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Honey Bee Population Decline in Michigan: Causes, Consequences, and Responses to Protect the State's Agriculture and Food System

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Abstract

Michigan's current level of food production and its agricultural economy are in jeopardy due to drastic honey bee population declines across the state over the past seven years. This problem should be a priority for policy makers; honey bee losses affect almost everyone in the state because over a third of the food we consume is pollinated by bees. The causes of honey bee population decline are multiple and interconnected. A growing body of research shows that the principal factors involved are parasites and pathogens, environmental stressors, and monocrop farming, widespread use of pesticides, and industrial beekeeping practices within the paradigm of conventional industrial agriculture. In addition to individual stressors, there are synergetic interactions between some stressors that increase the vulnerability of managed honey bee colonies.

Many of Michigan's agricultural products—such as soybeans, dry beans, apples, blueberries, cherries, cucumbers, and other produce—depend on honey bee pollination to produce a good crop. Michigan is a state that relies heavily on pollination services to maintain its agricultural production, but it has been hard hit by honey bee population declines. Honey bee losses of more than 30% annually have been reported by Michigan beekeepers over the past few years, with the 2013/2014 winter poised to be even worse. Honey bee population declines in Michigan will likely not improve, and could continue to worsen, unless the problem is addressed by policy makers and other stakeholders in a substantive way. Because the problem involves many different causal factors and actors spanning agricultural production and consumption, potential solutions are also complex. There are various local-level mitigation measures that beekeepers, farmers, and the general public can implement, such as improving communication with beekeepers about pesticide application, reducing or eliminating the use of insecticides, and improving the area of habitat for bee-friendly forage. Initiatives to connect and support Michigan beekeepers using sustainable practices are also promising. But on their own, local steps are likely not enough to stem honey bee population declines; higher-level institutional approaches are also needed. A combination of facilitated dialogue among key Michigan stakeholders, legislation, and litigation originating at the state or national level could provide the additional impetus needed to rein in and reverse honey bee colony losses in the state. This paper provides recommendations for effectively implementing a multi-stakeholder dialogue process, and proposes modifications to legislation targeted at improving honey bee populations nationally.

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"The way humanity manages or mismanages its nature-based assets, including pollinators, will in part define our collective future in the 21st century. The fact is that of the 100 crop species that provide 90 per cent of the world's food, over 70 are pollinated by bees. Human beings have fabricated the illusion that in the 21st century they have the technological prowess to be independent of nature. Bees underline the reality that we are more, not less, dependent on nature's services in a world of close to seven billion people."

-- Achim Steiner, UN Under-Secretary-General and UNEP Executive Director, 2011

The Road to Honey Bee Population Decline in Michigan

If you travel to the northern end of Michigan's famed highway M-22, you will find yourself in the pinky finger of the Michigan mitten, the Leelanau Peninsula. Leelanau is a rolling landscape of apples, pears, cherries, and grapes. Dotted among the orchards are fields of corn and soy, and patches of young woods. At first glance, the environment of the Leelanau Peninsula might appear to be an agricultural paradise. But where the asphalt turns into rough dirt at the dead end of the peninsula, you will find a bee yard strewn with discarded barrels of corn syrup and stacks of beehives from dead honey bee colonies. The bee yard belongs to Mr. Adams (name changed to protect confidentiality), a beekeeper who has kept honey bees almost his entire life. With nearly 10,000 hives, Mr. Adams maintains one of the largest commercial beekeeping operations in the state. He would be the first to acknowledge that his business, and the orchards that surround his bee yard, are endangered.

During the mid-1990s, Mr. Adams lost approximately 80 percent of his colonies to a tracheal mite epidemic. However, he, like the majority of other beekeepers who reported major losses, recovered his honey bee populations quickly as a result of a national tracheal mite mitigation campaign. In contrast to the brief dip in honey bee populations of the 1990s, Mr. Adams and beekeepers in many other countries have now been experiencing consistent heavy colony losses since 2005, which they say are unprecedented in severity and mystery.

Heading southeast across Michigan as the crow flies from the cherry capital of the world, Traverse City, toward the research and education hub of Ann Arbor, the path is flanked by some of the most important actors in the complex problem of honey bee population decline. At the beginning of the trip, one is surrounded by farms cultivating some of the nation's most robust crops of apples, blueberries, and cherries, all dependent on pollination services. Next along the path is Midland, home of Dow Chemical Company, a Fortune 50 corporation and one of the world's largest producers of pesticides. Then comes Lansing, Michigan's capital and home to the state Department of Agriculture and Michigan State University, a top agricultural research institution. All along the way, commercial and hobby beekeepers abound. In sum, Michigan exemplifies the diversity of actors invested in protecting food production and dealing with the crisis of honey bee population decline on a local, state, and national level.

This paper represents a one-year investigation into the complex causes and consequences of the current honey bee population decline, and potential responses that key stakeholders in Michigan can adopt to mitigate the problem. The investigation consisted of a literature review as well as author participation in various beekeeping conferences and meetings. Conversations with beekeepers in Michigan and other states, as well as other key stakeholders, also helped guide our research and recommendations.

We begin the paper by outlining the state of honey bee population declines nationally and in Michigan. The second section describes some of the consequences of these declines for Michigan's agricultural production and economy. The third section summarizes the various factors that likely contribute to current honey bee population declines. In the fourth section we briefly identify local mitigation techniques that can be (and are being) implemented by farmers and beekeepers in Michigan. In the fifth section we present recommendations for combating honey bee population decline at the state and national level.

