An assessment of beekeeping (*Apis mellifera*) taking into account changing weather patterns in Northwest Pennsylvania



ALLEGHENY COLLEGE

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Acknowledgements and Abstract

Acknowledgements

I would like to dedicate this study to my grandfather, Mel Bebee. You will always remain a role model in my life along with the memories I have of you.

I would like to thank my parents, as well. You have both inspired me to work hard in academics and extracurriculars my entire life. I obtained my ambition from you.

Abstract

Based on climate projections, the optimal zone for humans by 2070 includes Pennsylvania, suggesting that the temperature will increase by at least 3° F, and the change in seasons will be less drastic than is observed today (Xu et al., 2020). Heavy precipitation has increased by approximately 55% since 1958 in the Northeast U.S. region, a trend projected to continue in the future (Hayhoe et al., 2018). Seasonally, winter precipitation will likely increase 15-20%, and spring precipitation by 10-15% (ibid). A changing climate under these conditions could cause unprecedented changes to flora and honeybees in Northwest Pennsylvania. Valuations of crops pollinated by honeybees in 1987 and 2000 reached $9.3 billion and $14.6 billion, respectively, in the United States alone (Kevan et al., 2006). By 2005, crop pollination's worldwide valuation reached $168 billion, almost 10% of worldwide food production (Gallai et al., 2009). This study consisted of two main research objectives: to determine beekeeping management techniques by beekeepers within the Northwest Pennsylvania region and to investigate weather patterns specific to Erie, Pennsylvania, including temperature, precipitation, and snowfall over the past five years. The literature supported information gained from interviewing a local beekeeper. Overall, plant and honeybee phenology will likely advance together, but both species will be put in danger throughout the seasons by changing weather patterns. A longer growing season impacts plant processes such as reproduction and senescence and makes honeybees more susceptible to mite infestation and disease late in the pollination season. Future studies should follow a similar format with more interviews and data collection to determine future regional viability accounting for climate change.

Introduction

Significance of the honeybee

All honeybee species within the *Apidae* family benefit agricultural systems and the economy through crop pollination and honey and beeswax products. Valuations of crops pollinated by honeybees in 1987 and 2000 reached $9.3 billion and $14.6 billion, respectively, in the United States alone (Kevan et al., 2006). By 2005, crop pollination's worldwide valuation reached $168 billion, almost 10% of worldwide food production (Gallai et al., 2009). Pollinated crops advantageous to potential beekeepers are constantly put at risk as beekeeping becomes less appealing and economical to modern U.S. society. The most common factors leading to colony loss before the turn of the 21st century were a shortage of food, infestation, and infection by parasites and pathogens, as well as poor hive management (Stanimirović et al., 2019).

In recent years the honeybee population has rapidly declined, accentuating the benefits honeybees provide to modern society. The reality is that the current agricultural system and the processes it entails do not account for the hard-working pollinators that increase revenue while decreasing labor costs, thereby causing more stress to an already declining population (Melicher, 2019). The connection between pollinated crops' output and its impact on hive survivability and productivity is commonly spoken on and studied. On the other hand, the impact of a constantly changing climate on the honeybee leads to this investigation's principal question: how have changing weather patterns in Northwest Pennsylvania impacted the honeybee? This study addresses the honeybee industry's adverse conditions, such as the impact of changing region-specific weather patterns on both flora and the honeybee.

Adverse conditions currently facing the honeybee industry

During the 1990s, the ectoparasitic mite (*Varroa destructor*) population increased rapidly and weakened the honeybee's immune system, forcing the beekeeper to play a more direct role in maintaining hives. As a result, beekeeping is now more costly, timely, and labor-intensive than ever (Lezaun, 2010). Commercial beekeepers transport their colonies across the United States for pollination. Although this process is profitable it puts immense pressure on the bees. Smaller colonies are unable to thermoregulate properly after relocation, experience loss, and do not survive as long (Melicher, 2019). Stress response on the genetic level associated with chill stress, immune response, defense response, and methylation all experience increased gene expression after relocation (ibid). Pesticides and other substances applied to crops also remain a prevalent issue for beekeepers because they alter pollen's chemical makeup and make the hive more susceptible to death post-pollination (Dobre et al., 2017). It is problems such as these that

deter people from entering the field of beekeeping which causes the market to decline and prices to rise. In turn, this leads to severe consequences to crop yield and revenue for the agricultural industry.

Another factor contributing to the difficulties of beekeeping is unexpected colony loss. In 2006 and the years following, beekeepers witnessed an unusually high number of losses, unlike years prior. After the winter of 2007, a survey conducted with beekeepers discovered that almost 180,000 hives were lost, increasing 11.4% from the previous year, which also experienced increased losses (vanEngelsdorp et al., 2008). Sixty percent of the hives lost occurred without dead bees in or around the hive, subsequently coining Colony Collapse Disorder, or CCD (ibid). Essentially, the worker bees ran away from home, leaving behind a seemingly healthy hive, including brood, resources, and the queen (Farooqui, 2013).

The causes for colony collapse were unknown; however, hives suffering from CCD had a more significant pathogen presence (vanEngelsdorp et al., 2009). Thus, remedies and treatments assisted the hive in fighting against parasites and pathogens. Diseases such as deformed wing virus (DWV) are mechanical vectors and biological vectors, meaning mites can carry the virus, supporting the widely accepted idea that a combination of internal and external environmental stress factors contributes to CCD (Genersch & Aubert, 2010). Other diseases, such as American Foulbrood (AFB), are mechanical vectors induced by spores and spread by contact with infected nurse bees or active spores, which survive between 3-10 years (CIE, 2016). To prevent the continuation of increased losses, beekeepers began equipping hives with chemical substances and monitoring technology to ensure hive survivability, inadvertently increasing the beekeeper's responsibility yet again.

Beekeepers use two main treatment methods to maintain a healthy hive: mite treatment and disease prevention. Mite treatment usually consists of either chemical or natural treatments. The most effective way to prevent mites is by alternating between various treatments, so *Varroa* mites do not grow immune and infest the hive (Underwood & López-Uribe, 2019). Also, most of the treatments listed above do not contain contaminants that reside in bee products. Complex adverse environmental conditions such as parasites, pathogens, and even lack of nutrition demand high amounts of energy because they require the bees to adapt to various conditions (Grozinger & Flenniken, 2019). Over time honeybees have developed a wide variety of defense mechanisms to protect the hive against foreign parasites and pathogens. The insect carries out two known defense mechanisms to maintain a healthy hive: resisting and tolerating. Individual defense mechanisms categorized by mechanical, physiological, or immune response are the first defense level. If an individual cannot eliminate a stressor, the individual will groom with other bees (Evans & Spivak, 2010).

Impact of changing weather patterns on flora and the honeybee

Parasites and pathogens, however, are not the only environmental factors increasing stress on honeybee populations. Honeybees can manage some of these stress factors more than others and work as a hive to create the most optimal environment possible. In a feat of evolution, honeybees can maintain temperatures between 34-36 °C year-round (Meikle et al., 2017). Bees overwinter, spending the winter season huddled together inside the hive to survive freezing temperatures while feeding on the honey produced during the pollination season. A higher-than-normal expression of immune genes involved in antibacterial defense has been observed during winter months, suggesting bees adapted to resist pathogens and save energy. However, cellular immune function decreased during this time (Steinmann et al., 2015). Decreased immune function is likely due to *Varroa* mites, which lower immune system strength, thereby supporting the idea that the parasitic mite promotes virus transmission, even through the winter months. Hives are most commonly lost over the winter months, suggesting that overwintering makes the hive more compromised to pathogens, such as the deformed wing virus (Meikle et al., 2017).

Beekeepers and the bees they care for have endured many hardships over the years. However, the mutualistic relationship between honeybees in the *Apidae* family and flora is the most important to survivability. Flowering has been occurring earlier each year due to warmer temperatures in the late winter and early spring months. Plants with early first flowering dates (FFDs) are more likely to be affected by changing temperature patterns than flora that flower late in the season (Miller-Rushing & Primack, 2008). For example, two different goldenrod, *Solidago rugosa* and *Solidago graminifolia*, flowered 11 days apart as temperature increased by one-degree Celsius in January, May, and June in Concord, Massachusetts. Most flowering plants now flower approximately seven days before the first recorded data set in 1852. Hence, the temperature has an important impact on flowering plants but can vary significantly between species (ibid). A similar circumstance exists for blooming wooded plants in Edmonton, Alberta, Canada. On average, trees now bloom a drastic 26-days earlier than they did a century prior (Beaubien & Freeland, 2000).

Earlier blooming and flowering is significant because it can alter entire biomes. For example, the Aspen Parkland, one of Canada's most threatened ecozones, is predicted to be overtaken by southern boreal forests due to warming temperatures and drier air, which encourages earlier blooming times (Hogg & Hurdle, 1995). The most common cause of wildfires post-1970s is drought (Pausas & Fernández-Muñoz, 2011). If entire biomes transform, pollinators will need to adjust behavior to previously mentioned parasites and pathogens but weather patterns. Honeybees and flora require similar phenology because they have to take advantage of the entire pollination season to survive the winter. However, when the phenology for each species is asynchronous, both species will suffer from a mutualistic relationship, a concept referred to as phenological mismatch. For example, the honeybee and flora population would

decline, as there would be limited resources and pollination opportunities (Out of sync, 2020). The time of year that honeybees begin foraging is sensitive and strongly correlated with snowmelt timing, while flora is less sensitive and highly dependent on temperature (ibid, Miller-Rushing & Primack, 2008). To summarize the circumstance, there is sensitive phenology, that of the honeybee, which is highly dependent on insensitive phenology, that of plants. In this case, a phenological mismatch is inevitable.

