Shifting Seasonality and Its Impact on Urban Beekeeping

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Abstract

Climate change is shifting the timing of seasonal events across the world, impacting practices that rely on consistent seasonal patterns such as beekeeping. Beekeeping has become increasingly difficult as beekeepers struggle to adapt their techniques to unpredictable weather patterns caused by climate change. In collaboration with CALENDARS, a study examining seasonal events and how they impact societies, the team created a proposal for an app that will assist beekeepers in adjusting their practices in response to shifting seasonality. Through interviews with beekeeping associations, we determined a connection between the practices of a beekeeper and the way that they rely on seasons. However, the rise of precipitation and temperature trends in Germany emphasized the need for beekeepers to adjust their practices to the changes in seasonality.

Beekeepers have a diverse set of practices that they use to help maintain the health of their hives. Beekeepers and their organizations mostly subscribe to one of two philosophies. Some take a hands-off approach focused on natural hive strength and survival, which allows the bees to act as they would in nature, in the hopes of creating independent colonies. Other beekeepers take a more active role in managing their hives. This approach is marked by the adaptation of various chemicals to handle the rise of varroa mites during warmer winter months. A cultural difference was recognized within the beekeeping community, as some beekeepers utilized technology while others kept to the traditional methods of beekeeping. Based on a literature review and expert interviews, the main areas of technological innovation relevant to small-scale beekeeping were sensors and apps.

The team found an abundance of data stored within apps, but very few methods to draw conclusions. Finally, an app was proposed with novel features addressing problems found during research. These features include the tracking of weather patterns, creating a database of beekeeping practices, and developing a tool to draw conclusions for beekeepers about the data they collect. This app would enable beekeepers to understand the climate around them, its impact on their practice, and methods to curb these effects.

Unpredictable Weather and its Impact on Urban Beekeeping

Climate change is causing significant shifts in seasonality, affecting ecosystems and population growth around the globe.[1] Seasonality is the predictable change in seasons and weather patterns expected to occur in a year.[2] In recent years, rising global temperatures have persisted and extreme weather phenomena have been observed more frequently, emphasizing the disturbance in seasonality.[3] Temperature and precipitation influence factors such as evaporation rates, snow coverage, plant growth, and food availability, each of which has far-reaching impacts on the ecosystems that they are a part of.[4] This change has prompted the need for various seasonal practices to adapt in order to maintain a sense of normalcy.

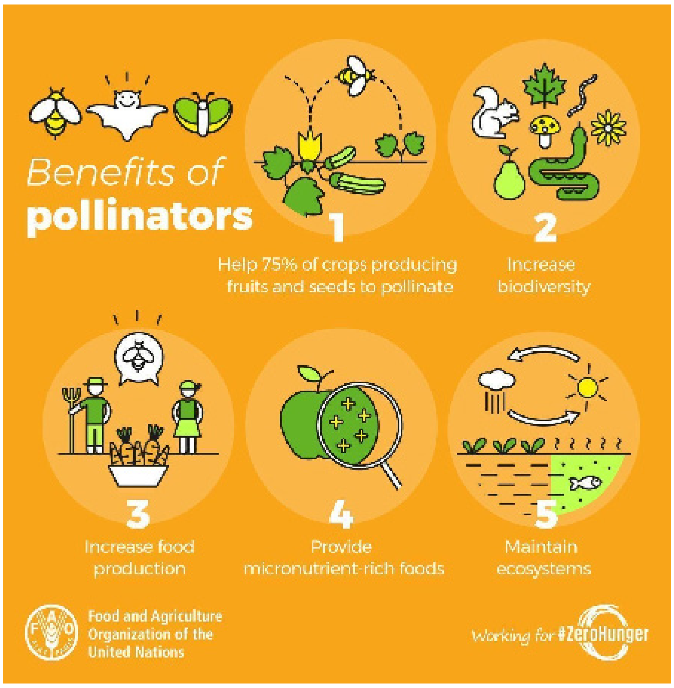


Figure 1. *Benefits of pollinators visual graphic, showing five different ways in which pollinators contribute to the environment.*[12]

One such practice heavily impacted by these seasonal shifts is beekeeping.[5] Beekeeping is the care and management of bee colonies to aid the ecosystem and environment.[6] As shown in Figure 1, bees serve an important role in nature as pollinators, which are integral to many ecosystems that humans rely upon.[7] Changing patterns in the seasons make it difficult for beekeepers to predict the weather,[1] leading to diminishing bee populations and escalated hive damage.[8] Seasonal unpredictability necessitates beekeepers provide additional resources to ensure their hive's survival. The effects of climate change are dramatically increased in urban environments due to the high density of buildings, infrastructure, and above-average human activity. These factors create urban heat islands, which are areas that experience increased temperatures compared to the surrounding rural areas.[9] They are areas with unpredictability of seasonal shifts, and emerging practices such as urban beekeeping are susceptible to heat island impacts.[10] A reduction in flora and overheating due to these heat islands has made the practice of urban beekeeping difficult to both start and maintain.[11]

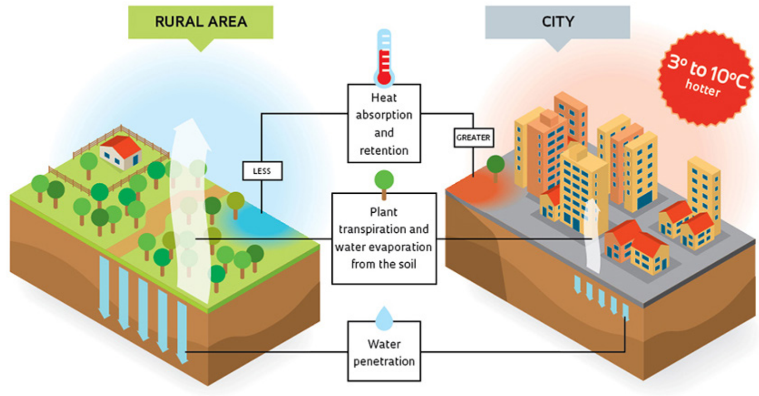


Figure 2. *Urban heat island effect*[15]

Beekeeping in German cities has increased in popularity; however, research and resources have been limited, challenging beekeepers' response to seasonality shifts.[13] These beekeepers also can find it difficult to identify support systems[10] and mentors to learn how to adapt to changes. Most beekeepers will make use of conferences established by urban beekeeping organizations, city beekeeping bloggers and content creators.[14] To further learn and understand their practices, urban beekeepers rely on each other as primary sources to gather information. As the practice grows in Berlin, research currently focuses on education and the growth of the field.[10] Many beekeepers in Berlin are novices and require additional guidance to ensure the survival of their hives. Although information on the educational portion of beekeeping can be acquired, little has been done to bridge the gap between the impacts of heat islands on Berlin's seasons and beekeeping. The technical knowledge required to understand weather data and patterns in addition to the growing popularity of this field necessitates further research accessible to everyone.

This project's goal is to create a proposal for an app that will assist beekeepers in adjusting their practices in response to shifting seasonality, using Berlin as a case study. The proposed app would provide short term predictions of future seasonal conditions and recommend techniques to best counteract the effects. This information has been gathered by conducting research on weather data, as well as conducting expert interviews with beekeepers. As the data is collected, our proposed app would have the ability to compile and sort the information that is relevant to the user. Additionally, to validate our findings, we conducted further research into secondary sources, primarily in the form of a literature review. This allowed us to connect specific weather patterns to beekeeping practices that proved effective under specific conditions. Another avenue of helping beekeepers maintain hive health is through the incorporation of technology. To address this, our team researched and consulted experts in beekeeping technologies and developments, with a focus on sensor use. By incorporating both meteorological weather patterns and internal sensor data into our app, beekeepers will be able to receive more precise recommendations on how best to help their hives.

The Dangers of Shifting Seasonality for Beekeepers

Seasons are one of the easiest and most visible ways that people track the passage of time. They can be defined as a series of patterns related to weather, precipitation, and daylight hours, among other factors. Seasons are also used to map out key events, such as growing seasons and holidays. The consistency and normalcy of these seasons is what makes them both relevant and important to people. Expecting certain events, patterns, and behaviors allows for a greater understanding of the wider world. Each season also brings with it an expectation that people plan around when thinking of the future, especially in fields such as agriculture, beekeeping, and fishing.[16] When variations and changes in these patterns occur, they can have devastating impacts on communities and organizations.

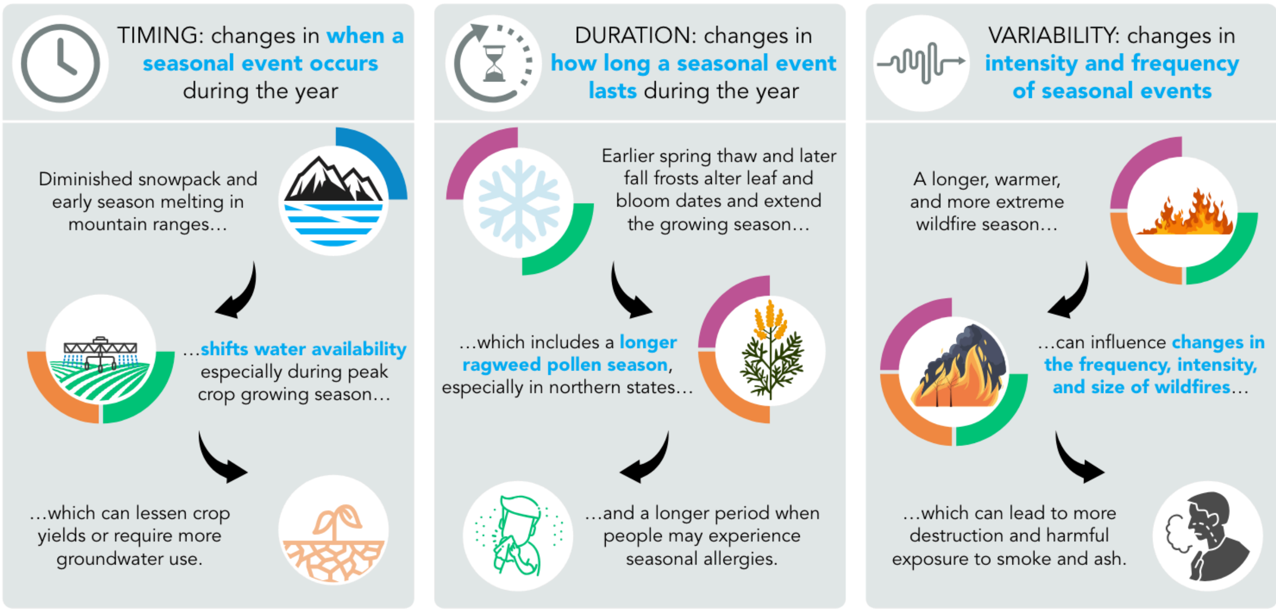


Figure 3. *The concept of seasonality refers to recurring events or processes that are correlated with seasons. Three aspects of seasonality that are impacted by climate change are: timing, duration, and variability.*[21]

Major changes in seasonal shifts can result in dangerous and potentially fatal impacts to communities. Agriculture, for example, is a highly vulnerable area to climate change.[16] Late winters and early summers can lead to later growing seasons and heavily reduced crop yields, causing widespread food insecurity and famine.[17] Shifts in seasonal events such as snowfall and melt, monsoon seasons, heat waves, and the like all heavily influence animal behavior and health. With so many natural cycles being interconnected, such as predator-prey relationships, the offset of one species' habits can have a rippling impact across entire ecosystems. This impact also extends to humans and their practices as well. Hunting seasons shift and change, land fertilization may occur at an offset time from farming practices, and some practices can even be rendered ineffective,[18] like beekeeping cycles and patterns.[13]

Beekeeping is vital in pollinating the world's ecosystem and is also very sensitive to seasonal shifts.[19] It has been observed that the historical climate has been changing, not only in temperature but also in weather patterns. Some examples of this are the winters are no longer as cold, and the summer season lasts for a longer period with a significantly higher temperature. With warmer winters, snow instead turns to rain showers[4] as well as no longer having a long enough cold period to rely on it killing off parasites, like varroa mites. High temperatures in the summer are also very dangerous, causing hives to overheat and go through heat stress.[20] Without proper countermeasures, these weather extremes can become devastating to a colony's well-being. Shifts in seasonality affect the ecosystems that they occur in, often negatively impacting the plants and creatures that have adapted to their historic environments.

