Air Quality Implications for Pollinator Species

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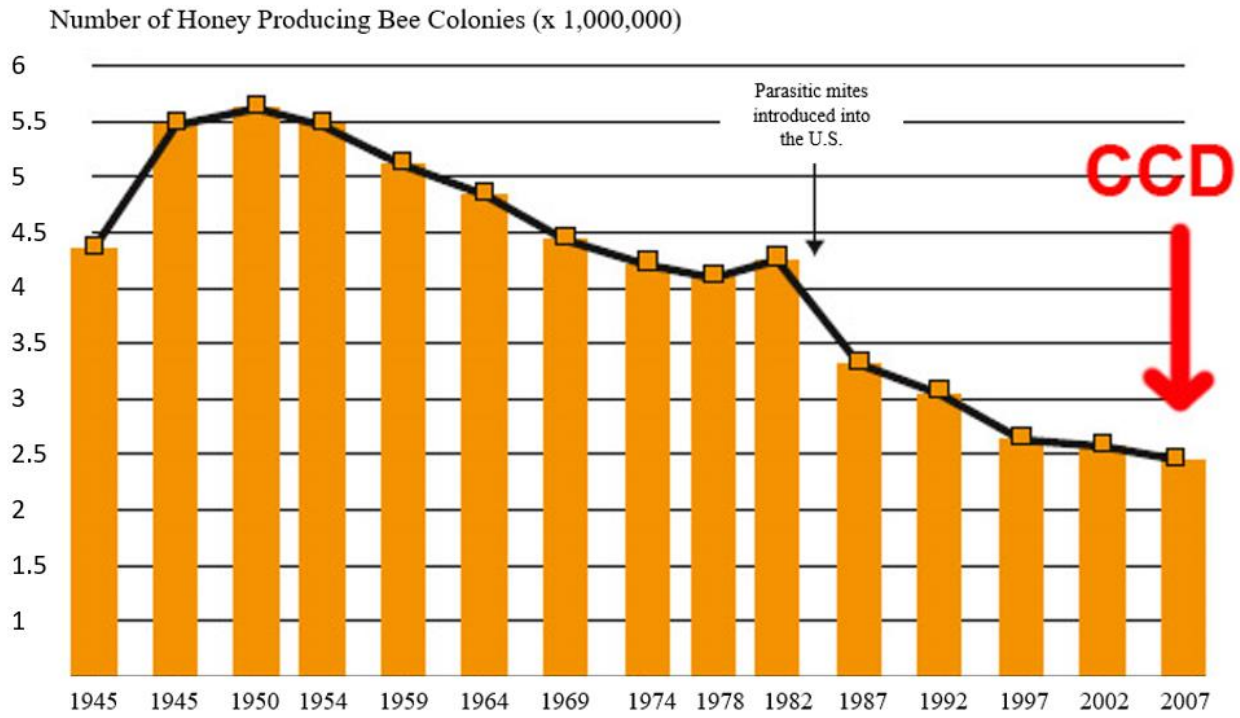

Figure 1. Data collected for producers with 5 or more colonies. Data Source: USDA National Agricultural Statistics Service https://www.nass.usda.gov/

Introduction

By pollinating many crop and flower species, honey bees and other pollinators are integral to ecosystem health and food resource security. Crops vary on their dependence on pollination, ranging from completely dependent to not at all. Crops that do not depend on insect pollination could be wind pollinated, self-pollinated, propagated asexually or develop without the need for fertilization. About 40 percent of crops rely on insect pollination to some extent. For example, blueberries, cherries and almonds, are almost completely dependent on honey bee pollination.

Calderone et al. (2012) described trends observed in pollinator-influenced crops over 1992 to 2009. This study quantified the severity of the economic influence of pollinators on food resource economics. According to the study, the value of directly pollinated crops in the U.S. has been on the rise, reaching $15.12 billion in 2009. The value of indirectly dependent crops decreased initially until 2004 but has since been observed to have an upward trend. However, the value took a dip in 2009 to $11.80 billion, so the total value of pollinator crops in the U.S. in 2009 totaled to about $27 billion. Specifically for honey bees, the value of directly pollinated and indirectly dependent crops was $11.68 billion and $5.39 billion, respectively. This quantifies the economic

impact of honey bees alone to be about $17 billion for 2009. Honey bees (*apis spp.*) are one of the major pollinating insects in the U.S., making their recent decline a major problem for food resource development and ecosystem sustainability. The amount of cultivated areas of crops that require benefit from pollination has increased, but these bee populations have decreased significantly. Observing these trends helps understand the magnitude of this issue and implications for sustaining the economic viability of some crops.

