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UNDERSTANDING, CONSERVATION AND PROTECTION OF PRECIOUS NATURAL RESOURCES - BEES

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Abstract

This publication concerns the role of pollinators, especially bees, in relation to our agriculture and economy. Besides being a critical participant in the reproductive process of most flowering plants, the bees' pollination services increase flowering crop yields, improve nutritional quality, and contribute significantly to the global economy. However, beekeepers that manage the domesticated European honey bee had noticed that huge numbers of their bees were dying in recent years, and apiculture is closely wedded to agriculture. Honey bees suffer from a variety of maladies attributed to pesticides, climate change, parasites, and disease, all of which contribute to increased bee mortality and catastrophic hive death such as Colony Collapse Disorder. A number of these issues appear to affect wild pollinators as well. In order to conserve and protect our pollinator resources, this chapter describes a number of major stressors that lead to bee mortality and offers suggestions to improve bee and ultimately general pollinator survival. Recommended actions for beekeepers include adoption of honey bee strains that are bred for specific climates and survival traits as well as maintaining diverse forage around the apiary. Farmers are recommended to maintain areas of wild plants for diverse foraging sources, where a healthy bee diet also aids in crop pollination. In order to protect food availability, control prices, and support agricultural sustainability, governments can review ongoing research concerning known bee and pollinator stressors and implement legislation and guidelines to control human-created stressors such as pesticides while encouraging pollinator-friendly land management.

Key Words

Pollinators, Pollination, Wild bees, Honey bees, Agriculture, Crops, Bee conservation and protection.

Acronyms

ABPV Acute Bee Paralysis Virus

AIV Apis Iridescent Virus

ARS Agricultural Research Service

CCD Colony Collapse Disorder

CRP European Union Conservation Reserve Program

DWV Deformed Wing Virus

FAO Food and Agriculture Organization of the United Nations

IAPV Israeli Acute Paralysis Virus

IPCC Intergovernmental Panel on Climate Change

KBV Kashmir Bee Virus

NASS National Agricultural Statistics Service

NRCS National Resources Conservation Service

NWRS National Wildlife Refuge System

OPMP USDA's Office of Pest Management Policy

USDA United States Department of Agriculture

US EPA United States Environmental Protection Agency

US FWS United States Fish and Wildlife Service

VSH Varroa-Sensitive Hygiene

US$ United States Dollar

EU€ European Union Euro

1. Introduction of Pollinators and Pollination

Pollinators are animals that allow 75% of flowering plants to reproduce; these plants include most fruits, vegetables, and nuts, where 87 of the leading 115 food crops are dependent on pollination services, where pollinators contribute an estimated one-third of global food production. Pollinators also play a key role in our agricultural economy, where they contributed more than $24 billion to the United States' economy in 2014, and honey bee pollination services specifically contributed more than $15 billion.

There are thousands of bee species. Most wild (native) bees in America are solitary. Honey bees, our most commonly managed pollinator, were imported to the Americas from Europe during colonial times in the 1600s. These are called European or Western honey bees; in this chapter, we will refer to them as European honey bees.

Honey bees are social insects; each colony has one queen, several drones, and thousands of worker bees living in a wax comb hive that they built themselves. In this hive they store food and rear their brood (eggs, larvae, and pupae). Work responsibilities are caste-based. The queen bee is responsible for reproduction and maintaining colony population; a drone's sole responsibility is to mate with a queen; worker bees do all other duties in maintaining the colony. Worker bee responsibilities include rearing the brood, caring for the queen, maintaining the wax comb structure, defending the colony, and foraging. Plant pollination occurs when worker bees are foraging on their flowers. The nectar and pollen gained from foraging are prepared and stored in the hive as the primary food supplies, where the nectar is converted to honey. When flowers begin to bloom again in the spring, the queen begins to lay eggs as worker bees leave the hive to forage and pollinate plants along the way, continuing the cycle. How do honey bees execute their colony responsibilities in a systematic way? They communicate with each other using pheromones and dances. Pheromones are chemical substances secreted from the sender's glands and received by the recipient's antennae or other body parts. All colony members from queen to even brood members can produce pheromones. Besides pheromones, honey bees also perform different dances to convey information or request services. The most famous dance is the "waggle dance," which conveys the direction and distance of a food resource.

For a very long time, the majority of honey bees in the Americas had been European honey bees. However, a scientist in Brazil imported pure African honey bees in 1956 with the intention of breeding more tropically adapted honey producing bees. Just one year later, twenty six African queen bees escaped into the wild. Since then, those African queens have hybridized with feral European honey bee populations, becoming Africanized honey bees. Six decades later, Africanized honey bees have spread from South America through Central America and to North America. By 2009, Africanized honey bees had been confirmed in ten southern U.S. states.

Africanized and European honey bees are cousins; they are of same species though different strains, and they share the basic characteristics. The Africanized honey bees' aggressive defensive behavior earned them the "killer bee" nickname. They are also more difficult to manage due to frequent swarming and high absconding rates. Beyond those negatives, however, Africanized bees exhibit more positive differences from their European cousins, such as resistant to *Varroa* mite, using more propolis, and adapting well to tropical zones. Since the introduction of Africanized honey bees in Mexico, honey production had dropped, which might have been attributed to beekeepers dropping out of the profession. Mexico's honey production has since recovered, and now they prefer Africanized honey bees.

In the United States, managed honey bee colonies have steadily declined in the past 60 years from 6 million in 1947 to only 2.5 million in 2014. Starting in 2006, commercial beekeepers in the United States reported an average of 30% per winter losses as opposed to the historical rates of 10 -15% colony losses. In the United States, where honey bees contribute billions of dollars in added value to the agriculture, these bee losses must be taken seriously. For many years the commercial managed honey bee losses were due to Colony Collapse Disorder (CCD), where a specific set of symptoms led to catastrophic death of a colony. The trend was alarming, but according to the newest reports from the U.S. Department of Agriculture, CCD was not among the major cause of winter losses in the last couple of years.

Many stressors are correlated with CCD, such as pesticides (insecticides, herbicides, fungicides), parasites, disease, poor nutrition etc. Many scientists believe that CCD is caused by a combination of the above factors, where the compounding variables make it much harder to study.

There is no doubt about there is economic impact due to honey bee population decline, but how much of an impact? We know that humans will not all die in four years if bees disappear from the surface because some of our most productive crops are wind-pollinated or self-pollinated. However, our food will contain less variety, cost more to produce and to purchase, and have less nutritional quality.

Beekeepers should follow best management practices to care for their bees: monitor colonies for any pest infestation and apply treatments at the best time, rotate treatment methods to prevent pests from developing of resistance, re-queen if necessary and use resistant-bred queens when possible. Since selective breeding programs are available, beekeepers may consider purchasing resistant-bred queens or even breeding themselves. Some of the potential breeding possibilities include breeding for *Varroa*-sensitive hygiene (VSH) trait, for the tropical hardiness and mite resistance of Africanized honey bees, and for cold weather and mite resistance of the Russian honey bee.

Everyone from individuals to governments should diligently contribute to protect and conserve the honey bees and other pollinators. The general public can grow bee-friendly flowering plants in their backyards and window sills; farmers can increase the habitat diversity in farmlands by planting native and non-native, flower-rich herbaceous plants in appropriate areas, which will in turn help nearby crop fields; beekeepers can also improve the bee yards by creating or allowing nectar-rich wild flower areas on the premises, planting a variety of flowers that can provide nectar and pollen across honey bees' foraging seasons. Government departments can apply pollinator-friendly best practices on government-controlled lands and encourage its citizens to cooperate through incentives.

Besides increasing habitat diversity for bees, everyone who must use pesticides should follow the pesticide usage best practices. Pesticides have been shown to cause notable problems for honey bees and other pollinators even if the effects are not outright lethal; research is still ongoing. Best practices include but are not limited to the following: use approved least-toxic pesticides, follow product instructions, start with the lowest recommended dose, select appropriate timing including when bees are not active, manage pesticides drift through weather conditions, application method, equipment settings, and spray formulation. At the same time, governments are reviewing research and may control pesticide use to protect honey bees and all pollinators in general.

Pollinators are animals that facilitate the reproductive cycle of over 75% of flowering plants, including most fruits, and vegetables. These animals include small mammals such as bats, birds, and many types of insects including the most well-known and accessible honey bee.

The reproductive cycle of flowering plants includes pollination, which is the transfer of pollen grains (male haploid gametophytes) to the female gametophytes, which contain the ovules. The pollen grains produce male gametes which in turn fertilize the ovules; these fertilized ovules develop into plant seeds. The ovary in which seeds are contained may develop into fruit. The seeds and/or fruit are then disseminated by various methods to fertile land in which they may grow as new plants. These plants then supply significant resources to other organisms including humans: food, building materials, fibers, and so on.

To incorporate pollinators into their life cycle, these plants produce flowers that contain pollen and nectar, which are both sources of food for bees and other pollinating insects. Besides providing food, serving as shelter and nesting spots for their various pollinators, plants also produce resins. Resin is an important compound that honey bees specifically retrieve to produce propolis, which is used to fortify the hive, improve hygiene by preventing parasites and inhibiting fungi and bacteria, and mummify carcasses they cannot remove from the hive. [1]

As the pollinator travels and gathers food and materials from these flowering plants, pollen grains stick to its body and are carried from flower to flower, fertilizing other plants of the same species along the way. Thus, pollinators and flowering plants have tightly integrated and mutually beneficial relationships. [2]

Pollination, particularly that provided by insects, is essential to agriculture, which not only provides food to humans but also fibers, fuel, and feed to our domesticated animals that further provide sources for meat.

While there is a very wide variety of animal pollinators contributing to the ecosystem, most animal pollinators are insects, and within insects, most are bees. Bees consist of thousands of species but are broadly split between two basic categories for the purposes of study in agriculture and other industries of interest to humans: wild (native) bees and honey bees.

1.1. Wild Bees

Wild bees, also referred to as native bees for a given locale, are those bees not managed by humans, where management involves breeding and generally tending to the bees' basic needs such as providing shelter and supplemental food. Wild bees may be either social or solitary.

More than 90% of the world's 20,000 plus bee species are in fact solitary, which makes both management and research very challenging compared to the highly social nature of honey bees that live in structured colonies. A solitary bee is simply one that lives alone, where each nest is built and occupied by a single female with no caste or role hierarchy. [3]

Bumblebees are social bees like honey bees, but their nest population numbers in the low hundreds, not the tens of thousands honey bees in a colony. Bumblebees are not as widely adopted into commercial apiculture (beekeeping) because they produce only small amounts of honey-like substance sufficient for their own consumption and are difficult and expensive to raise. Certain species are reared for commercial pollination in greenhouses, but most species of bumblebee are wild. [4]

Roughly 4,000 species of wild bee are native to the United States, and they are still credited with the majority of pollination activities with respect to native plants. For example, the imported honey bee either cannot or poorly pollinates tomato, eggplant, pumpkins, cherries, blueberries, and cranberries. [5]

However, consistent and accurate studies for wild native bees, most of which are solitary, can be difficult to achieve. The accessibility of managed honeybee colonies means more data on their pollinator role and environmental effects upon them, particularly in close relation to agricultural production.

1.2. Honey Bees

Farmers manage only 11 of over 20,000 bee species worldwide, with the European honey bee (*Apis mellifera*) being the most commonly managed bee species. [6]

Since honey bees are the primary subject of most pollinator-crop studies due to the close relationship between the beekeeping and agriculture industries, a basic understanding of their characteristics is necessary. Subspecies and hybrids exhibit variations in behavior and morphology, but all honey bees share the following general characteristics.

1.2.1. Honey Bee Colony Social Structure

The honey bee colony's social structure is particularly important when considering stressors that are transferred from individual to hive, such as infectious diseases and parasites that target concentrated populations of bees.

Honey bees are highly sociable insects. A honey bee colony consists of three types of adult bees: one queen, several drones, many workers, and brood (eggs, larvae, and pupae). All of them live in a hive constructed of wax comb containing many hexagonal cells; for managed hives, the comb is suspended within a frame, which can be plastic or wood. Within the cells, the bees store pollen and honey, and rear the brood.

Table 1. Queen, drone, and worker bees. 9

	Queen	**Drone**	**Worker**
Sex	Female	Male	Female
Number	Typically one per colony	~300 to 800	~20,000 to 80,000 (about 98% of the colony population)
Fertility	Fertile	Fertile	Sterile
Stinger	Yes; only for fighting other queens	No	Yes; for colony defense. Dies after issuing a sting that pulls out the stinger apparatus
Body size	Generally larger than drone and worker when mature	Larger than worker	Smallest
Anatomy	No pollen collecting apparatus	No pollen collecting apparatus	Has pollen collecting apparatus (pollen basket)
Responsibility	Mating and laying eggs to produce all the colony's offspring	Mate with a virgin queen from another colony; dies after successful mating	Hive upkeep, defense, foraging

There is only one active queen bee per colony—a fertile female bee larger than other bees and whose main responsibility is to reproduce by laying eggs to increase and maintain colony size. The queen bee mates only once with several drones and remains fertile for her lifespan, which can be several years. There are different mechanisms to replace a queen if it dies, such as feeding a larva royal jelly and allowing it to develop into a virgin queen, or adopting a queen exiting another colony that already has a queen. Under managed conditions, beekeepers (apiarists) will commonly purchase a fertilized queen bee from a reputable source.

Drone bees are fertile male bees and number approximately 300-800 per colony; stingless and lacking the physiology to forage or build hive comb, the drone's sole purpose is to mate with a queen, and dies shortly after doing so.

