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"Bees and Nothingness"
Extinction Risks in Western Honeybees (*Apis mellifera* Linnaeus, 1758)

par

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Abstract :
This monography discusses the importance of honeybees for human beings, and current problems caused by the phenomenon of massive bee disappearances, called "Colony Collapse Disorder" (CCD). It also examines the probable causative factors, including parasites and pathogens, neonicotinoid pesticides, and malnutrition due to habitat loss.

A chapter on parasites and pathogens focuses on 1) *Varroa destructor* Anderson & Trueman, 2000 mites and transmitted viruses, 2) *Nosema ceranae* Fries et al, 1996, a parasitic fungus, and 3) *Apocephalus borealis* Brues, 1924 or phorid flies. Among them, the *Varroa destructor* mite is one of the biggest threats to beekeeping and is considered potentially a key factor in Colony Collapse Disorder since this mite transmits to honeybees harmful viruses including Israeli acute paralysis virus and deformed wing virus.

The next chapter explains neonicotinoid pesticides and its affect on honeybees. Many researches proved that neonicotinoid pesticides impair honeybees' memory and orientation. It also refers to malnutrition due to monocultures, transportation and migratory beekeeping. Honeybees require a diversity of pollen for a balanced nutrition. However, for economical reasons, humans have created large monocultures where honeybees are forcefully transported and made to pollinate. This significantly weakens their health due to stress and malnutrition.

Furthermore, possible solutions against *Varroa destructor* mites are examined, mainly focusing on alternative solutions without chemical treatment. Among them, selective breeding of natural resistance in some honeybees seems to be the best method in the long term. One of the most highlighted characteristics in resistant colonies is called "hygienic behavior", a highly useful grooming behavior effectuated by worker bees.

This monography is titled "Bees and Nothingness", inspired by "Being and Nothingness", Jean-Paul Sartre's 1943 essay (original title: "L'Être et le Néant")

Front page drawing done by Erica Honeck

"If the bee disappears from the surface of the globe,
man would have no more than four years to live.
No more bees, no more pollination... no more men!"

Albert Einstein

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Section I: Introduction

For thousands of years, mankind has been highly dependent on insect pollinators, especially honeybees including *Apis mellifera* Linnaeus, 1758, to grow fruits and crops. As demands for pollination services have grown, honeybees have become a crucial element of the agricultural economy. They also play an important role to maintain biodiversity and ecosystems by pollinating wild flowers.

Approximately one out of three bites of our meal is directly or indirectly pollinated by honeybees (Walsh, 2013). More than 70% of economically important plants are pollinated by them (Imhoof & Lieckfeld, 2013). According to the US government, the contribution of honeybees to the US economy exceeds 15 billion dollars annually (Karimi, 2014).

However, massive bee disappearances called "Colony Collapse Disorder" (CCD) over the last decade have drawn widespread attention. There has been a 40% loss of honeybees in the US since 2006, and a 45% loss of commercial honeybees in the UK since 2010 (Jacunski, 2014). Cases of CCD have also been reported in other European countries including Switzerland (Imhoof & Lieckfeld, 2013).

Crops depending entirely on honeybees for pollination would be largely affected if they disappeared. These include almonds, apples, macadamia nuts, carrots, cauliflower, celery, pumpkins, sunflowers, and many more (Johnson, 2010). Loss of honeybees would also indirectly cause decreasing production of meat and dairy product, since feed for cattle such as alfalfa and clover need pollination for reproduction as well (Imhoof & Lieckfeld, 2013).

Colony collapse disorder is characterized by the rapid vanishing of adult worker bees, which are sterile females, from a hive. Unlike many seasonal colony losses experienced in the past, the losses that occurred in the US since 2006 were an unprecedented phenomenon (Imhoof & Lieckfeld, 2013).

Apart from the sudden disappearance of worker bees in CCD occurrences, the rest of the hive was normal: the queen was still healthy and laying eggs, a few other young bees were present as well as developing larvae called brood, and plenty of pollen and honey remained. No dead worker bees were found, neither inside nor around the hive. There were no signs of an attack to the hive, either. Bees are very colony-oriented, and normally they would never leave the queen and brood behind (Johnson, 2010). The fact that there remained plenty of food in the collapsed hive indicates that the lack of food was evidently not the cause of their disappearance. Furthermore, the remaining bees seemed reluctant to eat (vanEngelsdorp *et al.,* 2006).

In this monography, probable causes of Colony Collapse Disorder and some possible solutions are presented and discussed.