The Impact of Shifting Seasons on Bees Health

The increase in the heat over the summer period has negatively affected bees health in Germany. This is especially prevalent during a heat wave, a period "of at least three days on which the daily mean air temperature is above the 95th percentile of a reference period".[22] A large effect that heat waves have on bees and other pollinators is causing them to have heat stress. Heat stress has many physical effects on insects "include multiple aspects such as their growth, development, task-related physiology, immunocompetence, foraging activity, pollination services, and reproduction".[23] This can cause hives to die off from individual bees becoming too weak to gather pollen and other resources. Important traits for bee reproduction are also negatively affected by extreme heat, including male fertility, sperm count, and sperm DNA integrity, leading to lower investment in brood production.[22] Increased difficulty in reproducing causes complications in rebuilding and replenishing their population size throughout the year, which can also cause the hive to die. What this demonstrates is that with more frequent heatwaves, bee colonies health is going to be negatively affected by heat stress and reproduction difficulties.

With the rise in temperature during the winter seasons in Germany, the health of bees is being negatively affected. Due to the warming of temperature there has been a decrease in periods of frost during the winter season. This allows for parasites, like the Varroa mite that typically reduce in number during the frost due to lack of brood, to survive and reproduce more. The Varroa mite is a parasite that latches onto bees and spreads diseases that can be harmful to the health of the hive. "Varroa are present, virus concentrations rise and some bees may have deformed wings as a result of the DWV virus. The virus can grow in both the bee and the mite, and the mite transmits the virus to the bee during feeding".[24] This demonstrates that when the winter seasons are warmer the Varroa mite population is able to grow and spread deadly diseases to bee colonies that negatively impact the bees health, in addition to the colony collapsing due to lack of brood.

Figure 4. *Western Honey Bee (Apis Mellifera) with attached the parasitic Varroa mite.*[25]

The increase in precipitation in Germany is another climate change-driven trend that has adversely affected bees. This "higher than normal precipitation in the preceding spring and fall was negatively correlated with colony size change and with foraged nectar mass, respectively".[26] This is due to these extreme weather events causing more precipitation, making it harder for bees to collect pollen and damaging hives by the rainfall. Since "weather greatly influenced whether bees collect pollen or nectar. Pollen was preferably collected when it was warm, windy, and particularly when humidity was low; and preferably during the middle of the day".[27]

Therefore, rising precipitation due to the changing seasonality of Germany has had negative effects on bees as they are unable to collect enough food for their hives.

The interconnected factors between the practice of beekeeping and the changing of seasonality in Germany have had negative effects on bee health and productivity. The increased frequency of heat waves during the summer adversely affects bee populations leading to heat stress, compromised reproductivity, and ultimately weaker hives. Additionally, the rise in precipitation in Germany has negatively impacted the bee's ability to collect pollen and nectar which is essential to the survival of their hive. The changes in seasonality have forced bees to adapt to the ever-changing climate in Germany.

Practices Urban Beekeepers Use to Adapt to Seasonality

Constant changes in weather conditions negatively influence bees and essential hive maintenance. Beekeepers have to adapt to heat waves or increased precipitation and must monitor their hives to ensure the well-being of the colonies. As seasonal timings shift, beekeepers must adjust their methods to accommodate these changes in seasonality to maintain their hives' health. One region especially impacted by this seasonal shifting is urban centers. Urban centers are areas that are heavily populated,[28] and are mainly the home of hobbyist beekeepers[29] who have not had the chance to gather information and experience the necessary adjustments to changes in seasonality.

Among the diverse community of urban beekeepers, Berlin has seen a rise in individuals getting involved in the practice of beekeeping.[13] Urban environments have distinct climatic events and weather patterns due to seasonal shifts. Notably, heat islands are a prevalent weather phenomenon in densely populated urban areas.[9] This weather pattern not only subjects bees to heat stress[30] but also disrupts the availability of pollen sources, something crucial for beekeepers.[31] Fortunately, these challenges can be mitigated through strategic interventions employed by beekeepers.

As the summer heat increases, to prevent heat stress, bees "beat" their wings to keep their hives cool at a constant temperature of around ninety-five degrees Fahrenheit.[32] However, if bees entirely rely on wing beating it leads to heat exhaustion. To combat heat exhaustion, in summer days beekeepers have resorted to using various methods, one of them being implementing air ventilation in the hives. These systems spread air throughout the hive evenly to keep the optimal temperature of the hive. This provides bees with an extra form of ventilation that could make the difference in colony survival throughout the summer months.

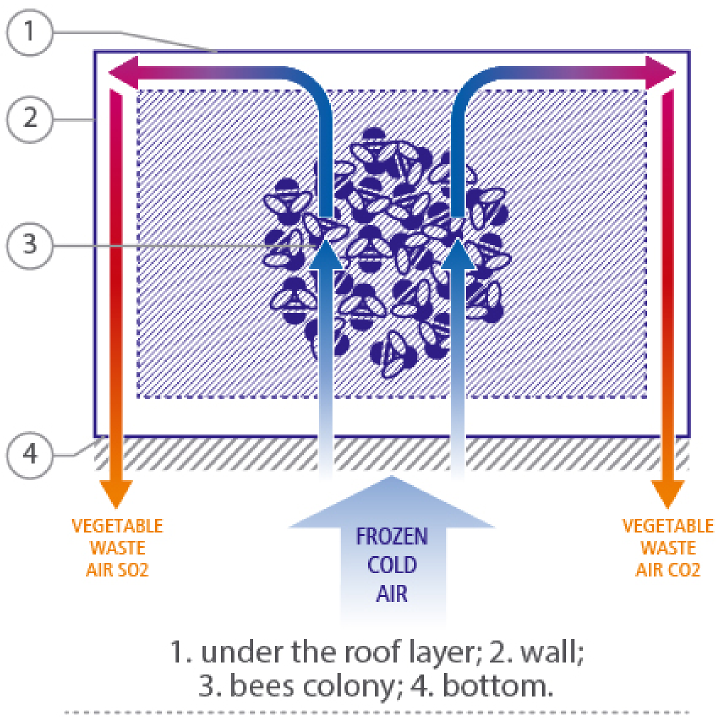


Figure 5. *Diagram of lowering ventilation, depicting cold air entering the hive through the inferior bottom.*[33]

Another method beekeepers promote is the placement of water sources near their hives to provide bees with an additional method of water collection.[32] Bees that are placed on wing-beating duty can evaporate the water brought into the hive as another method of cooling. As the water evaporates, it takes in the warm air within the hive causing a natural reduction of heat to occur.[34] Furthermore, urban beekeepers use other methods to try to make their hives cooler, such as painting the exterior and placing hives in shady areas. Additionally, some beekeepers paint their hives white or place metal on the sunny parts to reflect sunlight.[32] Reflecting this light can cool the hive and promote well-being as the bees exposure to heat is reduced and the chances of heat exhaustion are decreased. Along with painting their hives, beekeepers can place their hives in an area that provides more shade to block sun rays that could lead to hives overheating.

Figure 6. *Small branches or stones in water puddles allows bees to drink without risking falling in.*[36]

These methods are important as colony activity is completely halted when the hive becomes too hot. The queen will stop producing eggs and hive evacuation occurs with bees clumping together outside the hive.[32] Bee clusters located outside the hive are a good indication to beekeepers that the hive is too hot, and they must act quickly to prevent colony loss. The adaptive methods mentioned above could be some ways to combat overheating hives during the dryer summer months.

There have also been drastic shifts in the German winter season. During the cold months, bees remain in their hives where their overall goal is to keep their queen alive.[35] If the queen dies, colonies fall apart and rapidly begin to decline, leading beekeepers to provide some extra assistance to ensure survival. To combat the changes in winter conditions, beekeepers resort to various methods to foster survival.

Bees can regulate the temperature of their hives well, but in extreme temperatures they require assistance to survive. The hives have to stay at a constant ninety-five degrees Fahrenheit, thirty-five degrees Celcius, so that the hive can survive.[32] To maintain this temperature there are also additional steps that beekeepers can take to assist their bees. Beekeepers tend to avoid opening their hives when possible as this allows heat to escape. Beekeepers can also use other forms of human-made insulation sources such as foam, tar paper, or windbreaks like hay bales and fences. These insulators are placed around the hive, but beekeepers do leave one side uninsulated to allow bees to enter and exit as they please and to release built-up condensation.

Figure 7. *Preparation for winter months, installing 1 inch thick styrofoam walls with heavy duty tape.*[38]

In addition to leaving one side uninsulated, urban beekeepers may also place holes in the tops or fronts of their beehives to help release some of the excess moisture produced within the hive.[32] Normally bees do not need additional water resources during the winter months as they create enough moisture through wing-beating. Providing bees with adequate materials is an important extra step urban beekeepers can take to increase winter colony survival. One other key practice involves beekeepers providing their hives with additional food sources along with their heat-regulating measures.

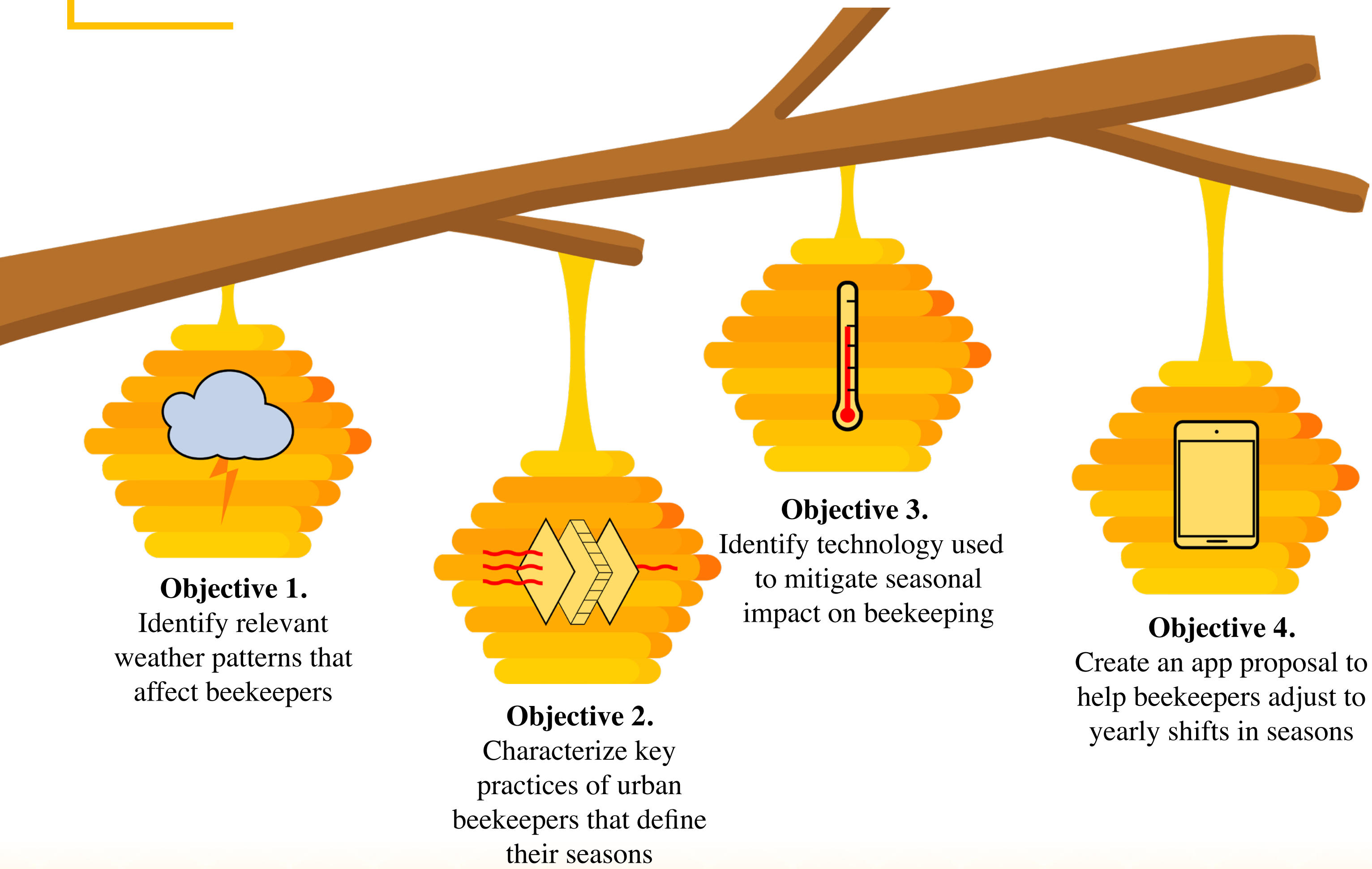
As increases in rainfall and warmer seasons become more common as winter transitions to spring, this increase in precipitation has been associated with higher colony loss as bees cannot prepare properly for the upcoming winter.[37] This leads bees to enter the winter months with less food reserves as they are unable to gather pollen and face hive damage due to this excess of precipitation.[32] Urban beekeepers can provide additional food sources such as sugar or fondant to help bees get some source of nutrients. Honey is the best nutritional food source for bees, but they need around thirty pounds of honey to survive the winter. Urban beekeepers may also place their bees closer to the top or front of the hive. This may be helpful as bees will not waste as much energy getting food and there would be less space for the bees to need to heat. These approaches are several of the more popular methods beekeepers use to manage their hives during the winter months and attempt to prolong the lifespan of their hives.