Worker bees are the smallest and most numerous colony members, numbering approximately 20,000 to 80,000 bees per colony and constituting over 98% of its population. They are sterile, female, and are responsible for numerous duties that are split between two main worker roles: house bee or foraging field bee. House bees are responsible for hive upkeep including cleaning, brood feeding (as "nurse" worker bees), caring for the queen, building hive comb and food storage, and defense. Field bees are responsible for foraging, which is the retrieval of various resources (pollen, nectar, propolis, water). House bees are typically young worker bees while field foragers are more mature worker bees. All worker bees have a sting and usually die after using it.

Flower nectar converted into honey is the bees' primary source of carbohydrates for energy. Pollen or "bee bread" is their primary source of protein, fatty acids, minerals, and vitamins, which are crucial for overall hive health and young bee development. [7]

Besides collecting pollen, nectar, water, and resin while foraging, worker bees also produce "royal jelly" to raise a queen, secrete enzymes to ripen honey, and produce wax for hive comb construction. One foraging worker bee makes a dozen or more trips in a day, visiting several thousand flowers in a range of two to five miles away from the hive. They typically limit themselves to one plant species per trip, which aids in the pollination process. A foraging bee can return to its colony bearing a pollen load weighing nearly 35% of its own body weight. The pollen gathered by worker bee "pollen baskets" located on their legs is also a food supplement used by humans and some other animals. [8, 9]

1.2.2. Honey Bee Reproduction

1.2.2.1. Individual

Worker bees build hexagonal comb cells using wax produced from their wax glands, and these cells serve as food storage for honey and pollen as well as incubation for the bee brood. The "brood" consists of eggs, larvae, and pupae, which are the bees' early developmental stages.

Sometime after her mating flight and being fertilized by multiple drones, the queen bee lays one egg in each cell; in the spring and early summer, she may lay up to 1,500 eggs per day. Fertilized eggs become female worker bees (sterile) while unfertilized eggs become male drones (fertile).

In three days, the egg hatches into a larva. Inside its beeswax cell, the larva is fed by the "nurse" worker bees, and after a few days, the worker bees seal the cell with a wax "cap." After being capped, the larva enters the pupa or transformation stage, where its grub-like form changes into an adult bee. The developed adult bee emerges from the cell 7.5 to 14.5 days after the capping, depending on its caste. 7

1.2.2.2. Swarming

Swarming, essentially colony-level reproduction, is the process of forming a new colony by leaving the parent colony and nesting in a new location. When environmental variables are favorable and food sources plentiful, a colony's population will increase to a certain point that causes crowding within the hive. At this point, the bees will begin to raise a new queen. As the new queen reaches maturity, the original queen flies away with a swarm consisting of at least half the existing worker bees and some of the drones, while the new reared queen stays with the parent colony. When the new queen matures, she will take mating flights and begin to lay eggs to increase the bee population as most had left with the swarm.

Swarms look intimidating but are usually harmless and rarely sting because the bees do not yet have brood, honey, or hive to defend. The exiting swarm will land somewhere nearby to rest, and the worker bees will cluster around the queen to protect her while some scout bees leave to search for another suitable home. Once a home location is found, the swarm will create a hive and continue their activities in foraging and raising bees. Under ideal conditions, European honey bee colonies swarm approximately once or twice a year. [10]

1.2.3. Honey Bee Communication

1.2.3.1. Pheromones

The honey bee has two primary modes of communicating with other members of its colony: pheromones and dances, particularly the "waggle" dance. Pheromones are chemicals secreted from honey bee glands that affect behavior in other bees and thus affect all aspects of colony life. The waggle dance is a physical activity done to convey spatial information of a resource location.

Pheromones are transmitted by direct contact as liquid or vapor and received by bees' antennae and other body parts to trigger behavioral or physiological responses, usually in the same species. [11] Pheromones are secreted by all colony members from queen, drone, worker bee, to brood (particularly the larvae), and allow communication among all castes. They are involved in all aspects of colony life including reproduction (queen mating and swarming), brood development, defense, foraging, building hive comb, and other activities. [12]

Some glands and pheromones are caste-specific. There are two types of pheromone effects: releaser, which temporarily affects the recipient's behavior, and primer, which has long-term physiological effects. The queen signal and brood pheromones are of the primer type, while most worker bee pheromones are considered the releaser type.

Queen bee pheromone (queen mandibular pheromone) has different effects on different bee castes. For example, it serves as a sexual attractant for drones during the mating flight while also serving to attract the queen retinue, which is a group of worker bees whose role is to attend to the queen. The pheromone is responsible for inhibiting additional queen rearing, suppressing fertility in worker bees, keeping a swarming bee cluster together, stimulating worker bee activity around the hive, and generally calms a swarm.

Drone pheromones are concentrated upon sexual activities, such as attracting other flying drones to aggregate at sites suitable for mating with a virgin queen. [13]

Brood pheromones secreted by larval salivary glands and serve to regulate brood development and care by chemically communicating needs to nurse worker bees. Along with queen pheromones, brood pheromones suppress worker ovarian development since fertile worker bees do not work as much as sterile. Finally, the level of brood pheromones can modulate behavioral maturation in worker bees: a low level decreases the adult bee foraging age, promoting a larger proportion of worker bees to become foragers; a high level of brood pheromone increases worker foraging age, stimulating young adult workers to remain as nurse bees for an extended period of time. [14]

Worker honey bee pheromones cover a wide range of functions. Depending on the age and role differentiation of the worker bee, glands develop at different times or produce different pheromones depending on the situation. For example, wax glands develop sooner and are more active in young worker bees for building comb, while alarm pheromone production rises in older guard and forager bees. The glands responsible for producing pheromone that suppresses worker bee fertility also produce alarm pheromone when the worker bee becomes a forager. [15]

1.2.3.2. Honey Bee Dances

All of the known species and subspecies of honey bee exhibit dancing behavior, but the form and details of execution vary among species. [16]

The following describes *Apis mellifera*, as it is in the most widely managed honey bee species. There are several known honey bee dances, including the waggle dance, round dance, tremble dance, and grooming dance. Each dance conveys information, but the use of said information may be context-dependent. [17]

The waggle and round dances are used by forager bees to communicate foraging locations. The round dance is performed by a returning scout or forager when it wishes to communicate a food source less than about 35 yards away from the hive; the bee will move in circles alternately to the left and right, without indicating specific direction, but it will share the scent of the food source. [18]

When a resource is more than 35 yards away, the honey bee will perform the waggle dance instead; this resource may be food, water, or even a new nest site. This is a more complex dance that communicates direction relative to the hive, distance, and odor of the target resource if applicable. [19, 20]

The waggle dance is usually performed on the vertical surface of the hive comb. The dancing bee first moves forward for a certain distance along the vertical line of the comb, and this vertical line serves as the reference base for the direction. Then the bee moves back to the starting point and begins her dance pattern. Each dance involves running through a figure-eight pattern with one straight phase and two half circle return phases; the dance move pattern is then repeated. On the straight stretch phase, the bee "waggles." The angle between the straight stretch and the vertical line is the angle of the target sources relative to the sun. If experiencing a long delay and the sun has moved, the dancing bee adjusts the angle accordingly. The distance to the target resource is expressed by the duration of the straight waggle phase. One second is approximately for one kilometer of distance. The time taken to complete the waggle phase is directly related to the distance, and the speed of the waggle is inversely related to the actual distance. 19

The speed or the frequency of the repeating dance pattern performed is an indication of the quality of the resource; the higher the speed of the dance means the better the quality of the resource. When dance repetition is low or reduced, it indicates potential risk. If a dead bee is found at a potential foraging site, for example, returning foragers and scouts perform fewer waggle dances relative to that location. [21, 22]

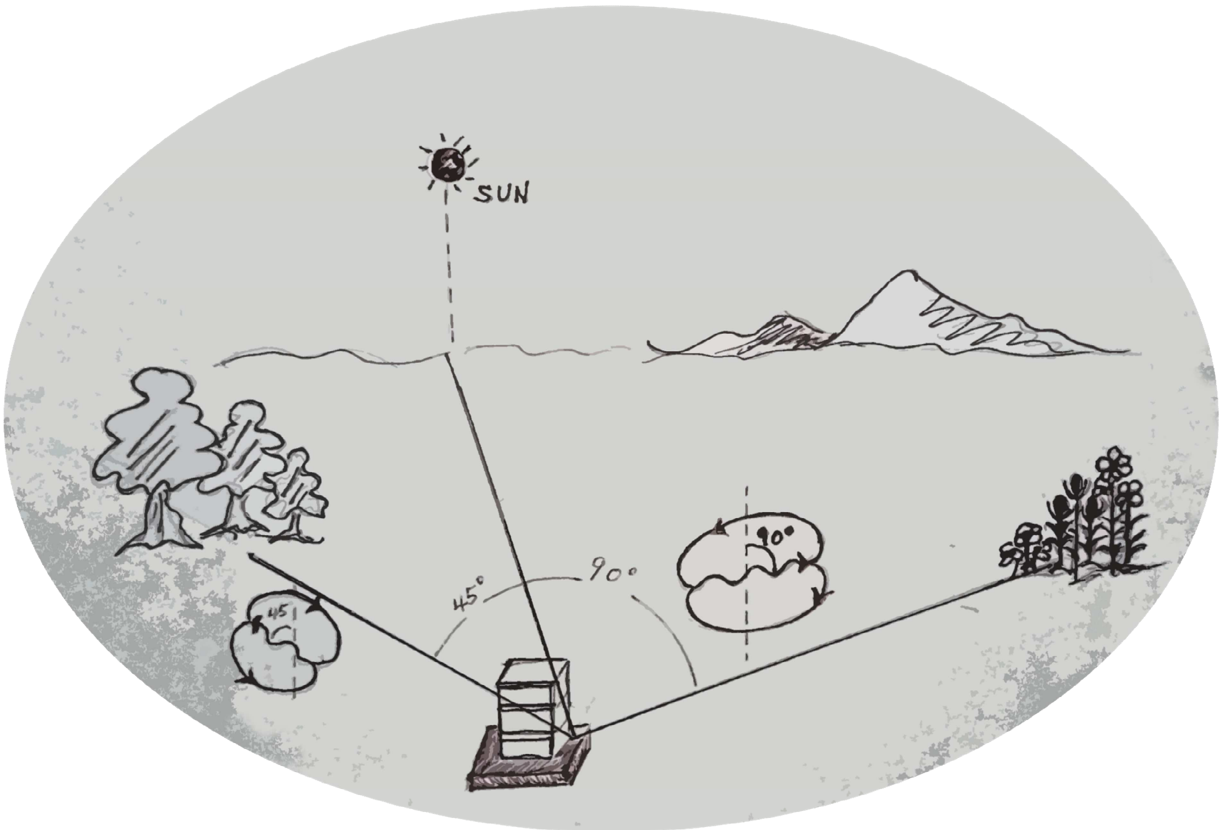

Figure 1. Honey bee waggle dance. [19]

1.2.4. European Honey Bees

The honey bee as we know it was not native to the Americas; they were, in fact, imported from Europe during colonial times in the 1600s. *Apis mellifera* was instead native to Europe, Asia, and Africa, and evolved into different subspecies by geography throughout Africa and Eurasia. These honey bees are referred to as European or western honey bees. [23] The majority of available pollination information is derived from European honey bee data for this reason.

Most crops grown in the U.S. are not native to the Americas either. Both the crops and honey bees evolved in other parts of the world and were brought to U.S. by European settlers. Today, more than 90 commercially produced crops in the U.S. rely on bee pollination. 7

Honey bee population numbers and temporal activity patterns are easily assessed by visual inspection. Physically managed hives can produce important information on hive conditions and activity, the timing of flowering and nectar access, and details about the interaction between bees and the environment. [24]

It is important to note at this point that "feral" honey bees are not considered the same as wild bees, which are native to the locale. Rather, feral honey bees are those that escape apiaries and establish colonies away from human management, but are still an alien species.

1.2.5. Africanized Honey Bee

All subspecies of *Apis mellifera* can interbreed or hybridize. The Africanized honey bee is a hybrid of the European honey bee and African bee, which are two separate strains of the same *Apis mellifera* species. Africanized bees acquired the appellation “killer bee” due to their highly aggressive defense behavior, which can often result in serious injury and death for humans and other animals. [25]

Pure African honey bees, *Apis mellifera scutellata,* were imported into São Paulo**,** Brazil in 1956. The intention was to breed the African honey bees, which were better adapted to a tropical environment, with European honey bees in order to improve country's honey production. Just one year later in 1957, twenty-six African queen bees were accidentally released or escaped from the managed facility into the wild. The cross-bred descendants of these African and European honey bees quickly established a large feral population of Africanized honey bees. This event unintentionally demonstrated the Africanized honey bee's superior adaptation to the tropical environment. In just over four decades, these wild AHB migrated to most of the tropical and subtropical area of America, from South to Central then to North America.

