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APICULTURE ADAPTATIONS IN A SHIFTING WORLD: THE BEEKEEPER'S EXPERIENCE ACROSS THE GLOBE

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APICULTURE ADAPTATIONS IN A SHIFTING WORLD:

THE BEEKEEPER'S EXPERIENCE ACROSS THE GLOBE

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"Peu importe où tu vas, vas avec tout ton cœur"

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Abstract

Existing research suggests that changes in climate, such as rainfall and temperature shifts, will threaten bees' main food sources and cause detrimental impacts on apiculture globally. Despite this, to the best of the author's knowledge, there is little available by way of research relating to how beekeepers themselves experience these increased pressures to their practices. This research project investigated the experiences of beekeepers in the United States, Malawi, and Cameroon. Surveys of US beekeepers, and interviews with Malawian and Cameroonian beekeepers were coded for emergent themes and surveys were analyzed via descriptive statistics. Major differences in challenges reported by beekeepers in the United States and Sub-Saharan Africa included a higher incidence of disease and pest prevalence in the US, and more issues surrounding resource and materials access in Malawi and Cameroon. Survey and interview observations on temperature and precipitation contained common emergent themes such as climate "unpredictability" and "extreme" weather events paired with adaptations including supplementary feeding, hive construction and placement alterations, temporal shifts in practices, and increased monitoring techniques. As pollinators such as honey bees are essential to food systems and biodiversity across the globe, all practices to promote the health of managed bee populations are to be encouraged. Beekeeping adaptation may be vital to ensuring continued pollination services, for which demands are expected to increase in the future landscape of agriculture. For these reasons the global community would benefit from more cross-cultural exchange of methods to practice beekeeping sustainably, and in-depth research into the adaptation themes uncovered in this study.

Objectives and Statement of Problem

This Capstone research project studies the way beekeepers in Sub-Saharan Africa and the United States experience climate variability and how it affects their beekeeping practices. This project investigates how changes in rainfall and temperature impact beekeeping techniques, practices, and resources in Cameroon, Malawi, and the United States. This study aims to provide recommendations for the exchange of climate-smart and adaptive apiculture knowledge and practice that may be replicated or adapted across multiple locations.

Apiculture is a sustainable agriculture practice that can aid the protection of biodiversity and forest ecosystems in developing countries (Warade, 2017). Modern beekeeping practices contribute to the Sustainable Development Goals through poverty alleviation, nutrition provision, sustainable harvesting practices, and biodiversity and forest preservation (FAO, 2021). While these are all benefits from the introduction of honey bees and beekeeping practices, it is important to note that introduced honey bee species may have a negative impact on native bee species, as they can compound threats to native bees via resource competition and associated shifts in plant communities (Alaux et al., 2019).

Like any agricultural endeavors there are associated risks with beekeeping, and one of the largest challenges facing apiculture today are the impacts of climate change on the health of bees and the quality and quantity of bee products (Ali & Jabeen, 2017). The negative impacts of a reduction in access to water (Rankin, Barney & Lozano, 2020) and extreme temperatures have been found to reduce the overall productivity and health of bees and their hives (Al-Ghamdi et al., 2016, Soroye et al., 2020, vanEnglesdorp et al., 2008). Investigating how beekeepers in Sub-Saharan Africa and the United States handle this variability may inform future decision making on the part of apiculturists in both regions of the world. The existing research suggests that changes in rainfall and temperature will threaten bees' main food sources (Le Conte & Navajas, 2008, Brown & Paxton, 2009, Ali & Jabeen, 2017, Soroye et al., 2020), which will have a detrimental impact on apiculture globally (Warade, 2017). In the face of such challenges, apiculturists may benefit from an exchange of adaptive apiculture knowledge, as a lack of knowledge of mitigations strategies such as supplementary feeding for bees can have detrimental impact on the adaptative capacity of colonies to environmental stressors (Aynalem, 2017).

I conducted surveys of United States beekeeping organizations to glean relevant information of climate variability experiences and shifting practices to provide a western perspective to climate apiculture adaptation. Key informant semi-structured interviews in Malawi and Cameroon comprised the data from Sub-Saharan Africa. I used these two methods to elicit information regarding practices that result in recommendations for the exchange of climate-smart and adaptive apiculture knowledge.

The broader impact of this project is a more detailed understanding of how different regions of the world react to pressures such as climate variability, and what adaptation strategies might be born from temperature and rainfall fluctuations that can be useful in other parts of the world. Beekeeping techniques, practices, resources, production, and marketing differ in Sub-Saharan Africa and the United States based on how these regions experience climate change, but the significance is in the ways that apiculturists can adapt to these experiences.

Background and Ethical Considerations

Apiculture Background

Before humans began keeping bees for their natural resources, ancient peoples practiced "honey hunting" and obtained their honey from wild hives (Gupta et al., 2014). The earliest record of the practice of honey hunting dates to 13,000 BCE via a cave painting in Spain **(**Harissis & Harissis, 2009). Early forms of beekeeping consisted of baiting honey bees by putting combs in wood boxes or clay and mud cylinders and waiting for swarms to move in (Engel et al., 2009). Apiculture, or the keeping of bees for the products they provide, is one of the oldest forms of food production and is focused mainly on the *Apis* genus of bees (known to most as honey bees) that form large social colonies and store significant quantities of honey **(**Gupta et al., 2014). The honey bees that are most common in beekeeping (*Apis mellifera*) are native only to Africa, Asia, and Europe, and do not occur naturally in North or South America but have since been introduced **(**Gupta et al., 2014). Western honey bees, or *Apis mellifera* L. (referred to from now on as "honey bees") are in fact one of the most widespread organisms and are present on every continent except for Antarctica (Crane, 2013).

Pollinators such as honey bees fill a vital role in our environment by promoting biodiversity and ensuring the health of crops. Bees make up 70-80% of essential insect driven pollination services, and their role in a plant's pollination can increase crop yields from 30-40%, with the overall economic value of pollination services ranging anywhere from 20-117 times higher than the value of apiculture derived products such as honey, wax, propolis, and royal jelly (Warade, 2017). While the overall value of bee products might interest people engaging in active beekeeping, the average farmer should also be invested in the overall health of their pollinators due to the high value of their pollination services (Warade, 2017). The global worth of bee-pollinated food crops is estimated at 184 billion USD, which is threatened by the observed decline of bees and other pollinators over large geographic areas across the globe due to pesticide exposure (Cullen et al., 2019), habitat loss and land use change (Picknoll, Poot, & Renton, 2021), and disease pressure (Boncristiani et al., 2020).

Honey bees require balanced nutrition to function, they need carbohydrates for energy, proteins for proper growth and development, and access to water, minerals and vitamins for overall health (Standifer et al., 1977). Honey bees acquire these resources from the nectar and pollen, and water in their environment. For example, a colony of 50,000 bees needs 1.1 liters of nectar (their source of carbohydrates) a day, or 700 pounds a year to function properly (Huang, 2010). Pollen is a bees' source of vitamins, minerals, lipids, and proteins (Herbert & Shimanuki, 1978). When bees experience a pollen shortage or collect pollen without sufficient nutritional content the brood rearing decreases as a result (Kleinschmidt & Kondos, 1976) and shortages of pollen resources (during rainy season, for example) can lead to a colony decline or complete collapse (Neupane & Thapa, 2005). Providing bees with a pollen supplement is one way that beekeepers can ensure that honey bee colonies get enough nutrition in times of resource shortages (Haydak, 1970).

Apiculture Challenges

There are several concerns about pollinators, managed honey bees specifically, that we face globally, and they may be grouped into three categories: lack of genetic diversity, pests and pathogens, and environmental stressors (malnutrition, chemical exposures, and mismanagement) (Potts et al., 2010). These are challenges that all beekeepers potentially face and are particularly difficult to deal with as these drivers may interact with one another, working together to form a positive feedback loop to the detriment of the health of a bee colony (Goulson et al.,2015). An example of a positive feedback loop in bees is chronic exposure to chemicals from agriculture weakening a healthy hive, making them susceptible to pests (such as the *Varroa destructor* mite) that they may have been able to fight off before a chemical environmental stressor damaged them (Potts et al., 2010).

Land use change resulting in the loss of natural habitat is a particular challenge to apiarists, or beekeepers, as it causes a loss of foraging/floral resources, which can decrease the yields of kept hives (Picknoll, Poot, & Renton, 2021). When there are limited floral resources around a hive, bees must work much harder to forage to find pollen and nectar, expending more energy than they gain and eventually reducing their foraging and creation of food stores inside the hive (Tomlinson et al., 2017). In areas with significant environmental degradation and few floral resources, apiarists might expect less honey (Tomlinson et al., 2017) and struggle to keep healthy, productive hives (Picknoll, Poot, & Renton, 2021).

A major concern centered around honey bees and their functionality is their continuing ability to act as pollinators for agriculture (Aizen et al., 2019). There is a global trend towards pollinator-dependent crops such as nuts, fruits, and oilseeds and a lower expansion rate of crops that do not depend on pollinators (Aizen et al. 2009). This high demand is not associated with an equal increase in access to pollination resources, and managed honey bees have not grown as fast as the agricultural dependence on pollinators, which is causing a stress on pollination capacity across the world (Aizen & Harder, 2009). The impact of agriculture on pollinators (death caused by pesticide and herbicide use, for example) is complicated issue, as cultivated pollinator-dependent crops can act as a food source for pollinators but can also be time-limited sources and be unsuitable habitats for nesting (Aizen et al., 2019). These concerns make it clear that, at least from an anthropogenic lens, the functionality and general health of kept honey bees is an important subject worth exploring.

Pathogens, Pests, and Pesticides

Honey bees are host to a myriad pests and pathogens and, as a result beekeepers often must spend time controlling for these various colony stressors (Boncristiani et al., 2020). The increase in colony losses in recent years has led to an international interest in honey bee health between 2005 and 2020, and publications on honey bee pests and pathogens have increased to better understand these colony losses (Boncristiani et al., 2020). Honey bees can become infected with bacteria, fungi, protozoa, arthropods, and viruses (Boncristiani et al., 2020). There are several arthropod species that feed on honey bees. These include the tracheal mite (present in the US and Malawi, and unconfirmed in Cameroon) (Table 1), the small hive beetle (present in all three countries), and the lesser and greater wax moths (present in the US and Malawi, unconfirmed in Cameroon) (Boncristiani et al., 2020).

The widely regarded deadliest threat to honey bees is the *Varroa destructor*, or varroa mite, due to its unique combination of hematophagy and its ability to act as a vector for viruses, compromising bee immune systems and potentially resulting in colony collapse and an increase in beekeeping costs **(**Rosenkranz, et al., 2010). The varroa mite evolved along with its original host, the Eastern honey bee *Apis cerana*, but has successfully shifted to the Western honey bee, which has none of the naturally selected defenses against the mite or the varroosis it causes (Rosenkrantz et al., 210).

Varroa mites are comprised of four species that parasitize on honey bees: *V. destructor*, *V. jacobsoni*, *V. rinderi*, and *V. underwoodi*, with the species that focuses on *Apis mellifera* referred to as the *V. destructor* or more commonly just “the varroa mite” (Traynor et al., 2020). The *V. destructor* acts as a vector for several major viral pathogens in honey bees including the deformed wing virus (DWV), acute bee paralysis virus (ABPV), and Israeli Acute Paralysis Virus (IAPV) (Genersch, 2010). The IAPV is a “significant marker” of colony collapse disorder (CCD) (Di Prisco et al., 2011), a phenomenon of major concern in the US between 2006-2008 when adult worker bees mysteriously left hives and caused massive losses of managed honey bees (vanEngelsdorp et al., 2009).

In the three study areas, the United States (Boncristiani et al., 2020) and Cameroon (Cham et al., 2017) have confirmed the presence of the *V. destructor*, and it is currently reported as absent in Malawi (Boncristiani et al., 2020). It is important to note in the case of Malawi that East Africa is not entirely free of the mite, the presence of the mite in Kenya (Muli et al., 2014) and other surrounding East African countries (Tanzania, Zimbabwe, and Mozambique) (Boncristiani et al., 2020) suggests the possibility for the future migration of the mite in the region, especially as shifting climates aid the spread of pests and pathogens outside of their current range (Giliba et al., 2020).