Studies conducted by the Bee Informed Partnership (https://beeinformed.org/), a collaboration of efforts that aim to understand best bee management practices, show that the annual loss of bee colonies is on the rise in recent years (Figure 2). Food demand is growing worldwide and global cultivation of pollinator-dependent crops are increasing (Aizen et al, 2008), but certain populations of native and managed pollinator species are declining or at risk (Figure 1). The relationship between honey bees and their environment is very complex. A more comprehensive analysis of factors influencing bee colonies would help better understand what management practices can be implemented to mitigate this effect.

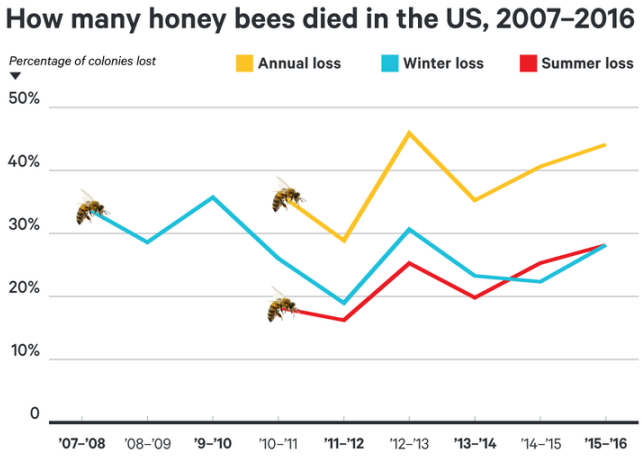

Figure 2. Trends in honey bee populations in the United States over recent years. This chart presents the recent trends in pollinator colonies while Figure 1 displays historical honey bee population data. Source: Bee Informed Partnership

Scientists have yet to fully understand the factors that are driving these declines in colonies and contributing to Colony Collapse Disorder (CCD). This is a recently developed phenomena that refers to a disorientation and disruption of honey bee social order that leads to a collapse of the population. Many studies have been conducted in order to understand the influence of mites, pesticides, and land use change on pollinator health. These have clear and direct impacts on pollinator health, so these studies have been assessing the magnitude of influence. However, various environmental factors also impact honey bee health in various ways – some directly, but many indirectly – that are not fully understood. The relationship between various environmental factors and honey bee health is largely unknown, so the extent of the influence is also unknown. Analysis of these factors could provide valuable insight into a problem as mysterious as CCD. I will describe the various ways in which we understand how a human-induced environmental factor – ozone air pollution – can influence pollinator health and discuss the implications of this information for future research and pollinator management.

Air Quality and Honey Bee Health

Various environmental factors influence bee population health – both directly and indirectly. The impact of tropospheric ozone, a criteria air pollutant, on bee populations appears to be mostly the latter. A quantitative effect of ozone on pollinators deals with the destruction of floral aromas that

bees use to detect pollen sources (McFrederick et al., 2008, Fuentes et al., 2016). Flowers emit mixtures of scents that mediate plant-insect interactions, such as attracting insect pollinators. Certain air pollutants that are highly reactive in nature, such as ozone, degrade these volatile, plant-emitted hydrocarbons downwind of the source (Figure 3). Studies have shown that even moderate air pollutant levels, such as an ozone mixing ratio of 60 parts per billion on a per volume basis, ppbv) substantially degrade floral volatiles and alter the chemical composition of released floral scents (Fuentes et al., 2016). To put this concentration in perspective, ozone exceeded an hourly average of 60 ppbv about one out of every three days during the 2018 summer in Beltsville, MD. The result of this modified floral scentscape is a reduction in insect success rate of locating plumes of floral scents and an increase in time spent foraging. With more time spent foraging, less energy is spent on pollination activity. This decrease in pollinator foraging efficiency could simultaneously decrease the pollinator's reproductive output and the amount of pollen flow in flowering plants (McFrederick et al., 2008). Furthermore, ozone has been shown to decrease searching success of parasitoid insects, such as *Asobara tabida*, by about 10 percent when exposed to ozone concentrations of 100 ppbv (Gate et al, 1995), with additional evidence that ozone may interfere with the olfactory responses of the parasitoids. This could have a positive effect on honey bees by reducing the threat of being parasitized by varroa mites, but the mechanism that leads to this impact on parasitoids could have similar implications for pollinators due to the insect's biological similarities.

