STRATEGIES TO REDUCE THE DECLINE OF WILD BUMBLE BEES IN NORTH AMERICA – ARE THEY WORKING?

by

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Pictures: N. Britt 2019

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ABSTRACT

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Bumble bees are major pollinators of the world's agricultural crops and wild plants and, as such, play a key role in maintaining economic prosperity and biodiversity. The decline of wild bumble bees in North America has been well-documented. However, the efficacy of strategies to prevent further decline have not been investigated thoroughly. This thesis involves a comprehensive literature review to examine the extent of, and reasons behind, the decline of wild bumble bee populations in North America and explore whether strategies implemented to prevent further decline are working. Results of this literature review revealed numerous stressors affecting bumble bee populations, but also indicated that reactions may differ between bumble bee species. The necessary species assessments are difficult to conduct because data pertaining to temporal and spatial occurrence are hard to obtain. Novel approaches to collecting bumble bee population data, such as the citizen science program Bumble Bee Watch, are important in augmenting the data collected by researchers. It is essential that existing databases be maintained to support ongoing monitoring. Long term conservation strategies must be established to preserve these important pollinators to ensure strong ecosystems have the necessary biodiversity to support the planet and its inhabitants. Essential areas of focus include habitat preservation and creation, bumble bee health and resource availability, use of pesticides, management of diseases and invasive species, building capacity through partnerships, education and training, research and effective monitoring programs. This information will be important in assessing the success of current mitigation strategies in the conservation and recovery of native bumble bees.

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INTRODUCTION

Wild bumble bees (*Bombus* spp.) (Insecta: Hymenoptera Apidae) play a key role as major pollinators of the world's agricultural crops and wild plants; they are essential to the proper performance of ecosystems and food webs (Cameron and Saad 2020). Biodiversity is dependent, in large part, on the successful reproduction of angiosperms. Bumble bees are considered a foundational species in natural ecosystems because of their unique ability to pollinate flowers that require high frequency sonication and their capacity to pollinate in colder regions (Colla 2016). Many ecological niches, particularly in tropical zones that have a high dependence on bumble bees, would suffer serious consequences without them.

The study of bees and their importance to both humans and terrestrial biodiversity has presented growing evidence of ongoing threats to their survival (Cameron and Saad 2020). The significant decline in bumble bee abundance and species richness in recent years is well documented and has prompted increased efforts by scientists to examine the potential stressors that impact bees. A number of environmental and anthropogenic stressors were subsequently identified, including loss of habitat, limited access to food sources, pesticides (particularly neonicotinoids), climate-related physiological changes, and increased susceptibility to parasites, pathogens and pests.

Mitigation strategies to address these stressors have been introduced world-wide. However, in-depth research on the success of these strategies is just beginning and has revealed a significant gap in historical data available for researchers to determine changes in population abundance over time (Cameron and Saad 2020). Innovative data collection methods will be important to augment the data collected by researchers. For example, the Bumble Bee Watch citizen science program encourages individuals to submit photographs of bumble bees in their area through a free software application. The species are verified by experts and added to a database used by researchers to track the status and conservation needs of North American bumble bees. Maintenance and enhancement of existing data bases will be required to support ongoing monitoring.

It is essential that long term conservation strategies be established to preserve this important pollinator and maintain strong ecosystems with the necessary biodiversity to support the planet and its inhabitants. Areas of focus must include habitat preservation and enhancement, bumble bee health, management of diseases and invasive species, pesticide management, education and training, additional research, and conservation partnerships (Goulson et al. 2008; Goulson et al. 2011; Colla 2016). This information will be important in assessing the success of current mitigation strategies in the conservation and recovery of native bumble bees.

This literature review will consider information from previous scientific studies in determining whether strategies implemented to date have been effective in reducing the decline of wild bumble bees in North America. It is expected that the information available will reveal the level of success of the various initiatives. Particular attention will be given to those strategies that can be further developed to strengthen future and long-term success.

METHODS AND MATERIALS

This literature review examined existing scientific research pertaining to wild bumble bee species in North America, the extent and cause of their decline, and the impact of conservation and mitigation strategies implemented to date. The majority of data was obtained from internet sources including Google Scholar, Mendeley, government publications and journal repositories such as Elsevier, Springer, PLos one, ResearchGate, Apidologie, COSSARO and the IUCN Red List, using specific search terms relative to the topic of bumble bee conservation. Information was also gathered from journals, literature and publications found in the Chancellor Paterson Library at Lakehead University as well as through direct connection with research authors.

The timeframe of information reviewed extends from 1999 to 2020, with most papers published from 2007 onward. Information was filtered to ensure relevancy by using key search terms, including *bombus*, bumble bees, decline, entomology, conservation, and strategies.

RESULTS

BUMBLE BEE SPECIES IN NORTH AMERICA

There are 46 recognized bumble bee species in Canada and the United States, all of which are native to North America (Schweitzer et al. 2012; Cameron and Saad 2020). Of those North American species, there are 8 subgenera of the *bombus* genus, consisting of *Alpinobombus* (4 species), *Bombias* (2 species), *Bombus* (5 species), *Cullumanobombus* (5 species), *Paitbyrus* (6 species), *Pyrobombus* (20 species), *Subterraneobombus* (2 species) and *Thoracobombus* (2 species) (Schweitzer et al. 2012). Most of these species have broad geographic ranges, as can be seen in Figure 1 (Schweitzer et al. 2012). However, there are increasing numbers of reports regarding range reductions and population declines in several species (Cameron and Saad 2020). The changes are not consistent, with varying levels of decline among co-occurring species indicating differences in susceptibility to environmental stressors (Colla 2016). Some species have experienced a gradual range reduction and decline in abundance over numerous decades (Colla and Packer 2008; Grixti et al. 2009), some have undergone rapid population declines over the last 20 years (Cameron et al. 2011) and other species have healthy, stable populations (Cameron et al. 2011; Jacobson et al. 2018).

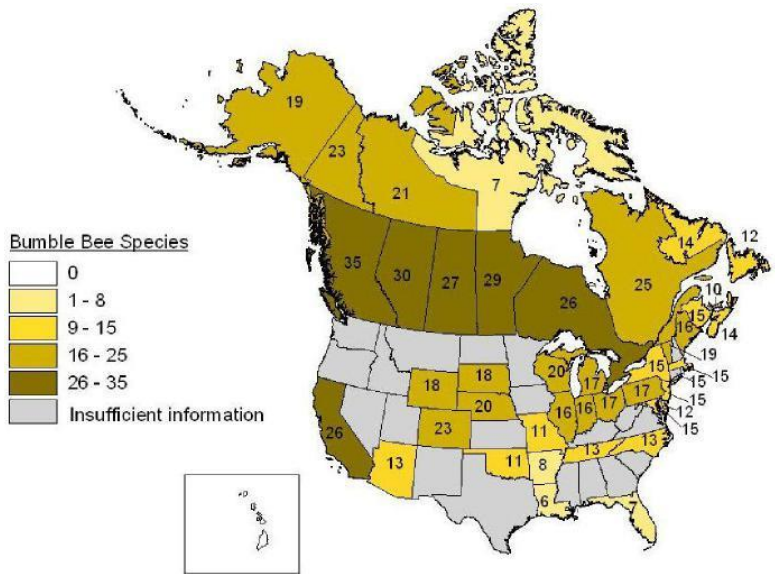


Figure 1. Documented bumble bee diversity in states or provinces for which adequate data are available. Figures for some states may still represent underestimates. Source: Schweitzer et al. (2012).

POPULATION DECLINES

Researchers have attributed the global decline of bumble bees to numerous stressors occurring at various spatial and temporal scales (Williams & Osborne, 2009; Goulson, 2015; Kerr et al., 2015; Baude et al., 2016; IPBES 2016; Main et al. 2019; Cameron and Saad 2020). Multiple surveys and reports published on the decline of bumble bees occurring across the globe have revealed reductions in distribution and abundance of numerous species over the past century (Cameron and Saad 2020). During the last decade, the number of reports increased rapidly (Cameron and Saad 2020). Figures 2(a) and 2(b) provide an illustration of the number of papers published in peer-reviewed journals between 1980 and 2018 and the results arising from the two search strategies (Cameron and Saad 2020).

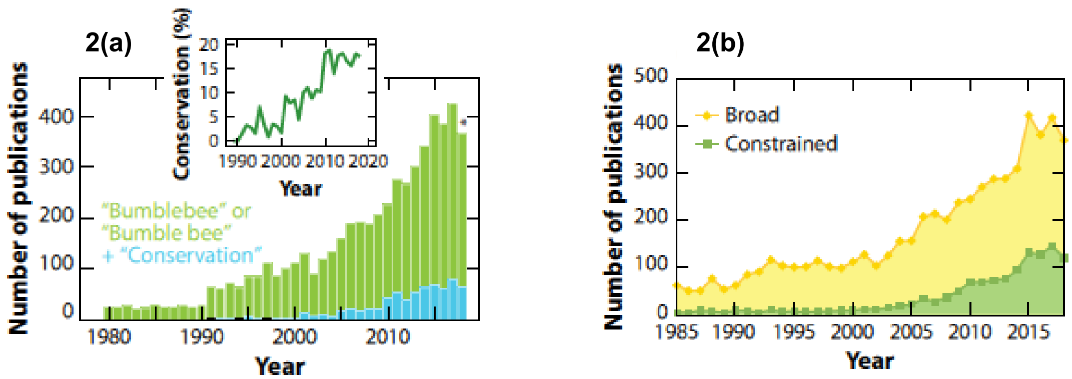


Figure 2. (a) Number of peer-reviewed journal papers published between 1980-2018 on bumble bees (green), and the number of those papers that focused on aspects of bumble bee conservation (blue). The inset depicts the exponentially increasing percentage of papers on bumble bees mentioning conservation (b). Type of search strategies used. Source: Cameron and Saad (2020).