The first permanent colonies arrived in City of Hidalgo, Texas from Mexico was in 1990; the first documented AHB case in the State of Florida near Tampa was 2001; by 2003, AHB had spread to Tampa and through out of the Florida state. By July 2009, AHB have been confirmed in ten southern United States: Texas, New Mexico, Arizona, California, Nevada, Utah, Louisiana, Oklahoma, Arkansas, and Florida. [26]

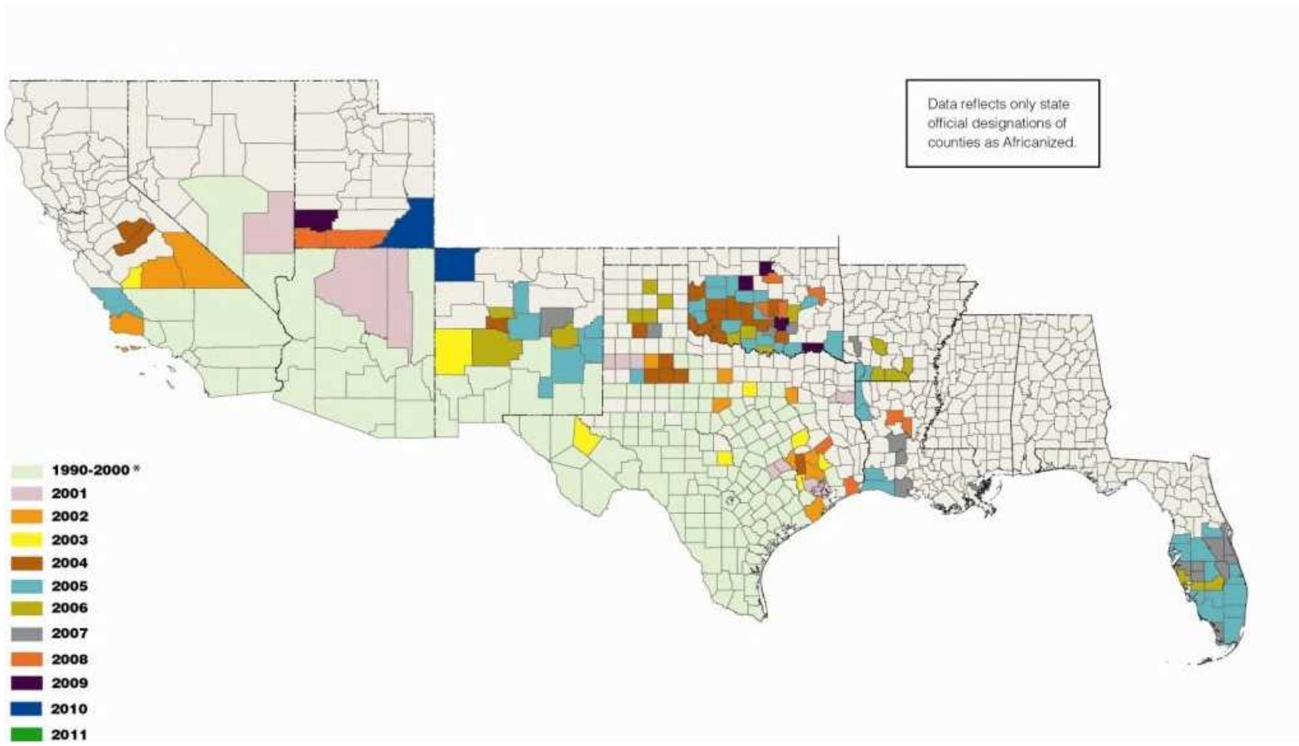

Figure 2. Spread of Africanized honey bees in the southern United States to 2011. Source: USDA 32

1.2.5.1. Africanized Honey Bee Characteristics Summary

Beyond the very aggressive hive defense behavior, Africanized bees exhibit additional differences from their European cousins.

Table 2. Differences between European and Africanized honey bees. [26, 27, 28, 29]

	European	**Africanized**
Defensive behavior	May send 10-20 guard bees up to 20 feet away from hive. 10-15 minutes to calm down. Calmed down by smoke. Disturbance may result in 10-20 stings.	May send hundreds of guard bees up to 120 feet away from hive. Hours to calm down or until sunset. Disturbance may result in 100-1,000 stings.
Climate adaptation	Temperate zones	Tropical zones
Swarm behavior	Swarm 1-2 times per year, only if crowded or to make new nest. Large swarms requiring larger volume sites.	Can swarm 10+ times per year. Smaller swarms requiring smaller nest sites.
Abscond (nest abandonment)	Rare	Often, relocating in times of stress (shortage of resources, infected nest, etc.)
Nest characteristics	Larger space (~38 liters).	Smaller cavities (~3-19 liters).
Survival Strategy	Expend energy in producing and storing honey and pollen to prepare for resource shortage (e.g. overwintering).	Use energy and resources in producing large numbers of progeny and generating many reproductive swarms
Varroa susceptibility	Susceptible to *Varroa* mites, which shuts down the bees immune system	Resistant to *Varroa* mites
Age-based worker behavior	Start foraging at older ages and harvest less pollen and more concentrated nectar	Start foraging at young ages and harvest resources with low concentrations of sucrose that include water, pollen, and low concentration of nectar
Physical differences (usually only distinguishable by tool)	Slightly larger	Slightly smaller

1.2.5.2. Heightened Defensiveness

The Africanized honey bee is notorious for highly aggressive defense behavior. However, they do not randomly seek out victims to attack. They are very sensitive to alarm pheromone and produce much more of it than European honey bees. [30]

They ardently guard and protect their hives within a wide range of at least 30 meters. Africanized bees also have a low threshold for disturbance; direct hive disturbance is not necessary to initiate an attack.

Merely noise or vibration from equipment can induce a quick, vicious response that persists for a farther distance than European bees. Their venom is no more potent than European honey bees, but they attack in much greater numbers, in the hundreds, where European honey bees may attack the same intruder with no more than 10-20 bees. [31]

1.2.5.3. Swarming

Africanized honey bees swarm frequently and unpredictably, which can be as often as every six weeks with more than one separate swarm each time. A European bee hive will typically swarm once a year. Africanized bee swarms are also smaller than European bee swarms. [32]

1.2.5.4. Abscond

During times of food resource shortage or repeated nest disturbance, Africanized bees have a high tendency of abandoning the entire nest including the brood, food stores, and hive. This is known as "absconding." The entire colony composed of adult bees relocates elsewhere. Absconding is something European honey bees rarely do, which also makes their management that much easier.

1.2.5.5. Nesting Locations

European honey bees prefer nesting in larger spaces such as tree hollows, chimneys, and so forth. Africanized honey bees are less selective about their nesting locations, and their choices rarely overlap with European honey bee hive location preferences. In general, Africanized honey bees will occupy much smaller spaces because their swarm sizes are smaller: hollow tree limbs, man-made structures like cement blocks, junk piles, meter boxes. Even holes in the ground can become their home nests. This is one reason why humans encounter Africanized bees more frequently.

1.2.5.6. Survival strategy

European honey bees devote their efforts to producing and storing honey in order to survive through the winter (overwintering); Africanized honey bees, on the other hand, endeavor to generate many swarms and produce larger number of descendants. The European bees' strategy makes them suited for temperate environments, while the Africanized bees' strategy allows them to quickly replace lost colonies either due to harsh environmental conditions or predators. In response to such stressors, Africanized honey bees are more likely to abscond, while European honey bees seldom do. This explains why Africanized bee colonies store proportionately less food than that of European honey bees. 26

2. Pollinator Contributions to Agriculture

Honey is the most well-known direct product of honey bees, but these insects produce altogether six hive products that humans collect and use: honey, beeswax, propolis, pollen, royal jelly, and venom.

According to the U.S. Department of Agriculture's (USDA) National Agriculture Statistics Service, U.S. honey production in 2013 was 67 million kilograms, valued over US$315 million. Beeswax is the second most important hive product from an economic point of view. It is commonly used for making candles, as an ingredient in artists' materials, in leather and wood polishes, and in cosmetics; drug companies use beeswax as binding agent, time-release feature, and drug carrier. The United States is a major producer of raw beeswax and supplier of refined beeswax.

However, the greatest contribution of honey bees to agriculture and human health is indirect, through their services as crop pollinators. Globally, 87 of the leading 115 food crops are dependent at least to some extent on animal pollinators, contributing an estimated 35% of global food production. [33]

When considering the scale of our dependency upon pollinators, primarily bees, crop studies have investigated both quantitative and qualitative effects. Quantitative studies look at amounts of seed and/or fruit produced via pollination, and qualitative studies look at the quality of the final fruit, particularly from a commercial perspective. Both quantitative and qualitative assessments of pollinator participation gain greater meaning when the results are estimated as economic values.

In quantitative studies, it is important to differentiate the plants' reliance upon pollination. Some plants are entirely dependent on external pollination services to produce seed and fruit, while some are partially dependent but can still produce over 90% of their yield without pollination help. Yet other crops achieve pollination by wind, gravity, or water. [34]

The value of directly pollinator-dependent crops in the United States reached an estimated US$15.12 billion in 2009; examples of such crops that require or benefit from insect pollination include apples, almonds, blueberries, and the gourd family (squash, melons, etc.). Of that 2009 crop value, US$11.68 billion was attributed to honey bees and US$3.44 billion attributed to other pollinators. The honey industry from the managed honey bee accounted for over US$300 million in the U.S. economy. [**7,** 35] Bee pollinators contribute at least EU€22 billion per annum to the European agriculture industry as well. [36]

Some crops like almonds are almost exclusively pollinated by honey bees. For example, California's almond industry requires 60% of all U.S. honey bee pollination services, about 1.4 million hives, to produce 80% of the worldwide almond crop, which is worth an estimated US$4.8 billion per annum. [37]

Animal-assisted pollination enhances both yield and quality of different crops to different extents. Yield is a measurement more economically relevant to farmers and is the amount of crop harvested per unit area as opposed to merely total product.

Rapeseed or oilseed rape, known in the United States primarily by its canola cultivars, is the third-largest source of vegetable oil in the world. The U.S. is also responsible for nearly a third of the world's strawberry production. In 2012, canola crop in the United States was valued at US$644.8 million, while strawberry production was valued at over $2 billion. [38, 39, 40]

In a 2014 report, both rapeseed and strawberry crop yields increased about 20% while field bean increased by 40% and buckwheat by 71% thanks to pollinators. Despite these average numbers illustrating significant impact by pollinating insects, region and variety can change a crop's animal-pollination dependency, where differences can vary up to 30% in rapeseed varieties. 34

For rapeseed, strawberry, field bean, and buckwheat crops, an increase in wild insect visitation was shown to improve fruit and seed set (formation) by twice as much as an equivalent increase in managed honey bee visitation. However, more research needs to be done to tease apart the differences in wild bee and honey bee effectiveness. [41]

The nutritional value of plants directly affects human health. The animal-pollinated plants above that are responsible for providing oils for our use are also primary sources of fat-soluble vitamins. Ninety-eight percent of vitamin C, a water-soluble vitamin, is provided by animal-pollinated citrus and other fruits and vegetables. Over 50% of available folate, a B vitamin, is found in crop plants including beans and green leafy vegetables, where animal pollination is responsible for over 7% direct yield increase. Of the plants that supply more than 70% of available vitamin A and nearly all of our carotenoids, pollinators are credited for at least 40% direct crop yield increase.

Besides vitamins, actively pollinated plants also contribute significant minerals to the human diet. For example, about 60% of both calcium and fluoride come from different crops that include heavily pollinator-dependent plants, such as fruits and nuts. We derive an estimated 29% of iron from crops that see a 6% increase in yield due to animal pollination. [42]

Quality is represented as cosmetically marketable product as well as nutritional value. For buckwheat, strawberry, and rapeseed crops, insect pollination has been shown to be directly responsible for overall fruit and seed quality. Rapeseed plants produced more oil in their seeds when properly pollinated, which is critical considering the vast economic value and uses in animal feed, human-consumed vegetable oil, and biofuel. In strawberries, the size of a strawberry's red, edible portion (receptacle) was found to be directly related to the number of pollination-fertilized achenes, which are the seed-like formations on the receptacle. 34

Bee-pollinated strawberries were found to be heavier, physically superior with fewer malformations, and were categorized in higher commercial grades than fruits fertilized by wind- or self-pollination. The bee-pollinated strawberries also had improved shelf life with reduced sugar-acid ratios and increased firmness, where the longer shelf life translated to reduced fruit loss by over 11%. This longer shelf life and market value has a direct effect on trade revenue, representing reduced waste. [43]

In a 2012 experiment, the cape gooseberry plant responded to bee pollination with increased fruit size, successful seed set, and germination rates compared to manual- and self-pollination. [44]

While experiments for animal-pollinated crops tend to be highly specific to cultivar, region, and other variables, they are important data points and support the conclusion that pollinator-dependent crops, including those partially dependent, show significant improvement in quantity and quality of yields when properly pollinated.

3. Pollinator Decline: Bees

3.1. History, Statistics

A significant decline in pollinator populations, particularly bees, is currently being investigated, with the majority of studies centered in the United States and Europe. While wild bees are known to be important for pollination activities, lack of data as to the full extent of their involvement means most of the extant information concerning pollinator decline necessarily comes from human-managed honey bees at this time.

Cumulatively, European countries have also seen significant losses in a similar time frame, and 2013-2014 overwintering mortality rate was not as severe as 2012-2013, leading to the suggestion that climate and weather patterns across regions may have contributed to differences. [45]

For the 2014-2015 winter season, the international COLOSS honey bee research association in Switzerland collected data from 31 countries and reported a range of loss data ranging from 5% in Norway to 25% in Austria. The proportion of colonies lost to either overwintering or post-winter queen problems was estimated to be 17.4%, or twice that of the previous winter. [46]

In the United States, managed honey bee colonies have steadily declined in the past 60 years from 6 million in 1947 to only 2.5 million in 2014. Starting in 2006, commercial beekeepers in the United States reported a significant increase in overwinter losses, averaging 30% per winter as opposed to earlier historical rates of 10-15% colony losses. The 2013-2014 overwintering loss was over 23%, less than the over 30% losses of the previous season but still notably higher than earlier historical data. Hives had an estimated value of US$200 each as of 2014; the cumulative loss has been estimated at 10 million hives thus far. To compensate, beekeepers must quickly rebuild colonies at great expense, which translates to increasing costs of commercial pollination. For example, the cost of renting honey bee hives for almond pollination in the United States rose from US$50 per hive in 2003 to US$150-$175 in 2009. 37 These increased costs are passed onto the agricultural producer and finally transferred to the consumer.

The above statistics are primarily derived from overwintering records supplied by beekeepers via survey. However, recent trends indicate that honey bees face significant stressors throughout the year and not just winter, at least in the United States.