Honey Bee Population Decline

Honey bees (*Apis mellifera*) are currently in a state of rapid decline in many places around the world. Since 2005, colony collapse disorder (CCD) and other causes of honey bee mortality have resulted in the loss of about 30 percent of all managed honey bee colonies in the United States annually, about twice the expected mortality rate (Smith et al. 2014; VanEngelsdorp et al. 2012). CCD is characterized by the mysterious disappearance of honey bees from their hive, except for the queen and brood, without evidence of a hive invader or dead bees remaining in the hive (Smith et al. 2014). However, while CCD has been one of the most visible and perplexing manifestations of honey bee losses over the past nine years, particularly in the United States, it appears to be a relatively minor component of a much broader decline in managed honey bee populations and health. As some researchers have pointed out, "we must be careful to not synonymize CCD with all honey bee losses" (Williams et al. 2010). In this paper we consider honey bee population declines in general, including from colony collapse disorder and other causes.

Statistics regarding the magnitude of honey bee colony losses are shocking. The Bee Informed Partnership, coordinated by the International Bee Research Association, began conducting an annual survey in 2006 of thousands of beekeepers across the United States about colony mortality rates and perceived causes of mortality (VanEngelsdorp et al. 2012). In total surveyed beekeepers have hundreds of thousands of honey bee colonies. Even with a net purchase of tens of thousands of colonies each year among those surveyed, the average honey bee colony losses over the last seven years are about 30 percent per year, roughly double the expected rate (see Table 1). Beekeepers consider acceptable colony losses to be around 13 percent, and researchers consider a normal (before the advent of CCD) annual mortality rate to be about 15 percent (Rucker et al. 2011).

Table 1. Total estimated losses of managed honey bee colonies in the United States, 2006-2013.

Winter season	Estimated percent of total colony losses in the U.S.
2006/2007	32%
2007/2008	36%
2008/2009	29%
2009/2010	34%
2010/2011	30%
2011/2012	22%
2012/2013	31%

Source: VanEngelsdorp et al. 2012; Bee Informed Partnership 2013

In Michigan, beekeepers reported a loss of 34.8 percent of the total colonies in the state in 2011/2012 (VanEngelsdorp et al. 2012). While official statewide numbers have yet to be released for colony losses over the winter of 2013/2014, there is reason to believe that this winter caused high mortality among Michigan colonies, with some small-scale beekeepers reporting losses of up to 90% of their colonies (SEMBA 2014). A 2014 USDA report states that "the harsh winter has taken a toll on bees across [Michigan]. In the Southeast, 70 beekeepers were surveyed and reported severe losses: in September 2013, 581 hives were reported alive and by March 2014, only 256 hives had survived, or a 56% loss…. Similar statistics have been reported in other regions of the state" (USDA National Honey Report 2014).

In spite of growing scientific and public awareness of these massive honey bee die-offs, efforts to date have been unable to substantively address the crisis. The dearth of collaboration and coordination to assess the challenges and propose solutions among policy makers and the scientific, corporate, farming, and beekeeping communities has presented a major barrier to comprehensively combating honey bee losses. A lack of broad consensus among key stakeholders regarding the causes of honey bee population decline also presents formidable obstacles to action. However, there is an extensive and growing body of research on the issue, with enough evidence to begin drawing conclusions and taking action based on the results of existing studies.

Consequences of Honey Bee Population Decline in Michigan

The crisis of honey bee population decline merits a swift and serious response from policy makers and other actors in Michigan and nationally. This is principally because of the strong reliance of a large proportion of agricultural production on pollination by honey bees and wild pollinators. Out of the 115 most important food crops globally, 87 (or 75 percent) depend on pollination by animals, such as honey bees, for the production of the fruit, vegetable or seeds (Klein et al. 2007). In terms of the quantity of global food production, about 35 percent of the food we eat requires pollinators (Klein et al. 2007). Honey bees pollinate almost all of the fruits, vegetables, and nuts grown in the United States. Thus, honey bee population decline is emerging as a significant threat to food production in the United States and many other countries (Potts et al. 2010).

In Michigan, the sharp decline in survivorship and health of honey bee colonies is a problem because many crops require the pollination services provided by managed honey bees. These crops generate significant income for producers and contribute to Michigan's food system and the cultural identity of the state. The agriculture and food industry in Michigan contributes over $90 billion annually to the state's economy, with the largest growth sector coming from farming (MI Department of Agriculture and Rural Development 2013). Michigan stands ninth in the nation in honey production (USDA National Honey Report 2014). Fruit and tree nut production in the state was worth an average of $344 million annually over the years 2008-2012, with the potential value being even higher (in 2007 these crops were worth close to $420 million) (National Agricultural Statistics Service 2013). Vegetable production generated an average of $249 million from 2008 to 2012 (National Agricultural Statistics Service 2013). In addition, some of these crops have significance for the cultural identity of Michigan and also contribute to tourism revenues, such as from the National Cherry Festival held in Traverse City.