Section II : Probable Factors Involved in Colony Collapse Disorder (CCD)

The exact causes of the increasing number of CCD cases still remain a mystery, but many scientists suggest that accumulated stress from a combination of various factors weakens the honeybees' immune systems and their sense of orientation. Suspected factors include parasites such as *Varroa destructor* Anderson & Trueman, 2000 mites and *Apocephlus borealis* Brues, 1924 flies, and pathogens including deformed wing virus, Israeli acute paralysis virus and *Nosema ceranae* Fries et al, 1996, pesticides, malnutrition and habitat loss due to monocultures (Imhoof & Lieckfeld, 2013).

1. Parasites and Pathogens

Mites and honeybees have coexisted for a long time, but because of additional factors weakening bees such as pesticides, stress from transportation and reduced food availability, the impact of the parasites has become more severe.

Honeybee hives are densely populated, which makes it favorable for spreading infectious diseases (Parker *et al.,* 2012).

In the case of significant loss of working bees, especially foraging bees, food supply will become low, which weakens the colony and make it prone to parasites and diseases. The hive also becomes susceptible to attacks from other honeybees looking for an easy food source. This provides an opportunity for parasites and diseases to spread to other colonies. (Imhoof & Lieckfeld, 2013)

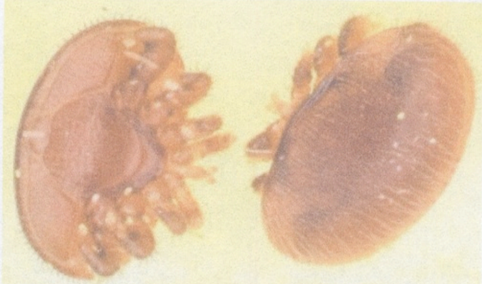

Figure 2: Varroa destructor Anderson & Trueman, 2000

http://www.die-honigmacher.de/kurs1/seite_53201.html

a. *Varroa destructor* Anderson & Trueman, 2000 Mite and Transmitted Viruses

The *Varroa destructor* mite is an ectoparasite considered as the biggest threat to beekeeping today (fig. 1 & 2) (see annexe 1 for the mite's life cycle). The original host of the *V. destructor* mite is the Asian bee, *Apis cerana* Fabricius, 1793, which has developed hygienic and grooming responses as a host-parasite coevolution to keep the mites' population low rather than becoming immune to them. The mite then spread to a new host, the Western honeybee, during the 1960s. (Robertson *et al.,* 2014)

Figure 1: Honey bee worker with a Varroa destructor Anderson & Trueman, 2000 *mite*

http://planbeeproject.wordpress.com/tag/varroa-destructor/

Not all colonies collapse under a *V. destructor* mite infestation, and a colony can remain healthy even with the presence of the mite. This means that the mites do not weaken colonies to fatal degree on their own (Imhoof & Lieckfeld, 2013). They do however suppress the honeybee's immune system and transmit viruses when they suck the hemolymph or bee's blood (Neumann *et al.,* 2012).

One of the viruses transmitted by the *V. destructor* mite is called the Israeli acute paralysis virus. When the mite is associated with this virus, it leads to immune suppression in the host, creating ideal conditions for virus replication (Prisco *et al.,* 2011). Infection by this virus interferes with areas in the brain implicated in navigation, orientation and memory, thus deteriorating their homing ability (Li *et al.,* 2013).

Another typical *Varroa*-transmitted virus is the deformed wing virus. This is a single stranded RNA virus of the Dicistroviridae family and does not have a DNA stage (Hunter *et al.,* 2010). This virus replicates in critical regions of the bee's brain associated with olfaction and vision, which can alter the bee's senses and behavior (Shah, Evans, & Pizzorno, 2009).

Infection by *V. destructor* mites vectoring the deformed wing virus can provoke symptoms such as a shortened and bloated abdomen, discoloration and a shortened life-span in addition to deformed wings (fig. 3) (Schöning *et* *al.*, 2012). Honeybee pupae become non-viable deformed adults or die in the pupal stage, only when they get infected by the mites which transmit virulent deformed wing viruses. This implies that the virus has already replicated in the *V. destructor* mite before being transmitted (Schöning *et al.*, 2012).

Figure 3: Honeybee worker with deformed wings and Varroa destructor Anderson & Trueman, 2000 *mites*

http://bees.tennessee.edu/ipm/combreplacement.htm

The deformed wing virus can be transmitted vertically and horizontally between bees. Vertical transmission occurs through infected eggs, and horizontal transmission occurs when nurse bees feed larvae with infected food (Locke *et al.*, 2012).

b. *Nosema ceranae* Fries et al, 1996

Nosema ceranae is a parasitic fungus that causes nosemosis, a highly infectious disease which frequently affects adult honeybees. Although this fungus can probably not be blamed for causing CCD by itself, it can sometimes lead to high mortality in honeybee colonies (Fernández *et al.*, 2012).

