bees could accumulate harmful levels depending on metabolization and excretion. Evidence suggests little direct mortality from seed treated crops to honey bees, but sublethal impacts likely. Lack of studies to other routes of exposure and accumulation problematic for making recommendations.	Goulson 2013

Regulatory risk assessment, imidacloprid applied as a seed treatment or granules on a variety of crops, from submitted studies, literature, and available EU evaluations and monitoring data. Gaps identified.	Exposure to residues succeeding crops in nectar, pollen, or guttation fluid could be a concern but data gap. Exposure from weeds in crop deemed low risk. High acute risk to honey bees from exposure via dust drift for uses in cereals, cotton, maize and oilseed rape. High acute risk for exposure via residues in nectar and pollen for uses in cotton, oilseed rape, and sunflowers.	Insufficient data to make conclusions for most crops, exposure routes, and impact type. In some crops and exposure routes, high (e.g., dust and nectar or pollen) or low risk was identified. **Exposure from pollen and nectar:** only uses on crops not attractive to honey bees were considered acceptable. **Exposure from dust:** risk to honey bees was indicated or could not be excluded. **Exposure from guttation**: Only one study and it showed acute effect.	EFSA 2013a,b,c
Collected incidence reports of pesticide impact on honey bee death in Canada as reported to the PMRA since incidence reporting began in 2007. Looked at category (major, medium, and minor) and cause (neonicotinoid, other pesticide, both).	110 incident reports, mostly from 2012-2013. Much missing data in reports. Neonicotinoids suspected in majority of reports, 91% 'minor'. Most major incidences due to non-neonicotinoid pesticides.	While significant bee deaths during corn planting with neonicotinoid coated seeds, most neonicotinoid incidences minor. Major/Moderate incidences from other pesticides ignored by popular press. Risks due to dust need to be mitigated, but older pesticides as foliar sprays can be more damaging to bee colonies. Deregistration of neonicotinoids in North America could cause growers to revert to increased use of old broad-spectrum pesticides.	Cutler et al. 2014
Regulatory risk assessment, all uses other than seed treatment and granules on a variety of crops, from submitted studies, literature, and available EU evaluations and monitoring data. Gaps identified.	For all the authorised uses, high risks were identified or high risks could not be excluded or the risk assessment could not be finalised. Uses in greenhouse, a low risk to honeybees was concluded for all exposure routes except from residues in surface water. Risk for honeybees from residues in surface water could not be finalised with the available information.	High risks were identified or could not be excluded. In other cases the risk assessment could not be finalised due to data gaps. Use of the three substances in seed or soil treatments is currently prohibited on crops attractive to bees and on cereals other than winter cereals, except for uses in greenhouses. Use in foliar treatments is prohibited on crops attractive to bees and on cereals, except in greenhouses or after flowering.	EFSA 2015a,b,c

Review of state of experimentation on bees and neonicotinoids, with gaps identified. Web of Science and PubMed search up to Jun 2015: (neonic* OR imidacloprid OR clothianidin OR thiamethoxam OR acetamiprid OR thiacloprid OR nitenpyram OR dinotefuran) AND (*bee OR *bees).	268 publications matched criteria. Half studies in last 3 yrs. 82% studies from Europe and North America. 112 studies laboratory, 92 field, 14 semi-field, 12 in silico (modelling), 25 combined approaches.	Large amount of research but still significant gaps. Field studies outside Europe and North America needed. Few studies on fruit and vegetable crops, or exposure from non-crop plants. Most studies on honey bees. Need more lab studies at realistic field levels and feeding regimes. No clear effects of neonicotinoids found in field studies on honey bees. But, low power in studies and can't control free-flying bees.	Lundin et al. 2015
'Restatement' of relevant evidence on neonicotinoids and bees, in a succinct way relevant to policy makers. Attempts to be policy-neutral, and weigh alternatives. Categorical system to describe nature of evidence. Consensus judgement by experts.	Average maximum in nectar and pollen 20 studies from seed treatment: 1.9, 6.1 ng/g. Higher with other application methods. 10^4 higher in guttation fluid. Dust drift is a source bee mortality, mitigation measures seed formulation. Other routes of exposure (eg, non-target plants, water) are of concern. Landscape and temporal exposure unclear. Sublethal effects at field realistic levels	Levels in nectar and pollen nearly always lower than acute effects level. Extent of exposure, spatially and temporally is poorly understood. Sublethal effects well-established at realistic levels. But application to the field uncertain. Most likely not a primary driver of honey bee loss, but could be contributing stressor. Many gaps in the knowledge and unable to provide much guidance to policy makers at this time.	Godfray et al 2014, 2015
Based on data submitted to the USEPA and available information from open scientific literature, and was conducted according to the 'Guidance for Assessing Pesticide Risks to Bees' collaboratively created by the PMRA, the USEPA, and the CDPR.	For all crops and application methods where on-field exposure is expected, there are risk levels of concern. Could be risk for all foliar uses off-field from spray drift. When crops are not attractive to bees there is low risk.	Risk is crop and application specific. In some crops and application methods, low risk was found. In other cases, there is the potential for risk to honey bee individuals and colonies. There are uncertainties due to lack of Tier II and Tier III studies.	USEPA 2016

Based on data submitted to the PMRA and available information from open scientific literature, and was conducted according to the 'Guidance for Assessing Pesticide Risks to Bees' collaboratively created by the PMRA, the USEPA, and the CDPR.	Potential risk from foliar application varies with application timing, but label restrictions minimize risk. Soil applications may pose risk, which varies based on amount used and timing pre-bloom. Lack of studies on Canadian crops for all application methods.	Foliar applications do not pose risk if not used before or during bloom on bee-attractive crops. Soil applications can pose risk for some crops and soil types. No potential risk indicated for seed treatment. Uncertainty in some areas due to lack of data on Canadian crops. Additional mitigation will be based on final assessment.	PMRA 2016

At the request of the European Commission, the European Food Safety Authority has produced a number of comprehensive reviews of literature on the impacts of imidacloprid, clothianidin, and thiamehoxam on bees for use in regulatory risk assessment (EFSA 2013b, a, c, 2015b, a, c). The reviews assessed risk to bees from seed treatments and other applications, derived from submitted studies and literature data, as well as European Union evaluations and monitoring data.

They concluded, where there was enough data to complete the risk assessment, that there was risk to bees from exposure to nectar and pollen from some uses of neonicotinoids. They found a high risk to bees from exposure to dust during planting of treated seeds. And, that there was little data on risk from guttation fluid but the few available studies showed acute effect on honey bees. These findings applied to all 3 neonicotinoids. Following these findings, the EU imposed a ban on neonicotinoid use in crops attractive to bees (Dec 2013-present), with a review of new research and the restrictions currently underway (http://www.efsa.europa.eu.ezproxy.library.uvic.ca/en/data/call/150522).

the USEPA published a review of the effects of imidacloprid on bees in early Jan 2016 (USEPA 2016). The document will be updated at the end of 2016 with all new information that is submitted. They used a three category system to identify 1. low risk, 2. uncertain or unknown risk, and 3. risk to individual bees. Registered uses that ranked in the highest risk category were for citrus and cotton, not crops that are relevant in Canadian agriculture. Tier III studies were lacking for much of the registered uses that ranked in categories 2 and 3 for risk, but many are expected to be completed within 2016. Table 1-2 in the USEPA (2016) document is useful for determining level of risk of various uses, and where data is insufficient to determine risk.

