Managed honey bee (Apis Mellifera L.) colonies in the United States began to die off in alarming numbers in the winter of 2006 [1][1]. This signaled the beginning of a mysterious syndrome, now known as Colony Collapse Disorder (CCD), which continues today. In the first winter of the epidemic, almost a quarter of commercial beekeepers in the United States lost an average of 45% of their colonies [2]. More than two million U.S. colonies were lost in the first two years of the epidemic and billions of honey bees around the world are thought to have perished [3].

This is not the first time honey bee colonies have mysteriously died off in great numbers—there have been at least 18 recorded episodes since 1869—but it is the first time that such large numbers have collapsed since the rise of monoculture farming and centralized commercial beekeeping in the United States [1]. And it is has been suggested that the magnitude and speed of these recent declines are likely unprecedented [4].

CCD can be recognized by the sudden disappearance of worker bees from hives containing adequate food and various stages of brood (unborn young) in abandoned colonies that are not occupied by honey bees from other colonies [5]. Also, there are no dead worker bees found in or around the affected hives, and there is a delayed invasion of the abandoned hive from pests and neighboring bees [1]. In other words, seemingly healthy hives that have not been attacked by other bees or pests are suddenly abandoned by their worker bees for no clear reason.

There are many viruses, mites, parasites, and pesticides that are known to kill honey bees [2]. The Apiary Inspectors of America concluded that prior to 2006,

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[1] The numbers in brackets correspond to those of the bibliography in the Annex.

beekeepers could expect to lose an average of 17% of their colonies to these various causes each year [2], so these new numbers (post 2006) represent a serious spike in mortality. Nearly all of these threats have been investigated as possible causes of CCD, but there seems to be a lack of agreement between scientists as to the cause.

Frames with larvae (brood) and insufficient worker bees. photo: doi:10.1371/journal.pone.0006481.g001

Why any of this should concern the average reader might be explained in terms of economics and food supply. In the last 50 years, pollinator-dependent crops have increased more than 300%, while the world population of managed honey bee populations has increased only about 45%—*this* before the onset of CCD [6]. Nearly 70% of the world's most important monoculture crops depend on pollination provided by animals, and honey bees are the most valuable providers of this service, as they can be easily maintained and transported to pollinator-dependent crops [4].

To give an example: each year, one million hives—almost half the commercial hives in the United States—are shipped to California to pollinate the almond fields, a $2

billion crop [7]. While humanity could probably survive without all those inexpensive almonds—and indeed, most of the world relies on foods that do not require animal pollination [4]—if that crop were to fail, a major economic stress would be put upon California, from lost tax revenues, as well as emergency relief for stricken farmers. One report suggests that honey bees provide a $20 billion service to North American agriculture through their pollination [8]. Without the honey bee, many foods might be lost or become prohibitively expensive.

Mankind has been observing and tricking the honey bee into working for his benefit for millennia. In 30 BC, the Roman poet Virgil wrote of how best to cultivate and keep bees in his poem on agriculture, *Georgics*. He advises one to "tear off the monarchs wings" [9] to prevent a colony from dispersing. Fast-forward to 1792 and an anonymous Massachusetts farmer explains to his new American countrymen how to capture wild honey bees for cultivation using smoke, wax, and honey from other bees, "for they are fond of preying on that which is not their own" [10]. In his short book, he provides a wealth of information on beekeeping and its benefits, even including a recipe for mead, the alcoholic beverage made from honey.

Karl von Frisch won a Nobel Prize for his observation of honey bees in 1973. In his Nobel Lecture, "Decoding the Language of the Bee," he explains how honey bee dances communicate information on foraging opportunities to other bees in the hive: "… a round dance is a signal that symbolically invites the hive members to search the immediate vicinity of the hive. The tail-wagging dance sends them to greater distances" [11]. The lecture goes on to give minute detail on how distance and direction

is communicated, and really demonstrates how thorough the scientific community's observation of the honey bee has become. This focus has only intensified since the rise of CCD.