By infecting honeybees, *N. ceranae* can disrupt protein regulated behaviors of worker bees, resulting in a faster maturing into a forager and a lifespan reduction of 9 days (Goblirsh, Huang, & Spivak, 2013).

The fungus is also suspected to increase levels of ethyl oleate in worker bees, a pheromone involved in foraging behaviors, thus altering the foragers orientation and homing behaviors (Dussaubat *et al.*, 2013).

Asian honeybees are originally the host of *N. ceranae*, but the parasitic fungus has now spread to Western honeybees and to bumblebees (Graystock *et al.*, 2013). Research done by Costa in 2011 states that there has been no significant correlation between *N. ceranae* and the deformed wing virus, so it is unlikely that these two pathogens act synergistically (Costa *et al.*, 2011).

c. Phorid Fly (*Apocephalus borealis* Brues, 1924)

The phorid fly *Apocephalus borealis* might become a new threat to honeybees. This fly is known as a bumblebee parasite, but honeybees can be infected by it as well. Honeybees parasitized by *Apocephalus borealis* abandon their hive at night and die. A week later, several *Apocephalus borealis* larvae emerge from the dead bees (fig. 4). This symptom seems similar to CCD affected worker bees in the sense that they fail to return to their hive (Core *et al.*, 2012).

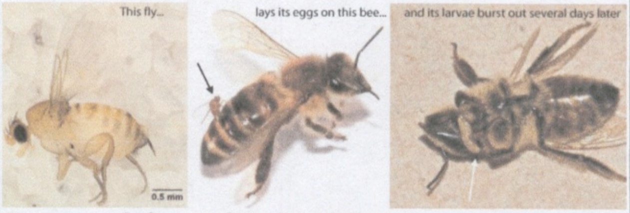

Figure 4: (left to right) phorid fly Apocephalus borealis Brues, 1924 , *Apocephalus borealis on a honeybee, Apocephalus borealis larvae bursting from its host*
http://blogs.discovermagazine.com/notrocketscience/2012/01/03/parasitic-fly-spotted-in-honeybees-causes-workers-to-abandon-colonies/#.VCh2i0uCiQs

Apocephalus borealis is also suspected to be a vector of *N. ceranae* and deformed wing virus, as these pathogens were found in both the flies and infected honeybees (Core *et al.*, 2012). However, more research is required to prove its connection with CCD.

2. Neonicotinoid Pesticides

Among many kinds of pesticides sprayed on crops, insecticides made with neonicotinoids, which are also used in Switzerland, are considered the most dangerous for bees. Only small amounts are needed to paralyze the nervous system and interfere with the ability of bees to fly and navigate. Affected bees also loose their communication skills and cannot indicate the location of food to the other bees by "dancing" as they normally do (Imhoof & Lieckfeld, 2012).

A new meta-analysis of the available literature announced by the International Union for Conservation of Nature (IUCN) in June 2014 (http://www.iucn.org/?uNewsID=16025) concludes that systemic pesticides such as neonicotinoids are posing a serious risk to many beneficial invertebrates and pollinators, and are a "key factor in the decline of bees". As noted by the IUCN, these pesticides are now the most widely used type of insecticides in the world, with an estimated market share of 40%. Insect pollinators are exposed to them through contaminated plants as well as air and water (http://www.iucn.org/?uNewsID=16025).

A study of honeybees exposed to sublethal doses of neonicotinoids shows that this was enough to impair memory and learning abilities. The neonicotinoids negatively affect their foraging behaviors and the ability to find their way back to the hive without killing them immediately (Williamson & Wright, 2013). Another recent research explains that neonicotinoids disrupt neuromuscular signaling pathways by acting as agonists of acetylcholine receptors in invertebrates, which immobilizes the target insect and ultimately leads to its death (Sandrock et al., 2014).

Ironically, neonicotinoids are claimed to be safer for farmers, because they soak seeds in the pesticide instead of dispersing the chemical into the air. However, after the seeds are planted, the pesticide will be present in the whole plant, including the nectar and pollen, which are exposed to bees. Furthermore, neonicotinoids also remain on the plant longer than other pesticides (Walsh, 2013).

Pesticides had been used long before CCD began in 2006, but neonicotinoids started to be used in the mid 1990s, which more closely corresponds to when massive colony losses were reported. Many apiculturists blame this particular pesticide as the cause of CCD. Although it seems very likely to be involved in the weakening of bees, it cannot be determined as the only factor. In fact, neonicotinoids have been banned in France since 1999, but colony losses continued in the country. In Australia, this pesticide is still used, but hives have been spared from CCD (Walsh, 2013).