Similarly, the Canadian Pest Management Regulatory Agency (PMRA) recently produced a re-evaluation of the effects of imidacloprid on bees (PMRA 2016). The review was based on data submitted to the PMRA and available information from open scientific literature, and was conducted according to the 'Guidance for Assessing Pesticide Risks to Bees' collaboratively created by the PMRA, the USEPA, and the CDPR.

The report concluded that there was potential risk to bees from foliar applications, but that label restrictions, such as no application allowed pre- or during-bloom for bee-attractive crops, minimize risk on fields. There is some risk to bees from soil applications for some crops, but few field studies in Canada. No potential risk was concluded for seed treated crops in Canada based Tier II and Tier III studies, which showed no notable effects on honey bees. Residues in pollen and nectar of seed treated crops typically are below risk levels for individuals and honey bee colonies. Appendices III - VII of PMRA (2016) shows risk conclusions for registered imidacloprid uses as of 17 August 2015. They note multiple areas where risk is uncertain in the field, at the colony level, largely due to field exposure uncertainty and lack of Tier II and III studies relevant to Canadian crops and application rates. The PMRA is considering comments received from the public in response to this document and will publish a Decision document with a final pollinator risk assessment. They anticipate the final review will be complete in December 2016.

Reviews in the open scientific literature generally indicate minimal field risk to bees from neonicotinoid treated seeds, and that neonicotinoids alone likely are not the primary driver of colony losses, but also note a number of knowledge gaps (Cresswell 2011, Blacquiere et al. 2012, Cutler et al. 2014, Godfray et al. 2014, Godfray et al. 2015). Others note evidence of sublethal effects that could cause colony impacts (Goulson 2013), and that the significant gaps in many areas are still too great to make conclusions (Lundin et al. 2015).

6.4 Other Crop Pesticides

6.4.1 Background

While much attention is being paid to neonicotinoids and their effects on honey bees in the media by regulatory bodies, other pesticides likely pose harm to bees and should be considered when addressing honey bee health. There are well-established protocols for testing emerging pesticides on honey bees prior to registration. The recent joint document by the EPA, PMRA, and CDPR (2014), "provides guidance to risk assessors for evaluating the potential risk of pesticides to bees, particularly honey bees (*Apis mellifera*)." It describes a tiered approach to testing, starting with laboratory toxicity tests and increasing to more field-realistic testing if levels of concern are surpassed and risk mitigation measures will not sufficiently reduce risk quotients. Studies should include different life stages and castes.

Due to relatively comprehensive toxicity testing on honey bees required for registration of crop protection products, there is less concern about the individual effects of these products in recent years than in the past when pest control product testing on honey bees prior to registration was less rigorous. Products deemed toxic to bees generally are registered for use on crops not attractive to bees or during crop stages that are not attractive to bees.

Despite this relative confidence in safety of modern non-neonicotinoid crop pesticides, a number of concerns remain. For instance, few tests of sublethal effects on honey bees are required which limits ability to predict pesticide effects at the colony level, and appropriate mitigation measures. Also, pesticide drift to non-target plants, accumulation in the environment, and other sources of exposure to honey bees are not well-studied. And finally, possible synergistic effects among multiple pesticide products may be occurring yet, are not well-studied (Mullin et al. 2010).

6.4.2 Documents and open scientific reviews

Recent reviews on effects of pesticides on honey bee health show potential for lethal and sublethal effects (Desneux et al. 2007, Johnson et al. 2010, Johnson 2015)(Table 6). Lethal effects to honey bees are not thought to be a common occurrence in Canada, largely due to label restrictions of the more toxic compounds. There were a total of 31 honey bee health incidences reported to PMRA as a result of non-neonicotinoid pesticides between 2007-2012, with about half of those being major incidents (at least 3000 bees from each of five or more colonies, or 30% of the bees in any one colony, die or exhibit abnormal behavioral effects) (Cutler et al. 2014).

Table 6 Recent reviews on effects of non-neonicotinoid pesticides on honey bees

Methods	Results	Conclusions	Reference
Review of sublethal effects of pesticides including learning performance, behavior, and neurophysiology, focusing mainly on honey bees and natural enemies.	Focus on LD50 misses many sublethal effects of pesticides including. Many laboratory studies show sublethal effects at field doses of various pesticides. Many effect colony honey bee colony health, or health could be buffered by colony structure.	Tests of sublethal effects on honey bees of emerging pesticides are more developed than for other beneficial arthropod groups. Links between sublethal effects and community level effects are not well understood. Standardized testing of sublethal effects prior to registration are needed.	Desneux et al. 2007
literature review of pesticides applied to crops, pesticides used in apiculture and pesticide residues in hive products, and the role that pesticides may play in colony collapse disorder and other colony problems.	GM crops with Bt do not harm bees and may benefit by decreasing pesticide applications. GM herbicide resistant crops can reduce forage. Given sensitivity of honey bees to many pesticides, difficult to make effective varroacides that do not harm the colony. Additional problem of mite resistance.	Widespread use of transgenic insect-resistant crops is beneficial to bees. In-hive pest control products problem for honey bee health, especially unregistered use. Interactions and synergistic effects of hive pesticides and crop pesticides is of concern for honey bee health, but little data on interactions.	Johnson et al. 2010
Large survey pesticide residues in honey bee colonies in the US and Canada	47% of wax and pollen samples had both in-hive acaricides and a fungicide. Pollen in hives contained many pesticides. 98% of comb wax samples were contaminated fluvalinate and coumaphos, and lower amounts of amitraz degradates and chlorothalonil, with an average of 6 pesticide detections per sample and a high of 39.	There is a remarkably high level of toxins and variety of toxins in bee brood and pollen. The effects of these products in combination and direct effect on declining bee health is unknown.	Mullin et al. 2010

Review of literature on xenobiotics from natural and synthetic sources, including in-hive pesticides	Honey bees always have been exposed to toxins and the colony is a repository. Natural toxins used in bee keeping (eg, formic and oxcalic acid, thymol) can cause significant harm to bees, as can some antimicrobial compounds used in-hive. Herbicides can cause indirect effects by reducing forage diversity.	Effects of many pesticides are well-documented in laboratory studies but harder to determine real world effects. Additive or synergistic effects of toxins, and toxins and pathogens, are likely but largely unknown. Toxicity is labile and varies depending on many factors including age, nutritional status, genetics, pathogens etc.	Johnson 2015

6.5 In-Hive Pesticides

6.5.1 Background

In addition to crop protection pesticides, pesticides used in the hive to control mites and other pests may cause significant harm to honey bees (Johnson et al. 2010). *Varroa destructor* is one of the biggest threats to colony health in North America, and growers often need to balance control of this and other in-hive pests with potential harm to honey bees from pesticide use (Johnson et al. 2010).

There are three main categories of varroacides: synthetic organic, natural products, and organic acid pesticides. Since the early 1990's there have been ongoing problems with evolving resistance to products and registration of new products that will provide mite control while not harming honey bees. Individual products registered in Canada must be minimally harmful to honey bees; yet, there is poor understanding of risks to honey bee health when bees are exposed combinations of in-hive pesticides, crop pesticides, and other stressors. In addition, misuse of in-hive pesticides can cause significant harm to colonies

6.5.2 Documents and open scientific reviews

We could find no reviews exclusively on effects of in-hive pesticides on honey bees. However, two reviews on effects of pesticides on bees include effects of in-hive pesticide products (Johnson et al. 2010, Johnson 2015)(Table 6). Johnson et al. (2010) commented that, "Beekeepers searching for the primary source of pesticides contaminating bee hives need only to look in a mirror". While referring to beekeeping in the US, there is little doubt there also are problems of overuse and misuse of in-hive pesticides in Canada. Direct impacts to honey bees of these combinations of pesticides are as of yet unknown.