Figure 3 depicts the proposed causes of bumble bee decline identified in the peer-reviewed literature, including those focussing on pesticides (Cameron and Saad (2020). More in-depth research regarding the impact of these stressors at the individual, colony, and population levels will inform policy conservation strategies for North American bumble bees.

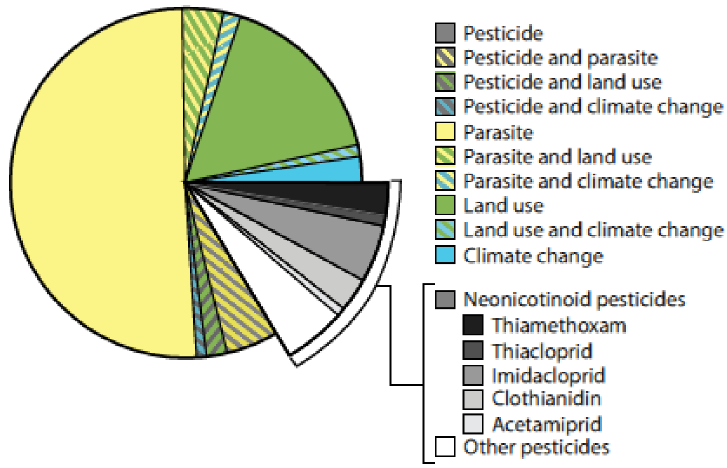


Figure 3. Proposed causes of bumble bee decline in peer-reviewed literature Source: Cameron and Saad (2020).

The research demonstrates the extent of decline is not consistent across the globe and attributes this, in part, to the highly variable response of bumble bees to anthropogenic factors such as pesticide use and changes in land use (Cameron and Saad 2020). Schweitzer et al. (2012) state that most North American bumble bee species are not currently threatened or recorded as declining, outside of areas of agricultural intensification. A steady decrease in other bumble bee and native bee populations over the past 50 years has led to the near extinction of some species (Schweitzer et al. 2012; Belsky and Joshi 2019). It is important to note that Colla (2016) found that some bumble bee species have increased in abundance in comparison to historical records. The proportion of bumble bees identified as at risk in North America is shown in Figure 4 below (Schweitzer et al. 2012).

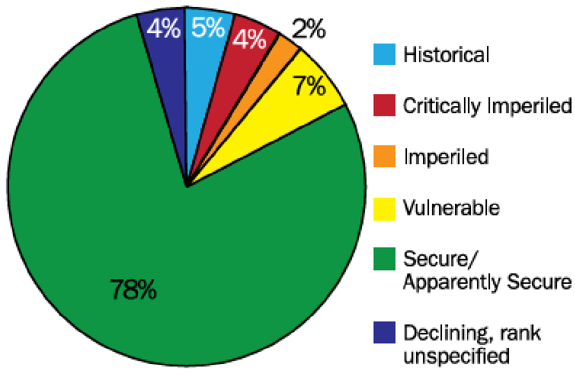


Figure 4. Proportion of North American bumble bee species at risk. Source: Schweitzer et al. (2012).

In 2011, the International Union for the Conservation of Nature (IUCN) Species Survival Commission Bumblebee Specialist Group (BBSG) was formed to evaluate the extinction risk of bumble bee species (Cameron and Saad 2020). The BBSG used the IUCN Red List of Threatened Species criteria and categories to assess the overall bumble bee species status for North America (Figure 5) and update the data base (Cameron and Saad 2020).

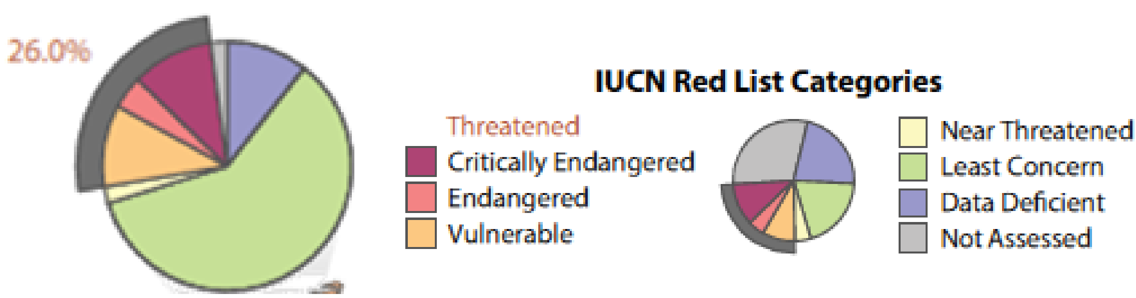


Figure 5. IUCN Red List assessment of the percentage of North American bumble bee species in decline. Source: Cameron and Saad (2020).

Their review revealed global assessments have been completed for 98% of described North American species and that species distributions are well data-based or published. Additional quantitative analyses are also available at regional (Colla and Packer 2008; Grixti et al. 2009; Jacobson et al. 2018) and national levels (Cameron et al. 2011; Koch et al. 2015). Schweitzer et al. (2012) also identified eight species from three subgenera that have declined drastically over the last 15-20 years. Table 1 lists these species, their G-rank, and their known range.

Table 1. Rapidly declining North American bumble bee species, conservation status and range (adapted from Schweitzer et al., 2012).

Scientific Name (subgenus)	Common Name	G-rank	Range
Bombus affinis (Bombus)	Rusty-patched Bumble Bee	G1G2	East central North America
Bombus franklini (Bombus)	Franklin's Bumble Bee	G1	Southern Oregon to northern California
Bombus occidentalis (Bombus)	Western Bumble Bee	G2G3	Western North America
Bombus terricola (Bombus)	Yellow-banded Bumble Bee	G2G4	Southern Canada, northern U.S., and in mountains south to North Carolina
Bombus ashtoni (Psithyrus)	Ashton's Cuckoo Bumble Bee	GH	Across Northern North America
Bombus suckleyi (Psithyrus)	Suckley's Bumble Bee	GH	Western North America
Bombus variabilis (Psithyrus)	Variable Cuckoo Bumble Bee	GU	Eastern and southwestern U.S., & disjunctly from southern Mexico to Honduras
Bombus pensylvanicus (Thoracobombus)	American Bumble Bee	G3G4	Eastern and southwest North America

Legend: Conservation status is denoted by the Nature Serve "G-rank" scheme, as follows:

- **G** – Ranks designated at the global (or range-wide) level (G-rank) where "G1" indicates the highest level of imperilment and "G5" the most secure.
- **H** – Possibly extinct or extirpated (of historical occurrence but not known recently extant, with some reasonable hope of rediscovery).

Almost one quarter of bumble bee species on the IUCN Red List are declining, including 26% of North American species (12 of 46) evaluated as threatened to some degree ranging from vulnerable to critically endangered (Cameron and Saad 2020). A phylogenetic connection has been documented with regional and global declines (Cameron et al. 2011), including links to habitat (Cameron and Saad 2020).

THREATS

This literature review pointed to numerous factors that negatively impact and stress bumble bee populations, most notably habitat loss, bumble bee health, resource availability, pesticide use, emerging diseases, invasive species and climate change. Researchers stated that these stressors work in synchrony and in isolation (Becher et al. 2018; Main et al. 2019; Cameron and Saad 2020).

Habitat Loss

The survival of any species is dependent on the stability of its habitat and the availability of sufficient resources. Scientists have researched the impact of habitat loss on the North American bumble bee population. The results of this research vary. Researchers indicate it is difficult to measure the effects of habitat loss on bumble bees due to their ability to maintain large, species-rich populations in areas not considered as “natural” habitat, such as powerline corridors, pastures and hayfields (Schweitzer et al. 2012)

Habitat loss and fragmentation and the associated decrease in floral resources and nest habitats are considered major causes of population decline in wild bumble bees (Biesmeijer 2006; Grixti 2009; Hatfield et al. 2012; Schweitzer et al. 2012; Jacobson et al. 2018; Belsky and Joshi 2019; Main et al. 2019). Conversion of land for urban and suburban development fragments bumble bee habitat (Jepsen et al. 2013), while road construction leads to fragmentation of bumble bee populations and creates barriers that hamper their access to available food resources (Wojcik and Buchmann 2012; ECC Canada 2016). The social nature of bumble bees makes them exceptionally sensitive to habitat fragmentation, particularly in areas where species populations are already small and isolated from each other (Goulson et al. 2011). The dispersal ability of each species determines the scale of habitat fragmentation each can withstand (Goulson et al. 2011). Bumble bees do not store large quantities of pollen or nectar, therefore, those that have long foraging ranges will be better able to manage in areas with sparse or patchy availability of floral resources than those with short foraging ranges (Goulson et al. 2011).

Schweitzer et al. (2012) state that bumble bees typically seek out new nest sites in the spring, when queens emerge to feed. Nest sites can be located either above or below ground, depending on the bumble bee species. Common choices include abandoned rodent nests, long grass and haystacks, preferably in south facing exposures, tree cavities and bird boxes. Many of these options have reduced availability in areas of intensified agriculture. For example, subterranean nesting sites are disturbed throughout the growing season by mowing, tilling or paving, making it difficult for bumble bee species to persist (Jacobson et al. 2018).

In urban areas with limited green space, common nest choices include spaces between cinder blocks, building foundations, furniture and decks, while mulch, rotting logs and loose soil are popular overwintering sites (Schweitzer et al. 2012). Although some bumble bee species will travel several kilometers from their colonies to search for food, most stay within 600-1700 meters of their nest site and require ready access to food resources (Schweitzer et al. 2012). Main et al. (2019) studied the effects of agricultural activities on bumble bee guilds in designated conservation areas and linked these activities to a reduction in species abundance and richness. The researchers report annual cropping in conservation areas resulted in reduced floral and nesting guilds.