Many insecticides of the neonicotinoid family are currently sold on the market. Bayer CropScience and Syngenta are two major manufacturers of products containing neonicotinoids (Jeschke *et al.*, 2011).

3. Malnutrition due to Habitat Loss

a. Monocultures

Like human beings, honeybees also need a balanced diet to stay healthy. This is usually provided by an environment with a large diversity of flowering plants.

A healthy immune system is essential for sterilizing the colony's food (Black, 2010). Bees that have a diet with various types of pollen also get a variety of protein and produce more fat. Anti-microbial chemicals are synthesized in bee's body fat. One of these chemicals, glucose oxidase, protects the brood and the whole hive against pathogen invasion by preserving food (Black, 2010).

Cedric Alaux from the French National Institute for Agricultural Research (INRA) notes: "bees fed with a mix of five different pollens had higher levels of glucose oxidase compared to bees fed with pollen from one single type of flower, even if that single flower had a higher protein content" (Black, 2010).

However, the insect population declines as the number of wild flowers diminishes and plant diversity is reduced. Some researchers suggest that a monoculture diet of pollen is deteriorating honeybees' health and immune systems (Black, 2010).

An example of extreme monoculture is the almond fields in California where all other types of flowering plants that could potentially distract the working bees from their almond pollination are eliminated with pesticides (Imhoof & Lieckfeld, 2013).

b. Transportation and Migratory Beekeeping

Monocultures of immense scale have created an inhospitable environment for pollinators to live in year round: food is only available during the limited blooming season of the particular crop in question.

In the 1890s, Nephi Ephraim Miller began sending his hives across the country. Since then, bee rentals for pollination has become a widespread business in the United States. This procedure is now crucial for US agriculture to keep up with the demand, because native pollinators are not sufficient (Imhoof & Lieckfeld, 2013).

Bees are transported by airplane or in large trucks often for many days at a time and across time zones (see annexe 2). The heat inside the trucks can kill large numbers of bees in just two hours, for example in a traffic jam. In addition to the stress caused by transportation, migratory beekeeping also contributes to spreading mites and diseases among colonies (Imhoof & Lieckfeld, 2013).

Honeybees' usual diet of nectar and pollen is also affected during transportation. They are fed sugar syrup and a protein supplement, which does not replace all the essential nutrients they need (vanEngelsdorp *et al.*, 2006).

A survey conducted in the United States in 2006 reveals that all the interviewed beekeepers who experienced CCD were practicing migratory beekeeping. They reported that their bees eventually suffered from significant "stress" at least two months prior to CCD, probably due to *V. destructor* mite infestation or malnutrition caused by overcrowding or poor nutritional crops (vanEngelsdorp *et al.*, 2006).

Section III: Possible Solutions against *Varroa destructor* Mites

As shown in the previous section, *V. destructor* mites are considered to be the number one problem in beekeeping and probably the strongest factor leading to CCD. In this section, some treatments against them and strategies to strengthen commercial honeybees are discussed.

1. Chemical Treatments and Side Effects

Resistance to disease and adaptation to the environment are important factors for the survival of a colony. However, honeybees with gentle disposition, high honey productivity, and low swarming (finding a new home to start a new colony elsewhere) are usually preferred and selectively bred for beekeeping. In order to compensate for lack of vitality or disease resistance, food supplements and chemicals have been widely used (Büchler, Berg, & Le Conte, 2010).

By using chemical products against *V. destructor* mites and colony losses, beekeepers risk creating a super-resistant mite which could become dangerous (Imhoof & Lieckfeld, 2013). There is also a risk of finding chemical residues in bee products including honey and wax (Rinderer *et al.*, 2010). Furthermore, acaricide treatments have limited efficacy and viral infection often remains. More aggressive treatments against *V. destructor* mites could end up harming the host (Francis, Nielsen, & Kryger, 2013).

In fact, some mites are already resistant to chemical products such as Apistan, Byvarol and Klartan (Bayer & Cie) (Imhoof & Lieckfeld, 2013). As a consequence of long-term use (50 years) of antibiotic treatments in the United States, beneficial microbes in the honey bees' stomach have accumulated resistant genes. The problem is that pathogens can use this stock of resistant genes and become resistant to the chemicals themselves (Tian *et al.*, 2012).

2. Alternative Solutions without Chemicals

As mentioned in the section above, searching for a more efficient chemical treatment against parasites may not be a sustainable approach. Some experimental alternatives are mite trapping by removing drone brood and sticky board traps, but these are often too laborious for beekeepers (Rinderer *et al.*, 2010).

a. Asian Bees and Africanized "Killer" Bees

Asian bees or *Apis cerana*, which is the original host of *Varroa* mites, have developed behaviors for mite-infested brood removal through coevolution with the mite (Rinderer *et al.*, 2010). The *Varroa* mite only reproduces in drone brood cells, limiting the number of affected worker bees (Behrens *et al.*, 2011).

