

The Case of The Empty Hives

Honey bees worldwide are abandoning their hives, and scientists aren't sure whether to blame pathogens, pesticides, or the artificial diets fed to the bees. It's not even clear if the phenomenon is new

DAVID HACKENBERG WAS THE FIRST beekeeper to draw attention to what is now one of the hottest problems in agriculture: a devastating collapse of honey bee colonies. Last October, while inspecting 400 of his company's hives in Florida, he noticed that 368 were almost empty, despite having been healthy just 3 weeks earlier. Gone were the swarming worker bees; instead, the eerily quiet hives housed just the queen bee and many doomed brood. All told, Hackenberg has lost 85% of his 3000 hives—and \$450,000 of income. Although beekeepers are used to abandoned hives and bee die-offs, the extent was far worse than Hackenberg had ever experienced—and he has tended bees for more than 4 decades. “It’s probably the most stressful year of my life,” he says.

Alarmed, Hackenberg contacted Diana Cox-Foster, an entomologist at Pennsylvania State University (PSU) in State College. Soon she and Dennis vanEngelsdorp, the state apiarist, heard of similar problems from beekeepers across the country. By January, the two had established a network of researchers from Florida to Montana to solve the puzzle of what they’re calling colony collapse disorder (CCD). “It’s a science-fiction scenario come to life,” says entomologist May Berenbaum of the University of Illinois, Urbana-Champaign.

Last year, Berenbaum led a National Research Council panel that warned of a looming pollination crisis if honey bees and other pollinators continue to decline in number (*Science*, 20 October 2006, p. 397). Some scientists now fear that the emergence of CCD will tip the balance, forcing many beekeepers out of business and raising costs for farmers who already rent hives because of a lack of natural pollinators. “We may be near the point when there are not enough bees,” says Danny Weaver, a queen breeder with B. Weaver Apiaries in Navasota, Texas.

At a recent meeting to devise a research strategy on CCD, scientists debated whether known bee killers, including pesticides, the varroa mite, viruses, and bacteria, were responsible. Others suspect a novel pathogen, and several top virologists are analyzing samples from afflicted hives at a breakneck pace. Researchers have even irradiated honeycombs to determine whether an infectious agent explains the disorder. Yet some blame the collapses on better understood problems, such as spells of bad weather that leave bees hungry. Or perhaps industrial-scale beekeeping—in which hundreds of thousands of hives are trucked around the country and pumped up with sugar syrups to boost their numbers—has made colonies more vulnerable.

Little consensus about the cause of CCD emerged at the meeting, which the U.S. Department of Agriculture (USDA) in Beltsville, Maryland, convened. It could be a variety of factors, notes Jeffery Pettis of the USDA bee lab in Beltsville, Maryland: “At this point, we’re proceeding not knowing which causes might be more important.” In fact, given that there are so



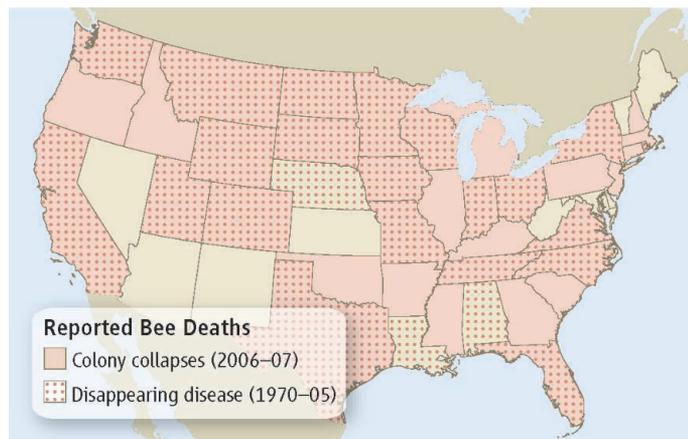
few data on the health of domesticated honey bees—and even fewer on wild populations—many scientists aren’t even convinced yet that what’s going on is really a new phenomenon.

In decline

Honey bees are indispensable farmhands, pollinating some 95 kinds of fruits and vegetables grown in the United States. An estimate by Cornell University researchers in 2000 placed the value of the insects’ services at \$14.6 billion in extra yield and improved crop quality. Yet honey bees, like other pollinators, have been in trouble for a while. The number of U.S. honey bee colonies fell from 5 million in 1940 to 2 million in 1989, a decline largely attributed to economic shifts in farming.

For the last 20 years, the biggest issue for beekeepers has been the varroa mite, first noticed in the United States in 1987. Once infected, an untreated hive can be totally wiped out in a few months. “Varroa mites are public enemy number one for bees,” says Pettis. The mites have nearly eliminated feral colonies of honey bees, which used to pollinate many vegetable crops. Many farmers must now rent bees for pollination, which has contributed to the growth of large-scale beekeeping; since the late 1980s, the number of colonies has expanded by 25% to 2.5 million.

