Bee-Ware: Investigating Bee Colony Decline and its Ecological Effects on Human Health

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The European honey bee, *Apis mellifera*, is well-known for its role in honey production, its ecological importance in plant reproduction and biodiversity, and more importantly, the pollination of many economically significant crops in the United States (Staveley, Law, Fairbrother, & Menzie, 2014; vanEngelsdorp & Meixner, 2010). The food we eat from the most nutritious crops in our diets – key fruits and vegetables – as well as some crops used as fodder in meat and dairy production significantly depend on the key ecosystem service that honey bees provide: natural insect-mediated pollination (Tirado, Simon, & Johnston, 2013). As the predominant and most economically important group of pollinators in most geographical regions, both managed and wild honey bees pollinate most wild plants so that they may reproduce, thereby directly or indirectly supporting wild habitats that provide other ecosystem services (Tirado et al., 2013). One can then see the possible ramifications of the ongoing bee colony decline in recent years; however, the economic and ecological consequences tend to be viewed separately in their own scope, and it is not entirely clear how the two areas intersect.

Thus, the purpose of this paper is to investigate the causative agents contributing to the decline of honey bee populations and similar pollinators in the U.S. and its ecological effects on human health. The paper does not cover the following topics regarding bees: the quality of bee-byproducts (i.e. honey, wax, etc.) and their effects on health; the use of experimental interventions or health models on bees for subsequent use on human health; and bee populations of other countries. A literature review is conducted to provide a better understanding and perspective on the current issue and its known or possible causes. This, in turn, produces a synthesis of findings on the economic and ecological consequences of bee colony decline and generates a set of recommendations that have been put forth by researchers, advocacy groups, and governmental organizations. The main sections of the paper are as follows: decline in bee colony populations, a multifaceted cause, human need for pollination services, outstanding questions and consensus, ecological implications, recommendations, and conclusion.

Decline in Bee Colony Populations

Since 2006, the decline of honey bees and other bee species have gained increased attention as commercial beekeepers started reporting sharp declines in their colonies (Fairbrother, Purdy, Anderson, & Fell, 2014; Johnson & Corn, 2014). In the U.S., the number of honey-producing colonies have particularly dropped 61% from the high of 5.9 million managed in 1947 to the low of 2.3 million reported in 2008 (vanEngelsdorp & Meixner, 2010). In a publication by the National Academy of Sciences, the number of colonies kept - partly a measure of the need for honey and pollinator services – over the previous 50 years or so has halved (Packer, 2014). Moreover, U.S. beekeepers have been reporting losses (overwintering mortality) of about 30% or more, but these losses have not resulted in a significant decline in the overall number of managed honey-producing colonies, because they have been replacing colonies to cover these losses (Johnson & Corn, 2014; Staveley et al., 2014; vanEngelsdorp et al., 2012). As a result of high death rates over the winter season but more so due to Varroa mites, the number of colonies in the wild – feral honey bees – have also declined dramatically, potentially being at higher risk compared to their managed bee colony counterparts (Packer, 2014).

A Multifaceted Cause

Bee colony decline is not attributed to a single cause nor is it under the influence of just any cause (Packer, 2014). It has been noted that multiple causes work additively, synergistically, or independently to affect the health of individual bees and/or the entire colony. Some causes are more documented and researched compared to others that are just emerging or otherwise unknown. The following are currently known, possible, or probable causes: parasites, pathogens, and diseases (Evans & Spivak, 2010; Flenniken, 2014; Highfield et al., 2009; Wu, Smart, Anelli, & Sheppard, 2012); environmental stressors and pesticides (Ciarlo, Mullin, Frazier, & Schmehl, 2012; Gill & Raine, 2014; Reimer & Prokopy, 2012; Tingle, Rother, Dewhurst, Lauer, & King, 2003; Wu et al., 2012); diet and nutrition; bee management practices; and genetic weakness (Clark, 2014; "Global honey bee colony," 2010). Among them, the cumulative and interactive effects of each must also be considered and investigated (Johnson & Corn, 2014). The severity and unusual circumstances of these declines led scientists to coin the phenomenon known as *Colony Collapse Disorder* (CCD) (Johnson & Corn, 2014).