Disease-resistance traits are observed among Africanized "killer" bees, which have also drawn interest because of their high honey productivity: they can produce 60 to 80 kilos of honey per colony per year, while European honeybees 50 kilos or less on average (Imhoof & Lieckfeld, 2013).

These bees are hybrids from an experimental cross between European honeybees *Apis mellifera ligustica* (Italian) and African honeybees *Apis mellifera scutellata* (two sub-species of *A. mellifera*). They were released by accident when a few lab bees and a queen escaped from a hive in Brasil (Imhoof & Lieckfeld, 2013).

When Africanized bees are infected by *V. destructor* mites, they signal by violent body movements to inform others of the presence of the mites, and so other bees are able to recognize the parasite and eliminate it. This way, they are able to maintain low mite infestation levels: 32.5% of contaminated bee larvae are eliminated by Africanized bees against 8% for Italian bees (Imhoof & Lieckfeld, 2013).

Bee viruses do not seem to affect the health of Africanized bees. It may be plausible that in addition to mite-resistance, they have also developed a tolerance to viruses (Locke, Forsgren, & Miranda, 2014).

However, because of their irritability and aggressiveness, due to which they were named "killer" bees, it is difficult to handle and keep them near any populated areas (Imhoof & Lieckfeld, 2013).

b. Resistance in Western Commercial Honeybees

Some commercial honeybees have survived *V. destructor* mite infestation. An experiment was conducted to find if their survival was due to resistance to viruses transmitted by the mite. *V. destructor* transmitted viruses (Israeli acute paralysis virus and deformed wing virus) were directly injected in resistant bees and normal/control bees. The results showed that *Varroa* surviving bees did not survive better than normal ones. This indicates that they survived not necessarily because of resistance to the viruses (Büchler, Berg, & Le Conte, 2010).

Instead, *Varroa* surviving bees evidently can keep virus levels low by reducing the number of mites that transmit these viruses. They are characterized by an over-expression of genes implicated in olfaction. This suggests that they are more sensitive to diseased brood odor (Büchler, Berg, & Le Conte, 2010).

This cleaning behavior is called "hygienic behavior". Worker bees detect, uncap defective cells, and remove diseased or dead brood from the hive. This is an efficient mechanism to resist diseases and *Varroa* mite infestation (Palacio et al., 2010).

Figure 5: Honeybee workers removing a diseased and varroa infected pupae
http://www.extension.org/pages/30361/varroa-sensitive-hygiene-and-mite-reproduction#.VCh2lEuCiQs

If a colony can reduce the *Varroa* mite's reproductive success in the hive, this will also limit infection by *Varroa*-transmitted viruses. Most of the time, parasites develop adaptive traits much faster than their host due to their shorter generation time. However, the *Varroa* mite has low genetic diversity, while the honeybee has a very high genetic recombination rates compared to other eukaryotes. This might have given the honeybee an advantage to develop resistance to the parasite in the process of natural selection during coevolution (Locke *et al.*, 2012).

This demonstrates that breeding bees with hygienic behavior seems to be a good sustainable and long-term solution against *V. destructor* mite infestation. In fact, in North America, three breeding programs including one from the University of Minnesota have been successfully selecting resistant honeybees that are suitable for commercial use. (Rinderer *et al.*, 2010)

In spite of such successful cases of breeding hygienic honeybees, this procedure still remains complicated, because these heritable hygienic genotypes are rare (Perez-Sato *et al.*, 2009), and resistant phenotypes are unstable: they can vary amongst honeybees of the same colony with time (Robertson *et al.* 2014).

c. Identifying Hygienic Behavior Influencing Genes

If the alleles influencing the hygienic behavior and resistance to mites are identified, it could greatly help the selection of honeybees for breeding (Rinderer *et al.*, 2010).

Although the use of microarrays has enabled researchers to identify the expression patterns of genes involved in other behavioral traits, this method might not enable to identify the genes for *Varroa*-sensitive hygiene, because the resistant genes may be controlling the expression of other genes, or they may only be expressed in certain tissues and at particular times (Rinderer *et al.*, 2010).

Another plausible method to isolate any heritable trait is to estimate the effect, location and the number of quantitative trait loci affecting a particular allele by using genetic markers. This technique has been useful for the identification of genes influencing traits such as stinging, foraging and foraging age, guarding, egg-laying and learning. Many meiotic recombinations occur in the honey bees' genome which is very useful for constructing a QTL map to find the genes involved (Rinderer *et al.*, 2010).

