RECOGNIZING THE EFFECTS OF CLIMATE CHANGE ON HONEYBEES

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by

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April 2021

A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

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ABSTRACT

Lanoix, F.K. 2021. Recognizing the effects of climate change on honeybees. (viii + 25 pages)

Keywords: Climate change, entomology, honeybees, bees, reproducing

Honeybees (*Apis mellifera* L.) are an essential pollinating species as they are important in building healthy and resilient ecosystems. Honeybees, now found all over the globe, were introduced to North America from Europe many decades ago. Because effects of climate change have begun to arise, it has been more difficult for honeybees to follow their similar activity patterns as in years past, and they have had trouble adapting due to their bodies being ectothermic and the temperature of their surroundings determining their activity. This has led to a severe decline of the species as well as other pollinating species of bees. Climate change has also affected honeybees by affecting the floral resources available to them and has introduced more of their natural enemies. Because significant numbers of honeybee populations are decreasing, researchers have investigated the correlations between climate change and honeybee decline along with declines of other vital bee pollinator species. Investigating the effects of climate change and implementing multiple conservation plans and policies has been a method that has been proven to improve, develop, and enhance pollinators such as wild bees and honeybees, their conservation, and habitat restoration.

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ACKNOWLEDGEMENTS

First of all, I would like to thank Dr. Don Henne for being my thesis supervisor throughout the entire thesis project. Dr. Henne provided an in-depth understanding of bee decline, and his advice about bees guided me every step of the way.

I would also like to Mr. Ryan Wilkie, my second reader, who also provided great feedback and information.

INTRODUCTION

Climate change is a general term to hear these days. According to the National Oceanic and Atmospheric Administration (NOAA) 2019 Global Climate Summary (NOAA 2021), the combined land and ocean temperature has increased at an average rate of 0.07 degrees Celsius per decade since 1880, and since 1981 is increasing faster (Lindsey 2021). This significant change in climate has affected many insect populations, as disruptions of local adaptations to climate could result in localized population extirpations (Liebhold 2011).

As vital pollinators, bees are an important group of insects, and climate change has impacted our wild bees the most. As temperatures rise, North American and European wild bee populations are dwindling. In their most southern ranges, bees are dying of exposure to high heat, and in their most northern ranges, their populations are shrinking (Turner 2019). There are roughly 4000 species of bees throughout the United States and Canada (University of Minnesota 2021) divided into seven families: Andrenidae, Melittidae, Stenetridae, Halictidae (which are solitary ground-nesting bees), and the Megachilidae and Colletidae (compromised of the solitary and robust bees). The seventh family of bees in North America, the Apidae, is the largest of the seven families of bees, and includes the honeybees and bumblebees, both of which have been exploited by humans for centuries (University of Minnesota 2021).

Historically, bees are necessary to our ever-evolving world. A bee is not just a pollinator that is responsible for the seeds, fruit, and nuts that feed other organisms; bees also play an important role in promoting genetic outcrossing of plant populations (Roubik 2020). As a result, bees contribute to complex interconnected ecosystems that allow a diverse number of species to persist and thrive. Knowing that bees play such significant roles in maintaining diverse ecosystems and provide many crucial contributions to healthy ecosystems, it is essential to educate ourselves about the impact of climate change on them.

Honeybees are ectothermic, meaning the temperature of their surroundings determines their activity. This means that climate change characterized by elevated temperatures could negatively affect their biology, behaviour, and dispersal. Climate change affects bees by also affecting the floral resources and natural enemies of bees (Kjhol 2011). Changing temperatures could create temporal and spatial mismatches between bees and their floral resources, having severe demographic consequences for bees (Raza 2021). Learning more about effects of climate change on our bees will give us the chance to adapt and implement plans that will save our bees before it is too late.

This thesis will evaluate the effects that climate change is having on bees, specifically honeybees. My objectives are to 1) examine studies that have shown that climate change has promoted the decline of bees, and 2) focus on conservation plans that have maintained or helped promote bee abundance.

I hypothesize that climate change is severely threatening our bees' existence and that deploying conservation plans will benefit their abundance once again.

MATERIALS AND METHODS

The information was collected by reviewing many sources. Information collected was focused on specific search words and topics, such as bee decline, climate change, bee populations, conservation status of bees, reproduction of bees, bee surveys, and conservation plans. By using these specific search terms through internet search engines, many of the internet sources used to collect the needed information included sites such as Google Scholar, Microsoft Academic, WorldWideScience, Sciencegov, Research Gate and lakeheadlib.

