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Supporting a Sustainable Beekeeping Industry: Healthy Queens Make Healthy Bees

Lauren Park

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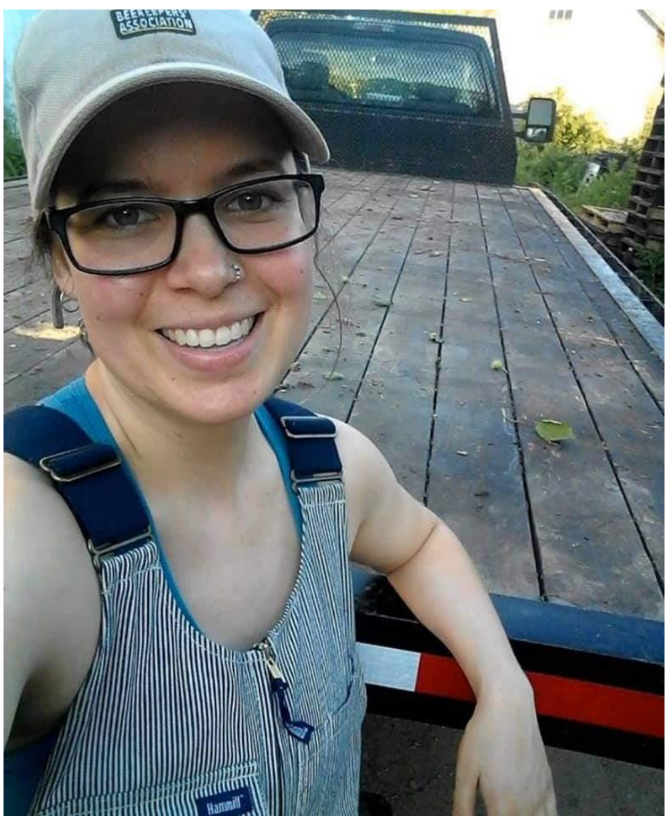
SCHOLAR PROFILE

Lauren Park is a first-generation farmer who has been working in agriculture for fifteen years. She is a beekeeper, specializing in queen bee rearing, in the Gaspereau Valley of Nova Scotia. In addition to her farm, Forest Hill Apiary, Lauren runs the 2000+ hive Cosman and Whidden Honey farm specializing in fruit pollination and honey production.

Lauren's passion for agriculture started quite accidentally fifteen years ago after riding her bicycle to the Cosman and Whidden Honey Farm and asking for a job. After growing up in southern Ontario and spending summer months on her family's farm in Grey Bruce County, bees gained a place in Lauren's heart. Lauren's mentor Tom Cosman always granted Lauren the freedom to grow the farm and to continue learning off farm whenever possible. Lauren is still as passionate about bees as she was fifteen years ago and loves the unique place bees have within our food system as pollinators and honey producers. Lauren loves the intersection between art and science she finds in working with bees. Lauren began rearing queen bees almost ten years ago with a goal of lowering overwinter loss rates within her operation. Queen raising has become Lauren's favourite niche and what she can be found doing in the peak summer months.



When the bees are dormant, Lauren spends time pursuing her other passion, music. Lauren is an accomplished musician who not only teaches, but has performed with the likes of Symphony Nova Scotia, Opera Nova Scotia, and at the Apimondia 2019 congress.

Lauren is active in a cross section of agriculture organizations. Presently a director with the Nova Scotia Federation of Agriculture Council, Lauren is passionate about ensuring farmers have a strong voice in the industry and to government. Lauren is past president of the Beekeepers Association of Nova Scotia and has been involved in key initiatives to ensure a sustainable beekeeping industry in the future.

ACKNOWLEDGMENTS

My Nuffield Canada experience was augmented by an absolutely amazing collection of people I met abroad and people I am lucky to have the support of here in Canada. I regret that it would be impossible for me to list them all individually but would like to acknowledge the kindness and generosity of the people listed below. These individuals answered my questions, hosted me on their farms, traveled with me, held down the farm at home while I was away and listened to absolutely endless talk about pollinators. To all of them I express a huge debt of gratitude.

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Dr. Medhat Nasr

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SPONSORSHIP

This Nuffield Report could not have been completed without the generosity of my principle sponsor the Canadian Canola Growers Association. This organization has had a strong relationship with Nuffield Canada for many years and my gratitude for their support cannot be understated.

EXECUTIVE SUMMARY

Honey bees are essential to Canada's agricultural industry and the broader environment. Canada is home to over 800,000 colonies of honey bees. These bees provide honey for human consumption and pollinate the fruits and vegetables we eat, in addition to essential crops that become livestock feed. Honey bees are under stress from a multitude of interacting factors. These factors need to be addressed through local queen breeding, increased diverse forage, continued disease and pest management, and industry collaboration.

The Queen bee is the most important bee in the hive, responsible for laying all of a colony's eggs. The Canadian beekeeping industry is heavily dependent on the importation of queen bees and there is strong potential to expand and formalize the queen rearing industry in Canada to create a queen suited to the Canadian climate that is available in spring when queen bees are in highest demand.

Queen failure is one of the leading causes of hive mortality. The causes of queen failure are poorly defined and misunderstood. Many factors affect queen health and need to be mitigated to ensure a sustainable future for the beekeeping industry. Challenges include climate change, queen longevity, the Canadian climate, a fragmented industry, transportation, and knowledge gaps in queen production.

Industry collaboration is a key part of bee health. Farmers, landowners, and urban populations all have a role to play in understanding and promoting bee health. The need for increased forage exists across all pollinator species. Cross-commodity collaborative efforts between agricultural and other stakeholders will strengthen the health of pollinators, specifically honey bees and therefore strengthen Canada's food system.

DISCLAIMER

This report has been prepared in good faith but is not intended to be a scientific study or an academic paper. It is a collection of my current thoughts and findings on discussions, research and visits undertaken during my Nuffield Farming Scholarship.

I acknowledge with gratitude the work being done by beekeepers and academia in many areas discussed in this paper and regret that I could not acknowledge all of them.

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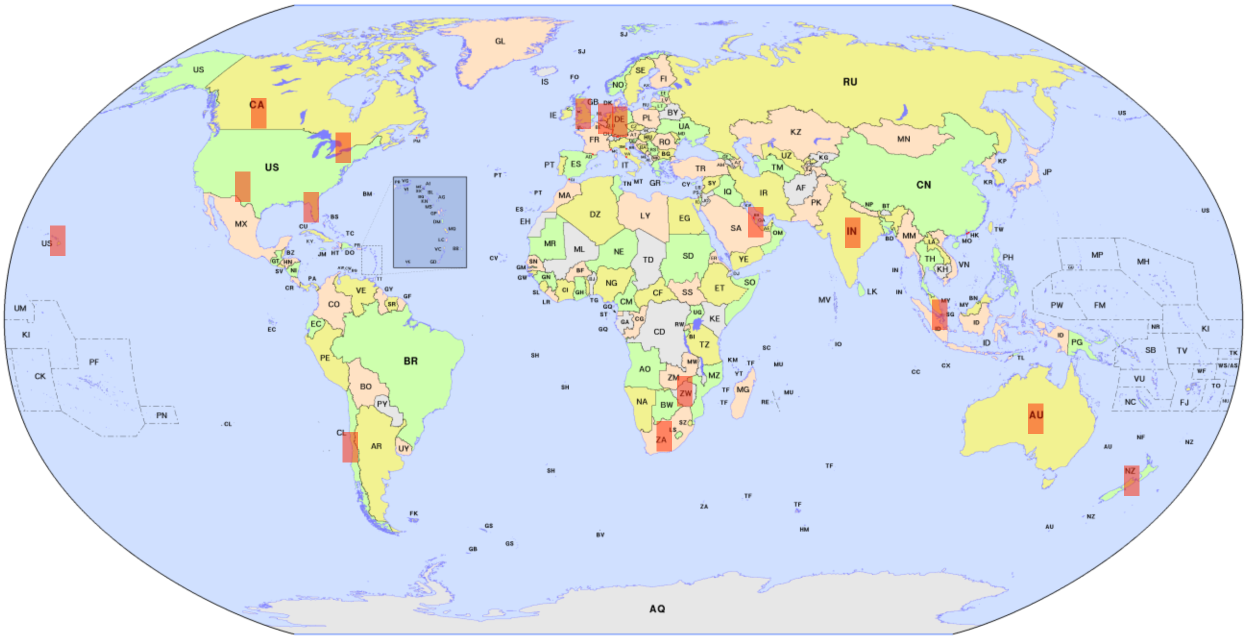
MAP



Over the course of my Nuffield Canada scholarship, I had the opportunity to travel to:

Australia
Canada (Alberta, Ontario)
Chile
Germany
India
Netherlands
New Zealand
Qatar
Singapore
South Africa
United Kingdom (England, Scotland)
United States (Florida, Hawaii, Nevada, Pennsylvania, Washington DC)
Zimbabwe

UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

My Nuffield Canada research was conducted through the lens of the seventeen United Nations Sustainable Development Goals developed in 2015 with particular interest in:

2. Zero Hunger

11. Sustainable Cities and Communities

15. Life On Land

Work needs to continue on all seventeen of these goals in order to take steps towards a more sustainable future in food production and consumption.