Diseases and pests of honey bees reported as present on the African continent include hive beetles, bee lice, wax moths, bee conopid, termites, and ants, with new pests and pathogens usually introduced to Africa via stowaway bees, or the purposeful import of bees (Kugonza, 2020). American foulbrood (AFB), a bacterial spore infection of bee brood, and its less serious cousin, the European Foulbrood (EFB) (Genersch, 2010) are both present on the African continent (AFB confirmed present in the USA, absent in Malawi, and unconfirmed in Cameroon, EFB confirmed present in USA, Malawi, and unconfirmed in Cameroon) (Boncristiani et al., 2020). It is important to note that in Africa, only 35 countries have data regarding honey bee diseases, with the lack of data in the remaining 20 countries making it impossible to declare an absence of these pests and pathogens (Kugonza, 2020). Commonly known fungal pathogens in honey bees include the *Nosema* spp (*Nosema ceranae* and *Nosema apis*), which are spores present in feces and pollen that cause dysentery in bees (Genersch, 2010). Research suggests that

Nosema ceranae, the more virulent of the two, is susceptible to freezing temperatures, and their virulence could be impacted by climatic conditions (Gidser et al., 2010).

These varied pathogens may be further complicated by bee nutrition, as much in the way humans are better able to fight off infections if we are healthy, honey bees can be more susceptible to infections if they are weakened by poor nutrition, creating a positive feedback loop of negative impacts to honey bee health (Dolezal & Toth, 2018). These pathogens can also reduce nutrition, whether that by affecting the gut interface of the bee in the case of the *Nosema spp*, or by reducing the host ability to store lipids, in the case of the *V. destructor* (Dolezal & Toth, 2018).

Added to the threat of pathogens and related nutrition issues is the risk of insecticide toxicity brought on by chemical agriculture (Douglas et al., 2020). In a recent study conducted in Canada on the effects on neonicotinoid insecticides (NNI), researchers found that colonies placed near corn fields and exposed to NNI naturally for 4 months had an increase in worker mortality, increased queenlessness, and declines in hygienic behavior via social immunity (Tsvetkov et al., 2017). Researchers also found that this toxicity of NNI doubled in honey bees when combined with exposure to a commonly used fungicide (Tsvetkov et al., 2017). These threats to bees are numerous and varied across the globe, but all represent a serious economic risk regarding food pollination (Cullen et al., 2019).

Table 1:Background information on beekeeping in study countries

	United States	**Cameroon**	**Malawi**
Number of Beekeepers	200,000 (Gupta et al., 2014)	18,000 (Hussein, 2001)	n/a
Type of *Apis mellifera* species present	*A. m. carnica, A. m. caucasica, A.m. intermissa, A. m. lamarckii, A. m.*	*Apis mellifera adansonii* (African honey bee) (Fletcher, 1978)	*Apis mellifera scutellata* (East African lowland honey bee) (Fletcher,

	ligustica, A. m. mellifera, A. m. scutellata, A. m. syriaca (Carpenter & Harpur, 2020)		1978)
Honey Exports (MT) 2019 (Tridge, n.d.)	7.77 million	976	3,270
Honey Value (USD) 2019 (Tridge, n.d.)	23.54 million	4,500	1,010
IPEV Vulnerability Insect Pollination Economic Value ratio of crop Economic Value (of region)	11% (Gallai et al., 2009)	10% (Gallai et al., 2009)	5% (Gallai et al., 2009)
Pests	*Varroa destructor*, AFB, EFB, *Nosema* spp., Tracheal Mite, Small Hive Beetle, Lesser and Greater Wax Moth	*Varroa destructor*, Small Hive Beetle (AFB, EFB, Tracheal Mite and Lesser and Greater Wax Moths unconfirmed)	EFB, *Nosema* spp, Tracheal Mite, Small Hive Beetle, Lesser and Greater Wax Moth

The Economics of Pollination

The value of insect pollination can be put into economic terms to understand the vulnerability of pollinators more easily across the globe. The insect pollination economic value (IPEV) is an estimation produced by taking the proportion of the contribution of pollination by insects and the economic value (EV) of the 100 most valuable crops for human consumption (Gallai, 2009). This ratio of IPEV: EV can help scientists measure how vulnerable different crops are to the loss of pollinators and parse the vulnerability down to region (Potts et al., 2010).

The general findings of the use of IPEV estimation have found that vulnerability is highest for nuts (31%), fruits (23%), edible oil crops (16%), and vegetables (12%), but lowest (0%) for roots, tubers, cereals, and sugar crops (Potts et al., 2010). This is important from a food security and sustainability standpoint, as these staple crops that have a low vulnerability are not the foods that possess most of the vitamins, minerals, and proteins in the human diet (Potts et al., 2010). Gallai et al. considered anything above 10% to be a high vulnerability region, and the United States and Cameroon fall into this category. Africa, and the United States, had an average vulnerability of 8% and 11% respectively (East Africa, where Malawi is categorized in this study, is at 5%, and West Africa where Cameroon is located is at 10%) (Gallai et al., 2009).

Apiculture in Sub-Saharan Africa

Archaeological evidence from the continent suggests that the practice of honey hunting played an important role in everyday life as far back as 3500 years ago in West Africa (Dunne et al., 2021). Honey hunting, traditional beekeeping (using baskets, clay pots, bark, and log hives), and modern beekeeping are all used in Africa to varying degrees and are mostly reliant on the trapping of endemic wild swarms of honey bees (Kugonza, 2020) instead of the bee breeding that is common in the US and Europe (Dietemann et al., 2009). There are ten subspecies of *Apis mellifera* in Africa (Hepburn, 1998) with the subspecies *Apis mellifera adansonii* considered the indigenous species in West Africa where Cameroon is located, and *Apis mellifera scutellata* (East African lowland honey bee) considered indigenous to the region of Africa where Malawi is located (Fletcher, 1978). In most African countries, beekeeping is a male dominated practice (Nel & Illgner, 2004; Ogaba & Akongo, 2001; Shackleton et al., 2011) despite its opportunities for rural women to diversify income with little startup capital and modest land requirements (Pocol & McDonough, 2015).

From a policy standpoint the African Pollinator Initiative (API), formed in Kenya in 2002, works to protect pollinator health in Africa (FAO 2007). The API is an Africa-wide group of people focused on preserving and promoting pollinators for the protection of livelihoods and biodiversity on the continent and is concerned with policies affecting pollinators such as honey bees in Africa (FAO, 2007). The API is part of the International Pollinators Initiative and works to provide a network for scientists studying pollinators throughout Africa (FAO, 2007).

The continent of Africa has an estimated 11.9-billion-euro IPEV (Gallai et al., 2009), and generates 9.8% of the honey and 23% of the beeswax produced worldwide, both for export and for home consumption (Ali & Jabeen, 2017). The production of Sub-Saharan Africa is relatively low compared to the projected capacity for beekeeping endeavors, which may be because adoption of new agricultural methods such as modern beekeeping in Sub-Saharan Africa is usually dependent on access to cash or credit, extension services, and farming groups (Amulen et al., 2017). It is important to note that there has been a push for improved agricultural production in Africa since the early 2000s with the "African Green Revolution", and thus a desire to increase production to the carrying capacity of Sub-Saharan Africa is an idea that can certainly be tied to this concept of economic transformation (Sanchez et al.,2009). Additional compounding factors to a lower export rate can be tied to a lack of laboratory facilities, market support, weak organization of small-scale producers, and inadequate enforcement of necessary quality standards (Mamo, 2016).

Cameroon, the first of the key informant sites, is divided into 10 regions with the Adamawa, West, and North West regions comprising most of the honey production (Hussein, 2001). Beekeeping in Cameroon consists of honey hunting from wild colonies, semi-modern hives, and use of the Kenyan Top Bar hive, especially in the Adamawa region due to training programs focusing on their usage (Figure 1) (Hussein, 2001). Our second country of interest Malawi benefits from a presence of miombo woodland especially in the Northern region, which is an excellent habitat for bees (Hussein, 2001) due to the foraging available in woodlands and the ample bark resources there for making traditional hives (Husselman et al., 2010). Traditional methods of beekeeping in Malawi include log, bark, and pot hives (Hussein, 2001) and modern hive (Figure 2). Figure 3 presents the subspecies of *Apis mellifera* and their respective ranges in Africa.

Figure 1: Traditional straw and mud hive in Cameroon (left), modern Kenyan Top Bar hive in Cameroon (right)- Author's photographs

Figure 2: Locally made Kenyan Top Bar hive mounted in a tree in Malawi-Used with permission from the photographer

Figure 3: Subspecies distribution of *Apis mellifera* in Africa. Adapted from Moritz & Neumann, 2005

Apiculture in the United States

As there were no honey bees indigenous to the Americas, this role was filled by stingless bees of the *Melipona* genus (Gupta et al., 2014). Historical references to both honey hunting and managed honey hive practices in the Americas date back to the Postclassic Maya society (1000-1520 CE) (Imre, 2010). Honey bees (*Apis mellifera*) arrived in the United States via pilgrims who brought English dark bees (*Apis mellifera mellifera*) across the ocean in 1622, where it remained the only subspecies of honey bee in the United States until about the 1850s (Figure 4) (Carpenter & Harpur, 2020). The next honey bee subspecies to be imported to the US was the

Italian honey bee *A. m. ligustica* in the 1850s, followed by the Carniolan honey bee *A.m. carnica* from Croatia in 1877, and the Caucasian honey bees (*A. m. caucasica*) around 1882 from Germany (Carpenter & Harpur, 2020). Other notable subspecies imported to the US include: the Egyptian honey bee (*A. m. lamarckii*), the Cyprian honey bee (*A. m. cypria*), the Syrian honey bee (*A. m. syriaca*), and the Tellian honey bee (*A. m. intermissa*) (Carpenter & Harpur, 2020). The first African-hybrid honey bee, or "Africanized bee" (AHB) (an *A.m. scutellata* hybrid) came to the United States in 1990 and has since spread to ten southern states via natural swarming (Carpenter & Harpur, 2020). The AHB resulted from a mating between *A.m. scutellata* queens from Tanzania and South Africa and the Brazilian honey bee population of European honey bee species, likely *A. m. iberiensis* (Carpenter & Harpur, 2020).

The biggest revolution in beekeeping following the arrival of honey bees in the United States occurred in 1851 when a man named L.L. Langstroth discovered that, if a space is left between the framed combs and the walls of a hive, bees would leave it clear of comb and it would be possible to have a movable frame hive, allowing for more precise control of the bee colony (Gupta et al., 2014). Following the innovation of the movable frame hive (known as the Langstroth hive) (Figure 5), Moses Quinby then began the practice of commercial beekeeping in the United States and invented the modern bee smoker in 1875, which allowed beekeepers to calm bees without killing them (Gupta et al., 2014). Additional contributions to beekeeping in the US in the 1900s include the modern beekeeping suit with the mesh veil, and the manufacture of bee hives and bee-packages by beekeeping innovator Amos Root of Medina, Ohio, who also wrote a very influential book on beekeeping in the US, *The A B C of Bee Culture*, which is still in print (Gupta et al., 2014). Women were not allowed to participate formally at the onset of these activities in the United States in the 1800s, as they could not join in at beekeeping association meetings, but they did practice beekeeping (Horn, 2012). A modern-day rough survey of beekeeping intuitions found that women comprise of 30.4% of leadership positions for national and regional beekeeping associations, while women make up 30% and 40% of leadership roles at the state and local levels respectively (Colopy, 2015).

The management of honey bees provides over 15 billion USD worth of pollination services to United States agriculture every year (Kulhanek et al., 2017), and the estimated IPEV is 14.4 billion euros (Gallai et al., 2009), making the health and success of those managed hives an important economic concern in the United States. It is estimated that there are approximately 200,000 beekeepers active in the United States (Gupta et al., 2014). An annual census of beekeeping in the United States found that the number of bee colonies producing honey in the United States had dropped from an all-time high of 5.9 million managed hives in 1947, to a low of 2.3 million in 2008 (vanEngelsdorp & Meixner, 2010). This decline coincides with the first report of colony collapse disorder (CCD) in the US in 2006, which helps to explain the record low numbers, with a recount in 2016 reporting 2.59 million colonies in the US (Kulhanek et al., 2017). Kulhanek et al. suggest that the slight increase post CCD outbreak is partially due to the ability of beekeepers to split colonies to replace dead ones, though this is cost and time intensive, especially for larger beekeeping enterprises. In addition to the overall historic decrease of colonies in the US, colony mortality due to decreasing forage availability, pesticide exposure, and parasitic infections (especially from the *Varroa destructor* mite) threaten the United States beekeeping business (Kulhanek et al., 2017).