LITERATURE REVIEW

1.1 **LIFE CYCLE OF BEES/DISTRIBUTION**

A honeybee's life cycle also describes those of other insects in the family Apidae, of the insect order Hymenoptera. A honeybee's life cycle includes four main stages: the egg, the larva, the pupa, and the adult (Britannica 2020). In a typical beehive, queen honeybees lay both fertilized and unfertilized eggs. Fertilized eggs turn into worker bees and queen bees. Worker honeybees are all female offspring of the queen. There is only one queen bee per hive and the only one that can reproduce (Laidlaw & Page 1984). Unfertilized eggs turn into drone bees, which are all males. Drones mate with virgin queens from other beehives, and these queens then start a new colony (Laidlaw & Page 1984).

Eggs in the beehive typically hatch in three days and then develop into larvae, known as grubs (Britannica 2020). At first, all grubs are fed royal jelly, but only the future queens are fed a "royal jelly." When fully developed, the grubs transform into pupae. This stage is when most parts of the adult honeybee form; wings, legs, abdomen, internal organs, and muscles (Britannica 2020). The main developmental differences between queen bees, worker bees, and drone bees is that queen honeybees emerge in 16 days and generally grow to estimated sizes of 20 mm, worker bees emerge in 21 days, growing to 11-15 mm, and drone bees emerge in 24 days, generally being a little bigger than the worker bees (Figure 1) (Britannica 2020).

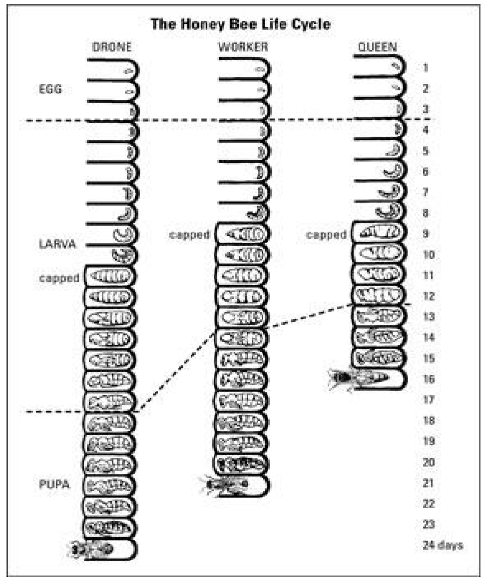

Figure 1. The lifecycle of bees (Lanzac 2016)

Once adult honeybees have emerged, the queen(s) will fight amongst themselves until only one remains in the hive (Britannica 2020). At this time, the hive has been recycled with new bees (queens and workers), as the old queen and majority of her workers typically have left (absconded) once the new queen and her workers have taken over (Britannica 2020). Once the present colony is taken over, the queen will mate with multiple drones—this behaviour is called polyandry (Laidlaw & Page 1984). Polyandry is a term that describes a mating method that allows an increase in genetic diversity within honeybee colonies, resulting in an improvement of a colony's fitness and survival. Characteristics of the genetically diverse colony will increase the size of a population, foraging activities, and food supplies (Laidlaw & Paige 1984).

Throughout the lives of these uniquely social insects, all three adult forms exhibit very different characters in longevity. The queens can live for up to 5 years, while worker bees only live 1 to 1.5 months in the summer and 4 to 6 months in the winter

(Prado 2020). Simultaneously, drone honeybees do not live more than six to eight weeks or until they mate with the queen bee.

IMPORTANCE OF BEES

Bees play important roles in the resilience of ecosystems. Bees serve as critical pollinators of many flowering plants, which helps with wild plant growth, providing many different varieties of fruits and vegetables that are important food sources, and assist in the strong growth of deciduous forests due to the production of seeds which are highly dependent on the pollination of bees (Williams 2014). Ecologically, bees are important pollinators of woodland spring ephemerals and montane meadow plants and many of the native plant species that make up the diverse ecosystems found through North America (Williams 2014).

Bees are important pollinators in most regions where flowering plants exist. Insects pollinate 80% of flowering plants worldwide, 85% of which are pollinated by bees, and as many as 90% of fruit tree flowers are dependent on bees (Tautz 2008). The list of flowering plants pollinated by bees includes about 170000 species (Tautz 2008). The number of flowering plant species dependent on bees, and without which they would no longer live, is about 40000 (Tautz 2008).