A survey of pesticide residue in honey bee colonies in the US and Canada found a high load of toxins in bee brood and pollen (Mullin et al. 2010). Residues of miticides from in-hive applications were found in progressively greater concentrations from honey to pollen to beeswax. Similar to Johnson et al. (2010) and Johnson (2015), they concluded that there likely were effects of these high loads of in-hive and crop pesticides, yet there is no direct evidence that it is resulting in declining honey bee health. Effects of combined pesticide exposure on honey bee colony health remains a crucial area for future study.

6.6 Interviews with Canadian Researchers and Stakeholders

With respect to neonicotinoids, three of 22 respondents identified research into neonicotinoids as a gap in our understanding, limiting our ability to support healthy honey bee colonies. Respondents that felt that Tier III or field studies were required, and should be the priority over additional lab or semi-field studies. Similarly, only two respondents mentioned neonicotinoids as one of the top three issues in honey bee health.

Of the respondents that discussed neonicotinoids, most felt that with limited resources, intense focus on effects of neonicotinoids was taking away from research in areas of honey bee health that they thought were more important. These responses were highly contrary to media attention and public sentiment on the issue of pesticides and bee health, particularly neonicotinoids.

Some respondents felt that more prescriptive rather than pre-emptive use of pesticides (in-hive and crop) would go a long way towards having healthier honey bee colonies. These respondents strongly felt that fewer pesticides, greater use of IPM, and more focus on healthy ecosystems and a holistic approach to research were crucial.

The majority of respondents were concerned with gaps in our knowledge of interactions among multiple stressors. More than half of the respondents felt that research into interacting stressors such as in-hive pesticides, crop pesticides, lack of forage, and pests and diseases was urgently needed. While exposure to pesticides, within hives and from crops, likely is an added stressor to honey bees, most respondents felt it was not a primary driver of colony loss.

6.7 Gaps Identified from Literature and Interviews

Table 7 Gaps in neonicotinoid, other crop pesticide, and in-hive pesticide research globally and in Canada as identified in review papers and through interviews with stakeholders. The list is meant to be a general list and while we tried to be comprehensive it is not necessarily an exhaustive list of gaps.

Gap	Identified by
neonicotinoids	
Sublethal impacts on learning, behaviour, and fecundity and chronic exposure	Cresswell 2011, Goulson 2013, EFSA 2013a,b,c
Possible synergies between neonicotinoids and other stressors such as other pesticides, pests, and diseases	Cresswell, 2011, Goulson 2013, Lundin 2015, stakeholder interviews
Data on agronomic and economic benefits of neonicotinoids	Cresswell 2011, Goulson 2013, stakeholder interviews
Lab studies at more field-realistic levels	Cresswell 2011, Lundin 2015
Studies on life stages and castes other than adult worker bees	Cresswell 2011
Studies on concentrations of neonicotinoids in nectar and pollen in agricultural settings, exposure levels in field, field effects on colonies including sublethal effects (Tier III studies)	Cresswell 2011, EFSA 2013a,b,c, EFSA 2015a,b,c, Lundin 2015, USEPA 2016, stakeholder interviews
Studies on residue levels and exposure in many crops from all other application methods (other than seed dressing)	EFSA 2013a,b,c, EFSA 2015a,b,c, Lundin 2015, USEPA 2016, PMRA 2016
Alternate exposure routes: levels, risk, and effects: dust from seeding, succeeding crops, water, field margins, soil, metabolites, guttation fluid, insect honey dew, ornamentals	EFSA 2015a,b,c, Goulson 2013, Lundin 2015, USEPA 2016
Studies on lower toxicity neonicotinoids which have less use restrictions	Lundin 2015

Residue data and effects studies on many legume, vegetable, berry, tree fruit	Lundin 2015, USEPA 2016
other crop pesticides and in-hive pesticides	
Sublethal impacts on learning, behaviour, and fecundity	Desneux et al. 2007
Interactions among pesticides and other honey bee stressors such as poor nutrition, pests and diseases, and colony movement	Johnson et al. 2010, Johnson 2015, Mullin et al. 2010, stakeholder interviews
Build up and impact of multiple crop and in-hive pesticides in colonies	Mullin et al. 2010, stakeholder interviews
Treatment thresholds for use to minimize build up and harm	stakeholder interviews

6.8 Current Canadian Research and Capacity

Research (Electronic Supplement 1) specifically into pesticides is being conducted at a number of research facilities across Canada (PI in brackets) including:

- York University (PI Amro Zayed, collaborating with Valerie Fournier, Laval University): laboratory and field studies on the effects of sublethal neonicotinoid exposure on brain state and behaviour of honey bee workers, and exposure levels from corn pollen.
- The University of Saskatchewan (PI Elemir Simko): laboratory studies on sublethal effects of neonicotinoids on embryogenesis, hygienic behaviour and grooming of worker honey bees.
- University of Guelph (PI Ernesto Guzman): laboratory studies on effects of miticides and neonicotinoids on the mite *Varroa destructor*, and on the health and behaviour of honey bees. And, laboratory studies on interactions between *Varroa* and deformed wing virus and effects on honey bee health.
- The Ontario Beekeepers Association, Tech Transfer Program (PI Les Eccles): laboratory studies on sub-lethal effects of neonicitinoids on queen fertility and drone sperm viability.
- Agriculture and Agri-Food Canada (PI Steve Pernal, in association with other AAFC researchers, and Rob Currie, University of Manitoba, Shelley Hoover, Alberta Agriculture and Forestry): Field studies manipulating and intensively sampling honey bee colonies to determine which of the major stress factors are associated with colony loss, including *Nosema ceranae*, viruses, poor nutrition, or exposure to pesticides.
- Laval University (PIs Valerie Fournier with Madeleine Chagnon, UQAM): Field studies on effects of neonicotinoid treated corn seed planting on honey bees, particularly from contaminated water sources. An additional study is underway to assess possible risk mitigation from providing clean water sources.
- Agriculture and Agri-Food Canada (PI Danica Baines): prebiotics as a tool to protects bees from various pesticides and pathogens.

Completed studies on effects of pesticides (particularly neonicotinoids) on honey bees include, but are not limited to;

- University of Guelph (PI Cynthia Scott-Dupree): Contact and oral toxicity of various pesticides including neonicotinoids on honey and other bees.
- University of Guelph and Dalhousie University (PIs Cynthia Scott Dupree and Chris Cutler) Tier III field studies on effects of neonicotinoid treated crops on honey bee colony health.

Facilities with experience assessing pesticide (mainly neonicotinoids, currently) effects on honey bees, in laboratory and/or field studies include, but are not limited to:

- AAFC (particularly Beaverlodge and Lethbridge, AB)
- University of Guelph
- Laval University
- The Ontario Beekeepers Association
- The University of Saskatchewan

Few studies on effects of non-neonicotinoid crop pesticides on honey bee health currently are being conducted in Canada outside of industry registration requirements of which results are not publicly available. Yet, pesticide testing for registration are done in isolation and interactive affects with other stressors are not part of the regulatory process, but could be causing impact to honey bee health in the field (Johnson 2015). In addition, sublethal effects are less-studied and may be occurring in the field (Desneux et al. 2007), and pesticide drift to non-target plants can result in exposure to honey bees. Development of the "Bee Health Mobile App" by Alberta Agriculture and Rural Development (PI: Medhat Nasr), which will be piloted in 2016, is intended to help reduce honey bee colony exposure to pesticides.