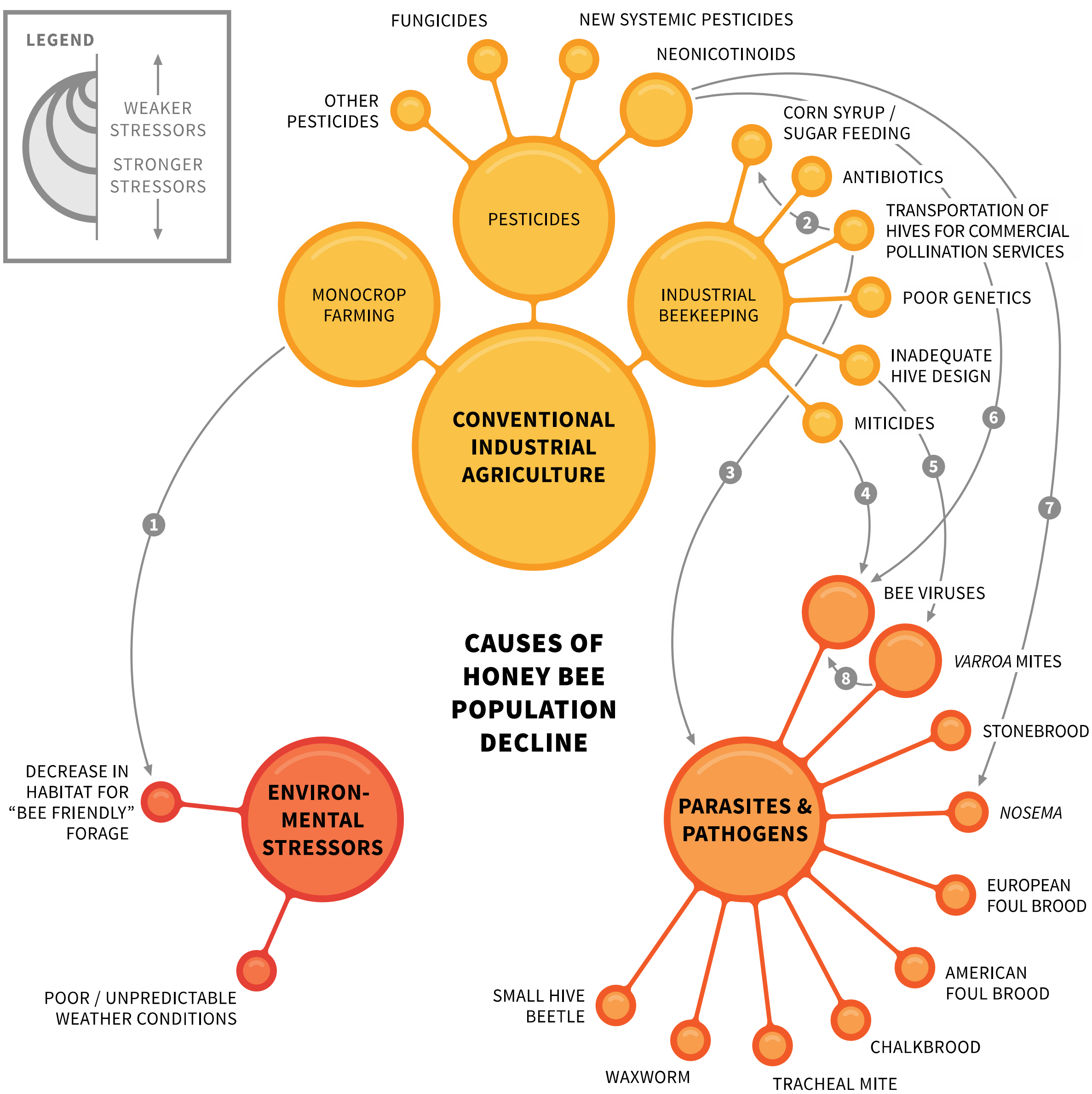
Apples, blueberries, cherries, cucumbers, dry beans, peaches, pears, plums, soybeans, and squash are all produced in Michigan. All of these either require animal pollination—mostly honey bees and wild pollinators—to produce, or the yield is significantly greater and of higher quality with animal pollination (Klein et al 2007). Estimations have not yet been made as to how much crop production and value has likely been lost in Michigan as a result of the decline in honey bee availability for crop pollination in recent years. But given the critical importance of pollination for the successful fruiting of so many crops produced in the state, we can expect further impacts of honey bee decline on the agricultural sector if the crisis is not rapidly mitigated. As just one example, the USDA's National Agricultural Statistics Service reported that in Michigan, usually the largest producer of tart cherries in the United States, "the majority of growers lost all of their harvestable crop" in 2012 because of atypical weather and the fact that "pollination conditions were poor." The combined factors resulted in a drop from 157.5 million pounds of tart cherries harvested in 2011 to an estimated 5.5 million pounds in 2012 (National Agricultural Statistics Service 2012).

In addition, with such high honey bee mortality rates, Michigan farmers face elevated and increasing costs of commercial pollination services. According to a local commercial beekeeper, the current price was $65 to $75 per hive in Michigan in the 2013 season. In California, where there is now an extreme shortage of honey bees owing to heavy losses, growers pay $145 - $165 per hive—more than triple the average cost before the emergence of CCD in 2005 (Olliver 2012).

Causal Factors

Research to date has identified several factors that are likely contributing to honey bee declines, and it is evident that the cumulative negative impacts of multiple stressors create lethal conditions for honey bees (Doublet et al. in press; Potts et al. 2010; Smith et al. 2014). Scientists and beekeepers have identified various causal factors which can be divided into three main categories: parasites and pathogens; environmental stressors; and conventional industrial agriculture. But rather than focus on individual stressors, it is critical to consider factors contributing to the current extremely high rates of honey bee mortality as an interconnected web of causality (Figure 1).

Figure 1. Web of causality for the current decline in honey bee populations across the United States.