For the 2014-2015 season beginning and ending in April, the United States Department of Agriculture reported a 42.1% loss of managed honey bee colonies. Winter colony loss records, considered from October 2014 through April 2015, posted a small improvement over previous years, but 2014 summer losses exceeded winter for the first time at 27.4%. The 2014-2015 U.S. losses exceeded the previous period's 34.2%.

Noncommercial beekeepers were more prone to mite infestations due to less aggressive mite control methods than commercial beekeepers, but commercial beekeepers saw more losses during the summer, indicating other factors were and are still at play. [47]

3.2. Causes

The notable decrease in honey bee colonies and probable wild bee populations is believed to be caused by numerous factors acting in conjunction: climate change, exposure to certain pesticides or herbicides, loss of natural foraging sources leading to inadequate diets, parasitic mite infestations and ensuing diseases, among other things. [**37,** 48]

The interactions among variables correlating with pollinator decline can be complex, with some of the posited variables themselves under contention. Some pesticides affect pollinators synergistically instead of additively. Many elements from chemical exposure to difficult weather and poor food sources can suppress immune response, which in turn promotes parasites and disease. Regional differences can also alter each variable's effect or produce a unique combination of stressors specific to a geographical area. [49]

Seasonal mortality plays a significant role in overall honey bee population health, particularly in northern climates across North America and Europe, where cold winters and lack of flowering plants make foraging impossible. This is called the overwintering period. By late summer or early autumn, honey bees will have accumulated significant honey and pollen stores in their hives that serve as their only food source over winter. Overwintering is thus the period of winter survival and a key setting in which the many variables interact to increase stress and mortality rate on bees. [50]

However, given the latest data (2014-2015) on summer colony losses in the United States, overwintering is only one period of expected bee stress. 47 The fact that data for annual including summer losses were only added recently in the major U.S. Department of Agriculture honey bee reports means there is still much to learn about how bee stressors interact to produce mortality across the seasons.

3.2.1. Colony Collapse Disorder: Honey Bee

At the forefront of the overall pollinator decline concern was the phenomenon of Colony Collapse Disorder (CCD); though CCD is visible only due to the beekeeping industry and specific to the managed Western honey bee, the catastrophically sudden nature of hive mortality was enough to turn attention to pollinator health in 2006.

According to the available research, a combination of variables contribute to CCD, investigated primarily in the United States and Europe. CCD is a complex phenomenon that affects managed honey bee colonies (*Apis mellifera*); the primary symptom is a rapid loss of adult worker bees, and since these bees are responsible for the majority of hive tasks, the death of the entire colony typically follows.

CCD has a defined set of symptoms and is just one form of honey bee colony loss. Between the years of 2007 through 2014, 30-60% of winter colony losses in the United States conformed to CCD signs and symptoms, which include: [51]

1. Rapid loss of adult worker bees. Sudden decline varies between days and a few weeks.
2. Remaining worker bees are young.

3. The queen is still present.
4. There are no dead bees inside or around the hive.
5. At the final stage, there are no adult bees left in the hive.
6. Presence of capped brood in an abandoned colony.
7. Ample food stores in the hive (honey and pollen).
8. Delayed invasion of pests such as small hive beetles and wax moths.
9. Kleptoparasitism from neighboring honey bee colonies (also known as "robbing").
10. Colonies suffering CCD are more likely to neighbor each other

A complex combination of variables correlates with CCD:

1. Pesticides: insecticides such as neonicotinoids used in crops, miticides used in beekeeping, some herbicides and fungicides.
2. Parasites and disease:
    - *Varroa* mite infestation that causes direct damage by sucking bee hemolymph and indirect damage by promoting infection by virus, fungus, or bacteria
    - Viral infections include Acute bee paralysis virus (ABPV), Israeli acute paralysis virus (IAPV) and Kashmir bee virus (KBV), Deformed wing virus (DWV), Apis Iridescent virus (AIV)
    - Bacterial infection
3. Poor nutrition: pollen and nectar deficiencies from a variety of causes such as lack of flowers, habitat loss, etc.

Pesticides are broadly defined any substance used to destroy or prevent various pests; in the context of agriculture, such chemicals include herbicides to kill weeds, fungicides to kill fungi, and insecticides to kill insects. These substances are most commonly used for crop protection, with global market revenues projected to be over US$50 billion in 2019. [52]

Other traditional pests and diseases such as foulbrood, chalkbrood, and *Nosema* fungal infection are not believed to be directly responsible for causing CCD because they did not have a history of inducing CCD-like symptoms. However, the complexity of CCD due to a combination of stressors does not rule out the possibility that any previously singular malady exacerbates a hive situation that can lead to CCD. [53]

A preliminary 2014-2015 honey bee loss report provided in collaboration between the USDA and Apiary Inspectors of America indicates that CCD has not been reported as the most troubling mortality cause to Western commercial honey bees in recent years, but its individual components may still be significant issues leading to current annual mortality rates that are still higher than acceptable levels. 47 This annual report relies on self-reported beekeeper survey data.

Table 3. The rate and leading causes of honey bee mortality. Source: Bee Informed Partnership [54]

Winter (from October to April)	Total Mortality Rate	Acceptable Mortality Rate	Reported Leading Causes of Mortality
2006 / 2007	32.0%		
2007 / 2008	36.0%		
2008 / 2009	29.0%		26% reported having at least one CCD loss
2009 /2010	33.8%	14.4%	28% reported having at least one CCD loss; Only 5% of beekeepers attributed CCD as the major cause for their losses. Starvation, weather, weak colonies in the fall, poor queens were listed as other causes.
2010 / 2011	30.0%	13.0%	31% reported having at least one CCD loss
2011 / 2012	21.9%	13.6 %	Poor wintering conditions, CCD, pesticides, weak condition in the fall, queen failure
2012 / 2013	30.5%	14%	Queen failure, pesticides, starvation, weak colony in the fall
2013 / 2014	23.2%	18.9%	Queen failure, poor winter conditions, *Varroa* mites
2014 / 2015	23.1%	18.7%	Mites (noncommercial)
Nine-year average	28.7%		

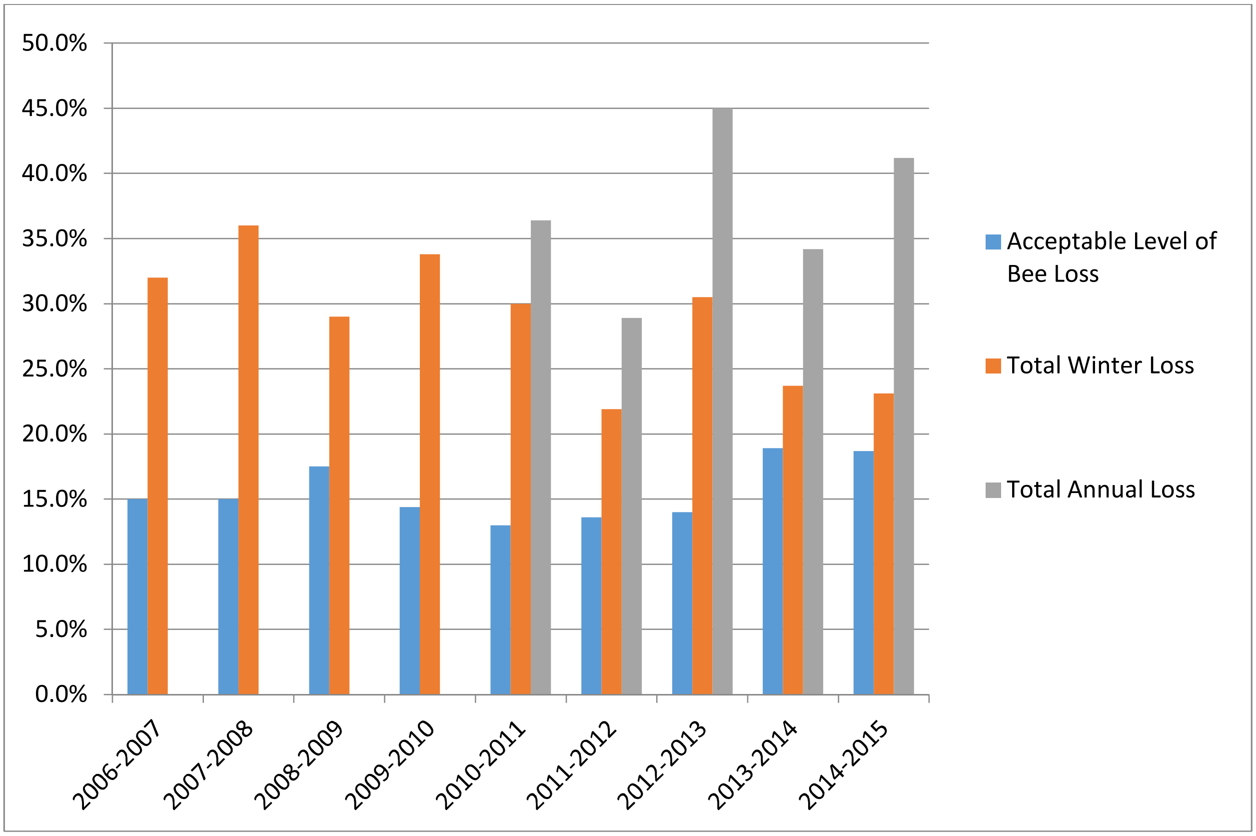

Figure 3. Total U.S. managed honey bee colony loss estimates (preliminary data for the 2014-2015 report). Source: Bee Informed Partnership 54

3.2.2. Insecticides

Neonicotinoid insecticides are effective insecticides chemically similar to nicotine and operate as selective agonists of nicotinic acetylcholine receptors, which are excitatory neurotransmitter receptors in insects. It is an extremely common class of pesticide used on 95% of United States corn and canola crops and the majority of numerous other crops such as cotton and a wide variety of popular fruits and vegetables. Besides direct crop application, it is applied to seeds for planting seasons. Neonicotinoids represent one quarter to one third of the global insecticide market and is thus a highly profitable product. [55, 56]

Assertions of neonicotinoid pesticides' negative effects upon bees have been a source of contention since CCD came to light, with studies pointing to insecticide correlations.

There is evidence that sublethal doses of neonicotinoid pesticide—doses that do not cause direct mortality—have the potential to cause a variety of problems in foraging honey bees, including memory and learning dysfunction and interference with navigation. Because honey bees are social creatures that communicate direction and distance to food sources by way of the spatial waggle dance, these sublethal effects can prevent foragers from finding food sources or returning to their hives. Either risk is highly threatening to colony health, as the ongoing loss of adult bees stresses the entire social structure and leads to colony collapse.

A study published in 2012 described an experiment with pesticide-exposed foraging honey bee populations, using thiamethoxam at commonly encountered yet nonlethal doses. Scientists found substantial mortality due to homing failure, where exposed foragers were far less likely to return to the colony than control bees: about 10% to over 30% of exposed honey bees would fail to return when foraging on pesticide-treated crops. The probability that a bee forager would die due to homing failure after exposure to treated crops was estimated to be twice that of natural death. [57]

Outside Europe and North America, a study conducted in Japan drew a more direct connection between neonicotinoid pesticides and CCD. Three field experiments were conducted between July 2010 and August 2012 using approximately 10,000 adult bees across ten hives. The scientists observed effects of two neonicotinoids, which were primarily used in rice fields, upon foraging bees. They found that foraging bees were killed instantly wherever the insecticides were sprayed. The immediate death of foraging worker bees stressed the colonies and forced a role change from house worker bees to foraging bees in an effort to find sufficient food. However, the lack of house bees led to an imbalance in the workings of the colony; house bees are adult worker bees responsible for cleaning the hive, feeding the brood, caring for the queen, building, and so on. This social structure imbalance stressed the queen, which led to a decrease in egg-laying and eventually, due to constant mortality of adult foraging bees from the pesticide, collapse of the colony.

The Japan study found that even if foraging bees escaped instant death due to a sublethal dose of pesticide, the surviving forager bees returned to the hive with contaminated nectar and pollen. Hive members including the queen ingested and accumulated enough of the pesticide that CCD would still eventually be triggered. [9, 58]

There have been numerous studies concerning varying effects of insecticides, particularly neonicotinoids, upon bee pollinator health and other ecosystem effects, though not all conclusions can be extrapolated to all situations. There are still knowledge gaps, but significant information now exists that indicates much greater caution should be exercised or alternatives sought. [59]

3.2.3. Fungicides

According to the American Phytopathological Society in 2004, fungi are the number one cause of crop loss worldwide. Fungicides thus have an important place in agriculture, functioning to control crop diseases which affect not only plant development but can be fatal to humans; increase plant productivity and reducing blemishes that affect market value; and improve the plants' storage life and quality. [60]

The fungicides involved in preventing post-harvest losses due to fungus-induced spoilage are primarily for the immediate benefit of human and animal consumption, but those chemicals applied on crops before harvest can have sublethal effects upon the crop pollinators.

A 2013 study that analyzed pollen from bees responsible for pollinating certain major fruit crops (apples, watermelons, pumpkins, cucumbers, blueberries or cranberries) found that fungicides were the most frequently found chemical substances, and the most common fungicide among the samples was chlorothalonil, which is widely used on apples and other crops. Bees that consumed the chlorothalonil-tainted pollen were found to be three times more susceptible to *Nosema* infection, a microspore fungal parasite; *Nosema* is known to be a major disease by beekeepers, where infected colonies fail to thrive shortly after overwintering. [61]

To further knowledge of fungicide exposure effects upon other pollinators besides honey bees, a controlled experiment was conducted upon a native bumblebee species. Colonies were exposed over a month to flowers treated with field-relevant levels of a fungicide and then quantitatively assessed by number and biomass of the three bee growth stages (larvae, pupae, adult). Exposed bumblebee colonies were found to produce fewer adult workers bees and lower bee biomass, including smaller and lighter queens, than control colonies. The number of worker bumblebees were reduced from an average 43 bees in control cages to a mere 12 in fungicide-treated cages.