Studies on in-hive pest control products usually focus on effectiveness of the product for pest control, however, these products can cause harm to honey bees (Johnson 2015). There is one current Canadian study examining possible harm of in-hive pesticides on honey bees;

- University of Guelph (PI: Ernesto Guzman), "Effects of miticides and agricultural pesticides on the mite *Varroa destructor*, and on the health and behaviour of honey bees".

A recently completed study assessed antibiotic and pesticide residues in hive products;

- AAFC (PI Stephen Pernal), "Chemotherapies for *Nosema ceranae* and detection of chemical residues in hive products".

Methodological advances in testing toxicity of products on bees are being developed at;

- University of Saskatchewan (PI: Elemir Simko), developing histopathological procedures for investigating toxicology of drugs/chemicals/pesticides on honey bees.
- Alberta Agriculture and Forestry and Agriculture and Agri-Food Canada (PIs: Danica Baines and Shelley Hoover), creating leaf cutter and honey bee cell lines for disease and pesticide toxicity assessment.

6.9 Outstanding Gaps in Canadian Research

We identified gaps in research using review documents and interviews with Canadian (and to a lesser extent US) honey bee researchers and stakeholders (**Error! Reference source not found.**). Due to the intense focus on neonicotinoids there were many identified gaps in the literature. Some of these gaps are being addressed by Canadian researchers as described above, including sub-lethal effects on honey bees, interactive effects of neonicotinoids and pests and diseases, and effects at the field level. However, gaps in Canadian research remain numerous, yet, at this time, most are not seen as a priority by Canadian experts. Some remaining gaps, that were identified as a priority in Canada include:

- Interactive effects of pesticides with other stressors to honey bee colony health, which was consistently identified as a significant gap related to pesticides.
- Tier III neonicotinoid studies were identified as somewhat of a priority in Canada but not as a high priority in terms of numbers of respondents that listed this gap.
- A better understanding and guidelines for when in-hive pesticides are warranted was frequently discussed by Canadian respondents as a gap in research. The large scale Canadian Honey Bee Health Survey project (PI Stephen Pernal AAFC) will help address some these issues. But, while there are studies in Canada on effectiveness of new in-hive products, we found only one study examining effects of these products on honey bee health, and no direct economic treatment thresholds studies.

6.10 Conclusions and Recommendations

Pesticide exposure most likely plays a role in honey bee colony losses, but recent reviews and expert opinion concurs that pesticides (including neonicotinoids) are not the main driver of colony losses. Neonicotinoids and other pesticides cause some sub-lethal effects and likely interact with other colony stress factors such as pests and diseases, colony movement, and poor nutrition. Effects of traditional crop pesticides generally are mitigated with label restrictions banning application pre- and/or during bloom for those found to be toxic to bees. Systemic pesticides (neonicotinoids) are present in pollen and nectar, along with other exposure routes, but mainly below acute and chronic effect levels.

Canada has not been a large contributor to global research on neonicotinoids; however, there were few experts that felt this was an area where Canada should put more resources. The one exception, mentioned by a number of experts was that honey bee health in Canada could benefit from more Tier III field studies on Canadian neonicotinoid treated crops. The consensus of experts was to focus on interactive effects of multiple stressors, at the field level. Due to the complexity of examining interactive effects, especially at the field scale and considering regional differences, additional large-scale, nationally coordinated studies are recommended to more fully understand the contribution of pesticides and other stress factors on honey bee health in Canada.

7. Interactions with other managed and wild pollinators

7.1 Chapter Highlights

- Researching into the synergistic and supportive aspects of crop pollination from combined honey bee and other managed or wild pollinators is providing benefits in blueberries.
- There is little direct research on competitive interactions between honey bees, other managed bees, and wild bees in agricultural or wild contexts.
- There is little direct research on pathogen spill over or other considerations from Canadian sources.

7.2 Background

Interactions between honey bees and other managed pollinators or wild pollinators can fall along a spectrum form positive and facilitative to detrimental with negative fitness impacts. Questions about the impacts that managed honey bees have on native ecosystems and wild bee species abound due in large part to variations in eusocial and solitary foraging strategies and the magnitude of the beekeeping industry. Most notably, there is concern that interactions between large numbers of social foragers will result in negative impact to wild species; honey bees will out-compete native or wild bees. While critical, very few studies have examined interactions between managed honey bees and other managed bees or wild bees in a cohesive and structured way.

Of the spectrum of interactions, information regarding pollination service enhancement and increased crop yield has been presented in some studies and this as a growing area of interest. For example, Greenleaf and Kremen (2006) found increased pollination provided by honey bees in the present of native bees on sunflower. Rogers et al. (2014) found the same in blueberries. Parallel studies of limited systems are underway in Canada.

7.3 Documents and open scientific reviews

There is limited information on the interactions of honey bees with other pollinators, even when a global perspective is taken. The following summarizes reviews and key research supporting the spectrum of bee-interaction knowledge.

Pathogens and Disease:

Furst MA, McMahon DP, Osborne JL, Paxton RJ and MJF Brown (2014) Disease associations between honeybees and bumblebees as a threat to wild pollinators Nature LETTERS 505: 364-366 doi:10.1038/nature12977

Singh R, Levitt AL, Rojotte EG, Holmes EC, Ostiguy N, vanEngelsdorp D, Lipkin WI, dePamphilis CW, Toth AL and DL Cox-Foster (2010) RNA Viruses in Hymenopteran Pollinators: Evidence of Inter-Taxa Virus Transmission via Pollen and Potential Impact on Non-Apis Hymenopteran Species. PLoS ONE 5:(12)e14357 doi:10.1371/journal.pone.0014357

Resource Competition and Fitness:

Goulson D (2003) Effects of introduced bees on native ecosystems. Annual Review of Ecology, Evolution, and Systematics 34: 1-26

Goulson D and K Sparrow (2009) Evidence for competition between honeybees and bumblebees; effects on bumblebee worker size. Journal of Insect Conservation 13(2): 177-181

Graystock P, Yates K, Darvill B, Goulson D, Hughes WO. 2013. Emerging dangers: deadly effects of an emergent parasite in a new pollinator host. J Invertebr Pathol. 114(2):114-9.

Kato M, Shibata A, Yasui T, and H Nagamasu (1999) Impact of introduced honeybees, Apis mellifera, upon native bee communities in the Bonin (Ogasawara) Res Popul Ecol 41:217-228

Shavit O, Amots D and G Ne'eman (2013) Competition between honey bees (*Apis mellifera*) and native solitary bees in the Mediterranean region of Israel – implication for conservation. Israel Journal of Plant Sciences 57(3):171-183.

Thomson DM (2004) Competitive interactions between the invasive European honey bee and native bumble bees. Ecology 85(2):458–470

7.4 Interviews with Canadian Researchers and Stakeholders

Few interviewed stakeholders mentioned research foci on honey bee interactions with other pollinators. Those that did have focused research on pollination service provisioning in cropping systems. There currently are no research initiatives investigating competition between managed honey bees and specific wild pollinators in Canada. Similarly, there are few studies investigating pathogen transmission between wild and managed populations. While pathogen loads are often considered higher in managed pollinators, disease transmission has been noted to proceed to and from wild populations (Singh et al. 2010). Stakeholders that noted an understanding and interest in these areas of investigation highlighted how deficient the research is globally, and particularly so in Canada.

7.5 Gaps Identified from Literature and Interviews

Table 8 Gaps in bee interactions papers and through interviews with stakeholders. The list is meant to be a general list and while we tried to be comprehensive it is not necessarily an exhaustive list of gaps.