Early spring phenology shifts are more likely to occur as climate change impacts continue to be more severe than years prior (Nürnberger, 2019). Brood rearing is principal to the survivability and productivity of the hive. Under normal circumstances, brood rearing is highly dependent on the temperature inside the hive (Crane, 2005). Logically, air temperature is the most influential factor affecting the ambient temperature. If warming occurs early in the season, it can cause the brood-rearing process to advance (Sparks et al., 2010). If spring bees are born before the blooming or flowering of nearby plants, the hive faces extreme adversity. Brood rearing is a process that consumes high amounts of food stores because the hive is expecting the brood to replenish that food with available pollen and nectar, but when this process occurs without the availability of these resources, the hive is more likely to experience food shortage. Another factor influencing brood rearing is resource input (Keller et al., 2005). In some cases, peak resource availability occurs five to six weeks following the peak brood area (Nürnberger, 2019).

Region-specific weather patterns and flora

Northwest Pennsylvania is in a unique situation regarding weather because it lies within the Great Lakes region, which experiences lake effect precipitation. From 1988-1994, lake effect precipitation in October occurred most frequently in the form of rain. Also, from September to November, lake effect precipitation occurs one out of every five days in the Lake Erie area (Miner and Fritsch, 1997). Similar results were found in the Finger Lakes region from 2006-2009, suggesting this trend remained constant (Laird et al., 2010). Historically, there are increases in above-average snowfall during the winter seasons. From 1930-1990, there was an 85% increase in snowfall, over 100 centimeters, occurring primarily during the winter months (Leather & Ellis, 1996). Honeybee phenology depends on the melting of this snow to indicate when to emerge from the hive (Out of sync, 2020).

More recently, temperatures have begun to warm. According to climate migration patterns over the past 6,000 years, the most optimal zone, based on temperature, for human life within the United States lies approximately within the 30° N and 40° N latitudes (Xu et al., 2020). However, the optimal zone will likely shift between the 40° N and 50° N latitudes by 2070 (ibid). The projected optimal zone by 2070 includes Pennsylvania, suggesting that the temperature will increase by at least 3° F, and the change in seasons will be less drastic, similar to Southern states than is observed today (ibid). Although the

Northwest Pennsylvania region's increased temperature may be naturally more optimal for humans, it could affect honeybees differently. It is possible hives could experience previously mentioned phenological mismatch with flora in the area; however, it can also maintain phenological synchrony and adapt to extend the pollination season. The body of this work will investigate these possibilities.

Furthermore, the temperature is only one weather trend that significantly impacts honeybees and the flora that require their pollination services. Heavy precipitation has increased by approximately 55% since 1958 in the Northeast U.S. region, a trend expected to continue in the future (Hayhoe et al., 2018). Also, there is a projected increase in winter precipitation by 15-20% and spring precipitation by 10-15% (ibid). These projected changes in precipitation could not only impact the phenology of plant-pollinator interactions, but it could also negatively impact foraging or increase pollen degradation in plants (Lawson & Rands, 2019). Northwest Pennsylvania lies within the Ayers and Harman honeybee forage map's agricultural interior region, which contains eleven identified species as essential nectar sources for pollinating species (Ayers & Harman, 1992). These essential nectar sources bloom or flower between March and October. This temporal range assists in regulating hive behavior to maximize food stores early in the season and adequately prepare for overwintering and changing phenology of these plants by either temperature or precipitation forces the honeybee to adapt or suffer due to changing weather patterns.

Research objectives

A significant portion of this research aims to understand better the impact of changing weather patterns on beekeeping in Northwest Pennsylvania by addressing four main objectives. The first objective is to determine beekeeping management techniques by beekeepers within the Northwest Pennsylvania region. The second objective is to investigate weather patterns specific to Erie, Pennsylvania, including temperature, precipitation, and snowfall over the past five years. The final two objectives aim to evaluate the impact of weather trends in Northwest Pennsylvania on the beekeeping industry over the past five years and to determine the implications of changing weather patterns on the future of beekeeping in the Erie region.

Methods

Rationale & interview preparations

The purpose of the interview portion of this study was to understand how beekeeping and honeybees have been affected over time by various biological and abiotic factors in Northwest Pennsylvania from a beekeeper's perspective. An interview is a supplemental form of primary literature that provides valuable insight into changes, advantageous and detrimental, to beekeeping in the area. The interview was conducted over Zoom software without a time limit for the overall interview or any one question. This interview required minimal risk and was approved by the Allegheny College International Review Board (IRB) before being administered. No compensation was awarded to the interviewee following the interview's completion; however, the participant was given access to the Allegheny College D-Space, where the study was archived upon completion.

The literature review portion of this study aims to compile existing literature regarding the effect of varying weather patterns, and the impact weather has on honeybees' physiology and biology. Region-specific weather data in Erie, PA, was aggregated to represent these patterns accurately. Furthermore, these research lines created a more accurate theory of the future of beekeeping, accounting for region-specific climate change. The data obtained from the interview and literature review together create a more definitive representation of the future of beekeeping in Northwest Pennsylvania as the climate continues to change.

This study's most general purpose is to investigate Northwest Pennsylvania as a viable region to keep bees in its projected future climate. Climate change will impact many regions worldwide, and some regions will likely become more or less viable as a habitat for honeybees. Current scientific research is sufficient in investigating the impact of changing weather on the honeybee. However, it lacks in pairing the reality of a changing climate with the effect on beekeeping to determine changes, if any, to continue maintaining similar pollination and production levels. Hence, this study aims to fill this research gap in the Northwest Pennsylvania region.

Participants

The interview attempted to reach an experienced beekeeper to investigate how hive survivability, productivity, and the course of beekeeping in Northwest Pennsylvania has changed in the past five years. This interview targeted a participant with a long history and a wide array of experience in the beekeeping industry. The participant was adequately informed of the interview's scope before its occurrence to allow for proper preparation of quantitative and qualitative data, including personal observations and experiences with hives.

The interview participant was Charlie Vorisek, the President of the Northwest Pennsylvania Beekeepers Association (NWPBA), on the legislative committee of Pennsylvania State Beekeepers, and an active member of the Penn State Center for Pollinator Research. Also, he is the owner of Vorisek's Backyard Bee Farm, LLC. This company pollinates crops such as pumpkins, apples, and blueberries in the area, removes swarms and sells queens, bees, honey, and other byproducts. His involvement in the beekeeping community provides him with extensive knowledge and social networks throughout Northwest Pennsylvania and beyond. In total, he keeps approximately 170 hives between his farm in Linesville and at other locations in Crawford County (Vorisek's Backyard Bee Farm, LLC, 2018).

Interview procedure

The leading researcher, Noah Bebee, conducted the interview over Zoom. At the beginning of the interview, the interviewer verbally obtained consent from the interviewee to participate and be recorded. The interviewer also acknowledged that these decisions were optional, that all recordings would only appear in this study to benefit the scientific community and the recordings would be destroyed upon completion of this study. Direct quotes or concepts discussed during the interview duration used in this study were obtained from the recordings. If anonymity was requested, then the participant's name, and personal information, was omitted from the final research paper and replaced with an anonymous nickname such as BEEK1. At this point, the interviewer began the audio recording with approved consent. Multiple, open-ended guiding questions, with follow-up questions, were posed to the participant after extensive research in the area of study to develop an open-ended questioning line (Appendix C). Information was collected regarding hive survivability and productivity over the past ten years and seasonal and annual observational data about the hives. Also, sales information was requested, if applicable. Then, the interviewer began a questioning line involving how the participant has reacted to conditions impacting the hive. Next, the participant was asked to discuss factors that are relied upon to improve survivability and productivity. Finally, he was prompted to hypothesize how he believes weather has and will impact beekeeping in the Erie region. Upon completion of the interview, the participant was read a short debriefing letter.

There was no time limit for this interview; the participant was free to speak without time restrictions. The interviewer rarely interjected but ensured the conversation remained timely and within the scope of research. The interview was administered with informed consent with approval from the Allegheny College International Review Board (IRB).

Literature review & data analysis

The literature review section consists of four main subsections written after researching a vast array of scholarly journal articles, personal accounts from local beekeepers, seasonal weather data, and personal knowledge and experience (Table of Contents). The most commonly searched journals consisted of 'Apidologie,' 'Behavioral Ecology and Sociobiology,' and 'Plos One.' Other research methods consisted of searching common terms on websites such as Google Scholar or in bibliographies of other relevant journal articles such as climate change, honeybee behavior, weather patterns, northwest Pennsylvania, phenology, overwintering, and pollination. Many times, research in the former method resulted in less relevant articles. Abstracts were reviewed to find more relevant studies and determine if the article warranted a further read.

Weather data was aggregated from Seasonal Climate Reports on the National Weather Service Forecast Office website at the Erie location dating back five years to Winter 2016 (Tables 1 & 2). This data was transferred to an excel spreadsheet to deduce trends over time. Condensed data tables used averages to show mean seasonal changes in temperature, precipitation, and snowfall. From these particular tables, scatter plots and bar graphs were created with standard deviation error bars.

Chapter 1: Summary of Interview

Background

Charlie Vorisek is an esteemed beekeeper in Pennsylvania. In 1992, his daughters made a bee farm for an agricultural project lasting nine years until he registered the farm. Mr. Vorisek became a full-time commercial beekeeper in 2009 and grew almost 30% each year after. Today, according to Mr. Vorisek, out of 6,000 total beekeepers, he is one of less than twenty full-time beekeepers in the state of Pennsylvania. He now keeps approximately 200-300 colonies throughout Crawford County. Twenty to thirty colonies are moved to Erie and Venango counties to pollinate apples, cherries, strawberries, and pumpkins. It is worth noting that Mr. Vorisek harvests honey about three times annually, usually near the end of June, July, and September. Honey from specialty crops, if available, gets harvested after September. Mr. Vorisek's journey into full-time beekeeping began with many difficulties, as do most. He counted on losing approximately 50-60% of bees in his beginning years, forcing him to buy and sell replacement hives. Once he was able to maintain 200-300 colonies, he began to focus on better production per hive, which is when he could use hindsight to observe long-term trends.