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1.0 BEES 101

European honey bees (Apis mellifera) arrived in North American four hundred years ago. There are no native Canadian honey bees. Although initially foreign to the landscape, honey bees quickly became an essential part of the agricultural and natural environment. A honey bee colony is a magnificent group of insects made up of one queen, female workers, and male drones. The colony is a superorganism. Bees are codependent on each other, and survive based on the successful completion their designated jobs. Bees make decisions as one and a colony of tens of thousands of bees behaves as a single organism. "But to understand the distinctive biology of this species of bee, it is often helpful to think of a colony in a slightly different way, not just as thousands of separate bees but also as a single living entity that functions as a unified whole. Just as a human body functions as a single integrated unit even though it is a multitude of cells, the superorganism of a honey bee colony operates as a single coherent whole even though it is a multitude of bees." (Seeley, 2011)

The importance of bees cannot be understated. While bees are responsible for producing honey that is enjoyed on tables across the country, it is the pollination of our foods and natural environment that defines how critical these insects are to our world. Over 80% of the world's flowering plants are dependent on pollination. (Cox-Foster, 2023) In addition to fruits and vegetables for human consumption, bees pollinate the forage that feeds livestock providing another important link in our food system. As a vital part of our natural landscape, bees pollinate trees, gardens and wildflowers from coast to coast contributing to the biodiversity and natural beauty of the earth.

Bees have co-evolved with flowers over tens of millions of years. The honey bee has been hunted for its honey and wax for at least 6,000 years and records of hive management date back to ancient Egypt (Crane, 2000). Over time, the bees have adapted to survive in a changing environment and growing food system. Bees overwinter in climates colder than was ever thought possible and never decline the endless challenges asked of them in the name of pollination and food production. Bees are under an incredible amount of stress. The demands on food production are increasing to feed a growing population and the demands for bee pollination are increasing in parallel. Honey bees are the canaries in the coal mine of our food system. They act as an indicator species. When bee health is in question, production agriculture is in question and the way our food is grown is in question. Farmers, consumers, beekeepers, and the general public need to respond when bee populations are suffering. Without healthy bees, the planet does not have a healthy food system. When the land is silent, something is wrong.

1.1 BEEKEEPING IN CANADA

Honey bees live in the beautiful and totally unique intersection between agriculture and nature. They are heavily dependent and influenced by both. In eastern Canada, the dominant variety of honey is wildflower, which, true to its name comes from the diverse blooms of fallow fields, gardens, trees and orchards. In western Canada, the dominant variety of honey is canola which is derived completely from managed farm fields. Bees are incredibly dependent on both the natural world and the agricultural sphere to complete their diet.

Beekeeping in Canada spans coast to coast and is defined by delicious honeys, diverse weather conditions punctuated by long winters, and fruit and crop pollination. There is a thriving commercial beekeeping industry driven by expansive honey and pollination events including blueberry and seed canola. Small scale hobby beekeeping has exploded in popularity. Bees are kept in backyards across the country and in every major city. Canada is an exporter of honey, producing far more than Canadians consume. Canadian honey is enjoyed across the country and on tables around the world. In the last ten years the number of honey bee colonies in Canada has been increasing to meet the demands for commercial pollination, honey production and backyard beekeeping. In 2011, Canada had over 550,000 colonies of bees. The number of colonies grew to over 800,000 by 2021. (Statistics Canada, 2022) Unfortunately, this increase in colony numbers also comes with an increase of colony losses.

Honey bees have a substantial impact on the Canadian agriculture industry. In 2021, Canadian beekeepers harvested 90 million lbs of honey valued at $270 million. (Agriculture and Agri-Food Canada, 2022) Most of Canada’s honey is produced in the prairie provinces where two thirds of the bees are kept. Canadian honey is exported around the world and the top export countries are the USA and Japan. (Agriculture and Agri-Food Canada, 2022) In addition to honey production, insect pollination is critical to the success of key crops. Although pollination is shared between honey bees, leafcutter bees and bombus bees, honey bees outshine as the most successful pollinator across many crops. Honey bees have the most populous hives and use a ‘power in numbers’ approach to pollination. The use of several species of bees simultaneously plays on the strengths of the different species and they coexist in the crop without conflict.

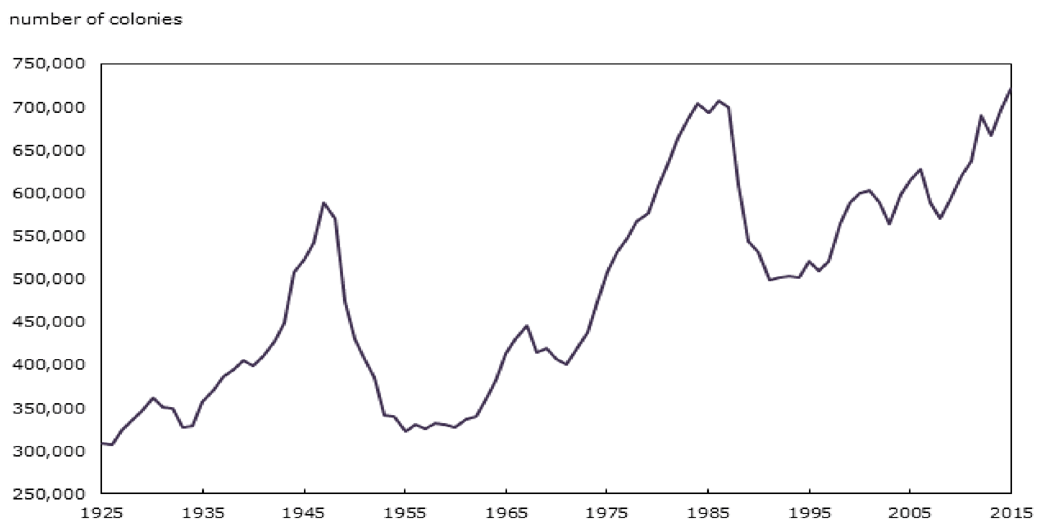
1: Blueberry pollination in Zimbabwe

In 2021 there was a $243 million total harvest value of apples, and blueberries (high and low bush) came in at $312 million. (Agriculture and Agri-Food Canada, 2022) Both of these crops are heavily dependent on the use of pollination by managed and wild pollinators alike. Total farm cash receipts for hybrid seed canola in 2021 were $12 billion. Understanding that the entirety of these harvests cannot be attributed to honey bees and taking into account the pollination dependency of different crops, "the economic harvest value contributed by honey bees could be as high as $7 billion per year." (Agriculture and Agri-Food Canada, 2022)

As demonstrated in the graph on the next page, honey bee populations wax and wane over time. In commercial operations, the demand for bees for pollination services and the price of honey often define the expansion or contraction of colony numbers. Additionally, bee health challenges are a major factor in the fluctuation of colony numbers. There have been several sharp increases and decreases in colony numbers in Canada over the last several decades.