Overall, these methods improve an urban beekeeper's ability to react to changes in the yearly seasonal timings to maintain beehive well-being. Determining the best strategies and discovering possible innovative solutions to aid beekeepers could be beneficial to overall hive survival as the seasons change. The methods described above are standard practices that most beekeepers have implemented to combat the increase in summer temperatures and increase in winter precipitation. These summer and winter strategies are some of the more popular and most common forms of beekeeping practices for the best chance of hive survival.

Methodology

The team is sponsored by Simon Meisch, a senior lecturer of interdisciplinary ethics and a CALENDARS Research Project member. CALENDARS is a research-based project that focuses on seasonal patterns and how these patterns affect seasonal rhythms through climate, environment, and social changes.[39] In recent years, CALENDARS has begun to investigate beekeeping, and how seasonal patterns are affecting the regular practices of beekeepers.[39] Currently, the shifting seasons within Germany and throughout Europe have caused beekeepers to have difficulties adjusting their hive management practices. The CALENDARS research team has tasked our group with determining how beekeepers' ability to react to yearly seasonal timing affects bees and how beekeepers can maintain hive wellbeing during these shifts. Please refer to Appendix A to gain more insight into our project and sponsor.

Our project aims to improve beekeepers' ability to react to changes in yearly seasonal timings and events to maintain their beehives' well-being through the proposal of an app. To achieve our goal, we have outlined four main objectives to help frame and organize the flow of research, which are as follows:



How Shifting Seasonality is Affecting Beekeepers

Methodology System Flowchart

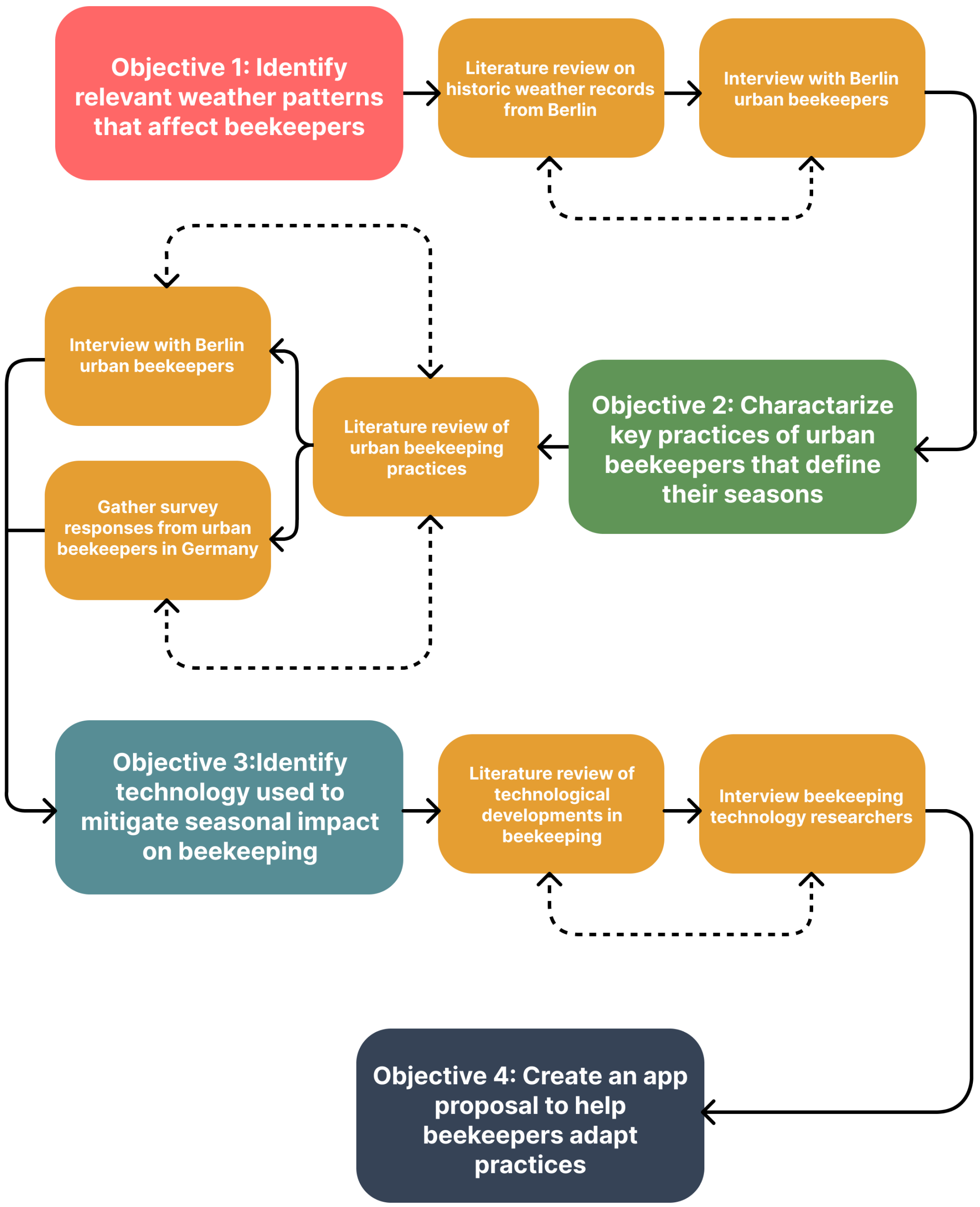
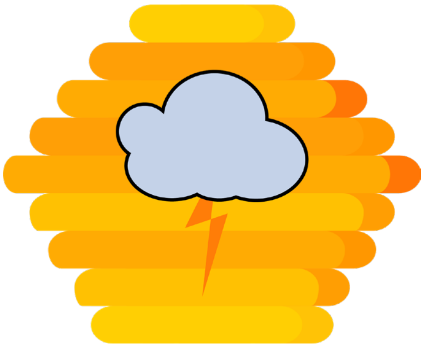


Figure 8. *How Shifting Seasonality is Affecting Beekeepers* methodology flowchart, displaying the systematic process of research.

Identified Relevant Weather Patterns that Affect Beekeepers



To understand how weather patterns in Berlin have been relevant to the practice of beekeeping, historic weather data was collected by our team. As we conducted an in depth analysis of the collected data, we identified patterns and trends that both have a high probability of continuing and that will affect beekeepers. We also interviewed beekeepers to compare our research to their lived experiences and gained further insight into how climate affects their practice. This information came together to assist us in connecting weather patterns to harmful events for bees.

As we researched weather patterns, our primary source of information gathering was weather pattern archives and literature reviews. Comparing the vast amount of meteorological data that Germany has collected,[40] our team was able to parse out significant weather patterns that lead to detrimental conditions for beekeepers. Additionally, this allowed us to compare historical seasonal events to current events that beekeepers and their organizations informed us of, so we could see if there were any emerging patterns from weather factors. The collection of historical meteorological data consisted of literature reviews of research papers with a focus on temperature, precipitation, and wind speeds.

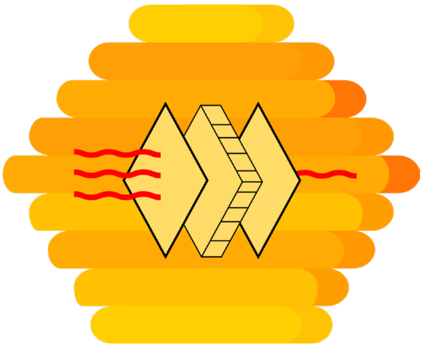
Taking this collected information, we then interviewed beekeepers to compare our historic data to their experiences and understanding of how the weather impacted their practice. For more information on the interview protocol, refer to Appendix B. For more information on the questions asked, refer to Appendix C. By comparing beekeeper's personal experiences with meteorological data of weather patterns, we could reason which weather patterns would likely forewarn of more severe, hive-threatening conditions. This weather information assisted the team in the transition between research and conducting interviews.

The main challenge we foresaw that could slow down progress was a language barrier. In the circumstance that the interviewee didn't speak English, the translation software, DeepL, was used to translate both the questions and the verbal answers. This proved effective in countering a difference in language, especially in translating very specific, technical terms that didn't have direct English translations.

While conducting interviews with the beekeepers, the team strived to complete most interviews in person but a remote option was also available when it proved more convenient for the beekeeper. Our intended participants for field data collection were reached through our sponsor or interviews were set up through email contacts. The goal is to have these meetings in-person, if possible, to form a better connection with beekeeper interviewees. These interviews gave insight on how the weather pattern research compared to the experiences of beekeepers. Our sampling method was a random and accessibility-based model to find interviewees who had beekeeping expertise. The average interview was between 30 minutes and an hour long. Two people minimum conducted the interviews, with one person's role being the interviewer and the other person taking notes. When storing the collected information, a secure Google Drive folder that only team members have access to was used.

To gain an understanding of the relevant weather patterns that are affecting beekeepers, we collected information through existing weather data sets and interviews. Through collecting data on historic weather patterns, we were able to make predictions about the future weather cycles that beekeepers are going to experience. Then through analyzing data from interviews with beekeepers, we were able to find what weather patterns are most detrimental and the warning signs for when they are coming.

Characterize Key Practices of Urban Beekeepers



Identifying the key practices of urban beekeepers allow individuals to understand the events and actions that define their seasons. The goal is to understand the methods and practices urban beekeepers are putting in place to confront changing seasonal patterns. Some examples of these methods are ventilation systems to manage increased heat or hive insulators used to warm hives during the winter to manage seasonality.

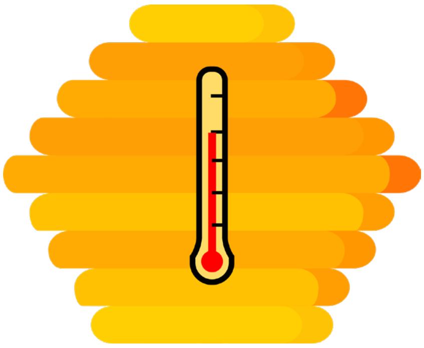
The primary methods that were used involved conducting literature reviews, interviews, and surveys. This involved delving into the topics by reading official sources from the internet, starting off as a broad overview and homing in on the literature that overlaps with our area of focus. Academic journals and peer-reviewed articles are the main sources, as these are reliable pieces of literature the team can trust. To find these sources, the team accessed published websites such as JSTOR, Science Direct, and the WPI Gordon Library research tool. Key words such as urban beekeeping, beekeeping methods, beekeeping practices, standard beekeeping practices, etc were inputted to obtain the proper results for the topic. These terms pulled articles that were used to understand beekeeping practices and how these practices have changed due to rising climate. With these articles, the team was able to explore deeper into the specific studies that were the most relevant to the project outcome.

In our research, we also conducted interviews with urban beekeepers in Berlin and collected information about successful beekeeping methods. Conducting interviews allows us to obtain a primary source of information about how beekeeping methods vary depending on the climate and fill in any gaps of information we could not find through our literature review. The interview protocol that was followed is stated in Objective 1. The perspective of urban beekeepers allowed us to have a greater understanding of their adaptability depending on climate factors. It also gave the group a chance to see if any methods found through the literature review are actively being used.

To broaden the reach of the project, the team also gave beekeepers the option to complete the interview questions in survey format. For more information on the survey questions, refer to Appendix D. This allowed beekeepers to answer our interview questions in a time frame that works best for them. The participation agreement was acknowledged at the beginning of the survey to abide by ethical standards and allowed participants to give consent. Analysis of these surveys provided the team with beneficial information that would not have been collected if this option was not available.