To elaborate on these previously described pollination characteristics, bees provide essential ecosystem services for migratory and resident birds who depend on forest seeds and fruits that are produced through the pollination of wild plants. Most flowering plants also need to be pollinated to reproduce, and bees are responsible for about 70% of that pollination (Canada Senate 2015). Additionally, approximately one-third of the human diet comes directly or indirectly from insect-pollinated plants (Canada Senate 2015). The importance of bees to food and seed production is noticeable. Services provided by bees are valued at $44 million in New Brunswick, $80 million in Manitoba, $400 million in Saskatchewan, and $10 million in British Columbia (Canada Senate 2015).

DECLINE OF BEES

A decline of honeybees and many other wild pollinators is now evident. It has been recently suggested that differences in the ranges and rates of decline among wild bee species and honeybees may relate to differences in their degree of habitat specialization (Goulson 2006). According to the Canadian Association of Professional Apiculturists (CAPA), the state of honeybee health, as measured by colony losses, can vary significantly from one province to another (Figure 2) (Canada Senate 2015).

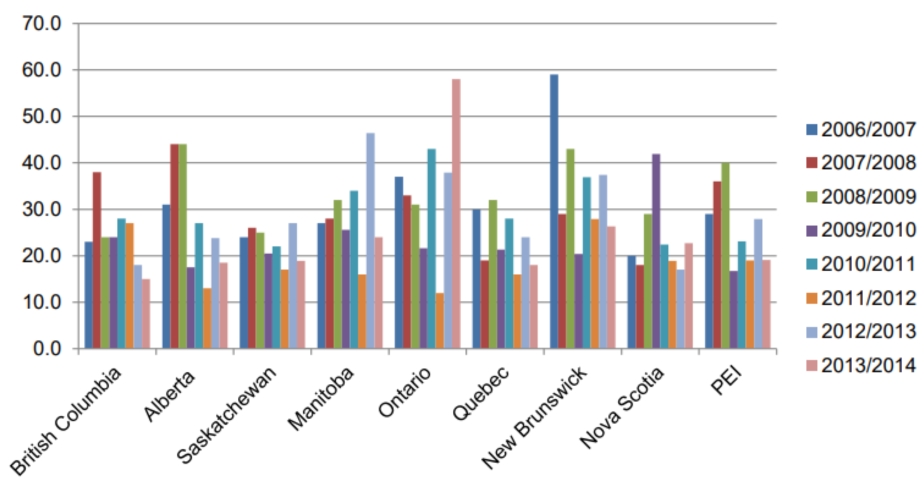

Figure 2. Honeybee winter losses (percent) by province, 2006/2007 to 2013/2014. Source: Canadian Association of Professional Apiculturists (Annual Colony loss reports).

A significant factor contributing to the loss of honeybee colonies is a direct result of climate change. Long winters or cool and prolonged springs result in higher honeybee mortality (Health Canada 2014). As indicated by apiarists, cold weather makes it difficult for honeybees to leave the hive for cleansing flights, making the colony more susceptible to disease (Canada Senate 2015). Throughout North America, commercial honeybee keepers observe a loss of 35% on average of their colonies every winter (Canada Senate 2015).

Many wild (native) bee species are also declining rapidly. Despite their ecological and economic importance as pollinators, North American wild bees have not been extensively surveyed. In fact, the primary conservation status of most native bees is unknown (Colla 2008). Two native bee surveys were conducted by Colla (2008) to determine native bee conservation status in Ontario. One survey was done from 2004-2006 in southern Ontario, and this survey was compared with the results of a previous survey done in the same area from 1971-1973 as part of an investigation into patterns such as changes in community composition (Colla 2008). The study found that native bees have declined in abundance not only throughout southern Ontario but throughout all ranges (Colla 2008). Several bee species that used to be common have now become very rare (Johnson 2014).

The first native North American bee species that was noticed to be in decline was the American bumble bee (*B. pensylvanicus*) in California, and the Franklin bumble bee (*Bombus franklini*) was once a common bee throughout its small range but was increasingly seen less and less frequently (William 2014). Despite extensive searches for this bee, it has not been seen for many years and was the first North American bee to be listed on the IUCN Red List of threatened species (William 2014). The rapid decline of the Franklin bee has motivated researchers to accumulate baseline data for all other North American species of bumble bees (William 2014). Most recent studies that have been done in the United States and Canada have shown that many native bee species are showing varying levels of declines, meaning that potentially more than half of North American native bee species may be at risk (William 2014).