Bumble Bee Health and Resource Availability

Bumble bees, like other living organisms, require access to a variety of nutrients in their diets, at specific ratios, for proper growth and development (Vaudo et al. 2015). Monoculture planting limits the availability of floral resources to the short blooming period during the growing season (Jacobson et al. 2018). This deprives bees of access to the diverse floral resources needed to meet their nutritional requirements, which include carbohydrates (sugar from nectar or honey), amino acids (protein from pollen), lipids, vitamins, minerals and water (Belsky and Joshi 2019). The type of monoculture planted will determine the effect on different species, as some species may thrive on the crop planted while others may be negatively impacted (Belsky and Joshi 2019).

Bumble bee species that exhibit niche specialization, such as diet, climate or habitat preference, may be more vulnerable to anthropogenic changes and interactions with food/plant availability, particularly those species that live on the edge of their ranges (Grixti et al. 2009). Previous studies have suggested that species that forage on specific flora are more likely to experience a decline in population when their preferred food is unavailable. For example, long-tongued species are more efficient foraging on long corolla flowers than from shallow flowers (Grixti et al. 2009; Colla 2016).

Other bumble bee species are better able to adapt to available floral resources (Colla 2016). Short-tongued species such as Bombus *(sensu strict),* have been known to pierce holes in flowers with long corollas to access nectar, while members of the subgenus *Pyrobombus* will use holes made by other bees to access nectar (Colla 2016). These adaptive traits vary between species and correlate to the varying effects related to foraging efficiency, increased competition and subsequent decline in colony fitness (Colla 2016).

Pesticides

Pesticides are considered one of the major drivers of bumble bee population declines, affecting bumble bees at both individual and colony levels (Arce et al. 2017; Baron et al. 2017; Wood and Goulson 2017). Life-history traits, foraging behaviour and phenology can vary significantly between bumble bee species, which may result in different levels of exposure and sensitivity to pesticides (Baron et al. 2017). Neonicotinoids, a class of pesticide introduced in the mid-1990s, have been used throughout the world since they were approved for use in the early 2000s (Health Canada 2014). Neonicotinoids were believed to be safer for humans and the environment than other pesticides available at the time due to their ability to be applied directly to a specific target at a higher toxicity and lower use rate (Health Canada 2014). Neonicotinoids are now the most broadly used class of insecticides in the world (Baron et al. 2017; Wood and Goulson 2017).

Although neonicotinoids are water-soluble and are designed to be absorbed by roots of developing plants, uptake of the pesticide is only 5% with the remainder dispersed into the surrounding environment (Wood and Goulson 2017). The speed at which pesticide residues move through the soil is difficult to measure due to differences in soil composition and chemical-specific reaction and degradation properties (Gradish et al. 2019). This makes it challenging to predict the level of effects on bumble bees as it may take years for the full impacts to become evident (Gradish et al. 2019).

Recent studies have shown lasting effects of neonicotinoids, including reduced queen and worker production, impaired social behaviour and foraging efficiency, and suppressed immunity to parasites (Goulson et al., 2015; Mallinger et al., 2015). Queen and worker bumble bees exposed directly to pesticides can die as a result of that exposure, while larvae that consume food contaminated with pesticide may experience minor to lethal effects (Schweitzer et al. 2012). Queens are particularly vulnerable to pesticide exposure prior to and during nest construction because they forage for their own food resources during this period (Hatfield et al. 2012; Gradish et al. 2019). This can cause direct bodily contact with pesticide residues in the form of particles from seed-treated crops or foliar sprays (Gradish et al. 2019).

Data pertaining to queen dietary and metabolic needs is lacking, making it difficult to assess their pesticide exposure from eating contaminated pollen and nectar (Baron et al. 2017). Exacerbating this problem is the lack of data pertaining to queen nectar and pollen consumption following nest establishment, when colony workers feed the mother queen (Baron et al. 2017). Goulson (2010) noted that some pesticides are more lethal than others. For example, Spinosad does not cause mortality in bumble bees, but does reduce foraging efficiency. A small loss of worker bees will not adversely affect a colony during the summer. That same loss during the spring can have a significant impact because colonies will not have had sufficient time to establish enough workers to ensure colony survival (Goulson 2010).

Recent studies have shown reproductive fitness to be negatively affected when sub-lethal compounds accumulate within the colony (Schweitzer et al. 2012; Baron et al. 2017; Woodcock et al. 2017). Bumble bee species with long colony cycles and those that nest above ground are more susceptible to the accumulation of toxins and residues left behind in the landscape. (Schweitzer et al. 2012; Woodcock et al. 2017).

Pesticide exposure also affects the ability of bumble bees to pollinate effectively (Stanley et al. 2015). Pesticide-exposed colonies provide lower visitation rates and collect less pollen, thereby reducing pollination services (Stanley et al. 2015). This can lead to a cycle of reduced plant populations, making them more susceptible to genetic erosion, inbreeding depression, decreased reproductive success and greater vulnerability to catastrophes and random alterations in environmental conditions which, in turn, leads to a decline in bumble bee populations (Berenbaum et al. 2007:203).

<u>Emerging Diseases</u>

Recent studies on emerging infectious diseases have linked declining bumble bee populations to pathogen spillover from commercially managed pollinators, such as honeybees and bumble bees (Cameron et al. 2011; Meeus et al. 2011; Fürst et al. 2014; Goulson and Hughes 2015). These colonies provide perfect breeding grounds, with high host density and abundant food supplies that enable infected bees to survive with what would otherwise be lethal disease loads in the wild (Meeus et al. 2011; Cameron et al. 2016).

The rapid spread of infectious diseases to new hosts has also been linked to the global trading practices of managed bee populations (Fürst et al. 2014; Goulson and Hughes 2015). Commercial colonies may promote the evolution of a greater parasite virulence and disrupt spatial patterns in local adaptation between hosts and parasites (Meeus et al. 2011; Cameron et al. 2016). These trading practices perpetuate a cycle of repeated disease outbreaks with continual reintroduction of the disease when colonies are returned to their home country as the source host acts as a disease reservoir (Fürst et al. 2014; Cameron et al. 2016).

A subjective example of this phenomenon is the parasitic mite *Varroa destructor.* This parasite has been decimating honeybee populations worldwide and is now threatening wild bumble bee populations (Fürst et al. 2014; Stokstad 2019). While bumble bees are not directly vulnerable to *V. destructor* (Carvell 2002), scientists have discovered a possible link to the Deformed Wing Virus (DWV), which is a potentially fatal virus transmitted by *V. destructor* (Genersch et al. 2006). DWV works in collaboration with *V. destructor* and causes multiple physical deformities (Genersch et al. 2006). Studies have shown a link between infestation of *V. destructor* and the honeybees suffering from DWV in North America, Europe and New Zealand (Mondet et al. 2014; Wilfert et al. 2016). DWV in European bumble bee populations has been correlated to the presence of DWV in honeybees, indicating the likelihood of pathogen spillover (Genersch et al. 2006; Evison et al. 2012; Fürst et al. 2014).

Other researchers have reported native solitary bees are not directly affected by *V. destructor*; while solitary bee species can be infected by honeybee viruses when they are in close proximity to apiaries (Ravoet et al. 2014). *V. destructor* can severely impact plant-pollinator networks and pollination services by altering pollinator syndromes through a change in bee abundance and communities (Genersch et al. 2006). The full effects from the spread of new parasites and pathogens may not become evident for years (Fürst et al. 2014; Wood and Goulson 2017).

A study conducted by Evison et al. (2012) on the pervasiveness of parasites in pollinators revealed bumble bees to be carriers of the common *Wolbachia, Ascosphaera,* microsporidian and DWV parasites. It is important to note the researchers acknowledged that infection, in some cases, may have been a result of vectoring rather than being a host species. The study noted the potential of these parasites to cause a significant decline in host fitness, particularly as a result of the shared use of flowers by multiple pollinator species and raiding the food supplies of others.

Meeus et al. (2011) studied the effects of invasive parasites on bumble bees by assessing parasite virulence, transmission mode, and infectivity. They proposed that microparasites and honeybee-associated viruses pose the biggest threat to native bumble bee populations. The study cited the presence of particular risk factors, such as the high likelihood of horizontal transmission of the trypanosome parasite *Crithidia bombi* Léger, 1902 and the introduction of non-native parasites to novel hosts, as important contributors to population decline.

Nosema ceranae (Fries et al. 1996), *Nosema bombi* Fantham and Porter, 1914, and *Crithidia expoeki* have also been identified as emerging infectious diseases impacting the decline in bumble bee populations (Colla et al. 2006; Meeus et al. 2011; Evison et al. 2012; Fürst et al. 2014). While Meeus et al. (2011) state it is doubtful that parasites would cause the extirpation of wild bee populations, they also indicate that spillover from a reservoir population with high parasite prevalence could lead to the eradication of small host populations.

Invasive Species

The introduction of non-native species has had devastating impacts on native ecosystems (Goulson et al. 2015; Goulson and Hughes 2015). The introduction of non-native plants has had similar negative impacts, including decreased availability of pollen and nectar for local bumble bee populations, where native vegetation, such as wildflowers, has been choked out (Berenbaum et al. 2007:94). Equally problematic is the introduction of non-native bees, which compete for floral resources and nest sites and bring disease and parasites with them (Berenbaum et al. 2007:89; Goulson et al. 2015). The presence of honeybees in the wild reduces the availability of nectar and pollen for native bees, including bumble bees, due to competition for floral resources (ECC Canada 2016). The resulting negative effects to bumble bees include reduced production of males and queens, smaller body size, male-biased sex ratio, reduced pollen collection and displacement of some species when they are foraging in the same area (ECC Canada 2016). Goulson and Hughes (2015) studied the anthropogenic spread of bee parasites and suggested that one of the major threats to bee diversity worldwide is the continued global distribution of bees. They state that without strict control measures for transportation, hygiene, and screening before and after transportation, the spread of disease will continue.