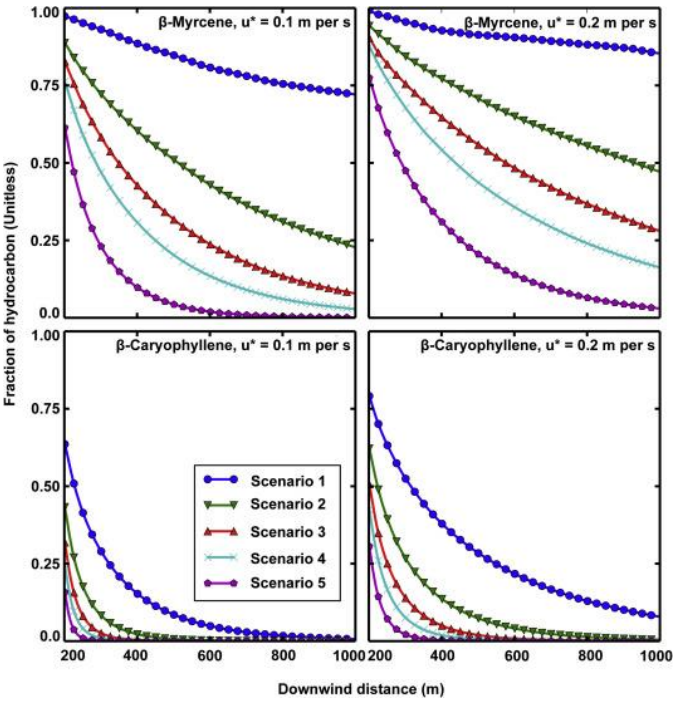

Figure 3. Fraction of multiple floral hydrocarbons decreasing with increased ozone concentrations. Scenario 1 refers to the lowest ozone concentration while scenario 5 refers to the highest ozone concentration.

Another harmful effect of ozone on honey bees is the decrease in plant health, which in turn could lead to a decrease in the health of honey bee populations that rely upon them for pollination activity. Similarly to the effect of how habitat fragmentation impacts bee populations, decreasing plant health could reduce the availability of flowering species, destroying their native habitat and forcing them to travel more for pollination. The impact of ozone on various plant species has been extensively studied for crop species (Averny et al., 2011, Van Dingenen et al. 2009), but also on native vegetation (Capps et al., 2016, Ashmore, 2005, Skelly et al, 1999). Tree species have a large range of sensitivity to chronic ozone exposure, with some tree species losing up to 30 percent of their productivity. Other native plants, such as common milkweed and cutleaf coneflower, have been shown to be especially sensitive to ozone when exposed to 8-hour ozone averages of at least 60-70 ppbv.

Furthermore, ozone has been shown to have an adverse effect on plant reproduction (Black et al., 2000). Plants, when exposed to ozone at 100 ppbv, were seen to have a decreased pollen germination percentage and pollen tube length, as well as delaying flower development and increased bud abortion/abscission. These studies were mostly conducted in the late 20th century when air pollution levels were markedly higher than present, but there are still observed events today that spike ozone concentrations to these experimental values. While there have been no studies linking the impact of ozone on plants to a direct impact on honey bees, it is worth noting since there is an understood interaction between honey bees and certain plants, so there may be a non-negligible effect.