IMPACTS OF CLIMATE CHANGE ON BEE POPULATIONS

The rapidly changing climate that is affecting the planet has already had severe consequences on honeybee populations and many other insect populations, and a changing climate will only continue to promote this decline. Among the environmental factors that may impact the delivery of provisioning services by honeybees and other species of bees, climate change has been an observed variable affecting a variety of different bees along different climatic gradients (Delgado 2012). Found at lower altitudes, honeybees remain active throughout the year, whereas at higher latitudes they pass through a period of complete inactivity due to very prolonged winters (Delgado 2012). This suggests that activity decreases significantly with increasing elevation due to the colder months (Delgado 2012).

Climate change can influence bees at different biological levels. It can directly influence bee behaviour and physiology, alter the floral environment's quality, and can also increase or reduce colony harvesting capacity and development (Conte & Navajas 2008). This can define new bee distribution ranges, giving rise to new competitive relationships among bee species and races and their parasites and pathogens (Belsky & Joshi 2019).

The effects of a changing climate can also influence a bees' development cycle. As an example of bees' development cycle being affected, in arid environments some bees such as honeybees could at one time develop in the Arizona desert. Survival requirements for these honeybees is a reliable supply of water, which they use in large quantities to raise the larvae and to regulate brood temperatures (Conte & Navaias 2008). Now in these hot and dry environments, flowers are not providing honeybees with enough water, leading to bee death. According to climate change predictions (Belski & Joshi 2019), desert regions will become even drier, which will lead to the disappearance of honeybees in these parts of the United States. Additionally, it has been studied that each race of honeybees develops at their own rate; any change in climate or movement of the race of honeybees from one region to an unknown one is bound to have measurable consequences on the bees' development (Conte & Navajas 2008).

Multiple factors play a part in the quickly declining population of honeybees. There is data suggesting that environmental changes directly influence honeybee development, such as the awareness of the impact that rain can have on honey harvesting by honeybees. For instance, when some flowers such as Acacia flowers are washed by rain, they are no longer attractive to honeybees, as it dilutes the nectar (Conte & Navajas 2008). This is also equally similar when it comes to drier climates, as it will reduce the production of flower nectar for honeybees to harvest, and examples pertaining to this include lavender flowers which produce no nectar when the weather is too dry, which makes harvesting by honeybees extremely difficult (Conte & Navajas 2008).

Phenology is applied to the recording and study of the dates of recurrent natural events, in relation to seasonal climatic changes (Britannica 2019). A study which analyzed climate-associated phenological changes in bee pollinators and bee-pollinated plants was done on ten different native bee species from northeastern North America. The purpose of this study was to evaluate the phenology of ecological processes modulated by temperature, and how these would make bees potentially sensitive to climate change (Bartomeus 2011). With data from 1970 to 2010, the assumption was that bee phenology changed a lot, and was assumed to be due to climate change. Supporting this assumption was that climate change is rapidly decreasing the phenological advances of bee pollinators (Bartomeus 2011). Furthermore, the rate of change in bee phenology over time was analyzed using a general linear mixed model by comparing bee phenology with the day of the year that specimens were collected. The overall analysis of the model, including all bee species, showed a significant negative slope, indicating that spring-active bees are advancing their phenology (Bartomeus 2011). Over the 40-year time period (1970-2010) model slopes have changed and have become twice as steep, implying that 69% of the total phenological advance has occurred since 1970, as compared to 1870-1970 where there were no drastic changes (Bartomeus 2011). This work indicates that changes in bee phenology are due to the onset of global climate warming (Bartomeus 2011).

Research measuring the effects of climate change on bees suggest that bees are only half as likely to be found in areas where they were once common. Weather is frequently getting too hot for bees in many places at the wrong time of a given year (Weber 2020). Using a century's worth of records and data on 66 different types of bee species from more than half a million locations, researchers showed a clear correlation between bee population surveys and weather that exceeded their tolerances. The studies found a strong connection between population decline in bees and climate, resulting in the assertion that climate change in North America has increased the risk of extinction of most bees (Weber 2020).

One aspect of climate change that was found through research conducted by Soroye (2020) is the increasing number of days with extreme heat. This research was conducted on the contributing factors of climate change that has led to widespread declines among bumblebees across the globe. Soroye (2020) analyzed a large dataset of bumblebee occurrences across North America and Europe and found that an increasing frequency of scorching days is increasing local bumblebee extinction rates, thereby reducing colonization and site occupancy and decreasing bumblebee species richness (Soroye 2020). Furthermore, bumblebees may be especially sensitive to the effects of climate change in Canada specifically since bee species tend to be more vulnerable to reductions in colonies if they have narrow climatic tolerances and are also close to their limit range (Environment and Climate Change Canada 2016). Proceeding, as average temperatures continue to rise, bees/bumblebees may face an untenable increase in the frequency of extreme temperatures (Soroye 2020).

