An Update on Colony Collapse Disorder:
What's Happening to the Bees?

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In the *Kalevela*, the Finnish national saga, the hero Lemminkäinen drowns in the river of Tuonela after he descends to the underworld to capture a black swan in his quest to wed a daughter of the witch, Louhi. Lemminkäinen's mother collects his shattered body, stitches the parts together, and then prays to the gods to restore life to her son—to no avail. Finally she entreats a bee to fly to the realm of the gods to bring back honey from the god Ukko to revive Lemminkäinen's body. Only after the hero eats the honey brought down from heaven by the bee does Lemminkäinen regain life.

The honey bee is a miraculous creature who offers the blessings of honey, mead, and wax; a model of industry, thrift, self-government, and, it must be said, effective self-defense. In our world, however, it seems it is we who must revive the bee.

In the winter of 2006-2007 more than a third of the managed bee hives in the United States collapsed in 36 states. Similar losses were reported in Europe, India, and Brazil. That year some beekeepers lost 90 percent of their colonies (vanEngelsdorp et al, 1; Nordhaus, 9). Many beekeepers left the industry. Most experts agree that almost all wild colonies were wiped out, although in some areas they seem to be rebounding. The inexplicable die offs in which worker bees simply vanished, leaving brood, honey, and even queen bees behind, baffled everyone. Scientists called the die-off colony collapse disorder (8). But the truth is honey bees have been in poor health for some time, suffering from a variety of serious problems.

After the winter of 2006-7, the number of colonies managed in the United States dropped to about 2.25 million in 2008. In comparison, in 1947 about 6 million colonies were managed in this country.[1] Mysterious honey bee die-offs are not unheard of; since

[1] Worldwide, in contrast, during the past 50 years there has been a 45 percent increase in the number of managed honey bee colonies. That trend, however, is not keeping pace with the 300 percent growth of bee-pollinated crop production during the same period (see Spivak et al; Aizen and Harder).

1869 there have been at least 18 such episodes in the United States.[2] But CCD—whatever it is—is more widespread, and the need for pollination leaves little room for a shortage of bees in the United States.

U. S. domestic honey production is at about half its 1990s level, and the total number of beekeepers is about half what it was 70 years ago (Shilling, 31). Cheap honey imports, some of the honey contaminated with heavy metals, antibiotics, or even adulterated, have flooded the country, undercutting domestic beekeepers' businesses.[3] Roughly 60 percent of the honey imported into the United States comes from Asian countries that are typically "laundering" Chinese honey, some of it seriously substandard (Schneider).

We know that honey bees do even more for us than provide honey and wax. They and their cousins, bumble bees and other so-called wild bees, pollinate our food crops, about a third of which depend on insect pollination for proper setting of fruit and vegetables (Mussen and Brandi, 3). Wild pollinator populations, which are tremendously important, actually may be in worse condition than honey bees. (Spivak et al, 34).

The economic contribution made by honey bees is in many ways incalculable, but researchers estimate that in 2010 in the United States honey bees pollinated $12.4 billion in dependent crops, and $6.8 billion in indirectly dependent crops (Calderone, 1).[4]

Despite the important role honey bees play in American agriculture as a whole, the almond business is where a shortage of bees will likely first occur. Each February in California's Central Valley, where 80 percent of the world's almond crop is produced, about 1.5 million colonies of bees are needed to pollinate nearly 800,000 acres of almond orchards.[5] That's about 60 percent of all the colonies managed in the United States. Almond growers this year will pay $200 or more per hive for pollination. As the almond industry grew over the past few decades its need for bees enticed many beekeepers to enter the migratory pollination business.

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[2] In 1891 and 1896 Colorado beekeepers reported a condition called "May Disease," which resembles CCD (see vanEngelsdorp et al).

[3] The European Union banned honey from India beginning in mid-2010, then lifted the ban 18 months later.

[4] According to the United Nations Food and Agriculture Organization, 71 of the 100 crops that provide 90 percent of the world's food are pollinated by bees at a value of more than $200 billion a year (see Wotecki).