Overall, the group collected both field and secondary research data to further acknowledge the challenges of beekeepers within this objective.[41] With these methods, the team was able to demonstrate that beekeepers and literature can provide a more in-depth response procedure to the current climate challenges faced by urban beekeepers.

Identified Technology Used to Mitigate Seasonal Impact on Beekeeping



Finding new and innovative solutions to the increase in problems caused by seasonal factors is imperative to keeping the practice of beekeeping going. Through a review on literature related to scientific advances in the field of beekeeping, as well as interviews with professionals developing said technology, the team sought to better understand the direction of solutions in development. This proved vital to linking new technology to emerging problems beekeepers face, especially problems unique to the urban landscape.

Like the previous objective, the methods used for this consisted of a combination of literature review and interviews. In this case, the topic of the literature review was on beekeeping technology that is either newly developed or in development that urban beekeepers would be able to utilize. Similar databases from the previous objective were used, with words such as beekeeping technology, beekeeping robotics, and beekeeping sensors representing some of the keywords used during the search.

For the interviews, once again our protocol stayed relatively the same but had a few changes. Our time for interviews, sampling method, and the division of roles all stayed the same. The key difference being the changes in interviewees and the need to develop a new set of questions that were specific for each interviewee. For more information on the questions asked, refer to Appendix E. The targets for these interviews were researchers who specialize in beekeeping technology and beekeepers to understand what technology they already use. Our sampling method was a random and accessibility-based model used to find interviewees who had proper expertise and perspective. These perspectives allowed us to link specific emerging methods and technology to specific problems that we found in previous interviews and research.

Together, this showed us the direction that beekeeping science is developing. We then used this in combination with the information learned from previous objectives to the development of these methods to seasonal problems occuring in Berlin. These connections proved extremely helpful while working on determining features for the app proposal in the next objective.

Create an App Proposal to Help Beekeepers Adapt Practices

Our team decided for the final deliverable, an app proposal and plan was the most beneficial culmination of our research. The app's proposed features were derived from our findings in various interviews, the survey sent out to beekeepers, and research done into existing tools and apps with similar goals. This was done to ensure that the potential product would be innovative and intuitive, as well as useful to the beekeepers practices. During interviews with beekeepers, our team was informed of apps and tools that were already in use. By collecting and understanding their key functions, we were able to determine what current beekeeping apps can do, and what gaps they have. This allowed our team to identify new areas to potentially innovate and add functionalities. Data collected daily, weekly, or annually may be used for beekeepers to understand certain indicators, such as weather patterns which historically signal abnormal seasonal events. Indicators could link certain beekeeping events with the past and current climate data to determine the best possible methods for beekeepers to manage their hives. By collecting all this data in one place, both weather and hive information, the app would then be able to analyze it and provide recommendations and directions for what steps to take next. For example, if a beekeeper inputted data showing an earlier summer that year, the app could recommend practices to prepare for that shift in weather.

To gain the insights needed to complete this objective, we used inductive reasoning to draw conclusions about the information gathered from objectives 1 through 3. Inductive reasoning is the process of collecting data from a set and making a generalized statement about the information collected.[42] We chose this method to bridge the information gap that was available in peer-reviewed literature to match that of the real world. Inductive reasoning allows our direction to be informed by the experiences of others, specifically through the interviews we conducted at all stages. One problem with this is accounting for the variability in response we got from different interviews. Different individuals will use unique methods with varying amounts of success; however, it is highly possible that multiple beekeepers will use similar methods and get different results. Therefore, it was imperative to record a holistic report of each beekeeper and their situation, to best understand the factors affecting their practice.

Results

To assist beekeepers in understanding how shifting seasonality is affecting beekeeping practices, the team researched the relationship between the two. Through this research, the team found a wide variety of opinions on the definition of a beekeeper's season. This diversity of philosophies highlighted the importance of conducting interviews with many unique groups, as it helps to understand where their seasonal definitions come from and why they differ from each other.

Through a literature review, the team found a drastic rise in temperature and increased variability of precipitation throughout urban environments over the past 100 years. This forces beekeepers to adjust their practices in various ways to utilize technology and chemicals to handle problems caused by changes in seasonality. A potential tool that can be leveraged is sensors that monitor hives and alert beekeepers when drastic changes are occurring. This allows beekeepers to start responding as soon as a problem arises. One problem with sensors is that there isn't an efficient way to utilize the vast amount of data that is being collected. With this research, we are proposing an app that records essential beekeeping information from both the user and sensors and quantifies it into potential methods to support the hive.

Perspectives of Beekeeping Seasonality

Beekeepers have a wide range of goals and practices when maintaining their hives. This has caused beekeepers across Berlin to have different definitions for their seasonal calendar. Some are in the practice for honey production. Others beekeep to assist in pollination and ecological development in their area. Others still keep bees just for fun as a hobby. Each beekeeper, while all engaged in the same practice, has unique methods and strategies to achieve their own goals. For example, beekeepers who gather honey are focused on a seasonal calendar based on honey production and how to optimize it. However, beekeepers who are engaged in the practice for hive survival have an alternative calendar focused on assisting the bees when they are at their most vulnerable. Mellifera and Stadtbienen, two of the largest beekeeping organizations in Berlin, demonstrate the need for beekeepers to have unique calendars based on their philosophies and goals. Mellifera takes a more natural and hands-off approach while Stadtbienen focuses more on an educational approach to attract more people to beekeeping. Understanding the differences between each group and how it impacts their seasonal calendars therefore became essential.

Mellifera was founded in Southern Germany in 1986 with the intent to bring biodiversity back into the bee population.[43] A major objective of this association involves widespread communication between beekeepers about issues ranging from treatment plans to starting a colony. Heinz Risse, founder of the Mellifera-Berlin chapter in 2013, gave insights into the impact that shifting seasonality has on both his hive management techniques and that of Mellifera. Heinz and many other members of the organization prioritize the health and well-being of a colony with an approach that is more natural selection-based.[44] These hobbyist beekeepers aim to produce naturally strong beehives that can survive independently. Therefore, it is not honey, but the overall health and survival of the hive, which is the metric for success for the beekeepers of Mellifera. To achieve this goal, Heinz described the steps that a typical Mellifera member would utilize to have successful seasons.

> *Well, if you look outside, you will see that the season of spring started much earlier than expected. So it's… warm since mid of February and usually the bees are not active during this time…But on the other hand, they start breeding quite early and this causes the problem of [less] food. Because if there…is enough food, that's alright…But if there is not enough food, usually, then this is a problem. And then there is starvation and the bees will not survive (Heinz Risse, 22 March, 2024).*[44]

Mellifera as an organization is very conservative with their intervention when their hives are struggling. Even if a warm season starts earlier than expected, the beekeepers of Mellifera allow their bees to try and find their own solutions. This is done, according to Heinz, in an attempt to make the colony stronger by itself.[44] By allowing the colony to attempt survival on its own, it allows the bees to be self-sufficient, which is core to Mellifera's philosophy. This has the unintentional effect of Mellifera beekeepers having a unique seasonal calendar, already in tune with the shifting of seasons because their practice is so disengaged. They react as needed in moments of need, meaning they are not restricted by seasonal timings. This became apparent as an area where they greatly deviated from other organizations, such as Stadtbienen.

Stadtbienen, founded in 2014, provides resources and educational experiences to individuals interested in urban beekeeping.[45] These chapters across Germany, Austria, and Switzerland raise awareness of the importance of bee biodiversity, especially within a city. Specialized beginner courses teach individuals everything that is needed to promote knowledge and proper practices when managing beehives. Jonas Geßner, the head of operations of Stadtbienen, began beekeeping in 2016 through a Stadtbienen course.[46] His focus has always been on the bees themselves, never having had an interest in the production of honey. This matches the principles of Stadtbienen as their goal is to assist colony survival while allowing bees to thrive naturally.

Stadtbienen members use specific seasonal markers to manage the well-being of their beehives, and these points were emphasized during the interview with Jonas. When asked about seasonal changes within beekeeping, Jonas discussed how flower blooming patterns can affect bee swarm formation during specific parts of the year.[46] A good indicator Stadtbienen uses to determine when bees will begin to emerge is the bloom of hazelnuts on hazel trees. This seasonal occurrence provides bees with nectar that can be used to start honey production and expand the hives' brood. Stadtbienen also uses the lime tree as a marker that peak crop season has been reached in urban environments. This provides beekeepers with the knowledge that this is the last mass crop and fewer food sources are available for colonies after this point.

> *…lime trees you reach kind of the peak of crop here in urban environments and at the same time it's the last mass crop we have. So afterwards there's…not as much food around and so we keep saying to people that bees in July they start to prepare for winter… I mean as you probably know the hives grow until mid-summer and that's when they reach their biggest size and then the brood would shrink again (Interview 2, 10 April, 2024).*[46]

Stadtbienen is very focused on defining their seasons around certain plant blooming periods or temperatures in which bees could leave their hives. Their process starts with setting up a hive by either catching a swarm or obtaining an artificial swarm. This step normally would take place in May, but with current weather conditions, it could be completed during April as well. The next step occurs during June when beekeepers prepare their beekeeping tools and equipment. This is necessary to ensure that hives are properly set up to provide bees with the best chance of survival with Stadtbienen's more hands-off approach. During the summer months, Jonas described two different steps that beekeepers should take specifically during July.Then you have in summer, it's basically two topics. Varroa treatment and honey harvest (Interview 2, 10 April, 2024).[46] The treatment of varroa during the summer months is crucial to prevent colony collapse later in the year. Additionally, the defining of the summer months by key practices instead of events reflects Stadtbienen's philosophy of hands on education.

This leads into the fall transition in September, where beekeepers begin to prepare their hives for the winter. Beekeepers check their hives to determine honey resources to make sure there is enough supply to last the colony throughout the winter. Weighted scales or manually counting the combs are ways in which beekeepers could estimate hive honey supply. The honey produced by bees over the summer could be an indication of the strength and chance of survival of the hive over the winter months. Once the hives are prepped for winter there is not much else beekeepers must do until December when they complete their winter varroa mite treatments. This is a very important period as mites thrive and reproduce off the colony's brood and the hope is that the colony is not reproducing.

Overall, beekeepers of different organizations have different ways to define their seasons and when certain practices should be performed. Mellifera defined seasonality based on the bee's natural cycle due to their hands-off approach. On the other hand, Statbienen uses more of a hands-on approach where the seven steps that coincide with their lessons align with the blooming patterns of certain plants. The seasonal calendar of beekeepers is unique based on the philosophy they subscribe to and is set based on the circumstances of their local environment.

Increased Temperature And Variability of Precipitation in Europe

With beekeepers deciding their practices based on seasonal events, it has become essential to understand how shifting seasonality affects beekeeping practices. Through analyzing temperature and precipitation data from the 1900s to 2024 it is possible to make broad predictions based on what future years are going to look like for beekeepers.

Temperature and precipitation data were collected from the Climate Data Center[40] to gather relevant climate and weather pattern information. This research covered a period from the 1900s to March of 2024, and the data was then averaged individually for each month's quarter-century increments. The data was summarized in this fashion to condense the number of data points present and to reduce the number of outliers within the records. Temperature and precipitation collection emphasized the importance of local climate when beekeeping as this affects a bees natural habitat and cycle. High temperatures increase the amount of energy a bee must exert to survive. These accelerated temperatures make it more difficult for beekeepers to treat hive populations for conditions such as mite infestation. To a similar effect, precipitation, especially rainfall, restricts bees' access to food, and regulating the conditions within their hives becomes a challenge.