One of the most significant changes in colony numbers in Canada occurred following the second World War when hive numbers plummeted. Honey bee populations in Canada in 1945 were similar to populations in 2011. One school of thought on this is that the biggest influence on this change in colony numbers is urbanization. In the generations since then, people have moved increasingly to cities and further away both geographically and metaphorically from their food sources. Homesteading and home gardens became a thing of the past and so did every family keeping some bees for their annual honey (sugar) supply. Additionally, commercial beekeepers at this time were largely not overwintering their bees in Canada. Their hives were depopulated in autumn and new bees were purchased from California or the southeastern United States the following spring. Longevity and multi-season problems were not relevant during this time. Another school of thought on the post-WWII decline lies within the major changes in agriculture. Agriculture has become more precise, and farms have gotten bigger and more efficient. Larger fields equate to fewer hedgerows which historically provided food for pollinators and cover for wild bees. Synthetic fertilizers, more advanced pesticides and herbicides used to maintain high yield monocultures have become normal. These pesticides are one factor in combination with a multitude of other factors, that add stress to bees and pollinators and impact bee health.

Chart 3
Bee colonies in Canada



Source: Statistics Canada, CANSIM table 001-0007.

Other than the steep decline in population after 1945, there was a steep drop in the 1980s and in the last 20 years, a yo-yo of colony numbers has become more common. In the 1980s, a combination of low honey prices and the eventual introduction on the invasive parasite Varroa destructor led to a sharp decrease in bees. Varroa mite is still a top issue beekeepers around the world combat on an annual basis. More recently, complex and interacting bee health issues (including queen issues) are the cause of unsustainable colony losses. There is agreement among commercial beekeepers that any loss above and beyond 20% over the winter is unsustainable. Canada now boasts over 800,000 colonies of honey bees thanks to the demand for bees in commercial pollination and to the explosion of hobby beekeeping. Canada surpassing 800,000 managed honey bee colonies is overall a good news story but it must be understood that with greater numbers also come greater losses. Annual losses in the United States average approximately 40%. (Bee Informed Partnership, 2022) Annual losses at this rate of any other kind of livestock would raise alarm bells worldwide.

Back in Canada, the Canadian Association of Profession Apiculturists (CAPA) distributes a survey to gather information on winter losses and why those losses occur according to beekeepers. The average of annual losses reported between 2007-2021 is a staggering 25.8%. (Canadian Association of Professional Apiculturists, 2022) In the winter from 2021-2022, Canada lost a devastating 45.5% of its honey bee colonies. Unfortunately, shockingly large numbers like this are becoming increasingly common in Canada and the United States.

Province	1st	2nd	3rd	4th
NL	Weak colonies in the fall	Poor queens	Starvation	Other
PEI	Poor queens	Weak colonies in the fall	Don't know	Ineffective Varroa control
NS	Poor queens	Weak colonies in the fall	Starvation	Don't know
NB	Don't know	Poor queens	Weather	Weak colonies in the fall
QC	Ineffective Varroa control	Poor queens	Weak colonies in the fall	Weather
ON	Poor queens	Weak colonies in the fall	Ineffective Varroa control	Weather
MB	Poor queens	Weak colonies in the fall	Starvation	Weather
SK	Poor queens	Weak colonies in the fall	Starvation	Ineffective Varroa control
AB	Ineffective Varroa control	Poor queens	Nosema	Weather
BC	Ineffective Varroa Control	Weak colonies in the fall	Starvation	Weather

(Canadian Association of Professional Apiculturists, 2021)

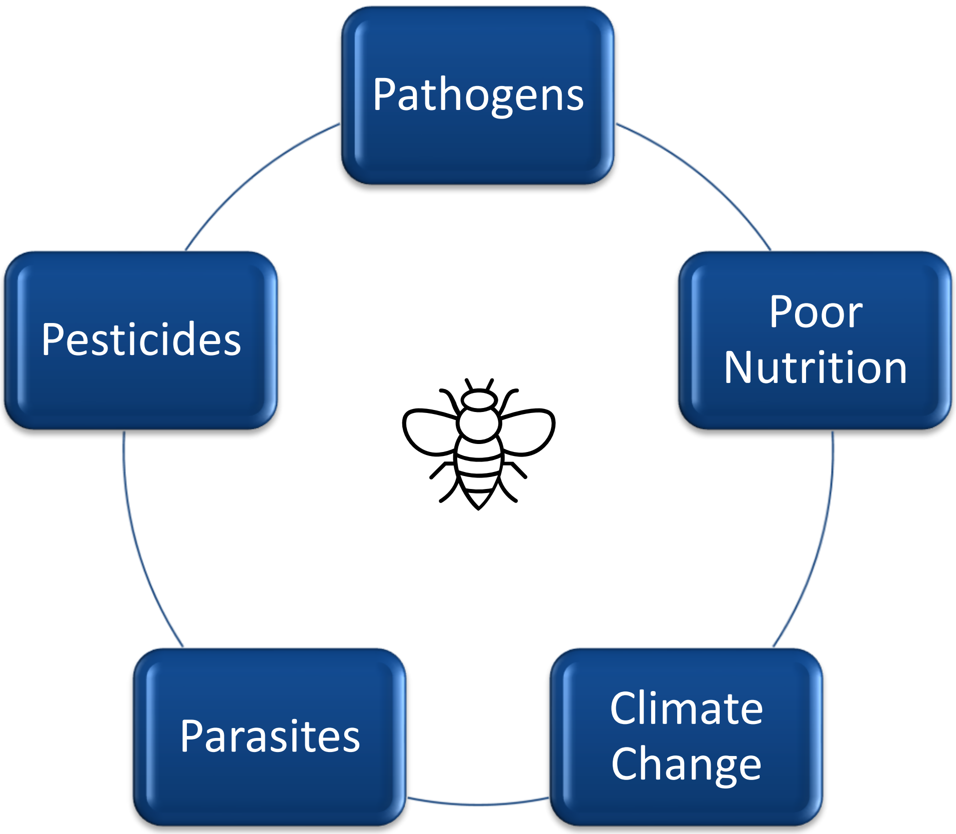
In 2021 "poor queens were reported as either the primary or second most common factor contributing to reported winter losses in nine provinces. Poor queens can result in weakened colonies entering the winter with an insufficient number of bees to survive.... Poor and failing queens may be the result of many factors including: inadequate rearing conditions, poor mating weather, reduced sperm viability, queen age, or exposure to pesticides within the hive or from the environment. This marked increase in poor queen quality as a reported cause of winter mortality is a concern that merits further investigation." (Canadian Association of Professional Apiculturists, 2021)

The COLOSS Association in Europe focuses on honey bee research and also administers a colony loss monitoring program. Their data encapsulates year round colony losses in 37+ countries accounting for all seasonal losses and not just in winter. (COLOSS, 2023) Annual loss is also a metric measured by the Bee Informed Partnership in the United States. This is an important distinction because it helps to pinpoint the stress times of year on these hives and what factors might be at play in the death of a hive. Collaborative loss surveys could be beneficial in the future for CAPA and the Canadian beekeeping industry with groups like the Bee Informed Partnership and COLOSS. Additionally, the added measure of colony loss outside winter could be added to the CAPA annual survey model, providing additional information to industry.

Understanding and balancing bee health challenges remains the top priority to mitigate the unnecessary loss of colonies. Unsustainable honey bee losses need to be taken seriously and an ‘all hands on deck’, multi-faceted approach focusing in research, nutrition and practical solutions needs to be implemented to ensure a sustainable future for the beekeeping industry and greater food system bees impact.

1.2 BEE HEALTH AND QUEEN ISSUES

To understand bee health is to first understand its complexity. There are a multitude of factors influencing bee health. Some of the main factors include parasites, pathogens, poor nutrition, pesticides, and climate change. Any of these factors can be categorized further. Poor nutrition can be broken down into floral density and diversity and habitat loss. Pesticides can be defined as agricultural pesticides and miticides used by beekeepers. Any one of these main factors can be potentially lethal to a honey bee colony. The complexity in bee health is that these factors are rarely lethal in their own right, and interact with each other and the environment. Many of these factors are also invisible within a beehive. The interactions between bee health factors (and environmental factors) are still largely unknown. The fact that many of these factors occur simultaneously and interact in unknown ways with each other defines the complexity of bee health. The balancing act of keeping a colony healthy is increasingly difficult.