[5] A colony is an individual hive usually consisting of 20,000 to 40,000 or more individual honey bees.

Without honey bees, an almond grower might manage a yield of 40 pounds an acre. If the grower brings in rented bees, the average yield is 2,400 pounds an acre, or even up to 3,000 in densely planted orchards (Nordhaus, 101). After the almond bloom, commercial bee operators truck their bees eastward, to Florida or Michigan, for the blueberry and apple blooms, then perhaps to Maine, or back to Florida, or to the Dakotas for the summer. The almond industry in effect subsidizes this country's honey bee business (Oliver, "Reflections," 890).

Eight years after the onset of CCD, beekeeping, traditionally a rural, politically low-profile, and family-dominated business, has become one of the hottest areas of agricultural research, marketing and public relations.

Monsanto, the $12 billion agrochemical giant, entered the bee industry in 2011 with its acquisition of an Israeli biotechnology company, Beeologics that has developed a treatment for bee viruses using RNA interference. In June 2013 the company co-hosted a Honey Bee Health Summit, featuring its newly formed Honey Bee Advisory Council comprised of top research entomologists, bee breeders and beekeepers. In October Monsanto announced its Clinton Global Initiative Commitment to Action on Honeybee Health, valued at $4 billion over three years.[6] The company also pledged its support for a coalition convened by the Keystone Center to be dedicated to honey bee health.

Meanwhile, Bayer, the huge chemical concern, has opened a Bee Care Center in Monheim, Germany, and next year plans to open another in Raleigh, N.C. BASF, another multinational chemical concern, also has launched a bee health campaign on its web site. Bayer, as well as Syngenta, another multi-national agrochemical concern, manufactures and markets neonicotinoids, the newest class of pesticides, which work by being taken up into the plant's system so that the entire plant, including its pollen, becomes toxic. In Europe, food regulators recommended in December that the use of neonicotinoids be

[6] Monsanto was the first to genetically modify a plant cell, in 1982, and the first to field-test genetically modified crops, in 1987. Monsanto invented glyphosate—better known as Roundup—in 1970, and then genetically modified corn, soybean, canola and other crops so that they are resistant to Roundup. Monsanto was ranked in 2010 by the Swiss research firm, Covalence, as number 581 in its ranking of the ethical performance of 581 multi-national companies, ranking just under Halliburton (Huffington Post). Forbes named Monsanto its company of the year in for 2009. Monsanto's legal scorched-earth tactics, however, not to mention its legacy of pollution and questionable marketing playbook, have left it with a global reputation as a corporate bully (see Barlett and Steele).

restricted even further than the two-year ban enacted by the European Commission in January 2013 (Hakim, "European"). Both Bayer and Syngenta are fighting the ban in the courts. To put it mildly, the entry of these big companies into the bee world has been met with mixed reviews.

Late last year Canada's Pest Management Regulatory Agency, calling current neonicotinoid use "not sustainable," enacted strict limits on the use of neonicotinoids. An Italian study has linked neonicotinoids to immunity suppression in honey bees (Carter, 87).

In the United States, an internal Environmental Protection Agency document leaked in 2010 said that the "major risk concern" of one neonicotinoid formulation, Bayer's clothianidin, was to "non-target insects (that is, honey bees)," calling clothianidin "highly toxic" (Hakim, "Accused").

Virtually every corn seed planted in the Midwest—indeed in the United States—is treated with one of two neonicotinoids—clothianidin or thiamethoxam—and a cocktail of fungicides (Hunt and Krupke, 889). Despite the huge volume of neonicotinoids used, bee kills caused by neonicotinoids are reported only sporadically—and these seem to be limited to the effects of seed-coating talc, which we'll address shortly. It seems as if the discussion on honey bee health has separated into two camps that are talking past each other: Regulatory agencies, agricultural entomologists and chemical companies cite the lack of direct evidence of bee kills as proof a particular substance causes no harm.