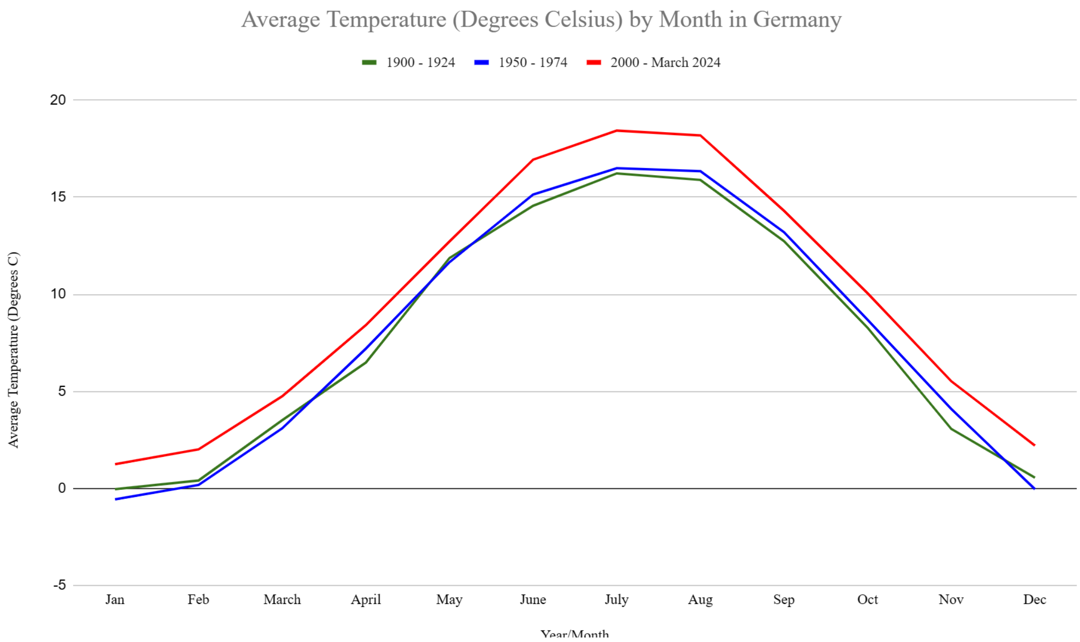


Figure 9. *The average temperature across Germany, historic data is compared to present averages. The graph has a strong upward trend in the average temperature as the years progress.*[40]

Each line shown in Figure 9 represents the average temperature for their respective 25-year period, split up by months. We confirmed that over the past 124 years, temperature has increased somewhere between a 1-2.5 degree Celsius increase on average depending on the month.[40] For beekeeping, a consistent increase in temperature of this magnitude can create harmful environments for bees.[47] This not only causes heat-related stresses but also increases the chances of disease spreading within the colony.[48] For example, in October through March this is typically a period where bees remain in their hive to conserve heat and energy. In Figure 9, there is a clear elevation in temperature from 2000-2024 compared to the 1950-1974 quarter century increment. Temperatures in these months historically reached a point where the hive was less active and this gave beekeepers a chance to treat for mites and other parasites as there would be a lack of larvae in the hive. Overall, increases in mean temperature also necessitate the need for bees to self-regulate the hive more frequently, takeing up valuable energy and can induce heat stress leading to colony death.[49]

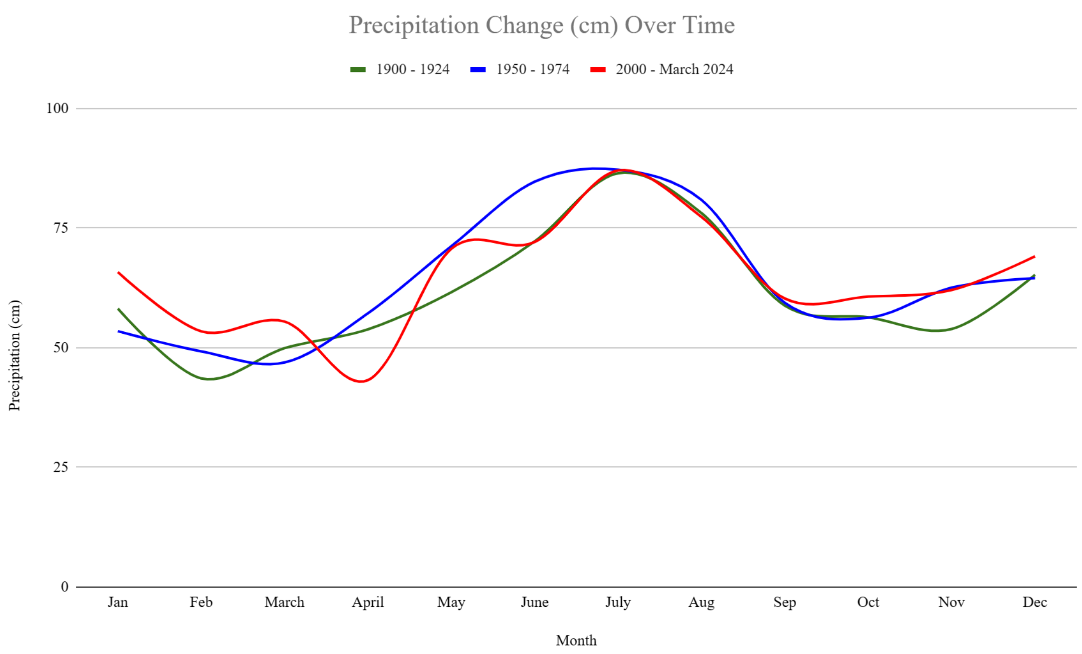


Figure 10. *Average precipitation across Germany, both historic data of 1900 - 1924 and current data of 2000 - Present are shown.*[40]

On the other hand, as seen in Figure 10, precipitation has also noticeably increased over the years, especially in the traditional spring months. In both previous periods of 1900-1924 and 1950-1974, the precipitation data created a smooth curve. In the most recent period, from 2000-2024, the curve has become erratic which indicates unpredictable precipitation patterns. One common trend occurs between July and August as all quarter-century data sets had more precipitation on average compared to other months. Though still true, May and June had a substantial increase in precipitation over the last century, which has formed a distinct period with escalated rainfall. When transitioning to the traditional autumn months from the summer, the precipitation has a notable decrease in September followed by a plateau until December. Continued seasonal progression from January until May depicts this increased instability in precipitation, as there is an escalated average but the data does not stay consistent. The precipitation variability during this time can gravely impact the ability of bees to regulate the conditions of their hive, especially in terms of humidity.[27]

The gathered data and patterns display a concerning increase in the severity and shifting of weather patterns. Specifically within Germany, it is expected that residents will continue to see an increase in temperature, with current data showing an exponential trend. Additionally, precipitation data indicates that Germany will have continued precipitation variability through the months of January to July. When both proven seasonal shifts and beehive preference for a stable environment are taken into account, it can be inferred that the health and well-being of bees will continue to be negatively impacted by seasonal changes. To further understand these conditions and how bees are directly affected, beekeepers across major urban environments within Germany were interviewed and surveyed.

Practices Beekeepers Use to Adjust to Change in Seasonality

As the seasonality shifts, it affects the natural processes of whole ecosystems. The average temperature has increased across Germany, precipitation has become increasingly erratic, and flower blooming periods are shifting. These effects ripple into all facets of beekeeping, necessitating the need for them to adapt their practices. From simple actions, such as feeding bees sugar water, to complex processes, such as timing mite treatments, beekeepers are adapting their practices to changing seasonality. Different beekeeping groups have come up with methods to adjust their practices, while still meeting their individual goals.

Certain organizations prefer to take a traditional and hands-off approach to beekeeping. An example of this is Mellifera, whose main priority is ensuring their beekeepers' hives can function independently of significant human intervention. Because of this ideology, the colonies of this organization have a unique dynamic calendar that doesn't rely on seasons but instead the natural actions of the bees. Recently, higher temperatures in later winter months have led bee colonies to emerge earlier. This could be beneficial as premature activity prevents diseases such as nosema, however these warm temperatures also promote brooding. With an escalated number of bees in the hive, food sources become limited and cause severe colony loss. Additionally, an increase in brooding too early in the spring or late winter also prevents beekeepers from performing the necessary treatments for hive infestations. Varroa mites thrive on the continuous production of brood and the winter months are necessary to combat the populations of mites that may infiltrate a colony.

One method used by Mellifera members to help their hives survive is through noninvasive methods to bolster the bees' natural abilities. For example, in the winter months, beekeepers will insulate their hives with natural materials to increase heat retention. Natural materials, typically paper or wood, have the additional benefit of reducing humidity within hives. Other forms of auxiliary help used by beekeepers are shade and water. Both of these methods help in reducing colony temperature in the summer, thus reducing the energy expenditure of worker bees to keep the colony cool. Another beekeeping method that particularly suits Mellifera members is keeping bees inside trees. The benefits Heinz shared were that it both provided better protection from predators and provided a good natural environment.[44] The downside of this method for most beekeepers is that you cannot observe the colony or collect any honey. However these are actions Mellifera members are less inclined to partake in. Heinz's insight on how beekeepers adapt to seasonal shifts and pressures both agreed with our findings and broadened our understanding of how an individual's goals affect their methods.

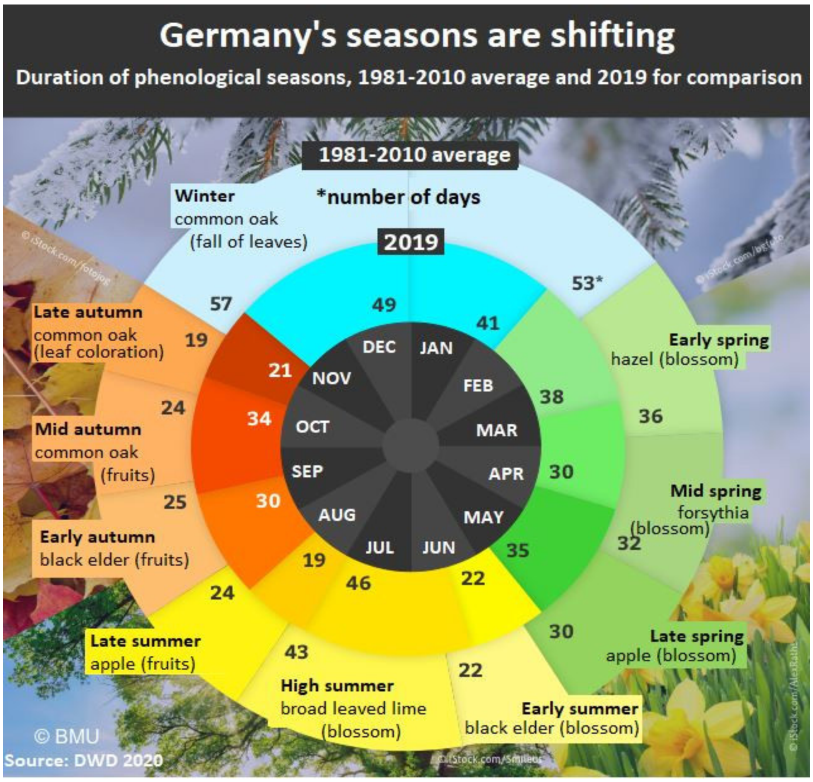


Figure 11. *The four seasons in Germany have been shifting over the last decades due to climate change, resulting in shorter winters and earlier summers.*[50]

Stadtbienen on the other hand uses the bloom patterns of plants to determine when certain beekeeping events should begin. This means that any deviations from these patterns can complicate their practice. For example, hazel, which Stadtbienen uses to determine the start of their season, is starting to bloom much earlier. This is shown by Figure 11, where hazel is starting to bloom in mid February instead of March. This has caused some beekeepers to start their practices too early, when the chances of colder and extreme weather is still present. Starting the spring practice too early in February can lead to starvation in the hive as the bees burn through their supplies before other forms of food are available.

During our interview with Jonas, he shared that bees in his opinion are good at adapting to any climate. To him and Stadtbienen, it is the plants that bees rely on for nectar that struggle.[46] Before drastic seasonal shifts, Stadtbienen viewed the temperatures in central Europe as perfect for beekeeping. Jonas mentioned that this "perfect climate" was no longer relevant and he noted shifts in temperature and precipitation that took place over the last three years. In 2023, Jonas discussed record temperatures that bees were able to adapt to accordingly, but there was concern about crop production. Fortunately, there was enough precipitation to allow for the continuous flow of nectar. The year before it was far too wet during the prime months of April-May as this is a key transition within the hive from winter bees to summer bees. With the wet and cold weather, the winter bees were overworked and hive development issues occurred as bees were unable to thrive in rainy conditions. The last year Jonas described was the complete opposite of rainy and cold weather, as the bees were affected by a drought. With the lack of precipitation, nectar production was low during the most vital months, as colonies were unable to contribute to their winter honey supply.