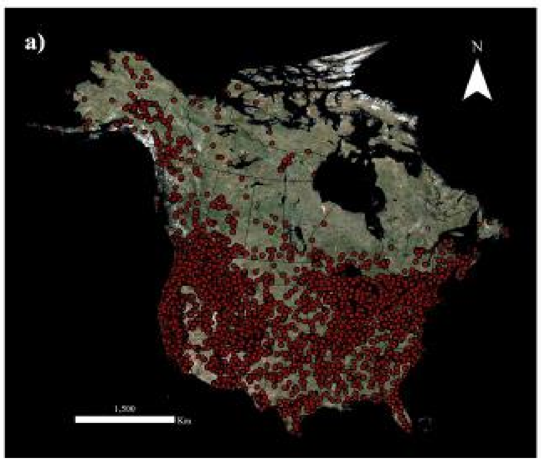
Climate Change

The earth's climate is changing. Rising air and ocean temperatures are contributing to global concern about the effects of climate change. The escalation of extreme weather patterns involving increased amounts of rain and snow, heat waves, drought and flooding continue to drive concerns about the short and long-term impact on all wildlife and vegetation (IPCC 2013). Schweitzer et al. (2012) state that North American bees are found in varying climates ranging through more than ten degrees latitude from coast to coast. The researchers state that these bees may not experience the same level of impact as other species for that reason. They propose that species most vulnerable to climate change are likely those with narrow ranges near the Pacific coast, such as *B. crotchii* Creeson,1878, *B. sitkensis* Nylander 1848, and *B. caliginosus* (Frison, 1927), and isolated species occupying high alpine locations.

Research regarding the direct and indirect effects of climate change on bee populations is currently limited. Direct effects pertain to survival and reproduction, while indirect causes involve alteration of resources such as changes in floral resource phenology (Ogilvie et al. 2017). Disruption of the synchronized emergence of bees with flowers in bloom results in reduced availability of varied floral resources and triggers physiological adaptations of bees (Goulson et al. 2015; Ogilvie et al. 2017; Belsky and Joshi 2019). For example, subalpine bees have short seasons of approximately ten weeks to grow and reproduce (Ogilvie et al. 2017). This limits the time available for them to take advantage of available floral resources, resulting in lower bee abundance (Ogilvie et al. 2017).

Rising temperatures may lead to a shift in the geographic range of bumble bees, which can have a significant impact on different species (OMAFRA 2016). Species that flourish in tropical environments are expected to increase their ranges, while bumble bees that thrive in smaller ranges with temperate climates are predicted to undergo range reductions, thereby increasing the risk of population decline. Flooding will have the greatest impact on ground nesting bees, while extremely cold weather can decimate bumble bee populations as a result of high overwintering losses.

A 2018 study conducted by Sirois-Delisle and Kerr on climate-driven range losses among North American bumble bee species determined that dispersal rates may not be enough to avoid catastrophic population losses and maintain species persistence. The survival of many species will depend on their ability to disperse and track suitable conditions in response to climate change. Results of the study support previous estimates of potentially severe range losses for some species and their inability to expand beyond their current geographical ranges to new climatically suitable areas. Figure 6 illustrates bumble bee observation points a) and species density b) between 1960 and 1999 were highest in areas with warmer climatic conditions, with small pockets of high density in the Yukon and Alaska.



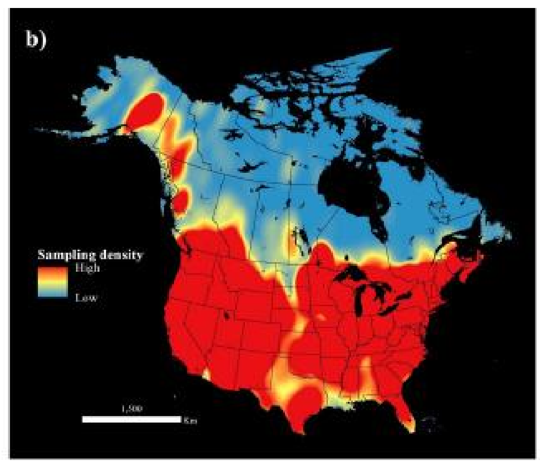


Figure 6. Dataset of georeferenced records for 31 bumble bee species sampled in North America between 1960 and 1990. Data were represented a) by observation points and b) by a heat map of relative sampling densities. Source: Sirois-Delisle and Kerr (2018).

The study further predicts range loss to continue as climate change progresses. Currently, less than 1% of areas identified as having range overlap for multiple species is designated as protected. This is expected to further advance a decline in species richness. Figure 7 demonstrates the change in species richness predicted by 2070.

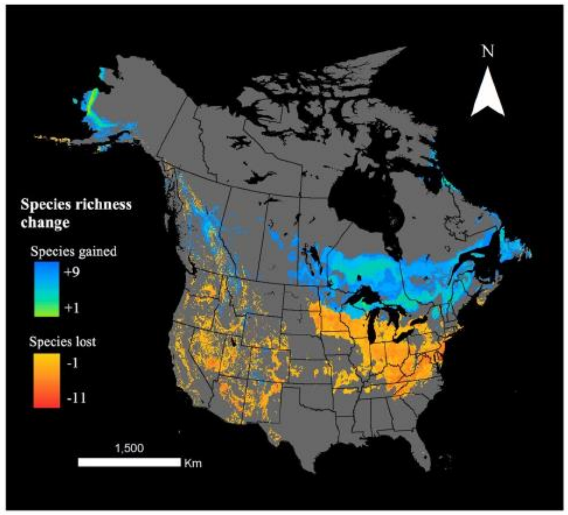


Figure 7. Projected species richness change by 2070. Source: Sirois-Delisle and Kerr (2018).

A recent study conducted by Soroye, et al. (2020) revealed that the growing frequency of unusually hot days is increasing local extinction rates, reducing colonization and site occupancy, and decreasing species richness within a region, regardless of the condition of the land or changes in land use. The researchers used long-term data for 66 bumble bee species across North America and Europe to predict species loss due to climate change. The method used spatially explicit predictions of climate change–related population extinction-colonization dynamics within species to explain observed patterns of geographical range loss and expansion across continents. The authors state that bumble bees may face an increased risk of extinction if temperatures and precipitation exceed species' historical tolerances. They also suggest that some species may benefit from climate change if areas previously considered uninhabitable become more suitable to colonization. The study demonstrated evidence of widespread declines in species occupancy across Europe and North

America by 17% and 46%, respectively, concluding that any gains in species colonization would be negated by the larger overall rate of species extirpation. The authors suggest that the model used in this study could aid in identification of those species vulnerable to climate change and where, identify those species that might benefit, and propose strategies to mitigate conservation risks.

KNOWLEDGE GAPS

It has long been acknowledged that there is a significant gap in the data required to justify and establish the need for conservation action for bumble bee populations in decline. Data on native bumble bee ecology, floral associations and historical abundances and distributions for regionally specific populations are essential to understanding overall trends and drivers of decline (Jacobson et al. 2018). This data will be used to inform current and future mitigation strategies for species preservation. It is difficult for scientists to predict future population changes and patterns without the necessary estimates of colony densities in the landscape (Osborne et al., 2008; Goulson et al., 2010). Challenges in locating colonies and measuring reproductive success in the field, as well as the differences in the annual and social life history of bumble bee species, make it difficult for scientists to gather this data (Becher et al., 2018). For the same reasons, it is also impractical to conduct regular empirical testing of the combined and interacting effects of stressors on bumble bee colonies on a global scale (Goulson et al., 2015; Henry et al., 2017; Becher et al., 2018).

Scientists agree that historical data on wild bumble bee populations is needed to establish a baseline for comparison with current data (Cameron and Saad 2020). The 2007 report "*The Status of Pollinators in North America"* acknowledged that there is no long-term monitoring program or corresponding baseline data for bumble bees in the United States, Canada or Mexico, which makes it difficult to definitively establish the status of bumble bees in North America (Berenbaum et al. 2007:141). MacPhail et al. (2018) state that while global and local declines in pollinators and the pollination services they provide are documented, there are large gaps in knowledge about the impact on natural ecosystems. They suggest that identifying and addressing these knowledge gaps will require a thorough understanding of species-specific ecological needs and natural history to establish efficient and effective species recovery management plans. The researchers noted a review of existing government documents pertaining to plant species status assessments and recovery strategies do not contain corresponding information about the pollination services required. It is difficult to tailor habitat to specific pollinators without that information. For example, bees that nest above ground will have different needs than below-ground nesters.

MacPhail et al. (2018) note that management plans rarely consider ecological needs or beneficial interactions between plant and pollinator species. They state that government documents on the biology of at-risk species provide limited knowledge in this area and suggest that recovery strategies should be prepared and written by a combination of pollination biologists, entomologists and botanists to ensure details of the plant pollinator relationship are covered.

OTHER CONSIDERATIONS

There are several other factors that indirectly affect the conservation and management success of bumble bees. Government policy, funding, public education and advocacy all contribute to conservation success.

Policy

Governments have the power to ensure pollinator protection through legislation, policy, strategies and plans (CWF 2019). Berenbaum et al. (2007:156) suggest that economic and policy incentives could be used to inspire land managers to adopt pollinator-friendly practices and promote knowledge exchange and outreach. In Canada, many municipal, regional and provincial governments have acted through bans or reduction in the use of neonicotinoid pesticides (CWF 2019). Calgary and Toronto have implemented pollinator-friendly projects that include grants for the creation of pollinator-friendly habitats containing wild flowers and various types of nesting habitats (Live Green Toronto 2018; CWF 2019). Ontario established a Pollinator Health Action Plan in 2016 committing the provincial government to monitoring the health of wild and managed bee populations (CWF 2019). Contrary to that plan, in 2019, the Ontario Government passed Bill 108, "*More Homes, More Choice Act".* The Bill affects 13 Acts, including the *Endangered Species Act (ESA), 2007*, significantly weakening the protection measures currently in place for at-risk species (Ontario Nature Serve 2019). Key amendments to Schedule 5 of the ESA that can affect bumble bee conservation include, 1) extending the time it takes for a species to be listed and protected from three months to twelve months, 2) removing automatic protections for species at risk and allowing the Minister to delay protection classification for up to three years based on social and economic considerations, 3) de-listing an endangered species if it safely exists in a nearby jurisdiction, 4) allowing the Minister to ignore expert opinion on activities that may jeopardize the survival or recovery of a species, 5) creating a new fund for developers, municipalities, and others to pay fees in lieu of taking certain actions to protect and recover species at risk, and 6) giving broad approval to developers who seek to build multiple projects in one area (Ontario Nature Serve 2019). There has been much debate on the negative impact these changes are expected to have on endangered species. The bill is increasingly being referred to as the "pay as you slay bill" (Schreiner 2019).

