

Where have all the insects gone?

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Surveys in German nature reserves point to a dramatic decline in insect biomass. Key members of ecosystems may be slipping away.

Entomologists call it the windshield phenomenon. “If you talk to people, they have a gut feeling. They remember how insects used to smash on your windshield,” says Wolfgang Wägele, director of the Leibniz Institute for Animal Biodiversity in Bonn, Germany. Today, drivers spend less time scraping and scrubbing. “I’m a very data-driven person,” says Scott Black, executive director of the Xerces Society for Invertebrate Conservation in Portland, Oregon. “But it is a visceral reaction when you realize you don’t see that mess anymore.”

Some people argue that cars today are more aerodynamic and therefore less deadly to insects. But Black says his pride and joy as a teenager in Nebraska was his 1969 Ford Mustang Mach 1—with some pretty sleek lines. “I used to have to wash my car all the time. It was always covered with insects.” Lately, Martin Sorg, an entomologist here, has seen the opposite: “I drive a Land Rover, with the aerodynamics of a refrigerator, and these days it stays clean.”

Though observations about splattered bugs aren’t scientific, few reliable data exist on the fate of important insect species. Scientists have tracked alarming declines in domesticated honey bees, monarch butterflies, and lightning bugs. But few have paid attention to the moths, hover flies, beetles, and countless other insects that buzz and flutter through the warm months. “We have a pretty good track record of ignoring most noncharismatic species,” which most insects are, says Joe Nocera, an ecologist at the University of New Brunswick in Canada.

Of the scant records that do exist, many come from amateur naturalists, whether butterfly collectors or bird watchers. Now, a new set of long-term data is coming to light, this time from a dedicated group of mostly amateur entomologists who have tracked insect abundance at more than 100 nature reserves in western Europe since the 1980s.

Over that time the group, the Krefeld Entomological Society, has seen the yearly insect catches fluctuate, as expected. But in 2013 they spotted something alarming. When they returned to one of their earliest trapping sites from 1989, the total mass of their catch had fallen by nearly 80% (see graph, below). Perhaps it was a particularly bad year, they thought, so they set up the traps again in 2014. The numbers were just as low. Through more direct comparisons, the group—which had preserved thousands of samples over 3 decades—found dramatic declines across more than a dozen other sites.

Such losses reverberate up the food chain. “If you’re an insect-eating bird living in that area, four-fifths of your food is gone in the last quarter-century, which is staggering,” says Dave Goulson, an ecologist at the University of Sussex in the United Kingdom, who is working with the Krefeld group to analyze and publish some of the data. “One almost hopes that it’s not representative—that it’s some strange artifact.”

No one knows how broadly representative the data are of trends elsewhere. But the specificity of the observations offers a unique window into the state of some of the planet's less appreciated species. Germany's "Red List" of endangered insects doesn't look alarming at first glance, says Sorg, who curates the Krefeld society's extensive collection of insect specimens. Few species are listed as extinct because they are still found in one or two sites. But that obscures the fact that many have disappeared from large areas where they were once common. Across Germany, only three bumble bee species have vanished, but the Krefeld region has lost more than half the two dozen bumble bee species that society members documented early in the 20th century.