Policies towards pollinators in the US shifted in 2014 with the formation of the Pollinator Health Task Force, co-chaired with the United States Department of Agriculture (USDA) and the Environmental Protection Agency (EPA), whose mission is to decrease losses of pollinators and to improve their overall health via federal strategies (Pollinator Health Task Force, 2015). This task force resulted in a “National Strategy to Promote the Health of Honey Bees and Other Pollinators” in 2015 and a subsequent standalone “Pollinator Research Action Plan” (PRAP) which aims to arrange strategies for restoration projects to benefit pollinators, identify best practices to reduce pollinator pesticide exposure, evaluate seed mixes for pollinators, coordinate studies on the health of honey bees and other pollinators (especially in regard to stressors that could cause colony collapse disorder), expand data collection in the field, and increase assessments of wild pollinator patterns (Pfrogner, 2019).

The US Farm Service Agency delivers aid to beekeepers who experience losses due to natural disasters. This aid is distributed under the Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish Program (ELAP) which gives monetary assistance for any honeybee mortality above a normal rate due to Colony Collapse Disorder or other natural causes. In fiscal year 2012 and 2013 approximately $28 million in payments were issued due to claims of this nature, which helped beekeepers to replace their hives and maintain financial stability following losses (Pollinator Health Task Force, 2015). As required by the 2018 Farm Bill and recommended by the Pollinator Task Force, the USDA releases an “Annual Strategic Pollinator Priorities and Goals Report” to assess the status of pollinators in the US (USDA, 2021).

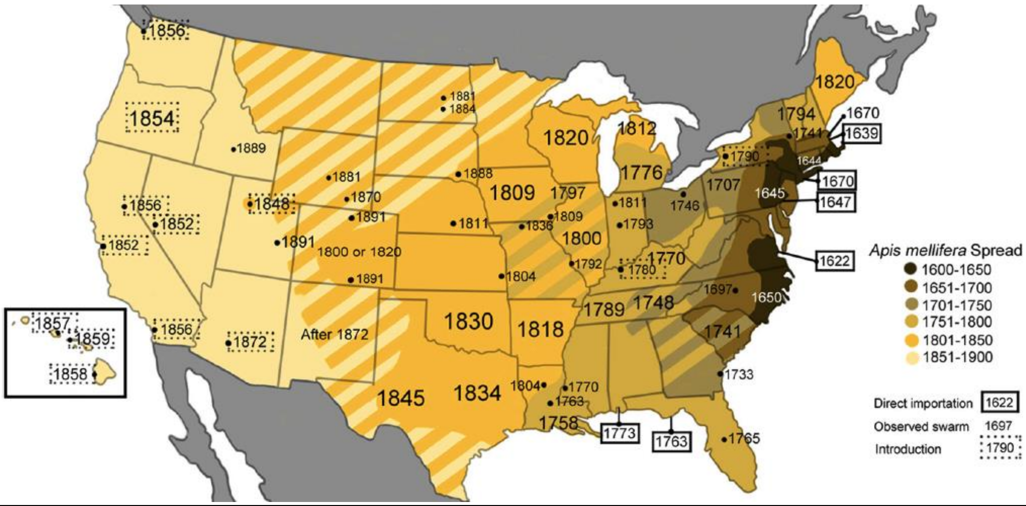

Figure 4: Historic spread of Apis mellifera in the United States from 1622 onward. All dates prior to 1859 are strictly *Apis mellifera mellifera*, all sightings afterwards could be *A. m. mellifera*, *Apis mellifera ligustica*, or hybrids. Adapted from Carpenter and Harpur 2021

Figure 5: Interior of Langstroth top bar hive (left) and exterior (right)-Adapted from Gupta et al. 2014

Climate Change Impacts on Apiculture

Climate change impacts agriculture directly via rising temperatures, droughts, increased flooding, and extreme weather events, and decreasing crop yields (FAO, 2016, Arora, 2019).

Apiculture does not escape the negative impacts of globally rising temperatures and increasing drought has been found to reduce the overall productivity of bees and their hives (Ali & Jabeen, 2017). In a study conducted between October and December of 2016 in Zambia by Ali and Jabeen, they found that a shorter rainy season, and resulting growing season reduced honey production by 50% when compared to a "typical" rainy season period. A water shortage led to late planting and lower pollen production, and this in turn impacted the productivity of the bees (Ali & Jabeen, 2017).

Increases in temperature across the globe has resulted in droughts, irregular weather patterns, flooding, heat waves, and other extreme events (Arora, 2019). In excessively dry environments plants will most certainly be negatively impacted and bees will suffer as their main sources of food are threatened (Stokstad, 2007). In a dry climate pollen production decrease, and the overall nutritional quality of honey produced by bees decreases (Ali & Jabeen, 2017). Not only does climate change reduce honey yields due to increased water stress and resulting decreased pollen production in flowering plants, but it also limits the arable land where bees can produce enough honey to survive (Ali & Jabeen, 2017).

In a review by Reddy et al. (2012), investigators found that climate change impacts bees both directly via physiology and behavior, and indirectly via floral quality. The alteration of the main food source of bees (flowers) by climate variability has an indirect influence on the development cycle of the honeybee. Potential influencers of bee life cycles include day length, maximum daily temperature, and number of days above a certain temperature threshold. The general temperature also influences bees' foraging, or food collection (Reddy et al., 2012). Under extreme conditions, bees must put in effort that would normally be expended on foraging to regulate the temperature of the hive to protect honey bee larvae and pupae, which must be kept at a proper brood nest temperature (Reddy et al., 2015). Pollinators in regions with generally high ambient temperatures are at risk of overheating, thus reducing the foraging efficiency of the hives (Reddy et al., 2012).

Research suggests that climate change may increase our reliance on insect pollination services for heat stressed crops (Bishop et al. 2016). As global agriculture in general is becoming more and more dependent on pollination (Aizen et al., 2019), the impact these shifts in temperature and rainfall have on bees is a cause for concern. Honey and pollination industries are currently limited by foraging resources in areas experiences habitat loss (Picknoll, Poot, & Renton, 2021) and the expansion of pollinator dependent crops such as the soybean in the US in recent decades have been tied to a decrease in crop diversity and pollination services (Aizen et al., 2019).

Table 2: Climate change impacts and resulting consequences on apiculture

Impacts	**Consequences**
Drought	Decreases pollen yield in plants and nutritional content in forage (Stokstad, 2007)
Extreme Heat	Energy expended on regulating brood temperature (Reddy et al., 2015) Limited foraging behavior (Reddy et al., 2012)
Extreme Cold	Energy expended on regulating brood temperature (Reddy et al., 2015). Limited foraging behavior (Reddy et al., 2012)
Temporal Shifts	Mismatch between flowering times and foraging behaviors of bees (Reddy et al., 2012)
Disease Pressures	Climatic habitat shift causing mixing between bee communities, spreading disease amongst populations (Reddy et al., 2012)

Adaptation Techniques in Apiculture

Some methods to mitigate the impacts of climate variability on beekeeping include planning ahead for necessary resources before and after crop flowering, reducing fragmentation of farmland to ensure the possibility for range shifting in response to a changing climate, and improving non-crop flowering resources (planting hedgerows, cover crops as supplementary forage for bees) (Reddy et al., 2012). A survey conducted by Dimelu and Nwuba of indigenous adaptations to climate change impacts to beekeeping in Nigeria between 2000-2015 found that small-scale beekeepers adapted their practices by moving their hives, shifting the timing of their beekeeping practices to more climate appropriate times, locating hives nearer to trees or planting trees to provide shade from the sun, and supplementary feeding of hives via sugar solutions or grain powder. The survey is a good example of the methods that small-scale beekeepers are using to counteract the challenges that result from climate variability and change and leads into the question of how these beekeepers perceive the effectiveness of these adaptive practices.

Another study conducted by Aynalem in Ethiopia in 2017 identified the increased usage of pesticides, herbicides, and insecticides to combat the growing disease pressures on crops and humans due to climate change as a negative influence on local bee populations. Beekeepers in the Eastern Amhara region of Ethiopia reported high levels of bee poisoning due to the use of these chemicals, an indirect impact of climate variability on the health of bee colonies and productivity of their beekeeping endeavors (Aynalem, 2017). Cooperation between crop and bee farmers is one of the main recommended methods from this study to reduce the negative impacts of these chemicals (Aynalem, 2017). Aynalem also found in the survey of beekeepers that about half of the farmers did not help sustain bees via supplementary feed during periods of dearth mainly due to a lack of awareness about this practice, suggesting that more farmers would practice this technique if they had the knowledge of its benefits. More training and knowledge sharing is needed in these cases to help small-scale beekeepers such as those in the Amhara region to mitigate these indirect impacts of climate variability on their apiculture practices.

Exploring this topic in a different region of the world, a study conducted in 2018 in NW Italy by Vercelli et al. investigated the perception of beekeepers to the impact of climate change on their bees, and the methods that they use to mitigate those impacts. Vercelli et al. discovered that the beekeepers found it necessary to provide supplemental sugar feeding to make up for scarcity of pollen and nectar, and in some cases moved entire hives to more mountainous areas where the climate was cooler and plants more numerous when the weather became too hot in the summer. The *Varroa destructor* mite was also a key identified threat, as climate change allows the mite to reproduce continuously over winter and required beekeepers to interrupt brood production artificially by caging the queen or completely removing the brood to prevent the spread of the mite.

A study conducted by St. Clair et al. in 2015 and 2016 on the impacts of diverse farming on honey bee health found that fruit and vegetable farms that were diversified increased colony growth and nutrition in honey bees from managed colonies. The researchers connected the diversity and abundance of plants (including both weeds and crops) with more foraging available to these bees. This diverse farming was compared to a monoculture of soybeans, which had lesser growth and nutrition on the part of the honey bees, but in contrast had positive effects on wild bees. The monoculture of soybeans had a positive effect on wild bees and attracted a wider diversity of wild bee species (St. Clair et al., 2020). So, in the case of managed honey bee populations, diverse farming in this case has a positive impact on colony growth and nutrition, but the response of wild bee populations cannot be guaranteed to be the same as that of the managed populations (St. Clair et al., 2020).

Positionality Statement

As a university educated white middle class citizen of the United States, I acknowledge that my upbringing impacts my world view. My personal experiences and education affect how I interact with the world, and my past travel and volunteer work abroad leaves me with certain inherent biases. As a Returned Peace Corps Volunteer from Cameroon, I have friends in the country, and as an intern for a farming group in Malawi I have an interest in the success of the people there. I was raised with inherent privileges, and my access to higher education affects my way of thinking. In turn, my years spent in a rural village in Sub-Saharan Africa gives me a unique perspective on daily life, albeit still through the lens of my own experiences and background. As a Climate Change and Global Sustainability graduate student I value climate smart activities and sustainable living, and as a scientist I value innovation. These biases make up my background as a researcher and impact my desire to pursue research in this field.

Methodology

Research Sites

This research took place in the United States with phone calls to key informants in Cameroon and Malawi. Beekeeping in the United States dates to 1622, when honeybees were shipped from England to the Virginia Colony (Oertel, 1980). In 2017, 2.67 million bee colonies produced 1.47 million pounds of honey in the United States (USDA, 2019). Beekeeping is indigenous to Africa (Dietemann et al., 2009), and the continent produces about 9.8% of the honey worldwide (135, 373 metric tons in 2006) and 23% of the beeswax worldwide (14,165 metric tons) (Adekola et al., 2006). More than 10 subspecies of the western honeybee reside in Africa, all called African honey bees, but the best-known subspecies is the *Apis mellifera scutellata* Lepeletier, or what is referred to as the Africanized honeybee when introduced outside of its natural range (Ellis & Ellis, 2009).