CONNECTIONS BETWEEN STRESSORS

1. **Monocrop farming ▸ decrease in habitat.** Can create “food deserts” when the crop does not provide forage for the bees, or when a crop that does provide forage is not flowering. Also tends to eliminate uncultivated habitat that provides diverse forage for bees.
2. **Transportation of hives ▸ corn syrup/sugar feeding.** Beekeepers often feed the bees corn syrup or sugar mixtures while they are in transit and unable to forage.
3. **Transportation of hives ▸ parasites & pathogens.** Facilitates rapid and geographically broad transmission of bee parasites and pathogens to previously uninfected bees.
4. **Miticides ▸ bee viruses.** May increase honey bees’ susceptibility to viruses (Locke et al. 2012).
5. **Inadequate hive design ▸ *Varroa* mites.** The typical honeycomb foundation pattern used in industrial beekeeping has been found to facilitate *Varroa* infestation (Piccirillo and De Jong 2003).
6. **Neonicotinoids ▸ bee viruses.** Can increase honey bees’ susceptibility to viruses by weakening their immune systems (Di Prisco et al. 2013; Doublet et al. in press).
7. **Neonicotinoids ▸ *Nosema*.** Can increase the severity of honey bees’ infection with the microsporidian *Nosema* (Doublet et al. in press).
8. ***Varroa* mites ▸ bee viruses.** Serve as a mechanical and biological vector for viruses. The mites provide viruses an entry point into bees’ bodies and help transmit viruses between bees (Martin et al. 2012).

Parasites and Pathogens

Parasites and pathogens are considered by many to be principal actors in the high losses of bees that are occurring in many countries in the northern hemisphere (Dainat et al. 2012; Smith et al. 2014). In particular, the parasitic mite *Varroa destructor* has received much of the blame for honey bee colony failures, especially because of its ability to serve as a vector for bee viruses (Martin et al. 2012). Three viruses in particular have been associated with heavy losses of honey bees during the winter: deformed wing virus, acute bee paralysis virus, and Israeli acute bee paralysis virus (Dainat et al. 2012). Other important viruses that can weaken or kill honey bees include Kashmir bee virus, black queen cell virus, chronic paralysis virus, and sacbrood virus (Chen and Siede 2007). Very recently, tobacco ringspot virus has also been posited by one group of researchers as a significant causal factor in honey bee weakening and winter colony collapse (Li et al. 2014). *Nosema*, a type of microscopic parasitic fungus, has also been identified as a potential agent contributing to honey bee losses, though its role remains unclear (Chen et al. 2008). These pathogens and parasites represent a small portion of the many viruses, fungi, bacteria, and arthropods that endanger the health of managed honey bee colonies. As Figure 1 illustrates, many of the pathogens and parasites that affect honey bees also interact synergetically with other factors which have deleterious effects on colony health and survivorship.

Environmental Stressors

Like all organisms, honey bees are affected by aspects of the environment in which they live. Changes in this environment such as extreme weather events and shifts in the global climate regime, may directly influence honey bee behavior and physiology, potentially "giv[ing] rise to new competitive relationships among species and races [of honey bees], as well as among their parasites and pathogens" (LeConte and Navajas 2008). While beekeepers cannot control the climate (except by transporting their bees south out of Michigan in the winter, which some commercial beekeepers do), it needs to be taken into consideration, especially the potential for harsh weather to exacerbate other challenges to colony health.

The area of habitat that can provide "bee-friendly" forage, both for managed honey bees and wild pollinators, has also greatly decreased from historical levels. Bee-friendly habitat includes areas of vegetation with diverse flowering species, including melliferous trees and native vegetation that provide ample shelter, nectar, and pollen-producing sources on a constant blooming cycle throughout the months bees are active. Unlike many wild pollinators, managed honey bees can do well in disturbed and fragmented habitats, but they still require sufficient food sources in these areas (Potts et al. 2010). In addition, pesticide drift into areas where bees forage may be a concern, though little is known about the extent of this problem (Pettis et al. 2013). The effects of pesticides are discussed below in the context of agriculture, but it should also be mentioned that use of neonicotinoids on gardens and lawns also negatively affect honey bees and other pollinators (Hopwood et al. 2012; Larson et al. 2013).

Conventional Industrial Agriculture: Monocrop Farming

Conventional large-scale agriculture in the United States today typically includes a suite of practices such as planting large areas with a single crop species, or monocropping; application of chemical fertilizers, pesticides, and herbicides (depending on the type of crop and variety); and the use of commercial pollination services for crops that rely on honey bee pollination. Monocropping to some extent necessitates the use of agrochemicals and industrial-scale beekeeping to provide pollination services. But on their own, large monocultures also pose a problem for the health and stability of honey bee populations as well as other pollinators. Monocultures have replaced large areas of native vegetation in some regions of the United States, including much of Michigan. Some researchers have suggested that poor bee nutrition resulting from foraging primarily on large monocultures is an important factor in honey bee losses (Johnson et al. 2010). Bee-pollinated monocultures provide an abundance of plants producing nectar and pollen for food, but only of one type and only for a brief period of time (Decourtye et al. 2010). Having access to a diversity of pollen sources at any given time may be an important missing link to maintain honey bee colony health.

Conventional Industrial Agriculture: Pesticides

An increasing number of studies have found that particular pesticides play a central role in the current high rates of honey bee mortality. Honey bees are exposed to pesticides and other chemicals commonly used in agriculture via numerous pathways including direct exposure, exposure through the pollen and nectar of plants treated with systemic pesticides, and exposure through the food that beekeepers feed to bees (pesticide residues in high fructose corn syrup).

