Colonies in collapse: What's causing massive honeybee die-offs?

November 12 2008, By Melissa Beattie-Moss

“To the bee, a flower is a fountain of life, and to the flower, a bee is a messenger of love,” wrote poet Kahlil Gibran. Whether or not love is involved in the exchange, the evolutionary dance between pollen-transporting honey bees and nectar-producing flowers is one of nature’s most extraordinary symbiotic relationships, a hundred million years in the making.

Yet what took eons to evolve can be undone in decades, as the growing roster of endangered species makes clear. While the words “endangered species” typically call to mind photogenic tigers, pandas or whales, an estimated 80 percent of all known animal species on Earth are insects, and their extinction often goes unremarked. A recent study notes that hundreds of thousands of insects could be lost in the next 50 years, and that the loss of “keystone” insect species — those on which many other species depend — could be particularly detrimental for ecosystems and people.

As the single bee species maintained by the vast majority of beekeepers in the United States and Europe, Apis mellifera, the western honeybee, is the very essence of a keystone insect. The economic worth of this crucial honeybee — which pollinates over one hundred different fruit and vegetable crops in the United States, including oranges, apples and blueberries, as well as almond trees and animal food crops like clover — has been estimated at more than $14 billion. California’s almond orchards alone require 1.5 million hives to pollinate them, and yield over $2 billion worth of almonds. In Pennsylvania, State Agriculture

Secretary Dennis Wolff has made it clear that “Honeybees are critical to Pennsylvania agriculture and to our state’s economy… We can’t afford to be lax in dealing with this problem.”

Of mites and men

Prior to 1987, life was considerably less stressful for commercial beekeepers and their bees. There were the standard bee afflictions, of course — fungal infections, animal attacks on hives and most notably a contagious bacterial disease called American foulbrood, which could be successfully treated with antibiotics. Yet overall, beekeepers were able to manage these challenges and keep their losses in balance. “By comparison, beekeeping back then was a piece of cake,” recalls veteran beekeeper Dave Hackenberg of Hackenberg Apiaries in Lewisburg, Pa. “You could put the hives out and still have time to go hunting and fishing.”

By 1984, the tracheal mite — a microscopic parasite that interferes with the honeybee’s ability to breathe and curtails its ability to fly — had entered the United States. Beekeepers fought back with vegetable oil, menthol and formic acid, substances that are relatively benign to humans and bees, though sufficiently damaging to tracheal mites to suppress their populations within the hive.

It wasn’t until 1987, when the blood-sucking Varroa destructor mite was introduced into North America — probably by hopping a ride on a queen bee smuggled here from abroad by a beekeeper — that the assaults on bees became more ferocious.

By all accounts, the varroa mite — maroonish brown and about the size of a sesame seed — is primarily responsible for the mounting losses in the North American beekeeping industry over the last two decades, including catastrophic die-offs in American bees during the winters of

1995-6 and 2000-01. A 2005 study led by Penn State entomologist Diana Cox-Foster found that once the mites take hold in a hive, they suppress bee immunity. “Varroa mites in a colony open the door for many viruses and bacteria,” says Cox-Foster, noting that the pest is “widespread across the United States.”

While the pesticides approved for use against varroa mites initially kept infestations in check, within several years mites in many parts of the country had begun to develop resistance to the chemicals. Since 1987, varroa mites have wiped out between 17 and 40 percent of the total American bee population annually, a crisis that has pushed many commercial beekeepers — who make their living transporting bees to farms that pay per hive for pollination services — out of business.

A crisis on top of a crisis

“When the mites came along, we thought we had problems.” reflects Hackenberg, a lanky, gregarious man in his late 50s. “But this mess makes mites look like a Sunday school picnic.”

Hackenberg can tell you exactly when the mess started for him. “On Nov. 12, 2006, I pulled into a location in Florida where I’d left 400 hives. Three weeks before, they were fine beehives, full of bees. Within three weeks, all but 30-something hives out of 400 had flat disappeared.

“So there I was, just sitting on a gravel lot next to all those empty hives, and there’s no dead bodies on the ground, there’s no bees in the hive, and there’s no wax moths or hive beetles, nothing trying to rob out the honey, the way they usually do.”