Evidence for precipitation influencing site occupancy by bees indicated bee declines in most sites that became drier (Soroye 2020). Bumblebee species richness declined in areas where increasing frequencies of climatic conditions exceed a bee species' historically observed tolerance in both Europe and North America (Figure 3). Local changes in thermal (A) and precipitation (B) position indices are shown in Figure 4 below. A darker red color in the figure indicates warmer regions and a darker blue indicates wetter regions and that, on average, bee species in a given assemblage are now closer to their temperature or precipitation limits (Figure 3) (Soroye 2020).

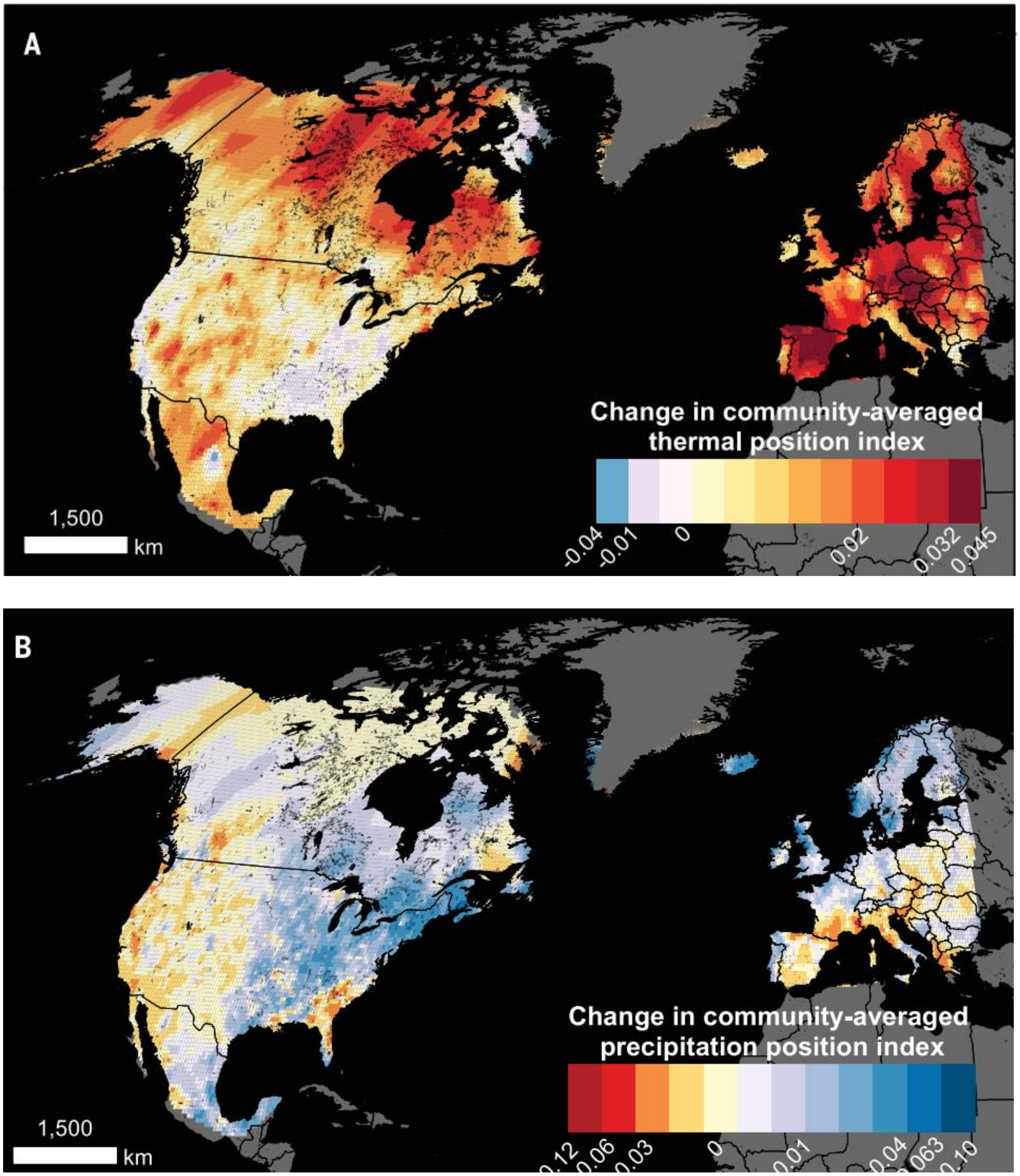

Figure 3. Change in community-averaged measures from baseline (1901-1974) to recent periods (2000-2015). Source: Soroye (2020)

Predictions from a detection corrected occupancy model projecting percent change in detection-corrected bumble bee species richness as a function of mean community-averaged thermal and precipitation position is seen below (Figure 4) (Soroye 2020).