Neonicotinoids are a type of systemic insecticide that act as a neurotoxin to honey bees and other insects. The neonicotinoid class of insecticides is the most widely used pesticide in the United States and internationally, and is increasingly being implicated in the decline of honey bee populations, despite a paucity of large-scale field studies (Blacquiere et al 2012). The neonicotinoid class of insecticides includes acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam, and others, manufactured under many different trade names in the United States, mainly by Bayer CropScience and Syngenta. A growing number of studies are finding that "at field realistic doses, neonicotinoids cause a wide range of adverse sublethal effects in honey bee and bumble bee colonies, affecting colony performance through impairment of foraging success, brood and larval development, memory and learning, damage to the central nervous system, susceptibility to diseases, [and] hive hygiene" (Van der Sluijs et al. 2013). Researchers recently concluded that initially sub-lethal exposure of honey bees to thiamethoxam later causes high mortality owing to homing failure (Henry et al. 2012). Another study found "convincing evidence that exposure to sub-lethal levels of imidacloprid in HFCS causes honey bees to exhibit symptoms consistent to CCD 23 weeks post imidacloprid dosing" (Lu et al. 2012).

Citing evidence from a growing number of studies, the European Union tightly restricted the use of three types of neonicotinoids (clothianidin, imidacloprid, and thiamethoxam) in 2013, although Bayer CropScience and Syngenta have sued to overturn the ban (U.S. EPA 2013). The U.S. Environmental Protection Agency (EPA) does not currently ban or severely restrict the use of neonicotinoid pesticides, although, "based on currently available data, the EPA's scientific conclusions are similar to those expressed in the [European Food Safety Authority's] report with regard to the potential for acute effects and uncertainty about chronic risk" (U.S. EPA 2013).

A new type of systemic insecticide about which many beekeepers and public stakeholders have expressed concern are sulfoximines. Sulfoxaflor is so far the only pesticide synthesized in this class and it is produced exclusively by Dow AgroSciences. Sulfoxaflor is acutely toxic to honey bees, but it has a very short half-life in the environment, which purportedly reduces the risk to bees

(Brinkmeyer, Juberg and Kramer 2013). Because it has only recently gained EPA approval (Federal Register 2013), few independent studies have been published about its effects on pollinators. The National Honey Bee Advisory Board, national beekeeping organizations, and individual beekeepers filed an appeal to the EPA in 2013 to rescind the approval of sulfoxaflor on the grounds that it has not yet been proven safe (Earthjustice 2013). More extensive and field-realistic testing is needed on the effects of sulfoxaflor and other systemic insecticides on honey bees, including impacts on colony overwintering success.

Conventional Industrial Agriculture: Industrial Beekeeping

There are several stressors resulting from current conventional beekeeping practices that likely contribute to the weakening of honey bee colonies and colony losses. Industrial-scale beekeeping practices are likely the biggest contributor, but conventional small-scale beekeeping practices can also be detrimental. Long-distance transportation of bees to provide pollination services likely causes stress to transported colonies, though there is little information to date about the effects of transportation per se on honey bees. More importantly, transportation of honey bee colonies for pollination and long-distance shipment of bees to form new colonies provide an opportunity for the spread of parasites and pathogens such as *Nosema* (Klee et al. 2007).

Prolonged exposure to moisture in the hive poses a threat to honey bees. Many small-scale beekeepers are debating whether the current industry standard Langstroth hive design, which has been used since the nineteenth century, provides adequate ventilation of moisture in winter conditions. Other research suggests that current honeycomb foundation patterns are set to a diameter conducive to *Varroa* mite infestation, and that the reduction of cell size (small-cell combs) may be a viable option for combating mites (Piccirillo and De Jong 2003). Therefore, while current commercial hive designs may be conducive to large-scale pollination services, the design may be a factor endangering honey bee populations. As a result, some small-scale beekeepers are looking to alternative hive designs, such as the top bar hive, that allow bees to dictate their own cell diameter as a means to combating *Varroa* mite infestations (Piccirillo and De Jong 2003).

Commercial beekeepers also typically rely on high fructose corn syrup (HFCS) to feed their bees in the absence of adequate nectar sources and during transportation. Current research suggests that the use of HFCS may be dangerous to honey bee digestion because it may form a toxic compound under typical temperature conditions (LeBlanc et al. 2009). Additionally, conventional beekeeping practices often utilize miticides and antibiotics to treat infections and infestations in honey bee hives. At least one research group has found that while the application of miticides is generally effective at controlling *Varroa* mite infestations, the miticide itself appears to increase honey bees' susceptibility to viruses (Locke et al. 2011). Furthermore, small-scale beekeepers are beginning to question whether miticides are beginning to produce miticide-resistant *Varroa* (SEMBA 2014).

Some research has shown that a lack of genetic diversity among honey bee populations significantly lowers the probability of colony survivorship (Potts et al. 2010; Tarpy et al. 2013). Many beekeepers have expressed concern over the lack of genetic diversity among managed honey bee populations in the United States, and are concerned with the possible risks associated with a small honey bee gene pool. The United States Department of Agriculture has begun to take the positive step of importing Russian honey bees (*Apis mellifera cerana*) which are more resistant to *Varroa* mites.

However, further research is needed to assess the potential for increasing the diversity of the national honey bee gene pool by importing heritage breeds of Eastern and Western European bees including subspecies *Apis mellifera mellifera*, *Apis mellifera carnica*, and *Apis mellifera ligustica*.