Researchers and many beekeepers, however, increasingly see evidence that chronic, low-level exposures to multiple compounds harms honey bees and other pollinators—effects that are more subtle than bee kills typically caused by previous generations of pesticides, but significant and pervasive none the less (Sakai, phys.org). In fact, the report published by the 2012 National Honey Bee Health Stakeholder Conference Steering Committee, a meeting of the nation's top bee experts, explicitly said the most pressing pesticide research questions involve "determining the actual field-relevant pesticide exposure bees receive and the effects of pervasive exposure to multiple pesticides on bee health and productivity of whole honey bee colonies" (Report, vi).

Technology has brought about incredibly productive, reduced-tillage, herbicide- and insecticide-dependent farming of vast monocultures of genetically engineered soybeans and corn. Corn yield per acre in the Midwest has generally tripled since 1960 to 2013 average yield per acre of 160. These monocultures create ideal breeding grounds for the explosive growth of pest populations. Traditional practices, such as rotation of fallow pasture or legumes, have given way to GMO seeds treated with systemic insecticides (Oliver, “Reflections, 890). Political pressures have created incentives to put fallow land into cultivation to grow even more corn for ethanol in the interest of “energy security.” The net effect of these practices, as Michael Pollan noted in his important book, *The Omnivore’s Dilemma*, has been to mine the soil itself, paradoxically creating biological deserts in the midst of some of the world’s richest farmland (Pollan). Meanwhile, for the honey bee, the appearance in the United States of the parasitic mite, *Varroa destructor*, in 1986 coincided with the intensification of industrialization in agriculture.

The plight of the honey bee is an indicator that our agronomic practices, indeed, our entire consumer culture, is unsustainable. This is the message they are bringing to us.

Our fascination with their social order highlights one of the most salient facts about social insects, in general, and honey bees, in particular: Their colonies are super-organisms consisting of thousands of individuals, but also functioning as one entity (Holldobler and Wilson, xvi). When a beekeeper opens a hive he feels a sense that he is looking into an utterly different reality, absolutely rational, more integrally woven into the natural world than are we; alien yet strangely familiar. The honey bee is an amazing creature that seems to have exploited every one of its roughly million neurons to create a complex social order, including what the 20th century bee researcher Karl von Frisch called the only “non-primate symbolic language” (Honey Bee Genome Sequencing Consortium, 931; Menzel and Muller, 379).

This language, their “waggle dance” behavior, places honey bees apart from all other social insects (E. O. Wilson, 94). The internal clock of honey bees is so well developed that they compensate for the daily and seasonal movements of the sun over time when engaging in the dancing behavior. Workers learn landmarks while foraging, and also learn to associate a flower’s color, shape, scent, or location with food reward. Moreover, honey bees can form the concepts of “sameness” and “difference,” as well as accomplish other cognitive performances that until recently were thought only to occur in some vertebrates (Giurfa et al, 930). After swarming, the location of the new colony is decided by a complex, consensual process (Seeley, *Honey Bee*, 99). Honey bees demonstrate a complex division of labor based primarily on worker bee age and glandular development.

Honey bees are extremely vulnerable during their larval and pupal stages. Worker larvae undergo six molts and a thousand-fold gain in their mass in six days (Musser and Brandi, 3). During the larval period bees are fed royal jelly, a protein-rich food produced by worker bees, as well as pollen. Young bees also consume pollen, which is combined with honey and enzymes to make what beekeepers call "bee bread." When the larval stage ends, worker bees seal the cell, then the larva spins a pupal cocoon, in which it will metamorphose into an adult. Rather than blood, bees, as invertebrates, circulate hemolymph, which is about 90 percent water, by means of a four-chambered heart in the abdomen. Hemolymph carries sugars, amino acids, fats, minerals, hormones and all the other nutritional requirements of bees (Winston, 33; Collison, 21).