Pausing a moment, he declares, “I’ve been trucking bees up and down the East Coast for 40 years and I’d never seen anything like this. This was different. For me, that’s the day a lot of bells started ringing.”

The telephone soon started ringing in the entomology offices at Penn State. Hackenberg's home base in central Pennsylvania meant he was already familiar with a few bee researchers at the University and with the strength of the entomology department. Diana Cox-Foster, a soft-spoken woman who exudes an air of calm, received Hackenberg's call, and took notes on what is now regarded as the first reported case of the mysterious bee die-off phenomenon later dubbed colony collapse disorder (CCD). Hackenberg explains that when he returned to Lewisburg, "I brought a lot of the dead stuff back to Penn State and that's what started the whole ball rolling."

Before long, reports began coming in across the Northeast of hives collapsing in the same characteristic way — a sudden disappearance of adult bees but no bodies in or near the hive; evidence of recent brood rearing, meaning the queen and young larvae are left behind; and an eerie absence of pests which typically pillage honey and bee bread (a mixture of honey and pollen that is the bees' main food) from dying or abandoned hives. To date, CCD has been identified in at least 27 states and Canada, as well as in countries across Europe, particularly France, Belgium and the Netherlands, with some beekeeping operations reporting 50 to 90 percent of their colonies missing and presumed dead.

"I have never seen colonies collapse like this," says Dennis vanEngelsdorp, State Apiarist with the Pennsylvania Department of Agriculture (PDA) and senior extension associate in entomology for Penn State. "When mites cause a colony to collapse, you'll find a lot of mites in the remaining colonies or in the brood. We're not seeing that here. These symptoms are very different."

To fully grasp the mystery posed by CCD, adds vanEngelsdorp, it helps to know that a beehive — home to tens of thousands of bees — is an almost entirely female society, and honeybees are fiercely maternal. "It is extremely uncharacteristic for these bees to leave their young and

never return to their hives," he says.

Maryann Frazier, senior extension associate at Penn State, concurs. "They're leaving behind their brood, the honey, the pollen, all their resources. For bees, this is very, very odd behavior."

Whodunit?

To solve a murder mystery with millions of victims and no smoking gun requires CSI-style teamwork, or as Pennsylvania state apiarist Dennis vanEngelsdorp likes to say, "a coordinated effort that takes a page from the beehive, where all the individuals play a role to make the hive successful."

Penn State's entomology department, long recognized for its strengths in disease research and chemical analysis, has emerged as a leader in honey bee and CCD research nationwide. "We are one of the major contributors in understanding bee health," notes Diana Cox-Foster, professor of entomology and co-chair of the Colony Collapse Disorder Working Group. She adds that currently 19 faculty and graduate students on the University Park campus are doing research projects related to bee health.

Notes Cox-Foster, "We've got Maryann Frazier, Chris Mullins and Jim Frazier working together, asking questions about the impact on the bees of pesticides, including insecticides, fungicides and herbicides — and they've been making a lot of discoveries there."

Jim Tumlinson, a National Academy of Sciences member and director of the Penn State Center for Chemical Ecology, "is working with his grad students on a honeybee pest called the small hive beetle and looking into developing traps to keep them from moving around."

In the Department of Crop and Soil Sciences, Dave Mortensen is interested in fencerows — plantings on the edges of fields — that will encourage pollinators to move into the crops for natural pollination.

In fact, adds Cox-Foster, “There are several people working on different aspects of pollination. Rob Berghage in Horticulture is collaborating with the Master Gardeners association to develop guidelines for pollinator-friendly gardens. He also directs the University’s Center for Green Roof Research.”

We’re also looking at what role mites could be playing, she continues. “Nancy Ostiguy and I are investigating the relationship between varroa mites and bee diseases — particularly endemic viruses — in honeybee colonies.”

Adds Frazier, “Penn State is the No. 1 land-grant university working on this problem. Others are definitely contributing significantly, but Penn State has maintained a commitment to apiculture research and extension programs while many universities have given that up.”

Cautious optimism, then frustration

As news of the crisis spread, the public began weighing in with theories (a “mind-boggling” number, admits Cox-Foster) about CCD’s cause. Proposed culprits include everything from viruses, pesticides and genetically modified crops, to cell phone radiation, erratic weather, conspiracy theories and even a “Bee Rapture.”