Synergetic Effects

Further complicating the picture, some of the multiple factors that are likely contributing to honey bee losses also interact synergetically with one another: the combined effect is greater than the sum of the deleterious impacts of individual factors (also known as additive interaction). For example, researchers have demonstrated that exposure to field-realistic sub-lethal doses of neonicotinoid pesticides may weaken bees' immune systems, making them more vulnerable to pathogens and parasites such as *Nosema* and bee viruses (Di Prisco et al. 2013; Doublet et al. in press). Other researchers have found that the combinations of different insecticides and fungicides to which honey bees are exposed during foraging in agricultural fields and surrounding areas can have sub-lethal negative effects on the bees, including increased probability of *Nosema* infection (Pettis et al. 2013). The susceptibility of honey bees to pathogens and parasites is also likely influenced by climate. For example, particularly harsh winters seem to produce greater colony losses. However, much more research is needed to better understand the interactions between different factors that are likely contributing to the widespread decline in managed honey bee populations.

Local Steps to Mitigate Honey Bee Population Decline in Michigan

Considering the complex web of causality contributing to steep losses of honey bees in Michigan and across the United States, it is probable that multiple actors are contributing to the problem either directly or indirectly. In addition, it is clear that honey bee population declines are having negative effects on both large- and small-scale farmers, commercial and hobby beekeepers, the food processing industry, consumers of Michigan produce, and many others. To address the interconnected factors contributing to honey bee population decline, a multifaceted and coordinated response from a variety of stakeholders is required. We need to address honey bee population declines both on the ground—in farm fields and bee yards across Michigan—and at the level of local, state, and national institutions.

There are many strategies that farmers, beekeepers, and the general public can implement to reduce the number and intensity of stressors on honey bees, leading to healthier and more resilient colonies and a reduction in the incidence of hive mortality. These strategies promote the development of agricultural and ornamental (lawn and garden) environments that are more conducive to honey bees and native pollinators. A "bee-friendly" environment may have the following characteristics:

- Contains significant areas of habitat with diverse food sources throughout the months that bees are active, including melliferous species of trees and native vegetation (those with flowers that contain nectar and pollen accessible to honey bees).
- Provides an adequate supply of clean water.
- Reduces or eliminates the use of pesticides and other agrochemicals, with an emphasis on eliminating systemic pesticide exposure.

Strategies for farmers to promote bee-friendly environments include the following:

- Planting or allowing growth of native vegetation, including cropland margins, that provides a diverse range of food sources for honey bees.
- Reducing monocropping in favor of a more diversified planting scheme (intercropping), which could include the use of melliferous cover crops.
- Reducing or eliminating the application of pesticides, particularly systemic insecticides, and avoiding pesticide drift onto field margins and other native vegetation.
- Communicating with beekeepers within a six-mile radius of pesticide application sites to ensure that honey bees are kept away from fields during and after application (the duration of time depends on the type of insecticide), and treating crops long before blooming occurs to reduce the number of pollinators in the vicinity and provide time for the chemicals to break down.
- Incorporating beekeeping as an integral part of agricultural practices.

Some of these changes, such as improving communication between farmers and neighboring beekeepers, can be implemented relatively easily and are already occurring in some cases. Other changes, such as increasing the area of bee-friendly habitat and reducing the use of insecticides, require a fundamental shift in how conventional agricultural commodities are produced. But one doesn't need to look very far to find examples of Michigan farmers that are implementing viable solutions to protect local honey bee populations. One such farmer is Jim Koan, owner of Almar Orchards, an organic apple farm and cider brewery. Almar Orchards features a variety of melliferous crops maintained by agroecological methods that promote integrated pest management and a bee-friendly landscape. Almar Orchards demonstrates that a bee-friendly farm can adequately satisfy the triple bottom line of social, environmental, and economic sustainability, while producing high-value agricultural products.

In addition to farming practices, some small-scale beekeepers are passionately pursuing sustainable practices with the goal of stabilizing honey bee populations in Michigan. One such beekeeper is Dr. Therese McCarthy, a veterinarian in southeast Michigan who began beekeeping four years ago. Dr. McCarthy has committed herself and her resources to fighting honeybee population declines. She is also a treatment-free beekeeper, rejecting the use of miticides, antibiotics, and sugar/HFCS feeding, and is a model for small-scale beekeepers committed to good practices. She keeps extensive journals for each colony to monitor conditions of the hive in relation to conditions in the environment. She regularly checks her bees and monitors for potential parasites and pathogens. In addition, she communicates with the farmer next door and locks her bees in the hive when she knows the fields around her are going to be sprayed with pesticides.

However, the emergence of better beekeeping practices such as Dr. McCarthy's has so far been slow and isolated. This is largely due to a lack of organization and communication among first-tier stakeholders. In response to this deficit, Dr. Meghan Millbrath, a beekeeper and researcher at Michigan State University, founded the Northern Bee Network (NBN) in 2014. The NBN is "an organization designed to support beekeepers in the Northern States by promoting collaboration between beekeepers and by providing resources for more sustainable beekeeping" (Northern Bee Network 2014). Its objectives include "improving the stock of locally adapted northern bees, providing an interface to connect Northern beekeepers, providing resources for sustainable apiary expansion, [and] increasing access to local bees" (Northern Bee Network 2014). The project, which exists largely as a website, hosts a directory of beekeepers who sell honey bee drones and queens, and are willing to mentor new beekeepers. The NBN also seeks to facilitate a queen/drone exchange to promote genetic diversity and to facilitate bulk purchases of queens to strengthen desired genetic traits. The Network also provides a forum for clubs to list their information and events, thus allowing beekeepers in Michigan to communicate with each other and to build community. However, the NBN is largely a labor of love and is dependent on both Dr. Millbrath's volunteered time and resources.