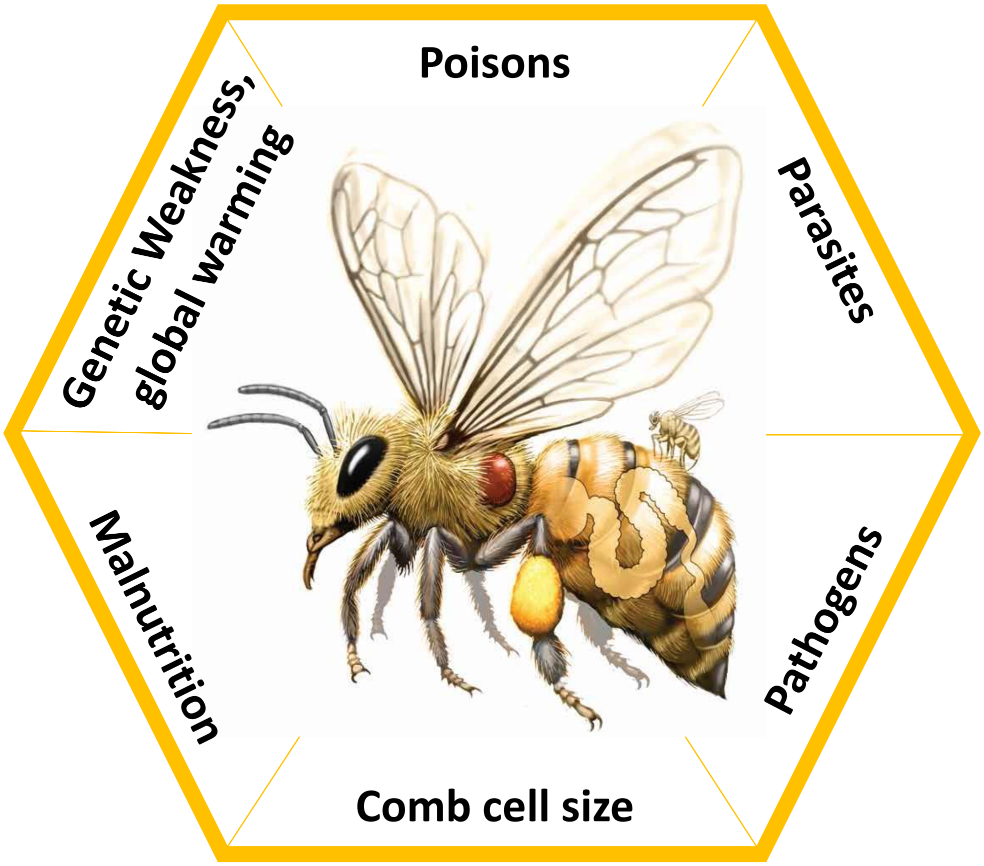
Colony Collapse Disorder

CCD is defined as a multi-factor syndrome of the relatively sudden disappearance or early death of the majority of adult worker bees from an otherwise healthy hive with a queen and brood (larvae) (Evans & Schwarz, 2011; "Global honey bee colony," 2010). Essentially, adult bees abandon the hive unexpectedly, usually completely disappear, and most likely die off in massive numbers away from the hive, despite the hive containing substantial food stored that supposedly would sustain the bees if they were ill (Stankus, 2008). Clark (2014) adds that, “Colony collapse appears to be linked to a variety of factors that work in concert to weaken bees.” The following may be symptoms indicative of CCD: loss of older worker bees, bees avoid supplemental foods by beekeeper, abandoned hive contains excess of cells holding developing young bees, honeycomb pests delay their entry into the hive, and abandoned hive lacks dead bees (Clark, 2014). Full-blown CCD is likely to be attributed to preceding causes or stressors (e.g. environmental conditions or diseases) that seems to predispose the hives for massive failure when occurring in some as-yet-undetermined combination (Stankus, 2008). In opposition, one argument against the CCD phenomenon in the U.S. is that the half-century decline in their numbers may reflect decisions by honey producers to leave the industry due to competition from cheaper imported honey, given that the U.S. increasingly relied on imported honey beginning in the late 1960s (Aizen & Harder, 2009). Up to now, honey bee colonies have also continued to dwindle annually for reasons no solely related to CCD (Johnson & Corn, 2014). These causes may operate in synergy or impact colonies independently, but it is important to recognize their individual effects as well as in combination with other causal factors and their interactions.

Proposed bee stressors in CCD.

Historically, common medical, parasitical, and predatory problems in hive management possibly serve as contributing stressors to CCD. Exaggerated overwinter loss can be owed to poor ability of the bees to thermoregulate the hive if the outside temperature drops low enough for a long duration to impact the health of the adults and the young (broodstock) being attended to. With predation and parasitization predisposing bees to follow-on diseases, larger animals can also cause sudden, greater damage to hives, but there is lack of major reports of increased mammalian predation and the contrasting experience of CCD in more portable (mobilized) pollinator hives (Stankus, 2008). To illustrate proposed bee stressors contributing to CCD, refer to *Figure 1* below, which includes but is not limited to the following: poisons, parasites, pathogens, comb cell size (larger is worse), malnutrition, and genetic weakness/global warming.