Trends from Satellite Air Quality Data

Satellite and ground observations have shown that air quality has been improving over recent years, but concentrations have still been found to be high enough to exacerbate human and plant health concerns. Ozone is formed in the troposphere through reactions involving nitrogen oxides (NOx) and volatile organic compounds (VOCs). The OMI instrument collects satellite data products in order to determine atmospheric nitrogen dioxide (NO_2) concentrations, a major component of NOx which is then used to estimate tropospheric ozone levels. Largely due to environmental regulations, such as the Clean Air Act, a decline in concentrations has been observed for all major air pollutants in the United States (Figure 4, Figure 6).

Observing the spatial and temporal distribution of air pollutants provides necessary information that is used when managing air quality. NASA has a variety of satellites that monitor air pollution from space at a global level. Using the Aura Satellite's (https://aura.gsfc.nasa.gov/) Ozone monitoring Instrument (OMI), scientists have been able to track trends in air quality over recent years (Duncan et al., 2016).

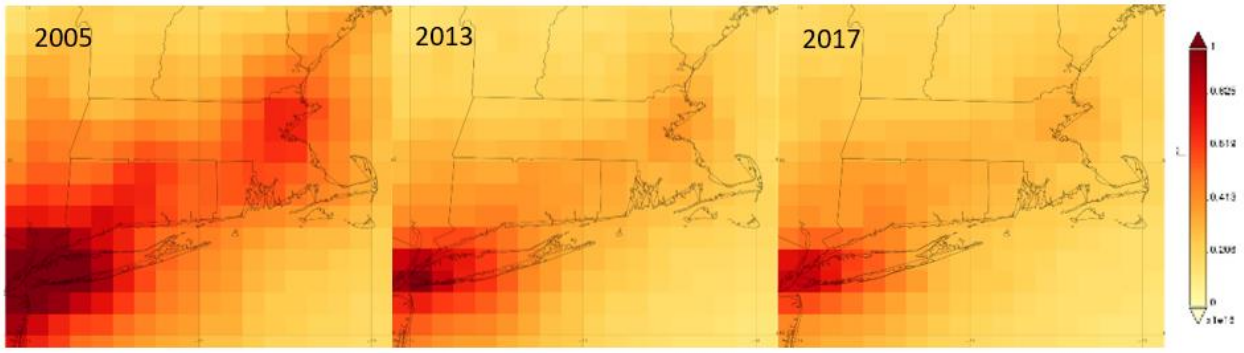

Figure 4. Trends in NO_2 concentration observed from the Aura Satellite's OMI for New England. NO_2 is a major component of NO_x, emitted from combustion of fuels. This is why the concentrations are highest in urban settings. NO_x can be used to estimate tropospheric ozone levels.

Ozone levels are often highest in industrial regions because human activities, such as combustion of fuel, leads to high levels of NO_x. However, there are other factors that have cause ozone spikes, even some in more rural areas. For example, the application of nitrogen-containing fertilizers in agricultural areas contributes to local NO_x concentrations and ozone spikes. Ozone formation and transport is a complex process that is impacted by meteorological factors and atmospheric

chemistry. This often leads to a heterogeneous distribution of pollutants in a region, which requires ozone impact assessments to account for a variety of factors and their uncertainties when conducting research.

Incorporating satellite data into this analysis of honeybee health allows for the effect of air pollution to be put into spatial context. Satellite air quality data could be used in future studies to determine if some relationship between honey bee health and air pollution exists – and to what extent. This future analysis would also provide the benefit of directing further study variables and regions. Major air pollutants are declining, however, other contaminants, such as pesticides and herbicides, are not observed but may be considered pollutants. There are thousands of other air pollutants that are not observed or studied, so there could be an unknown pollutant that is not being considered.

Additional Influential Factors

Other factors that influence honey bee colony health must be well understood in order to maintain ecosystem and crop health. Insect infestation by varroa mites has been established as a major threat to health of bee colonies across the nation. These parasitic mites attach to the honey bees, eventually leading to the death of the bee. Knowing how to prevent and respond to these pests is integral for sustaining healthy bee populations, so bee managers across the nation are learning how to respond. This biotic factor plays a major role, but the key to understanding the complexity of this issue may lie in the abiotic factors, such as air quality, temperature, humidity, and precipitation. Many factors have a capacity to influence bee colonies – in the northeast U.S. and across the world – therefore, studies on how these various environmental factors influence pollinators is key for the sustainability of healthy populations. An environmental health indicator, such as NDVI, could also be used to better understand honey bee colony health (Figure 5). Satellite data provides a clear spatial resolution that may reveal information that may otherwise would have lain dormant. Satelite NDVI values could be used to track a correlations between plant and honey bee health.