In 2006 the honey bee genome sequencing was completed, which helped researchers to understand honey bees' vulnerabilities:

- Compared with other insects' genomes, the honey bee genome suggests "honeybees use novel immune pathways, are poorly defended against pathogens at the individual level, and/or have immune systems that are narrowly focused on a relatively small group of coevolved pathogens."
- Honey bees are unusually sensitive to certain pesticides, and have fewer detoxifying genes than other insects. Sub-lethal effects of pesticides affect honey bee initial learning and odor responses, traits directly linked to foraging."
- Genes governing circadian rhythms are more similar to vertebrates than other insects studied.
- Their protection against infectious disease is smaller than that of a fruit fly, which the genome team noted was paradoxical because of the high pathogen load associated with bees' highly developed social organization.
- Genetic makeup associated with detoxification genes and defense against other organisms are smaller than the fruit fly, perhaps because of the protected, managed environment of the hive (HBGSC, 938).

Honey bees exhibit an amazingly complex range of social behaviors, adaptations, and abilities. They have evolved this effectiveness, it seems, somewhat at the expense of their defenses against their threats, which can be summarized as "pests, pathogens, and pesticides." To those three we can add a third, poor nutrition.

The biggest threat to honey bees in our time is one pest, a parasitic mite, *V. destructor*.[7] The varroa mite is an obligatory parasite that feeds on the hemolymph of developing and mature honey bees.

Mites invade cells of bee larvae, particularly drones, just before they are sealed, then feed on the hemolymph of the developing bee and proliferate there. When the adult bee emerges, the attached female mites emerge with it. They may then transfer to another bee or another bee larval cell.[8] Untreated, honey bee colonies infested with *V. destructor* typically collapse within 2 to 3 years. Originally a parasite of an Asian honey bee, *A. cerana*, the varroa mite was first seen in North America in 1986.[9]

The varroa mite suppresses the honey bee's immune system, and is a vector for at least five bee viruses.[10] Two other types of mites also parasitize honey bees, but the varroa mite poses the greatest threat.[11] Beekeepers have used a range of responses to combat the varroa mite, often making matters worse by excessive use of insecticides inside the hive aimed at killing the mite without crippling the bee colony. Integrated pest management techniques—which do not involve insecticides—are the most benign for the bees, but these steps alone have not been an adequate response.[12] Synthetic chemical control, using various

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[7] Only two haplotypes of *V. destructor* successfully parasitize *A. mellifera*: the Korean, and to a lesser extent the Japan/Thailand haplotype (Rosenkranz, Aumeier and Ziegelmann). The mite was originally called *Varroa jacobsoni* and in 2000 renamed *V. destructor.*

[8] The life cycle of the varroa mite begins with mated females entering larval bee cells shortly before the cells are capped. The mites hide in the layer of food provided by nurse bees in the bottom of the cell. They then climb onto the bee prepupae. Within 60 hours she produces her first egg, a male. After thirty hours she produces fertile female eggs. The adult female pierces the exoskeleton of the bee pupa so she and her daughters can feed on the host. Mites prefer drone pupae because the longer maturation time enables them to produce as many as three daughters. When the parasitized pupa emerges as an adult from its cell, one or more female mites emerge with the bee and attach to a passing bee. Female mites pierce the cuticle of the host bees at skeletal joints to feed on hemolymph (Caron and O'Connor)

[9] In *A. cerana*, mites do not reproduce in worker brood, only among drone larvae and pupae. *A. cerana* actively groom and then kill the mites, and entomb drone brood that are parasitized (Rosenkranz, Aumeier, Ziegelmann).

[10] Including deformed wing virus, Israeli acute paralysis virus, and Kashmir bee virus (Sammataro, Gerson, and Needham; Yang and Cox-Foster).

[11] *Acarapis woodi*, a tracheal mite, and *Tropilaelaps clareae,*

[12] These include screened bottom boards, drone brood trapping, heat, and powdered sugar dusting.

acaricides, has been somewhat effective, but at a cost: not only do mites develop resistance to the chemicals, the acaricides accumulate rapidly in wax, pollen, and nectar. Scientists have been able to detect and measure this contamination in wax, pollen and bees.