Figure 1. Honey bee stressors of colony collapse syndrome (adapted from Clark, 2014)



Among the role of various insects affecting honey bee populations, mites – two of the most cited including the internal-organ-infesting tracheal mite and the exterior-shell-and integument-piercing mite Varroa destructor – are by far the organisms above the microbiological size most suspected of involvement in CCD. For protozoans, the most commonly noted are *Nosema apis* and more recently *Nosema ceranae*, which infects the bees' digestive tract and spreads by spores and thereby shortens adult bee life, reduces the production of food, and ultimately causes heavy winter mortality. Two bacterial diseases compete with each other: the most common in the U.S. called American foulbrood caused by *Paenibacillus larvae* and the other being European foulbrood caused by *Melissococcus pluton*, which is also present in the U.S. In terms of viruses, at least 15 strains seriously damage broodstock or adult bees with most of them being members of the *Picorna* family; these viruses commonly attack honey bees in conjunction with other nonviral pathogens. Global warming potentially makes it so that bees are missing more and more of the nectar each year since nectar flows are occurring earlier each year with the warmer weather. Urbanization and changing land use patterns have also been postulated to reduce the total number of plants of all kinds to pollinate at any time alongside mono-crop agriculture, which reduces the diversity of plants that bees can pollinate at a particular time. More controversial for CCD is the use or abuse of pesticides by beekeepers and farmers and their negative health effects, particularly cognitive in nature, because symptoms of CCD are relatively uniform whereas the mix of these chemical agents changes in different areas, (Stankus, 2008).

Effects on Bee Health

Parasites, such as the very damaging Varroa mite, suppress the bees' immune systems and transmits viruses (Clark, 2014). Bees that are weakened by Varroa mites or pesticides may then become more susceptible to other pathogens, such as *Nosema*, a single-celled fungus. While infected worker bees abandon the colony, other evidence suggests that the invertebrate iridescent virus further increases the risk of the colony collapse. Pesticide chemicals, such as neonicotinoids, appear to impact the immune system, thereby making them more susceptible to new diseases transmitted by other bees brought all over the place for pollination; it also makes them less capable of finding their way home, causing disorientation and a loss of ability to learn and communicate. Nutrition and feeding from only a single crop without a broad range of flowers when transported far distances to pollinate increase the bees' vulnerability to contracting diseases, especially if supplement diets like high fructose corn syrup are contaminated with chemicals that cause ulcers, dysentery, and early death. Management practices such as employing unusually large, artificial honeycomb templates tend to harbor bees with compromised immune systems, and their young bees may even take a longer time to develop. Genetic weakness arises from the fact that most queen honey bees in the U.S. are derived from a limited pool of breeder queens, leading to poorer genetic diversity and becoming more susceptible to new pests and pathogens. Climate disruption can distort nectar and pollen production, thereby reducing honey output and adding more stress on hives (Clark, 2014).

Human Need for Pollination Services

The degree to which we depend on honey bees to pollinate plants for food production has only taken notice in light of the recent excess decline in the domestic honey bee population (Packer, 2014). Some of the fruit, nut, and vegetable crops pollinated by bees include the following: almonds, apples, apricots, avocados, blueberries, cantaloupes, cashews, coffee, cranberries, cucumbers, eggplants, grapes, kiwis, mangoes, okra, peaches, pears, peppers, strawberries, tangerines, walnuts, and watermelons (Clark, 2014). Consequently, Stankus (2008) warns that, “Without these trucked-in, interstate, time-critical pollinators, declines in the setting of fruits, seeds, and nuts can reach up to 80% with dependence solely on self-pollination, wind-driven pollination, or on local wild pollinators.” Honey bees may be viewed as the most economically important pollinators, but other managed bee species are important as well, including numerous species of bumblebees, mining bees, mason bees, sweat bees, leafcutting bees, and carpenter bees (Hooven, Sagili, & Johansen, 2013). Even in global food production, both commercially managed bees and wild bees play an important role (Johnson & Corn, 2014). Thus, the trend of dying bee colonies can potentially lead to human health issues and serious effects on world food security, since 35% of the human diet is thought to benefit from pollination (e.g. meeting micronutrient needs) (Stindl & Stindl Jr, 2010; vanEngelsdorp & Meixner, 2010).

Economic and Ecological Consequences

On the surface, the value to U.S. agricultural production via insect pollination – three-fourths being attributable to both commercially managed honey bees and wild bees – is estimated at $16 billion annually in 2010 (Johnson & Corn, 2014). With bees pollinating about 130 fruit, vegetable, nut, ornamental, and fiber crops in the U.S., their efforts contribute about $15 million annually through improved crop yield and product quality, manifesting in larger or more appealing produce (Flores, 2007; Hooven et al., 2013). For example, one study showed that bee-pollinated fruits were heavier, less malformed, reached higher commercial grades, and even longer shelf life (Klatt et al., 2014). Both managed bees and wild bees need to be considered to address losses in agricultural production. The economic value of pollination services is nevertheless difficult to quantify, as most estimates are derived from crop pollination by managed honey bees with data on native bees tending to be limited (Johnson & Corn, 2014).