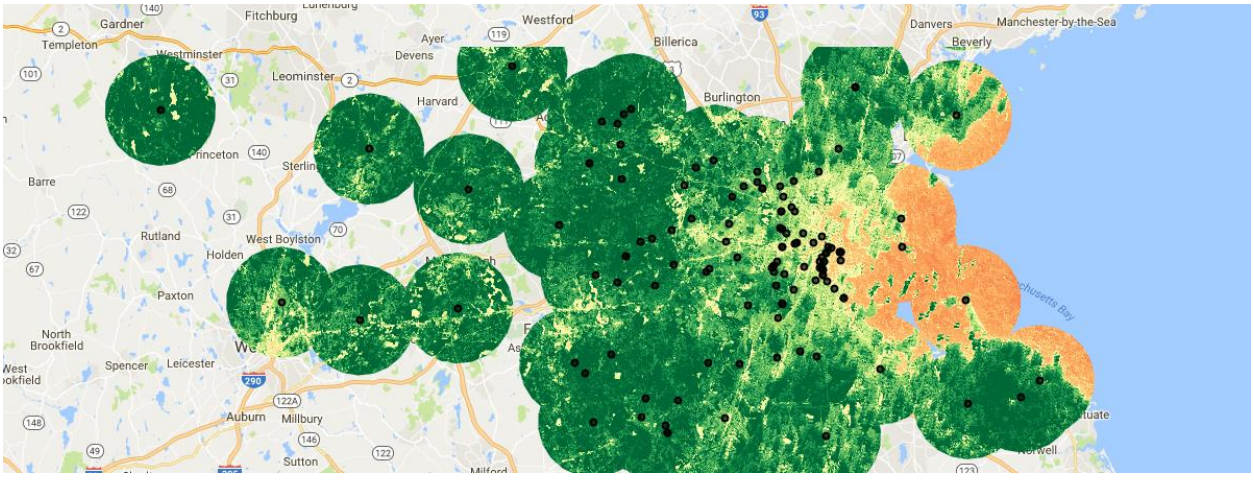

Figure 5. UBL data in Google Earth Engine with buffers around the points showing max NDVI collected from Sentinel 2 during 2017. Image by the NASA DEVELOP New England Agriculture and Food Security Summer 2018 Project

Habitat fragmentation and land use change have altered the landscape for bee populations to interact with natural scenes. In many cases, pollinators have to travel longer distances and through man-made obstacles in order to carry out their pollinating activities. Furthermore, Pesticide usage in the U.S. has also been a major suspect in the decline of bee population, since bee populations have been declining since the middle of the 20th century during the Green Revolution. While most of the pesticides that were determined to be environmentally harmful are no longer used, a new wave of pesticides, a class of neonicotinoids, have been shown to have negative effects on bee health. These pesticides provide a pathological challenge to pollinators, along with a political challenge for Americans. The Trump Administration recently announced a plan to ease restrictions on neonicotinoids for agricultural purposes. These human-induced factors can be more easily adjusted in order to better sustain pollinator health. Determining what class and dosage of pesticides damages pollinator health would provide crucial information for crop and honey bee management alike.

Discussion

Air pollution is one of many abiotic factors that can influence bee populations. Studies have shown no direct link between ozone pollution and honey bee health, however, the influence on floral aromas and flowering plant health creates a reason to believe that there is a relationship between the two. The extent of this influence should be further studied and understood, especially in regions where air quality is a major concern. Air quality in the U.S. has improved over recent years, with some of the greatest improvements observed in the Northeast. Therefore, despite the fact that not all pollutants are observed, it is unlikely that further air quality improvements will lead to a major improvement in honey bee colony health.