Seasonal Trends & Irregularities

Honey Yields

Honey yields change by year and season, but one trend Mr. Vorisek noticed in his many years of beekeeping is that wet seasons tend to produce more honey and dry seasons tend to produce less honey. To support this claim, Mr. Vorisek observed that the pollination season of 2017 was the driest over the past five years. Key factors that contribute to increased honey production are the amount of flowers within foraging range, high secretion of nectar-sugar, and optimal weather for foraging (Crane, 2015). This year, he harvested 16,179 pounds, about 15 to 20 pounds more per hive than average (Table 11). However, the year prior, 2016, required 130 hive replacements (Table 11). Furthermore, 2015 resulted in the highest percent loss in the past five years (Table 11). A time that is a crucial indicator of the success of the hive for the rest of the season is the first bloom period. In the last five years, there has been a break in February where temperatures will increase to about 50 °F, and some trees will begin to produce pollen. Believing this is an indicator that the pollination season is beginning, the hive begins the brood-rearing process. Brood rearing is a rigorous process that requires lots of energy, meaning more honey consumption. At this time, the hive may use more food than they have to survive the season. Mr. Vorisek supplements his hives with candy blocks during this time, but if the colony is not healthy, meaning high mites counts or high disease presence, the hive will likely not survive. Although he has not needed to

supplement his hives in the past few years, he tries to leave colonies with 60 pounds of honey in preparation for the winter.

Furthermore, in Crawford county, the first target crop is *Robinia pseudoacacia*, or Black locust, a hardwood deciduous tree. Normally expected weather patterns during this boom period, which only lasts between five and seven days in the last week of May, are essential because the bees depend on this food to continue raising broods throughout the season. Mr. Vorisek has observed rain and frost during this blooming period in the past, forcing the bees to remain in the hive and miss a pollination period which is very important to ensure food availability for the remainder of the year. For example, the Bergamot of the genus *Monarda* produced 1,367 pounds of honey in 2018 instead of the following year when it produced 290 pounds (Figure 7). Mr. Vorisek attests that this was due to frequent rain.

Flora

Mr. Vorisek does not plant for his bees but harvests honey multiple times throughout the year, so he is fully aware of what plants produce honey. Naturally, as his colony numbers have increased, so have the crops pollinated by his bees. Today, his bees pollinate a total of twelve different crops each year. Spring blossom, clover, wildflower, and goldenrod consistently produce the most honey. Honey from spring blossom and clover are harvested in the spring, during wildflower, and goldenrod in the fall. From 2015-2019, these four crops have made up 81.4% of all of Mr. Vorisek's honey production (Table 11, Figure 7). He also noted that plants such as Lamb's ear and Purple loosestrife produce significant amounts of honey; however, they are both invasive species. Mr. Vorisek describes these plants as a 'double-edged sword because although they are beneficial to pollinators, they are also an invasive nuisance. Other plants such as Bergamot, otherwise known as bee balm, and Black locust are highly variable sources of nectar for the bees but, with the right conditions, can produce significant amounts of honey. Another notable crop is Buckwheat. There is not much demand locally for this crop, but it is sometimes used as a cover crop since it has soil improvement and protection qualities. Most years, Buckwheat does not produce a surplus of honey; however, it is unknown whether this is a cause of seed variety or weather. The plant tends to be very temperature and moisture sensitive, requiring very high ground moisture and temperatures around 70 °F. Rain usually stops nectar flow for this crop. In any case, Mr. Vorisek attempts to get his bees on Buckwheat every year. Working closely with Ernst Conservation Seeds, the largest native seed producer and supplier in the eastern United States based locally in Crawford County, Mr. Vorisek can test how the bees respond to various native flora not found in large quantities in the area anymore. One of the plants he has tested was canola to gauge its viability as an oil-producing crop. Typically planted in late summer and dormant over the winter, it will produce flowers in May and

harvested in June. In general, this crop bloomed too early, which meant that the bees would use it to assist in brood production and would not create a honey surplus.

Pathogens and Parasites

Mr. Vorisek mentioned a few diseases that affect his colonies. American foulbrood and *Nosema spp.* are not seen often in the area. Only the veterinarian can treat American foulbrood. *Nosema spp.*, on the other hand, is actively prevented by Mr. Vorisek. Aware that a cause of this disease is too much moisture in the cold, he takes two very calculated precautions. First, he creates more ventilation. Second, he will take his honey off the hive about a week earlier than most of his fellow beekeepers and packs down his bees. Honey is hygroscopic, meaning it collects moisture and becomes water-like under high-moisture conditions. Taking these precautions allows the bees a few weeks of warm weather and a manageable amount of honey to effectively reduce moisture in the hive, making it possible to cap honey cells and overwinter. Not only does this method provide the bees with usable honey in overwintering, but it also effectively reduces *Nosema spp.*

The most common disease observed by Mr. Vorisek is the deformed wing virus (DWV). When DWV clusters emerge, he will segregate the affected colonies into their yards and treat them accordingly. He stressed that DWV is very closely related to mites in his hives. Colonies that had high mite counts were much more susceptible to this virus. Most of Mr. Vorisek's losses are due to mites, and it is most certainly the most significant detriment for the bees. To resolve this issue, he has attempted to use different bees and alter treatment methods. Since the start of his bee farm, Mr. Vorisek had used Africanized honeybees from Florida, but with a high loss each year, he thought that the issue was not so much the bees could not overwinter but that they could not effectively control mites. Since 2018, he has begun to replenish his losses from bees with stronger survivorship and mite-resistant genetics. In 2006 after Colony Collapse Disorder set in, Mr. Vorisek used synthetic controls, but mites grew resistant, and treatments became less effective, leading him to use organic treatments such as formic acid or oxalic acid treatments but he has difficulties getting to his hives to treat them properly. Although beekeepers who used known, listed treatments maintained 30% more colonies than beekeepers who did not use these methods, Mr. Vorisek still felt these treatments were not as effective for the high prices they cost him (Seitz et al., 2015). In 2019, he reverted to one-time use of synthetic compounds because of increasing mite counts for these reasons that Mr. Vorisek is more adamant than ever to switch all his hives to mite-resistant bees with strong survivorship genetics.

Summary

The topics discussed throughout the interview with Mr. Vorisek can be categorized into two sections, direct and indirect implications of weather upon the honeybee. One direct implication of the interview was that wetter weather produces more honey, while more dry weather produces significantly less honey. Also, Mr. Vorisek recalled extreme colds, such as January 2009, where temperatures reached -10 °F. Although weather changes drastically year to year, extreme winters keep the bees in the cluster, allowing them to move throughout the hive, consume food and maintain heat. However, more mild winters encourage the bees to go on cleansing flights and even start raising brood resulting in a separation of the cluster, making it more difficult to maintain heat and preserve food for the remainder of the winter the following spring.

In most cases, extreme winters resulted in higher survival rates more so than mild winters. Another direct implication of weather is observed in the spring when there are warm spells that can get up to 60 °F for about a week, causing trees to begin producing pollen. Pollen, this early in the season, can be either good because it allows the bees to take cleansing flights, but if they become too active, they may use more food than they have to survive the remainder of the season. However, supplemental feeding resolves this issue. Warm weather too early in the spring followed by cold weather can also put the bees at risk if they have begun the brood-rearing process and become active for the pollination season as they will likely not have enough food to survive the following winter.

There are many indirect implications as well. Building upon the previously mentioned warm weather occurring earlier in the season, the phenology of flora and honeybees are advancing significantly. Earlier emergence of pollen and pollinators could result in a longer growing season or a high risk of malnutrition the following winter, as mentioned above. Furthermore, a longer growing season inherently results in a higher risk of infestation of *Varroa* mites. Spring blossom, clover, wildflower, and goldenrod consistently produced the most honey for Mr. Vorisek and should be focused on as essential flora in the region. Other implications include high moisture content in the air later in the season. Honey, being hygroscopic, will absorb that moisture and make the honey water-like and impossible to cap, creating wet conditions within the hive that encourages disease. As Mr. Vorisek mentioned, it is difficult to deduce these trends because it takes an entire year to notice the effects of something that happened the year prior. Also, he says, "We cannot live long enough to experience all the weather there is to experience," and it is for this reason that it is so difficult to draw a single conclusion about the impact of weather on the honeybee, especially during a changing climate.

Chapter 2: Climate change and the honeybee, specific to Northwest Pennsylvania

Introduction

Weather is the most influential factor contributing to the success of the honeybee. The complex relationship between weather and the honeybee constantly changes from season to season and from year to year. This section strives to address three main research objectives: assessing the impact of weather on the honeybee, the impact of changing weather trends in the Northwest Pennsylvania region, and utilizing scientific research to connect the two objectives mentioned above in order to deduce how the honeybee is and will be impacted by weather as the climate continues to change. Before understanding how the honeybee responds to certain conditions, there must be consideration of why the honeybee responds. Apis mellifera is a social insect that constantly changes its behavior year-round to adapt to adverse conditions, similar to humans. Thomas Seeley phrased it well in the title of his influential 2010 book based on decades of his own and fellow scientists' research. It is a Honeybee Democracy. Thomas Seeley's title is an accurate representation because, in the world of a honeybee, every action by an individual is a feat of evolution working in conjunction with the rest of the hive to create the most optimal conditions for the colony, best seen through the act of swarming (Seeley, 2010). However, swarming is a last resort effort to create better conditions for the hive. Factors influencing the decision to swarm consist of environmental factors such as weather, nutrition, disease, and pests. Managing adversity from these factors tends to be a democratic process as well, as will be exemplified throughout this chapter.

Assessing the impact of weather on the honeybee

Present-day, weather is highly variable, which presents an obstacle the honeybee is quite familiar with but an obstacle. Bees have lived through changes in the environment since their speciation about 130 million years ago. It took about 50 million years for bees to evolve into social insects, and approximately 65 million years after speciation, an asteroid struck the Earth (Goulson, 2013). Volcanic eruptions, tidal waves, and dust so thick that sunlight was blocked resulted in below freezing temperature and challenging conditions for any organism to survive in, yet insects recovered much more quickly than other species, according to fossil records (ibid). Although this asteroid was not a natural process occurring over time, the concept of extreme changes to the environment remains constant. First encountered in 1904, the honeybee began suffering from a disease called Isle of Wight, named after its place of origin, which would cause unprecedented loss, which many beekeepers believed to be caused by consistently inadequate weather conditions (Mace, 1912). Later analyses suggested that weather was unrelated to the spread of the deadly disease, now known as *Nosema*, a disease still prevalent today (Adam, 1968).