In recent years, the perceived decline of bee populations has been well documented, but often exaggerated in the media. Globally, total insect populations are somewhat stagnant, however, some insect populations like mosquitoes are increasing while other groups like pollinators represent some populations in jeopardy. (Milman, 2022) In the mid 2000s Colony Collapse Disorder (CCD) was commonly in headlines as the new mysterious bee disease. It turns out, CCD was a breaking point in bee health when it became apparent that many factors were at play simultaneously to impact bee survival. The late 1980s and early 1990s saw the introduction of Varroa mite and Africanized honey bees or 'killer bees' to the United States. More recently, in 2021, the Asian giant hornet was found in the US, grabbing every headline with its nickname 'murder hornet'. These stories are often hyperbolic, for example when one colony of bees dies it is listed as 75000 bees to increase the impact to the reader. Everything from cell phone towers to monoculture to domestication of bees has been to blame over the years. There should be a shift in this narrative from the decline in bee populations (which wax and wane) to the decline in bee health. The truth is, there is still a lot to learn about the complexities of bee health.

Pesticides often get blame by beekeepers and the public when discussing declining bee health. Agricultural pesticides and miticides used in-hive to combat Varroa mites can both have negative implications on honey bee health. Fungicides, once seen as benign to bees, are now in the bee health mix too. (Walker , Brock, Arvidson, & Johnson, 2022) The continuous advancement of these products arguably also makes them safer for bees and pollinators over time. Even though a pesticide may not outright kill a bee, the effects potentially have a complex sublethal effect on an individual bee and the colony that still holds lots of unknowns. (Tosi, Sfeir, Carnesecchi, vanEngelsdorp, & Chauzat, 2022) Bees can bring contaminated pollen and nectar back to the hive and feed it to the queen or young brood, be affected by a direct pesticide application or by the drift associated with that application. Continued monitoring of label requirements, strict label use and further research into the possible interactions between different agricultural products are essential to mitigate the risk of pesticides.

Within the hive, the queen bee is the single most important bee in a colony and a colony cannot survive without a queen. The queen is responsible for all of the egg laying in the hive. She is the only bee that is mated and can lay fertilized and unfertilized eggs. She can lay her bodyweight in eggs daily, numbering over 2000 eggs a day. (Laidlaw & Page, 1997) A sick queen puts brood rearing in jeopardy. The health of the queen is important to the success of a hive and the identification of queen issues in Canada is a cause for concern that is impacting broader honey bee health and the overwintering success of colonies. Although queen issues have been identified in Canada, they continue to be poorly defined and misunderstood.


2,3: New spring colonies in central Chile

The worker bees in the hive have a graduated job system they move through as they age. These jobs include cleaning, feeding young brood, taking care of the queen, wax building, guarding the hive and foraging. These jobs can be interrupted by bee health issues, nutritional concerns, or environmental factors, throwing the order of the hive into chaos. When the queen is sick, one caste of bees is sick or one worker bee job is interrupted, it puts the colony in jeopardy. This upsets the delicate balance the bees strive to keep within the colony.

To gain a deeper understanding of queen health, it can also be broken down into many categories. These categories will be explored below following an overview of the queen industry in Canada.

2.0 QUEEN REARING IN CANADA

It is estimated that less than 5% of all Canadian beekeepers raise queens for sale or to supply their own operations. (Bixby, Guarna, Hoover, & Pernel, 2019) The demand for queens in Canada is significant. Canada imports queens annually and imported well over 300,000 queens in 2022 valued at $12.5 million. (Agriculture and Agri-Food Canada, 2022) An individual queen is valued at approximately $50 and the price increases annually. There is incredible potential for expansion in the Canadian queen sector.

The vast majority of queens imported into Canada come from California and Hawaii. These queens are reared by qualified and experienced queen breeders but are intended to thrive in the climates they are bred in. For a queen from one of these climates to adapt immediately to a quick honey flow followed by a long Canadian winter may be asking too much. Additionally, there are challenges with transport and the introduction of the new queen in the hive. More beekeepers in Canada need to begin raising their own queens and more existing queen breeders need to scale up to meet some of the demand. Canadian queens need to be selected based on Canadian conditions in order for them to thrive.

There are several challenges associated with the large-scale importation of queens into Canada. During the Covid-19 pandemic, navigating shipments across international borders became a near impossible task. Although the Covid-19 transport challenges have largely been resolved, challenges with the transportation of queens continue. Currently Canada can import queens from the United States, Chile, Australia, New Zealand, Italy, and Ukraine. In order for bees to get from farms around the world to Canadian farms, queens must spend a significant amount of time in transit. It is known that temperature fluctuations while queens are in transit can negatively impact queen sperm viability. (Pettis, Rice, Joselow, vanEngelsdorp, & Chaimanee, 2016) Further research into the complications of transporting queens, including the effect on ovary size and pheromone levels, is still ongoing and needs to continue to be taken under consideration. The demonstrative negative effect of queen transportation alone is a strong incentive to raise more queens in Canada.

Queens bees around the world are selected using similar criteria. In Canada, beekeepers select for overwintering success, honey production, hygienic behaviour, disease/pest resistance and gentle behaviour. Canadian hives are in a unique position of having to survive one of the most challenging winters on earth. Queens are reared by selecting the mother line and allowing the queens to open mate. Some beekeepers also select for drones by analyzing the hives against the same queen criteria they use for the breeder selection. There is some artificial insemination of queens being done in Canada and abroad, however, this is done for breeding genetics and not to rear field queens. The artificially inseminated queens have truncated lifespans and do not thrive inside the hive. Selection for specific traits sought after by Canadian beekeepers translated into a larger number of Canadian raised queens has incredible potential to benefit the industry.

There are many advantages and disadvantages to raising queens in Canada. The biggest challenge to the Canadian queen industry are the long, cold winters. The greatest demand for queens is in the spring for beekeepers to use in new hives to replace colonies lost during winter. This demand is in line with the pollination needs which are often in the first half of the beekeeping season. Unfortunately, due to the Canadian climate, it is not possible to raise queens in Canada in early spring because of cold temperatures for mating and a lack of drones in the colony. The drones do not overwinter with the colony and need sustained warm temperatures for the queen to rear new drones and for the drones to become sexually mature. The queen production window in Canada is short. It starts in some parts of British Columbia in April and will be finished across Canada by August. In order to have new queens for spring hive splits, a beekeeper would raise queens in the previous summer and overwinter them in nucleus colonies, or half sized hives. This can be expensive due to the extra costs associated with feeding and treating for pests before winter. To mitigate the cost of overwintering queens in nucleus colonies, beekeepers and researchers are studying the possibility of overwintering queens in an indoor bank which is groups of queens isolated in cages within one colony. (Levesque, Rousseau, & Giovenazzo, 2022) This is an attractive option but the success and survival of banked queens over winter does not yet match the success of new field queens. The survivability of the banked queens is also challenging in the final part of winter and early spring due to food shortages.

It is almost impossible to do a comparative cost analysis of importing queens vs. raising them on farm due to the many ways the queens can be reared. Many beekeepers who raise queens on their farm understand that dollar for dollar it costs more to do in-house than to import the queens but see other benefits. Queens raised locally are often the best queens within an operation and additionally do not have to endure the stress of transport. There is undoubtedly a learning curve associated with raising queens on-farm, but commercial operations that implement a queen program see the positive effects within a few seasons.

Queens reared during summer and overwintered come into spring ready to work with beautiful brood patterns. The costs of imported queens has been steadily increasing and are a challenging item to balance in a farm's annual budget. A beekeeping operation with a queen program also has the added advantage of having queens on hand when they are needed.