Compounds in bee larva's cuticle can induce egg-laying in *Varroa* mites. This tendency might be used to select honeybees which suppress or reduce mite reproduction with their cuticle's composition. The advantage of using this trait is that phenotypes are easily controlled by direct observation of mites in brood cells. Furthermore, fewer genes are involved in determining bee cuticle composition than in complex actions such as hygienic behavior. Therefore, marker-assisted selection (MAS) technique can be applied (Behrens *et al.*, 2011).

d. Decreasing Negative Effects of Viruses in Honeybees

Besides breeding hygienic honeybees, RNAi technology may be used to silence virus genes. Post-transcriptional gene silencing is a defense mechanism within the cell found in many species including plants, and can retard or prevent pathogen infections. The expression of foreign genes (RNA) is suppressed after being cleaved by an endonuclease called RNA-induced silencing complex (RISC). RNAi can be fed to or injected in honey bees to silence the insect's endogenous genes, which efficiently prevents the virus infected bees from succumbing (Hunter *et al.*, 2010).

e. Propolis: Social Immunity and Self-Medication

Through evolution, various physiological defenses have been developed to resist diseases and parasite infections, as well as non-immunological traits such as behaviors. Honeybees scrape sticky resins from leaves of certain kinds of plants, which they bring back to the hive, mix with wax and use to build their nest. This mixture called propolis is also used by humans as medicine, since the resin has antimicrobial properties (Simone-Funstrom *et al.*, 2012).

Beekeepers, however, tend to breed out the propolis foraging trait, because the sticky substance makes it more difficult to manage their hives (Imhoof & Lieckfeld 2013). Consequently, the use of propolis as a way for bees to defend themselves against pathogens has not yet been profoundly researched (Simone-Funstrom *et al.,* 2012).

One study shows that an infection of a colony by a fungal parasite, *Ascophaera apis* (Maasen ex Claussen) L.S. Olive & Spiltoir, 1955 or chalkbrood, decreased after the hive was experimentally enriched with resin. Colonies infected by the fungal parasite also increased their resin foraging rate (Simone-Funstrom et al., 2012). Another study in 2013 using Africanized honeybee colonies reveals that colonies with high propolis-producing traits had a significantly higher brood cell uncapping rate than those with lower propolis-producing colonies (Nicodemo *et al.*, 2013).

P-coumaric acid is a compound found in honey, pollen and propolis. Compounds present in honey, including p-coumaric acid, can help detoxify certain pesticides. An RNA-seq analysis shows that they act as inducers of detoxification genes, and p-coumaric also up-regulates antimicrobial peptide genes. When beekeepers feed honey substitutes such as high-fructose corn syrup, bees may become more vulnerable to pathogens and pesticides (Mao *et al.*, 2013).

Section IV: Discussions and Conclusion

Neonicotinoid pesticides are probably not the only factor causing CCD, since hives have not been collapsing in Australia, where those pesticides are used. However, as discussed earlier, it almost surely contributes to the weakening of honeybees as well as other invertebrates and pollinators.

Controlling the usage of pesticides and regulating migratory beekeeping is possible, but with great economical impact. As an alternative approach, we still can help slow down habitat loss simply by planting flowers to provide bees and other pollinators with more food especially in the surroundings of large monoculture crops. Research efforts should also be aimed at selective breeding of disease- and mite-resistant honeybees instead of searching for stronger miticides and antibiotics.

On the other hand, many studies show that high genetic diversity is crucial for a colony's health. Queen honeybees mating multiple drones promotes fitness of the colony, which directly affects the winter survival and the population growth rate. Productivity in foraging and storing food increases with a honeybee population's genetic variability as well (Matila & Seeley, 2007). A more genetically diverse colony also enables to improve thermoregulation of the hive and minimize temperature fluctuations, since the relevant stimuli result in slightly different responses among the worker bees (Jones *et al.*, 2004).

Promiscuous mating behavior of queen honeybees may have been selected over time as an adaptation to prevent serious infections. In fact, an experiment using fungal spores from *Ascosphaera apis*, which kill honeybee brood, shows that colonies in which the queen honeybee has mated only one drone have higher variance in disease occurrence (Tarpy, 2003). This could be because the amount of beneficial bacteria increases and eventually reduces pathogens in genetically diverse colonies (Matila *et al*., 2012).

A direct link between decreased genetic variability in managed honeybees and CCD is still unclear, and more research is needed to clarify this connection. If there is indeed a significant decrease of genetic variability among honeybee populations, it can be one of the many causes behind massive colony losses and weakening of honeybees.