However, many beekeepers' primary claim was not unprecedented as more recent studies found that temperature and *N. apis* are negatively correlated (Chen et al., 2012). Although not the leading cause, weather influenced and most likely encouraged the spread of the disease. More than a century after the emergence of *Nosema*, Colony Collapse Disorder was first observed in 2006 and yielded similar, if not more, loss. Hives that experienced CCD had particular symptoms such as the rapid loss of adult worker bees with excess brood populations, lack of dead worker bees in and around the hive, and delayed infestation of parasites and pests, as well as invasion of neighboring bee colonies (vanEngelsdorp et al., 2009). Naturally, scientists and beekeepers looked to identify causes and develop remedies to save the honeybee population. One of the identified contributing causes is the weather.

One similarity between the asteroid, *Nosema*, and CCD effects is that the honeybee has adapted to the adversity it faces in ways unique from other species. As climate change continues to set in, the highly evolved honeybee faces another roadblock in the path of life. The natural phenomena of weather and human-influenced changing climates, yet again, presents every hive with decisions regarding survivability and productivity; only this time, it should be considered the main threat instead of exacerbating a separate threat. Climate change will likely alter the honeybee physiologically and behaviorally and its relationship with environmental factors such as flora, parasites, and diseases (Le Conte & Navajas, 2008). Hence, beekeepers will have to alter management methods to account for an evolving species. Also, there will be a change in the flora and weather patterns within the Northwest Pennsylvania region, encouraging the abundance of certain species over others. In summary, bees will either adapt gradually over time to a different environment or drastically alter their behavioral patterns.

Impact of weather on the honeybee

Pollination Services

Pollination is by far the most beneficial trait that the social honeybee has developed throughout its life history. Weather can have a significant impact on pollination efficiency by the honeybee. Optimal pollination depends heavily on factors such as temperature and humidity.

Foraging temperature occurs anywhere between 50 °F and 104 °F, while humidity is less of a factor in dictating foraging, especially in temperate climates (Abou-Shaara et al., 2017). In some cases, pollinators increase foraging rates during times of high humidity, possibly due to increased secretion of nectar (Peat & Goulson, 2005). On the other hand, bees collect pollen during warm, windy, and dry conditions (ibid). Under optimal weather conditions, foraging bees spend the daytime pollinating. However, non-optimal weather conditions result in reduced forage levels (Riessberger & Crailsheim, 1997). When forage levels decrease, the hive responds by eating less and conserving energy even if there

is no shortage of pollen or honey. Nurse bees will also feed young brood significantly less often, most likely in response to the diminished food flow (ibid). Older larvae receive preferential treatment when conditions are not optimal to maintain a healthy population within the hive for when conditions improve (Schmickl & Crailsheim, 2002).

In summary, pollination is disrupted by non-optimal weather conditions in the long and short term, worsening nutritional stress for the brood population from decreased forage activity. Nutritional stress increases the infection of *Nosema spp.* (Branchiccela et al., 2019). In the long term, young bee populations in the hive suffer from nutritional stress and food availability or even halt of brood production altogether, resulting in reduced colony populations in subsequent seasons (Brodschneider & Crailsheim, 2010 & Branchiccela et al., 2019). Also, within the optimal temperature range, foragers from high brood colonies tend to collect more pollen and take longer foraging trips than foragers in low brood colonies suggesting individual foragers recognize the colony state, place value on resources such as pollen and nectar, and adjust foraging behavior accordingly (Eckert et al., 1994). Hence, pollen and brood are positively correlated, signifying that colonies suffering from a lack of nutrition are more likely to observe a decrease in brood levels and vice versa for warm and cold seasons (Hellmich & Rothenbuhler, 1986, Free & Racey, 1968). When extreme weather, events, and temperature, become more frequent with the onset of climate change, survival rates will likely decrease.

Local flora is also weather-dependent and impacts pollination services. Northwest Pennsylvania is a temperate, mesic zone in which variability in temperature, precipitation, and snowfall in a changing climate can have extreme effects on plant life. A critical time for trees and plants is between the bud's emergence and the first flowering date, when cells are most active (Vitasse et al., 2014). Until flower or leaf emergence, the plant or tree is susceptible to low temperatures and frost, an increasing worry with more common warm spells in winter months (ibid). This time frame is critical because if pollinators do not have access to these early season pollen and nectar sources, then the mid-to-late-season adult population will significantly diminish. Changing weather patterns impact flowering and fruition more so than vegetative tissue meaning the plant will continue to perform photosynthesis and grow through varying weather. However, there will be negative implications for the parts of the plant important to pollinators (Borghi et al., 2019).

Overwintering

Honeybees are very responsive to environmental conditions, and there are physiological and biological factors that influence the winter survival rate of honeybees. Just as extreme heat negatively impacts bees, so does the cold. In most cases, hives are lost over the winter months, suggesting that

adverse overwintering factors compromise the hive's immune function. The hive has to be adequately prepared and exceptionally healthy entering the winter to emerge the following spring, ready to recover.

Honeybees experience physiological changes in the transition between the warm and cold seasons. On a physiological level, summer bees have a much shorter lifespan, approximately three to four weeks, due to the increased foraging activity. Winter bees, on the other hand, can survive up to six months. This evolutionary trait is possible primarily because of food stores' preparation in the summer, which allows the hive to cluster over winter months, conserving heat and energy. Bees begin to cluster at a temperature of 64.4 °F; however, disruption to motor functions occurs at about 46.4 °F. The hive forms one of three cluster formations (droplet, ring, disc) based on temperature conditions (Sumpter & Broomhead, 2000). Droplet clusters do not consist of moving bees as opposed to ring and disc clusters. Droplet clusters tend to occur under extreme freezing conditions when the heat from individuals is more significant than any other heat source inside the hive. All bees gather in inactive groups around the hive in this cluster formation (ibid). Bees can do this because they are endothermic insects. As heat sources arise in the hive, the cluster becomes active, allowing the bees to influence the ambient temperature. The bees begin with a disc formation, which rapidly increases the temperature within the cluster. Once there is sufficient heat, the cluster begins a pulsating motion, which involves bees creating a ring with a core allowing the bees on the ring to feed on honey stores while the bees in the core maintain high temperatures. After feeding occurs, the bees in the core disc will disperse into a ring, and the bees on the mantle, or ring, will gather in the core disc resulting in a pulsating-like motion (ibid). Maintaining a comfortable temperature while being able to feed is necessary for bees to be able to overwinter. If the hive experiences frigid temperatures or extreme weather and cannot work together to control the ambient temperature, then the hive will not overwinter successfully.

The physiology of bees alters significantly from warm to cold seasons, as does the biology. The biological changes that occur have a significant influence on the physiology and behavior observed over the winter months. Weather can compound with other environmental stressors, such as *Varroa* mites, to cause detrimental effects to bees' biological makeup and, in some cases, death. Winter bees exhibit a high expression of genes involved in antibacterial defense and a decrease in immune and physiological function compared to summer bees, resulting in a more significant number of deformed wing virus cases (Steinmann et al., 2015). Increased disease in the hive results from *V. destructor* mites as they are known carriers for viral diseases categorized as biological vectors such as *Nosema spp.* and deformed wing virus (Genersch & Aubert, 2010, Mariani et al., 2012). These mites likely reduce immune system strength in both developed and developing bees, thereby supporting the idea that the ectoparasite mite *V. destructor* promotes the transmission of viruses, even through the winter months, in some cases by a factor of 300 (Steinmann et al., 2015). Since honeybees do not forage during winter months, *Varroa* mites tend to be

accumulated over the pollination season and then nest on bees or with capped brood, thereby inhibiting the development or encouraging the presence of disease inside capped brood cells (Calderón et al., 2009). If mite populations become too stressful for the hive, not only will bees die from mites, but they will also exacerbate the impact of viral, bacterial, fungal, and additional infectious diseases in adult and newly emerged bees (Grozinger & Flenniken, 2019).

In some cases, the hive can recover from infection with the beekeeper's treatments early in the spring. However, a recent study observed that all hives with high mite counts and high mites per 300 bees during late August died by December, likely due to shortened lifespan caused by *Varroa* infestation (Seeley & Smith, 2015). Crowded colonies tended to have the highest mite counts (ibid).
In summary, mite infestation late in the pollination season will either cause death to the colony or shorten all bees' lifespan and facilitate disease in the individuals that remain. With reduced immune and physiological functions, surviving individuals will likely not be able to effectively contribute to the clustering method used to maintain a comfortable temperature in the winter, a process that requires the participation of the entire colony.

Phenological Relationships

To summarize from the introduction of this study, phenology is the seasonal weather, plants, and animals' seasonal timing. For example, many plants bloom or flower significantly earlier due to global warming than they have in the past (Miller-Rushing & Primack, 2008, Beaubien & Freeland, 2000). In turn, this disrupts the natural cycle of the honeybee because the weather is highly variable. Global warming trends impact more than just the seasonal timing of these species. Also, phenophases such as greening, budding, flowering, and fruiting, which are essential to the survivability and productivity of a plant, are dependent on events earlier in the season. Hence, changes in plant processes early in the season can disrupt processes later in the season (Ettinger et al., 2018). For example, if plants flower or bloom earlier in the season due to global warming, processes throughout the season such as reproduction, growing season, and senescence are impacted (Steltzer & Post, 2009). Honeybees depend on the life history of plants to be able to gather enough food to overwinter appropriately.

Eleven plants are currently of interest in the Northwest Pennsylvania region due to their importance as a nectar source (Ayers & Harman, 1992). *Acer rubrum*, the red maple, has advanced 19.13 flowering days on average in a study conducted from 1970 through 1999 (Abu-Asab et al., 2001). Although the red maple does not produce a significant amount of nectar, it is one of the first nectar sources for honeybees in the region and vital to understanding the plant-pollinator phenological relationship. Blackberry and Raspberry, *Rubus spp.*, has advanced between 7-13 flowering days (Diskin et al., 2012). *Liriodendron tulipifera*, the tulip tree, flowered 10.18 flowering days earlier on average.