In one analysis more than 97 percent of the pollen samples contained pesticides (Mullin et al, 1; Frazier, 784). These synthetic chemicals, such as the organophosphate coumophos and the pyrethroid fluvalinate, also combine synergistically with other insecticides, fungicides, and herbicides brought into the hive from agricultural and household applications. So unfortunately, beekeepers—especially large-scale operations—have greatly compounded problems as they have fought the Varroa mite. Neonicotinoid marketers have been quick to point out that beekeepers themselves have been responsible for much of the contamination of bee food and wax, which has been borne out by studies.

So-called "soft" chemical treatments, such as formic acid, oxalic acid, and thymol (essence of thyme), have been successful. Application is labor intensive, and in the case of formic and oxalic acid, hazardous without respiratory protection.

One mite treatment that holds a lot of promise is RNA interference. Still in trial stages, it involves placing double-stranded RNA in bees to be transferred back to mites as they feed on bees' hemolymph. The double-stranded RNA engenders targeted gene silencing in the varroa mite, decreasing the mite population (Garbian et al).[13] RNA interference has also been demonstrated to silence certain bee viruses, the basis of the Beeologics technology.

Bee researchers have focused on breeding bees that resist the varroa mite, primarily through grooming and so-called hygienic behaviors. The Russian strain of European honey bees tolerates Varroa mites better than other European strains, which geneticists have been

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[13]"The finding that sequence-specific gene silencing occurs in response to the presence of double-stranded RNAs has had an enormous impact on biology, uncovering an unsuspected level of regulation of gene expression. This process, known as RNA interference (RNAi) or RNA silencing, involves small non-coding RNAs, which associate with nuclease-containing regulatory complexes and then pair with complementary messenger RNA targets, thereby preventing the expression of these mRNAs. Remarkable progress has been made towards understanding the underlying mechanisms of RNAi, raising the prospect of deciphering the 'RNAi code' that, like transcription factors, allows the fine-tuning and networking of complex suites of gene activity, thereby specifying cellular physiology and development." (Siomi, Haruhiko and Siomi, Mikiko C. "Review Article On the road to reading the RNA-interference code." Nature. *Nature* 457, 396-404 (22 January 2009).

attempting to understand and use in developing honey bees that exhibit so-called Varroa-sensitive hygiene, or VSH traits. Surviving wild colonies can be valuable resources in this effort.

Honey bees can also be afflicted with a variety of pathogens, including 18 types of viruses (Borst, 623). Particularly serious are the bacterial brood diseases, European foulbrood and American foulbrood.

The most serious, widespread adult bee disease is nosema, caused by two types of single-celled parasites, or microsporidia, *N. apis* and the more recently identified *N. ceranae*, which previously only was found in Asian honey bees. Nosema, a gut fungus, affects overwintering bees in colder climates more severely because of the extended periods bees are confined to their hives. Nosema weakens bees, rendering them more susceptible to other pathogens. Some research has shown that bees exposed to field-level doses of one neonicotinoid and one fungicide left bees more susceptible to nosema (Mussen, projectapis.org).[14] Researchers have also found that microbes in honey bees' midgut play an important role in bee health.

Pesticides have been around long before humans discovered the natural substances that plants, such as tobacco and chrysanthemums, evolved to defend against insects. Determining how pesticides affect honey bees is complicated by the fact that there are more than 1,200 chemicals are used in agriculture in the United States in more than 18,000 formulations (Frazier et al, 779).

Some chemicals act synergistically when combined. More than 1.1 billion pounds of pesticides, including herbicides, insecticides, and fungicides, are used annually in the United States, 80 percent in agriculture (Grube et al, epa.gov). The combinations of these substances, the active ingredient plus adjuvants—so-called "inert" substances that enhance the insecticidal properties—turn the job of figuring out how beneficial insects are affected into a mind-boggling puzzle. In tests various proprietary adjuvants, surfactants and enhancers have proved to be much more toxic to bees than the active ingredients, which has prompted one influential researcher to call for increased monitoring and tests (Mullin et

[14] The ability of honey bees to detoxify harmful substances works better at higher temperatures, so overwintering bees are more susceptible to sub-lethal doses of pesticides, compounding this vulnerability (Mussen).

al, “The Formulation,” us1.campaign-archive2.com). These formulations make the job of analyzing the chemical landscape much more difficult.