While these effects were sublethal, reduced individual and colony health has direct bearing on ability to resist variable environmental conditions and stressors. [62]

Fungicides have been typically believed to be safe for bees, but sublethal effects observed in recent studies should be taken into consideration for future agricultural control efforts, otherwise the long-term result may be trading fungicide advantages for pollinator decline that can still lead to reduced crop production.

3.2.4. Herbicides

Herbicides are pesticides that target plants perceived to be weeds, or those plants that compete against crops or preferred ornamentals in the same land space.

The herbicide market is projected to be worth nearly US$30 billion by 2019, with glyphosate occupying the largest market segment. [63] Glyphosate is a broad-spectrum herbicide used for weed control, which some may remember as the original retail product Roundup. As of 2007, glyphosate was the most common herbicide used in the United States agriculture market and the second-most used herbicide in the home garden market. [64]

An experiment to study sublethal effects of this herbicide upon honey bees was conducted using field-realistic doses of glyphosate, exposing the bees chronically or acutely to the herbicide. In the groups chronically exposed to concentrations within the range of recommended doses, a reduced sensitivity to sucrose and reduced learning performance were found. Acute glyphosate exposure decreased learning and short-term memory retention when compared against control groups. These results implied that glyphosate at common concentrations found in standard spraying can reduce sensitivity to nectar reward and impair associative learning in honey bees. However, no effect on foraging-related behavior was found, which implies that successful forager bees could become a source of constant inflow of nectar with glyphosate traces that could then be distributed and stored in the colony, causing long-term negative consequences on colony performance. [65]

Another sublethal experiment revealed that honey bees that had been fed with a glyphosate solution of a common concentration took a longer time to return home and took more indirect flight paths than control bees or bees treated with lower glyphosate concentrations. Furthermore, after a second release at a release site, the proportion of direct homeward flights performed increased in control bees but not in treated bees, where one would expect the bees to remember the local topography due to experience. This result suggested that exposure to glyphosate doses commonly found in agricultural settings impairs the cognitive capacities needed to successfully return to the hive, such as navigation and memory. Long-term negative effects on pollinator colony health are likely as forager bees are lost and house bees are forced to begin foraging while still young, creating a social structure imbalance. [66]

3.2.5. Habitat Loss

Habitat loss, which is the reduction of natural and semi-natural home environment, is believed to negatively affect pollinators by loss of diverse floral resources from their diet. This is likely more of an issue for wild bees, which are major yet largely invisible participants in crop pollination, than for managed honey bees. Managed beehives are rented out to farmers and thus can be physically moved between floral sources, but wild bees do not have such a luxury.

For honey bees, deficiencies in quantity and quality of pollen and nectar lead to decreased colony population. A pollen deficiency causes low colony populations and further reduces the number of foraging bees responsible for food gathering.

Modern industrial agriculture systems that use an annual cropping schedule and simple rotations across large swaths of land have resulted in monocultures, particularly wind- or self-pollinated crops, with greatly reduced plant diversity. Monocultures of bee-pollinated crops may not only have a short duration of massive flower blooming but also insufficient nectar and pollen variety for honey bee needs. Then, once the mass bloom is over, there is little else for bees to forage upon across the large monocropped landscape, which can prove challenging to their overwintering preparation.

Besides nectar as a basic food source, pollen quality and diversity have been shown to improve bee immune system health. Both are so important in the bee diet that beekeepers must often provide supplements to prevent nutritional deficiency and potential colony failure. However, pollen supplements and sugar syrup do not provide the same nutritional quality as natural pollen and nectar. [67]

In comparing the seasonal contribution of rapeseed and sunflower mass-flowering crops versus other floral resources in the bee diet, scientists found that bees collected nectar mainly from the crops, but pollen came from a diverse range of plant species in nearby semi-natural habitats or from weed plants among crops. Weed species actually constituted the bulk of the honey bee diet between the mass flowering crop periods. [68]

One of the first studies to specifically address wild bee participation helped illustrate the importance of diverse habitat alongside crop lands. A study set in France investigated effects of forest edges upon pollinator activity in rapeseed fields. Scientists caught bees within the crop fields at measured distances from forest edges and found that, out of several thousand identified bees representing multiple taxa, both the number of bees and species diversity declined with increased distance from a forest edge. The bee taxa included those that nested in particular wilderness habitats. The data indicates that nearby natural and semi-natural habitats such as forest edges may serve as "reservoirs" of pollinators and would directly benefit agriculture by providing shelter and mating sites appropriate for specific bee species. [69]

To further the implication that uncultivated plants play a critical role in both bee health and crop success, several other past studies have shown that pollination services increase in crops near forest patches or other semi-natural areas rather than in uniform crops surrounded by yet other crops. [70]

It thus stands to reason that as pollinator activity increases with the presence of diverse wild habitat near croplands, loss of such habitat will reduce pollination potential at the same time. Moreover, if managed honey bees are imported to mitigate wild pollinator loss, the increased operating costs will be passed onto consumers as well.

3.2.6. Parasites

A number of pests and parasites target honey bee colonies and pose significant risks to individual bees as well as overall colony health due to the bees' close proximity to each other in the hive. Not all pests are associated with CCD, though their presence could precipitate additional issues such as infection that may lead to CCD symptoms.

Honey bee pests and parasites include *Varroa* and tracheal mites, *Nosema* fungal microsporidian infestation, small hive beetle, and wax moths; risks vary by region and climate.

The *Varroa destructor* mite is the most dangerous to honey bees and is associated with CCD; it is a parasitic mite about 1-2 millimeters long. It was first identified in the 1960s in Japan and the former U.S.S.R. It made its way across the world and was introduced (identified) in many European countries in the decades following, reaching the United States in 1987, with the latest identification in Hawaii in 2007. [71]

Parasitic mite infection begins when the female mite enters a honey bee brood cell. As soon as the cell is capped (sealed with food), the *Varroa* mite lays eggs on the bee larva, which typically hatch into several females and one male; they hatch at about the same time as the young bee develops, and the mites thus leave the cell with the host bee. Infestation occurs when the young developed bee emerges from the capped cell, allowing the *Varroa* mites to spread to other bees and larvae. The mite preferentially infests drone cells. The adults suck the "blood" (hemolymph) of adult honey bees, leaving wounds and weakening the adult bees such that their immune systems become compromised. These weakened, mite-infested bees become prone to a variety of viral, bacterial, and fungal infections. [72]

The primary lethality of *Varroa* mite infestation occurs during the overwintering period, particularly in longer winters where honey bees are under environmental stress and surviving within their hives on food stored in the previous spring through fall seasons. Close proximity in hives promotes infestation, and because the bees are weakened by the mites, they are also less likely to fend off other infectious diseases. This compounded scenario of stressors is one of the primary variables believed to be responsible for CCD. [73]

Chemical treatment, such as fluvalinate, have proven to be mostly successful, but a small percent of surviving mites after treatment become resistant and eventually immune. Treatments are still being developed. A number of other countermeasures may be used, whether chemical, physical, or behavioral, but the mite threat continues.

3.2.7. Disease

Honey bee colonies are also prone to a number of viruses and bacteria that thrive in the close quarters of the hive. There are numerous viruses, some of which are associated closely with *Varroa* mite infestation, and some bacterial infection that can produce significant rapid losses. [74] Any of these diseases can be associated with CCD as a compounding variable.

1. Bacterial
    - American foulbrood
    - European foulbrood
2. Fungal
    - Chalkbrood
    - Stonebrood
3. Viral
    - Cripaviridae
    - Dicistroviridae
    - Cloudy wing virus
    - Sacbrood virus
    - Iflaviridae
    - Iridoviridae
    - Secoviridae
    - Lake Sinai virus

While honey bee colonies most obviously suffer the consequences of infestation and infection due to the physical proximity of their members, new research suggests that managed bee services introduce parasites and disease to local wild populations when high concentrations of such services are imported to new areas. These alien stressors upon the local pollinator populations are associated with both declines and extinctions, a problem which must be addressed with some urgency because merely compensating with more managed bees is not a sustainable answer. [75]

3.2.8. Climate change

Climate change is a very broad, long-term, and complex process that affects global ecologies in a chain reaction across organismal relationships. Due to its long temporal nature, climate change in relation to the highly seasonal life cycle of bees can be challenging to study. The most symptomatic effect of climate change in the pollinator-plant relationship is the influence upon plant flowering time, which in turn can affect the pollinators' primary food sources.

An early observation of potential climate change effects upon pollinator activities, particularly the honey bee, came from a NASA oceanographer, Wayne Esaias, who observed changes in his hobbyist beehives; his background and access to large data sets allowed him to piece together the effects of climate change upon local flora and thus his honey bees. Esaias began noticing changes in his hives in the early 2000s, where the hive weight in preparation for overwintering showed symptoms that local Maryland flowering was occurring earlier in the year, an observation in-line with long-term trends from flowering records dating back to the 1970s.

The co-dependency of pollinators and plants can be interrupted by climate changes when their respective life cycles in response to the environment shift in different ways. The relationship between plants and their pollinators are at risk for desynchronizing when environmental cues are different and when there is not sufficient overlap of generalist pollinator populations. For example, some insects' larval stage is timed to mature when local flowers first bloom and nectar begins to flow. The pollinator for one plant may begin foraging when air temperature rises to a specific point, but that plant may begin to produce flowers and nectar flow when the snow melts. [76]

While some of the earliest observations of climate change effects upon pollinators came from managed honey bees due to necessary human interaction and thus accessibility of data, wild pollinators have not been entirely ignored. However, because the habitats and life cycles of typically non-social wild species can vary substantially as opposed to the standardized rearing of the European honey bee, research on wild bees must be taken with understanding of native wild plants and the local ecology instead of standardized agricultural crops.

A Colorado, U.S. study indicated that local environmental conditions are the primary cues for insect emergence, particularly between wild plants that have evolved alongside a number of wild pollinators. Furthermore, seasonal cycles of plants, bees, and wasps in the area are regulated similarly by temperature, but plants are more likely than insects to advance their cycle in response to spring warming. Thus, flowering before the emergence of local pollinators is a real possibility according to the 2011 Colorado study. Despite that risk, none of the native pollinators were specialized to a single plant species, which helps mitigate more catastrophic cycle shifts in specific plant species if the pollinator were completely dependent. However, even generalist bees may be affected as both larval development and survival can vary by available pollen diet.

The local wild bee pollinators were shown to have evolved specific coping mechanisms for a variable local environment on a year-by-year basis, but a prolonged succession of poor seasonal conditions could prove to be too much for localized mechanisms. The Colorado area saw warmer and drier years in the past few decades, which correlated with midsummer floral scarcity, while some plant species have suffered a series of poor flowering years due to spring frost damage. This combination of poor plant conditions over a longer period of time due to climate change may prove to be a much broader threat to the pollinator-plant relationship than just their life cycle asynchrony. [77]

The Food and Agriculture Organization of the United Nations (FAO) took a broader approach and surveyed available research in 2011. They found a small number of studies that investigated how increased temperatures might instigate temporal mismatching between plants and pollinators. For example, a 2005 study centered on the Iberian Peninsula researched seasonal life cycle responses of plants and pollinators in relation to increased temperatures, finding a potential desynchronization between them. A 2009 study found that both *Apis mellifera* honey bees and *Pieris rapae* butterflies advanced their activity timing in response to warmer temperatures while their main floral resources did not, producing a temporal mismatch between pollinator and plant. A Japanese 2004 study found that early-flowering plants would flower earlier in a warm spring, but bumblebee queen emergence was not affected by spring temperatures. A 2007 study on the effects of increasing temperature on a plant-pollinator network showed that seasonal cycle shifts reduced floral resources for 17% to 50% of pollinator species. These studies indicate that temperature-based temporal mismatches between pollinator and plant do occur, but vary by species and region. [78]

Out of the probable stressors upon pollinator health, climate change itself and its complex ecological effects are still nebulous, but extant research suggests it should not be ignored as a variable that can affect agriculture and our own food supply in the long term.

3.3. Effects of Pollinator Decline (Bee Loss)

Though variations of the inaccurately attributed quote "If the bee disappears from the surface of the earth, man would have no more than four years to live" have appeared in mass media when news about the declining bee population periodically resurface, the actual projected effects of pollinator loss are more protracted and complex. [79]

There are numerous studies of specific crop improvements thanks to pollinator activity, but calculations for estimated impact of loss upon agriculture can differ substantially depending on the methods and data used. It is important to note that most of the studies focused upon attempted analysis of pollinator decline effects must extrapolate to some extent; much like climate change science, such information is intended for preventative use before negative impact becomes irreversible. Reports agree that both ecosystems and agriculture will be negatively impacted as pollinator populations fall. Three basic viewpoints from which bee loss impact can be analyzed and extrapolated are as follows:

1. Direct crop yield reduction
2. Economic impacts
3. Human health impacts

3.3.1. Direct Crop Yield Reduction

One approach to calculating the impact of pollinator loss is by measuring crop output and land use in relation to what we know about pollinator dependency and yield improvements. Just like prior yield improvement studies, however, it is important to remember that different crops in different regions rely on pollinators to different extents.

In a 2009 study attempted to estimate global crop losses should animal pollination fail. Using extensive 1961-2006 data from the Food and Agricultural Organization of the United Nations, pollination dependency was calculated for 87 important crops. Though about 75% of flowering crops benefit from pollinators to varying degrees, only 10% depend fully on pollinators for seed and fruit production; these dependent crops account for an estimated 2% of global agricultural production by 2009. If those crops with the highest pollinator dependency failed due to lack of pollination, global crop production would decrease by an estimated 8%.