(Abu-Asab et al., 2001). Common milkweed, *Asclepias syriaca*, has advanced approximately 3.93 flowering days from 2011 through 1016 (Howard, 2018). Also, *Melilotus officinalis*, a sweet clover species, exhibited a later flowering date but was statistically insignificant (Abu-Asab et al., 2001). *Trifolium repens*, the white clover, has observed a 7.50-day advance of the first flowering date per decade since 1978 (Williams & Abberton, 2004). As sumac, *Rhus* has been delayed 12 flowering days in the past century (Dunnell & Travers, 2011). *Robinia pseudoacacia*, or Black Locust, was found to have advanced significantly by 5.70 flowering days (Abu-Asab et al., 2001). *Tilia*, or basswood, advanced between 6-8 flowering days on average from 2012 through 2015 (Dąbrowska et al., 2016). Flowers such as *Solidago*, goldenrod, and *Asteraceae aster*, have statistically insignificant changes in flowering times (Johnston & Reekie, 2008). All of the plants mentioned above bloom between March and May. Goldenrod and asters are the only exceptions, blooming in June and July.

A direct correlation exists between all of the plants found to have an earlier first flowering date and an increase in air and or soil temperature of 1 °C, or 1.8 °F. The alteration of flowering or blooming dates will undoubtedly change how plants progress through the season, but it is not the focus of this study (Steltzer & Post, 2009). Depending on total emissions reduction in the coming years, the Northeast United States could observe an increase anywhere from 3 °F to 10 °F by 2080 (Horton et al., 2014). As this warming effect gradually sets in, more drastic changes in plant phenology will be observed depending on the severity, which could mean an extended growing season, which would result in a reduction of carbon dioxide in the atmosphere due to carbon sequestration and increased forest and plant growth (Hayhoe et al., 2018). However, an increased growing season also makes plants much more vulnerable to extreme temperatures. When plants begin to bud early in the season, they lose tolerance to cold temperatures and frosts during this time, impacting the entire growing season. In some cases, this can cause dramatically reduced crop yields or forest growth (ibid). If early blooming plants die, such as the ones mentioned above, due to late frost following an early bloom, pollinators face a precarious situation.

Pollinators, too, are beginning to emerge earlier in the spring. First cleansing flights have advanced more rapidly than the previously discussed plants, likely due to increased temperatures (Sparks et al., 2010). In fact, over the past 25 years, the first cleansing flights have advanced by 34 days, or approximately 1.35 days per year (ibid). The honeybee's ability to correct the phenological mismatch caused by global warming in such a short amount of time is encouraging; however, it is not without adversity. One issue created by an advanced plant-pollinator phenological relationship is that if plants suffer from late frost after an early bloom, then the honeybee is left without a nectar source. Similar to plants, once honeybees begin foraging after their first cleansing flight, they begin using honey stores to start the brooding process for summer bees based on the assumption that they will have a constant food source for weeks to come. Cold weather, rain, and frosts can disrupt this process leaving the hive

malnourished for the season's remainder, a claim supported by the direct positive relationship between honeybee flights and temperature (Burrill & Dietz, 1981). Another similarity between plants and honeybees' phenology is that neither species is advancing phenology due to a learning process but rather as a response to the environment, showcasing the honeybee's ability to adapt to adverse conditions (Sparks et al., 2010). Not only do they adapt, but they also excel by producing more honey from an increased number of harvests on average from 1965 through 2010 (Langowska et al., 2017). Honeybees respond to the environment because increased temperatures in the summer and fall encourage colony growth and good food stores for overwintering. If a colony is healthy, then the cluster will be more active due to more individuals giving off heat.

In some cases, populated colonies can rear brood in the winter months (ibid). However, these active processes require food, and with the consumption of food comes fecal production, encouraging an earlier first cleansing flight (ibid). Another issue worth noting is the involvement of *Varroa* mites. Colonies that rear brood earlier in the season can be three times more infested by mites than colonies that reared brood later (Nürnberger et al., 2019). High *Varroa destructor* levels early in the season result in reduced worker populations later in the season, directly associated with reduced winter survival (ibid).

Weather events, specific to Northwest Pennsylvania

Temperature

Winter had the most significant temperature variation out of all the four seasons over the past five years (Table 2, SEM = 1.07). Winter exhibited the most significant rise in temperature from typical, expected values, averaging +3.68 °F at 32.98 °F over the past five years (Figure 2, Table 3). This significant rise in average temperature is above freezing. However, during 2018 there was a low winter average of 29.60 °F (Table 1). Although the average winter temperature of 2018 is an outlier, it is closer to the expected average of 29.30 °F (Table 3).

Spring had the lowest variation in temperature of all four seasons over the past five years (Table 2, SEM = 0.53) and the lowest deviation from typical, expected values, rising 0.77 °F (Table 3). In 2018, there was a slight decrease in spring temperature, but on average, the temperature gradually increased closer to the observed average of 46.70 °F (Figure 1).

The summer of 2018 and 2020 exhibited the greatest average temperature of 73 °F and 73.1 °F over the past five years (Table 1). Over the past five summers, there has been significant temperature variation. (Table 2, SEM = 0.77). There was an average increase of 1.88 °F over the past five years (Table 3). Also, summer months tended to alternate between a rise and fall of approximately three degrees Fahrenheit each year over the past five years.

Fall temperatures increased 2.40 °F on average over the past five years (Table 2) with moderate variation (Table 2, SEM = 0.67). The highest average spring temperature was in 2016 at 58.0 °F, deviating 4.60 °F from the average expected value of 53.40 °F (Tables 1 & 3).

Precipitation

Overall, precipitation varied greatly through the four seasons. Winter observed the lowest variation (Table 5, SEM = 0.72). Also, winter precipitation deviated from the normal expected value by +2.24 inches, the most of any season (Figure 4, Table 6). 2018 had the highest precipitation in winter over the past five years with 13.97 inches, +2.65 inches more than the normal expected value (Tables 4 & 5).

Spring observed the most variation out of all four seasons (Table 5, SEM = 1.26). There was a moderate change in average precipitation of +0.72 inches over the past five years in comparison to average expected values (Table 6). Spring precipitation also varied greatly over the past five years ranging between 6.56 inches and 13.55 inches (Figure 3, Table 4).

Similar to spring, summer observed significant variation in precipitation (Table 5, SEM = 1.10). Precipitation amounts varied between 7.92 inches and 14.29 inches (Table 4). However, summer was the only season with a decrease in precipitation, -0.124 inches, from the typical, expected values due to seasons like the summers of 2018 and 2020, which experienced only 8.87 inches and 7.92 inches of precipitation respectively (Table 6).

Fall experienced deviations similar to the spring with only a 0.88-inch increase in precipitation (Table 6) and moderate variation (Table 5, SEM = 1.02). Four out of the five years graphed obtained between 14 inches and 15 inches of precipitation, with 2019 being the outlier receiving only 9.43 inches (Table 4).

Snowfall

Winter observed the most snowfall compared to the other three seasons over the past five years, with the most variation amongst annual averages (Table 8, SEM = 18.51). Over the past five years, 82.62 inches of snow were observed on average, 7.32 inches greater than the standard expected value of 75.30 inches (Table 9). 2018 received significantly higher snowfall figures, reaching 156.40 inches (Table 7).

Spring observed a decrease in average snowfall of 4.36 inches from the standard expected value (Table 9). However, spring 2018 obtained 42.00 inches of snowfall (Table 7). This outlier contributed to a high variance over the past five years (Table 8, SEM = 7.51).

Fall also experienced a decrease of 1.13 inches from the standard expected value of 8.70 inches (Table 9). 2018 was an outlier in this season as well, recording 19.5 0inches (Table 7). Also, there was a low variance among snowfall in this season (Table 8, SEM = 3.55).

Summer months received no snowfall, as expected, over the past five years (Table 7).

Future of beekeeping in Northwest PA, considering current weather trends

Earth's climate is inevitably changing due to human impact, and as a result, change occurs in all aspects of an ecosystem. Pollinators are emerging earlier as plants are blooming or flowering earlier. Bees adapt to the changing climate in less time than plants and other species in a truly magnificent feat of evolution. Winter temperatures have risen +3.68 °F to above freezing over the past five years (Figure 2, Table 3). Fall temperatures have risen +2.40 °F on average (Table 2). To that end, summer and winter temperatures have been highly variable (Table 2). Summers have become drier, while springs have been highly unpredictable (Table 6, Figure 3 & Table 4).

Additionally, aside from the 2018 snowfall outlier, there has been an average decrease of -11.13 inches of snowfall reinforced by record-high water temperatures in the Great Lakes during the summer of 2020 (Table 7 & Table 9). The early melting of lake ice likely causes water stratification based on temperature, forcing warmer water to the top of the lake, thereby reinforcing warming air temperature trends (Carlowicz, 2020). The states bordering the Great Lakes have observed a +1.4 °F increase (Wuebbles et al., 2019). Warming temperatures and decreasing snow levels make a longer growing season possible, but not necessarily optimal. Warmer temperatures negatively impact flowering and fruition. A longer growing season impacts plant processes such as reproduction and senescence and makes honeybees more susceptible to mite infestation and disease late in the pollination season. Both plants and pollinators are put at risk by extreme weather and cold spells following warm temperatures earlier in the season, a trend that has been increasingly observed (ibid).

Chapter 3: Beekeeping, accounting for climate change

Discussion

In an ecosystem, high complexity comes with intersectionality. In the case of the honeybee, this intersectionality involves relationships with flora, weather, and other bees. This study analyzed these relationships to answer the question, how have changing weather patterns in Northwest Pennsylvania impacted the honeybee? Today, most scientific literature suggests that temperature will increase in most zones worldwide as a result of warming and the greenhouse gas effect (Xu et al., 2020). Also, many extreme weather events will become more frequent (ibid). For the honeybee, this could potentially have beneficial and or detrimental effects. Higher temperatures throughout the year logically suggest a longer growing season. Honeybees have advanced their first cleansing flights by 34 days in the past 25 years and every essential nectar source in northwest Pennsylvania has advanced first flowering dates by anywhere between 3.93 to 19.13 days (Sparks et al., 2010 & Abu-Asab et al., 2001 & Diskin et al., 2012 & Howard, 2018 & Williams & Abberton, 2004 & Dunnell & Travers, 2011 & Dąbrowska et al., 2016).