Certainly, the economic implications of bee colony decline are inherent in the agriculture industry, but such are confined within our natural ecosystems. In addition to projected and anticipated deficits in food production, a more significant consequence may be one that cannot be as easily predicted and calculated in the long-term: without bees, the impact on natural ecosystems could entail fewer plants setting seed in fewer nuts and berries, and fewer nuts and berries can lead to fewer birds and bears (Packer, 2014). Yet, the decline of some bees have paralleled the dramatic increases in other bee populations, such as that of the bumblebee (Packer, 2014). On the other hand, another study found that increasing pollinator diversity can synergistically increase pollination service (Brittain, Williams, Kremen, & Klein, 2013). This is important to consider since the estimated annual value of crops pollinated by wild, native bees in the U.S. is estimated to be $3 billion or more (Hooven et al., 2013). Nonetheless, the consequences of bee colony decline is both economic and biological in nature and need to be analyzed and interpreted within their scopes of study. The former focuses on the economic ramifications of reduced agricultural production yields and quality whereas the latter focuses on the more systematic effect that bee colony decline has in our natural ecosystem, impacting humans and wildlife alike. While losses due to pests, parasites, and disease are not uncommon, the ecological and economic roles of honey bees have led to increasing concerns of bee health declining at a faster rate in both the U.S. and the world (Plischuk et al., 2009); however, the exact reasons for these losses are not yet known (Johnson & Corn, 2014).

Outstanding Questions and Consensus

Despite the field of honey bee pathology, microbiological questions remain as to whether gene-based sampling will reveal high beta diversity for bee microbes, the effects of concurrent multi-parasite infections, the long-term effects of pesticide accumulation on the microbial diversity, and the effectiveness of management strategies to limit parasite resistance to chemical control (Evans & Schwarz, 2011). There are also a lack of studies that link CCD with either cellphone-tower radiation or genetically modified crops (Clark, 2014). From what is currently known about bee pathology, majority of the causes responsible for bee colony decline are attributed to cumulative burden, with a few exceptions resulting from acute insults/changes. The question as to whether there is indeed a “pollination crisis” is left to interpretation. The U.S. is one of the regions in the world experiencing declines in pollinators or insufficient pollination for particular crops that has led to evidence for a global crisis, but such can be a result of economic globalization drivers rather than biological causes (Aizen & Harder, 2009). Another question is whether the expansion of cultivation of pollinator-dependent crops can lead to future pollination issues for both these crops and native species in surrounding areas, as honey bees are an invasive species in practically any area they are introduced (Aizen & Harder, 2009).

Among these outstanding questions on the bee colony decline, there is no consensus about the cause or combination of causes related to reduced overwinter survival of managed honey bees (Staveley et al., 2014), but there is consensus that a complex set of stressors and pathogens is associated with CCD (*Report on Honey Bee Health*, 2012). These multiple factors weaken colonies and make them more susceptible to pathogens, leading to a new hypothesis that bees may be suffering from compromised immune systems due to critically shortened telomeres in long-lived winter bees or *telomere premature aging syndrome* (Stindl & Stindl Jr, 2010). Asides from CCD, disease/pathogenic factors in general may have been significant in honey bee declines a century ago, but their role in current declines is likely minimal compared to the emerging mite parasitism (Varroa mites and their associated virus complex) (Fairbrother et al., 2014; vanEngelsdorp & Meixner, 2010). Fairbrother et al. (2014) support this, stating:

> Public awareness and scientifically sound studies funded by governments and agricultural interests, including agricultural chemical companies, have identified the interaction of multiple stressors including parasites (*Varroa* mites), pathogens (viruses, *Nosema* fungus), and nutrition (monofloral vs polyfloral pollen and nectar resources), as primary factors influencing honeybee health. (p. 730)

Ecological implications

Currently, the Earth is losing about 1-10% of its biodiversity – the degree of variation of life – per decade, primarily due to habitat loss, pest invasion, pollution, over-harvesting, and disease ("Global honey bee colony," 2010). It is this biodiversity that provides us with natural ecosystems for ecosystem services such as pollination for a various crops that are vital for human societies ("Global honey bee colony," 2010). Honey bees as well as butterflies, moths, flies, beetles, and wasps are well-known for the vital pollination service they provide to maintain not only biodiversity but also agricultural crop yields (Gill & Raine, 2014; Tirado et al., 2013). With their ecological importance in plant production and pollination for economically important crops (Staveley et al., 2014), *A. mellifera* and other pollinating insects essentially shape natural ecosystems through their facilitation of gene flow for the angiosperms (Evans & Schwarz, 2011). Hence, their health and well-being are crucial in sustaining natural habitats and, more importantly to human interests, contributing to local and global economies ("Global honey bee colony," 2010). Packer (2010) portrays the decline of pollinating species and its ecological effects in a similar broad perspective in his book titled *Keeping the Bees*: “We could reach a situation where the number of pollinating species falls below a threshold and the ecological system collapses, becoming less diverse, less aesthetically pleasing, and less ecologically (not to mention nutritionally) productive.”