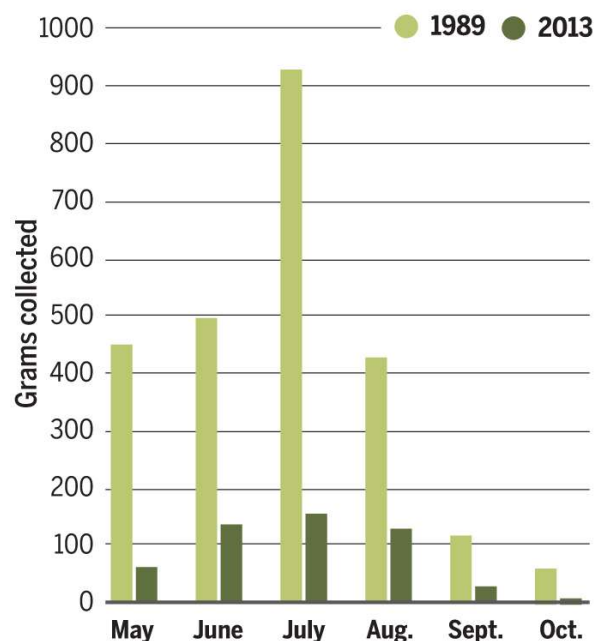
MEMBERS OF THE KREFELD SOCIETY have been observing, recording, and collecting insects from the region—and around the world—since 1905. Some of the roughly 50 members—including teachers, telecommunication technicians, and a book publisher—have become world experts on their favorite insects. Siegfried Cymorek, for instance, who was active in the society from the 1950s through the 1980s, never completed high school. He was drafted into the army as a teenager, and after the war he worked in the wood-protection division at a local chemical plant. But because of his extensive knowledge of wood-boring beetles, the Swiss Federal Institute of Technology in Zurich awarded him an honorary doctorate in 1979. Over the years, members have written more than 2000 publications on insect taxonomy, ecology, and behavior. The society's headquarters is a former school in the center of Krefeld, an industrial town on the banks of the Rhine that was once famous for producing silk.

Disused classrooms store more than a million insect specimens individually pinned and named in display cases. Most were collected nearby, but some come from more exotic locales. Among them are those from the collection of a local priest, an active member in the 1940s and 1950s, who persuaded colleagues at mission stations around the world to send him specimens. (The society's collection and archive are under historical preservation protection.)

Tens of millions more insects float in carefully labeled bottles of alcohol—the yield from the society's monitoring projects in nature reserves around the region. The reserves, set aside for their local ecological value, are not pristine wilderness but "seminatural" habitats, such as former hay meadows, full of wildflowers, birds, small mammals—and insects. Some even include parts of agricultural fields, which farmers are free to farm with conventional methods. Heinz Schwan, a retired chemist and longtime society member who has weighed thousands of trap samples, says the society began collecting long-term

Weighty disappearances

The mass of insects collected by monitoring traps in the Orbroicher Bruch nature reserve in northwest Germany dropped by 78% in 24 years.



records of insect abundance partly by chance. In the late 1970s and early 1980s, local authorities asked the group for help evaluating how different strategies for managing the reserves affected insect populations and diversity.

The members monitored each site only once every few years, but they set up identical insect traps in the same place each time to ensure clean comparisons. Because commercially available traps vary in ways that affect the catch, the group makes their own. Named for the Swedish entomologist René Malaise, who developed the basic design in the 1930s, each trap resembles a floating tent. Black mesh fabric forms the base, topped by a tent of white fabric and, at the summit, a collection container—a plastic jar with an opening into another jar of alcohol. Insects trapped in the fabric fly up to the jar, where the vapors gradually inebriate them and they fall into the alcohol. The traps collect mainly species that fly a meter or so above the ground. For people who worry that the traps themselves might deplete insect populations, Sorg notes that each trap catches just a few grams per day—equivalent to the daily diet of a shrew.

Sorg says society members saved all the samples because even in the 1980s they recognized that each represented a snapshot of potentially intriguing insect populations. “We found it fascinating—despite the fact that in 1982 the term ‘biodiversity’ barely existed,” he says. Many samples have not yet been sorted and cataloged—a painstaking labor of love done with tweezers and a microscope. Nor have the group’s full findings been published. But some of the data are emerging piecemeal in talks by society members and at a hearing at the German Bundestag, the national parliament, and they are unsettling.

Beyond the striking drop in overall insect biomass, the data point to losses in overlooked groups for which almost no one has kept records. In the Krefeld data, hover flies—important pollinators often mistaken for bees—show a particularly steep decline. In 1989, the group’s traps in one reserve collected 17,291 hover

flies from 143 species. In 2014, at the same locations, they found only 2737 individuals from 104 species.

Since their initial findings in 2013, the group has installed more traps each year. Working with researchers at several universities, society members are looking for correlations with weather, changes in vegetation, and other factors. No simple cause has yet emerged. Even in reserves where plant diversity and abundance have improved, Sorg says, “the insect numbers still plunged.”