Canada does not have a federal plan to guide protection and recovery of pollinators despite the commitment to support the development of national plans and strategies for the conservation of pollinator diversity as a member of the Convention on Biological Diversity (CBD) (CWF 2019). Canada has moved forward with some of the objectives of the CBD's draft Pollinator Initiative Plan of Action for 2018-2030, including pesticide use restrictions. Canada has yet to establish a pollinator protection strategy.

The United States developed an action plan through *"The National Pollinator Health Strategy"* (CWF 2019). The U.S. strategy's Pollinator Research Action Plan provides a roadmap for federally supported research to collect baseline data, assess environmental stressors, restore habitat, support stakeholders and provide opportunities for knowledge exchange (CWF 2019).

The plan has fostered the restoration of hundreds of thousands of acres of meadow habitat (CWF 2019).

Funding

Research funding agencies can play a pivotal role in supporting further research to obtain long-term population data, which is vital to monitoring population trends (Cameron and Saad 2020). Examples of funding programs follow. The Canadian government's Habitat Stewardship Program for Species at Risk provides funding for projects that contribute directly to the recovery objectives and population goals of species at risk (Government of Canada 2020). Species must be listed on Schedule 1 of the *Species at Risk Act* (SARA) and/or have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as endangered, threatened, or of special concern but have not yet been listed on Schedule 1 of SARA (Government of Canada 2020). Priority species are selected based on their likelihood to benefit from stewardship activities and includes those that may not benefit from other Environment and Climate Change Canada funding sources (Government of Canada 2020). The Western Bumble Bee, Gypsy Cuckoo Bee and Yellow-banded Bumble Bee are currently featured as priority species on the list.

The United States Department of Agriculture (USDA) offers research funding through various programs, including the Natural Resources Conservation Service, Agricultural Research Service and the National Institute of Food and Agriculture (USDA 2020). These programs are designed to advance resource conservation and agricultural research through the development of scientific tools and innovative solutions to address agricultural concerns, sustain agroecosystems and natural resources and ensure economic competitiveness (USDA 2020). Grants have been awarded through these programs to investigate bumble bee-related issues such as population declines, nutritional requirements and rebuilding pollinator habitat (USDA 2020).

Public Education and Advocacy

As with any initiative, it is important to have the support of key stakeholders. In the case of bumble bee preservation, the stakeholder group is large and diverse, with representatives from multiple sectors across North America. Raising awareness of the issues impacting bumble bees will be crucial to its conservation success. Communication strategies should focus on engaging with the public through the most wide-reaching means available (Goulson et al. 2011). Traditional methods include articles in national newspapers, journals and magazines and radio and television stories, ads and documentaries (Goulson et al. 2011). Social media sites such as Facebook and Twitter have created mechanisms to expand outreach opportunities to influence audiences world-wide. This promotes opportunities for collaboration and advocacy amongst the many organizations working towards bumble bee conservation (Goulson et al. 2011).

Increasing international collaboration will enhance opportunities for advocacy and knowledge exchange and hasten the collection of population status data for the creation and expansion of online databases (Cameron and Saad 2020). These databases will provide detailed ecosystem analyses on changing geographic ranges, relative abundance and phenological shifts (Cameron and Saad 2020).

DISCUSSION

This literature review demonstrates scientific evidence of the valuable role of bumble bees in the lifecycle of the planet's flora and fauna and the importance of ongoing conservation strategies that manage the threats to preserve these essential pollinators. The ultimate goal is to maintain strong ecosystems with the necessary biodiversity to support the planet and its inhabitants.

CONSERVATION STRATEGY PRIORITIES

Conservation management must consider the needs of bumble bees during their active period from spring to late summer when they establish and grow their colonies (Colla 2016). Efforts should focus on achieving the best possible outcomes during this timeframe. Scientific evidence points to the need for strategies that target habitat preservation and creation, conservation breeding, pesticide controls, disease and invasive species management, knowledge enhancement, partnerships and monitoring programs (Goulson et al. 2008; Goulson et al. 2011; Colla 2016; Cameron and Saad 2020).

HABITAT

Habitat plays a significant role in the successful conservation of any species. Preserving existing habitat and exploring opportunities to expand habitats in areas with limited availability should be key considerations in the development of land management plans for the protection of bumble bees.

Preserving Habitat

All bumble bee species require suitable habitat for nesting and foraging in close proximity, as well as overwintering sites to complete their annual cycles (Colla 2016). Global and national initiatives have been established to address these needs and restore pollinator habitats and populations. Research demonstrates that even small changes can provide considerable benefits. Schweitzer et al. (2012) suggest that management strategies should be tailored to the type of land being managed. For example, management of natural lands should concentrate on maintaining a variety of native flora that would bloom throughout the nesting season, while prairie regions should focus on restoring native species and eliminating activities such as plowing along roadsides. Main et al. (2019) state that public land management plans should maintain diverse plant communities with taller vegetation (100+ cm) near cultivated fields and consider modification of agricultural production practices to ensure pollinator species diversity, including wild bumble bees.

The impact of floral resource availability on bumble bee population dynamics requires further investigation, particularly in relation to the link between bee nutrition and environmental stressors and how bee-flower preferences and decline are influenced by the removal of a plant species from an ecosystem (Woodward and Jha 2017). Native plants are genetically adapted to specific regions and site conditions and are the preferred plants to be used for habitat restoration or preservation (Berenbaum et al. 2007:175). Appropriate planting mixes must factor in plant/pollinator interactions and include a floral mix that will bloom throughout the active period of bumble bees to provide the necessary resources for breeding, nesting and overwintering (Berenbaum et al. 2007:175).

Sirois-Delisle and Kerr (2018) propose that discussions on assisted colonization in conjunction with conventional conservation strategies that focus on habitat should be a priority. They also suggest that land management strategies to address areas of range loss overlap should be established to maximize benefits across numerous species.

Ontario established a Pollinator Health Strategy to address pollinator stresses through the creation of a Pollinator Health Action Plan. The strategy was created to strengthen pollinator health and ensure the continuation of a healthy agriculture system and maintenance of natural ecosystems (OMAFRA 2016).

Colla and Dumesh (2010) suggest that phylogenetically conserved traits may influence vulnerability to specific threats. Short-tongued, early emerging species associated with mixed and woodland habitats, such as the Rusty-patched Bumble Bee (*Bombus affinis*) and the Yellow-banded Bumble Bee (*Bombus occidentalis*), will have different ecological needs than long-tongued, late emerging, aboveground nesters such as the American Bumble Bee (*Thoracobombus pensylvanicus*). Policy makers must take into account the species-specific ecological needs of common and at-risk bumble bee species

(Colla 2016). Grixti et al. (2009) suggest further research in this area is needed to obtain a better understanding of these ecological needs. Until that knowledge is available, increased efforts are needed to set aside diverse patches of natural habitat for bumble bees and other pollinators, particularly in areas of agricultural intensification (Grixti et al. 2009).

Knowledge about the specific nutritional and habitat needs of local bumble bee species will be important in planning ecosystem restoration strategies (Vaudo et al. 2015; Filipiak 2018). Strategies need to consider pollen and nectar requirements at different life stages, as well as availability of floral resources throughout the span of a full day and temporal season (Vaudo et al. 2015; Filipiak 2018). This focussed approach will address the individual needs of both generalist and specialist species by targeting use of specific plants, customized to local regions and habitats (Vaudo et al. 2015; Filipiak 2018).

Gibson et al. (2018) propose that adaptive management strategies be implemented in protected areas. Adaptive management involves monitoring biodiversity data collection and habitat maintenance to ensure the native/natural biodiversity is preserved. The data provides historical information regarding features of local ecosystems for restoration of areas outside of the protected area, such as at-risk species forage availability. Land managers can use data about the preferences of at-risk bumble bees for particular floral species or plant families to promote and ensure an abundance of these are included in the landscape. This strategy would support ongoing plan adjustments based on the most current ecological data obtained from within and outside the protected area.

Expanding Habitats

Habitat loss continues to be a major driver of bumble bee decline (Cameron and Saad 2020). A key factor in recovery strategies for threatened populations is the preservation and expansion of habitats (Schweitzer et al. 2012). Private and public landowners can work collaboratively to create pollinator pathways linking fragmented habitats by providing pesticide-free corridors of high-quality native plants rich in nutrients (CWF 2019). Such pathways could link farmland pastures, roadside boulevards in towns and cities, backyard gardens, solar arrays, wind farms and transmission and pipeline corridors (CWF 2019). The goal is to connect properties through corridors that are within the foraging range of local bumble bee populations (CWF 2019).

Habitat must be created on the premise of increasing the abundance and diversity of floral resources to improve bee density and diversity and assure continuity of nectar and pollen resources during active periods (Hatfield et al. 2012; Schweitzer et al., 2012). Newly established habitats should provide suitable nesting and foraging habitat, preferably in close proximity, during the annual period of bumble bee activity (Schweitzer et al., 2012). Ideally, nesting habitat is located within 500-800 meters of foraging habitat. Nesting and overwintering sites should include unplowed, undisturbed areas with logs, clumps of grass and artificial nest boxes (Schweitzer et al., 2012).