Sampling and Methods

The researcher received Institutional Review Board Approval for this research and completed CITI (Collaborative Institutional Training Initiative) prior to the initiation of research. All participants were briefed either via written or spoken methods of their rights as subjects and confidentiality protocol. This research was conducted in the United States between June 29th and July 30th, 2021 via convenience and purposive sampling in the form of an internet survey and via personal connections of the researcher to beekeepers. Research was conducted in Malawi and Cameroon via recorded key informant semi-structured interviews in July of 2021. Key informant interviews were conducted and recorded only after participants were briefed by the interviewer as to their rights and agreed to the terms of the study. All survey participants were required to type their name to indicate their agreement to and understanding of the terms of the study presenting prior to the content of the survey itself. The United States survey was formatted in Google Forms and posted on Facebook and Reddit beekeeping groups, as well as in the newsletter of a major non-regional American beekeeping organization (American Honey Producers Association), Bee Culture Magazine Daily Buzz article, and Project Apis and the Honey Bee Health Coalition social media (sample size n=37) to ensure the representation of each major area of the United States.

Key informants from Malawi and Cameroon were selected via purposive sampling (sample size n=2 per country), and interviews in Malawi took place with a scripted dialogue in English with a translator into the local language of Chichewa, while interviews in Cameroon took place with a scripted dialogue in English by the researcher, and with the aid of a translator into French. The scripted dialogue was intended to explore the beekeepers' work, as well as any observations they may have made of past climate conditions and how those might interact with their beekeeping experiences and challenges. The interviews in both Malawi and Cameroon were limited by language barrier and the virtual nature of the conversation, which the researcher mitigated as much as possible via audio recording and the use of translators.

The Google Forms survey resulted in 37 responses from beekeepers in the United States. General demographic data was collected, and participants were asked via a Likert scale to categorize their "hive observations". The Likert scale ranged from 0 to 4, 0 being that they have not observed or experienced the challenge at all, 4 being that the challenge is severe, with 2 acting as the intermediate category. Participants were then asked climate observation questions with a range of 0-4, in this case 0 denoted a decrease in temperature or rainfall, and 4 denoted an increase in temperature or rainfall with 2 as "no change".

The United States surveys included open ended follow-up questions to allow for qualitative information to further inform the beekeeper's practices and experiences. These responses were coded and interpreted to gain insight into the challenges and observations of beekeepers across the country. The United States surveys were limited by the number of respondents willing to fill out the forms, and by members of beekeeping groups that have access to internet platforms. Respondents could opt in for a follow-up interview, and two respondents were successfully interviewed to add depth to the data collection. Some respondents had to be removed because they were outside the limits of the study but were analyzed separately to glean key information. This includes beekeepers who have been practicing less than three years (n=4) and beekeepers from outside the United States (n=4).

Data Analysis

Data from both interviews and surveys was collected, tabulated, and organized to allow for analysis. Survey respondents outside of the limits of the study were removed and analyzed separately. Qualitative data results from interviews were coded for emergent themes related to climate change adaptation in beekeeping practices. Survey analysis was interpreted via descriptive statistics in Microsoft Excel software. Data was presented in both data and figure format.

Analysis and Discussion

Malawian Key Informants

I interviewed two key informants in Malawi, hereafter referred to as Informants A and B, who are active beekeepers in their community (Table 3). A is involved in two beekeeper endeavors, one at the local teaching farm, and one at home. Informant A harvests honey twice a year, while B harvests three times a year at the end of each season. Informant A's farm project consists of 5 hives which each yield around 7-8 liters of honey during the first yearly harvest and 4-5 liters the second yearly harvest. The home project is newer and is not ready to be harvested yet. Informant A lacked materials to make a large hive, so they are a one chamber locally made Kenyan Top Bar (KTB) model. Top bar hives can be made from local materials and have a ten-year life span as opposed to the two-year maximum of a traditional hive (FAO, 2001). In traditional hives, all combs can be brood comb (comb containing bee larvae) and honeycomb. In modern hives like the KTB hive, the combs are separate, which makes harvesting without damaging the bees much easier (FAO, 2001).

Informant A cited a difference in floral resources for the variation in honey yields at the two times of year for harvesting. The difference in resources may be due to the nature of the climate in Malawi. Malawi experiences a cold season that spans from May to mid-August, a hot season from mid-August to November, and a rainy season November to April (World Bank Climate Knowledge Portal, n.d.). Informant A and B noticed general "shifts" in temperature in the past 10 years, especially regarding extremes. Informant A mentioned cold season being either "less cold or colder than expected" and dry season "less hot or hotter than expected". Informant B stated that the cold season this year (2021) was colder than usual.

Both Informant A and B mentioned a higher than usual rainfall this year (2021) especially compared with the rainfall last year (2020). Informant A cited a decrease in rain overall in the past 10 years, making this past year of higher rainfall an anomaly. Informant B brought up variable rain time making it difficult to predict rain season start times. Historic data of rainfall in Malawi suggests the quantity is variable year to year but does not seem to be consistently decreasing (World Bank Climate Knowledge Portal, n.d.).

General beekeeping issues cited included a lack of access to resources on the part of both informants, and broken materials (bee smoker). Difficulty attaining two bee suits to harvest honey was a particular issue for Informant A. Informant B mentioned difficulty in predicting the onset of rain as a challenge, as it makes it difficult for him to weatherproof his hives and the rain can enter the structure and rot the wood. While pathogens were not mentioned when the interviews were questioned on pests and pathogens, Informant A had had issues with ants in the past, and B mentioned access to clean water as an important aspect of bee health. Informant B stated that bees would not drink dirty water, and that they needed access to clean water to "have a healthy life". Informant B keeps clay pots full of water ear the hives, and stated that he knew when to refill the pots because "when the water is out the bees come to my home"

Adaptations to beekeeping practices included supplementary feedings on the part of both Informants A and B in the form of maize flour, an alternative to sugar water supplements. Informant A referenced "diverse natural plants" surrounding the hives as a source of food as well. Informants cited the high price of sugar as reasoning to not utilize sugar supplements, as well as a lack of knowledge of this process. Researchers have studied the value of maize flour as a bee nutritional supplement, sometimes combined with some other materials like milk powder and sugar (El-Hady, 2012; Mahmood, 2013; Younis, 2019). Informant B also utilizes a fire break around the forest where his hives are placed to reduce danger from wildfires. Informant B hangs his hives from trees, and spreads ash around the trunks to deter ants. Hanging hives from trees is a method used to deter thieves and grazing animals, prevent attack from termites, and to reduce the incidence of stings to children (Himsel, 1991).

Informant A also reported planting trees and floral resources for bee foraging and encouraging the community to plant trees by giving them as gifts and selling them locally through the teaching farm. As bees forage in patches and may ignore plots of floral resources if they are not sufficient (Donkersley, 2019) the importance of planting resources and ensuring their abundance is logical.

Cameroonian Key Informants

I interviewed two key informants in Cameroon, hereafter referred to as Informants C and D, who led beekeeping groups in their respective villages (Table 3). Both Informant C and D were trained via a Peace Corps funded training on modern beekeeping techniques in 2019, and supplied with 10 Kenyan Top Bar hives, along with the necessary equipment (suits, smokers, etc.) to start their projects. Informant C has been beekeeping for 10 years, as he has been practicing traditional beekeeping prior to the modern training and has 10 traditional hives outside of his village that he uses the revenues from to invest more money into his modern beekeeping project. Both informants were trained to do their harvest three times a year but currently harvest twice, but C mentioned switching to twice a year as he found there was not enough honey to support three harvests. Informant A gets a maximum of 10 liters of honey per harvest, and B gets 4-5 liters per harvest.

Cameroon has a rainy season that spans May-November, and a dry season from February-April which contains the yearly highest temperatures from February-April (World Bank Climate Knowledge Portal, n.d). Both Informant C and D have noticed shifts in rainfall, with C noting less and more irregular and unpredictable rain in recent years and in the past decade. Informant D reported that the rain is coming earlier in the past decade, and that recently it is very irregular, with little rainfall last year (2020) especially.

Informant C noticed general temperate rises recently and in the past decade, and D noted more extremes in temperature (sometimes very high, sometimes very cold especially in the rainy season). Mean annual temperatures across Cameroon have risen 0.7 degrees Celsius since the 1960s, and the average annual precipitation has decreased by 2.9 mm per decade since the 1960s, with meteorological stations observing decreasing rain during rainy season in the West, Southwest, and Northern regions of the country (World Bank Climate Knowledge Portal, n.d).

Both informants have their hives located close to a source of water, around 10 meters away, and did not need to provide supplementary water. Only Informant D reported issues with pests, specifically ants getting into the hive and attacking the bees, despite the hive placement on metal stands. Informant C cited issues with swarms leaving and disappearing from hives, which could be due to seasonal absconding typical in the off-season of hives in tropical Africa (Mutsaers, 2010). In the off season when foraging is less plentiful, it is not uncommon for new, smaller hives to leave and find a new nesting area, which can be detrimental to beekeepers as bees do not start making enough honey for harvest until the second year (Mutsaers, 2010).

Informant C noted various challenges in his beekeeping including a concern over thievery of modern hives as well as the high cost, complexity, and availability of modern beekeeping equipment. Both C and D mentioned a lack of floral resources. Informant D specifically mentioned issues with year where the trees do not flower at all, reducing resources for the bees. Again, as bees can ignore insufficient plots of floral resources (Donkersley, 2019) a decrease in flowering trees has implications for bee nutrition.

Informant C explained that he placed his modern hives close to the village (2 km away) to deal with thievery issues, while his modern hives were further "in the bush". Both informants mentioned planting for the bees to deal with a lack of foraging, Informant D has planted "maize, moringa trees, and piment (chili peppers)" to provide additional food for the bees.

Table 3: Sub-Saharan Africa key informant responses

	Informant A	**Informant B**	**Informant C**	**Informant D**
Country	Malawi	Malawi	Cameroon	Cameroon
Age	36	51	28	37
Gender	Male	Male	Male	Male
Length of time beekeeping	5 years	10 years	10 years	2 years
Method of training	Locally taught	A teacher who visited his village	Learning via experience with traditional	Peace Corps funded training program in 2019

			methods in village Peace Corps funded training program in 2019	
Beekeeping role	Sole decision maker at home (but takes advice from teaching farm)	Sole decision maker	Head of village beekeeping group	Head of village beekeeping group
Location of hives	2 locations: on the local teaching farm and at home in a ravine 300 meters from his house	His forest (3 acres), in walking distance of his home	Traditional: In the bush Modern: 2 km from village in the forest	3 km from town in the bush
Water Source	At home: Ravine	Clay pots in the forest that he refills with clean water from the nearby river and borehole He knows that the water is low when the bees come to his home	Small creek, 10-15 meters away from the hives	Small creek, 5-10 meters from the hives
Number of hives	2 at home (modern) 5 at the farm (modern)	8 modern	10 traditional 10 modern	10 modern
Type of hives	Locally made Kenyan Top Bar hive	Locally made Kenyan Top Bar hive	KTB	KTB
Yearly harvests	2	3	2 (was trained to do it every 3 months but found there wasn't enough honey and	2 times (April/May and November)

			switched to every 6 months in March/April/May and Sep/Oct/Nov)	
Yield per harvest	Farm: 7-8 liters first harvest, 4-5 liters second harvest Home: Have not harvested yet	200 liters	10 liters per hive	4-5 liters per hive
Bee Health Concerns	Ants destroying the honey and attacking bees	Bees will only drink clean water, they need a "healthy life"	Don't have an issue with pests as much as the bees moving and disappearing from hives	Ants getting into the hives
Supplementary Feeding	Put out maize four	Put out maize every month, at the beginning and towards the end of the month	Planting for bees, don't have any other methods	Planting resources
Observed changes in rainfall (10 years)	Mostly noticed a difference in the past 5 years	In his parent's time the rain was more predictable	Less rainfall in general More extremes in weather	The rain is coming earlier
Observed changes in rainfall (recently)	Decrease in rainfall the past 4 years (2016-2020) but an increase in rainfall this year (2021)	Past few years the rain was late, and it has been difficult to predict when the rain would stop. Increase in rainfall especially this year (2021)	It used to rain for 3-4 months, but now it is irregular and a lot less rain in general	It is very irregular. Last year (2020) it didn't rain much
Observed changes in temperature (10 years)	Cold season is not as cold or colder as expected	Has noticed a general change	General temperature rises	More extremes: sometimes very high, sometimes very cold (in

	Dry season is sometimes not as hot or is hotter than expected			rainy season)
Observed changes in temperature (recently)	Temperatures are not what is expected	Cold season this year has been much colder	General temperature rises	More extremes: sometimes very high, sometimes very cold (in rainy season)
Unique challenges	Lack of materials, they are expensive and hard to get Access to 2 bee suits for harvest A broken smoker	A broken smoker The unpredictability of the rain makes it harder to protect the hives, they get destroyed by water and rot	Thievery of modern hives Lack of floral resources Cost of hives Complexity of hives Animals like goats interfering with the hives	Rain coming earlier interferes with the bees producing honey Some years trees don't flower which is an issue for bees Ants getting into the hives
Adaptations	Planting trees and floral resources, encouraging the community to plant trees (giving them as gifts and selling them)	Building a fire break around his forest Hanging hives from trees Spreading ash around the trees to deter ants	Planting for the bees Placing hives near town for security	Planting for the bees: moringa trees, corn, piment

United States Survey Findings

Survey participants were 40.5% female and 56.8% male, with the highest number of respondents in the 61-70 age range (29.7%) and located in the Western region of the United States (35.1%) (Table 4). Most participants had either a Bachelor's (35.1%) or Master's degree (35.1%).