Due to the changing seasons, it has also become increasingly difficult for beekeepers to control mite populations in a hive.[24] As below zero temperatures and frost periods become less common, an occurrence that beekeepers previously relied on to limit mite populations, other forms of chemical mite treatment have become necessary in the fall. After the mite treatment is applied, beekeepers should not disrupt their colonies until March when beekeepers check that their colony has enough food. If not enough food is present, Stadtbienen beekeepers may give their bees a sugar paste as an alternative for low honey supplies. This is also a time when colony reorganization may occur. Beekeepers may remove combs to keep their bees closer together to preserve heat sources and promote brooding. Once colonies begin the brooding process to transition from winter bees to summer bees, beekeepers may add more combs to their hives in April. The months of April-July are important for colonies as this period of time determines what kind of winter a beekeeper should expect for their colonies.

Chemical Methods of Mite Management

In addition to the typical practices that beekeepers take, there is also technology that can be used in various ways to enhance their practice. With changes in seasonality becoming more drastic year after year, beekeepers need extra assistance in adapting. Through utilizing technology, beekeepers of certain groups like Statbienen can have an easier time adapting their practices to the challenges that changing seasons create. One way that technology can help is through using chemicals and mechanical methods to combat the increased mite population during warmer winter months.

Beekeepers are using a variety of technologies to mitigate the rise of Varroa mites. The team researched how traps and chemicals can be used to handle mites. These technologies help beekeepers adapt to the challenges posed to them as a result of shifting seasonality.[5] Management of mites and other parasites is essential to the survival and well-being of a hive, especially with the current Varroa mite invasions.[51] As seasonal shifts limit the number of natural ways for a hive to treat itself, it falls on the beekeeper to take a more active role. While there are numerous methods and tools available, they fall into five main categories which are: cultural methods, physical/mechanical solutions, biological methods, chemical control, and conventional pesticides (Figure 12). The team decided to focus on chemical methods due to these methods already being used by more hands-on beekeepers and because they can be easily implemented into beekeeping practices.

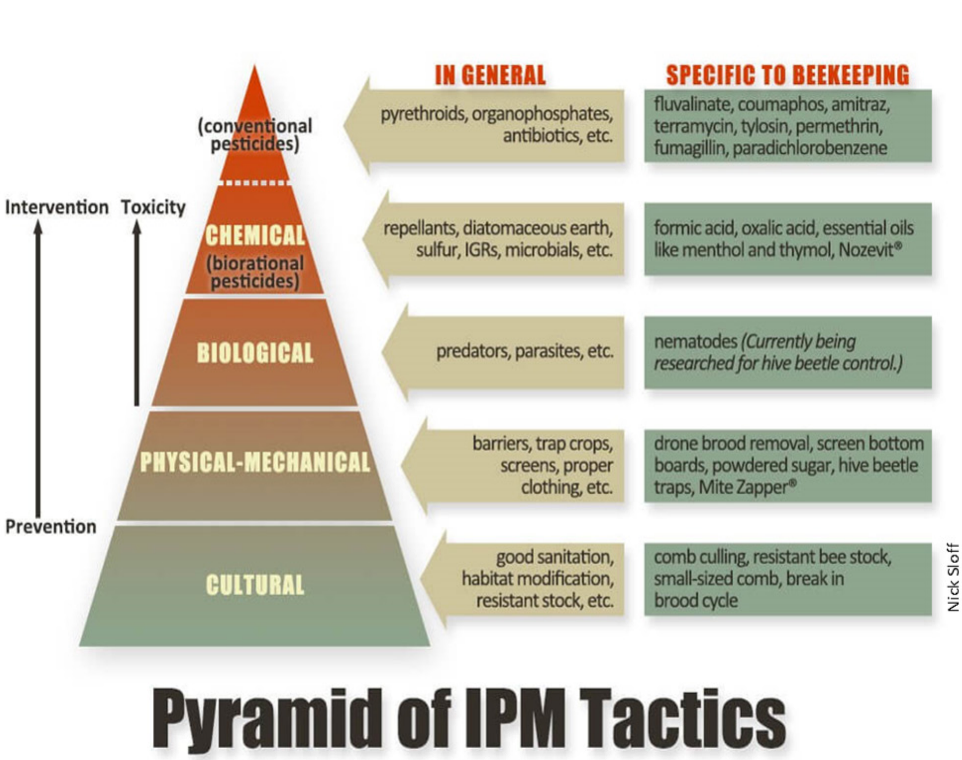


Figure 12. *Pyramid diagram depicting what methods are safe to use for varroa mite prevention that will cause minimal or no hive damage.*[52]

Chemical Usage in Beekeeping

Name Of Chemical	Benefits	Cons	When to Use
Formalic Acid Soft Chemical	Natural to the venom of honey bees Kills mites through dissolving their capping	Increases brood mortality Can kill queen if used outside temperature range	Between 29.4° C and 10° C inside of the hive
Oxalic Acid Soft Chemical	Can be used as a vapor or liquid Does not penetrate capping	Increase larvae mortality and reduce brood area Decrease activity of worker	During brooding periods (winter or early spring)
Thymol Soft Chemical	Control mites on adult bees Does not penetrate the capping	Can't reach brood cells Can reduce overall area of brood Increase robbing aggression in bees	Late summer and fall
Hop Beta Acid Soft Chemical	Does not dissolve the cell capping	Inefficient and requires multiple uses	Any time
Amitraz Hard Chemical	Does not contaminant honey	Increase mortality in bees Mites can gain a resistance to the chemicals	Late summer

Figure 13. *Table of the chemicals that can be used to handle Varroa Mite infestations. Describes the benefits that go with each of the chemicals, the downsides that are harmful to the bees, and the appropriate time to use each of the chemicals.*[51]

Chemical use in a hive has proved to be both very effective, but also potentially harmful, with side effects that can harm the hive as well.[51] The soft chemicals, which are derived from nature, that were researched were formic acid, oxalic acid, thymol, and hop beta acids. The hard chemicals, which are synthetically derived, that were researched are amitraz. Each of the chemicals benefits, draw backs, and timing of when to use them for the greatest impact were analyzed as seen in Figure 13. A majority of beekeepers choose to use soft chemicals over hard chemicals when treating their hives, due to their more natural composition and the reduced risk of harm.

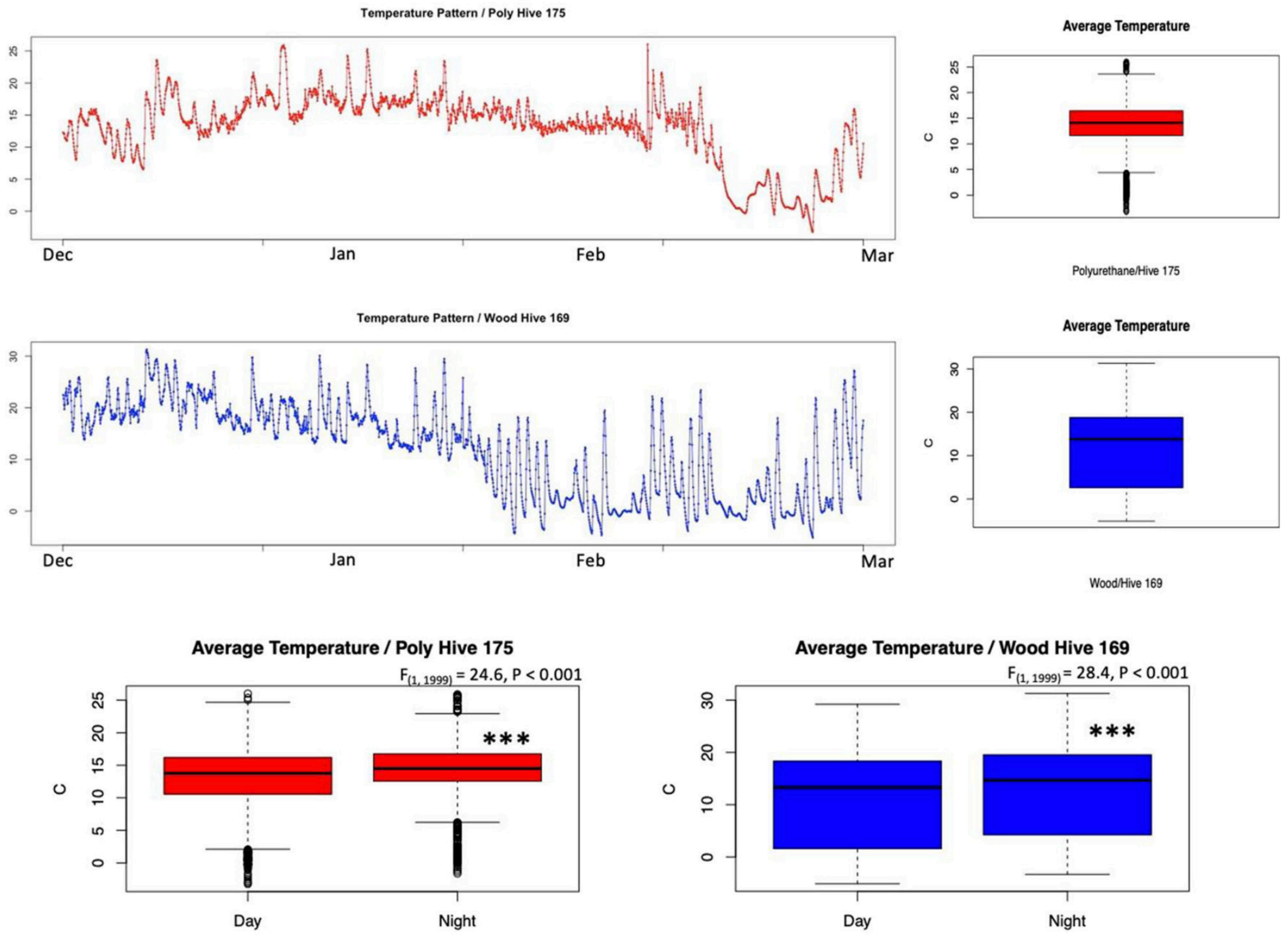


Figure 14. *A comparison of the overall average of the inner hive temperatures between polyurethane and wood constructions.*[53]

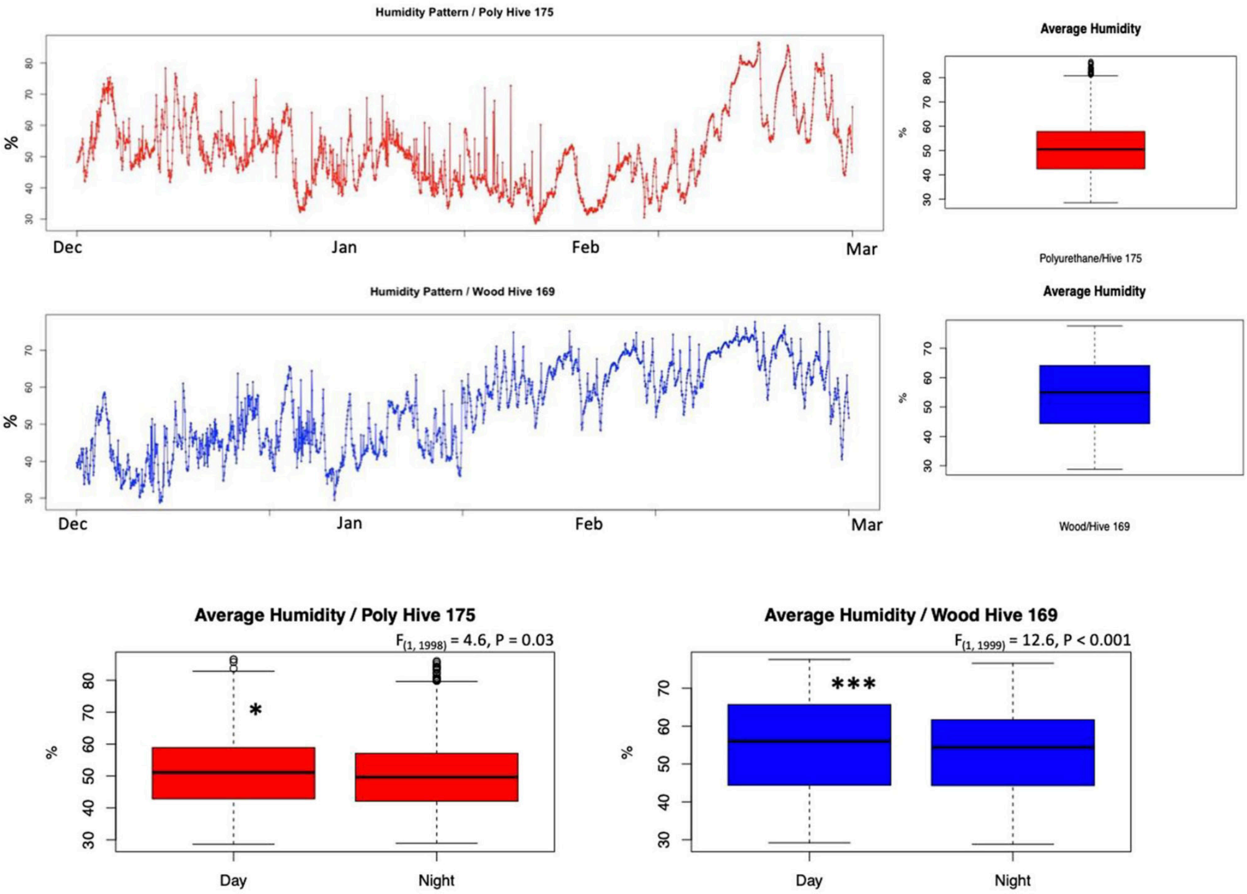


Figure 15. *A comparison of the overall average of the inner hive humidity levels between polyurethane and wood constructions.*[53]