The efforts of individuals such as Jim Koan, Dr. Therese McCarthy, and Dr. Meghan Millbrath have yet to be supported at the state level. However, encouraging and providing resources to expand the implementation of sustainable bee-friendly practices on the ground and supporting incipient organizations like the Northern Bee Network are very proactive and feasible steps the state government could take to protect Michigan's agriculture and food systems.

Institutional Approaches to Mitigate Honey Bee Population Decline in Michigan

To reduce the threat of continued honey bee population decline, we must pursue synergetic solutions at multiple levels of decision making. Stepping back from local mitigation strategies to a state- and national-level perspective, we have identified three avenues to protect Michigan's food production from continued honey bee population decline: facilitated multi-stakeholder discussion, legislation, and litigation.

These three paths are not mutually exclusive and should not be pursued in isolation. Rather, these actions are interrelated and, if pursued without open communication among stakeholders, they could prove counterproductive to effectively mitigating honey bee population decline. For example, in the absence of attempted open dialogue, the path of litigation could result in inhibited information sharing and communication. Communication is critical to resolving the interwoven set of challenges associated with honey bee population decline. Similarly, legislation in the absence of open dialogue and stakeholder engagement can produce policy that fails to comprehensively address the challenges of honey bee population decline. Finally, open dialogue can arguably only go so far; in the absence of policy changes—whether governmental or organizational—discussion can have limited impact.

Facilitated Multi-Stakeholder Discussion

Taking into consideration these interconnections and the dearth of inter-sectoral collaboration on this issue, our recommendation is to create an inclusive, facilitated set of discussions among key stakeholders. Stakeholders should represent expertise in diverse areas related to pollinators, honey bee population decline, and the food system. This stakeholder engagement process could start in Michigan, but could also serve as a model for similar processes regionally and nationally.

There are many models for stakeholder engagement. However, given the diversity of key actors impacted by honey bee population declines in Michigan, it is critical to design a stakeholder engagement process that builds trust, transparency, and communication, and facilitates collaborative and effective solutions. Valuable lessons can be drawn from three examples of multi-stakeholder engagement processes: Sustainable Harvest, a U.S.-based coffee importer founded in 1997; the Pebble Mine in Bristol Bay, Alaska; and the Dow Chemical Company's partnership with People for the Ethical Treatment of Animals (PETA).

Sustainable Harvest is a certified B Corporation, purchasing coffee from 84 producer organizations in Latin America and Africa. Their work supports nearly 200,000 farmers. This company, which has experienced rapid growth over the past decade, has been remarkably successful in tackling sustainability challenges through hosting annual "Let's Talk Coffee" gatherings, a series of events aimed at facilitating international, inter-sectoral, intra-supply chain collaboration (Sustainable Harvest 2013). "Let's Talk Coffee" involves key actors in the coffee supply chain, as well as experts in related subjects, in a multi-day conference aimed at relationship building and "cultivating a community of trust" (Sustainable Harvest 2013). The conference includes workshops, lectures, communal meals, and time for informal interactions and collaboration. Attendees include both small and large coffee producers and roasters, corporate executives from large-scale coffee buyers/sellers (e.g. Walmart), politicians, agronomists, climate scientists, and many others (Sinclair 2012). All of the participants' work and lives are intertwined with the coffee business in the fields, markets, and laboratories. Sustainable Harvest provides an innovative, scalable model that could inspire multi-stakeholder discussion to mitigate honey bee population decline in Michigan.

Additional lessons can be drawn from stakeholder engagement experiences with the Pebble Mine in Bristol Bay, Alaska and the Dow Chemical Company's partnership with PETA. While both of these cases have lengthy histories and warrant further study, there are two highly applicable lessons to the challenge of mitigating honey bee population declines in Michigan. First, productive, lasting partnerships, common ground, and collaboration can be cultivated between entities with seemingly divergent objectives. The Dow Chemical Company and PETA have starkly different missions; one is a leading chemical and plastics company, the other an international non-governmental organization dedicated to animal rights. However, the two have found some common ground and formed a strong partnership through a lengthy process that included shareholder petitions followed by open dialogue (Gregory Bond 2013).

Second, a neutral third party should convene the discussion series as well as choose the facilitator to mediate the process. Pebble Limited Partnership (PLP)—a large company that proposed a copper mine near Bristol Bay, Alaska—hired a policy resolution group to review the copper mine proposal and convene a stakeholder dialogue about mining in the area. However, key stakeholders in the process saw PLP's efforts as not being made in good faith and not helping to build trust (Reynolds 2012). This example shows that effective stakeholder dialogue around contentious problems is best when convened by a third party and when that third party selects the facilitators, as opposed to a party with vested interests facilitating the dialogue.

Weaving these lessons from Sustainable Harvest, Pebble Mine, and the Dow/PETA partnership together, an effective multi-stakeholder discussion series could be designed to find solutions to mitigate honey bee population decline in Michigan. A consortium of universities around Michigan, such as the University of Michigan, Michigan State, Michigan Tech, Central Michigan, and Wayne State, could serve as a convening body and provide or help select facilitators. The organizers of these discussions could pursue Federal and state government funding opportunities and reach out to Michigan-based foundations that may be invested in the issue. The multi-stakeholder discussion could include participants from the government, the private sector, NGOs, and research universities, representing a diverse array of fields including, but not limited to: agriculture (industrial, small-scale, organic); apiculture (commercial and non-commercial, treatment-free and conventional); entomology; toxicology; agricultural chemical production and sales; ecology and biology (including entomological neuroscience and neurology); law; and local, state, and federal policy (including legislators, EPA, and the Michigan Department of Environmental Quality).