Table 4: US Beekeeper Demographics

Demographics	**Participant n (%)**
Gender	

Female	15 (40.5)
Male	21 (56.8)
n/a	1 (2.7)
Age	
30-40 years	8 (21.6)
41-50 years	4 (10.8)
51-60 years	8 (21.6)
61-70 years	11 (29.7)
70+ years	4 (10.8)
n/a	1 (2.7)
Region	
Northeast	4 (10.8)
Midwest	9 (24.3)
South	10 (27)
West	13 (35.1)
n/a	1 (2.7)
Education	
High School	6 (16.2)
Trade School	3 (8.1)
Bachelor's Degree	13 (35.1)
Master's Degree	13 (35.1)
Ph.D. or higher	1 (2.7)
Prefer not to say	1 (2.7)

Most beekeepers were hobbyists who do not market their bee products (48.6%), with sideliner (beekeepers who market their bee products for a supplementary income) as the next most common classification (43.2%) (Table 5). Most respondents had been keeping bees from 3-5 years (40.5%) and had less than five hives (35.1%). The most common learning method was formal training at 62.2%, and 86.5% stated that they were part of a beekeeping group.

Table 5: Beekeeping History Statistics

Beekeeping History	Participant n (%)
Beekeeping Classification	
Hobbyist	18 (48.6)
Sideliner	16 (43.2)
Commercial Beekeeper	2 (5.4)
Researcher	1 (2.7)
Time Beekeeping	
3-5 years	15 (40.5)
6-10 years	9 (24.3)
11-15 years	8 (21.6)

16+ years	5 (13.5)
Hive Number	
<5	13 (35.1)
5-10	5 (13.5)
11-15	5 (13.5)
16-20	3 (8.1)
21+	10 (27)
n/a	1 (2.7)
Learning Method	
Self-taught	8 (21.6)
Formal Training	23 (62.2)
Mixed method	6 (16.2)
Beekeeping Group Membership	
Yes	32 (86.5)
No	5 (13.5)

The highest mean response to hive health observations in the past five years (0 being not at all affected and 4 being severe) was to the question on severity of colony loss (Table 6). The mean answer so respondents was 2.22 (slightly above an intermediate observation in colony decline) with a standard deviation of 1.00, with a three-way tie for the mode between selections 1,2, and 3. The mean of the other hive health questions were all below 2, the intermediate level, with the lowest being observation of pollination declines at a mean of 0.95, with 54.1% of respondents selecting 0, or “not at all”. 54.1% of participants did not observe bee product quality decline in the past five years, and 45.9% of respondents selected “not at all” for observations related to pollen resource decline.

Table 6: Hive and bee health descriptive statistics of the past five years for US respondents (Likert Scale 0-4: 0 being that the challenge was not observed, 4 being the challenge was severe, 2 being the challenge was intermediate)

Observations	**Mean of Responses**	**St. Dev. Of Responses**	**Mode (% of responses)**
Hive Health Decline	1.5	1.32	0 (30.6) 2 (30.6)

Colony Loss	2.22	1.00	1 (29.7) 2 (29.7) 3 (29.7)
Pollen Resources Decline	1.14	1.29	0 (45.9)
Pollination Decline	0.95	1.18	0 (54.1)
Bee Product Quality Decline	1.05	1.33	0 (51.4)

Of the qualitative responses of the 37 participants to bee disease inquiry, the most frequently referenced pest was the varroa mite (Table 7). 75.7% of participants mentioned varroa mites, with the next most common issue being small hive beetles for 35.1% of beekeepers, and wax moths at 18.9%. Only two participants, or 5.4% of the population, had no disease pressures listed. One of the possible reasonings for such high rates of varroa mite infestations specifically amongst participants relates to their beekeeping practice. In the wild, bee populations colonies are usually located far enough apart to prevent spreading the mite to other swarms, and the swarming practice also helps to thin the pests and associated pathogens out of the population (Entomological Society of America, 2017).

Table 7: Pest and pathogen thematic results from qualitative open-ended inquiry of US respondents

Theme	**Subthemes**	**Examples**	**Frequency**	**Percent of Respondents**
Pests	Varroa mites	"Mite populations really boom in some years for some unknown reason"	28	75.7
	Small hive beetles	"Small hive beetles are a big issue where I live"	13	35.1

	Wax moths	"Wax moths absolutely devastated a hive; it was a truly horrific sight"	7	18.9
	Ants	"Ants are my nemesis in the last couple of years!!"	2	5.4
	Wasps/Hornets	-	1	2.7
	Mice	-	1	2.7
	Unspecified pests	-	1	2.7
Fungus	*Nosema* spp.	"We get more pressure from things like chalkbrood and Nosema"	3	8.1
	Chalkbrood		1	2.7
Viruses	Deformed Wing Virus (DWV)	-	1	2.7
	Unspecified viruses	-	1	2.7
None	-	-	2	5.4

The highest mean from the Likert scale on climate observations was from the questions on observed summer temperature changes (Table 8). With 0 being a decrease in temperature, 2 being no change, and 4 being an increase, the mean of 2.62 with a standard deviation of 1.14 was the highest mean reported in this section. The mode of the summer temperature scale was 3, with 40.5% of the respondents selecting this option. 3 was also the mode for winter temperature change (48.6% of participants) and spring temperature (43.2%).

Table 8: Climate descriptive statistics of the past five years for US respondents (Likert Scale 0-4: 0 being a decrease, 4 an increase, 2 being no change)

Observations	Mean of Responses	St. Dev. Of Responses	Mode (% of responses)
Rainfall	2.17	1.40	1 (30.6)
Winter Temperatures	2.57	1.12	3 (48.6)

Spring Temperatures	2.46	0.96	3 (43.2)
Summer Temperatures	2.62	1.14	3 (40.5)
Fall Temperatures	2.43	0.99	2 (43.2)

When respondents were asked to describe their observations about climate in the past five years, the most frequently referenced theme was the unpredictability of weather, with 42.9% of respondents referencing some sort of temporal shift in weather that was atypical, such as "more and earlier spring rains" (Table 9). The next most common theme mentioned was "drought" with 28.6% of respondents referring to instances of drought. Three respondents (8.8%) provided qualitative answers of observations of "no observed change" in climate.

Table 9: Rainfall thematic results from qualitative open-ended inquiry (past five years) of US respondents, sample size=35

Theme	Subthemes	Examples	Frequency	Percentage of Respondents
Rainfall	Decrease	"Less rain this year, it's very dry here" "Less rainfall overall in my area"	6	17.1
	Increase	"Increase of rain in Spring" "Increase in amount of rainfall"	6	17.1
	Drought	"Consistent droughts every year" "Drought more often"	10	28.6

	Unpredictability	"Different time of year" "More and earlier spring rains"	15	42.9
	Extreme Events	"More and stronger storms" "Heavier rain events" "Rain more intense"	8	22.9
	No Change	"This is a slightly wetter year, not sure if I've seen a large-scale change"	3	8.8

Qualitative responses to temperature observations resulted in 57.1% of the 35 surveys referring to an "increase" in temperatures, such as "winters not as cold, summers hotter" (Table 10). The next most common observation was of an unpredictable nature of temperature "temperature ranges are getting further apart" at a frequency of 45.7%. 8.8% of surveys noted no change in temperature.

Table 10: Temperature thematic results from qualitative open-ended inquiry (past five years) of US respondents, sample size=35

Theme	Subthemes	Examples	Frequency	Percent of Respondents
Temperature	Decrease	"Colder winters and spring" "Cool wet spring prevents pollination of fruit trees"	3	8.8
	Increase	"Hotter summers and warmer falls" "Winters not as cold, summers hotter"	20	57.1
	Unpredictability	"Hot earlier in the season"	16	45.7

		"Temperature ranges are getting further apart"		
	Extreme Events	"Hotter summers with more storms" "Summers are MUCH hotter"	4	11.4
	No Change	"Average, about the same"	3	8.8

62.2% of Survey respondents adapted their practices to temperature and precipitation changes (Table 11). Most of the group uses supplementary feeding, at 35 of the 37 responses, or 94.6%. 54.1% of people have adapted their methods of pest control, 43.2% have not adapted these practices in the past five years.

Table 11: Adaptation Practices (past five years)

Adaptations	Participant n (%)
Adapted to temperature/precipitation changes	23 (62.2)
Yes	14 (37.8)
No	
Using supplementary feeding	
Yes	35 (94.6)
No	2 (5.4)
Adapted methods for pest/parasite control	
Yes	20 (54.1)
No	16 (43.2)
No response	1 (2.7)

Open ended inquiry into adaptation techniques resulted in major themes such as water, hive construction, hive placement, timing, supplementing, monitoring, and no change (Table 12). These themes included subthemes such as ensuring water sources and irrigation/watering, altering hives to allow for better air flow in the form of screened hive bottoms and ventilation, and placing hives in the shade, in sheds for protection, and providing wind breaks. There were also references to temporal shifts to suit new climate conditions, such as working earlier or later in the day to avoid heat, a reduced window for harvest, and focusing on rearing bees during dry years. Supplementing nutrition practices included planting for bees and feeding more often and increasing monitoring of food supplies and growing seasons to ensure proper nutrition. 16.7% of respondents did not refer to any climate-based adaptations. The most cited adaptation was increasing airflow, via screened hive bottoms (16.7%) and adding ventilation (20.8%).

Several qualitative responses included language directly tying climate to beekeeping challenges, some with adaptations included, for example: "Lack of rainfall equals lack of flowers", "started tracking growing degree days to better forecast nectar flow", "planting more flowering trees and herbs to lengthen honey flow", "if it is too wet the bees cannot collect nectar and we get more pressure from things like chalkbrood and Nosema" and "logistically it gets harder to move the bees to pollination when it's too wet".

Table 12: Climate adaptation results from qualitative open-ended inquiry sample size=24

Themes	Subthemes	Examples	Frequency	Percent of Respondents
Water	Watering	"Moved most yards to sprinkler or irrigated alfalfa fields. Lack of rainfall equals lack of flowers"	2	8.3
	Water Sources	"Ensure water access always"	2	8.3
Hive Construction	Screened bottoms	"Slatted bottom boards and screens"	4	16.7
	Ventilation	"I ventilate hives more in winter"	5	20.8
Hive Placement	Shade	"Putting hives in afternoon shade"	3	12.5

	Wind Breaks	"Wind breaks around colonies to moderate wind chill effects"	2	8.3
	Protection	"This year I'll be putting the hives inside a shed"	1	4.2
Timing	Work	"Avoiding the hottest days/times of day to work colonies"	2	8.3
	Harvest	"Much more limited window for honey harvesting"	1	4.2
	Rearing	"We get less honey in dry years, so we focus on raising bees during that time"	1	4.2
Supplementing	Planting	"Began planting cover crops" "Planting more flowering herbs and trees to lengthen honey flow"	2	8.3
	Feeding	"More feeding has to happen when it is dry" "Feeding more in mid-summer"	2	8.3
Monitoring	-	"Monitor food stores and pest loads" "Started tracking	3	12.5

		growing degree days to better forecast nectar flow”		
No Adaptations	-	“No real climate adapting, just adapting to different pest/mite pressures”	4	16.7

United States Follow-Up Interviews

A follow-up interview with two survey respondents added depth to the information that they provided via the survey format (Table 13). Both informants stated that they practiced supplementary feeding, Informant E feeds honey back to the bees as necessary, and Informant F provides a sugar water 1:1 ratio for two months during the fall and winter seasons. Both informants cited health concerns for the bees, the biggest being pests, small hive beetles in the case of E, and varroa mites in the case of F. Informant F cites issues with pests and pesticides but described the varroa mites as her biggest challenge in beekeeping, one that requires her to test and treat for the pests every year and constantly change treatment methods. Informant F uses formic acid to do her treatments to give the bees a “fighting chance” but learned to be proactive about the treatments the hard way, she lost 4 hives to varroa mites despite testing and treatment as it came slightly too late. Informant E also cites deeper health issues to bees, mentioning that she cannot keep swarms for more than a couple of years. Her method to deal with this challenge is to buy bees from different suppliers, especially from a local Amish family.