There are already many examples of successful queen rearing programs in across Canada. British Columbia and Ontario both have bee breeder associations as a branch of their provincial beekeeping associations. The BC Bee Breeders Association (BCBBA) focuses on education, involving all interested beekeepers. Bee breeders are able to trade queens with others and have their queens tested for sperm count, viable sperm, and queen weight amongst other metrics. (BC Bee Breeders Association, 2022) The Ontario Bee Breeders Association (OBBA) has a mandate to "encourage and support Ontario beekeepers in their production of high quality queens, queen cells and nucs through education and practical support." (Ontario Beekeepers' Association, 2023) Ontario has had a selection program to isolate colonies with resistance traits since 1992. A large percentage of Saskatchewan commercial beekeepers have in-house queen programs. Saskatchewan bees are reputed as being strong honey producers and the Saskatchewan Bee Development Commission is now regularly testing the queens reared locally to assess their quality. Saskatchewan is also home to the Saskatraz breeding program that has an objective to breed gentle and productive colonies and works collaboratively with a queen breeder in California to ensure these queens are available in early spring. (Robertson, 2010) The province of Quebec has several successful longstanding queen programs that offer queens for sale across the country. Through Genome Canada, the Beeomics project seeks to develop “new genomic and proteomic tools that will enable beekeepers to rapidly and cost-effectively breed healthy, disease-resistant, productive bee colonies that are better able to survive our harsh Canadian winters.” (Beeomics, 2016) This collaborative project involving bee researchers across the country has been ongoing since 2016 and the support for this research should continue. Canadian beekeepers have the opportunity to build on the success of these cross-Canada existing breeding projects to meet local demand.

Additionally, there is room for increased formalization in the sector. Canada would benefit from a Canadian Bee Breeders Association. Australia has had a Queen Bee Breeder's Association (AQBBA) since the mid-1980s and works to enhance Australia honey bee stocks, liaise with government and pursue research. (AQBBA, 2023) Their Queen Bee Breeders Association is made up of a cross-section of industry members from beekeepers to researchers. The development of a Canadian Bee Breeders Association would raise the profile of Canadian queens, increase research capacity, allow further genetic development and unify a currently burgeoning but fragmented industry.

"There are important roadblocks in the quest for increasing local queen supply that must be understood and addressed. The timing of queen breeding including production and delivery in a northern country presents some challenges, particularly as the needs of beekeepers and pollination dependent crop producers are generally highest at the beginning of the season." (Bixby, Guarna, Hoover, & Pernel, 2019) Weather, timing, education, labour and cost prove to be barriers in increasing the local Canadian queen market. These factors need further research and mitigation to ensure the successful expansion of the Canadian queen industry. Canadian queens are one the greatest areas of untapped potential to unlock a sustainable future for both the beekeeping and pollination industries.

2.1 QUEENS…AND CLIMATE CHANGE

Climate change is affecting bees although the effects can go undetected. Bees are negatively impacted by the presence of forest fire smoke, inhibiting their ability to fly and forage. In addition, extreme heat or moisture can have significant impacts on colonies. Extreme moisture, other than the obvious risk of flooding, can wash nectar out of flowers and create rainy conditions the bees cannot fly in, impacting their ability to forage. Conversely to the effect of too much water on flowering plants, drought and extreme heat can dry nectar right out of flowers. Either extreme potentially creates a food dearth for a colony.

A colony regulates its temperature regardless of the time of year and maintains a core temperature between 32-36 degrees Celsius. (Owens, 1971) In wintertime, the bees create a cluster around the queen and flex their muscles and wings creating the perfect amount of heat. In the summer, foraging bees will collect water to bring back to the hive to create a cool air circulation system. During abnormally high or low temperature swings, foraging bees' jobs are disrupted from gathering pollen and nectar. This disruption to the graduated job system the worker bees live by may seem benign, but it can have implications for the other worker jobs within the hive as well. A foraging bee is the oldest of the worker bees in the colony, having worked her way through all other jobs before graduating to foraging behaviour. Bees graduating to foraging status prematurely (to make up for the shortage of bees gathering both food and water) could result in a shortage of nurse bees or guard bees. This could have implications on the development of brood, wax production, or in the security of the colony.

In relation to queens, beekeepers know that queens are susceptible to heat and cold stress during shipment. (Pettis, Rice, Joselow, vanEngelsdorp, & Chaimanee, 2016) There is still much more to glean about the effect of heat stress and queen production. In the main areas of queen production in the United States (California and Hawaii), heatwaves and other extreme weather conditions are increasingly common. This could put the quality of queens reared in these areas at risk. In recent seasons, Canadian beekeepers have received poor quality queens from California due to poor climate conditions during queen rearing. The introduction of poor queens has the potential to be detrimental to Canadian beekeeping operations.

More work needs to be done to understand heat stress on queens and in male bees, the drones. Virgin queens mate with drones in the air during flight. How a queen knows when she has finished mating and why she settles on a certain number of drones is not fully understood, however it is known that a queen mates with an average of 12 drones. Once the queen has begun ovipositing she does not mate again for the rest of her life, using the sperm she has stored. When the queen is fully mated, her pheromone profile changes which has a big influence on colony behaviour and performance. It can be assumed that there are effects on the queen of mating in extreme heat but more work needs to be done. As for the drones, it is possible that the increased frequency of extreme heat during in-flight mating is compromising the sperm. This is turn could truncate a queen's laying time and therefore lifespan due to poor sperm count, or non-viable sperm. The mating success of this queen could be average, but the sperm count or amount of viable sperm could be negatively impacted by heat stress in drones. With more extreme heat in the forecast for upcoming seasons, the beekeeping industry needs to understand the implication on the colony's matriarch- the queen and the quality of sperm she collects.

2.2 QUEENS… AS A SYMPTOM

A queen's role within the colony is to lay eggs. The worker bees are otherwise responsible for cleaning the queen, feeding her, and taking care of her in all ways necessary. Living as part of the superorganism, the queen is not the decision maker in the hive. The success of a queen is not judged based on her colour or size but on her egg laying performance.

When the outside temperature increases in spring, the queen will increase the number of eggs she lays daily based on this temperature, pollen (protein) entering the hive and the increase in daylight hours. Conversely, the queen will slow down her laying pattern in times of pollen dearth or as the season becomes cooler and daylight hours decrease. During the cold Canadian winter months, no new brood is reared in the colony.

When assessing the health of a colony, a beekeeper will look at factors like population and food stores. One of the most telling ways to assess the health of a colony is by analyzing the brood quantity and brood pattern. The brood is where several signs of disease can be found and the pattern of eggs the queen is laying can be an indication on floral availability and the quality of the queen. The quality of the queen in the eye of a beekeeper often boils down to the amount, consistency and number of the eggs that she is laying.

4: Research apiary at Punjab Agricultural University, India.

Photo credit: Sandi Roberts

If a queen exhibits a poor brood pattern with spotty eggs for example, the easy solution is to find and kill the queen and install a new one in the hive. (A queen can not be installed when there is an existing queen in the colony or the two queens will fight to the death). When installing a new queen, the colony is given a short brood break as the brood from the old queen hatches out and the new queen begins laying eggs. During this brood break, bees that are normally tasked with feeding the young larva will switch to other tasks freeing up more bees to clean the hive. This often acts as a time to clean out any signs of disease the hive may have and when the new queen begins laying the hive will already look improved. There are still several unanswered questions as to whether the improvement within the hive is thanks to the new queen that was installed, or the brood break the hive was given to clean out any signs of disease. It is likely that some of the colony improvement is due to this brood break and that beekeepers could be replacing queens unnecessarily when really what the hive needs is a brood break. When beekeepers replace queens, the queen is simply killed and a new queen is installed. Therefore, the amount of sperm, viable sperm, ovary size and other metrics of the outgoing queen are all unknown and it can be assumed that beekeepers are killing a percentage of perfectly healthy queens.

There was a study done in the United States to investigate the association of brood pattern with a failing queen. In this study, queens identified as having a poor brood pattern were switched between colonies with queens identified as having a strong brood pattern. It was "…observed that brood patterns of queens originally from poor-brood colonies significantly improved after placement into a good-brood colony after 21 days, suggesting factors other than the queen contributed to brood pattern." (Lee, Gorblirsch, McDermott, Tarpy, & Spivak, 2019) This is a clear and strong indication that a poor brood pattern in a colony is a more complex issue than just being the fault of the queen. This further strengthens the theory that beekeepers who replace queens based solely on brood pattern could be eliminating healthy queens from their operations.