Many implications come with a longer growing season. The first flowering dates of early blooming or flowering flora do not occur until spring, even though they are advancing. Hence, there are still no pollen or nectar sources over the winter months. Combined with warming temperature in the cold season, overwintering becomes much more difficult for the honeybee because it encourages cleansing flights and brood rearing, in some cases, which require a significant amount of consumption of honey stores. Low honey stores at the beginning of the spring make it difficult for the hive to recover and overwinter the following year. Cold winters force the bees to cluster and maintain warmth and food stores with excellent efficiency allowing for ample food stores as spring approaches to begin brood rearing of summer bees (Sumpter & Broomhead, 2000). Unpredictable weather in the early spring has negatively impacted hives in the northwest Pennsylvania region and beyond. Warm spells in early spring are commonly interrupted by cold weather, rain, or snow, which can trick the bees into thinking there is enough pollen to begin foraging, causing them to use more food than they have to survive the remainder of the season. It can also negatively impact flora because plant cells are most active between the bud's emergence and first flowering date (Vitasse et al., 2014). During this time, plants are susceptible to low temperatures and frost, events that impact flowering, fruition, and pollen-producing parts of plants for the rest of the season (Borghi et al., 2019). Pollinators that do not take advantage of these early nectar and pollen sources suffer from nutritional stress late in the season. Nutritional stress can lead to an increased presence of parasites like *Varroa destructor* and diseases such as *Nosema spp.* and deformed wing virus. Increased mite presence leads to increased transmission of biological vector diseases because mites place

themselves inside the capped brood (Genersch & Aubert, 2010, Mariani et al., 2012). Additionally, a longer growing season will likely increase mite presence in the hive due to frequent flights.

To conclude, the honeybee is quite versatile and has not only overcome adverse conditions such as the asteroid which hit Earth 65 million years ago, the emergence of Nosema spp., and most recently, the onset of colony collapse disorder. The species will likely be able to adapt and survive, but to what extent depends on the relationships discussed throughout this study. It is impossible to conclude if the northwest Pennsylvania region becomes more or less suitable in a changing climate. The effects, however, will undoubtedly be of significant variation and high complexity, giving the honeybee a challenging task to overcome.

Limitations and Further Research

The most significant limitation of this study was the inability to interview more than one beekeeper. Although Mr. Vorisek is one of the leading beekeepers in the Northwest Pennsylvania region, accounting for the experience of multiple beekeepers in the area would have made all conclusions much more reliable. Also, data collection was an issue. Many beekeepers in the region do not record or collect annual honey yields, loss numbers, or simple observations. Much of this information is stored mentally by beekeepers but recording this data could be essential to deducing trends between weather and the honeybee. In addition to encouraging beekeepers to record and store such data, scientists should also attempt to monitor conditions such as behavior, development, and physiological changes throughout the seasons and over multiple years.

Literature today is unsure of the impact of weather on beekeeping in specific regions. As climate change continues to worsen, many studies analyze which regions will experience specific effects. As a result, some studies are investigating the impact of those same effects on the honeybee. This study aims to assess current literature regarding climate change and its impact on the honeybee while considering regionality. By analyzing current literature regarding a particular region, a better idea of how suitable, in this case, Northwest Pennsylvania, a region is and will be for the honeybee. Hence, further research should aim to continue similar investigations on a broader scale, taking into account the experiences of multiple beekeepers in a region and any new literature that arises. Specifically, data collection is vital to deducing a more apparent trend than the one found in this study.

Future studies should analyze developmental changes throughout the season concerning weather patterns early in the season. For example, the frequency of warm fronts early in the spring and its impact on the colony over multiple pollinating seasons. Additionally, studies should closely monitor the phenology of both plants and pollinators. As shown throughout this study, many different changes occur at the biological level for both taxa, and a better understanding of these changes within specific regions

will help to deduce what regions will be most suitable for the honeybee in a next-century climate. Most importantly future studies should consider weather as the problem, not a factor contributing to a problem.

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Appendix A: Tables

Table 1: Observed seasonal temperature values, in Farenheit, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

	Spring (°F)	Summer (°F)	Fall (°F)	Winter (°F)
2016	48.4	72.7	58	34.9
2017	48.4	69.8	55.3	34.5
2018	45.9	73	54.2	29.6
2019	46.6	69.8	54.9	31.3
2020	48.3	73.1	56.6	34.6

Table 2: Summary statistics for observered seasonal temperature values, in farenheit, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

Winter	MEAN (°F)	32.98
	STDEV	2.391024885
	SE	1.069298836
Spring	MEAN (°F)	47.52
	STDEV	1.186170308
	SE	0.530471488
Fall	MEAN (°F)	55.8
	STDEV	1.508310313
	SE	0.674536878
Summer	MEAN (°F)	71.68
	STDEV	1.722498186
	SE	0.770324607

Table 3: Observed and expected average seasonal temperature values, in Farenheit, in the Erie region by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

	Expected Temperature	Observed Average Temperature
Spring	46.7	47.52
Summer	69.8	71.68
Fall	53.4	55.8
Winter	29.3	32.98

Table 4: Observed precipitation values, in inches, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

	Spring (in.)	Summer (in.)	Fall (in.)	Winter (in.)
2016	6.56	14.29	14.72	10.1
2017	12.57	11.38	14.6	11.3
2018	13.55	8.87	14.56	13.97
2019	8.85	10.77	9.43	9.97
2020	10.68	7.92	14.04	11.26

Table 5: Summary statistics for observed precipitation values, in inches, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

Winter	MEAN (in.)	11.32
	STDEV	1.607591366
	SE	0.718936715
Spring	MEAN (in.)	10.442
	STDEV	2.821749457
	SE	1.26192472
Fall	MEAN (in.)	13.47
	STDEV	2.273433527
	SE	1.016710382
Summer	MEAN (in.)	10.646
	STDEV	2.470734709
	SE	1.104946153

Table 6: Observed and expected precipitation values, in inches, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

	Expected Precipitation (in.)	Observed Average Precipitation (in.)
Spring	9.72	10.442
Summer	10.77	10.646
Fall	12.59	13.47
Winter	9.08	11.32

Table 7: Observed snowfall values, in inches, in the Erie region from Spring 2016 to Winter 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

	Spring (in.)	Summer (in.)	Fall (in.)	Winter (in.)
2016	4	0	2.4	66.7
2017	10.3	0	0.5	65.9
2018	42	0	19.5	156.4
2019	5.1	0	7.9	65.7
2020	1.3	0	1.1	58.4

Table 8: Summary statistics for observed snowfall values, in inches, in the Erie region from Spring 2016 to Winter 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

Winter	MEAN (in.)	82.62
	STDEV	41.3805147
	SE	18.5059288
Spring	MEAN (in.)	12.54
	STDEV	16.7893716
	SE	7.50843526
Fall	MEAN (in.)	6.28
	STDEV	7.94808153
	SE	3.55449012
Summer	MEAN (in.)	0
	STDEV	0
	SE	0

Table 9: Observed and expected snowfall values, in inches, in the Erie region from Spring 2016 to Winter 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

	Expected Snowfall (in.)	Observed Average Snowfall (in.)
Spring	16.9	12.54
Summer	0	0
Fall	8.7	7.575
Winter	75.3	82.62

Table 10: A data set containing temperature, precipitation, and snowfall spanning Winter 2015/16 to Fall 2020. Deviation from normal averages derived from the Climate Normal Period, 1981-2010. Data was obtained from the Erie, PA Seasonal Climate Summary for each respective season from the National Weather Service Forecast Office of the NOAA. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

Time	Temperature (F)		Precipitation (inches)		Snowfall (inches)	
	Observed Average	Deviation from Normal	Observed Total	Deviation from Normal	Observed Amount	Deviation from Normal
12/1/2015 – 2/29/2016	34.9	5.6	10.1	1.02	66.7	-8.6
3/1/2016 to 5/31/2016	48.4	1.7	6.56	-3.16	4	-12.9
6/1/2016 – 8/31/2016	72.7	2.9	14.29	3.52	0	0
9/1/2016 – 11/30/2016	58	4.6	14.72	2.13	2.4	-6.3
12/1/2016 – 2/28/2017	34.5	5.2	11.3	2.22	65.9	-9.4
3/1/2017 to 5/31/2017	48.4	1.7	12.57	2.85	10.3	-6.6
6/1/2017 – 8/31/2017	69.8	0	11.38	0.61	0	0
9/1/2017 – 11/30/2017	55.3	1.9	14.6	2.01	0.5	-8.2
12/1/2017 – 2/28/2018	29.6	0.3	13.97	4.89	156.4	81.1
3/1/2018 to 5/31/2018	45.9	-0.8	13.55	3.83	42	25
6/1/2018 – 8/31/2018	73	3.2	8.87	-1.9	0	0
9/1/2018 – 11/30/2018	54.2	0.8	14.56	1.97	19.5	10.8
12/1/2018 – 2/28/2019	31.3	2	9.97	0.89	65.7	-9.6
3/1/2019 to 5/31/2019	46.6	-0.1	8.85	-0.87	5.1	-11.8
6/1/2019 – 8/31/2019	69.8	1.6	10.77	-0.52	0	0
9/1/2019 – 11/30/2019	54.9	1.5	9.43	-3.16	7.9	-0.8
12/1/2019 – 2/29/2020	34.6	5.3	11.26	2.18	58.4	-16.9
3/1/2020 to 5/31/2020	48.3	1.6	10.68	0.96	1.3	-15.6
6/1/2020 – 8/31/2020	73.1	3.3	7.92	-2.85	0	0
9/1/2020 – 11/30/2020	56.6	3.2	14.04	1.45	1.1	-7.6

Table 11: A record of colony loss, colony replacements and total honey yield totaled from Mr. Vorisek's colonies from Fall 2014 through Spring 2020.