From wild pollinator species, animal-based pollination services can support reproductive potential and genetic resilience in many ecosystems ("Global honey bee colony," 2010). So, how would this ecological process affect our economy? The answer lies within agricultural production, which naturally stems from ecological processes in order to produce the food we now eat today. For fruits, benefits of improved pollination can be seen in the reduction of the time between flowering and fruit set and the reduction of the risk of exposing fruit to pests, disease, bad weather, agro-chemicals, and saving on water ("Global honey bee colony," 2010). This would be similar to vegetable and nut crops as well. The intersections of biodiversity, which provides vital ecosystem services like insect-mediated pollination, and the economy in which we operate the agriculture industry for foods impact human health in one common way: the ability for us to meet our nutritional needs, namely the intake of micronutrients and fiber (Klatt et al., 2014; "Preserving the pollinators," 2014). Not only do we rely on the pollination services that honey bees provide for food consumption, but we also rely on their ability to maintain the biodiversity of habitats upon which we rely on other ecosystem services. On the societal level, a decline in pollination services can even ripple effects into our social hierarchy as agricultural shortages are more likely to make the foods we now take for granted unaffordable for most people, putting us at risk for increased social inequity between the rich and the poor (Packer, 2010). More importantly, the concern of food security could put the U.S. at risk for malnutrition, regardless of the fact that such an public health emergency is not likely within reach as of yet. It will therefore be of interest to consider recommendations put forth to address the decline of honey bees, both managed and wild, as well as other pollinators.

Recommendations

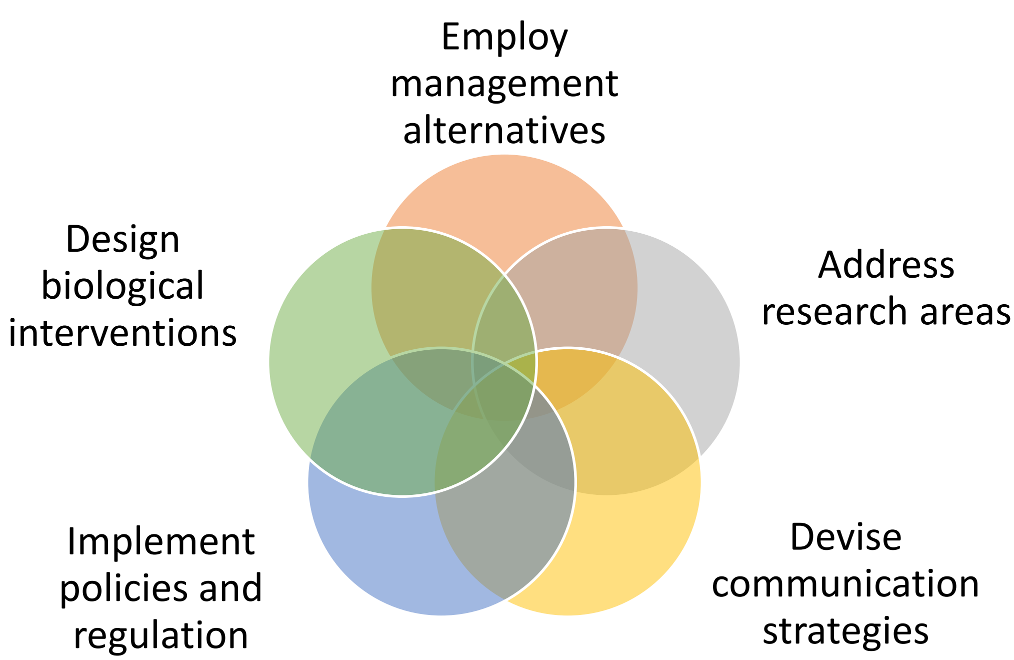
Several known practices and approaches for supporting healthy bees have already taken precedence to address the bee colony decline at the individual, local, and community level. The average person can do several things to bolster bees and their health. This includes planting a wide variety of bee-friendly flowers and avoiding the use of pesticides as well as eating foods grown without them (Clark, 2014). In terms of a good bee environment, establishing suitable garden environments should include sparsely vegetated soil and planting those for ornamentation or for food should have simpler, open flowers for easy accessibility (Packer, 2014). Despite the problematic nature of addressing bee colony decline, the following recommendations have been proposed to alleviate this complex problem and are organized by the type of approach:

- Alternatives to management practices:
    - Enable natural defenses through management and breeding decisions by the beekeeping industry (Evans & Spivak, 2010)
        - Improve nutrition for honey bees (Johnson & Corn, 2014)
        - Consider pollination habitat and fauna in ecological restoration planning, perhaps via ecological or organic farming, which maintains high biodiversity without any application of chemical pesticides or fertilizers (Rundlöf, Nilsson, & Smith, 2008; Tirado et al., 2013)
        - Rely on alternative non-toxic methods, such as natural enemies and environmentally friendly practice to control pests, insects, and weeds ("Global honey bee colony," 2010; Van der Sluijs et al., 2014)
    - Switch to some of the 20,000 species of wild bees or other pollinators, considering factors including the sufficient numbers of available insects, a maximum foraging range, and increasing pollinator diversity to synergize pollination services (Brittain et al., 2013; Clark, 2014; "Global honey bee colony," 2010; Packer, 2014; Rader et al., 2009; Shuler, Roulston, & Farris, 2005; Stankus, 2008; Winfree, Williams, Dushoff, & Kremen, 2007
- Additional research areas:
    - Conduct causal analysis to evaluate impacts of causal factors (Staveley et al., 2014)
    - Formulate an integrated model to simulate multifactorial impacts on colony (Becher, Osborne, Thorbek, Kennedy, & Grimm, 2013)
    - Conduct more pesticide research (Johnson & Corn, 2014; Van der Sluijs et al., 2014)
        - Consider the chronic effect of specific pesticides on foraging performance of bees (Gill & Raine, 2014)
- Communication strategies:
    - Collaboration and information sharing (Johnson & Corn, 2014)
        - Voluntary approaches to raise awareness of sites sensitive to pesticide drift in rural landscapes (Staveley et al., 2014)
    - Teach beekeepers to manage their bees in a manner similar to that of other livestock operators, as herd/colony health depends on an in-depth understanding of animal nutrition and disease management (Fairbrother et al., 2014)

- Policies and regulation:
    - Obama implemented the Pollinator Health Task Force that focuses on federal efforts to stem pollinator loss and USDA $8 million incentives to farmers and ranchers in five states who establish new habitats for honey bees (Clark, 2014)
    - Revise the risk assessment data requirements and process for pollinators (currently undertaken by the Environmental Protection Agency) (Hooven et al., 2013)
    - Ban the use of neonicotinoids by January 2016 through the U.S. Fish and Wildlife Service's National Wildlife Refuge System (Woody, 2014)
- Biological interventions:
    - Address risks to honey bees from parasites and disease (Johnson & Corn, 2014)
        - Antiviral (Flenniken, 2014; Hunter et al., 2010) and antibiotic (Feldlaufer, 2006) defenses
        - Give breeders a way to bring out sought-after genetic traits (Flores, 2007; Rangberg, Diep, Rudi, & Amdam, 2012; Stindl & Stindl Jr, 2010)
        - Increase genetic diversity in bee colonies (Johnson & Corn, 2014; Mattila, Rios, Walker-Sperling, Roeselers, & Newton, 2012)

Altogether, the solution to solving bee colony decline will involve a multifaceted approach that takes a combination of these recommendations into consideration, as shown in *Figure 2* below.

Figure 2. Multifaceted approach to bee colony decline



Conclusion

Honey bees, both managed and wild, as well as other pollinators serve as critical assets for the ecology and biodiversity of the Earth as well as our economy, world agriculture, and food security. Overall, the solution to solving the honey bee colony decline in the U.S. will involve incorporating a multifaceted approach that systematically addresses known/probable causes while considering the feasibility and effectiveness of interventions within it. As vanEngelsdorp and Meixner (2010) reiterate, "In all likelihood, no one factor on its own can account for all loses or gains over a given time period. Many factors can occur simultaneously and some influence one another." Further research may require more longitudinal studies and improved survey methods that employ sampling and analysis of a representative portion of colonies in order to determine causes of mortality (vanEngelsdorp et al., 2012; vanEngelsdorp & Meixner, 2010).

As honey bees are strained with stressors contributed by both man-made and natural processes, Packer (2010) cautions industrial agriculture against continuing their use of these industrial-scale pollinators and to rather look to other species, but they can only do this as long as they are available, as some are already disappearing amidst this decline. For now, it will be important to consider our human activities and their environmental impacts on bee health that may negatively impact some species but benefit others, taking note of the potentially counterintuitive causal linkages since we have become pollinator-dependent ("Global honey bee colony," 2010). Moreover, regulatory agencies should consider prevention and precautionary methods to enforce regulations on pesticides like neonicotinoids and fipronil (Van der Sluijs et al., 2014). While further research into alternatives is warranted, equally significant is the need to educate farmers and other practitioners on more bee-healthy management practices as well as to implement policies and regulations to incentivize the adoption of agricultural strategies to manage pests (Van der Sluijs et al., 2014). By taking into consideration the multiple causes of the decline and the available options we have, only then are we able to successfully curtail and hopefully stop this deadly trend of death that afflicts honey bees and other pollinators alike.