The queen is influenced by the environment around her (within the hive and beyond) and by the comb she lives on and lays her eggs in. The food the queen eats comes from the environment around the hive that the queen will never visit herself once she has completed her mating flights and egg laying has begun. The beeswax comb that makes up the home for the bee bread (pollen), honey and eggs is a sponge for minute amounts of beekeeper applied miticides as well as a multitude of agrochemicals. (Calatayud-Vernich, Calatayud, Simo, & Pico, 2018) In today's landscape, this comb needs to be rotated out of the colony in no more than five years to attempt to mitigate the toxic leeching of the cocktail of sublethal toxins held within the comb. The effects of sublethal amounts of agrichemicals and miticide contamination in the colony's food and wax are still largely unknown but are potentially a significant factor in colony and brood health.

Taking the many factors into account that influence the queen that she has no control over such as the contaminated food coming into the hive, or contaminated wax within the hive, it is possible that the queen is not failing as often as beekeeper's think, but that the queen is a symptom of a larger bee health problem. The queen is the bee that lives the longest in the hive and her compromised health could indicate a larger environmental problem, disease problem or food problem. More research is needed to understand this further.

2.2 QUEENS… AND LONGEVITY

It has become common practice within commercial beekeeping operations in Canada to replace 50% of queens within an operation annually. This is done in an attempt to replace these queens before they exhibit poor brood pattern, the queen runs out of viable sperm, or supercedure occurs withing the colony. An overwhelming number of beekeepers, researchers and queen producers equate queen problems in the hive with the Varroa mite. Varroa destructor mite is a parasitic mite that is originally a host of the Asian honey bee. It is agreed that the Varroa mite is the principle challenge that beekeepers are addressing within hives and without treatment, the Varroa mites and the viruses they vector are very successful at killing honey bee colonies. Varroa and virus loads are another challenge beekeepers balance in the spectrum of bee health. While it is true that Varroa and the viruses they vector have negative impacts on a colony and their ability to survive, Australia provides a contrast to the idea that Varroa are responsible for queen issues.

Australia was the last major beekeeping location in the world to exist without Varroa mite until June 2022 when Varroa mite was found at a port and unfortunately had already begun spreading throughout the country. Commercial beekeepers in Australia are also commonly replacing 50% of the queens within their operations annually. Commercial beekeepers in Australia are only just beginning to see and deal with the most commonly blamed reason for frequent queen replacement: Varroa mite. This indicates that there is more going on with queen longevity than Varroa mites and the viruses they vector. This could be the result of climate change impacting queen rearing conditions or the result of agricultural pressures in areas where bees are kept. This could also be the result of nutritional stress due to a lack of diverse forage. More research is necessary to investigate the non-Varroa mite factors impacting queen longevity.

As was stated earlier, the brood pattern does not necessarily indicate the health of a queen and it is possible that the frequent replacement of these queens is weeding out healthy queens and negatively impacting queen longevity.

5: Old queen cell cups in Tasmania

It has become normal in beekeeping operations that raise queens, and are not using artificially inseminated stock, to select breeder queens based on strong performance in their first year. Selecting only relatively young queens as breeder stock, however, potentially means that the act of raising queens is having a negative impact on queen longevity. It is possible queen producers are breeding longevity out of queens. It may be advisable to normalize the selection of two or three year old queens to ensure that longevity is as important as other selection traits. A generation ago, beekeepers had stories of queens that lived regularly to three or four years and now, queens are in and out the door. Queen longevity needs to be more highly prioritized in breeding operations around the world.

The way that queens are banked has a potential impact on queen longevity. Banking a queen means she is put in a small cage and stored in a colony until ready to ship. The queen has worker bee attendants to take care of her during this time but there is a level of unknown stress associated with banking queens. The length of time the queen is banked has a potential impact on ovary size, how many days it takes the queen to begin laying again and overall queen success. In theory, the longer the banking period, the more compromised the queen. A standard for how long a queen can be banked without negative implications needs to be understood and adhered to by queen producers.

The age of a queen when harvested could also have a negative impact on queen success and longevity. When a queen cell is ripe and before it hatches, it is transferred into a mating colony. The queen then hatches and takes several mating flights to mate with a range of drone bees. As was stated above, once the queen has finished mating, she does not mate again for the entirety of her life. The queen will then start laying eggs and shortly after this time, is pulled from the mating colony and sold or transferred to a production hive. There is a potential problem in relation to the age of the queen when harvested from a mating colony. In Australia, a study was done looking at the age the queen was harvested from a mating colony or queen bank and the success of introduction and further success at 15 weeks. In the study, completed over three years, there was a 90%+ success rate in introducing queens that were harvested at 35 days, and only a 47.5% success rate with queens harvested at 17 days. (Rhodes, Somerville, & Harden, 2004) A 17 day old queen would be newly mated and it is not uncommon for commercial queen breeding operations to harvest their queens shortly after mating is complete in order to meet the demand for their queens. Interestingly, this study was completed from 1999-2003 when Australia "reported that the number of commercially reared queen bees surviving introduction into established honey production hives are often low." (Rhodes, Somerville, & Harden, 2004) In North America, queen issues have gotten a lot of traction in recent years but this study indicates that queen issues have been a global problem for decades, and that some of the solutions can be found within bee breeding operations.

It is agreed among beekeepers who raise queens for use on their own farms that the queens that are reared and raised in a mating colony and grow within the same colony instead of being transferred or banked are the most successful queens. Further research is needed to prove queens are more successful when reared this way, and the beekeeping industry needs to standardize the practice of allowing queens to mature to a specific age before harvesting or caging them. This will increase the success of the queens and potentially positively impact their longevity inside the hive.

6: Colourful honey frames in NSW, Australia

Early supercedure has also been a top concern with beekeepers. Early supercedure means a colony is replacing a queen within a few weeks of introduction even though she has been accepted by the colony and has begun ovipositing. The reasons that a colony chooses to supercede their existing queen are largely unknown and the fact that premature supercedure is increasingly common is a cause for great concern. Supercedure could be related to a problem with queen mandibular pheromone, meaning there is a disruption in how the queen communicates with the colony. More research is needed to understand the reasons behind the increased frequency of supercedure so it can be mitigated.

There is still a lot that beekeepers and researchers do not understand about queens within the hive. More research into queen introduction and queen banking in relation to how many days the queen is dormant and how long the queen lives would greatly benefit queen producers and beekeepers alike. Queen rearing is an art and a science and there is still a lot to learn to continuously improve the stock being used in Canadian apiaries whether it is reared locally or abroad.

2.3 QUEENS… VARROA AND SELECTION

It is impossible to have successful honey bee colonies without the management of Varroa destructor mite. Recently, more work into the viruses that these mites vector has been ongoing. Many of these viruses are invisible to the beekeeper and cannot be treated. The ongoing virus research sheds more light on a challenge that is difficult to solve. The Varroa mites feed on the fat bodies of the bees and if untreated, a colony dies due to the mite infestation and/or the virus loads brought by the mites. The previously recommended treatment threshold for Varroa mite is when the mites reach a level of 3 per 100 bees in the colony or 3%. "Recent findings indicate that even those maintaining the commonly suggested 3% action threshold may still lose colonies to mite-related issues." (Bee Informed Partnership, 2023)

In recent years, the theory of mite bomb hives has led to a potential variation in mite management methods in apiaries. A mite bomb is a term for a colony collapsing due to Varroa mites and the viruses they vector until it is robbed out by another hive in the apiary, transferring many of the mites around the apiary through the robbing behaviour. These colonies have levels of mites that are so high, treatments are often ineffective. A few mite bomb hives within an apiary can be the bad apples that impact the health and winter survival of all hives within an apiary. For a commercial beekeeper, an apiary averages 30+ hives. The identification and individual treatment of these mite bomb colonies can potentially result in less miticide use overall (through individual colony vs. apiary treatments) and fewer losses by weeding out the bad apples within a location. When these mite bombs can be identified, they can be relocated to a hospital apiary where they can be isolated from other colonies and either treated or destroyed.