Informants E and F noted changes in temperature and precipitation. Informant E (located in Ohio) has seen a shift that includes more rainfall in recent years, with temperatures that are either colder or hotter than expected. Information F (located in California) noted that every year it gets hotter with less rain. To deal with these climate issues, Informant F puts her hives in the shade with a screened bottom and plants vegetation that the bees can use for forage.

Table 13: US follow-up interview responses

	Informant E	**Informant F**
Age	46	35
Gender	Female	Female
State	Ohio	California
Length of time beekeeping	11 years	3 years
Method of training	Self-taught (books and online resources)	Formal training (beekeeping introductory course, classes, apprenticeship)
Beekeeping role	Hobbyist (does not market products)	Hobbyist (does not market products)
Number of hives	2	3
Bee Health Concerns	Small hive beetles	Varroa mites
Supplementary Feeding	Gives honey back to the bees	Sugar water 1 to 1 for two months during the fall and winter
Observed changes in climate	More rainfall in the past few years Either colder or hotter in certain months, there has definitely been a shift	Every year it gets hotter sooner with less rain
Challenges	Cannot keep a swarm more than a couple of years and keeps buying their bees from different places.	Pesticides being sprayed
Adaptations	Now purchase bees from a local Amish family to have healthier bees	Putting hives with screened bottom boards and in afternoon shade Trying to grow as much food for the bees

Newer Beekeepers

Although the survey requested for respondents with three or more years of experience beekeeping, four beekeepers with less than three years of experience responded. These results were separated from the main data and analyzed for key information. Of the four respondents, three mentioned issues with pests including varroa mites, small hive beetles, and wax moths. The fourth respondent has only been keeping bees for a few months and had not noticed any pests or other diseases. Of the four respondents, three practice supplemental feeding, all with sugar water and one uses pollen patties in addition to sugar. One respondent stated that they plant native species in their yard to give the bees plenty of food. One participant cited lack of experience (two years) as a challenge and described winter as the most stressful time for their beekeeping as they lost 1/3 of their colonies the previous winter.

Respondents Outside the United States

Although the survey was limited to US participants, some international beekeepers mistakenly filled out the form. These results were separated and analyzed for key information. Countries represented include the United Kingdom, Sweden, Fiji, and Canada. It was interesting to see from these results the different challenges the beekeepers in these locations faced. The UK respondent described "typical British weather with some dry and wet spells" and has not made any climate-based adaptations. The respondent from Sweden noted warmer summer and autumns and less rain than usual with warmer and drier summers and has adapted to climatic shifts by leaving more honey in hives for the bees to have for the whole season. The Fiji beekeeper cited no changes in temperature or precipitation, but "bigger storms" and the need to tie hives down during cyclone season, a unique adaptation to this respondent due to their location. The Canadian respondent noted no change in precipitation or temperature but selected “yes” when asked if they have adapted their practices to temperature and precipitation changes. All the international surveys mentioned a pest issue of some kind (moths in a weak hive in the UK, much disease and varroa in Fiji, varroa in Sweden, and varroa and small hive beetles in Canada). All also mentioned supplementary feeding of some kind (syrup and protein cakes in the UK, dry sugar in Fiji, honey in Sweden, and pollen supplements in Canada).

Conclusions

Climate change impacts agriculture via rising temperatures, droughts, flooding, extreme weather, and decreasing crop yields (FAO., 2016, Arora, 2019). The pressures that climate change exerts on plants and our food systems impacts pollinators via their foraging resources (Ali & Jabeen, 2017), habitat loss and land use change (Picknoll, Poot, & Renton, 2021), and disease pressure (Boncristiani et al., 2020) and in turn a decrease in pollination capabilities of pollinators puts stress on our food security (Cullen et al., 2019). It is thus vital from an anthropogenic standpoint, positive impacts of pollinators on biodiversity notwithstanding (Warade, 2017), to encourage the good health of bees. A healthy and climate-smart method of beekeeping is a sustainable method towards this end.

From the general trend of responses in the survey data and interview data the US struggles with pest and disease pressure on a larger scale than the respondents in SSA. Resource and material availability was a larger issue for beekeepers in Malawi and Cameroon, with common issues being access to beekeeping accessories and supplies such as bee suits and smokers and wood for hive construction. When asked about providing supplemental nutrition for their bees, 94.6% of respondents in the US stated that they used supplemental feeding methods such as sugar and pollen, while key informants in Malawi referenced providing maize flour as food and Cameroonian informants stressed the planting of trees and foraging materials for the bees. This is likely attributable to limited access to materials such as sugar and pollen patties and is an example of a difference in adaptation methods that have developed to be locally relevant and user-friendly.

When asked to describe changes in climate, both US and SSA informants elaborated on some aspect of extreme weather and changes or “unpredictability” in onset of temperature and rain. From these coded qualitative results, it is clear that at least some of the beekeepers in the United States and SSA are noticing a shift in climatic conditions. While the methods to adapt to these shifts may differ from country to country overall the common themes are constant: providing suitable shelter, changing timing of practices, giving supplementary nutrition (whether via sugar or a local method or planting forage material), and changing hive construction/placement. While these practices are all colored by access to materials and resources, the general concepts and motivation behind them are the same: to increase productivity and decrease loss in bee colonies.

Based on the data that I collected in this research and my own knowledge of beekeeping in the US and abroad I believe firmly that cross-culture information exchange has the potential to be useful and indeed vital in the future landscape of beekeeping. Though the challenges may seem different on a case-by-case basis, the opportunity for information exchange between global regions exists. Beekeepers in areas such as Africa, where pressures may be access to resources, could absolutely benefit from the knowledge base in the US, where schematics for homemade beehives and methods for dealing with pests are just a Google search away. In the US, where many pressures are disease related, it is entirely possible that more nature friendly inclined beekeepers might be interested in natural homemade methods of caring for their bees, whether via pest control (in the case of ash spread around hives to deter ants), or natural supplements (in the form of maize flour).

The spread of bee diseases and pests outside of their typical range also bodes ill for those regions where bee diseases are not yet a major pressure, and in this case all beekeepers could benefit from the knowledge of those who can easily identify and have methods for dealing with pests and pathogens. Through my qualitative collection of data from US participants, I observed that they all have experience with dealing with bee health issues at some level. Though key informant interviews in Malawi and Cameroon didn't result in a great deal of information on observed pests, that does not mean that they are not present and merely unidentifiable due to lack of sufficient knowledge, or that they will not become an issue in future. Overall, the data I collected in this study gives me reason to hope that, were this data collected on a larger scale, even more methods of adaptations would come to light that are worth sharing with the beekeeping community.

Limitations

The research is partially limited by the participant's knowledge of climate variability and climate change and the impacts that they may have on beekeeping practices. I attempted to mitigate this issue by approaching the subject of climate from various angles and focusing on the subject's "observations" rather than their knowledge of climate variability and allow for a wide variety of perspectives on the subject. These limits may also vary based on history of the participants and their cultural background, as not all communities experience environmental factors in the same way.

The data collection methods also had limitations. The nature of an online survey limits responses to those with access to the internet and ability to fill out an online form. Key informant interviews in Cameroon and Malawi were also limited to participants that had a working relationship with the researcher and were available for phone interview. The existing relationship for these key informants made collecting data from a distance more accessible.

Conducting direct "comparisons" of the countries of interest was limited (and indeed not the goal of the study) by the sheer difference in practices and challenges that beekeepers in these countries face. Disease pressures in each country were unique, as were the methods that subjects used to deal with these diseases and other challenges in their beekeeping. Putting these differences in context helped to reduce the impact it had on the results of the study.

Recommendations

I recommend that further studies are conducted on the unique challenges faced by beekeepers across the globe so that the scientific community is better able to help beekeepers prepare for and adapt to any issues they may face. In future, trainings on beekeeping practices should stress the importance of adapting practices to suit climate variability and other relevant pressures. I also recommend that any policies related to pollination in the United States, Malawi, and Cameroon include references and possible funding for research into how beekeepers specifically may alter their practices to better suit challenges such as disease pressures and climatic pressures (extreme weather events, shifting climate patterns, etc.). With the global importance of bees as pollinators, it is in our best interest to make sure that managed bee populations are healthy and productive, and understanding how to make that possible requires research and funding.

It would be very helpful for the future of beekeeping in regions where there are not many bee diseases present if future aid projects on beekeeping include trainings on disease identification and mitigation. The most useful step would be to provide illustrated materials that trainees or apiculture group members could take home and reference for future use, regardless of literacy status. These suggestions are also applicable to climate impacts on beekeeping. Several US respondents mentioned increasing ventilation in their hives via screened bottoms or propped lids and gaps within the hives to promote airflow. If my informants in Malawi and Cameroon know of this practice, they did not mention it in their climate mitigation techniques. To the best of my knowledge, the Peace Corps sponsored training where my Cameroonian informants learned their beekeeping methods made no mention of climate adaptations. Activities such as encouraging ventilation (and planting for bees, which both Cameroonian and Malawian informants knew of) should be encouraged when new beekeepers are trained and will involve adding material to typical beekeeping training programs.

Future Research

The limits of this study present opportunities for future research. Additional questions came up during the data collection that would be worth investigating. I would like to go more in depth into the gender dynamics of beekeeping in each region and see if that has any impact on practices or climate change observations. An additional aspect of the study that I believe warrants more exploration is the role of beekeeping in tandem with farming. Beekeepers who are also active farmers or are involved in agriculture in some way may have a different lens through which they view pollinators. I would like to add these questions into the mix of qualitative and qualitative data collection in all future research on beekeepers and climate change.

The responses from Cameroon, Malawi, and the United States present an interesting question as to how people in various environments experience climate changes differently, and how they might categorize those changes. The differences in disease pressures between countries has wider implications as scientists seek to understand how to reduce hive deaths from pathogens and pests. It would be worthwhile to explore further how beekeepers in other countries outside of Africa and the United States are responding to environmental pressures in their beekeeping, and whether those practices would be applicable across different regions. During the interview process, I began to question whether cultural differences might impact how beekeepers perceive and discuss climate change and whether that might skew results. It would be very interesting to see if the language that various cultures use to understand their surroundings are different, and if that has any bearing on my results. I would ideally like to continue this research by opening the survey and key informant interviews to other countries outside of the United States, Malawi, and Cameroon, and investigate what unique challenges these countries face in their beekeeping. Ideally, I would eventually collect enough data to run some statistical tests of significance on beekeeper's climate and hive observations, and their adaptations techniques.

References

Adekola, P.J.; Ojo, M.O; Samuel, a.A.; Aruwayo, A. & Aderounmu, A.F. (2006): Apiculture in Nigeria, A viable source of livelihood. *Journal of Forestry Research and Management, 3, pp. 59-67*

Aizen, M. A., Aguiar, S., Biesmeijer, J. C., Garibaldi, L. A., Inouye, D. W., Jung, C., … Seymour, C. L. (2019). Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. Global Change Biology. doi:10.1111/gcb.14736

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A., & Klein, A. M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of Botany, 103, 1579– 1588. https ://doi.org/10.1093/aob/mcp076

Aizen, M. A., & Harder, L. D. (2009). The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. Current Biology, 19, 915–918. https ://doi.org/10.1016/j.cub.2009.03.071

Alaux, C., Le Conte, Y., & Decourtye, A. (2019). Pitting wild bees against managed honey bees in their native range, a losing strategy for the conservation of honey bee biodiversity. *Frontiers in Ecology and Evolution*, *7*, 60.