However, the 8% crop impact is merely an estimate of a direct reduction and does not represent economic or nutritional effects, so the given calculation is an abstraction. As it turns out, indirect negative impacts can be significant. If the yield of a land unit is reduced, then more land would be turned over to agriculture, resulting in yet more pollinator habitat loss and other related ecological threats. The estimated increase in cultivated land area necessary to compensate for the production deficit was several times higher than normal, especially in the developing world, which already supports two-thirds of global agricultural land. [80]

A 2013 study centered in the European Union approached the problem with a different method and reached a different conclusion. Instead of calculating pollinator dependency of individual crops, scientists assessed "relative pollination potential," which is the relative potential or capacity of an ecosystem to support crop pollination. When insects begin foraging, their host ecosystems or "land cover" such as forest edges have the potential to increase yields of adjacent pollinator-sensitive crops; this potential represents the wild pollinator's economic value and can be measured as yield contribution or the cost savings when compared to replacing with managed honey bees. Using existing foraging data of wild bees with short flight distances, pollination potential was linked to regional European crop production statistics. Representing data limited to those pollinating insects with short foraging distances, the crop production deficit was estimated to be 2.5%. However, as more data of species with increased flight range were added to the map, pollination potential would increase up to 25%.

That is, under this method and using aggregate data of different pollinator species, the yield reduction of partially and fully pollination-dependent crops without insect pollination was estimated to be at least 25%, also taking into account habitat diversity. These estimated results were specific to Europe. [81]

There is thus some disparity among results from studies that attempt to estimate direct yield reduction, due to different methods, crops, as well as regions. However, a decline of some sort is noted in all cases.

3.3.2. Economic Impacts

Besides a direct yield reduction estimation, the economic impact to the agricultural and apiculture industries would be significant though variable depending on the cost-benefit analysis.

The total economic value of crop pollination, considering different levels of pollination dependency, was estimated to represent 9.5% of the world agricultural product value in 2005. [82]

In a study that employed geographically-bounded information on global yields of 60 crops that either benefitted or depended upon pollinators, scientists investigated economic vulnerability in relation to pollinator decline as the portion of agricultural economy depending upon pollination benefits. The general pollination dependency of agricultural economy appeared stable from 1993 to 2009, but producer prices for pollination-dependent crops increased in the same time period. [83]

Some economic studies can only provide specific examples due to cultivar and regional specificity, but they are nonetheless illustrative of negative impact. A 1997 Canadian study estimated that pollination-improved apples provided returns of about 5-6% to the farmer compared to orchards without honey bees. With pollination services costing about 1% of production expenses, the improved yield represented a 700% return to the farmer. A loss of pollination services would introduce a notable reduction of economic value for the grower in this case. [84]

More generally, a number of variables point to pollinator shortage as an actual, recorded impact upon food economics. The demand for pollination services has been increasing with the expansion of pollinator-dependent crops by acreage, at the same time the supply of managed honey bees in some regions is declining; the rate of growth of pollination service demand outstrips the managed bee supply rate of growth. The cost of managed honey bee colony rentals in regions of the United States has increased dramatically. For example, Pacific Northwest hive rentals increased from US$19.25 in 1992 to nearly US$90 by 2009; if pricing followed the U.S. inflation rate, hive rental cost should have been US$25.73 in 2009. Colony Collapse Disorder losses by 2007 forced a loosening of trade restrictions of imported honey bee queens in order to sustain the vast almond industry; compensating for lost locally managed colonies thus introduced additional costs to rebuild hive populations and potentially new pathogens. [85]

Taking into account economic factors such as calculated costs and crop conversion to monetary units, it is therefore possible to better understand the impact of pollinator decline in relation to economic trade as opposed to just a direct yield reduction.

3.3.3. Human Health Impacts

Significant pollinator decline would also affect the nutritional quality of agriculture produce. Pollinated crops are responsible for supplying the majority of available fats, vitamins A, C, and E, and minerals such as calcium, fluoride, and iron to the human diet. Crops that are partially or fully dependent upon pollinators account for more than 90% of our dietary vitamin C, for example. [86]

A 2015 modeling analysis estimated that assuming a complete loss of pollinators, over 70 million people in low-income nations would become vitamin A deficient; 173 million people would experience folate deficiency. A globally estimated 22.9% of fruit supplies, 16.3% of vegetables, and 22.1% of nuts and seeds could be lost without pollination, with significant variation by country. Annual global human deaths due to malnutrition could increase by 1.42 million, while a 50% loss of pollination services is estimated to potentially cause 700,000 additional annual deaths. [87]

Yield increases associated with pollinator activity in these crops are not insignificant, so a decline in crop yields means lower produce availability, nutritional quality, and increasing prices of varying urgency around the world. Even considering the possibility for human diet supplementation and fortification, many governments do not regulate their food industries to the same extent as more affluent countries. Moreover, the fact that many dietary supplements are actually derived from pollinator-dependent plants adds a catch-22 to the threat of pollinated-crop declines.

4. Conservation and Protection of Bees

4.1. Beekeepers

Recommendations for bee management will vary from region to region, as a southern United States climate and particular issues like local predators will differ from one in Canada, for example. These recommendations may come from a variety of sources such as commercial apiary experts to government resources and apply to anyone seeking to manage their own bees, including hobbyists.

Best practices include general recommendations not only for direct bee monitoring and treatments but also managing the surrounding areas where bees are kept. [88, 89]

1. Create or allow nectar-rich wild flower areas on the premises.
2. Plant a variety of flowers that can provide nectar and pollen across the length of the honeybee's foraging seasons, including early-flowering plants and plants for late autumn.
3. Plant and manage hedges of mixed flowering species that are good for bee foraging (the list will differ based on location, but examples include hawthorn, hazel, crab apple, willow).
4. Leave wild plants and weeds until they stop flowering before removing them.
5. Avoid cutting back nectar plants that flower late autumn into winter, or plants that continue to flower while still producing berries.
6. Mow lawns containing white clover only after the flower heads have turned brown.

Management of honeybee health and pests may vary among geographical regions, and the specifics will vary among bee strains as well. American beekeepers in the state of Florida, for example, must deal with local black bears that target and destroy honey bee hives. [90] Some bee management recommendations include the following: [91]

1. Use only products approved in your country.
2. Read and follow all instructions on disease or mite control product labels before application.
3. Monitor colonies for levels of mite infestation.
4. Apply treatments before infestations or infections become damaging. Autumn feed should be provided before temperatures are too low for bees to safely break cluster.
5. Rotate *Varroa* treatments to prevent development of resistance. For example, use a synthetic mite strip in spring and formic acid treatment in autumn.
6. Avoid using temperature-dependent treatments such as formic acid or thymol above the recommended thresholds.
7. Treat all colonies that require treatment at the same time.
8. Follow recommended treatment withdrawal times; do not use treatments when honey supers (portion of a managed beehive used to collect surplus honey) are attached, unless otherwise specified by treatment instructions.
9. Use oxalic acid only as a follow-up treatment in late autumn after a primary early autumn treatment, unless *Varroa* mite levels are low.
10. Use resistant-bred queens when possible.

Along with the above best management practices, beekeepers may also participate in breeding or acquire honey bees that have been specially bred through hybridization or trait selection. This approach introduces pest and pathogen resistance into European honey bee stock and allows beekeepers to reduce or altogether eliminate chemical treatments in their apiaries. Additionally, hybridization or trait breeding can increase colony survival rates when the selectively bred bee is more adapted to a given environment.

4.1.1. Varroa-Sensitive Hygiene (VSH) Genetic Trait

Varroa-sensitive hygiene (VSH) is a genetic trait that compels the honey bee to remove mite-infested pupae from the capped brood, which is the *Varroa* mite's preferred target. The capped brood are young, developing bees that are sealed inside cells of the comb with a protective layer of wax. Because the brood is hidden below the wax seals, the mites are sometimes difficult for bees to detect. While honey bees are naturally hygienic and often remove diseased brood from their nests, VSH is a specific form of nest cleaning aggressively focused on removing Varroa-infested pupae. The VSH honey bees will chew and cut through the cell cap and discard the infected brood plus mites from the broodnest.

After testing and hybridization, mite population growth was shown to be significantly lower in VSH and hybrid colonies than those without the trait. Hybrid colonies had half the VSH genes compared to pure VSH bees but still retained significant *Varroa* mite resistance. [92]

Since the mid-2000s, USDA scientists in Baton Rouge, Louisiana, developed honey bees with high expression of this trait, and VSH bees are now commercially available to beekeepers. [93]

4.1.2. Africanized Bees

The Africanized honey bee is particularly invasive in the Americas and has settled across numerous southern states of the U.S., so it is important to understand their advantages and disadvantages in agriculture as they continue to hybridize with European honey bee stocks.

To most people, Africanized honey bees are perceived as a threat due to its fierce defensive behavior. In reality, while deaths attributed to "killer bee" attacks are violent and frightening, they number far fewer than other causes and, in North America, pose greater danger to the beekeeping industry and agriculture than to the general public.

European honey bees were selected and imported by beekeepers for their predictable and manageable traits such as gentleness, limited swarming behavior, and high honey production. On the other hand, Africanized honey bees often behave unpredictably in comparison. Once Africanized honey bees enter European colonies, mating between them results in more hybrid bees having African genes and expressing African traits over European ones. The behavior of the entire colony may suddenly shift to highly defensive and short-tempered. Even though the defensiveness of Africanized honey bees varies from colony to colony, just a few colonies within an apiary expressing excessive aggression could cause a beekeeper to abandon apiculture. The Africanized bees' higher tendency to abscond also makes them less desirable in managed beekeeping. [94]

Due to higher swarming and absconding rates of Africanized honey bees, honey production per colony does decline. However, since there are many more, smaller Africanized colonies participating in pollination and honey-producing activities, the overall apiary yield may actually increase. When Africanized bees first arrived in Mexico, the country's honey exports initially dropped by more than 50%, which might be attributed to beekeepers abandoning their trade due to the bees' unmanageable aggression. Mexican honey production had recovered to 75% of historical levels by 1986. [95]

Over two decades since the first arrival of Africanized Honey Bees in the United States in the 1990s, there were no reports of significant effects upon the honey production and investment behavior of beekeepers in the United States. [96]

In terms of pollination activity, competition for nectar and pollen resources among Africanized honey bees, wild bees, and European bees is expected. However, Africanized honey bees have shown good work ethic by working earlier, longer, and even under undesirable conditions of a desert or rainforest. At least in Mexico, it is believed that these hybridized bees helped the coffee plant to flourish. [97]

Despite negative traits that make management difficult, Africanized honey bees have significant advantages over their European counterparts as well. Africanized bees have shown higher resistance to parasites such as *Varroa* mites and certain diseases, reducing or negating the need for chemical treatments such as antibiotics. [98]

Africanized honey bees produce and use more propolis than European honey bees. Honey bees collect saps and resins from trees and mix with self-produced wax to make propolis, which has various antibiotic properties. Bees use propolis to seal cracks, close potential entries to the hive, to embalm dead intruders too large to easily remove, and most importantly, to prevent diseases and parasites from invading the hive. [99, 100] In fact, Africanized honey bee lines bred for high propolis production were found to have superior hygienic behavior as well as increased honey and pollen storage. [101]

Beekeepers in areas affected by significant Africanized bee populations such as Brazil and Mexico have since adapted their management practices and now prefer Africanized honey bees due to their greater hardiness and adaptation to those tropical and subtropical climates, as opposed to the European honey bee. [102]

Thus, it is possible to selectively breed Africanized honey bee colonies for preferred traits, such as increased propolis usage, mite resistance, honey production, and so forth. This does not mean that the increased aggressiveness must be accepted in managing hybridized stock, however. In fact, selective breeding of Africanized honey bees has been shown to reduce aggressiveness after only a few generations. [103, 104]

Feral honey bee populations cannot be controlled this way, of course, but for the purposes of apiculture and its relation with agriculture, selective breeding of Africanized stock in appropriate climate zones may prove to be beneficial for a variety of reasons.

4.1.3. Russian Bees

The Russian honey bee is actually derived from European honey bees that originated in the Primorsky Krai region of Russia. This bee strain was imported into the United States in 1997 in response to parasitic *Varroa* mite infestations during overwintering periods that would precipitate colony collapse.

The USDA bee lab in Baton Rouge compared Russian colonies to domestically raised European bee lines and found that Russian bees are resistant to three of the major honey bee stressors: *Varroa* mites, tracheal mites, and cold temperatures. [105] Specifically, Russian honey bees have been found to be about one-third to one-half more resistant to mite infection than the European honey bee, and mite infestation is a major variable in Colony Collapse Disorder. [106]

They exhibit much higher hygienic behavior in opposition to parasitic mites. Experts reported that Russian bees are more aggressive in grooming themselves and each other, biting and removing mites and infected brood from the hive. Russian honey bees are not actually immune to *Varroa* mites but instead have developed a resistance via behavior adaptation after 150 years of exposure in Russia.

Durable overwintering is one of the Russian honey bee's strongest traits, a product of the strain's originating cold, northern climate. After five winters in northeast Iowa, entomologists observed that Russian bees are less likely than European bees to lose members to cold weather. 105

Russian queens shut down earlier, and the worker bee population drops to winter levels sooner than their European counterparts. In the overwintering months, Russian bees are frugal in their consumption of stored food compared to other managed bee strains, and their hives have plenty of leftover winter food stores by the time spring begins. [107]

Importing or hybridizing with Russian honey bees has the primary advantage of developing mite resistance in locally managed honey bees, while the bees' honey production abilities were shown to be sufficient. Moreover, the bees' temperament is reported to be rather docile. A number of beekeepers have shifted to Russian or Russian-hybridized honey bees for their pollination and honey-producing capacities. Initial reports of honey production were conservative, where quantities were below European counterparts, but current estimates place their honey-producing capacity as in-line with or more than European honey bees.