To create a way for CCD investigators to exchange information and collaborate on the most promising research avenues, Cox-Foster and colleagues pulled together a coalition called the Colony Collapse Disorder Working Group (CCDWG) in the early months of 2007. The group — which she co-directs with entomologist Jeff Pettis, of the

USDA's Agricultural Research Service — is a network of scientists, regulatory officials, extension educators and industry representatives, including members from the University of Montana, the University of Illinois, North Carolina State, the Florida and Pennsylvania Departments of Agriculture, and Columbia University.

Three fundamental questions emerged as they began formulating hypotheses: Are new or re-emerging pathogens responsible for CCD? Are environmental chemicals causing the immunosuppression of bees and triggering CCD? Or is a combination of factors, such as varroa mites, diseases and nutritional stress, interacting to weaken bee colonies and allowing stress-related pathogens such as fungi to cause a hive's final collapse?

The group started conducting autopsies on bees from hives suspected of undergoing collapse — and what they found surprised them.

Van Engelsdorp recalls staring through the microscope in his Harrisburg lab, expecting to see the usual perpetrators, namely mites or amoebae. Instead, he was confronted with the sight of swollen and blackened internal organs, scarred intestinal tracts and discolored sting glands — all signs of weakened immune systems and infection. "The more we looked, the more we found," he says. "There were multiple infections within each bee, including mites, fungi and a parasitic disease called Nosema ceranae."

Bees are normally pretty resilient creatures, Cox-Foster notes. When dissected bees show traces of nearly every known bee disease that has been observed over the last century, it's clear that their immune systems have been compromised. "It's like bee AIDS," observes Hackenberg. "Their bodies are broken down and every little thing that comes into their system causes them problems."

Still hoping to identify a singular — or, at least, dominant — cause for CCD, Cox-Foster organized a research team including scientists from Penn State (including Edward Holmes of the Center for Infectious Disease Dynamics), the Columbia University Mailman School of Public Health, and the University of Arizona — to investigate one of their strongest hunches, namely that a particularly destructive virus might be responsible for the disorder. Using genetic technologies such as high-throughput DNA sequencing, and new analytic methods developed at Columbia, the team surveyed the microflora in numerous samples of CCD hives, normal hives and imported royal jelly.

Their findings were dramatic: Genetic tests revealed that in 96 percent of the hives stricken with CCD, a little-known virus called Israeli acute paralysis disease (IAPV) was present. All of the bee samples for the study came from operations that had imported bees from Australia — a country that, since 2005, has sold large stocks of bees to American beekeepers trying to keep up with the growing demand for almond pollination in California.

Results from the group's study were published in Science in September of 2007, in an article titled "A Metagenomic Survey of Microbes in Honey Bee Colony Collapse Disorder." In the article, the researchers declared that IAPV was "strongly correlated with CCD," and, with those hopeful words, news spread rapidly that researchers had made the first big break in the case and were closing in on a definitive answer. (The finding that abandoned hives could be sterilized with gamma radiation and successfully repopulated with healthy bees strengthened the belief that an infectious agent — most likely, IAPV — was the prime suspect in CCD.)

Despite the researchers' efforts to qualify their results as preliminary ("I hope no one goes away with the idea that we've actually solved the problem," the USDA's Pettis told The New York Times) their study was

hailed in the media as a major breakthrough — and subsequently found itself the target of criticism and controversy. Two prominent Australian entomologists, Denis Anderson and Iaian J. East, issued a rebuttal in Science, calling any links between IAPV and CCD "tenuous" and pointing to the facts that non-Australian bees with IAPV had been identified in the U.S. since 2002 — three years prior to the surge in importation of Australian bees — and that IAPV is not proving to be lethal among Australia's bee colonies. "It would now be appropriate for the authors of the Science report to issue a retraction of the claims linking CCD to importation of Australian bees," they wrote, adding that future collaborations between the U.S. and Australia would "result in more secure trade for package honeybees to meet the growing demands of the United States pollination industry."

In her response, Diana Cox-Foster and colleagues defended their study, and concluded that although "research on products important to international trade may lead into politically and economically sensitive territory," they hold to the belief that "trade issues should not color research." Cox-Foster has since published another paper examining the different strains of IAPV, which supports the belief that imported Australian bees are one source of the virus in the U.S.