But now CCD threatens to erase that small comeback—and with lightning speed. Although bees occasionally abandon their



Déjà vu? Beekeepers across the country have reported colony collapses. A mysterious syndrome, called disappearing disease, struck similarly in the 1970s.



Scrutinized. Scientists are probing the enigmatic disappearance of worker bees, with brood and queen left behind (*right, bottom*). Parasitic mites (*right, top*) could be a factor.



hives if disturbed, the demographics of these recent collapses are odd. The queen usually remains, surrounded by untended brood. And other insects, such as wax moths or small hive beetles, don't rob the abandoned hives of honey or nectar, suggesting some sort of contamination. "It's bizarre," says Berenbaum.

Puzzling sudden losses of bees have happened before. In 2004, beekeepers had trouble with struggling hives sent to California for pollinating almond trees. And in the 1960s and '70s, before the arrival of mites, beekeepers around the country reported disappearing bees. "It sounds for all the world like what happened last year," says Eric Mussen of the University of California, Davis. Even an article in a bee journal from 1897—long before synthetic pesticides—describes healthy hives collapsing within a week, with the queen still there.

Severe bee losses do appear to be a widespread problem (see map, p. 970). Some 29% of 577 beekeepers across the country reported CCD and losses of up to 75% of their colonies in the last 16 months, according to a survey run by Bee Alert Technology in Missoula, Montana. Losses range from 35% to 100% of hives in each operation. Other countries are also having problems with rapid losses of wild and domesticated honey bees. In Europe, beekeepers from Spain to near the Arctic Circle are reporting deaths or disappearances of their insects, but the symptoms aren't exactly the same as in the United States.

Still, honey bee researcher Nicholas Calderone of Cornell University says it's not clear that these collapses are something other than normal losses. "We're getting a lot of reports of CCD that are not narrowly defined," says entomologist Robert Danka of the USDA bee lab in Baton Rouge, Louisiana.

Rogues' gallery

Assuming that something new is occurring, researchers since January have investigated the usual suspects, including pesticides and other environmental chemicals. The main focus of Cox-Foster's working group is on nicotine-based compounds called neonicotinoids, which were first introduced as pesticides in 1992. One idea is that low doses interfere with a bee's ability to navigate back to the hive. And lab studies have shown that at least one such compound, imidacloprid, can kill bees at high doses.

There are few data that imidacloprid harms bees in fields, however. And other lines of evidence argue against blaming these pesticides. In 1999, France banned imidacloprid after beekeepers complained that it was causing up to 40% of their colonies to die. Yet the colonies don't seem to be doing much better now, notes Yves Le Conte of the Laboratoire Biologie et Protection de L'Abeille, INRA, in Avignon, France.

And in the United States, there has been no spike in imidacloprid usage that might account for the recent colony collapse. "Pesticides

can't be an explanation for why organic beekeepers are losing their colonies," Berenbaum says. The CCD working group has nevertheless sent samples of wax, honey, and pollen from hives to be tested by USDA food-testing labs for more than 200 chemicals, including fungicides, pesticides, and their metabolites.

To assess whether pathogens explain CCD, Cox-Foster and her colleagues have collected samples from Pennsylvania of bees remaining in collapsed hives, as well as bees from nearby hives that were healthy or declining. USDA researchers also went to California to get bees from afflicted hives; all told, members of the working group have begun to examine samples from more than 200 hives.

At the meeting, Cox-Foster presented some initial results. "We were shocked by the huge number of pathogens present in each adult bee," she says. The highly diverse array of teeming pathogens included bacteria that cause a condition known as American foulbrood, which turns bees gooey and smelly, a fungus that causes a disease called chalkbrood that turns the insects into white mummies, and four kinds of viruses.

Some researchers suspect that an infectious agent may be spreading between hives via the wax combs and other equipment used by beekeepers. In February, Pettis and his colleagues took combs from CCD-affected colonies in Florida and gamma-irradiated or fumigated some of them before inserting the combs into

hives with mite-free bees imported from Australia. Six weeks later, the scientists counted the number of missing brood cells as a measure of colony health. Because the hives with the irradiated combs had fewer missing brood than ones receiving untreated combs had, Pettis suspects pathogens as a possible cause of CCD.

Adding to suspicions that one or more new pathogens are behind CCD are the results from a team led by Ian Lipkin of the Mailman School of Public Health of Columbia University, which has been doing high-throughput DNA sequencing of bulk bee samples from strong, weak, and recovering colonies. The bees from CCD-afflicted colonies have bacteria, fungi, viruses, and parasites that don't match any known bee pathogens and are not in the healthy colonies, Lipkin says. Cox-Foster suggests that the discovery of so many kinds of pathogens in the collapsed colonies indicates that the bees in them, for whatever reason, have suppressed immune systems.