Millions of acres of land in Canada are occupied by natural gas pipelines, electric transmission corridors, solar arrays and wind farms (CWF 2019). Some companies have already started to make use of these lands to create pollinator habitat (CWF 2019). For example, BC hydro is working with the public to create pollinator habitat beneath their power lines (CWF 2019). In Ontario, the Sarnia Solar Farm has planted native plants between solar arrays and the Canadian Wildlife Federation is working with Hydro One, Lanark County and the National Capital Commission to restore pollinator habitat along roadsides, bike paths and hydro lines (CWF 2019). Wojcik and Buchmann (2012) suggest further research into the use of roadside rights-of-way and lands beneath electrical transmission lines as potential conservation and management strategies to expand pollinator habitat. With over 25 million kilometers of road and 300,000 kilometers of electrical utility corridors in the United States alone, these managed infrastructure landscapes could provide a full range of habitat requirements and act as conservation reserves.

It is anticipated there will be positive and negative ecological effects related to the creation of roadways and electrical transmission line corridors (Wojcik and Buchmann 2012). For example, construction of new roadways can cause habitat fragmentation but can also create new habitat for ground-nesting bees along roadside edges. Creation of electrical transmission corridors can negatively affect larger habitats by dividing them into smaller islands but can also provide ongoing access to early successional stages of floral resources through regular maintenance of vegetation (Wojcik and Buchmann 2012). Tables 2 and 3 show the projected positive and negative effects for roadways and roadsides and transmission power line corridors and maintenance roads respectively (Wojcik and Buchmann 2012).

Table 2. Proposed ecological effects of creating new roadways (adapted from Wojcik and Buchmann 2012).

Roadways and Roadsides	
Negative Effects	Positive Effects
• Direct elimination of habitat area (new installation) • Bisect and fragment landscapes into habitat islands (new installation) • Conduits for dispersal of weeds and exotic animals • May alter migratory patterns • Allows deep access into wild lands for further exploitation • Increases frequency of wildfires (tossed cigarettes) • Introduction and spread of gasoline, exhaust fumes, rubber particles from tires • Mortality due to interactions with vehicles and traffic (road kill)	• Water runoff creates hedgerow effect on new growth • Increased flowering promotes bees, other pollinators, grazing by herbivores • Thoughtful management fosters or resets succession promoting colonizing species • Creates new bare ground along edges, promoting bee nesting

Table 3. Proposed ecological effects of creating new electric power transmission lines and maintenance roads (adapted from Wojcik and Buchmann 2012).

Transmission Power Line Corridors and Maintenance Roads	
Negative Effects	Positive Effects
• Bisect otherwise unbroken habitats into habit islands (new installation) • Electric and Magnetic Field (EMF) radiation from high voltages may pose threats to animals living under them	• Chemical or mechanical thinning opens up habitats • Bumble bees have access to increased floral resources during repeat early successional stages • Bare soil in maintenance roads favours ground-nesting bees. • Increased rodent nesting may favour bumble bees

Roadside and electrical rights-of-way enhancement strategies include restoration of native vegetation and natural habitats, maintenance processes that minimize disturbance of pollinators, and improvement plans that promote diversity and species richness (Wojcik and Buchmann 2012). Successful management of these landscapes will require established guidelines and techniques (Wojcik and Buchmann 2012).

Field rows and hedge margins can also provide valuable pollen and nectar strips as forage areas within agricultural settings, as well as nesting sites (Goulson et al. 2011). The restoration and creation of species-rich grasslands and clover leys also offers access to protein-rich pollen Fabaceae (Goulson et al. 2008). The United States established the “Rights-of-Way as Habitat Working Group” in 2015, with more than 200 agencies participating in knowledge exchange opportunities on pollinator restoration ideas and best management practices for habitat conservation on working landscapes (CWF 2019).

Bumble Bee Health and Conservation Breeding

The success of any species is dependent on the overall health of its populations. Nutritional needs must be met in order to achieve and maintain good health and produce healthy offspring. Previous studies have demonstrated that access to a large variety of plant species leads to increased colony fitness and growth rates as a result of higher resource intake and food stores (Belsky and Joshi 2019). Belsky and Joshi (2019) propose research on designing monocultures that incorporate adequate provisions for all bees within an ecological guild. The goal would target use of specific flowering plants of numerous managed and feral bee species to create landscapes within crop layouts. Crops and wildflowers should be selected for traits influencing the quality of their pollen and nectar. This would result in monocultures and surrounding areas being planted with floral resources containing a range of key nutrients essential for optimal bee health to mitigate bee declines arising from removal of native plant species, while contributing to ecological and environmental restoration efforts.

Woodward and Jha (2017) state that future studies regarding the influence of floral resource availability in relation to bee population dynamics would be of value. They recommend studies focus on nutrients and their impact on bee health, synergies between bee nutrition and environmental stressors and how the removal of one plant species from an ecosystem can alter bee-flower preferences and lead to the decline of some bee species. They also suggest future research on the synergistic effect of stressors on bee learning and memory.

Berenbaum et al. (2007:157) suggested further research on bumblebee colonies that are mite and pathogen resistant be developed as a long-term solution. In 2014, the Native Pollinator Initiative’s Bumble Bee Recovery Program in Ontario began exploring methods to establish conservation breeding colonies of at-risk native bumble bee species (NPI 2019). The program collects rusty-patched bumble bee queens from across the province each spring to establish managed bee colonies that are ultimately self-sustaining and free of disease. The bumble bees are raised in captivity, thereby providing opportunities to observe all facets of colony lifecycles and collect essential data on species biology to obtain a better understanding of possible reasons for their decline (NPI 2019). To date, the research on captive colonies has yielded insight into threats facing wild populations, including genetic variations, parasite levels and impacts of pesticide use (NPI 2019). The end goal is to safely reestablish these bees in their historical ranges (NPI 2019).

Pesticides

Worldwide efforts are underway to better manage and regulate pesticide use. Examples of environmental management strategies in Canada, the United States and Europe are highlighted below. Health Canada's Pest Management Regulatory Agency, established in 1995, is the federal authority responsible for pesticide regulations and works jointly with key stakeholders, including provincial ministries, to establish agricultural practices designed to protect pollinators. Health Canada also works with international pesticide regulators to improve pesticide risk assessment methods and data requirements to promote a better understanding of the effects of neonicotinoids on bees and mitigate the risks (Health Canada 2020).

In 2014, Ontario became the first jurisdiction in North America to propose regulation of neonicotinoid pesticides as part of its Pollinator Health Action Plan. (OMAFRA 2016). The plan proposed an 80% reduction in the number of acres planted with corn and soybean seeds treated with neonicotinoids by 2017 (OMAFRA 2016). In Canada, neonicotinoids are used for seed and soil treatments, foliar sprays on a diverse range of agricultural crops, tree injections, turf applications, in structures and outdoor residential areas and in pet care products (Health Canada 2014). In April 2019, Health Canada's Pest Management Regulatory Agency (PMRA) completed re-evaluations of the allowable uses of imidacloprid, thiamethoxam and clothianidin neonicotinoids to assess the risk to pollinators, including bumble bees, in response to international updates to the pollinator risk assessment framework (Health Canada 2020). The comprehensive review considered relevant published literature and data submitted by registrants and included use of internationally accepted risk assessment methods using current risk management approaches and policies, as well as a value assessment of the active ingredient being used by different sectors (Health Canada 2020).

The risk assessments revealed the three neonicotinoids had varying effects on bumble bees, with some uses having no discernible effect and others requiring mitigation measures to limit exposure (Health Canada 2020). The measures include changes to use patterns, such as cancelling or reducing foliar applications to specific types of vegetation and/or in particular jurisdictions, and label improvements that require additional use statements to limit exposure (Health Canada 2020). Health Canada states that the reduced exposure to bumble bees resulting from user compliance with these mitigation measures is considered sufficient to reduce risks to acceptable levels. The measures are to be implemented by April 11, 2021 (Health Canada 2020).

In April 2018, most European Union states voted to ban the use of imidacloprid, clothianidin, and thiamethoxam neonicotinoids in open fields by the end of 2018, although greenhouse use will still be permitted (Kwon 2018). The decision was influenced by scientific advice contained in a report provided by the European Food Safety Authority (EFSA 2015) which concluded that neonicotinoids were harmful to both wild bees and honeybees (Kwon 2018). In May 2019, the United States Environmental Protection Agency (USEPA) cancelled the registrations of twelve neonicotinoid-based pesticide products containing clothianidin and thiamethoxam used in agricultural applications (Hou 2019). The cancellation stemmed from a December 2018 settlement won by beekeepers and environmental groups related to the Endangered Species Act, which called for the USEPA to address the effects of pesticides on bees (Hou 2019).

Application of pesticides during optimal spraying times and conditions that promote rapid breakdown of toxins and avoid drift were common themes to reduce the impact to bumble bee populations in the literature reviewed (Schweitzer et al. 2012; Wood and Goulson 2017).

<u>Management of Diseases and Invasive Species</u>

Researchers have identified numerous factors that impact the manifestation of disease on bee populations and have proposed a variety of potential solutions to mitigate the risks. For example, Evison et al. (2012) identify the need to determine the diversity and impact of parasites. They state the inclusion of multi-species pollinator interactions is required to correctly model and forecast parasite population-level dynamics to inform the development of pollinator conservation strategies. Meeus et al. (2011) suggest stronger infectious disease control measures for imported bees to manage the spread of disease and invasive species. They propose the use of molecular screening protocols, comprehensive sanitation methods, legislative changes and collaboration between governments, nongovernmental organizations and commercial breeders would realize immediate results. Fürst et al. (2014) suggest similar control measures for managed bees, including regulation for importation and hygiene levels, could reduce pathogen transmission between managed bee species and wild bumble bees and prevent further declines in wild bumble bee populations. The study acknowledged that beekeepers, including commercial producers and growers, must be involved in the change process because they will be the drivers of any actions. Beekeepers will require appropriate management tools, methods and skills to monitor and control emerging infectious diseases in their respective bee colonies to mitigate further declines.