A complex moving target

To further investigate the potential link, Cox-Foster and her graduate students are exposing healthy hives to IAPV to see if CCD develops. To date, these greenhouse studies suggest that IAPV is a particularly pathogenic virus. Yet while Penn State researchers still believe that IAPV is one marker for CCD, they agree that it is not necessarily the cause.

"We were very hopeful early on that we would find something wrong and we could fix it," says Maryann Frazier. "Unfortunately, I don't think

there's going to be one pivotal 'A-ha!' moment that solves the problem."

Dennis vanEngelsdorp reluctantly agrees. "I was really hoping we would discover a distinct cause, but we haven't found that yet. So the next logical thing is to move towards a multifactorial analysis, with the assumption that a combination of factors — some of which don't cause colony mortality on their own — are operating together to tip the balance."

Bad chemistry?

Dave Hackenberg and other beekeepers in the trenches have their own opinions about what is going on.

Hackenberg doesn't mince words. "Our scientists are working their heads off on a little bit of nothing. All we're doing here is slowly reinventing the wheel of what Europe has already figured out."

What France and Germany have done is ban a class of insecticides called neonicotinoids (or "neonics"), an artificial form of nicotine that acts as a neurotoxin to insects. Seeds are typically treated with the chemicals before they are planted or are sprayed while growing in the fields. Their use has been strictly curtailed in France since the 1990s, when they were linked to a mass die-off of bees. In May of 2008, Germany suspended sales of eight neonicotinoid products after two-thirds of the bees in the country's Baden-Wurttemberg region died following the use of the pesticide clothianidin — sold in Europe under the name Poncho — in local fields.

Neonicotinoid manufacturers say that their pesticides are safe if properly applied. But the U.S. Environmental Protection Agency describes clothianidin as a non-selective poison that is "highly toxic to honey bees."

Says Hackenberg, his voice strained with frustration, “If you look at what the manufacturers tell you about how these neonics affect the targeted insects — termites, grubs, what-have-you — they say first of all it breaks down their immune systems, it causes the insect to quit feeding, it causes nervous system disorders, it causes them to be disoriented so they can’t find their way back home. Well, guess what? All four of them things are what’s happening inside of a bee hive with CCD. “

Says Cox-Foster, “Researchers here at Penn State don’t have any evidence to support that these neonicitinoids are the compounds that underlie CCD.” Frazier agrees, adding “Many different kinds of pesticides probably are part of a “perfect storm” of stress factors that have been building in intensity for decades, leading to a decline in honey bees and other pollinators, says Frazier. “This situation is just like a cup. You can put so much in that cup, but at some point it’s going to overflow.”

Working with her colleague (and husband) James Frazier, as well as lead investigator Chris Mullin (“one of the few insect toxicologists working in the U.S. land grant system,” she notes) Frazier has investigated the accumulation of chemicals within bees and their hives. Explains Frazier, almost all known categories of insecticides, as well as some herbicides and fungicides, are detectable in the bees they have analyzed. “What we have found in terms of pesticides is really unprecedented,” she says. “We have found such high levels of pesticides in the wax, in the pollen, and in the bees themselves—beyond the level that was expected when the chemicals were introduced and approved for use. In a total of 108 pollen samples analyzed, 46 different pesticides were identified. We’ve found as many as seventeen different pesticides in one pollen sample from one colony. We’ve identified as many as twenty-four pesticides in one sample of bees. And then there’s the issue of the interactions of these chemicals—things the manufacturers are not required to test.”

Some of these chemicals, such as the pesticides fluvalinate and coumaphos, are commonly used by beekeepers against varroa and tracheal mites. “We certainly see high levels of these miticides in the bees’ pollen and wax,” Frazier says. “We’re starting to ask the question ‘Are the pesticides as much a problem as the mites?’”

Adds Cox-Foster, “Some of the pesticides you and I can buy in garden stores and spray on our roses have the exact same compounds and the exact same concentration as the ones farmers are buying, and they have no warning labels. In order to get rid of weeds and make our flower beds look immaculate, we may have been poisoning some of our bees and pollinators.”