In 2007, the United States Department of Agriculture (USDA) initiated a "Colony Collapse Disorder Action Plan" to help scientists tackle the problem as a unified front [12]. In 2008, the United States Congress passed the Farm Bill, which allocated more than $17 million dollars annually for the next five years to researching CCD and the health of pollinators [8]. This has been a boon to the scientific community, which has sprung into action since the dire numbers began appearing. While some warn that "We must be careful to not synonymize CCD with all honey bee losses" [4], most are willing to agree that a cause must be found to stop one of the more prevalent and mysterious killers of honey bees.

Some researchers have not fared as well as others. The British newspaper *The Telegraph* printed a story suggesting that researchers in India had successfully pinned the blame for CCD on radiation from cell phone towers [13], a claim they later retracted. Another scientific study posited the idea that Iridiovirus and Microsporidian conspired to cause to CCD, without any mention of pesticides as a possible factor [14]. The author of this study was later blasted for not revealing that he had received a large grant from Bayer, the maker of neonicotinoid pesticides [15], which many consider as a probable contributor to CCD. Further, another report in the scientific journal *Molecular and Cellular Proteomics* found "fundamental flaws in the interpretation of their data" [16].

Neonicotinoid pesticides are nicotine-based and have been shown to negatively affect honey bees' learning, foraging activities, and nest-site orientation at sub-lethal doses [8]. The beautifully communicative dance that von Frisch observed in his Nobel lecture breaks down under the influence of nicotine. In 1999, France banned the use of Bayer's neonicotinoid Imidacloprid after a third of its honey bees died [15]. The USDA's "CCD Action Plan" suggests pesticides as one of three main areas for scientists to focus their research—the other two are parasites/viruses and environmental stresses. As Spivak et al point out, increased stress factors have come from poor nutrition, cross-country transportation for pollination jobs, as well as rising pesticide use and new viruses and pathogens [8]—a*ll* of these things seem to be working together to make honey bee health and immunity weaker than ever before.

But some of the most recent studies have laid the blame for CCD squarely on pesticides: "The impact of pesticides on honey bees is an issue that has been studied for many years and is now being reconsidered because controversy still exists with the relationship of insecticides and Colony Collapse Disorder" [17]. The authors of this study assert that Bayer and other producers of pesticides have hired scientists to buy their silence on the issue of CCD.

The issues of poor nutrition and pesticide use seem to come together in another article that appeared in the *Bulletin of Insectology* just this year [5]. As the anonymous Massachusetts farmer suggested in his 1792 treatise, bees love to prey on "that which is not their own" [10]. Modern beekeepers have used this trick and now feed their bees high fructose corn syrup (HFCS) as a supplement to their own honey [5]. Corn is

pollinated by the wind and so does not rely on bees [18]. Subsequently, neonicotinoids are often used as pesticides for helping with the corn crop, and trace amounts are left over in the HFCS that beekeepers feed their bees [5]. In this study, 15 of the 16 hives treated with neonicotinoid were dead within 23 weeks with CCD-like symptoms. "The observed delayed mortality in honey bees caused by Imidacloprid in HFCS is a novel and plausible mechanism for CCD, and should be validated in future studies" [5] is the conclusion of this encouraging study.

Is this the final solution to the CCD problem? Hopefully yes, but the answer is likely "no," as politics and emotion seem to have entered the picture, and the best efforts of the USDA on down might not be able to assuage the competing interests of beekeepers and big agribusiness. And the most recent numbers are not terribly encouraging: the winter of 2010/2011 saw total losses from managed honey bee colonies in the United States at 30% from all causes [19]. The previous winter that number was 34% [19]. The winter of 2012 was milder and may have helped total losses drop to 21.9% [19], but these numbers are still higher than the acceptable average that existed before 2006 and the rise of CCD.

Colony Collapse Disorder has entered the public's imagination and will likely keep popping up in the mainstream news as scientists come closer to solving the problem. If researchers fail to solve the problem and the honey bee is wiped out altogether, the news will likely be of food shortages and economic disaster.

Annex

(informative)———————————————————————————

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