Goulson and Hughes (2015) concur that stronger mitigation measures are needed to avoid further adverse effects on bumble bee populations stemming from anthropogenic movement of managed bees. They propose that proper implementation of a multi-level prevention strategy aimed at all stages of commercial bee production, including bee growth, distribution and on-site management, would significantly reduce the possibility of additional negative impacts on wild and managed bumble bees. Figure 8 demonstrates the potential routes of transmission and proposed mitigation strategies to prevent pathogen spillover to wild bumble bee colonies.

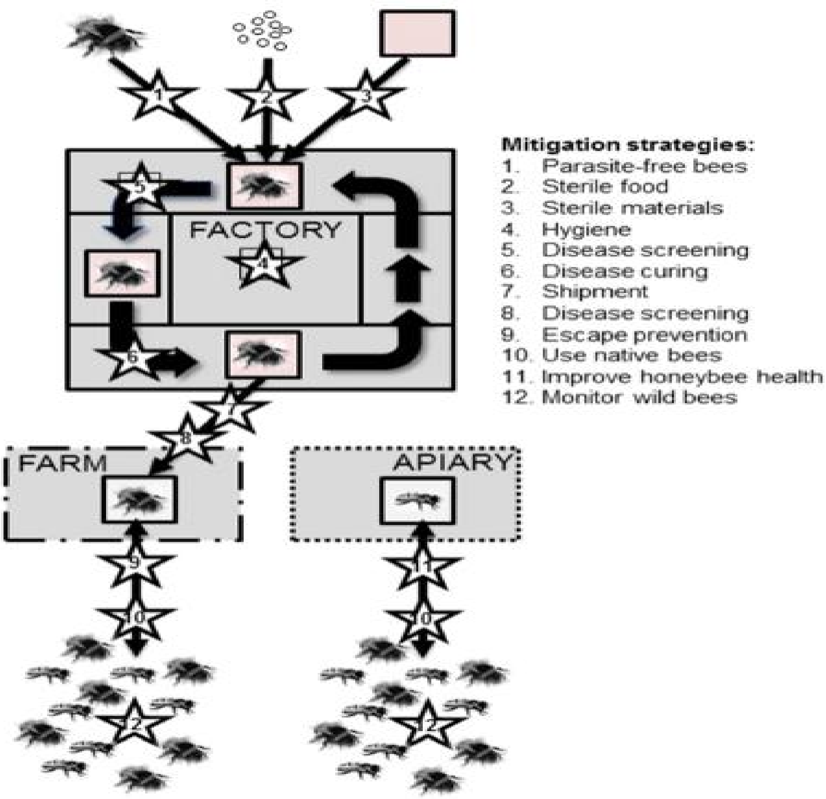


Figure 8. Schematic illustrating the many opportunities for mitigating the impacts of parasites associated with managed bumble bee and honeybee colonies on wild pollinators. Source: Goulson and Hughes (2015).

BUILDING CAPACITY

The decline of wild bumble bee populations is a global concern. Management solutions require the concerted effort of diverse partners, including scientists, educators, advocates, politicians, policy makers, funders and the general public. The goal is to build capacity, enhance knowledge, and facilitate action at all levels.

Partnerships

Strong, world-wide partnerships provide increased opportunities for knowledge exchange, research, advocacy and policy change. Numerous formal and informal strategies are underway throughout North America.

1) Pollinator Partnership Canada (P2C) is a registered not-for-profit organization dedicated solely to protecting and promoting pollinators and their ecosystems through conservation, education, and research. The partnership is a federal-provincial-territorial initiative established to collaborate on a series of land management guides for conserving habitat for pollinators on Ontario's farms, utility lands and along roadsides (P2C 2019). Pollinator Partnership Canada established a designated week each June as National Pollinator Week to celebrate pollinators and share protection strategies to address the decline in pollinator populations, including bumble bees (P2C 2019).
2) The North American Pollinator Protection Campaign (NAPPC) is a collaborative group of more than 160 diverse partners, including scientists, researchers, conservationists, government officials and dedicated volunteers. Members promote and participate in important programs to protect pollinators, raise awareness and provide education on the crucial role of pollinators (NAPPC 2019). NAPPC was established in 1999 and has made significant contributions to the protection of pollinators, including the creation of a National Academy of Sciences NRC panel. This led to the first scientific-based report "The Status of Pollinators in North America" 2007

(NAPPC 2019). Other contributions involve participation in the development of thirty-one web-based eco-regional planting guides for all U.S. regions to create pollinator-friendly landscapes, provision of research grants related to honey bee health and sharing information that lead to the inclusion of pollinator programs in conservation and research titles in the 2008 Farm Bill in the U.S. (NAPPC 2019).

3) The Island Pollinator Initiative is a program of Pollinator Partnership Canada; it is a coalition of groups working to protect pollinators on Vancouver Island and the Gulf Islands in British Columbia, Canada. The initiative offers guides on pollinator friendly planting, bee identification, bee-friendly farming, building bee homes and teacher resources, as well as lists of university talks and resources (IPI 2019).
4) Insight Citizen Science is a free mobile application that enables individuals and organizations to participate in meaningful pollinator research and conservation by recording their pollinator observations in the application. The software's observation methodology was developed in collaboration with scientific experts. Participants have access to a learning guide about the observation process and identification of pollinators, making it user-friendly (Insight Citizen Science 2019).
5) Border Free Bees is a long-term collaborative public art initiative with a mission to "raise awareness of the plight of wild pollinators, empower communities to actively engage in solutions for habitat loss, and transform underutilized urban sites into aesthetically pleasing and scientifically viable pollinator pastures". The initiative is supported by the Social Sciences and

Humanities Research Council of Canada and involves a number of related projects in partnership with scientists, specialists, community groups, businesses, and municipalities. Their website provides publications, tips and advice on how to create bee-friendly areas. Resources available to the public include a Mason Bee Home Fact Sheet, Bumble Bee Guide, Gardening Tips, and Bee ID Information, including a link to their Insight Citizen Science Bee ID Application (Border Free Bees 2019).

Education and Training

Training scientists and the public in bee taxonomy and identification to address the steady decline in the number of taxonomists overall, including those specializing in bee taxonomy, will be important (Batley and Hogendoorn, 2009; Eardley et al., 2009; Patiny et al., 2009). The advent of DNA barcoding is expected to partially alleviate the loss of taxonomists, although it cannot replace traditional taxonomy in measuring and understanding bee species richness (Brown & Paxton 2009).

Research

Numerous scientists have acknowledged the lack of historical baseline data available about bumble bee populations and have explored potential solutions to address this information challenge (Goulson et al. 2010; Jacobson et al. 2018; Cameron and Saad 2020). Berenbaum et al. (2007:141) suggest two alternative sampling strategies could be substituted to obtain historical population data.

The first strategy involves the use of a combination of historical and recent survey data to perform focussed assessments on the status of bumble bees in North America, for example re-survey previously surveyed areas to determine species existence. The second strategy incorporates a long-term annual monitoring plan to establish the necessary baseline for future evaluation of bumble bee populations. This method would enable ongoing monitoring to identify trends in species abundance and determine the potential correlation between alterations in community composition and acknowledged environmental causes of change (Kremen, 1992; Kremen et al., 1993). Such knowledge is critical for the development of mitigation strategies pertaining to environmental change and management of species continuance.

Grixti et al. (2009) state that museum collections hold valuable baseline data on species distribution and richness across large geographic and temporal scales. An electronic database of this information would enable researchers to explore the effects of anthropogenic changes such as habitat destruction and climate change on biodiversity. Combining museum collections with current biodiversity surveys would also create an invaluable resource for conservation biology. Murray et al. (2009) reinforce the importance of obtaining autecological data to provide information on species-specific requirements and environmental tolerances of individuals to the geographic distribution of the species. This data, combined with long-term population data, will be used to predict imminent population declines and effective management strategies. Pollination studies, apart from the well-known model crops, flowering plant species and bee taxa, are also needed (Brown & Paxton 2009).

Schweitzer et al. (2012), suggest that gaps in knowledge related to bumble bee biology would benefit from further research throughout North America. Studies related to 1) spatial and temporal population changes, 2) effects of habitat quality variations for overwintering, foraging and dietary needs of different species, 3) bumble bee diversity correlation to forest habitat, 4) habitat and climate commonalities where severely declining species remain, 5) fire and fire management effects, and 6) the extent of pathogen spillover threats from non-native bees to native bumble bees, are needed.

In-depth studies on levels of infectivity and landscape scale distribution of emerging infectious diseases in wild pollinator populations would be beneficial in determining their presence and prevalence (Evison et al. 2012; Fürst et al. 2014). Additional research on the diversity of parasites and species impacts will be essential to accurately predict population level dynamics of pollinator parasites (Evison et al. 2012).

Becher et al. (2018) established a *Bumble*-BEEHAVE mechanistic, multi-level model to evaluate the resilience mechanisms at the individual, colony, population and community levels of bumble bee populations under stress. The study demonstrated the success of the model in predicting the effects of numerous stressors occurring at multiple scales in spatially explicit ways at individual and population levels. The study also suggests the *Bumble*-BEEHAVE model may be of use in solving questions related to bumble bee ecology and conservation and assist in the design of field experiments, risk assessments and formulation of recommendations for landscape scale management strategies. Belsky and Joshi (2019) suggest that priorities for future solitary bee research should focus on how the interactions of biotic and abiotic stressors increase solitary bee declines, as well as the impacts of stressors at a molecular level.

Monitoring Programs

Effective management strategies must include monitoring programs to measure the success of conservation efforts. Use of historical data would facilitate ongoing comparisons of current and past distributions and relative abundance to determine the level of species decline and risk status (Cameron and Saad 2020). Berenbaum et al. (2007:141-143) suggest that current pollinator monitoring programs do not provide enough information to properly assess the status of wild bumble bee populations and pollination services. They state that an overarching framework encompassing broad-scale use of standardized, long-term protocols must be established to develop cost-effective, practical monitoring programs to accurately gauge any changes and identify the need for action. Longitudinal studies and repeat research have been identified as potential strategies to monitor bumble bee populations.