Conversely to mite bomb colonies, there is breeding potential. If a small number of hives within an apiary are likely to be mite bombs, it can be assumed that a small number of hives within an apiary have excellent natural mite resistance and could be potential candidates within an operation's breeding program. Raising queens with some potential to naturally manage a hive's own mite population could have significant positive impact on bee health. While there is currently a lot of research being done into genetic selection for mite resistance, locating the natural mite resistance within a beekeeping operation is an easy way to bolster a local breeding program. Identifying mite bombs or naturally mite resistant colonies would require a change in management style for many commercial apiaries that sample a few hives per apiary for mites instead of all hives within an apiary. Randy Oliver in California is already managing his commercial apiary on an individual hive basis to monitor for diseases and pests and for queen selection purposes. Oliver identifies hives within his operation with a zero or low Varroa count as 'potential breeders' and the hives are assessed 4-5 additional times over the season before they enter his breeding program. In this way, Oliver is identifying his naturally mite resistant colonies. He looks for colonies that exhibit characteristics "that in combination confer the (heritable) trait of Varroa resistance." (Oliver, 2023) This method has the potential to be time consuming for commercial apiaries that are already struggling with labour shortages. The challenge of time and labour should be weighed against the benefits of individual hive knowledge of diseases and pests. This method has excellent potential to lower stress associated with mites while augmenting a farm's breeding program through a more advanced hive selection process.

3.0 INDUSTRY AND PUBLIC COLLABORATION

In order to ensure a sustainable Canadian beekeeping industry for future generations to come, an increasing amount of industry and public collaboration is necessary. It is well documented, although often understated, what bees do to benefit agriculture. It is now time to explore what agriculture can do to benefit bees. In no small part, farmers, land owners, gardeners, and city dwellers have the ability to positively impact the outlook for bee health. The simple act of purchasing 100% Canadian honey can support local farms in their efforts to keep their bees healthy. From planting pollinator friendly plants in a home garden to ensuring diverse forage is available on farmland, Canadians have a huge amount of potential to positively benefit the diet of pollinators from coast to coast. Honey bees, like people, require a great diversity in foods in order to stay as healthy as possible. Some flowers produce pollen, while others produce nectar and others again are unattractive to bees. Most flowers that produce pollen represent incomplete proteins for the bees. Just as people seek a balanced diet by eating from all food groups, bees require diverse floral resources to get the proper balance of proteins and carbohydrates. In addition to their complex dietary needs, honey bees in Canada are dormant for the winter months when it is too cold for them to forage and there are no flowers available. Bees need to make enough honey during the warm season to have honey for the winter, supplemented by feed provided by the beekeeper.

7: Helping with a school tour in South Australia with N'Sc 2010 Ben Hooper

There is incredible work being done by Bee City Canada, part of Pollinator Partnership, to connect urbanites across Canada with the concept of pollinator health. There are currently 81 Bee Cities in Canada and several schools and campuses designated with pollinator friendly status. "Pollinator habitat creates beauty. Selecting pollinator friendly plants including native trees, shrubs, vines, forbs and grasses, along with herbs and vegetables, provides food for wildlife and humans too. A Bee City improves its municipal environment and the physical and mental health of the residents by connecting people with nature and encouraging healthy, clean food consumption." (Canada B. C., 2023) (Canada P. P., n.d.)

Other organizations like Honey Bee Health Coalition are leaders in collaboration with a mission statement to "collaboratively implement solutions that will help to achieve a healthy population of honey bees and other pollinators in the context of productive agricultual systems and thriving ecosystems." Their work includes the Bee Integrated Program that pairs beekeepers and landowners to explore best management practice that positively impacts the farm and benefits pollinators in tandem. HBHC also works to educate beekeepers and promote bee habitat. (Honey Bee Health Coalition, 2021)

The Pollinator Stewardship Council is another example of a group doing great collaborative work to benefit pollinators. Their mission to "defend managed and native pollinators vital to a sustainable and affordable food supply from the adverse impacts of pesticides" (Council, 2023) focuses on advocacy and works to effect legislative change in the USA. They offer resources on the importance of bees to our food system and the need for a symbiotic relation between pollinators and food production.

Project Apis m. is an organization focused on research. They fund projects across several bee health challenges in Canada and the United States. Additionally, their Seeds for Bees program promotes pollinator-friendly cover cropping in the western United States. They have a youtube channel featuring lectures and best management practice information for beekeepers. (m, 2017) Project Apis m. also promotes diverse forage in California almonds, which other than almond flowers for a weeks of the year, is a food desert for bees.

8: A pollinator garden at Penn State, USA

Increased collaboration between beekeepers, land owners, the public and agricultural organizations and groups like Bee City Canada, Pollinator Partnership Canada, Honey Bee Health Coalition, the Pollinator Stewardship Council, and Project Apis m. will have the added benefit of breaking down barriers between managed and wild pollinators. Their needs are often the same and they can be supported as pollinators as a whole, without conflict between species.

South of the border in the United States, since 2008, several US States have developed Managed Pollinator Protection Plans or MP3s. In 2008, the Environmental Protection Agency created a Pollinator Protection Strategic Plan as a response to the growing concern over Colony Collapse Disorder, which at the time was a mysterious disease, causing hive mortality and/or bees to seemingly vacate hives. The EPA equates the need for pollinator protection with public health. (Environmental Protection Agency, 2023) Healthy bees indicate a healthy and more secure food system. These MP3 plans have been created and adopted by several states including Michigan, New York, and Pennsylvania. These are generally non-regulatory collaborative guidance documents. Michigan's aims to "improve and protect the health of pollinators in Michigan, while simultaneously protecting our crops, property, and human health." (Michigan State University, 2022)

The Honey Bee Health Coalition has guidelines for the creation of Managed Pollinator Plans which inlclude:

- Public stakeholder participation
- Methods for stakeholder groups to communicate with each other (aka mapping systems)
- Methods to minimize risk of pesticides to bees including Best Management Practices
- A clear and defined plan for public outreach
- A mechanism to measure MP3's effectiveness
- A process to periodically review and update the plan (Honey Bee Health Coalition, 2021)

In Canada, there is often conversation about the interaction between honey bees and native/wild bees. Honey bees are often blamed for competing with other kinds of bees and dominating the landscape due to their large colony sizes. This conversation is mirrored around the world especially in places where honey bees are not native like the United States, Canada and Australia. The conversation around the competition of bees for forage needs to turn into a conversation about how our landscapes and farms can support a variety of apis and non-apis bees through increased floral count and floral diversity. There is a lot of positive research into the non-competitive nature of different bee species while foraging. Unfortunately, it is also true that its possible for bees to transmit pathogens to different species through floral contact. (Cox-Foster, 2023) In Vermont, a modelling study was done to prove that increased floral density will decrease the spread of pathogens between bees and promote a stronger diet for bees as well as improved health through the mitigation of pathogen transmission. (Burnham, 2023)

Canadian provinces taking on the MP3 model is an opportunity to bring different organizations and stakeholders to the table to prioritize pollinators in urban, rural and agricultural settings alike. Approaching pollinator health as a pollinator wide issue- not just honey bees, bombus bees or butterflies- opens doors for increased collaboration across conservation authorities, agriculture and urban areas. Bees play a unique role in all of these areas. Although initially USA MP3 plans focused specifically on the mitigation of negative effects of pesticides on pollinators, the development of these plans in Canada should focus more broadly on education and bee health through a multi-faceted solution-based approach.

4.0 CONCLUSION

Honey bees have the potential to be a pillar of sustainability within the agricultural industry. The health of the bees is a strong indicator that teaches us about the health of our food production system. Bee health is complex, multi-faceted and still holds many mysteries. Continued research by beekeepers and academics alike needs to focus on the broader understanding of bee health and how food production and the natural environment can augment the health of bees through their practices. A solutions-based approach to bee health has the potential to increase yields of agricultural crops and honey while improving the health of a broad range of pollinators that call our agricultural and wild landscapes home.

A healthy queen is essential to the health and success of a colony of bees. Many factors influence queen health and some of them can be mitigated by raising more queens locally in Canada. Canada is lagging behind in their queen production sector and has incredible potential for growth and formalization in this sector. Pressures like climate change will only become more problematic in the future, and a greater understanding of the impacts of climate change is necessary in order to combat the challenges in changing weather conditions.