Gap	Identified by
Pollination service enhancement	Stakeholder Interview
Understanding resource competition	Thompson, Goulson, Shavit, Stakeholder Interview
Pathogen and disease spillover	Graystock, Singh, Stakeholder Interview

7.6 Current Canadian Research and Capacity

There is very limited research into managed honey bee and wild bee interactions in Canada. Pollination facilitation between managed and wild pollinators in blueberry systems is being conducted by PI's Cutler and Giovennezo (separately). A portion of PI Pernal's 'Health of Bee Pollinators in Canadian Agriculture' includes an investigation of pathogen spill-over as a deliverable. There is no current investigation into resource competition. Overall interactions between managed honey bees and other bees or other pollinators are understudied, however this also is the case globally.

7.7 Outstanding Gaps in Canadian Research

Overall there is only a minor understanding of interactions between honey bees and other managed pollinators. More specific gaps exist in:

- Pollination service enhancement
- Understanding resource competition
- Pathogen and disease spillover

7.8 Conclusions and Recommendations

There is a substantial and significant gap in our understanding of the facilitative and potentially negative interactions that can occur between managed honey bees, other managed pollinators, and wild pollinators. Overall, an increase in this type of investigation, as well as general community ecology studies in ecosystems and agroecosystems that include honey bees are needed. With particular focus on maintaining the health of honey bees, more investigations into pathogen and disease transfer are recommended. Studies of pathogen spillover and transfer indicate that transmission can occur from wild populations into managed populations. Enhancements of on-farm habitat that promote biodiversity increase the likelihood of honey bees interacting with wild bees. While this interaction could be benign, or even beneficial, it could also be detrimental to either entity; we simply don't have enough background to predict outcomes and develop BMPs. There also is a significant deficit in understanding how honey bees present in large quantities for pollination contracts impact local and nearby communities of wild pollinators. Understanding carrying capacity of various ecosystems is also an area that requires more investigation. In relation to supporting pollination services and crop productivity, community pollination studies are recommended to build our understanding of how the full set of managed and wild bees (and other pollinators) can support crop pollination needs. Crop specific and regionally specific approaches are also advised as the global body of literature indicates there will be regional differences.

8. Genetics and Breeding

8.1 Chapter Highlights

- Key concerns in genetics and breeding include the maintenance of local adaptations, especially winter hardiness.

- Research activities within Canada are active in developing an understanding of the genetics of Canadian bees, with attention to regionally specific trends.
- Breeding programs are active to support the further development of local lineages and resistant lines.

8.2 Background

All aspects of honey bee colony life and function are defined by colony and queen genetics. Beekeepers have been breeding bees and selecting for traits that are desirable from the advent of beekeeping. There is now an added complexity with the commercialization of bee breeding, especially with many queens and nuclei coming into Canada from breeders outside of Canada. An understanding of honey bee genomics is creating an opportunity to better understand not only the genetic diversity that exists in honey bees but also capacity and plasticity. Genetics and breeding remains an area of parallels between classic selection of high-performing lineages and genomic approaches to understanding this selection.

Since the sequencing of the Honey bee genome genetic drivers and responses to pathogens, toxins, and environmental factors have come under study, providing an additional layer of insights into these fields.

8.3 Documents and open scientific reviews

The Honey bee genome was sequenced in 2006 through collaborative work by the Honeybee Genome Sequencing Consortium. Assess to the genomic database can be found through Bee Base: http://hymenopteragenome.org/beebase/

The Honeybee Genome Sequencing Consortium. Insights into social insects from the genome of the honeybee *Apis mellifera*. Nature. 2006;443(7114):931-949. doi:10.1038/nature05260.

8.4 Interviews with Canadian Researchers and Stakeholders

Six of the interviewees responded as being directly involved in genetic and breeding research. Outstanding gaps in overall capacity were not highlighted by these individuals or by others. There is an overall view that breeding programs are addressing current and emerging issues. Impressions of advances in genomic research are considered similarly. The general impression was that there is sufficient momentum and we are expecting results and new insights from a series of current and upcoming research programs. In particular, the development of a better understanding of how disease and other colony responses can be drive by genetics are expected.

8.5 Gaps Identified from Literature and Interviews

Table 9 Gaps in genetics and breeding found in review papers and through interviews with stakeholders. The list is meant to be a general list and while we tried to be comprehensive it is not necessarily an exhaustive list of gaps.

Gap	Identified by
Local lineages	Stakeholder Interview

Winter hardiness	Stakeholder Interview
Full genomic understanding and understanding of how disease and other factors can be genetic	Stakeholder Interview

8.6 Current Canadian Research and Capacity

- Developing a diagnostic assay for Africanized honey bees (AHB) and establishing a baseline dataset on the genetics of Canadian Honey Bees genetics and breeding (PI Zayed).
- Genomic studies of complex behaviour: honey bee genes, behaviour, and adaptation genetics and breeding (PI Zayed).
- Understanding the genetic basis of social behaviour from honey bee and other insect models genetics and breeding (PI Thompson).
- Sustaining and securing Canada's honey bees using 'omic tools genetics and breeding (PI Foster/Zayed).
- Assessing the effect of sperm viability on queen performance and colony productivity genetics and breeding (PI Guarna).
- Optimizing drone selection and production genetics and breeding (PI Giovenazzo).
- Protecting the genetic diversity of the honey bee (*Apis mellifera*): Preservation methods of drone semen genetics and breeding (PI Giovenazzo).
- Strengthening competitiveness and self-sufficiency by improving nuclei production genetics and breeding (PI Giovenazzo).
- Assessment of factors that affect sperm viability in queen genetics and breeding (PI Pernal).

8.7 Outstanding Gaps in Canadian Research

Breeding and genetics has a long history of capacity. Nevertheless, there are areas that could see move improvement and investment given Canada's unique climate and management scenarios. These include:

- Local lineages
- Winter hardiness
- Full genomic understanding and understanding of how disease, resistance, and other factors can be genetic

8.8 Conclusions and Recommendations

Canadian research in the areas of genetics and breeding is on a steady trajectory that will provide expanded insights relevant to many other overlapping areas of honey bee health. Maintaining the status quo is a sound strategy as this field is actively expanding and has good capacity with active programs. An internal awareness of gaps that are actively being filled also is present. Best management practices and the importation of genetic stock not locally adapted to the realities of Canadian climates remain as outstanding gaps, although these are not directly defined as gaps in research.

9. Climate Change

9.1 Chapter Highlights

- Climate change is altering wild bee and plant phenology.
- There are no published studies to date on effects of climate change on managed honey bee health in Canada or globally.
- Possible impacts to managed honey bees include fewer/altered floral resources, new pests and diseases, complications in pollination service provision, and difficultly managing colonies with climate variability.
- No current research in Canada is directly examining effects of climate change on honey bees.
- Given that climate change will result in added stress factors to honey bee health, research in Canada should be initiated to address potential problems and solutions.

9.2 Background

Global climate change is likely to cause large impacts on bees and the plants they interact with (Winfree 2013). Some potential impacts of changing climate include phenological shifts and mismatches between bees and plants, range shifts of bees and plants, range shifts of pests and diseases, changes in development, and variation in crop pollination services (Le Conte and Navajas 2008, Kjohl et al. 2011, Rader et al. 2013). Many of these disruptions apply to wild bees; managed honey bees will be buffered from some of the effects of climate change by human intervention. However, there likely will be some impacts on managed honey bee colonies, and there is little information in this area.

9.3 Documents and open scientific reviews

The lack of information on climate change and bees is highlighted by a Web of Science title search, “Climate (change or warming) and (bee or bees or pollinator*” which shows 33 results. Changing the second part of the search equation to “honey bee*” shows 2 results, one on impacts of climate change on honey bees (Le Conte and Navajas 2008) and one on honey bee crop pollination services (Rader et al. 2013) (Table 10).