Yet contradictory results have just come in from bee researcher Jerry Bromenshenk of the University of Montana, Missoula, and Bee Alert Technology and his colleagues. In December, they collected samples from hives in Florida. Preliminary analysis by researchers at the U.S. Army's Edgewood Chemical Biological Center in Maryland found similar viral burdens in healthy, failing, and collapsed hives. "It doesn't seem to fit the idea of a suppressed immune system," Bromenshenk says.

Perhaps the most obvious suspect for CCD, the varroa mite, was also a matter of debate at the Maryland meeting. Mites don't seem to be the main problem, at least in California, says Pettis, because the weak colonies on average didn't have more mites than the strong colonies had. But others argued that mites shouldn't be ruled out yet. Marla Spivak of the University of Minnesota, Twin Cities, cautions that even if beekeepers eliminate a mite infestation, weakened colonies may be set to collapse later.

Dangerous diet?

Modern beekeeping itself, some suggest, puts the insects at risk. In the past 2 decades, as the United States started importing cheap honey from abroad, large beekeeping operations began to make more of their income from renting hives to farmers. California's almond growers, for example, pay a premium rate for pollination.

For bees, that means annual trips to California's central valley, where spring starts early

and can be cold and damp. In October and November, more than 1.2 million colonies are trucked into California from all across the country and put into holding yards. Hives are normally inactive during this time of year. But the colonies need to be jam-packed with bees when placed into the flowering almond groves in February, so beekeepers feed them a high-fructose sugar syrup. "They are trying to totally reset the natural cycle of bees," says Marion Ellis of the University of Nebraska, Lincoln. "It's throwing the bees' rhythms out of whack."

The syrupy diet may impair the bees' health, putting them on the verge of a colony collapse. "We can't raise feedlot bees," Ellis says. Pettis doesn't think the syrup is to blame but agrees that no one has hit upon a perfect nutritional formula yet. Last fall, USDA researchers compared two commercial



Outbreak? The large concentration of hives waiting to be placed in California almond groves could allow diseases to spread.

syrups and an experimental one, all designed to stimulate larger increases in bee colonies for almond pollination. None of the diets did the trick, but the experiment did confirm that bee numbers decreased if the insects weren't fed any supplements.

Contaminants in such syrups have also been an issue, Mussen notes. Last summer, beekeepers in California noticed that their syrup smelled and tasted wrong. Lab tests revealed that it had high levels of hydroxymethylfurfural (HMF), a compound that can be toxic to bees. But Hackenberg, who sells supplements, doubts that HMF was the problem. Bees will eat HMF-laced syrup, but last fall they weren't taking in any syrup or pollen supplements at all. "They just wouldn't eat the stuff," he says.

On the road again

Ellis and others suspect that the increased trucking of hives may also cause problems for bees. This concern is in part related to nutrition too; whereas bees in Nebraska, for example, used to spend winters in Texas with excel-

lent forage, now they head for California. An abnormally dry season there means fewer wildflowers and less nectar, which weakens the colonies. Mussen wonders whether that caused the problems for hives in California earlier this year. "As soon as they were taken off the almonds, they started going downhill," Mussen recalls. "They were not big, fat bees; they looked malnourished."

Ellis speculates that the physical movement of hives from state to state disturbs the colonies. And placing vast numbers of colonies in one part of California raises the risk of spreading diseases, he says. Mussen agrees on the latter possibility but points out that hives have been trucked around for many years, making that an unlikely explanation for the recent spurt of colony collapses.

The working group is testing the role of shipping using colonies from three large beekeeping operations. Two, including Hackenberg's, were hit by CCD, and one wasn't. In the experiment, 140 hives are staying in one place for honey production, while another 140 are being moved five times for various pollination jobs. At each point, bees will be sampled and sent to PSU and USDA for pathogen analysis.

Researchers at the Beltsville meeting agreed that the immediate top priority is better surveillance to establish the true incidence of colony collapse. They called for a \$2 million survey of bee health by USDA's Animal and Plant Health Inspection Service, which the agency had proposed last year but was not funded. Ultimately, researchers want to be able to predict and then prevent CCD. "We need practical bioassays for beekeepers—and to be able to tell them what to do in response," says vanEngelsdorp.

Despite the recent colony collapses, almond growers expect a bumper crop this year, says Marsha Venable of the Almond Board of California. But they've had to raise their payments for renting hives from \$50 a colony a few years ago to \$120 this spring. And with another 40,000 hectares of young almond trees that will need pollination in the next few years, the price will only go higher if the riddle of the abandoned hives isn't solved. Beekeepers, Pettis says, "aren't going to meet the demand without something changing."

Indeed, Hackenberg, who has spent the past months trying to rebuild his colonies, worries that another year like this one will put him out of business: "This is do or die."

—ERIK STOKSTAD