It is largely believed that domesticated honeybees have less genetic variability than wild honeybees, since this is usually the case for other domesticated animals and plants which have been selectively bred by humans. However, a 2012 study proves that managed colonies of honeybees are actually more genetically diverse than wild honeybees in Europe, as beekeeping promotes admixture (Harpur *et al.*, 2012). Clarifying this misunderstanding would help orient the goals for possible solutions to address CCD symptoms.

Genetic diversity is an important factor in ensuring honeybee colonies' survival, and it should be carefully studied in the process of planning breeding strategies. There should be a balance among preserving a lineage of disease resistant honeybees, genetic diversity and productivity. To avoid creating other kinds of aggressive honeybees similar to Africanized "killer" bees, the focus should be placed not only on resistance, but on gentleness as well in terms of feasibility of practical use.

To help address CCD and related honeybee issues, many institutes have been established all around the world. One of them in Switzerland is the COLOSS (Prevention of honeybee COlony LOSSes) group, an international non-profit association headquartered in Bern and composed of scientific professionals from 69 countries, aiming at advocating for bees, coordinating international research, disseminating knowledge and promoting youth development (http://www.coloss.org).

Accomplishments of COLOSS to date include standardizing honeybee research methodologies, conducting the Pan-European Genotype-Environment Interaction Experiment between 2009 and 2012 estimating the importance of genotype-environment interactions, and publishing and disseminating honeybee related data and information (http://www.coloss.org).

It is reported that honeybees may become extinct around 2035 in the United States if they continue to disappear at the same rate as today (Imhoof & Lieckfeld 2013). As most scientists strongly agree, we cannot afford to lose them.

Overall, honeybee conservation projects need to be comprehensively discussed from social, political and scientific points of view. At the same time, more attention should be paid to other kinds of wild bees and pollinators, which are also greatly affected by population declines.

Annexe 1 : life cycle of the *Varroa* mite on honey bees

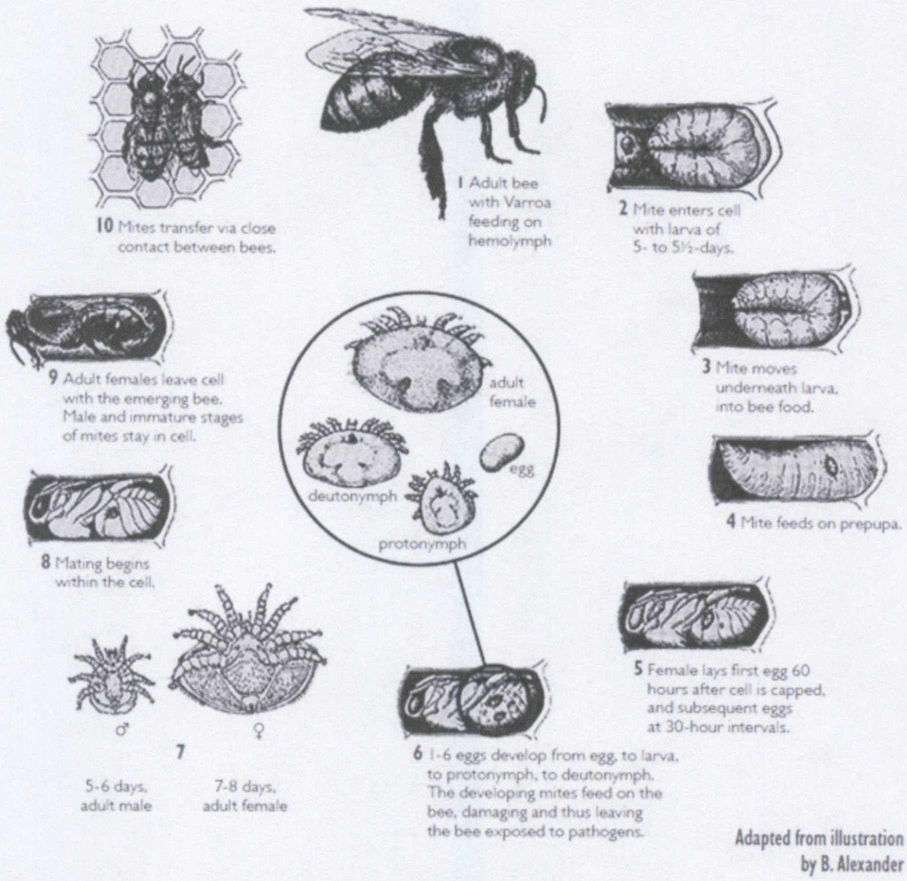

Figure 6: The life cycle of the Varroa destructor

http://mainebeekeepers.org/the-bee-line/varroa-destructor-the-pest/

Annexe 2 : Migratory beekeeping

Bees without Borders

In the U.S., many farmers cannot rely on native bees or even local honeybees to sufficiently pollinate their vast swaths of cropland. Rather they rent honeybee hives from the 1,600 or so migratory beekeepers who traverse the country between February and November. This annual migration mingles sick insects with healthy ones and deprives bees of proper nourishment when on the road.