Al-Ghamdi AA, Alsharhi MM, Abou-Shaara HF (2016) Current status of beekeeping in the Arabian countries and urgent needs for its development inferred from a socio-economic analysis. Asian J Agr Res 10:87–98

Ali, S., & Jabeen, U. A. (2017). THE EFFECTS OF CLIMATE CHANGE ON APICULTURE INDUSTRY. *European Journal of Business, Economics and Accountancy*

Ascher, J. S. and J. Pickering. (2020) Discover Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). http://www.discoverlife.org/mp/20q?guide=Apoidea_species

Amulen DR, D'Haese M, Ahikiriza E, Agea JG, Jacobs FJ, de Graaf DC, et al. (2017) The buzz about bees and poverty alleviation: Identifying drivers and barriers of beekeeping in sub-Saharan Africa. PLoS ONE 12(2): e0172820. https://doi.org/10.1371/journal.pone.0172820

Aynalem, T. (2017). Beekeeping, climate change and food security: the case of Eastern Amhara Region, Ethiopia. *Livest Res Rural Dev*, *29*, 83.

Arora, N.K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability* 2, 95–96. https://doi.org/10.1007/s42398-019-00078-w

Bishop, J., Jones, H. E., Lukac, M., & Potts, S. G. (2016). Insect pollination reduces yield loss following heat stress in faba bean (Vicia faba L.). *Agriculture, ecosystems & environment*, *220*, 89-96.

Boncristiani, H., Ellis, J. D., Bustamante, T., Graham, J., Jack, C., Kimmel, C. B., … Schmehl. (2020). World Honey Bee Health: The Global Distribution of Western Honey Bee (Apis mellifera L.) Pests and Pathogens. Bee World, 1–5. doi:10.1080/0005772x.2020.1800330

Brown, M. J., & Paxton, R. J. (2009). The conservation of bees: a global perspective. *Apidologie*, *40*(3), 410-416.

Carpenter, M. H., & Harpur, B. A. (2021). Genetic past, present, and future of the honey bee (Apis mellifera) in the United States of America. *Apidologie*, *52*(1), 63-79.

Crane, E. E. (2013). The world history of beekeeping and honey hunting [Internet] (1st ed.). Routledge. https://www. taylorfrancis.com/books/9780203819937

Cham, D. T., Fombong, A. T., Ndegwa, P. N., Irungu, L. W., & Raina, S. K. (2017). Scientific note on the first report of Varroa destructor in Cameroon. Journal of Apicultural Research, 56(4), 397–399. doi:10.1080/00218839.2017.1336371

Colopy, M. 2015. Women in beekeeping. *Bee Culture*. https://www.beeculture.com/ women-in-beekeeping/

Cullen MG, Thompson LJ, Carolan JC, Stout JC, Stanley DA (2019) Fungicides, herbicides and bees: A systematic review of existing research and methods. PLoS ONE 14(12): e0225743. https://doi.org/10.1371/journal.pone.0225743

Delaplane, K. S., Dag, A., Danka, R. G., Freitas, B. M., Garibaldi, L. A., Goodwin, R. M., & Hormaza, J. I. (2013). Standard methods for pollination research with Apis mellifera. *Journal of Apicultural Research*, *52*(4), 1-28.

Dietemann, V., Pirk, C. W. W., & Crewe, R. (2009). Is there a need for conservation of honeybees in Africa?. *Apidologie*, *40*(3), 285-295.

Di Prisco, G., Pennacchio, F., Caprio, E., Boncristiani Jr, H. F., Evans, J. D., & Chen, Y. (2011). Varroa destructor is an effective vector of Israeli acute paralysis virus in the honeybee, Apis mellifera. *Journal of General Virology*, *92*(1), 151-155.

Dimelu, M. U., & Nwuba, L. E. (2018). Indigenous Climate Change Adaptation Strategies used by Honey Producers in Rural Communities of Enugu State. Journal of Agricultural Extension, 22(2), 180-192.

Dolezal, A. G., & Toth, A. L. (2018). Feedbacks between nutrition and disease in honey bee health. Current Opinion in Insect Science, 26, 114–119. doi:10.1016/j.cois.2018.02.006

Donkersley, P. (2019). Trees for bees. *Agriculture, ecosystems & environment*, *270*, 79-83.

Douglas, M. R., Sponsler, D. B., Lonsdorf, E. V., & Grozinger, C. M. (2020). County-level analysis reveals a rapidly shifting landscape of insecticide hazard to honey bees (Apis mellifera) on US farmland. *Scientific reports*, *10*(1), 1-11.

Dunne, J., Höhn, A., Franke, G., Neumann, K., Breunig, P., Gillard, T., ... & Evershed, R. P. (2021). Honey-collecting in prehistoric West Africa from 3500 years ago. *Nature communications*, *12*(1), 1-11.

El-Hady, A. M. E. (2012). Influence of some pollen substitutes on brood rearing of honey bee and workers longevity. *Journal of Plant Protection and Pathology, 3*(3), 299-306.

Ellis, J. D., & Ellis, A. (2009). African Honey Bee, Africanized Honey Bee, Killer Bee, Apis mellifera scutellata Lepeletier (Insecta: Hymenoptera: Apidae). *EDIS*, *2009*(2).

Engel MS, Ismael A, Hinojosa-Diaz APR (2009) A honey bee from the Miocene of Nevada and the biogeography of Apis (Hymenoptera: Apidae: Apini). Proc Calif Acad Sci 60(3):23–38

Entomological Society of America. (2017, May 9). How varroa mites take advantage of managed beekeeping practices: Closer colonies and less swarming allow mite populations to grow and spread. *ScienceDaily*. Retrieved August 2, 2021 from www.sciencedaily.com/releases/2017/05/170509141907.htm

FAO (2001). Beekeeping: How to keep bees and process honey, TECHNOLOGIES and PRACTICES for SMALL AGRICULTURAL PRODUCERS, 1-4, *FAO*, Retrieved February 15, 2021 from http://www.fao.org/3/CA2542EN/ca2542en.pdf

FAO (2007). *The Plan of Action of the African Pollinator Initiative.* Rome, FAO.

FAO (2016). *The State of Food and Agriculture: Climate Change, Agriculture, and Food Security*. Rome, FAO.

FAO (2021). *Beekeeping*. TECA - Technologies and Practices for Small Agricultural Producers. http://www.fao.org/teca/en/categories/Beekeeping.

Fletcher, D. J. C. (1978). The African Bee, Apis Mellifera Adansonii, in Africa. Annual Review of Entomology, 23(1), 151–171. doi:10.1146/annurev.en.23.010178.001055

Gallai, N., Salles, J.-M., Settele, J., & Vaissière, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics, 68(3), 810–821. doi:10.1016/j.ecolecon.2008.06.014

Genersch, E. (2010). Honey bee pathology: current threats to honey bees and beekeeping. *Applied microbiology and biotechnology*, *87*(1), 87-97.

Gisder S, Hedtke K, Möckel N, Frielitz MC, Linde A, Genersch E. Five-year cohort study of Nosema spp. in Germany: does climate shape virulence and assertiveness of Nosema ceranae? Appl Environ Microbiol. 2010 May;76(9):3032-8. doi: 10.1128/AEM.03097-09. Epub 2010 Mar 12. PMID: 20228103; PMCID: PMC2863439.

Giliba, R. A., Mpinga, I. H., Ndimuligo, S. A., & Mpanda, M. M. (2020). Changing climate patterns risk the spread of Varroa destructor infestation of African honey bees in Tanzania. Ecological Processes, 9(1). doi:10.1186/s13717-020-00247-4

GOODWIN, R M (1992) Feeding sugar syrup to honey bee colonies to improve pollination: A review. Bee World 78: 56-62.

Goulson, D., Nicholls, E., Botias, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science, 347(6229), 1255957–1255957. doi:10.1126/science.1255957

Gupta, R. K., Khan, M. S., Srivastava, R. M., & Goswami, V. (2014). History of beekeeping in the developing world. In *Beekeeping for poverty alleviation and livelihood security* (pp. 3-62). Springer, Dordrecht.

Harissis HV, Harissis AV (2009) Apiculture in the Prehistoric Aegean: Minoan and Mycenaean symbols revisited, British archaeological reports S1958. John and Erica Hedges, Oxford

Hepburn, H. R. & Radloff, S. E. *Honeybees of Africa* (Springer, 1998).

Herbert Jr, E. W., & Shimanuki, H. (1978). Chemical composition and nutritive value of bee-collected and bee-stored pollen. *apidologie*, *9*(1), 33-40.

Himsel, H. H. (1991). Traditional beekeeping in the Republic of Niger. *Bee world*, *72*(1), 22-28.

Horn, T. (2012). *Beeconomy: What Women and Bees can Teach Us about Local Trade and the Global Market.* University Press of Kentucky.

Huang, Z. (2010). Honey bee nutrition. *American Bee Journal*, *150*(8), 773-776.

Hussein, M. H. (2001). Beekeeping in Africa: II—Central, southern African countries and islands. *Proc. 37th Int. Apic. Congr., Durban, South Africa*.

Husselman, M., Moeliono, M., & Paumgarten, F. (2010). Bees in the miombo: buzzing toward the Millennium Development Goals. *CIFOR Infobrief*, (23).

Imre, Dylan M. (2010). "Ancient Maya Beekeeping (ca. 1000-1520 CE)." University of Michigan Undergraduate Research Journal, 7, pp. 42-50.

Kleinschmidt, G. J., & Kondos, A. C. (1976). Influence of crude protein levels on colony production. *Australasian Beekeeper*.

Kugonza, D. R. (2021). Africa under attack: a continent-wide mapping of pathogens, parasites and predators afflicting the hived honey bee Apis mellifera L.(Hymenoptera: Apidae). *African Journal of Rural Development*, *5*(2), 1-27.

Kulhanek, K., Steinhauer, N., Rennich, K., Caron, D. M., Sagili, R. R., Pettis, J. S., ... & vanEngelsdorp, D. (2017). A national survey of managed honey bee 2015–2016 annual colony losses in the USA. Journal of Apicultural Research, 56(4), 328-340.

Le Conte, Y., & Navajas, M. (2008). Climate change: impact on honey bee populations and diseases. *Revue Scientifique et Technique-Office International des Epizooties*, *27*(2), 499-510

Mahmood, R., Wagchoure, E. S., & Sarwar, G. (2013). Influence of supplemental diets on Apis mellifera L. colonies for honey production. *Pakistan J. Agric. Res. Vol*, *26*(4).

Mamo, Y. S. (2016). The honey industry in COMESA: Opportunities and challenges. *Bulletin of Animal health and Production in Africa*, *64*(1), 207-216.

Moritz, R. F. A., Härtel, S., & Neumann, P. (2005). Global invasions of the western honeybee (Apis mellifera) and the consequences for biodiversity. Écoscience, 12(3), 289–301. doi:10.2980/i1195-6860-12-3-289.1

Muli, E., Patch, H., Frazier, M., Frazier, J., Torto, B., Baumgarten, T., … Grozinger, C. (2014). Evaluation of the Distribution and Impacts of Parasites, Pathogens, and Pesticides on Honey Bee (Apis mellifera) Populations in East Africa. PLoS ONE, 9(4), e94459. doi:10.1371/journal.pone.0094459

Mutsaers, M. (2010). Seasonal absconding of honeybees (Apis mellifera) in tropical Africa. In *Proceedings of the Netherland Entomological Society Meeting* (Vol. 21, pp. 55-60).

Nel, E., & Illgner, P. (2004). The contribution of bees to livelihoods in southern Africa. *Rights, Resources and Rural Development: Community-based Natural Resource Management in Southern Africa*, 127–134

Neupane, K. R., & Thapa, R. B. (2005). Pollen collection and brood production by honeybees (Apis mellifera L.) under Chitwan condition of Nepal. *Journal of the Institute of Agriculture and Animal Science*, *26*, 143-148.

Oertel, E. (1980). History of beekeeping in the United States. *Agriculture Handbook*, *335*, 2-9.

Ogaba, M.R., & Akongo, T. (2001). *Gender issues in beekeeping – The Uganda case*. Durban: In APIMONDIA Congress

Pfrogner, M. G. (2019). *PLAN BEE—UNDERSTANDING THREATS TO THE HONEY BEE POPULATION AND EXAMINING STRATEGIES TO PROMOTE AND PROTECT POLLINATORS* (Doctoral dissertation, Monterey, CA; Naval Postgraduate School).

Picknoll, Joanne L., Pieter Poot, and Michael Renton. (2021). "A New Approach to Inform Restoration and Management Decisions for Sustainable Apiculture" *Sustainability* 13, no. 11: 6109. https://doi.org/10.3390/su13116109

Pocol, C. B., & McDONOUGH, M. (2015). Women, Apiculture and Development: Evaluating the Impact of a Beekeeping Project on Rural Women's Livelihoods. *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Horticulture*, *72*(2).