References

Aizen, M. A., & Harder, L. D. (2009). The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. *Curr Biol*, *19*(11), 915-918. doi: 10.1016/j.cub.2009.03.071

Becher, M. A., Osborne, J. L., Thorbek, P., Kennedy, P. J., & Grimm, V. (2013). Towards a systems approach for understanding honeybee decline: a stocktaking and synthesis of existing models. *J Appl Ecol, 50*(4), 868-880. doi: 10.1111/1365-2664.12112

Brittain, C., Williams, N., Kremen, C., & Klein, A.-M. (2013). Synergistic effects of non-Apis bees and honey bees for pollination services. *Proceedings of the Royal Society B: Biological Sciences*, *280*(1754). doi: 10.1098/rspb.2012.2767

Ciarlo, T. J., Mullin, C. A., Frazier, J. L., & Schmehl, D. R. (2012). Learning impairment in honey bees caused by agricultural spray adjuvants. *PLoS One, 7*(7), e40848. doi: 10.1371/journal.pone.0040848

Clark, P. (2014). We all get stung by bee colony collapse. *The Washington Post.* from http://apps.washingtonpost.com/g/page/national/we-all-get-stung-by-bee-colony-collapse/1108/

Evans, J. D., & Schwarz, R. S. (2011). Bees brought to their knees: microbes affecting honey bee health. *Trends Microbiol*, *19*(12), 614-620. doi: 10.1016/j.tim.2011.09.003

Evans, J. D., & Spivak, M. (2010). Socialized medicine: individual and communal disease barriers in honey bees. *J Invertebr Pathol*, *103 Suppl 1*, S62-72. doi: 10.1016/j.jip.2009.06.019

Fairbrother, A., Purdy, J., Anderson, T., & Fell, R. (2014). Risks of neonicotinoid insecticides to honeybees. *Environmental toxicology and chemistry., 33*(4), 719-731.

Feldlaufer, M. F. (2006). Honey Bees Get a New Antibiotic. *Agricultural Research, 54*(7), 23-23.

Flenniken, M. L. (2014). Honey bee-infecting plant virus with implications on honey bee colony health. *MBio, 5*(2), e00877-00814. doi: 10.1128/mBio.00877-14

Flores, A. (2007). Honey Bee Genetics Vital in Disease Resistance. *Agricultural Research, 55*(1), 14-14.

Gill, R. J., & Raine, N. E. (2014). Chronic impairment of bumblebee natural foraging behaviour induced by sublethal pesticide exposure. *Functional Ecology*, n/a-n/a. doi: 10.1111/1365-2435.12292

. Global honey bee colony disorders and other threats to insect pollinators. (2010) *United Nations Environment Programme* (pp. 1-16).

Highfield, A. C., El Nagar, A., Mackinder, L. C., Noel, L. M., Hall, M. J., Martin, S. J., & Schroeder, D. C. (2009). Deformed wing virus implicated in overwintering honeybee colony losses. *Appl Environ Microbiol, 75*(22), 7212-7220. doi: 10.1128/aem.02227-09

Hooven, L., Sagili, R., & Johansen, E. (2013). How to reduce bee poisoning from pesticides (pp. 1-35): Pacific Northwest Extension.

Hunter, W., Ellis, J., Vanengelsdorp, D., Hayes, J., Westervelt, D., Glick, E., . . . Paldi, N. (2010). Large-scale field application of RNAi technology reducing Israeli acute paralysis virus disease in honey bees (Apis mellifera, Hymenoptera: Apidae). *PLoS Pathog, 6*(12), e1001160. doi: 10.1371/journal.ppat.1001160

Johnson, R., & Corn, M. (2014). Bee Health: Background and issues for Congress (pp. 1-29): Congressional Research Service.

Klatt, B. K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E., & Tscharntke, T. (2014). Bee pollination improves crop quality, shelf life and commercial value. *Proceedings of the Royal Society B: Biological Sciences, 281*(1775). doi: 10.1098/rspb.2013.2440

Mattila, H. R., Rios, D., Walker-Sperling, V. E., Roeselers, G., & Newton, I. L. (2012). Characterization of the active microbiotas associated with honey bees reveals healthier and broader communities when colonies are genetically diverse. *PLoS One, 7*(3), e32962. doi: 10.1371/journal.pone.0032962

Packer, L. (2010). *Keeping the Bees*. Toronto, Ontario, Canada: HarperCollins Publishers.

Packer, L. (2014). Biologist says promoting diversity is key to 'Keeping the bees'. In T. Gross (Ed.), *NPR*.