With the appearance of new beekeeping technologies, beekeepers have become split on the adoption of these changes to their practice. Traditional beekeepers were generally found to prefer the historic, hands-on aspect of beekeeping and saw no need to involve new methods in their hives. Other beekeepers, often new to the field, see it as another way to ensure their hives are free of potential dangers. One area that this split in opinions becomes most apparent is in the use of modern hive materials like polyurethane versus using traditional wooden hives. Based on a literature review, the team found that polyurethane hives, as shown by Figure 14 and Figure 15, have a better chance at maintaining a stable humidity and temperature within the hive when compared to the traditional soft wooden hives. Manuel Hempel, a commercial beekeeper of 12 years, noted that the research that the team conducted about polyurethane hives being a more stable environment "is consistent with my experience. But polyurethane hives are not a problem if a top cover is chosen that allows for water vapor diffusion." This is further backed up through discussion with Philip Donkersley, a researcher with a focus on beekeeping at Lancaster University, who said that "some beekeepers insist on the [polyurethane] hives because otherwise they use all their stores up and it's a really long hard winter with the bees".[54] But when discussing with hobbyist beekeepers like Jonas, he informed us that "it's true that they keep the temperature better, but in terms of humidity, they're even worse because they're completely insulating". When discussing this difference in finding with Tim Landgraf, a researcher of collective intelligence in beekeeping, said, "Yeah, it's a cultural thing. There's no clear data, I think".[54] Regardless of data, many beekeepers are hesitant when considering adopting polyurethane as it makes the process less natural. This idea of a less natural process is indicative of a larger trend of how some beekeepers are hesitant to incorporate newer technologies into their hives.

Utilizing Modern Technology to Improve the Practice of Beekeeping

Outside of hive materials, there are other types of technology that newer beekeepers are utilizing to minimize risk to their hives. The internal status of the hive is vital to its success, therefore making the tracking of said conditions important. During the winter months, it can be difficult for beekeepers to check their hives' temperature.[55] Beekeepers that open their boxes risk releasing heat that the bees have created and in turn, affecting bee health as they try to re-adjust. Temperature sensors are one solution that can be added to hives to check on the internal state while not disturbing their natural cycles during the winter or summer months, as seen in Figure 16. This allows bees to conserve much-needed energy and beekeepers can track the hives' temperature to gain insight on the overall strength of the hive. Access to more data also allows beekeepers to plan for the future with a more informed view on the well-being of their hives. In a study from 2016 on the application of a wireless network of sensors for beehive management were discussed. Results from this study showed that collected data of the interior conditions of the hive can indicate potential hive swarming.[56] As shown in Figure 17 the temperature is able to be accurately read throughout the day. This shows the effectiveness of using a sensor to detect variations in temperature throughout the day.It demonstrated that one can accurately track and detect internal temperature levels of the hive, which gives beekeepers time to employ countermeasures in the case of abnormal variations.

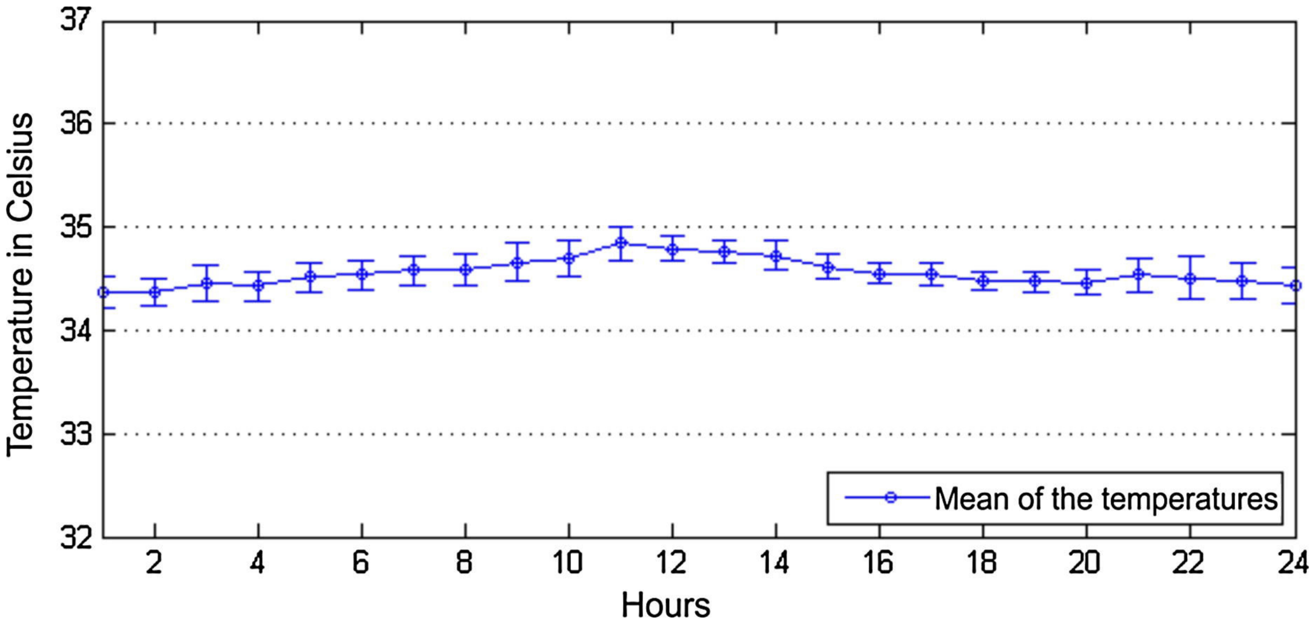


Figure 16. *Mean temperature collected within the hives over a twenty-four hour period.*[56]

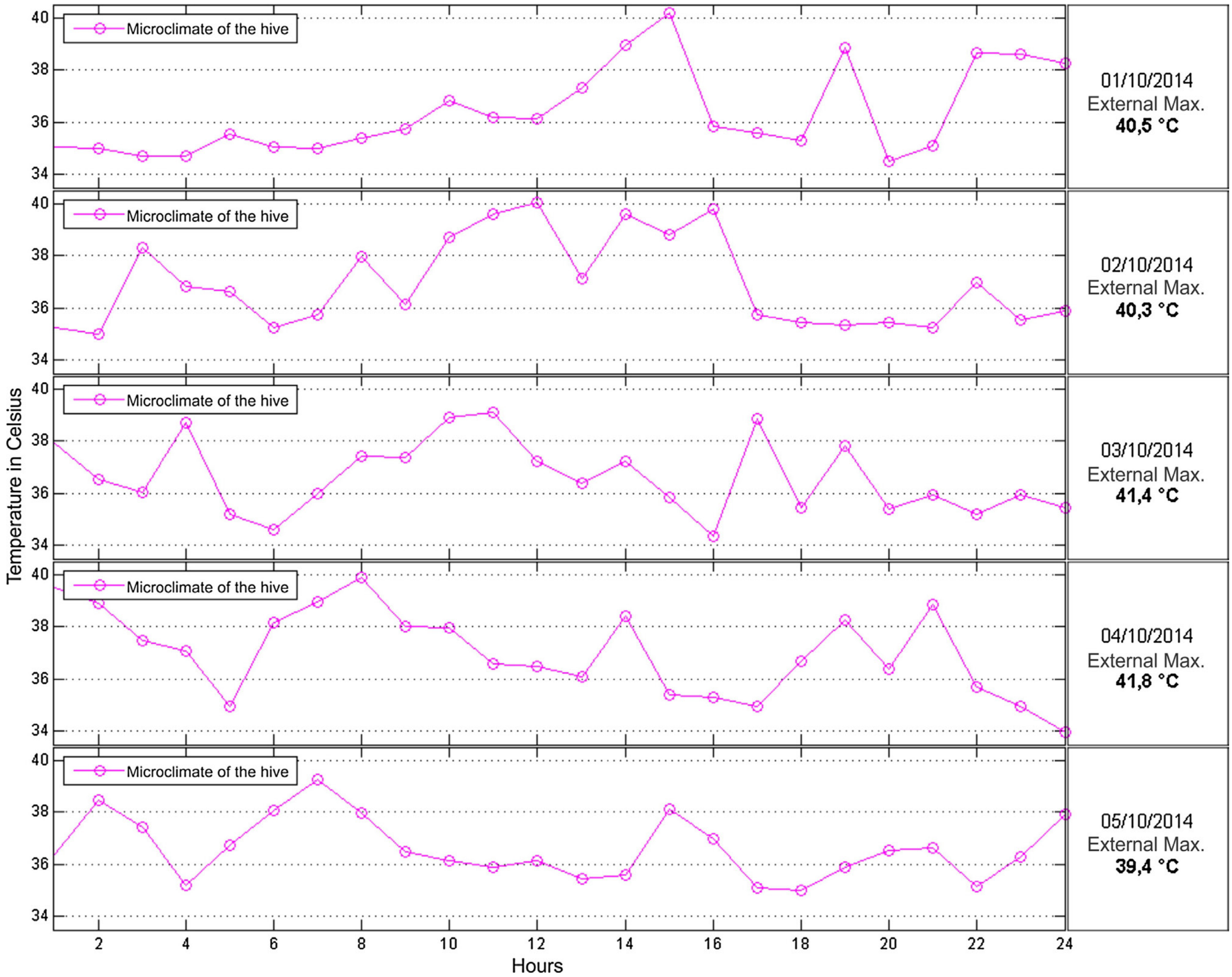


Figure 17. *"Atypical internal temperatures. In unfavorable temperature conditions, thermoregulation microclimate is impaired, destabilizing the homeostasis of bees. This Figure shows the in-hive thermal variation for five consecutive days of October 2014".*[56]

Temperature can also significantly affect the outcome of a beekeeper's year. One such area is in the treatment of pests and other mites with chemicals within the hive. As was mentioned previously, each chemical that can be used has ideal temperatures that make them more effective. For example, formalic acid works best when internal temperatures are between 29.4 C and 10 C inside of the hive, as seen in Figure 12. Therefore, when the hive is within this temperature range, the beekeeper will be able to determine that formalic acid is a viable treatment option. By monitoring internal conditions, beekeepers can better plan out the treatment of their hives, as well as use their resources most effectively.

The use of these types of sensors is slowly on the rise, with the first adopters primarily being those of the younger generation of beekeepers. To gain a better understanding of how sensors and technology can be utilized for the future of beekeeping, the team had an interview with Professor Tim Landgraf. Professor Landgraf is a researcher studying complex social systems like the ones found in bees, using mathematics and computational science. He has worked on the development of robotic bee systems to gain a better understanding of bee communication. His primary area of focus is how the waggle dance, a movement made by bees that convey a vector, directs bees to a location. This has also made him an expert on sensors and their application within hives.