Year	October/November Colonies	Next April Live Colonies	Loss (%)	Replacements (colonies)	Honey Yield (lbs.)
2014	135	68	50	50	9,455
2015	160	61	62	70	11,772
2016	160	64	60	130	15,352
2017	173	116	33	61	16,179
2018	186	148	20	32	15,587
2019	191	95	50	74	12,209
2020	195	150	23	49	12,968

Appendix B: Figures

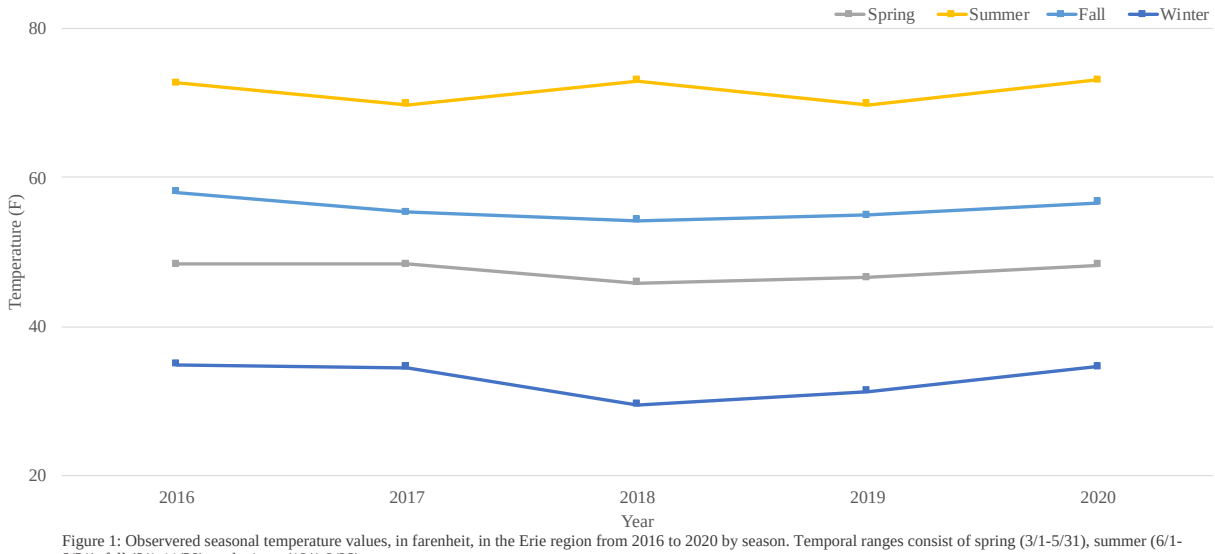

Figure 1: Observered seasonal temperature values, in farenheit, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

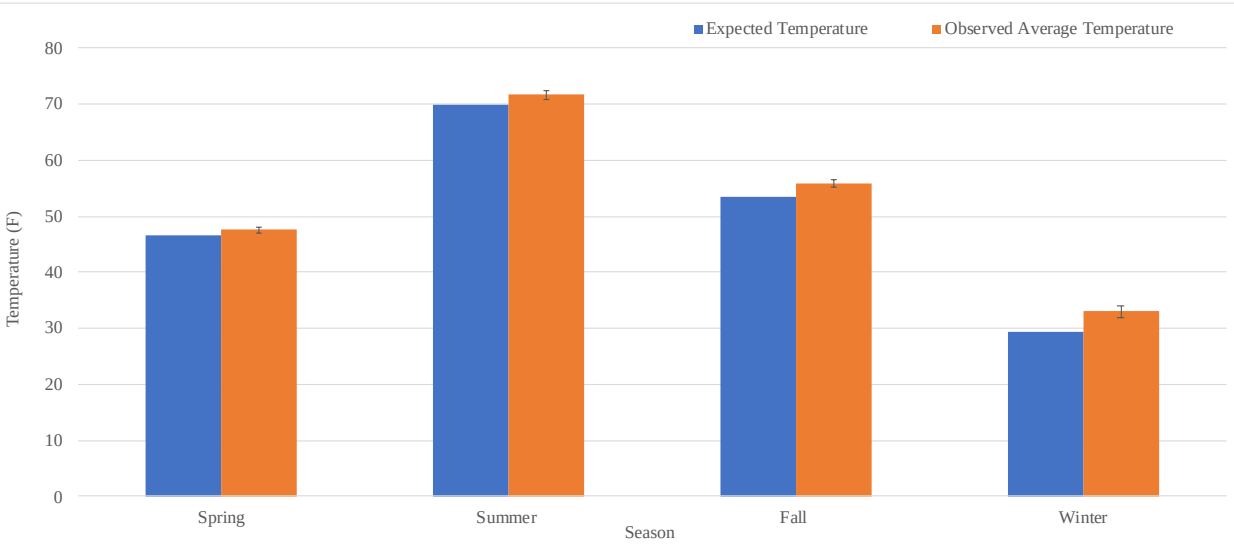

Figure 2: Average observed seasonal temperature values (Mean±SEM), in farenheit, shown in comparison to expected temperature values, in farenheit, in the Erie region from Spring 2016 to Winter 2020. Temporal ranges consist of spring (3/1-5/31; n=5), summer (6/1-8/31; n=5), fall (9/1-11/30; n=5), and winter (12/1-2/28; n=5).

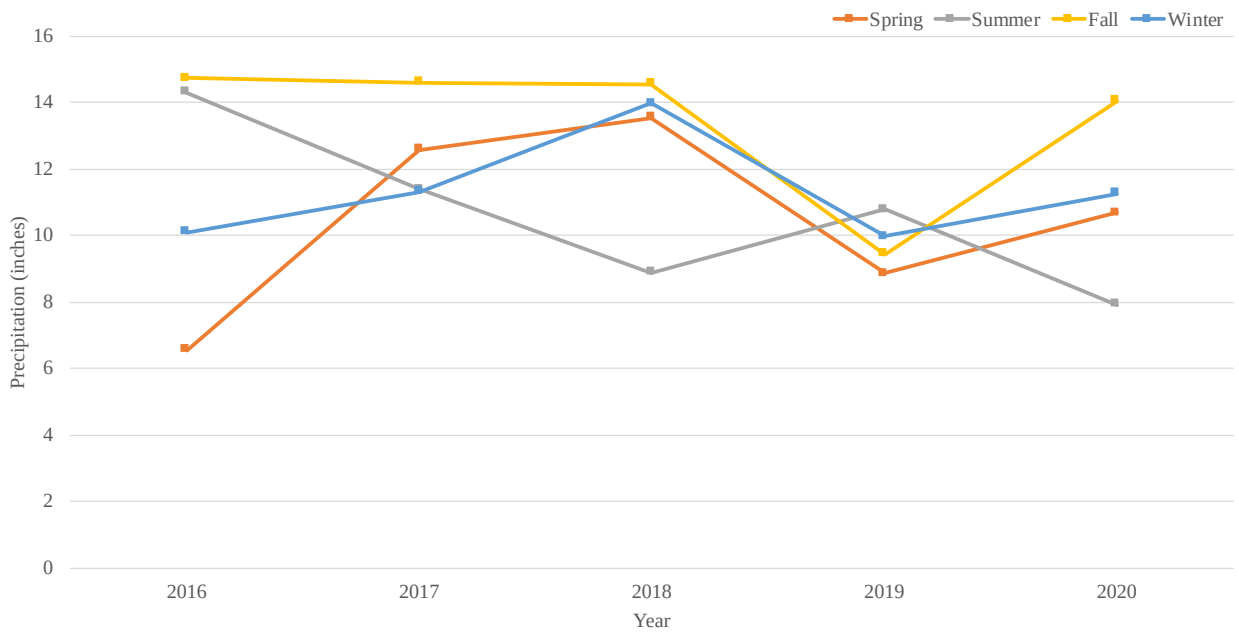

Figure 3: Observed precipitation values, in inches, in the Erie region from 2016 to 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28).

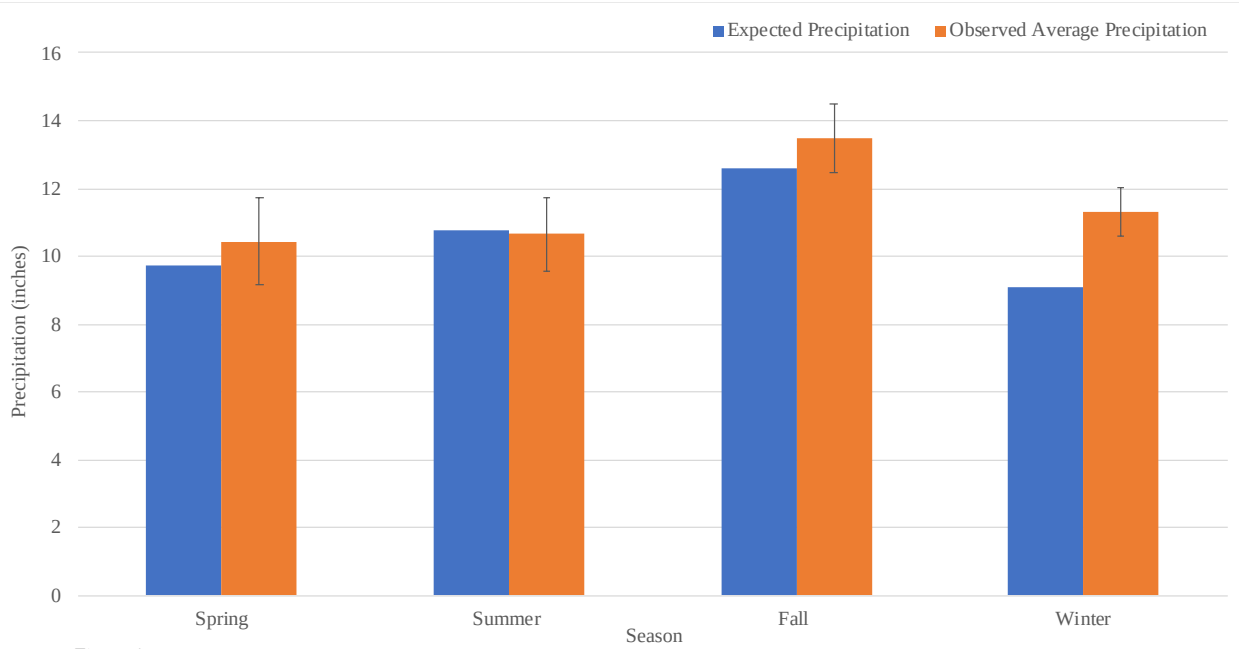

Figure 4: Average observed precipitation values (Mean±SEM), in inches, shown in comparison to expected temperature values, in inches, in the Erie region from Spring 2016 to Winter 2020. Temporal ranges consist of spring (3/1-5/31; n=5), summer (6/1-8/31; n=5), fall (9/1-11/30; n=5), and winter (12/1-2/28; n=5).