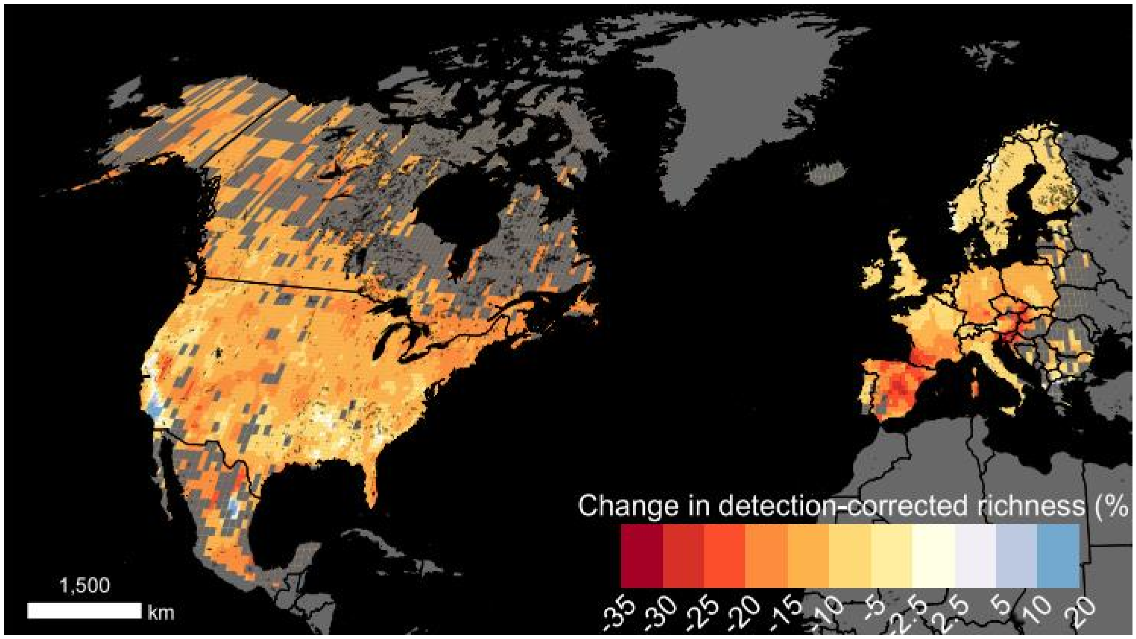

Figure 4. Climate change-related change in bee species richness from past (1901-1974) to recent period (2000-2014) Source: Soroye (2020)

The projections (Figure 4) above suggest that recent climate change has driven more substantial and more widespread bee declines than previously reported. European estimates of observed bee species richness rely mainly on observations from well-sampled regions that were cooler in the baseline period and experienced fewer warming temperatures (Soroye 2020). Additionally, the climate is expected to warm rapidly in the future. Overall, climate change-related extirpation rates among bee species greatly exceed those of colonization, contributing to pronounced bee species decline across North America (Kerr 2015).

CONSERVATION AND STRATEGIES TO HELP THE BEES

Bees are declining in abundance in many parts of the world, primarily due to intensive farming, mono-cropping, use of agricultural chemicals, and higher temperatures associated with climate change, all of which are not only affecting crop yields but also bee nutrition (FAO 2021). With the help of science, technology, and accessible international communication around the world, conservation plans and strategies have been implemented to understand the seriousness of decline in bees and how to minimize specific drivers of bee decline to conserve bees.

Bees are the primary pollinators of the world's wild plant species and provide economically valuable pollination services to cultivated crops. Developing bee conservation plans to conserve bees implies that, in order to complete their life cycle, all bees need a nesting habitat, flowers for nutrition, and a place for queens to overwinter (Schweitzer 2012). Also, bees must avoid lethal and sub-lethal chemicals and pathogens (Schweitzer 2012). Conservation aims should be to promote flower availability and provide available nesting habitats (Schweitzer 2012). To provide steady reproduction of bees, a lot more research is needed, including identifying which of many areas best conserve wild bees. (Government of Canada 2016).