While Varroa mites remain a significant and complicated problem in beekeeping around the world, queen problems can not solely be blamed on the increased pressures of Varroa. Other factors need to be explored including pesticide and miticide influences. Queen longevity remains a top concern. Unless queen longevity becomes a top priority in the selection of breeder queens and in commercial beekeeping operations, queens will continue to be replaced at alarming and unnecessary rates. Queen longevity and resilience go hand in hand.

Everyone has a role to play in the health of bees. People who eat honey, fruits and vegetables, plant flowers, live in cities, actively farm and everything in between are all positively impacted by bees and pollinators. Living in the intersection between agriculture and nature, bees are heavily dependent on all types of land use to maintain a healthy balance. Pollinators feed the planet and in turn, through education and collaboration, Canada needs to help to feed them and support them. With healthy bees, comes a healthy food system in Canada.

5.0 INDUSTRY RECOMMENDATIONS

- Canadian beekeepers should take responsibility to raise and improve their own stock. More commercial apiaries need to address their bee health challenges through the implementation of local queen programs.

- Canada should formalize their queen industry through the formation of a Canadian Queen Breeders' Association.

- More regulation should be considered for non-apis managed pollinators (bombus and leafcutter bees) to mitigate disease spread and biosecurity risk.
    - There is a lack of regulations surrounding the proper disposal of bombus colonies at the conclusion of a pollination event. This puts the greater bee population at risk of Varroa mite and disease spread.

- Canadian government should support the expansion of industry and public collaboration through funding for the development and implementation of provincial Pollinator Protection Plans.

- Provincial beekeeping organizations should pursue stronger pollinator/bee-related recommendations within provincial Environmental Farm Plans by putting forth recommendations related to bee health, pollinator diversity, habitat conservation, and biodiversity.

- It is imperative that businesses, governments, stakeholders, and other relevant organizations continue to fund bee health research (lead by researchers and beekeepers) so industry can mitigate challenges through greater understanding of the complexities of bee health.

5.1 PERSONAL FARM RECOMMENDATIONS

- Select breeder stock from 2+ year old queens.

- Explore alternative forms of queen mating allowing for increased control of drone genetics.

- Sample each hive in a set number of apiaries for Varroa mites to gain knowledge on mite bombs and mite resistant breeding potential.

- Liaise with farmers and land owners to broadly support managed and wild pollinators and increase bee pasture.

- Consider lowering treatment threshold for Varroa mites to mitigate the effects of virus loads.

6.0 GLOSSARY

Apiary: location where bees are kept; bee farm

Apis mellifera: European or Western honey bee

Brood: eggs, larvae and pupae

Colony: hive; a group of workers and drones with one queen. This can occupy one or several boxes.

Dearth (in relation to bees): a scarcity of pollen and/or nectar.

Drone bee: male bee. The male lives within the hive seasonally and are responsible for mating with new queens and spreading the genetic material of a colony. They make up approximately 5% of a colony's population.

Drone layer: a queen that can no longer lay worker brood and can only rear drones.

Hive: colony; a group of workers and drones with one queen. This can occupy one or several boxes.

Mite bomb: a colony collapsing due to varroa mite and the viruses they vector.

Nuc or Nucleus colony: a small colony of bees, often five frames.

Oviposit: to lay eggs.

Pollination event: a crop's bloom period when bees are contracted to pollinate a crop.

Queen bee: the mother of the colony responsible for egg laying. There is normally one queen per hive.

Robbing behaviour: when bees take the resources from a failing colony. Bees may also inadvertently acquire disease and pests loads from said colony.

Split: the division of a colony into two colonies. This is often done in spring to replace colonies lost during winter.

Superorganism: a term used for a group of interacting individuals that act as one organism.

Supercedure: when a colony replaces a queen without beekeeper intervention.

Worker bee: female bee. The worker is responsible for all hive tasks (food production, security, cleanliness) with the exception of brood rearing. They make up over 90% of the hive population.

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8.0 APPENDICES

A: BACKGROUND INFORMATION AND RECOMMENDED RESOURCES

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B: ADDITIONAL NUFFIELD SCHOLARSHIP HIGHLIGHTS AND INSIGHTS

I was very fortunate to visit beekeepers, farmers, researchers and government officials across 6 continents over the course of my Nuffield Canada Agricultural Scholarship. Through travel in the USA and Chile, I was able to attend several American Beekeeping Federation conferences as well as the international Apimondia Congress in Chile. These conferences highlight the most recent bee research around the world and provided an invaluable window into current global bee health issues. Additionally, I was able to visit bee researchers and labs in Florida, Hawaii, Punjab, New South Wales and the Netherlands. Keeping up with as much up-to-date research as possible paved the pathways for me to a greater understanding of bee health and the work being done to combat bee health challenges globally.

9, 10: Queen production in Scotland and NSW, Australia

While in New South Wales Australia, I visited the Horner farm (figure 10) to see their unique way of mating queen bees using train tracks. The beekeepers (Joe and son Wayne) keep the mating nucleus colonies inside of a blackout building during the day and set them out on train tracks before dusk to allow them to mate when the feral drones have already finished flying for the day. It was incredible to see this totally unique set-up in person. The potential for alternative queen mating set-ups and rigorous genetic selection criteria were big take-aways from my beekeeper visits in Australia. I was also fortunate to compare notes on commercial pollination as Australia is home to many crops dependent on insect pollination including canola and almonds. Lastly, biosecurity is taken incredibly seriously in Australia and it was incredible to witness how strong biosecurity measures can work to protect the beekeeping and broader agriculture industries.

11: Koppert Biological Systems, the Netherlands

I had the opportunity to visit one of Koppert's facilities while in the Netherlands to learn about the manufacturing of bombus bees for commercial pollination. Bombus bees are often used alongside honey bees to pollinate commercial crops such as blueberries. These bees follow a different regulatory criteria and pose a potential risk to broader bee health through disease and pest transmission if they are not disposed of correctly after the conclusion of the pollination event they are purchased for. This visit really drove home that bee health encompasses more than just honey bees and the health of all pollinators needs to be prioritized simultaneously in order to have sustainable ecosystems and effectively pollinated crops.

12: A gourd hive and top bar hive in Harare, Zimbabwe

Beekeeping in Zimbabwe was an interesting and unique opportunity because of the subspecies of honey bee present in the country: Apis mellifera scutellate. These bees are reputed as being extremely ill-tempered however, I was impressed by their natural disease and pest resistance. I have never worn so much bee equipment at one time! In Canada, our honey bees are a mixture of many different subspecies and while they have unique characteristics, beekeeping in Zimbabwe was the first time I was able to work with a unique and pure strain of Apis mellifera. The breeding potential locked in Apis mellifera subspecies around the world is incredible. There are many wonderful traits that would suit the Canadian beekeeping season. I was prepared to dislike these bees due to their poor temperament, but instead they opened up my mind to the importance of preserving global Apis mellifera subspecies and isolating desired genetic traits. Although these bees were aggressive, they were also incredibly hardworking and to avoid the heat they started foraging before 5am.

13, 14: Bombus and Apis dorsata in India. Photo credit Sammy McIntyre, Aimee Snowden

There is such an incredible diversity of bees in India! It was amazing to see 4 dominant types of honey bees: Apis mellifera, dorsata, cerana, and florea. Apis mellifera is the only one of these bees present in Canada. There is incredible potential to learn about the Tropilaelaps mite and the spread between bee species in India. I also had no idea honey bees likes to drink from banana flowers. I hope that researchers and beekeepers will use India as a ground for learning about the interactions between honey bee species and the pests they share.

The Nuffield network provides scholars important contacts and opportunities to visit embassies and individuals working in government and trade organizations in countries around the world. I really enjoyed the opportunity to meet with several branches of the USDA, Bayer Crop Science, Australia Meat and Livestock (in Singapore and Qatar), embassy delegates from several countries while in Washington, DC, and embassy staff in Delhi and Doha just to name a handful. These meetings are invaluable to give a greater understanding of agricultural policy, trade agreements, food security and food production in a global context.

15: Visiting the Australian Embassy in Doha, Qatar