Because neonicotinoids work by being taken up into a plant’s circulatory system, the chemicals—properly applied—do not need to be widely dispersed, so they promised greater safety for vertebrates: mammals, birds, fish, reptiles, and amphibians, as well as “non-target” invertebrates. Initial tests showed a honey bee’s lethal ingested dose of a neonicotinoid, such as imidacloprid, at about 192 parts per billion, while typical agricultural treatment contaminated bee food at levels of 4-10 ppb. Subsequent tests have shown neonicotinoids, however, have surprisingly strong effects on bees’ nervous systems even at very low exposure levels (Mussen, projectapism.org; Hunt and Krupke, 889).

Research by Purdue University scientists on bee kills in Indiana found that soil samples and pollen, including dandelion pollen, brought back to the hive by honey bees, tested positive for neonicotinoids and fungicides at low levels. The effects of low levels of contamination, less than 100 parts per billion, are under research, but the talc used to lubricate neonicotinoid-coated seeds during planting clearly poses an immediate threat. Treated seeds are sticky, and talc is used to coat the seeds so they will flow freely through the planting mechanisms. This contaminated talc is vented during planting and planter machinery maintenance. Vented talc vented was found to have extremely high levels of neonicotinoids, up to nearly 700,000 times the lethal contact dose for a bee (Krupke et al).

As noted earlier, the Canadian government has taken action to limit the use of two neonicotinoids, clothianidin and thiamethoxam (Health Canada, hc-sc.gc.ca). This step arose from bee kills in Quebec and Ontario in 2012. In September 2013 Canada issued a report confirming the bee colony losses were caused by talc and dust from neonicotinoid-treated corn and soybean seeds, and recommending action be taken to mitigate future harm to bee populations. The status quo, the Canadian government’s report said, was unsustainable. The European Commission had already in (January 2013) restricted the use of three neonicotinoid substances for two years. France moved in 2004 to restrict the use of neonicotinoids.

Earlier this year a coalition of environmental groups and beekeepers filed a lawsuit in Northern District Court of California demanding that the EPA restrict the use of clothianidin and thiamethoxam. The filing also challenged the EPA’s use of “conditional registrations.” Since 2000, more than two-thirds of pesticide products, including clothianidin and thiamethoxam, have been brought to market under conditional registrations, according to the groups (Gillam, “Groups sue EPA,” reuters.com).

Meanwhile, the EPA has responded to its critics by taking several steps, including mandates requiring new labeling, calls for new technology to reduce dust drift during planting, promoting public awareness campaigns to protect pollinators; and, accelerating the review of six neonicotinoids, including imidacloprid, clothianidin, and thiamethoxam. [15]

Other steps include ordering new enforcement guidance on reported bee kills; pledging to develop new data requirements addressing sub-lethal effects of pesticides at all life stages; and, a stated commitment to work with European and Canadian health agencies.

Agricultural areas have become dominated by intensive cultivation of a few crops, particularly corn and soybeans. According to Dr. Jeff Pettis of the USDA Agricultural Research Station in Beltsville, Md., beekeepers and researchers agree that land use patterns have changed so much that less forage land is available to bees. Weed control along highways and on forested government land has reduced pesticide-free weeds once available to bees.

Migratory beekeeping has also adopted an industrial model, as we saw earlier with almond pollination, which stresses bee colonies. Many commercial beekeepers have used the summer months to rejuvenate their colonies by parking them in the Dakotas for honey production and to enable hives to strengthen through the beneficial nutrition bees find in open rangeland forage.