Plischuk, S., Martin-Hernandez, R., Prieto, L., Lucia, M., Botias, C., Meana, A., . . . Higes, M. (2009). South American native bumblebees (Hymenoptera: Apidae) infected by Nosema ceranae (Microsporidia), an emerging pathogen of honeybees (Apis mellifera). *Environ Microbiol Rep, 1*(2), 131-135. doi: 10.1111/j.1758-2229.2009.00018.x

Preserving the pollinators to protect human health. (2014). *Horizon 2010: The EU Framework Programme for Research and Innovation.* from http://ec.europa.eu/programmes/horizon2020/en/news/preserving-pollinators-protect-human-health

Rader, R., Howlett, B. G., Cunningham, S. A., Westcott, D. A., Newstrom-Lloyd, L. E., Walker, M. K., . . . Edwards, W. (2009). Alternative pollinator taxa are equally efficient but not as effective as the honeybee in a mass flowering crop. *Journal of Applied Ecology, 46*(5), 1080-1087. doi: 10.1111/j.1365-2664.2009.01700.x

Rangberg, A., Diep, D. B., Rudi, K., & Amdam, G. V. (2012). Paratransgenesis: An approach to improve colony health and molecular insight in honey bees (Apis mellifera)? *Integr Comp Biol, 52*(1), 89-99. doi: 10.1093/icb/ics089

Reimer, A. P., & Prokopy, L. S. (2012). Environmental attitudes and drift reduction behavior among commercial pesticide applicators in a U.S. agricultural landscape. *J Environ Manage, 113*, 361-369. doi: 10.1016/j.jenvman.2012.09.009

Report on the National Stakeholders Conference on Honey Bee Health. (2012).

Rundlöf, M., Nilsson, H., & Smith, H. G. (2008). Interacting effects of farming practice and landscape context on bumble bees. *Biological Conservation, 141*(2), 417-426. doi: http://dx.doi.org/10.1016/j.biocon.2007.10.011

Shuler, R. E., Roulston, T. a. H., & Farris, G. E. (2005). Farming Practices Influence Wild Pollinator Populations on Squash and Pumpkin. *Journal of Economic Entomology, 98*(3), 790-795. doi: 10.1603/0022-0493-98.3.790

Stankus, T. (2008). A Review and Bibliography of the Literature of Honey Bee Colony Collapse Disorder: A Poorly Understood Epidemic that Clearly Threatens the Successful Pollination of Billions of Dollars of Crops in America. *Journal of Agricultural & Food Information, 9*(2), 115-143. doi: 10.1080/10496500802173939

Staveley, J. P., Law, S. A., Fairbrother, A., & Menzie, C. A. (2014). A Causal Analysis of Observed Declines in Managed Honey Bees (Apis mellifera). *Human & Ecological Risk Assessment, 20*(2), 566-591. doi: 10.1080/10807039.2013.831263

Stindl, R., & Stindl Jr, W. (2010). Vanishing honey bees: Is the dying of adult worker bees a consequence of short telomeres and premature aging? *Med Hypotheses, 75*(4), 387-390. doi: http://dx.doi.org/10.1016/j.mehy.2010.04.003

Tingle, C. C., Rother, J. A., Dewhurst, C. F., Lauer, S., & King, W. J. (2003). Fipronil: environmental fate, ecotoxicology, and human health concerns. *Rev Environ Contam Toxicol, 176*, 1-66.

Tirado, R., Simon, G., & Johnston, P. (2013). Bees in Decline: A review of factors that put pollinators and agriculture in Europe at risk (G. R. Laboratories, Trans.).

Van der Sluijs, J. P., Amaral-Rogers, V., Belzunces, L. P., Bijleveld van Lexmond, M. F. I. J., Bonmatin, J.-M., Chagnon, M., . . . Wiemers, M. (2014). Conclusions of the Worldwide Integrated Assessment on the risks of neonicotinoids and fipronil to biodiversity and ecosystem functioning. *Environmental Sciences and Pollution Research of Springer Verlag*.

vanEngelsdorp, D., Caron, D., Hayes, J., Underwood, R., Henson, M., Rennich, K., . . . Pettis, J. (2012). A national survey of managed honey bee 2010-11 winter colony losses in the USA: results from the Bee Informed Partnership. *Journal of Apicultural Research, 51*(1), 115-124. doi: 10.3896/IBRA.1.51.1.14

vanEngelsdorp, D., & Meixner, M. D. (2010). A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *J Invertebr Pathol, 103, Supplement*(0), S80-S95. doi: http://dx.doi.org/10.1016/j.jip.2009.06.011

Winfree, R., Williams, N. M., Dushoff, J., & Kremen, C. (2007). Native bees provide insurance against ongoing honey bee losses. *Ecology letters., 10*(11), 1105-1113.

Woody, T. (2014). The U.S. Bans GMOs, Bee-Killing Pesticides in All Wildlife Refuges. *TakePart.* from http://www.takepart.com/article/2014/07/31/us-bans-gmos-bee-killing-pesticides-national-wildlife-refuges

Wu, J. Y., Smart, M. D., Anelli, C. M., & Sheppard, W. S. (2012). Honey bees (Apis mellifera) reared in brood combs containing high levels of pesticide residues exhibit increased susceptibility to Nosema (Microsporidia) infection. *J Invertebr Pathol, 109*(3), 326-329. doi: 10.1016/j.jip.2012.01.005