Each February most migratory beekeepers converge in the Central Valley to pollinate more than 800,000 acres of almonds. Apples, plums and cherries in California and nearby states require honeybee pollination, too.

In summer months, many commercial beekeepers head to North and South Dakota, where they allow their bees to gorge on fields of alfalfa, clover and sunflowers and to produce the bulk of their honey for the year.

In the spring and summer, some beekeepers travel to blooming blueberry fields in Michigan and cranberry bogs in Wisconsin. Others opt for watermelons, cantaloupes and cucumbers in Texas, which also draws beekeepers in the fall for pumpkin pollination.

Because Florida's climate varies from subtropical to tropical, some plant or other is always flowering in the Sunshine State. Florida depends on honeybees to pollinate blueberries as early as February, tupelos and gallberries in April and Brazilian pepper trees in September.

Migratory beekeepers travel up and down the East Coast year-round as well, visiting apples, cherries, pumpkins, blueberries, cranberries, lettuces, and various veggies in Maine, Pennsylvania, Massachusetts, New York and New Jersey.

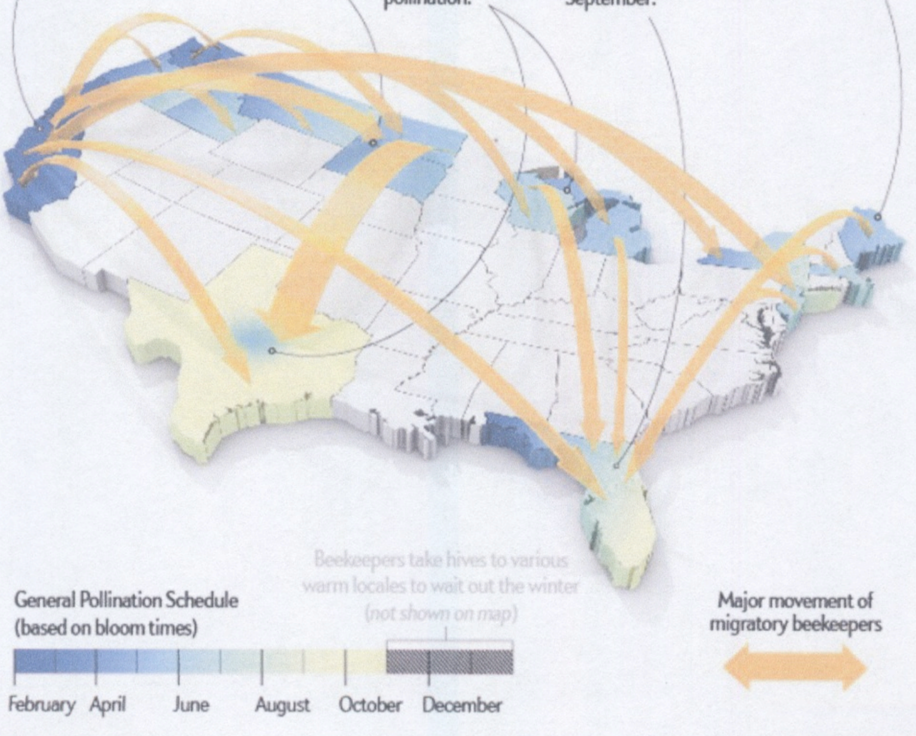

Illustration by Bryan Christie, for SCIENTIFIC AMERICAN

Figure 7: Migratory beekeeping in the United States
http://www.scientificamerican.com/article/migratory-beekeeping-mind-boggling-math/

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Illustrations:

- Figure 1: Honey bee worker with a Varroa destructor mite

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- Figure 2: Varroa destructor

  http://www.die-honigmacher.de/kurs1/seite_53201.html accessed on 7 February 2015.

- Figure 3: Honey bee worker with deformed wings and varroa mites

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- Figure 4: (left to right) phorid fly, phorid fly on a honey bee, phorid fly larvae bursting from its host

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- Figure 5: Honey bee workers removing a diseased and varroa infected pupae http://www.extension.org/pages/30361/varroa-sensitive-hygiene-and-mite-reproduction#.VCh2lEuCiQs accessed on 7 February 2015.

- Figure 6: The life cycle of the Varroa destructor

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- Figure 7: Migratory beekeeping in the United States

  http://www.scientificamerican.com/article/migratory-beekeeping-mind-boggling-math/ accessed on 7 February 2015.