When asked about other sensors that can be used for beekeeping besides temperature and precipitation sensors, Tim described using electrostatic sensors for the purpose of measuring the electric field of the hive. This came from a project titled Umweltsperre, where they put in sensors that measure electrostatic fields produced by bee wing movement.[54] A way to implement an electric field sensor into the hive is through using a grid system that is distributed throughout the hive walls. Tim described it by saying:

> *…you would have to have a grid, if you really wanted to have the full distribution of where these things come from. You might not need that full distribution. Maybe one sample is enough. But yeah, I would always combine global information, like temperature or humidity, with local information. And yeah, I think all this information could be used to track not only the survivability, but how active the hive is. (Interview 3, 18 April, 2024).*[54]

This sensor, in conjunction with a wider grid, allows beekeepers to monitor many bees simultaneously. However, one problem with sensors is the immense amount of data they generate. Especially with the chance for data to become corrupted, sensors running 24/7, or if a device malfunctions and returns wrong numbers or zeroes, it becomes extremely difficult to manually input and manipulate the information. Artificial intelligence and other machine learning programs could allow beekeepers to gain a better understanding about the health and trends of their hives. The machine would do a great deal of the tedious labor for the user, which would allow for greater transparency on what beekeepers should do to help their hives and how to react to the negative effects of changes in seasonality. Tim backed up this assertion, in his interview stating that AI would assist greatly in understanding what is occurring, visualizing our influence on the bees, and making transparent how well they are or are not doing.[54] He believed it might also be possible for AI to give some assistance to beekeepers at making their job easier.

Several apps that have been released that could aid beekeepers in their hive documentation are BeeInTouch and Beep. These collaborative apps provide beekeepers with the tools to stay in connection with other beekeepers while maintaining a detailed log of hive data. Both tools are quite similar as the user can record weather conditions or tasks that must be completed in order to maintain the well-being of their hive. One issue that Jonas mentioned with these apps was that many beekeepers were collecting this data but there was no way for them to analyze or digest the outputs.

…there is people who have put a lot of electric gear nowadays in hives where you can measure temperature, weight, humidity, and you get that sent to your smartphone 24-7… But at this stage, I see there's a lot of data collected, but it's not used or processed a lot yet (Interview 2, 10 April, 2024).[52]

This further highlighted the need for a tool to bridge the gap between the collected data and analysis. Even with all the data at one's fingertips, it doesn't do anything without a way to organize and make sense of it. The team believes that AI, when used correctly, could solve this problem and allow for greater analysis of hive patterns, as well as the impact of external factors such as climate. Therefore, AI working in tandem with sensors within hives proved to have great potential for positive impact on beekeepers, especially those that are new to the field or more adept in using new technologies.

Key Features of an Application to Combat Unpredictable Seasons

With all the gathered research, the team narrowed key features for a potential app to have into two focus areas. The first is based on existing apps and features that they have, as any proposed app should first meet the standard of what already exists before new features can be added. To gather these concepts, the team looked into BeeInTouch[57] and Beep.[58] Both of these apps feature hive management tools that allow users to keep digital diaries and notes on their hives. These apps were discovered through the team's interview with Jonas Geßner, where he stated that these apps are popular within the beekeeping community. The second area of focus involved proposing new features that solve existing problems found through our research. These problems include unpredictable weather patterns, a lack of gathered beekeeping educational resources, and analyzing vast amounts of data into usable information.

Viewing the existing apps, we noted several similarities between BeeInTouch[57] and Beep.[58] Both apps function as hive management systems, where one can create and differentiate hives and apiaries from one another by assigning them names, colors, titles, and other relevant details. Individuals may also record conditions, tasks, and various notes or relevant data types that may impact the hive within these applications. Throughout our research, we found that not every beekeeper is working for the same objective or seasonal goal. For example, Mellifera takes a more hands-off approach, compared to Stadtbienen who is more willing to aid colony survival. Therefore, we found it imperative that within the proposal, we emphasize the importance of a wide and diverse set of data types, covering as many aspects of beekeeping as possible. The team also found through our research and comparison of both apps that it would be important to connect these data types in an easy-to-understand user interface like that found in Figure 18. It also would be important to have the vast amount of data types organized in a method similar to that seen in Figure 19. The user would be able to efficiently find where they need to input their data so that they can monitor the trends in their hives effectively. Collaboration also proved to be a key area of focus for existing apps, as many beekeepers work in groups. The ability to assign tasks to specific people, as well as share hive records and progress was found to be a key feature of both existing apps. By having features such as an easy-to-use user interface, organized data into subsets, and collaboration being implemented into the app, it would allow the potential app to reach the current standard of the industry.

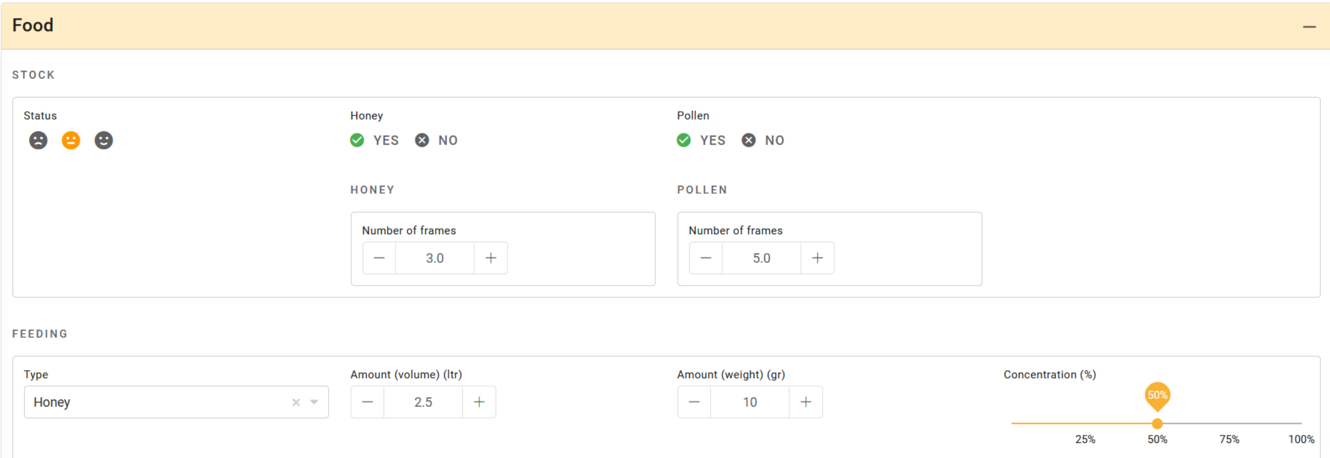


Figure 18. *View of entry field from the Beep application, displaying the food section of an inspection process, showing the variety of data entry types.*[58]

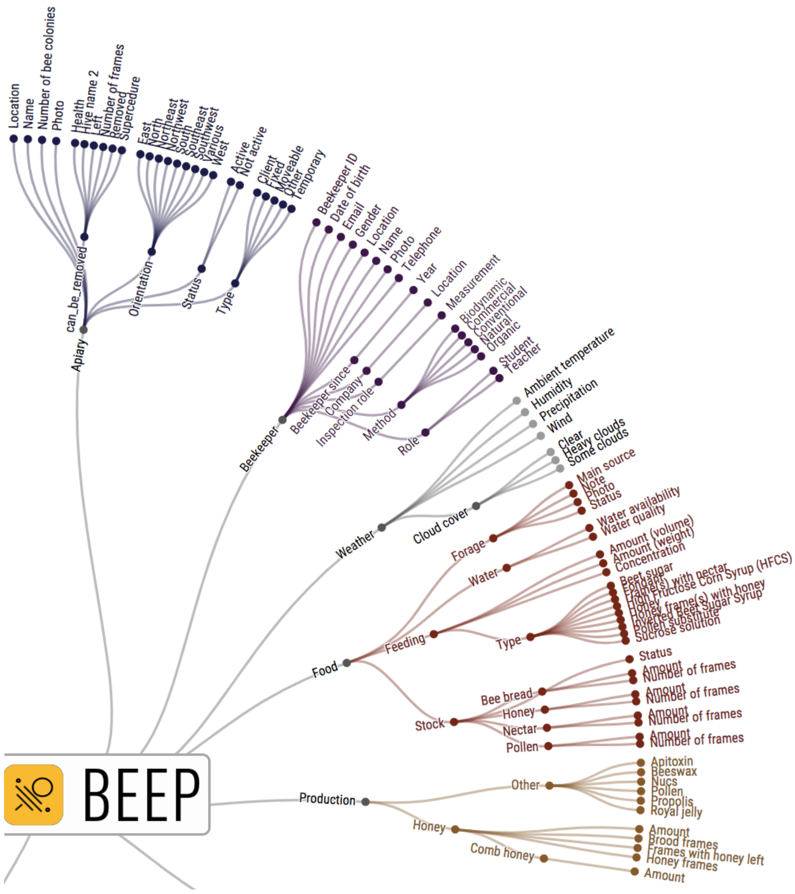


Figure 19. *A portion of Beep's standardized bee data structure, displaying the variety and diversity of entry fields.*[58]

The other part of our recommendation focuses on new and innovative features that would benefit beekeepers' practices. These features each derive themselves from one of the three previous objectives. The first of the features proposed is a weather alert system that is integrated into the app. This would take in the real-time weather data for the area that hives are located in and send alerts to beekeepers for dangerous weather conditions that would affect them. For example, heat waves, which are a highly dangerous weather event for hives, would be identified by the app. This automatic detection system would then notify the beekeeper so they could take the necessary steps to protect their hives. The next feature is a digital library with beekeeping techniques and practices. Each of these would be linked to conditions and situations where they are effective. We recommend that this library have a way to add new practices as they are created which would allow the database to stay up to date and relevant. The final feature that we are proposing would be through the use of a predictive algorithm. This algorithm would recommend new practices and techniques based on both local weather data as well as data entered by the beekeeper. This feature would use the real-time weather data and the library of practices, as well as the data entered by the beekeeper on their hive. The algorithm would then use this data to predict when a certain weather event might take place and the practice that would be most helpful in that scenario. For example, if a member of Mellifera noticed a mite infestation during the winter, they would input the relevant data into their hive record in the app. The algorithm would then predict the warmer temperature during winter and recommend that they use a hands-off approach to solve the problem. Meanwhile, if a younger member of Stadtbienen used the app in conjunction with different sensors, the app would alert them to mite outbreaks and then recommend the relevant chemicals that can be used to handle the outbreak, taking into account the hive’s temperature. With this combination and integration of features, we believe it is possible to create a robust and useful tool for beekeepers that would make it easier for them to react to the shifting seasonality.

Conclusion and Recommendations

Over the course of this project, the team has assessed the effects of shifting seasonality on beekeepers in Germany. By understanding how the shifting seasonality is affecting beekeepers, the team identified beekeeping practices which, if implemented, would benefit hive health. While there is no individual or group that can return the climate to its historical normalcy to meet the bees needs, beekeepers can take a variety of actions to ensure that these effects aren't a significant threat to their hive. Many of these practices are well known and have been used and documented in the past. What is lacking for most beekeepers is the precise application, know-how, and accessibility of these methods in specific situations that would ensure these actions best benefit the hive.

Based on meteorological station data, our team identified how weather in Germany has shifted over the past century. From increased precipitation variability in the spring, to an exponential increase in temperature, weather patterns are becoming more unpredictable. Honeybees themselves are a very adaptable species, able to live in many diverse environments across the world, but they struggle most when weather patterns are unstable. If beekeepers do not intervene during a period of unstable weather conditions, the bees may not be able to acclimate fast enough and suffer, often irreversibly so.

Beekeepers can assist their bees in many forms, from pesticides used to treat mites to simply providing sugar out of season. Internal monitoring of the hive's temperature, electric field, humidity, and precipitation data will provide valuable assistance to beekeepers if applied properly. Unfortunately, though gathering the data is easy, quantifying it into a plan is rather complex. If the beekeeper does make a plan, they may come upon solutions that do not take into account significant components. Variables such as future weather patterns or if a treatment is effective on their particular species of bee may simply be overlooked. To the average hobbyist, taking into consideration all of these factors when determining a plan may be a daunting task and leads to no action.

Due to the magnitude of options available to beekeepers on how best to treat their hives, our team proposes an app. Based on our expert interviews and surveys, hobbyist beekeepers should find this app especially beneficial in compiling their information into a usable product. This app would automatically learn the hive's location and collect regional information regarding climate, and internal hive information. Using this information, the app would be able to make suggestions to the beekeeper on what steps they are able to take to assist their hive. This can range from simple recommendations, such as throwing a blanket over a hive, to something more complicated, such as changing the beehive material. The creation of this app as a future project will be highly beneficial to urban beekeepers. It would address needs that were previously left unmet by existing apps, as well as providing a method for beekeepers to adjust their practice to the shifting of seasons.

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