In one example, a U.S. breeder in the late 1990s reported that after a harsh winter, 1200 to 1400 of his European bee stock perished, while only two out of 2000 Russian-bred colonies did not survive. The breeder also reported average honey yields of approximately 60-68 kilograms per hive, well above the usual 38 kilograms. 73

The U.S. Department of Agriculture's research agency is continuing their Russian bee breeding program, where this strain of honey bee has a particular advantage versus European honey bees in more northern climates.

4.2. Farmer: Habitat Diversity

There are a number of actions that farmers can take to improve foraging conditions for honey bees and wild pollinators. It is important to note that habitat conservation to enhance nectar and pollen forage for wild bees would benefit managed honey bees, but the opposite may not be true. 67

Those in the agricultural industry can help mitigate effects of bloom de-synchronization, monoculture limitations, and poor diet by local planting practices. By improving landscape conditions for both wild and managed pollinators, farmers stand to improve their own crop yields and quality to remain competitive in the agricultural economy.

In order to sustain bee populations, support honey bee health, and assist beekeeping activities, diverse native and non-native, flower-rich herbaceous plants should be maintained in fallow areas, field margins, and buffer strips. Landscapes with ample flowers containing good quality pollen and nectars are vital for enriching pollinator health. This in turn also helps nearby crop fields. 67

By conserving and creating diverse habitats on farmland, farmers can help address bloom de-synchronization due to climate change or nectar and pollen shortage due to monoculture. Providing diverse supplemental forage resources to both wild bees and managed honey bees would both increase survival rates and improve the bees' capability to pollinate.

4.2.1. Cultivated Arable Farmland

Arable farmland is land that can be cultivated for agricultural use. Cover crops are annual or perennial plants temporarily sown to protect non-cultivated land from erosion, prevent weed spread, disrupt crop pest life cycles by replacing pest host plants, and improve soil quality by adding nitrogen and organic matter to the soil, or reducing nitrogen runoff in water. [108]

4.2.1.1. Annual Cropping Systems

In annual cropping systems, a single annual crop rotation has resulted in mostly monocultures of very low plant diversity across large expanses of land. To supplement honey bee diets and help wild pollinators as well, the following conservation activities are recommended:

11. Plant flowering plants in non-cropped areas to supplement forage resources between the bloom times of cultivated crops.
12. Maintain large strips (6-12 meters in width) of native or non-native melliferous plants between crop fields as "bee pastures."
13. Mitigate herbicide usage within cropping systems to support bee foraging through the increase of flowering weeds near the crop areas.

To aid pollinators, use plants with short, rapid flowering life cycles as cover crops in the spring before the primary crop is sown will provide early forage for honey bees and other pollinators. Similarly, these plants can follow the primary crop in rotation to provide late season forage sources. Examples of plants suitable for this purpose are annual clovers and mustards. Using longer-lived or even perennial cover crop plants are preferred for a cover crop rotation between two *Gramineae* craps such as barley and corn. [109]

4.2.1.2. Perennial Cropping Systems

Perennial cropping systems are those that do not require replanting on an annual basis, thereby reducing necessary inputs, erosion losses, and water pollution, as well as increase biological carbon sequestration. [110]

Typical conservation efforts in perennial cropping systems consist of planting flowering hedgerows, strips of vegetative plants surrounding field margins, flowering meadows, and designated bee pastures. These practices serve multiple purposes including providing supplemental foraging for bees while crops are not in bloom, reducing erosion, serving as buffers against pesticide drift, and providing food for other wildlife. [111]

However, the presence of these flowers has a potential risk of exposing bees to insecticide when crop is treated outside of crop's bloom period. Pesticide mitigation strategies should be incorporated with the supplemental nectar and pollen plants in perennial crops. 67

4.2.2. Non-Cropped Lands

Non-cropped lands are defined as natural and semi-natural habitats that are field margins (strips bordering crop fields), hedgerows (linear scrub along field boundaries), ponds, woodlands, ditches, and fallow farm fields. These lands may or may not be arable, are less disturbed than cultivated lands, and they can better maintain overall biodiversity. The flowering plants in non-cropped farmland can help restore and increase habitat for both honey bees and wild pollinators. [112]

There are two basic methods to enhance floral diversity in non-cropped areas: Allow native wildflowers to regenerate naturally, or sow a variety of annual and perennial flowering plants.

4.2.2.1. Fallow Areas

Fallow areas are defined as farmland plowed and harrowed but left unsown for some time to allow restoration of fertility as part of a crop rotation or to avoid surplus production. The original purpose of fallow farmland was the latter, where farmers were compensated by government incentive payments for removing part of their land from production, but now fallow field objectives have expanded to include conservation of biodiversity. [113]

For example, under the EU Conservation Reserve Program (CRP), participating farmers have been paid an annual rental fee for the conversion of highly erodible farmland to a land planted with a mixture of native grass and wildflowers. [114]

As of 2010, the national limit of fallow set-aside programs in the United States was capped to 15.8 million hectares (about 39 million acres), and it was capped at 2.8 million hectares in the European Union. 67

4.2.2.2. Field Margins

Field margins are narrow strips of land adjacent to crop fields, roads and railways, hedgerows, and forest edges. Individually, these areas may seem negligible, but cumulatively they amount to significant unexploited acreage. Field margins can serve a variety of purposes including river bank stabilization, erosion prevention, and buffer zones for pesticide drift. Many USDA Natural Resources Conservation Service programs actively manage field margins for erosion control and have adapted management standards to incorporate forage for pollinators as an additional benefit. 111

4.2.2.3. Plant Selection for Non-Cropped Land

The value of non-cropped farmland to honey bees and other pollinators depends very much upon the plant species available within this land. Two strategies are recommended to improve nutritional resources for honey bees: sow plants that provide good pollen and nectar, and conserve native plants. 67

For example, legumes (*Fabaceae*) are among plants most visited by bees for pollen and nectar. Some legumes that are particularly attractive to honey bees are those having a long and multi-annual flowering periods. [115] Some farmers may be concerned by legumes' slow growth due to lack of flowers the first year of planting, in which case they can plant a mixture of annual, biannual, and perennial plants including wildflowers to ensure early and extended flowering for both honey bees and wild pollinators. 67

4.2.2.4. Farm Practices for Non-Cropped Land

Besides actively encouraging plant diversity, land management in non-cropped areas is important as well. Among recommended management practices are the limiting of chemical and mechanical destruction of non-crop floral resources and preventing pesticide drift to bee foraging areas.

To reduce mechanical destruction of floral resources, the following is recommended: [109, 116]

1. Avoid mowing high-nectar plants during flowering to reduce foraging honey bee mortality rates.
2. Delay the first cutting of vegetation in the spring to allow more flowering plants and thus more pollinator visits.
3. Cut grass at the end of summer or in autumn to conserve grasslands.

4.3. Farmer: Agrochemical Practices

Besides habitat conservation and agricultural land-use practices, both farmers and the general public can alter the type, amount, and timing of pesticide application to help reduce or eliminate risk to bees. Ideally, pesticides are best avoided whenever possible, but if they must be used, these strategies are recommended.

4.3.1. Pesticide Usage

Use the least toxic pesticides when possible and follow label instructions, starting with the minimum manufacture recommended dose. Granular form applications are usually the safest method around bees. Prior to spraying with insecticides, remove flowering weeds, which may be attract bees; if ground-cover plants are in bloom, mow before spraying.

Stay away from bee hive areas. Notify beekeepers to move nearby bee colonies prior to treatment, so the hives can be relocated or covered. Place buffers around important pollinator foraging, nesting, and overwintering areas. [117]

Both Pyrethrin, and spinosad are commonly used pesticides in organic farming. These broad spectrum insecticides will kill pests and beneficial species indiscriminately. However, other approved organic products, such as horticultural oils and insecticidal soaps, are safer to use if not applied where pollinators are present. [118]

4.3.1. Timing of Application

Fungicides are recommended to be applied at the end of bloom. If this is not possible, then application several days before honey bees are brought to the orchard is recommended. [119]

Try to avoid applying pesticide to blooming plants or on plants where bees are active. Applying at night or at lower temperature is one way to reduce the chance of bee exposure since they typically are not active in those situations (though this does not avoid other potential pollinators).

4.3.2. Managing Pesticide Drift

While applying pesticides, the chemicals can move or drift beyond the target and cause harm to bees and other wildlife more than a mile away. Some contributing factors are weather conditions, application method, equipment settings, and spray formulation. To minimize wind-related drift, try to spray when wind speed is lowest, often during early morning or evening. Avoid mid-day spraying especially during low humidity and high temperatures; as the ground heats, the spray droplets evaporate into smaller particle size, which may remain aloft for a longer time and travel farther. The best weather conditions to spray chemicals with minimal drift is when temperatures are moderate, air is slightly humid and with a very mild steady wind or no wind.

The application methods and equipment settings when spraying pesticides are also important factors of chemical drift. Since small droplets will most likely drift farther, aerial applications and mist blowers should be avoided when possible. When using standard boom sprayer equipment, set the nozzle as low as possible and operate the sprayer at the lowest effective pressure; always calibrate the sprayers to make sure that no excess amount of pesticide will be applied. 117 118

4.4. Government: Legislation

4.4.1. General

Different governments have reacted differently to pollinator decline threats based on beekeeper and agriculture industry input and available research. Governments may issue regulations or laws for the purposes of supporting pollinators, while departments and organizations under government oversight may issue their own guidelines. Not all governments recognize threats to honey bees or wild pollinators to the same extent. Moreover, regulations are constantly changing due to political influences, lobbyist pressure, and new findings. Legislation and regulations will often address pollinators in general as opposed to only managed honey bees.

For example, the European Union have restricted or banned the use of neonicotinoid insecticides and Fipronil in 2013, but the regulations are under review. The United Kingdom recently suspended a neonicotinoid ban, allowing use on 5% of England's rapeseed crop up to 30,000 hectares. The province of Ontario, Canada began restricting neonicotinoid-treated seeds in July 1, 2015 under the Pesticides Act, where the number of acres using treated seeds will be reduced by 80% by 2017. [120, 121, 122, 123]

In the United States, the U.S. Environmental Protection Agency (US EPA) is empowered to implement legislation, share knowledge with stakeholders, issue guidelines, and other activities relevant to pollinators in relation to environmental health. The Saving America's Pollinators Act of 2013 (H.R.2692) requires the US EPA to suspend neonicotinoid insecticide registration from that point forward, until the agency has a full review of scientific evidence plus field studies to demonstrate that these chemicals have no unreasonable negative effect on animal pollinators. [124]

In 2014, the National Wildlife Refuge (NWR) System under the United States Fish and Wildlife Service began to phase out the use of genetically modified crops and neonicotinoid pesticides in agricultural programs, where a third of crops grown across less than 50 system refuges were left for wildlife consumption. The use of genetically modified crops was deemed unnecessary for the scope of wildlife management, while neonicotinoid pesticides typically used as seed treatments were determined to be linked to bee population declines and a substantive risk to local ecosystems. The complete phasing out of neonicotinoid pesticides across the NWR System is aimed for early 2016. [125]

Following President Obama's June 2014 memorandum that established the Pollinator Health Task Force between the US EPA and USDA, a research action plan was produced to serve as a roadmap for pollinator health research. The Pollinator Research Action Plan was released as part of the May 2015 National Strategy to Promote the Health of Honey Bees and Other Pollinators, which outlines an approach to reduce stressors on pollinator health. This Strategy includes the following targeted outcomes:

1. Reduce honey bee colony winter losses to a sustainable level of no more than 15% in ten years (by 2025).
2. Increase the Eastern wintering population of the monarch butterfly to 225 million butterflies in five years (by 2020).
3. Restore or enhance 7 million acres of forage land for pollinators in five years (by 2020).

In addition, a comprehensive "Pollinator-Friendly Best Management Practices for Federal Lands" draft was produced to help facilitate the stated Strategy goals. The document lists six common habitat types located on U.S. federal lands; some of these habitat management recommendations for increasing pollinator populations and diversity are as follows: 117

4.4.2. Forests
Create canopy openings to allow understory pollinator-friendly plants to grow (determine specific species for tree thinning and shrub control, treat invasive species of infected tree stands, manage shrubs and mid-story trees based on a variety of factors, determine if seeding native plants is necessary to supplement foraging sources)

4.4.3. Roadsides
Manage roadside vegetation to provide for pollinator needs (plant native flowering herbaceous plants to provide food for pollinators' limited foraging ranges, choose exposed roadsides with access to sunlight, determine areas for tree removal to allow more sunlight)

4.4.4. Arid and Semi-Arid Western Shrub Lands
Restore and rehabilitate western rangelands to increase ground cover and food diversity for native pollinators (sow native flowering plants in arid and semi-arid shrub lands recently scorched by fire, use annual and short-lived perennial native forb species to provide blooms in the first year, seed forbs with different flowering times, cover seeds with weed-free hays to retain moisture, consult local experts)

4.4.5. Grasslands
Open grasslands including parks, roadways, railways, wild lands, recreational areas can be managed to become quality pollinator habitats in addition to their intended uses (take regional approach, restore native prairie, convert non-native grasslands to native prairies and meadows, increase native flowering species, reduce mowing or time after blooming, remove undesirable plant species, plant a variety of flowering species to provide floral resources across a longer period of time)

4.4.6. Riparian Areas
Manage areas around riverbanks, wet meadows, springs, fens, etc. to provide diverse plants for foraging (maintain hydraulic function within watersheds to aid water-dependent native plants, reduce wetland drainage that reduce riparian plant cover, seed native plants, maintain vegetative structure for pollinator nesting, control invasive plants, develop grazing policies if needed, minimize broad-spectrum pesticides)

4.4.7. Wildlife Openings

Artificial gaps in dense forest can stimulate more natural heterogeneous habitats and forage for pollinators (remove woody plants for more sun, replace non-native species with native, use mixed wildflower seed to provide floral resources for a longer period of time, select plants that can serve as butterfly larval hosts, plant pollinator-friendly trees along field margins for long-term floral resources, maintain wildlife openings with mowing and control of woody species)

5. Conclusions

The honey bee is essentially our ambassador for pollinators. Given the importance of pollinators to not only our environment but a significant proportion of our agriculture and economy, it behooves us to actively support both managed honey bee and wild populations. Failure to address pollinator decline within our abilities will harm apiculture sustainability, reduce crop production, lower the quality of our plant food sources, and increase operating costs that cascade down to everyone who buys food to put on the table.