Table 10 Literature reviews of climate change on pollinators, focusing on reviews that apply to potential impacts on honey bees and pollination services by honey bees.

Methods	Results	Conclusions	Reference
Review of literature on plant-pollinator mismatch. Assessment of potential for observational or experimental approaches to address aspects of the issue.	Overall little indication of mismatch between pollinators and plants, although data mostly from north temperate regions. Most data show parallel shifts in phenology. If mismatch, observational studies some indication that could be reduced seed production, but experimental studies do not show this.	Phenological shifts are occurring but may be mainly in parallel between plants and pollinators. Larger mismatches may be increasing in frequency but no evidence. Integration of observational and focused experiments will be needed to better forecast effects of climate change on plant-pollinator interactions.	Forrest 2015
Examined pollination in watermelon, model behaviourally mediated pollination service change under various climate change scenarios.	Honey bee pollination predicted to decline because future warmer temperatures will be beyond the optimal activity range. Especially for mid-summer crops. Most wild bee taxa are predicted to increase pollination services. Net effect is small change if diverse pollinator population.	Honey bee pollination predicted to decline with climate warming and serious implications for crop pollination if not buffered. Maintenance of ecosystem functions and services will be enhanced by having a diverse assemblage of bee species.	Rader et al. 2013
Literature review on effects of climate change on honey bees	Climate change can alter honey bee behaviour and physiology, floral environment, foraging capacity, development. Alter ranges, competitive relationships. Alter parasites and pathogens relationships. More imported stock could lead to new pathogen introductions, could threaten local ecotypes.	Climate induced stress will add to other honey bee stressors. Genetic variability should be maintained to meet future challenges, many of which can't be predicted. Need a better understanding of stress factors to bees.	Le Conte and Navajas 2008

Modeled expansion and northern limit of AHB focusing on phenological data, and current location, distribution modelling, environmental, and climatic data	Climate variables had greater importance in the model than phenology and other satellite products. Bee forage availability also important predictor.	Their model predicted a further northern movement than previous models. Phenology (nectar flow) and climate both important. Model shows movement into south-western Canada	Jarnevich et al. 2014
Literature review focusing on effects of warming temperature on crop pollination	Warming will have greater effect on pollinators in tropical zones. Temporal and spatial mismatches in crops and pollinators likely in future. Thermal sensitivity is important but unknown for most crop and pollinator species.	To date, very little data on climate change and crop pollination. To ensure future sustainable food production need to better understand effects of climate change on pollinator-crop interactions, and interactions with other stressors.	Kjohl et al. 2011

One of the more well-studied areas of climate change on wild bees is in activity timing, known as phenological shifts. With changes in local temperatures and other aspects of climate, floral bloom can shift to earlier in the season, possibly resulting in mismatches between when flowers are in bloom and when their associated pollinators are active. Most evidence to date shows that bees shift in parallel to bloom timing, resulting in little or no asynchrony (in Forrest 2015); however, data are scarce and further research is needed.

Some of the repercussions of climate change on wild bees also may impact managed honey bees. For example, drought could cause declines in floral resources (Forrest 2015), requiring beekeepers to increase supplemental feed or move colonies to new locations. Bloom for many crops may shift to earlier in the spring (Memmott et al. 2007, Kjohl et al. 2011) with warming temperatures when colonies are not yet sufficiently developed, and beekeepers and growers may need to adjust practices to ensure synchrony between colonies and crop bloom. Crops that previously did not overlap in bloom time could shift to greater overlap, making it difficult to keep past schedules of colony movement among crops. Higher temperatures during crop bloom could fall out of the optimal range for honey bees, decreasing pollination services by honey bees (Kjohl et al. 2011, Rader et al. 2013). And, there likely will be movement of pests and diseases into areas where they previously were not present (Le Conte and Navajas 2008).

Some factors that could help in reducing the impacts of climate change on managed honey bees include maintenance of genetic diversity in honey bees which could aid in providing stock that is adapted to changing conditions (Le Conte and Navajas 2008). Preservation of more natural and semi-natural land can provide greater diversity and abundance of floral resources which can help ensure pollination services and food availability amid uncertainties with future climate change (Bartomeus et al. 2013, Rader et al. 2013, Winfree 2013). In addition, baseline data on current honey bee health in Canada, importance of various stressors to honey bee health, and further development of best management practices will help prepare beekeepers and stakeholders for any additional stress from climate change factors. Finally, maintenance or restoration of a diverse native bee community, which can provide crop pollination services and buffer effects of variable honey bee services, is an important avenue for action (Rader et al. 2013).

9.4 Interviews with Canadian Researchers and Stakeholders

One respondent listed climate change as a major gap or priority in Canada honey bee health research, and only one Canadian respondent discussed it in any other context. They were concerned that extreme variation in winter conditions among years was causing increasing difficulty in managing overwintering colonies. Despite the lack of direct address, many respondents discussed the need to understand interacting stressors on honey bee colony health, and relative impacts of various stressors. In addition, future invasion of new pests and diseases and our ability to respond was a common concern among stakeholders. While only speculative at this point, climate change is likely to result in multi-faceted, additional stressors to honey bee colony health and create new challenges for management and pollination services.

9.5 Gaps Identified from Literature and Interviews

Table 11 Gaps in knowledge of effects of climate change on honey bee health and pollination services. The gaps are in general categories and while the list is meant to be comprehensive it is not necessarily exhaustive.

Gap	Identified by
Altered floral resources (phenology shifts, spatial shifts, drought, response to other climate change conditions)	Le Conte and Navajas 2008, Bartomeous 2013, Forrest 2015
Changes in crop timing	Le Conte and Navajas 2008, Kjohl et al. 2011
Thermal sensitivities and temperature ranges of pollinators	Kjohl et al. 2011, Rader et al. 2013
Altered colony development and winter management	Le Conte and Navajas 2008, stakeholder interviews
Altered pest and disease ranges	Le Conte and Navajas 2008
Genetic variability of honey bees to adapt various new climatic conditions	Le Conte and Navajas 2008
Possibility of more northern movement of Africanized honey bees	Le Conte 2008, Jarnevich et al. 2014
Data on crop requirements and important pollinators	Kjohl et al. 2011, stakeholder interviews

9.6 Current Canadian Research and Capacity

There is no current Canadian research specifically on effects of climate change on honey bees. Baseline data on colony health is being collected in the large scale monitoring of Canadian honey bee colonies and pests and disease, "Honey Bee Health Surveillance in Canada" (PIs Stephen Pernal AAFC and Carlos Castillo Grand Prairie Regional College). These baseline data will aid in making necessary adaptations to keep colonies healthy in the face of a changing climate. Similarly, the large 'omics studies (PIs Leonard Foster UBC, Amro Zayed York University) will provide tools for selective breeding to better create healthy and productive honey bee colonies which could also be used in selecting traits suitable to a changing climate. Another large-scale project, "Health of Bee Pollinators in Canadian Agriculture" (PI Stephen Pernal AAFC) has a component assessing native bee composition in six agricultural ecoregions across Canada. The "Canola Pollination: Maximizing bee health and pollination services" (PI Shelley Hoover Alberta Agriculture and Forestry) will further provide baseline information on honey bee and wild bee pollination in the Canadian landscape. These data will aid in our understanding of wild bee populations, honey bee pollination services, and resilience in crop pollination services with changing future climate (Garibaldi et al. 2011, Rader et al. 2013).