Pollinator Health Task Force. (2015). *NATIONAL STRATEGY TO PROMOTE THE HEALTH OF HONEY BEES AND OTHER POLLINATORS*. Obama White House Archives.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. Trends in Ecology & Evolution, 25(6), 345–353. doi:10.1016/j.tree.2010.01.007

Rankin E.W., Barney S.K., Lozano G.E. (2020). Reduced Water Negatively Impacts Social Bee Survival and Productivity Via Shifts in Floral Nutrition, *Journal of Insect Science*, Volume 20, Issue 5, September 2020, 15, https://doi.org/10.1093/jisesa/ieaa114

Reddy, P., Verghese, A., & Rajan, V.V. (2012). Potential impact of climate change on honeybees (Apis spp.) and their pollination services. *Pest Management in Horticultural Ecosystems*, *18*, 121-127.

Reddy, P. R., Rashmi, T., & Verghese, A. (2015). Foraging activity of Indian honey bee, Apis cerana in relation to ambient climate variables under tropical conditions. *Journal of Environmental Biology*, *36*(3), 577.

Rosenkranz, P., Aumeier, P., & Ziegelmann, B. (2010). Biology and control of Varroa destructor. Journal of Invertebrate Pathology, 103, S96–S119. doi:10.1016/j.jip.2009.07.016

Sanchez, P. A., Denning, G. L., & Nziguheba, G. (2009). The African green revolution moves forward. *Food Security*, *1*(1), 37-44.

Shackleton, S., Paumgarten, F., Kassa, H., Husselman, M., & Zida, M. (2011). Opportunities for enhancing poor women’s socioeconomic empowerment in the value chains of three African non-timber forest products (NTFPs). *International Forestry Review*,136–151.10.1505/146554811797406642

Soroye, P., Newbold, T., & Kerr, J. (2020). Climate change contributes to widespread declines among bumble bees across continents. *Science*, *367*(6478), 685-688.

Standifer L.N., Moeller F.E., Kauffeld N.M., Herbert E.W., Shimanuki H. (1977) Supplemental Feeding of Honey Bee Colonies. U.S. Dep. Agric. Bull, 413

St. Clair, Zhang, Dolezal, O'Neal, Toth (2020). Diversified Farming in a Monoculture Landscape: Effects on Honey Bee Health and Wild Bee Communities, *Environmental Entomology*, Volume 49, Issue 3, June 2020, Pages 753–764, https://doi.org/10.1093/ee/nvaa031

Stokstad, E. (2007): The Case of the empty Hives. *Science, 316 (5827): 970-972.*

Tomlinson, Sean & Dixon, Kingsley & Didham, Raphael & Bradshaw, Don. (2017). Landscape context alters cost of living in honeybee metabolism and feeding. Proceedings of the Royal Society B: Biological Sciences. 284. 10.1098/rspb.2016.2676.

Traynor, K. S., Mondet, F., de Miranda, J. R., Techer, M., Kowallik, V., Oddie, M. A., ... & McAfee, A. (2020). Varroa destructor: A complex parasite, crippling honey bees worldwide. *Trends in Parasitology*, *36*(7), 592-606.

Tridge, "Honey Suppliers, Wholesale Prices, and Global Market Information." *Tridge*, www.tridge.com/intelligences/honey.

Tsvetkov, N., Samson-Robert, O., Sood, K., Patel, H. S., Malena, D. A., Gajiwala, P. H., … Zayed, A. (2017). Chronic exposure to neonicotinoids reduces honey bee health near corn crops. Science, 356(6345), 1395–1397. doi:10.1126/science.aam7470

USDA (2019). Honey Final Estimates 2013-2017, 2017 Census of Agriculture, National Ag Statistical Service (NASS), USDA. 2019.

USDA (2021). USDA ANNUAL STRATEGIC POLLINATOR PRIORITIES AND GOALS REPORT. *US Department of Agriculture.* https://www.usda.gov/sites/default/files/documents/pollinator-priorities-2021R4-508-version.pdf

vanEngelsdorp, D., Evans, J. D., Saegerman, C., Mullin, C., Haubruge, E., Nguyen, B. K., … Pettis, J. S. (2009). Colony Collapse Disorder: A Descriptive Study. PLoS ONE, 4(8), e6481. doi:10.1371/journal.pone.0006481

vanEngelsdorp D, Hayes J, Underwood RM, Pettis J (2008) A survey of honey bee colony losses in the US, fall to spring 2008. PLoS One 3:e4071. doi:10.1371/journal.pone.0004071

vanEngelsdorp, D., & Meixner, M. D. (2010). A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. Journal of Invertebrate Pathology, 103, S80–S95. doi:10.1016/j.jip.2009.06.011

Vercelli, M., Novelli, S., Ferrazzi, P., Lentini, G., & Ferracini, C. (2021). A Qualitative Analysis of Beekeepers' Perceptions and Farm Management Adaptations to the Impact of Climate Change on Honey Bees. *Insects*, *12*(3), 228.

Warade, N. V. (2017) APICULTURE: TECHNOLOGY FOR RURAL DEVELOPMENT AND SOCIO-ECONOMIC UPLIFTMENT–A REVIEW. Cognizance : An Online International Journal of Interdisciplinary Research

“World Bank Climate Change Knowledge Portal”. (n.d.). For Global Climate Data and Information! Retrieved July 23, 2021, from https://climateknowledgeportal.worldbank.org/country/malawi/climate-data-historical

“World Bank Climate Change Knowledge Portal.” *Homepage*, climateknowledgeportal.worldbank.org/country/cameroon/climate-data-historical.

Younis, M. S. (2019). Evaluation of Ten Supplemental Diets to Enhance Some Honey Bee (Apis mellifera L.) Activities during Winter Season in Egypt. *Egyptian Academic Journal of Biological Sciences. A, Entomology*, *12*(6), 101-109.

Appendix A: Survey Questionnaire

Administered to Survey Respondents via Google Forms

This survey aims to collect information about beekeeper's experiences with climate variability, and how it may be impacting their beekeeping practices. This research is part of the coursework for a graduate student seeking a MA degree in Climate Change and Global Sustainability for the School for International Training (SIT). This study requires that you have been participating in beekeeping for at least 3 years.

The researcher requests your consent for participation in a study about beekeeping in the United States. This consent form asks you to allow the researcher to use your comments to enhance understanding of the topic. The form also asks your permission to use related observations as data in this study.

Participation in this study is completely voluntary. If you decide not to participate there will not be any negative consequences. Please be aware that if you decide to participate, you may stop participating at any time and you may decide not to answer any specific question.

The researcher will maintain the confidentiality of the research records and data, your name will not be used in the research.

By typing your name below, you are indicating that you have read the description of the study, are over the age of 18, and that you agree to the terms as described.

If you have any questions, or would like a copy of this consent letter, please contact me at: katherine.lloyd@mail.sit.edu.

Thank you in advance for your participation, and please feel free to share this form with other beekeepers you know!

Katherine Lloyd

Type your name here to signify your consent to the terms of the study

What is your age?

What gender do you identify as?

What state do you live in?

What is the highest degree or level of education you have completed?

How long have you been beekeeping?

What kind of beekeeper would you classify yourself as?

How many hives do you have?

How did you learn about beekeeping?

Please describe your beekeeping learning experience

Are you a member of a beekeeping organization?

If yes, please include the name of your beekeeping organization here

Where did you hear about this survey?

Hive Observations:

The following questions will ask you to rate your observations of general hive health from the past 5 years, 0 being you have not observed or experienced the challenge at all, 5 being the challenge is severe

In the past five years, to what degree have you noticed a decrease in overall hive health? (0 being not at all)

In the past 5 years, to what degree have you experienced colony loss? (0 being not at all)

In the past five years, to what degree have you observed a decline in pollen resources near your hives? (0 being not at all)

In the past five years, to what degree have you observed a decline in pollination in the foraging region of your hives? (0 being not at all)

In the past 5 years, to what degree have you experienced a decline in the quality of bee products (honey, wax, etc) (0 being not at all)

In the past 5 years, to what degree have you experienced parasite or pest infestations? (0 being not at all)

If you have observed parasite/pest infestations, please describe them here

Climate Observations:

The following questions will ask you to rate your observations of climate change from the past 5 years

In the past 5 years, have you noticed a change in rainfall in your beekeeping region? (2 being no change)

Please explain your rainfall observations

In the past 5 years, have you noticed a change in temperature during the winter in your beekeeping region? (2 being no change)

In the past 5 years, have you noticed a change in temperature during the spring in your beekeeping region? (2 being no change)

In the past 5 years, have you noticed a change in temperature during the summer in your beekeeping region? (2 being no change)

In the past 5 years, have you noticed a change in temperature during the fall in your beekeeping region? (2 being no change)

Please explain your temperature observations

Adaptations:

The following questions will ask you to describe your adaptation techniques, or how you have changed your beekeeping practices to better suit your environment, in the past 5 years

Have you adapted your beekeeping techniques to these temperature and precipitation changes in the past 5 years?

Have you had to utilize supplementary feeding (sugar water, pollen supplements/substitutes) in the past 5 years?

If you have used supplementary feedings, what kind have you used, and how frequently in the past 5 years?

Have you had to change methods for parasite or pest control in your beekeeping in the past 5 years?

How have you changed your methods for parasite and pest control in the past 5 years?

Please detail any other relevant methods you have used to adapt your beekeeping to climate shifts in your region

What other challenges have you experienced related to your beekeeping?

Please explain any adaptations you have made to mitigate these challenges?

Follow Up:

Are you willing to be contacted for a follow up conversation about your beekeeping practices?

Would you like the researcher to send a copy of the results of the study?

If yes to the above, please provide your email for a follow up conversation or to receive research results

Appendix B: Semi-Structured Interview Script for Key Informants

Hello. My name is Katherine Lloyd, and I am a graduate student from the School for International Training. Before graduate school I was a Peace Corps volunteer in Cameroon where I started a beekeeping group. This study is about how beekeepers change their beekeeping practices based on temperature and precipitation. You do not have to answer any questions you don't want to answer. All of your answers and any identifying information (i.e., your name and contact info) will be kept completely confidential. I would like to ask you some questions about your work as a beekeeper and specific experiences you've had with beekeeping in your region. The interview may take up to an hour of your time. You may stop the interview at any time. I will be using this information for a paper I am writing for my degree, but we will not identify you or associate your comments with your name.
Do you understand this?
Do I have your permission to proceed?
Is it OK if I audio record our conversation?

1. What is your name?
2. What is your age?
3. What is your gender?
4. What is your highest level of education?
5. Where do you live?
    a. How long have you lived in this location?
6. Do you participate in beekeeping?
    a. What is your role?
        i. Beekeeper
        ii. Marketing
        iii. None
        iv. Other
7. How did you learn about beekeeping?
8. Tell me a bit about your beekeeping
9. For how many years have you been involved in work related to beekeeping?
10. Who else do you know that keeps bees?
    a. Has anyone near you shown an interest in beekeeping?
11. How many hives do you have?
    a. What kind of hives?
12. Is your beekeeping work located in a rural or urban area?
    a. How far is it from your home?
    b. How far is it from the nearest city?
13. What water source do you have for your bees?
    a. How far from the hives is it?
14. What is your role in your beekeeping project?
    a. Sole decision maker
    b. Joint decision maker
    c. A worker for the decision maker

15. How many times do you harvest a year?
16. How much honey do you harvest each time?
17. Have you noticed changes in rainfall in your region over the past 10 years?
    a. If yes, please explain
        i. Have you noticed changes in rainfall in your region over the recently (past 5 years)?
            1. If yes, please explain
18. Have you noticed changes in temperature in your region over the past 10 years?
    a. If yes, please explain
        i. Have you noticed changes in temperature in your region over the recently (past 5 years)?
            1. If yes, please explain
19. Other than changes in temperature and rainfall, are there unique challenges related to beekeeping? Y/N
    a. If yes, please list
    b. If multiple, please rank these challenges in order of severity
20. Have you had to change your beekeeping techniques to a changing climate?
21. Have you observed an increase in supplementary feedings for hives?
22. Have you ever experienced a problem with bee health?
23. Have you seen any methods for parasite or pest control in beekeeping?
24. Anything you would like to add?
25. Do you have any questions for me?