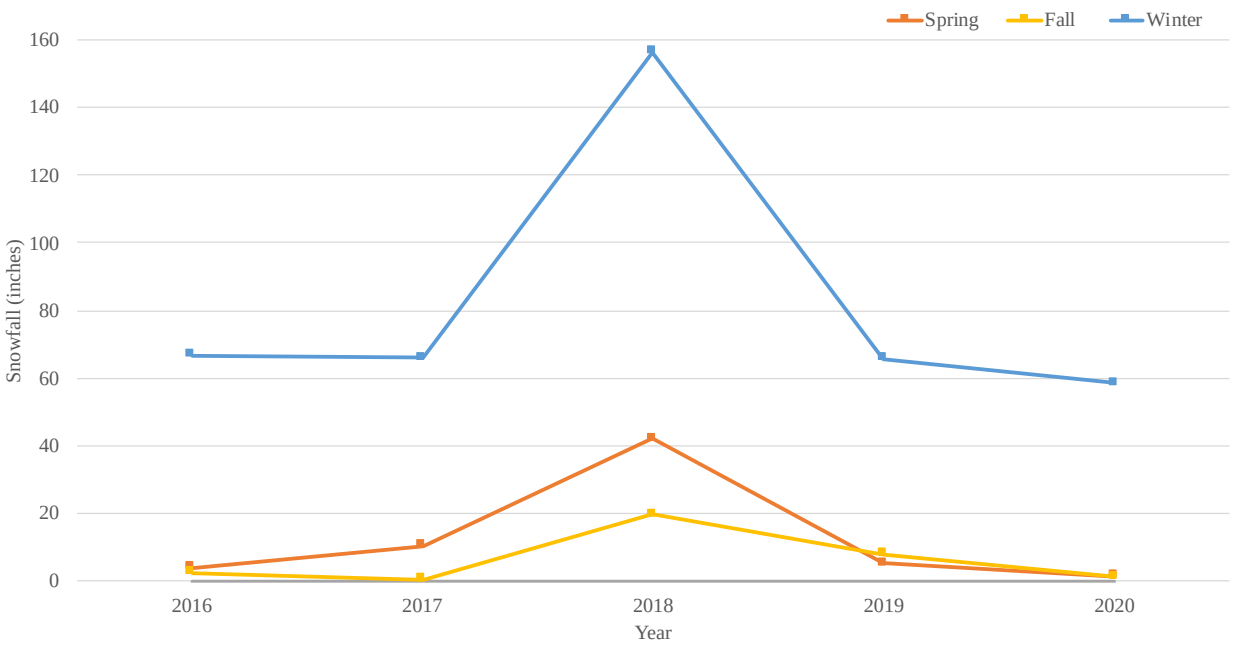

Figure 5: Observed snowfall values, in inches, in the Erie region from Spring 2016 to Winter 2020 by season. Temporal ranges consist of spring (3/1-5/31), summer (6/1-8/31), fall (9/1-11/30), and winter (12/1-2/28). Summer snowfall measurements remained at 0 inches each year.

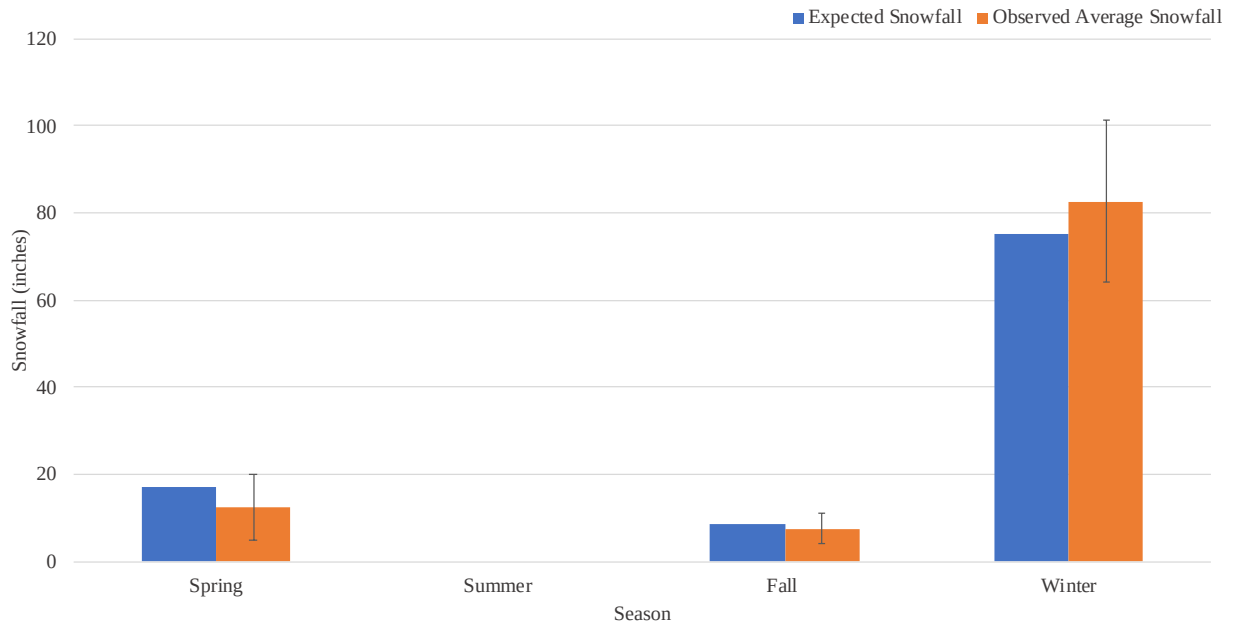

Figure 6: Average observed snowfall values (Mean±SEM), in inches, shown in comparison to expected snowfall values, in inches, in the Erie region from Spring 2016 to Winter 2020. Temporal ranges consist of spring (3/1-5/31; n=5), summer (6/1-8/31; n=5), fall (9/1-11/30; n=5), and winter (12/1-2/28; n=5).

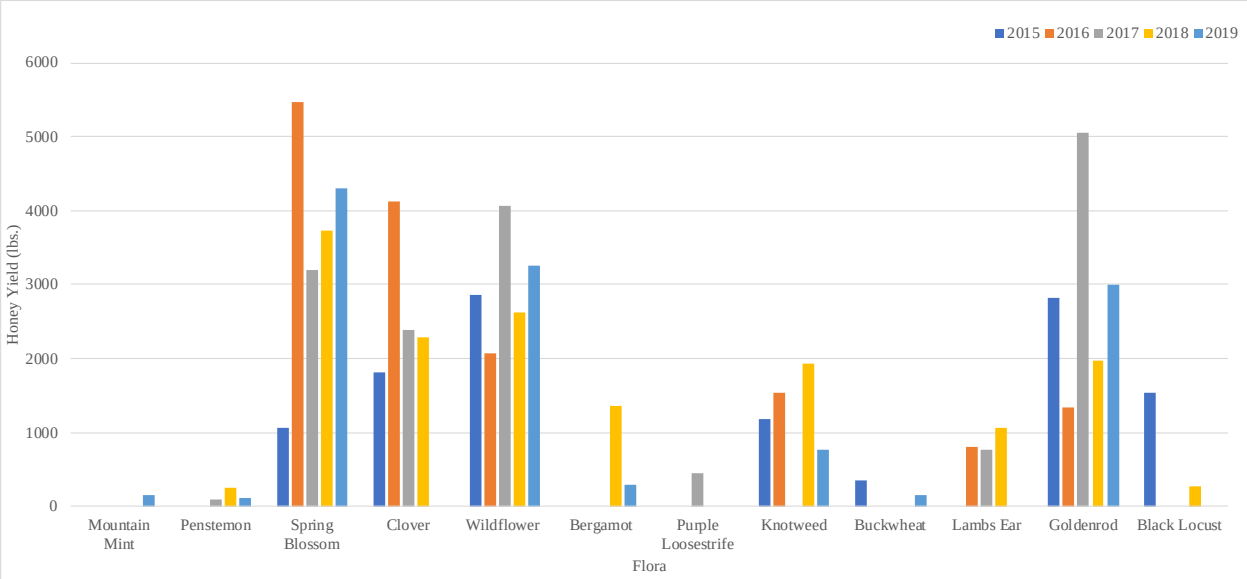

Figure 7: Honey yields for each plant harvested from Mr. Vorisek's colonies across Crawford County from 2015 through 2019. Not all plants were harvested every year.

Appendix C: Survey Questions

1. What does beekeeping look like for you? How many hives do you have? How do you treat or supplement your hives? Do you harvest honey once a season or multiple times throughout the season?
2. Do you keep records of your honey harvest and winter survival rate? Do you sell bee products? If so, do you keep records of those sales? Would you be willing to share this data after the interview?
3. Have you noticed any irregularities in hive survivability or productivity (i.e., hive health, honey production, size of the hive)? If so, how long have these irregularities been occurring? How has your management tactics as beekeeping changed following these irregularities? What do you believe is the cause of these irregularities?
4. Have you noticed a change in the length or start/stop times of the nectar/pollen-producing season? Have you noticed changes in the trees or plants that your hives forage? Are there any new plants/trees that the bees are visiting?
5. Do you believe your hives have impacted by weather in the past 5-10 years? If so, what measures have you taken to prevent hive loss as a result?
6. How do you believe beekeeping might change as a result of changing weather patterns?