Ontario and most other provinces in Canada have launched conservation plans to specifically protect bees, as we now understand that protecting pollinators like bees will keep ecosystems and crops healthy. The new pollinator action plan in Ontario includes restoring and protecting one million acres of pollinator habitat across the province, supporting new pollinator health research, and collecting more data to better monitor managed honeybee colonies and wild pollinators, and also track neonicotinoid levels in the environment (Ontario 2016). Wildlife preservation Canada's native pollinator initiative recognizes the value of engaging communities in pollinator conservation programs such as bees (honeybees), provinces such Alberta and Manitoba have also been investing in community programs since 2017, by harnessing communities of volunteers which watch abundance of bees (Rowe 2019).

The departments of agriculture in both the United States and Canada have been conducting annual honeybee pest and disease surveys. These surveys aim to monitor the absence of honeybee colony health (Canada Senate 2015). Additionally, agriculture stakeholders in Canada are highly involved in actions to preserve honeybee health. Actions are undertaken through collaboration, better communication, research projects, knowledge transfer, and best management practices. Most of these actions are sometimes undertaken in consultation with the federal government (Canada Senate 2015).

Through ongoing research activities, agricultural stakeholders (including seed companies and equipment manufacturers) are involved in activities and projects that enhance the abundance of honeybees. Manufacturers have started designing and developing new planters that minimize the effects of insecticide seed coating when mixed in the exhaust fan airflow (Canada Senate 2015). Manufacturers have started to do this as it mitigates honeybee exposure to dust emitted during the planting of seeds, which enhances the abundance of honeybees in the area (Canada Senate 2015). Involvement through governments has also been in collaboration with agricultural stakeholders. Beekeepers, seed companies, and Alberta's government are investing in honeybee research, particularly bee health, bee habitat, colony pollination efficiency, and the effect of beehive moving on canola pollination (Canada Senate 2015). In

Saskatchewan, over $1.1 million over three years was committed to honeybee research by Saskatchewan's Agriculture Development Fund. The research projects focus on honeybee breeding, honeybee disease management, and bee disease management, and the specifications and cataloguing of wild orchard populations (Canada Senate 2015).

From an international level, multiple conservation plans have been reviewed, such as the International Pollinator Initiative-Plan of Action (IPI-POA). This international agreement outlines guidance for improving and developing policies and practices to enhance pollinator conservation and habitat restoration (Byrne 2009). The Initiative-Plan of Action was designed to promote many aims that would be coordinated at a global level. The following aims of the IPI-POA are to monitor pollinator decline, its causes, and its impact on pollination services, address the lack of taxonomic information on pollinators, assess the economic value of pollination and the economic impact of the decline of pollination services, and promote the conservation and the restoration and sustainable use of pollinator diversity in agriculture and related ecosystems (Byrne 2009). The International Pollinator plan of action has four elements: assessment, adaptive management, capacity building, and mainstreaming (Byrne 2009).

Conservation and restoration strategies aiming to protect biodiversity should consider the types of land use and socio-economic development in the region. The use of biodiversity-friendly agroecosystem strategies, such as beekeeping and ecotourism in critical areas that are enriched with the plants used by bees to forage and nest, are suggested to be economical while protecting the pollinator species (Gianni 2017).

DISCUSSION

Bees are declining at very high rates because of climate change. Climate change, as defined by global warming combined with unpredictable weather conditions, has affected the symbiotic interactions of bees and the flowering plants they pollinate (Belsky & Joshy 2019). Linearly correlated changes exist for increased temperatures and earlier flowering dates, with increased temperatures and earlier first appearance of honeybees and bumblebee spring flight time (Belsky & Joshy 2019). Because honeybees are declining at such fast rates, there has been an increase in honeybee research programs and studies throughout North America and the globe, which aid in renewing honeybee colonies.

As we proceed with researching plans to renew honeybee colonies, it is essential to keep in mind why they are so important. Honeybees help pollinate more than 80 agricultural crops, which account for about a third of what we eat (Canada Senate 2015). To keep these honeybees pollinating, it is vital to note the efforts made by beekeepers and also note the percentage of honeybees that are spread throughout Canada and the different types of crops they help pollinate. For example, Alberta beekeepers account for 10.6% of honeybees. Honeybees in Alberta are the primary pollinator for canola crops. Ontario accounts for the largest share of beekeepers by province (37%), relying on honeybees to visit corn and soybean crops to collect pollen. Quebec and the Maritimes, accounting for a very small portion of the share of beekeepers by provinces, rely on bees to pollinate blueberry crops (Canada Senate 2015) (Figure 5).