9.7 Outstanding Gaps in Canadian Research

Because there is so little research in the area of climate change, managed honey bees, and crop pollination the gaps in our knowledge are widespread (Table 11). While climate change was not specifically identified as a priority by Canadian respondents, interacting stress factors frequently were stated as a major concern and therefore climate change could become a priority.

9.8 Conclusions and Recommendations

Climate change likely will contribute additional challenges to honey bee health such as altered floral resources, variable and unpredictable weather, and introduction of new pests and diseases. Pollination service provision could become more problematic with crop timing changes and high temperatures during bloom, although temperatures higher than the optimal range for honey bees are less likely to occur in Canada than in warmer regions. In addition, colony management with uncertain weather conditions will pose new challenges. Canadian research focusing on baseline data and optimizing pollination services will indirectly help the honey bee industry maintain honey bee colony health and pollination service provision in the face of changing climate. Yet, because there is no direct research in Canada on how climate change might play a role in future honey bee health we are leaving ourselves vulnerable to future problems. It would be in the best interest of Canada's honey bee product and pollination service industry, and for Canadian agriculture to focus some resources on this pressing and understudied issue in order that beekeepers will be better able to adapt to future change.

10. Management Practices

10.1 Chapter Highlights

- Research and gaps from other topic chapters are relevant to creation of best management practices (BMPs).
- Because research is scarce in many areas, fully formed BMPs also are lacking.
- Large national scale monitoring and genetics programs, and regional studies are addressing some of the gaps.
- Main areas where more research is required in Canada to better create BMPs include pest and disease management, nutritional requirements, and landscape management.
- Where research is sufficient to provide management guidelines, extension to beekeepers is lacking in some regions.

10.2 Background

Keeping honey bee colonies healthy and being able to adequately respond to continually fluctuating health issues requires beekeepers to have knowledge and access to up-to-date, science-based practices. In the last 10 years, keeping honey bees has become increasingly difficult due to a complex array of stress factors that has resulted in weaker colonies and unsustainable levels of overwintering colony loss in some regions. Research into best management practices (BMPs), identification of knowledge gaps, and dissemination of information to beekeepers is crucial to the future of providing reliable honey bee hive products, and pollination services to crops in Canada and globally.

10.3 Documents and Open Scientific Reviews

A recent compilation, summary, and gap analysis of BMPs for Canadian honey beekeepers (Eccles et al. 2015) is available online:
http://www.hortcouncil.ca/uploads/file/English/Hort%20Shorts/Honey%20Bee%20Best%20Ma

nagement%20Practices%20Final%20(2).pdf. They tabulated BMPs for honey bee keepers from a variety of sources including government agencies, universities, and extension programs in consultation with provincial and regional apiary specialists. The focus was on Canadian BMP documentation, but practices from the US and trading partners such as Australia, New Zealand, and Chile also are provided. Using this information, gaps in Canadian BMPs were identified. This document provides a comprehensive compendium of BMPs in Canada and from trading partners and is an excellent resource for finding national and regional BMPs. We therefore do not attempt to duplicate this work but summarize some of the major findings in terms of sufficiency and gaps in Canadian BMPs and where further research is needed. A newer document by Eccles et al. is being completed at the same time as this report.

From Eccles et al. (2015), some areas where BMPs are satisfactory in Canada include: 1. Information on integrated pest management (IPM) generally is comprehensive and consistent among provinces due mainly to collaboration through the Canadian Association of Professional Apiculturists (CAPA). 2. Quantities of sugar fed to provide overwintering stores are well established in Canada. 3. Information regarding overwintering honey bee colonies are well documented and available but lack regional specificity.

While there is an abundance of documents available on BMPs in Canada and globally, other than the above, there are few syntheses, reviews, and gap analyses of BMPs. Doke et al. (2015) reviewed literature on factors affecting overwintering success of colonies and provide management suggestions to increase overwintering success. They found that the single factor most commonly associated with winter losses was levels of *Varroa*, and suggest and IPM approach to control *Varroa* before overwintering while minimizing potentially harmful pesticide over-use. Virus load, queen quality, colony size, and nutritional stores also all impacted overwintering survival. Colony size had a large effect on winter survival and the authors suggest beekeepers facilitate brood rearing by maintaining colonies in nutrient rich locations, using supplemental nutrition, using brood pheromone when warranted, and combining small colonies in early fall. Other recommendations include sheltering and wrapping colonies in winter and minimizing crop pesticide exposure.

10.4 Interviews with Canadian Researchers and Stakeholders

Management practices involve all areas of honey bee health and the ultimate goal of most research into honey bee health is to provide beekeepers and other stakeholders with BMPs. Not surprisingly then, all Canadian researchers and stakeholder respondents identified some area of hive management as a major gap in our knowledge and priority area of research. The top gaps and priorities identified (Figure 2 and Figure 3) were in knowledge of effects and management of pests and diseases, honey bee nutrition, and thresholds for treatment and treatment protocols. Without further national and regional research in these areas BMPs cannot be developed for beekeepers.

Some specific areas, directly relating to management practices, that were commonly mentioned by researchers and stakeholders were 1. Lack of economic treatment thresholds available for many pests and diseases, 2. Lack of research into nutrition, lack of regulation of nutritional products, and consequently few guidelines for beekeepers, 3. Lack of research and guidelines into habitat restoration and/or preservation for better forage and nutrition, and 4. When research was available, lack of extension and accessible documents for beekeepers.

10.5 Gaps Identified from Literature and Interviews

Table 12 Gaps in best management practices (BMPs) in honey bee health as identified in literature reviews and stakeholder surveys. Because BMPs refer to guidelines available to growers, we specify in brackets, where applicable, when the gap is in research and BMP guidelines, or where there may be enough research, but BMPs are not readily available to beekeepers.

Gap	Ided by
Management of culled frames: wood and plastic. Hive and apiary organization (BMP gap)	Doke et al. 2015, Eccles et al. 2015
Pesticide exposure prevention: outreach to growers, communication between growers and beekeepers such as DriftWatch, minimizing in-hive pesticide use, recovery after exposure (BMP gap)	Doke et al. 2015, Eccles et al. 2015, stakeholder interviews
Thresholds for treating *Varroa* and other pests and diseases during different seasons; when, what products, and how (Research and BMP gap)	Eccles et al. 2015, stakeholder interviews
Management practices specifically for keeping bees that provide pollination services (Research and BMP gap)	Eccles et al. 2015, stakeholder interviews
Queen breeding and rearing BMPs (only guides for Ontario and Quebec). Lack important information, eg: maintaining genetic diversity, local stock, rearing nutrition, selection, when to replace queens (Mainly BMP gap)	Eccles et al. 2015, stakeholder interviews
Types of sugar to feed for overwintering not accessible to beekeepers (BMP gap), few BMPs on pollen, protein, and other nutritional supplementation (Research and BMP gap)	Eccles et al. 2015, stakeholder interviews
Variation among provinces in registration of beekeepers and extent of inspection and extension programs	Eccles et al. 2015, stakeholder interviews
Monitoring resistance to older and new varroacides for up to date IPM guidelines (Research and BMP gap)	Eccles et al. 2015
Overwintering colony BMPs, national and regional specific guidelines (Research and BMP gap)	Doke et al. 2015, Eccles et al. 2015, stakeholder interviews
Optimal landscape management for better forage	Stakeholder interviews

10. 6 Current Canadian Research and Capacity

It is difficult to categorized research in Canada into those that are relevant to management practices since much of the research being conducted ultimately will guide BMPs. Therefore, for a discussion of Canadian capacity in each area that leads into BMPs, refer to chapters 4 through 9. Direct development and extension of BMPs to beekeepers is somewhat distinct from research used to inform BMPs. Because other chapters discuss capacity in each of the honey bee health topics, herein we discuss current Canadian capacity for developing management guidelines for beekeepers and extension. Because the mandate of this report is to identify honey bee health research gaps, we keep our discussion of Canadian capacity in BMP extension brief.