The objective of the discussion series would be to share cutting-edge research findings and best practices in a manner that enables and expedites constructive, scalable approaches to mitigating honey bee population decline and ensuring the viability and health of honey bee populations in perpetuity. This type of multi-stakeholder discussion series could take many forms, but looking to lessons learned from similar processes yields recommendations that the discussions should be

- convened by a neutral third party;
- facilitated by a neutral third party agreed upon by both public and private sector participants with objectives and timeline agreed upon by all parties;
- conducted using Chatham House rules (or similar to ensure candid participation from stakeholders);
- located in an environment and setting that facilitates both formal and informal interactions, community, and group cohesion (e.g., around communal meals, collaborative projects/activities).

Legislation and Litigation

Facilitated multi-stakeholder dialogue has the potential to catalyze trust and collaboration across sectors to develop strategies to mitigate honey bee population decline. However, in concert with discussions, the need for legislation or litigation may arise. Legislation and litigation have the potential to be collaborative, but if done in the absence of efforts to engage in constructive dialogue may be seen as divisive and antagonistic. Given the scale of the challenge of pollinator decline both in Michigan and the United States, there is a dire need for policy change via state and federal legislation on the issue, as well as shifts in the internal policies of major stakeholders that impact pollinators, such as commercial beekeepers, large-scale farmers, and agrochemical companies.

Legislation is currently pending in the U.S. House of Representatives that aims to, at least in part, address some potential causes of honey bee population decline. The legislation, titled "Save America's Pollinators Act of 2013" (H.R. 2692), is sponsored by Michigan Representative John Conyers, Jr. It directs the EPA Administrator to suspend the registration of neonicotinoids until it is scientifically proven that such pesticides do not "cause unreasonable adverse effects on pollinators, including honey bees." H.R. 2692 also calls on the EPA Administrator to conduct a series of additional studies regarding the impacts of neonicotinoids on pollinators. As of April 2014, the bill has bipartisan support and 57 co-sponsors. It was referred to the House Subcommittee on Horticulture, Research, Biotechnology, and Foreign Agriculture in July 2013 (Library of Congress 2013).

The introduction of H.R. 2692 demonstrates that the issue of honey bee population decline is of national importance. As the legislation goes through the process of committee mark-up, it would greatly benefit from additional stakeholder input. To be more comprehensively effective, the scope of the legislation should be broadened from only addressing the "nitro group of neonicotinoid insecticides" to incorporate "all systemic insecticides, including the nitro group of neonicotinoid insecticides and sulfoximines."

Successful enactment of much tighter protections of honey bees and other pollinators at the national level would probably be more effective at mitigating honey bee population decline than state-level legislation, in part because of the long interstate distances over which honey bees are transported. However, given that federal-level action seems unlikely in the short term, Michigan's policy makers should take immediate action to protect the state's food production and agricultural economy by promulgating legislation similar to the "Save America's Pollinators Act of 2013." Like national policy, state legislation should be developed as a collaboration among beekeepers, farmers, scientists, economists, agrochemical companies, environmental advocacy groups, and legislators. Such collaboration would not only strengthen the efficacy of pollinator legislation, but also prevent the promulgation of policies that threaten pollinator health.

Conclusion

The causes of honey bee population decline are multiple and interconnected. A growing body of research shows that the principal factors involved are parasites and pathogens such as *Varroa* mites and bee viruses; environmental stressors like loss of foraging habitat; and monocrop farming, widespread use of pesticides, and industrial beekeeping practices within the paradigm of conventional industrial agriculture. Synergetic interactions between some stressors reinforce the web of causality leading to honey bee population declines. For example, sublethal exposure to neonicotinoid insecticides has been shown to increase honey bees' susceptibility to bee viruses. These various interacting stressors increase the vulnerability of managed honey bee colonies in the United States and many other countries, and jeopardize the yields of pollinator-dependent crops.

Michigan is a state that both relies heavily on pollination services to maintain its agricultural production and has been hard hit by honey bee population declines over the past few years. Many of Michigan's agricultural products—such as soybeans, dry beans, apples, blueberries, cherries, cucumbers, and other produce—depend on honey bee pollination to produce a good crop. It is particularly concerning that honey bee losses of more than 30% annually have been reported by Michigan beekeepers over the past few years, with the 2013/2014 winter poised to be even worse. Honey bee population declines in Michigan will likely not improve, and could continue to worsen, unless the problem is addressed by policy makers and other stakeholders in a substantive way.

Because the problem involves many different causal factors and actors spanning agricultural production and consumption, potential solutions are also complex. No silver bullets are evident. There are various local-level mitigation measures that beekeepers, farmers, and the general public can implement, such as improving communication with beekeepers about pesticide application, reducing or eliminating the use of neonicotinoid insecticides, and improving the area of habitat for bee-friendly forage. Initiatives to connect and support Michigan beekeepers using sustainable practices such as the Northern Bee Network are also promising. But as important as they are, these local steps are likely not enough to stem honey bee population declines because the problem transcends the local level. Higher-level institutional approaches are also needed. A combination of facilitated dialogue among key Michigan stakeholders, legislation, and litigation originating at the state or national level could provide the additional impetus needed to rein in and reverse honey bee colony losses in the state. In addition to further identifying the causes and impacts of honey bee population decline, facilitated multi-stakeholder dialogue and collaboration could prove critical to exploring and implementing solutions to this wicked problem.

The reality is that honey bee population decline affects almost everyone in Michigan; we all buy food that was pollinated by honey bees. Michigan's current level of food production and its agricultural economy are clearly in jeopardy unless honey bee populations are stabilized. This problem should be a priority for policy makers in Lansing and Washington, D.C. alike.

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