Replication studies, such as the one conducted by Marlin and Laberge (2001), are important in assessing the level of change in bumble bee populations or species extirpation over the long term. The study suggests diverse habitats embedded directly in the environment, such as forests, open woods and rural grasslands, resulted in little change in bee communities in the seventy-five years since the initial study, despite the significant landscape changes that occurred during this period. Roubik (2001) concluded that surveys must include at least four years of sampling to effectively document seasonal trends and measure year-to-year changes to determine the statistical importance of such trends in bee population abundance.

Berenbaum et al. (2007:141-142) suggest the implementation of a two-pronged approach to monitoring wild bumble bees. The strategy involves use of an initial assessment to determine the current population status (Figure 9), followed by the establishment of a framework for long-term monitoring of populations and function over time (Figure 10). The assessment program would make use of data from past surveys and museum collections by focussing on re-assessment of previously well-surveyed areas for ongoing, high-intensity sampling. A long-term monitoring program that combines the work of professional scientists with the monitoring activities of citizen scientists would provide a cost-effective data collection strategy.

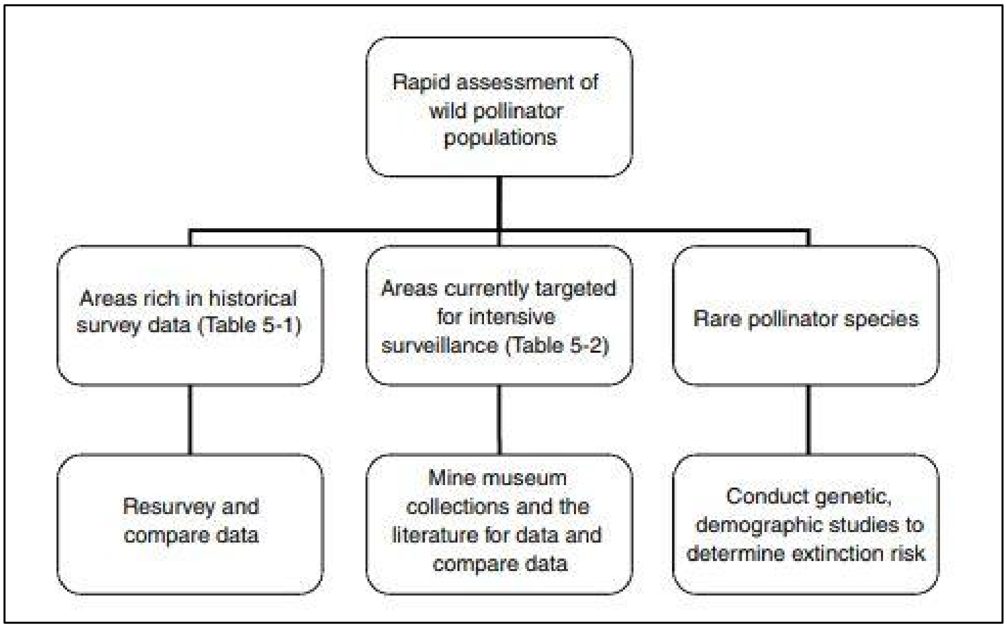


Figure 9. Assessment program. Source: Berenbaum et al. (2007:142).

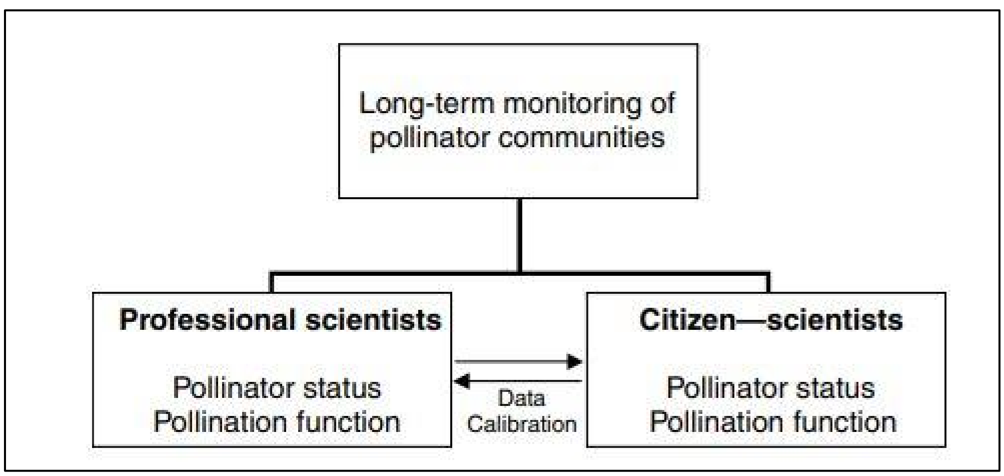


Figure 10. Monitoring program. Source: Berenbaum et al. (2007:143).

In Ontario, the Native Pollinator Network (NPI) conducts bumble bee population surveys for at-risk species throughout the province, from Norfolk County in the south, to Thunder Bay in the North (NPI 2019). Surveys target historic and current locations of at-risk bumble bees to monitor their local population health over time (NPI 2019). Baseline data for identified at-risk bumble bees have been collected since 2013 in these locations. In 2018, the Network added field crews to expand its survey areas with the goal to discover new populations. Species monitored include the yellow-banded bumble bee (*Bombus terricola*), rusty-patch bumble bee (*Bombus affinis*), gypsy cuckoo bumble bee (*Bombus bohemicus*), the American bumble bee (*Bombus pensylvanicus*), and the yellow bumble bee (*Bombus fervidus*).

Northern Ontario and the arctic region are two of the few places in North America with little to no data on the type of bumble bee species present (Gibson et al., 2018). In an effort to add to the data base, Gibson et al. (2018) conducted a study using the sampling of invertebrates collected by the Ontario Ministry of Natural Resources and Forestry (OMNRF) between 2009 and 2015 as part of a comprehensive, multi-taxa survey known as the Far North Biodiversity Project (FNBP). That information, together with data from associated studies conducted near Moosonee, Ontario, and Akimiski Island, Nunavut, were included with the eleven species collected by the researchers to confirm species presence. Three species were confirmed to have a more northern range than previously identified, three were confirmed as range gap infills, two validated species range and three were identified as first or second provincial/territorial records. The researchers noted that they caught one species of *B. terricola*, which is listed as Special Concern (COSEWIC 2015), in Northern Ontario's "Ring of Fire". This area is situated in the James Bay Lowlands region, approximately 500 kilometers northeast of Thunder Bay and is currently being explored for mineral extraction. The results of this study will be useful during the environmental assessment process for this project and will contribute to future historical range record data for this area, highlighting the importance of ongoing monitoring in conservation efforts.

BumbleBeeWatch.org is a citizen science website that uses information entered by individuals to identify areas with declining bumble bee species, assess changes in population size and distribution, and track invasive species throughout North America (NPI 2019). This information is vital to inform future conservation and recovery strategies (NPI 2019). Citizen scientists are trained to use the same survey techniques employed by professional researchers and are provided with the equipment and knowledge to independently monitor native bumble bees within the targeted locations (NPI 2019). This initiative has yielded numerous additional recordings of sightings of rare species at these sites (NPI 2019). The program continues to expand its reach throughout Ontario and into Alberta and is currently developing a “train-the-trainer” citizen science program for organizations and landowners interested in running their own bumble bee watch programs (NPI 2019).

TRANSLATING RESEARCH INTO ACTION

Researchers are publishing scientific papers on bumble bee declines with growing regularity (Cameron and Saad 2020). The research is anticipated to provide a better understanding of these declines and how to reverse them. While government agencies often contribute funds to scientific research through grants, it is not clear how the results are then translated into action, particularly in relation to the development of government policies (Goulson et al. 2011). The inclusion of researchers in discussions about environmental priorities and policies would provide opportunities to close the gap between research and implementation of conservation strategies (Goulson et al. 2011).

CONCLUSION

Wild bumble bees provide crucial pollination services. They are considered a keystone species in natural ecosystems and an economically valuable crop pollinator in agricultural systems. Ongoing concerns regarding continuing population declines in some species prompted a surge in scientific research over the past decade. Researchers revealed multiple stressors and causative factors threatening bumble bee populations across the globe.This growing body of scientific evidence highlights the key drivers of population decline. Habitat loss, reduced resource availability, pesticide use, emerging diseases and invasive species are advancing the world-wide collapse of bumble bee populations. Scientists concur that more published field data is desperately needed on the long-term effects of these destructive ecological disturbances before we can determine if current strategies are working. The challenge is how to translate this scientific evidence into governmental conservation policy. This can only be achieved through increased advocacy by multiple stakeholders, additional funded research and public/political support. In the interim, the public can play a key role in advancing conservation plans. Preservation and creation of habitat for threatened populations of native bumble bee species, with a spotlight on enhancing the size and connectivity of existing populations, must take precedence. Habitat should be designed with native species in mind, promoting the creation of landscapes rich in floral diversity and containing high quality pollen and nectar options. These areas could be interspersed amongst those with nutritionally poor resources to promote linkages with existing populations.

Many jurisdictions have already implemented innovative strategies to prevent further declines. For example, the City of Toronto developed a comprehensive “Pollinator Protection Strategy” to support bumble bee conservation, contribute to resilient ecosystems and enhance urban biodiversity. Toronto was the first city in Canada designated as a “Bee City” signifying their participation in, and commitment to, pollinator protection. Toronto’s strategy addresses key elements of conservation, including habitat, green spaces, partnerships, investments and incentives and education and training. Similar strategies can be implemented in any city or town.

Additional research on the topics presented in this paper could provide the data needed to support the development and implementation of mitigation strategies to stop further declines and impacts to the ecosystem. The most successful strategies can be achieved when scientists and leading advocates from throughout the world work together to achieve a common goal of bumble bee health.

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