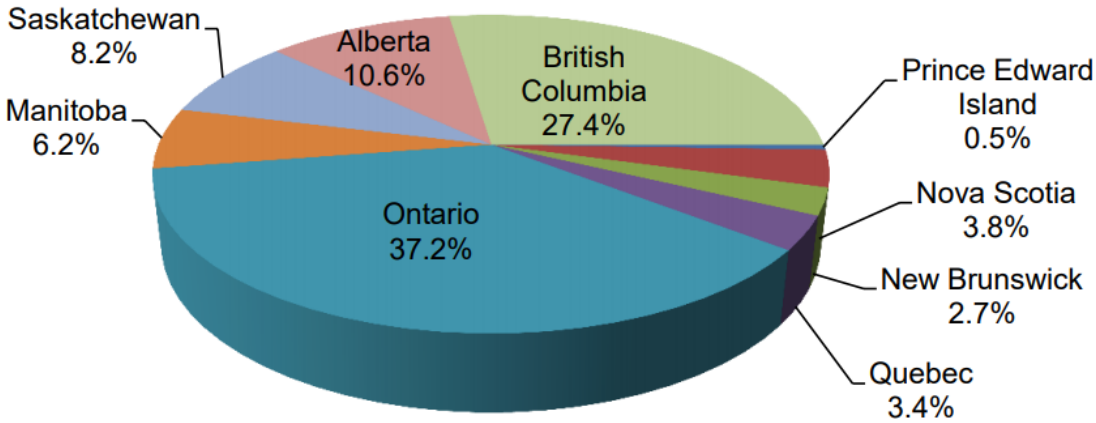

Figure 5. Share of Beekeepers by Province in Canada. Source: Canada Senate. 2015

Not only is it important to learn about the importance of honeybees and the crops they help in pollinating, it is also imperative to remember the other values they provide, such as maintaining biodiversity by pollinating numerous cultivated plant species whose fertilization requires honeybees (Conte & Navajas 2008). Furthermore, as we begin to notice the values of bees and honeybees, it is important to educate ourselves on the many factors that affect their populations such as pesticide exposure, the spread of parasites, and environmental changes, all of which are significant factors to blame for the widespread collapse of honeybee colonies in previous years (Bernstein & Aguilera 2021).

As global environments change and global temperatures rise, North American honeybee ranges are getting smaller. Like snowmelt or air temperature, factors that let bees know when spring has arrived, weather patterns and temperatures are shifting beyond normal levels, and plants and bees together may become more and more out of sync, resulting in bees emerging long before the plants are ready to be pollinated (Turner 2019). Overall, results in Bartomeau (2011) that phenological changes in bees have paralleled changes in the plants they visit, a phenological mismatch has occurred as warming temperature rates increase. Therefore, there is a need to apply more mechanistic physiological models for bees of a more extensive widespread range (Bartomeau 2011) and a need to invest in more programs and studies to help bees.

Throughout this thesis, it is argued that there is a correlation between climate change and an extensive decline in honeybees and other pollinating insects. Understanding this problem between bees and the environment they live in means that it is important to apply any measures or studies that can be done to solve problems of habitat loss and other severe threats to their existence. In North America, each country has an agriculture department that has been conducting annual honeybee pest and disease surveys, aimed at monitoring honeybee colony health (Canada Senate 2015). From a global standpoint, multiple conservation plans like the International Pollinator Initiative-Plan of Action (IPI-POA) have been reviewed. The IPA-POA aims to monitor pollinator decline and promote conservation and the economic value that honeybees provide (Byrne 2009). Adapting these measures is important to implement as it can compare statistical data and analyze differences in the abundance of global pollinators like honeybees. As we continue to understand how climate change is threatening honeybees and many other pollinators, it is important to continue investing money in research plans and studies that will help conserve honeybees and other pollinators.

CONCLUSION

Honeybees are an important pollinator species globally and serve as a critically important economic species as well as a species that serves a great importance in the maintenance of healthy ecosystems. Due to the effects of changing weather patterns worldwide each year, honeybee and other essential pollinator populations have dropped significantly every year. Implementing surveys, research projects, new technology, and accessible communication worldwide will help to understand the seriousness of bee decline. Thorough implementation of these tactics will help conserve and augment global honeybee populations, and the only way this can be done is through proper funding, proper research support, and public participation.

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