But now more land is being cultivated in North and South Dakota, reducing available forage. Nearly half a million colonies are located in 11,000 out-yards registered with the North Dakota Department of Agriculture (Kellison, 36). Meanwhile, the decline in Conservation Reserve Program participation has taken 6 million acres out of available range for honey bees and other wild pollinators. Many researchers feel poor nutrition,

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[15] The plight of the honey bees also highlights problems in the way the EPA reviews pesticides. Bayer CropScience, which introduced the neonicotinoid clothianidin in 2003 based on conditional approval by the EPA, provided additional information to the EPA in 2007—three years late. Despite the fact that Bayer’s testing studies did not follow protocol, noted by EPA reviewers, clothianidin was switched to full registration in 2011 (Helblig).

brought about to a great degree by a lack of adequate forage land, has been an important component in CCD.

CCD is increasingly understood as a synergistic threat to bees, in which parasites, pathogens, pesticides and poor nutrition have compounded their effects in the context of an increasingly industrialized, chemical-dependent, agricultural landscape. In response to the almond industry and other pollination customers, commercially managed bee colonies have become more like other livestock: intensively managed and dependent on feeding, medication, and selective breeding (Oliver, “Reflections,” 890). Monsanto’s entry into the bee business doubtless was driven by an appreciation of this trend. Most commercial beekeepers re-queen their colonies twice a year, something unheard of years ago.

Wild pollinators, such as bumble bees and their relatives, as well as honey bees, are threatened. Bees are a powerful indicator that our system is unsustainable. Cultural and geopolitical factors come into play because inexpensive food has been a keystone of American domestic economic policy. It’s no accident that in Europe, where quality and purity are more widespread concerns and more tightly enforced, agricultural issues, including bee safety, have been taken much more seriously.

A growing body of peer-reviewed research—but not necessarily USDA published statements—supports the contention that low-level contamination of bee food by all types of pesticides, including neonicotinoids and beekeeper-applied chemicals, is harming bees. Seed-coating talc generated during planting is generally agreed by all sides to be a threat to bees. Studies typically find 100 or more different chemical residues in bee pollen, beeswax and adult honey bee food (Mussen, projectapism.org). Meanwhile, beekeepers can do little immediately about the varroa mite—a proven vector for bee viruses—except rotate treatments and breed mite-resistant bees. And beekeepers have been in many ways their own worst enemy by using insecticides excessively in their own hives.

The ideal response would be to develop and initiate a new model of agriculture that returned farming to less reliance on pesticides—herbicides, fungicides, and insecticides—and increased crop rotation and diversification. Moreover, we would move to less reliance on pesticides throughout the landscape: homes, gardens, roadsides, and golf courses. This, however, is unlikely to happen, unless driven by economic pressures.

CCD, according to the most recent consensus, is a complex, rather than a single event.

- The varroa mite remains the worst pest of honey bees, and is closely associated with overwintering colony losses.
- Multiple virus species have been associated with CCD.
- Varroa is a known vector and amplifier of viruses.
- Nutrition has a major impact on individual bee and colony longevity.
- Acute and sublethal effects of pesticides on honey bees have been increasingly documented, and are a primary concern.
- The most pressing pesticide research questions lie in determining the actual field-relevant pesticide exposure bees receive and the effects of pervasive exposure to multiple pesticides on bee health and productivity of whole honey bee colonies.
- Genetic variation improves bee thermoregulation, disease resistance and worker productivity.
- Genomic insights from sequencing the honey bee genome are now widely used to understand and address major questions of breeding, parasite interactions, novel controls (e.g., RNA*i*), and management to make bees less stressed and more productive.

This emerging consensus that CCD is a complex, rather than a single problem, in some ways is the best outcome we could want at this stage. What honey bees are telling us is that our techniques have outstripped our wisdom, that our exploitation of economies of scale violates environmental sustainability. We have demonstrated amazing productivity, but in the language of economics we are beginning to internalize the externalities—and these costs we can see are unacceptably high. Will we demonstrate the wisdom to change how we use our most fundamental resources—soil, water, air, and other species—for the benefit of all stakeholders?

Only time will tell.

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