Our knowledge has been expanding to include information about wild pollinators as public awareness first began with managed honey bees, but the necessary research areas are still quite vast with many unknowns. Many studies have since acknowledged the importance of wild pollinators to agriculture, but challenges in measuring their contributions and declines persist; as new species of bee are still being identified, how many have also gone extinct? Merely importing more managed honey bees to offset other pollinator losses is not the ideal answer, as doing so merely increases operating costs and causes more problems for the remaining local populations.

Much like climate change, which is a long-term and very complex event covering multiple ecological systems, different parties must actively participate and cooperate to properly address pollinator decline.

Both hobbyist and commercial beekeepers should investigate many avenues to maintain hardy managed populations, which would lower operating costs and help reduce disease transmission to local wild pollinators. In light of available research, a few specific recommendations are as follows:

1. Beekeepers in northern regions with temperate and continental climates may adopt honey bee breeds such as the Russian bee, which are adapted to harsh winters and resistant to mites.
2. Beekeepers in southern regions of the Americas where Africanized honey bees have invaded may participate in breeding programs to select for the Africanized bee's positive traits while making it more manageable.
3. Introduce additional diversity to honey bee stocks such as bees carrying the *Varroa*-sensitive hygiene trait.

Farmers can assist long-term pollinator health by creating and maintaining diverse habitat on their lands and reducing pesticide use whenever possible. Even backyard gardens can be converted to pollinator-friendly micro-habitats.

1. Add diverse floral plants to appropriate areas around crops and other unused lands such as ditches and forest edges.
2. Favor native plants.
3. Use pesticides sparingly or not at all.

The pesticide industry has little incentive to protect pollinators as their revenues are not directly affected by pollinator decline, but government legislation will impact their interests as more research is accumulated and regulations created. [126] In the United States, the comprehensive 2015 "Pollinator-Friendly Best Management Practices for Federal Lands" document can be adopted at all levels of government including state and city. This and related federal pollinator documents are located at the U.S. Department of Agriculture, Forest Service website. Private landowners can also adopt these general recommendations where applicable. Recent management by the US Environmental Protection Agency (US EPA) can be found from the literature [127-129]

Two possible avenues to apply pollinator-friendly best management practices include incentives and state mandate:

1. A minimum acreage of public land in each state may be set aside under specific pollinator-friendly practices including a complete chemical ban; this would aid wild bees and other pollinators specific to each state to repopulate and sustain healthy ecosystems. Such protected pollinator areas could also serve as reservoirs for nearby crop pollination when necessary. The National Wildlife Refuge is already on track to ban neonicotinoid pesticide use from its crop lands by 2016, but this approach may be further expanded.
2. A tax incentive may encourage private landowners and Homeowner Associations common in the U.S. to adopt pollinator-friendly practices on their residential properties. Though private lands do not individually provide much area for pollinators, numerous small oases would provide increased forage diversity and also help migratory pollinators such as certain butterflies.

Finally, consumers who buy food products to feed ourselves should become aware of how pollinator decline and its challenges would affect us, such as increased costs and lowered nutritional value and availability. Public awareness correlates with political awareness and increased dialogue, a necessary ingredient for the creation and implementation of national strategies to address the complex problems our pollinators face.

Glossary

Absconding swarm - an entire colony of bees abandons the hive, often because of disease, wax moth, excessive heat or water, lack of resources, or other reasons

Annual plant - a plant that completes its life cycle from germination to the production of seed within one year then dies

Apiary - colonies, hives, and other equipment assembled in one location for beekeeping operations; also known as a bee yard

Apiculture - beekeeping; the keeping of bees, particularly on a commercial scale

Breeding - in the context of managing domesticated animals, to cause an animal to produce offspring in a controlled and organized manner

Brood - immature bees that have not yet emerged from their cells; brood of different ages can be in the form of eggs, larvae, or pupae

Colony - all the worker bees, drones, queen, and developing brood living together in one hive or other dwelling

Drone - the male honey bee

Fallow - (of farmland) plowed and harrowed but left unsown for a period in order to restore its fertility as part of a crop rotation or to avoid surplus production

Field margins - generally the least productive areas of a field and just a 1-metre grass strip between the outer edge of the hedge and the crop edge can benefit wildlife in many ways

Forage - (of a person or animal) search widely for food or provisions

Fungicide - a chemical that destroys fungus

Herbicide - a substance that is toxic to plants and is used to destroy unwanted vegetation

Hive - the structure used by bees for a home

Honey crop - the amount of honey produced per bee colony per season

Insecticide - a substance used for killing insects

Melliferous - yielding or having to do with honey

Miticide - a substance that kill mites

Nectar flow - a time when nectar is plentiful and bees produce and store surplus honey; also called honey flow

Parasite - an organism that lives in or on another organism (its host) and benefits by deriving nutrients at the host's expense

Perennial crops - crops developed to reduce inputs necessary to produce food by greatly reducing the need to replant crops from year-to-year

Pesticide - a substance used for destroying insects or other organisms harmful to cultivated plants or to animals

Pheromones - chemical substances secreted from bee glands and used as a means of communication; honey bees secrete many different pheromones

Pollination - the transfer of pollen from the anthers of a flower to the stigma of the same flower or of another flower; pollination is a prerequisite for fertilization, and fertilization allows the flower to develop seeds

Pollinator - the biotic agent (vector) that moves pollen from the male anthers of a flower to the female stigma of a flower to accomplish fertilization or 'syngamy' of the female gametes in the ovule of the flower by the male gametes from the pollen grain

Primary swarm - the first swarm to leave the parent colony, usually with the old queen (see secondary swarm)

Propolis - sap or resinous materials collected from trees or plants by bees and used to strengthen the comb and to seal cracks; also called bee glue

Queen - a female bee with a fully developed reproductive organ, and larger and longer than a worker bee

Riparian - of, relating to, or situated on the banks of a river

Robbing - stealing of nectar or honey by bees from other colonies, which occurs more often during a nectar dearth

Super - a part of commercial or other managed beehive that is used to collect surplus honey. Normally it is placed over or above the brood chamber

Surplus honey - honey removed from the hive which exceeds what needed by bees for their own use

Swarm - a large number of worker bees, drones, and usually the old queen leave the parent colony to establish a new colony

Swarming - the natural process of honey bee reproduction at colony level

Worker bee - a female bee with undeveloped reproductive organ; the majority of the honey bees in a colony are worker bees, and they do all the work in the colony except laying fertile eggs

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EDITORS PAGE

Editors of

"EVOLUTIONARY PROGRESS IN SCIENCE, TECHNOLOGY,

ENGINEERING, ARTS AND MATHEMATICS (STEAM)"

1. Dr. Lawrence K. Wang (王抗曝)

Lawrence K. Wang has over 30+ years of professional experience in facility design, environmental sustainability, natural resources, STEAM education, global pollution control, construction, plant operation, and management. He has expertise in water supply, air pollution control, solid waste disposal, drinking water treatment, waste treatment, and hazardous waste management. He was the Director/Acting President of the Lenox Institute of Water Technology, Engineering Director of Krofta Engineering Corporation and Zorex Corporation, and a Professor of RPI/SIT/UIUC, in the USA. He was also a Senior Advisor of the United Nations Industrial and Development Organization (UNIDO) in Austria. Dr. Wang is the author of over 700 technical papers and 45+ books, and is credited with 24 US patents and 5 foreign patents. He earned his two HS diplomas from the High School of National Taiwan Normal University and the State University of New York. He also earned his BS degree from National Cheng-Kung University, Taiwan, ROC, his two MS degrees from the University of Missouri and the University of Rhode Island, USA, and his PhD degree from Rutgers University, USA.

Currently he is the Chief Series Editor of the Handbook of Environmental Engineering series (Springer); Chief Series Editor of the Advances in Industrial and Hazardous Wastes Treatment series, (CRC Press, Taylor & Francis); co-author of the Water and Wastewater Engineering series (John Wiley & Sons); Co-Series Editor of the Handbook of Environment and Waste Management series (World Scientific) and Co-Series Editor of the Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics (Lenox Press). Dr. Wang is active in professional activities of AWWA, WEF, NEWWA, NEWEA, AIChE, ACS, OCEESA, etc.

2. Dr. Hung-ping Tsao (曹恆平)

Hung-ping Tsao has been a mathematician, a university professor, and an assistant actuary, serving private firms and universities in the United States and Taiwan for 30+ years. He used to be an Associate Member of the Society of Actuaries and a Member of the American Mathematical Society. His research have been in the areas of college mathematics, actuarial mathematics, management mathematics, classic number theory and Sudoku puzzle solving.

In particular, bikini and open top problems are presented to share some intuitive insights and some type of optimization problems can be solved more efficiently and categorically by using the idea of the boundary being the marginal change of a well-rounded region with respect to its inradius; theory of interest, life contingency functions and pension funding are presented in more simplified and generalized fashions; the new way of the simplex method using cross-multiplication substantially simplified the process of finding the solutions of optimization problems; the generalization of triangular arrays of numbers from the natural sequence based to arithmetically progressive sequences based opens up the dimension of explorations; the introduction of step-by-step attempts to solve Sudoku puzzles makes everybody's life so much easier and other STEAM project development.

Dr. Tsao is the author of 3 books and over 30 academic publications. He earned his high school diploma from the High School of National Taiwan Normal University, his BS and MS degrees from National Taiwan Normal University, Taipei, Taiwan, his second MS degree from the UWM in USA, and a PhD degree from the University of Illinois, USA. Currently Dr. Tsao is the Co-Series Editor of the "Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics" eBook series (Lenox Press).

Editors of the eBOOK Series of the *"EVOLUTIONARY PROGRESS IN SCIENCE, TECHNOLOGY, ENGINEERING, ARTS AND MATHEMATICS (STEAM)"*

Dr. Lawrence K. Wang (王抗曝) - - left

Dr. Hung-ping Tsao (曹恆平) -- right

E-BOOK SERIES AND CHAPTER INTRODUCTON

Introduction to the eBOOK Series of :

the *"EVOLUTIONARY PROGRESS IN SCIENCE,*

TECHNOLOGY, ENGINEERING, ARTS AND MATHEMATICS (STEAM)"

and This Chapter

"UNDERSTANDING, CONSERVATION AND PROTECTION OF

PRECIOUS NATURAL RESOURCES - BEES"

The acronym STEM stands for "science, technology, engineering and mathematics". In accordance with the National Science Teachers Association (NSTA), "A common definition of STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy". The problem of this country has been pointed out by the US Department of Education that "All young people should be prepared to think deeply and to think well so that they have the chance to become the innovators, educators, researchers, and leaders who can solve the most pressing challenges facing our nation and our world, both today and tomorrow. But, right now, not enough of our youth have access to quality STEM learning opportunities and too few students see these disciplines as springboards for their careers."

STEM learning and applications are very popular topics at present, and STEM related careers are in great demand. According to the US Department of Education reports that the number of STEM jobs in the United States will grow by 14% from 2010 to 2020, which is much faster than the national average of 5-8 % across all job sectors. Computer programming and IT jobs top the list of the hardest to fill jobs. Despite this, the most popular college majors are business law, etc., not STEM related. For this reason, the US government has just extended a provision allowing foreign students that are earning degrees in STEM fields a seven month visa extension, now allowing them to stay for up to three years of "on the job training". So, at present STEM is a legal term. The acronym STEAM stands for "science, technology, engineering, arts and mathematics". As one can see, STEAM (adds "arts") is simply a variation of STEM.

The word of “arts” means application, creation, ingenuity, and integration, for enhancing STEM inside, or exploring of STEM outside. It may also mean that the word of “arts” connects all of the humanities through an idea that a person is looking for a solution to a very specific problem which comes out of the original inquiry process. The acronym STEAM stands for “science, technology, engineering arts and mathematics”. STEAM is an academic new term in the field of education.

The University of San Diego and Concordia University offer a college degree with a STEAM focus. Basically STEAM is a framework for teaching or R&D, which is customizable and functional, thence the “fun” in functional. As a typical example, if STEM represents a normal cell phone communication tower looking like a steel truss or concrete column, STEAM will be an artificial green tree with all devices hided, but still with all cell phone communication functions. This ebook series presents the recent evolutionary progress in STEAM with many innovative chapters contributed by academic and professional experts.

This ebook chapter, *“UNDERSTANDING, CONSERVATION AND PROTECTION OF PRECIOUS NATURAL RESOURCES - BEES"* is the author's collection of thoughts, literature search, data analysis, discussion, and conclusion of proper management and procedures for protection of our precious natural resources of bees. The author (Cynthia Li) is a scientist who is warning us if bees are gone, human beings will be gone too. Her evolutionary scientific study needs to be read carefully by all. For proper protection of our precious bees, a STEAM team needs to be assembled to work with all level of governments and international organizations, such as United Nations. We must connect all of the humanities through STEAM , and through the idea that we are looking for a solution (bees protection), to a specific problem (bees are dying worldwide) which may come out of a joint inquiry process.