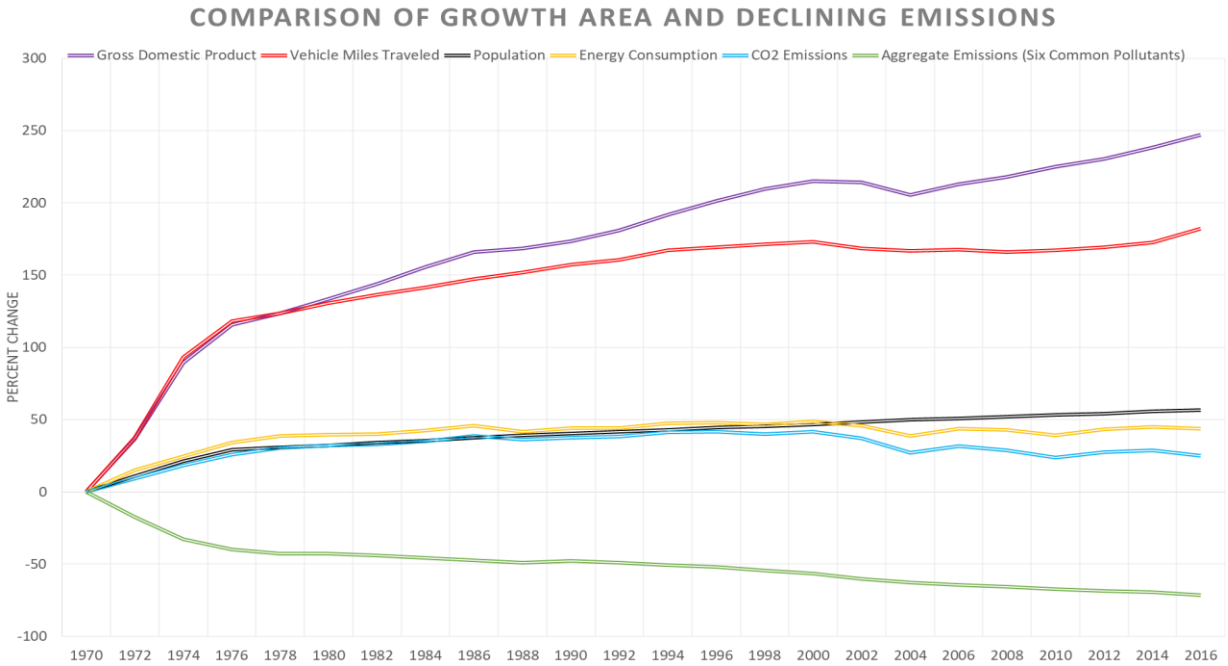

Figure 6. Data showing the trends in air pollution (green) compared to various growth characteristics. Despite US growth in the past decades, emissions from the six criteria air pollutants have decreased via environmental regulations. Source: US EPA

It seems paradoxical for activities that lead to more pollution (transportation, economic growth, energy usage) to be increasing, but pollution levels have actually been declining (Figure 6). Trend analysis of these observations would provide reason to believe that air quality improvements have not done much to increase honey bee populations. However, this issue is undeniably complex. In order to understand what is occurring, a more in depth and comprehensive analysis should be conducted that could reveal information that was unknown. This may also speak to extent of the influence of air quality on pollinator health. Air quality improvements could have a positive impact on honey bee health, but the increases in pesticides, land use change, and parasites potentially have concealed this effect. In any case, trend analysis alone will not be sufficient to make any conclusions about how ozone and honey bee health are related. Ozone could impact pollinator behavior in a way that has not been observed directly or through population trends.

Honey bees and other pollinators are undeniably essential for agriculture and ecosystem health. Air quality is likely one of a variety of environmental factors that influences the success of pollinators. Changing environmental conditions provides a challenge for predicting how pollinators will respond in the future. Bee managers should be aware of ozone pollution around their colonies and adjust some of their practices in the case of pollution events. In order to provide better advice on how to manage bee populations during an ozone event, this impact needs to be further researched.

Resources

For more information about trends and applications of air quality, visit the NASA Air Quality Website (https://airquality.gsfc.nasa.gov/). Resources include downloadable fact sheets, images and animations of air pollution satellite data and additional resources for data users.

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