National organizations such as the Canadian Association of Professional Apiculturists (CAPA), the Canadian Honey Council (CHC), and the federal government Agriculture and Agri-Food Canada engage in coordination of honey bee research, development of outreach documents, and extension to growers. Each province has a provincial apiarists and their activities include using research to develop accessible guidelines for beekeepers, liaising with beekeepers, and monitoring beekeeping activity in their provinces. In addition, some provinces have technical transfer personal (usually jointly funded by the government and provincial beekeeper groups) who conduct applied research and engage in extension. DriftWatch, a successful US program the facilitates communication between pesticide applicators and beekeepers, is now available in Saskatchewan (http://www.agriculture.gov.sk.ca/cpn2014-Driftwatch), and a mobile bee app similarly designed to connect beekeepers with pesticide applicators is being developed in Alberta (PIs Medhat Nasr, Pramod Kumar Alberta Agriculture and Forestry).

10.7 Outstanding Gaps in Canadian Research

Gaps in Canadian research required to develop BMPs for beekeepers are outlined in the preceding chapters. Some of the outstanding gaps directly related to honey bee management in Canada include:

- Facilitation of communication between beekeepers and pesticide applicators. Although there are now some programs being developed in Canada, there are yet no nationally available programs.
- Treatment threshold development for many pests and diseases is a large gap in Canada, identified by many interview respondents. Development requires targeted research and baseline data. This is somewhat being addressed in Canada but due to the scope of the issue, involving many different economically important pests and diseases, interactions among pests and diseases and other stress factors, and regional differences, more national co-ordination and funding will be required.
- Better landscape management to support honey bees and wild bees with more diverse, abundant, and consistent forage is not being addressed in Canada except as a component of one larger study on canola pollination.
- Management practices directed at honey bee keeping for pollination services are only being considered in one current study and should have greater investment.
- Honey bee nutrition is poorly understood and therefore there is little in the way of guidelines for beekeepers wanting to supplement colonies.
- Regional gaps in management guidelines are problematic in some areas such as the Maritime provinces. Where there are regional gaps, beekeepers are relying on guides from other regions that may not provide the best practices for their climatic conditions. More consistent funding and management guidelines across the country would be beneficial.
- Availability of high quality queens was identified by a number of respondents as a factor limiting colony health.

- Interviews with Canadian stakeholders consistently identified lack of extension to beekeepers as major limitation in Canada's ability to advance honey bee health and pollination services. While this is not a gap in research, extension is essential to securing the future of healthy honey bee colonies and reliable, secure pollination services in Canada.

10.8 Conclusions and Recommendations

Best management practices will be improved from the large national honey bee health monitoring studies and the 'omics studies which will aid in better stock selection. Most of the other studies are of smaller scale, and while they ultimately will help in the creation of better management practices, a larger scope and more broad, national approach to research will be required in Canada to better address these complex issues. Areas that are particularly lacking and that should be of top priority for expanded funding and research include, pest and disease impacts and treatment thresholds, effects and management of interacting stressors, nutritional research, regional variation in BMPs, landscape management, and extension programs.

11. Overall Conclusions and Recommendations

Gaps are present in all areas of investigation as we work towards achieving a holistic and complete understanding of honey bee health management. A changing world, adapting and evolving pests and pathogens, and shifts in the drivers of bee management will inevitably result in new challenges. Certain areas of honey bee health currently have more robust capacity. Pests and disease; genetics and breeding; pesticides, and best management practices have a greater capacity, but nevertheless do contain critical areas where future research is needed. Greater gaps in capacity exist in nutrition and forage, climate change, and interactions between wild and manage bees. These particular topics are overall poorly developed and would benefit from increased research attention and funding. A summary of specific areas within each topic that require more targeted research approaches includes:

Pest and disease:

- Co-ordination of longitudinal studies of current pest and disease loads to understand trends, status, and thresholds across Canada; focus on regionalized and local approaches.
- Increase focus on biosecurity to both prevent new introductions and reduce local spread of pests and disease throughout Canada.
- Continue research into alternative treatments for *Varroa* and *Noseam* spp.

Forage and Nutrition:

- Develop an understanding of the nutritional value of crops, forage plants, and wildflowers.
- Enhance research and developing in supplements and diets to include local and colony life cycle considerations.
- Develop an understanding field-based nutritional complements to crop pollination.

Pesticides:

- Enhance and increase nationally coordinated studies that examine interactions and long term impacts of pesticides.
- Conduct more Tier III field studies on all pesticides used in cropping systems and especially on neonicotinoid treated crops.
- Develop a broader strategy to study synergisms between multiple pesticides, both in-hive and crop, as well as other products and stress factors.

Interactions with other managed and wild pollinators:

- Develop researching into forage-based interactions (competition and/or facilitation) of managed honey bees and other pollinators, aim to understand carrying capacity in semi-natural systems.
- Develop broader research programs into understanding multi-species pollinator systems and the land/pollinator management strategies that improve and support them.
- Enhance studies relating to pathogen transmission and spillover between wild and managed pollinators.

Genetics and Breeding:

- Continue to support genomic studies that examine genetic responses to stressors, hygienic behaviour, and variables such as disease, pesticides, climate, nutrition, and others.
- Focus on enhancing local genetic stock and adaptations relevant to Canadian climate, concerns, and pollination systems.

Climate Change:

- Focus on developing a better understanding of relationships with natural forage as climate change will likely have the largest impact on plant phenology.
- Continue research into overwintering.

Best Management Practices:

- Increase research into crop-specific pollination strategies, both for systems using only honey bees and those using combinations of honey bees and other managed or wild pollinators.
- Continue to support more board national programs that support longitudinal data that will better inform BMPs.
- Coordinate development of BMPs with upcoming research programs.
- Increase extension to beekeepers.

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Appendix 1. List of interview respondents and affiliations.

Province	Name	Affiliation
AB	Shelley Hoover	Alberta Agriculture and Forestry
AB	Steve Pernal	Agriculture and Agri-Food Canada
AB	Medhat Nasr	Alberta Agriculture and Forestry
AB	Rod Scarlett	Canadian Honey Council
AB	Paul Thiel	Bayer CropScience Canada
BC	Mark Winston	Simon Fraser University
BC	Leonard Foster	University of British Columbia
BC	David MacDonald	Capital Region Beekeepers Association
MB	Rob Currie	University of Manitoba
MB	Rheal Lafreniere	Provincial Apiarist (MB)
NS	Jason Sproule	Provincial Apiarist (NS)
NS	Chris Cutler	Dalhousie University
ON	Amro Zayed	York University
ON	Ernesto Guzman	University of Guelph
ON	Peter Kevan	University of Guelph
ON	Cynthia Scott-Dupree	University of Guelph
ON	Les Eccles	Ontario Beekeepers Association, Tech Transfer Program
ON	Maria Trainer	Crop Life Canada
ON	Paul Hoekstra	Syngenta Canada
PEI	Sean Murray	PEI Beekeepers association
QC	Pierre Giovenazzo	Laval University
QC	Valerie Fournier	Laval University
YK	Randy Lamb	Yukon Agriculture
USA	Gloria DeGrandi Hoffman	ARS Tucson Cal Hayden Bee Lab
USA	Christina Grozinger	Pennsylavania State University
USA	Dennis VanEngelsdorp	University of Maryland Bee Informed Partnership
USA	Julie Shapiro	Honey bee Health Coalition