“You set a hive of bees down and you can’t put a fence around 'em!” exclaims Hackenberg. “Honey bees are a barometer of the environment. They’re going to fly miles in every direction to gather food, so if there’s anything out there that’s contaminated, they’re going to find it.”

For his part, Hackenberg now quizzes farmers about what pesticides they use on their crops before he’ll rent his colonies out for pollination. “I was never one of those people to push for organic farming and all that stuff … but I guess I’m agreeing a whole lot more these days,” he says. “You have to wonder how much of this stuff is not just affecting insects, but is affecting us. I mean, think of the corn going into corn syrup, the soy going into our food supply — all this stuff is treated with these chemicals.”

An endangered occupation

“Things don’t just happen to one species in isolation,” notes Frazier. “People are beginning to look at bees and their decline as an example of what we are doing to our environment. To some degree, the honey bees could be seen as an indicator species telling us what’s out there and what

pollinators are being exposed to, as well as being a potential canary in the coal mine, if you will."

"What I can say fairly confidently," she continues, "is that the bees will get by, but the beekeepers may not. When large numbers of bees are lost, they bounce back over time. But we don't have that many commercial beekeepers in this country and many of them are on the brink of financial disaster. If we lose them, we lose the ability to pollinate our commercial agriculture corps."

Says vanEngelsdorp, "In a way, beekeepers are the last nomadic farmers in America. They tend to be family businesses, passed from father to son. And it's hard to see these hardworking people scared by these huge, unexplained losses."

"Imagine that you're a dairy farmer," Hackenberg explains, "and you go out one morning and find 60 or 70 percent of your cows are dead. So you replace them but two weeks from now, 50 percent of those are dead. You can't go on that way."

In the last two years, CCD has driven winter mortality rates to new highs in America's 2.4 million beehives and made deep cuts in the number of beekeepers still working. Without federal support, says Frazier, the profession faces an almost insurmountable challenge. "The big grain farmers have support. They have crop insurance to help them through a few bad years. I would like to seem some similar support for our commercial beekeepers."

Ice-cream, wildflowers and public education

Cox-Foster feels that people are beginning to realize that honey bees are the unsung heroes of the food chain. "It's clear that many people didn't appreciate what it took to get their food on the table," she says. "Now

we're becoming aware that if we knock out the pollinators with these migratory beekeepers, you basically limit the foundation under a lot of our vegetable and fruit production."

The people at Haagen-Dazs have taken note, citing that 40 percent of their ice cream incorporates "bee-dependent" (a term they've coined) ingredients, such as raspberries, peaches, and almonds. As part of their "Haagen-Dazs Loves Honey Bees" consumer education campaign, the company has given $150,000 to Penn State's Honey bee and Pollinator Research Program.

Whole Foods Market, the country's largest retailer of natural and organic foods, has also targeted Penn State's entomology department as a recipient of its cash register donation coupon program.

Penn State has been chosen as the recipient of personal donations as well. Elizabeth Schetman, a seventeen year old from Brooklyn, New York, singlehandedly raised over $5,000. "I wanted to support CCD research in particular," she explains, "and after a bit of online research decided that Penn State was where I should donate the money I would raise. Their efforts led by Dr. Diana Cox-Foster definitely stood out."

With the Haagen-Dazs contribution, among others, Penn State will purchase two expensive pieces of equipment that will enable faster processing of samples, and will also provide small grants for student research on bee-related topics. In addition, notes Frazier — the head of apiculture extension programs — some funds will go to Pennsylvania's Master Gardeners program, to help each county's group develop pollinator-friendly demonstration gardens and certification guidelines throughout the state. (It is important to think of plants—including so-called weeds such as dandelions and clover — as food sources for bird and butterflies, she explains, adding that native plants that have evolved to grow in your region are best for pollinators. What looks very lush to

us — manicured lawns and gardens — is actually a desert for bees and other pollinators. “We’re actually starving them with these landscapes.”)

Despite all that is wrong, is there reason to hope? “Yes, very much so,” says Frazier. “Big agriculture is not going to easily change, but we’re beginning to see people become interested in locally grown, locally consumed food, with less pesticide. I think there’s a tremendous move in the direction of sustainable agriculture, and the bee situation is only going to help push this forward.”

Source: By Melissa Beattie-Moss, Research Penn State