Changes in land use surrounding the reserves are probably playing a role. “We’ve lost huge amounts of habitat, which has certainly contributed to all these declines,” Goulson says. “If we turn all the seminatural habitats to wheat and cornfields, then there will be virtually no life in those fields.”



Hover flies, often mistaken for bees or wasps, are important pollinators. Their numbers have plummeted in nature reserves in Germany.

As fields expand and hedgerows disappear, the isolated islands of habitat left can support fewer species. Increased fertilizer on remaining grazing lands favors grasses over the diverse wildflowers that many insects prefer. And when development replaces countryside, streets and buildings generate light pollution that leads nocturnal insects astray and interrupts their mating.

Neonicotinoid pesticides, already implicated in the widespread crash of bee populations, are another prime suspect. Introduced in the 1980s, they are now the world's most popular insecticides, initially viewed as relatively benign because they are often applied directly to seeds rather than sprayed. But because they are water soluble, they don't stay put in the fields where they are used. Goulson and his colleagues reported in 2015 that nectar and pollen from wildflowers next to treated fields can have higher concentrations of neonicotinoids than the crop plants. Although initial safety studies showed that allowable levels of the compounds didn't kill honey bees directly, they do affect the insects' abilities to navigate and communicate, according to later research. Researchers found similar effects in wild solitary bees and bumble bees.

Less is known about how those chemicals affect other insects, but new studies of parasitoid wasps suggest those effects could be significant. Those solitary wasps play multiple roles in ecosystems—as pollinators, predators of other insects, and prey for larger animals. A team from the University of Regensburg in Germany reported in *Scientific Reports* in February that exposing the wasp *Nasonia vitripennis* to just 1 nanogram of one common neonicotinoid cut mating rates by

more than half and decreased females' ability to find hosts. “It's as if the [exposed] insect is dead” from a population point of view because it can't produce offspring, says Lars Krogmann, an entomologist at the Stuttgart Natural History Museum in Germany.

No one can prove that the pesticides are to blame for the decline, however. “There is no data on insecticide levels, especially in nature reserves,” Sorg says. The group has tried to find out what kinds of pesticides are used in fields near the reserves, but that has proved difficult, he says. “We simply don't know what the drivers are” in the Krefeld data, Goulson says. “It's not an experiment. It's an observation of this massive decline. The data themselves are strong. Understanding it and knowing what to do about it is difficult.”

THE FACTORS causing trouble for the hover flies, moths, and bumble bees in Germany are probably at work elsewhere, if clean windshields are any indication. Since 1968, scientists at Rothamsted Research, an agricultural research center in Harpenden, U.K., have operated a system of suction traps—12-meter-long suction tubes pointing skyward. Set up in fields to monitor agricultural pests, the traps capture all manner of insects that happen to fly over them; they are “effectively upside-down Hoovers running 24/7, continually sampling the air for migrating insects,” says James Bell, who heads the Rothamsted Insect Survey.

Between 1970 and 2002, the biomass caught in the traps in southern England did not decline significantly. Catches in southern Scotland, however, declined by more than two-thirds during the same period. Bell notes that overall numbers in Scotland were much higher at the start of the study. “It might be that much of the [insect] abundance in

southern England had already been lost” by 1970, he says, after the dramatic postwar changes in agriculture and land use.

A weather station for biodiversity

Researchers in Germany hope to develop a set of automated sensors that will monitor the abundance and diversity of plants, animals, and fungi with the help of pattern recognition and DNA and chemical analysis.



The stable catches in southern England are in part due to constant levels of pests such as aphids, which can thrive when their insect predators are removed. Such species can take advantage of a variety of environments, move large distances, and reproduce multiple times per year. Some can even benefit from pesticides because they reproduce quickly enough to develop resistance, whereas their predators decline. “So lots of insects will do great, but the insects that we love may not,” Black says.

Other, more visible creatures may be feeling the effects of the insect losses. Across North America and Europe, species of birds that eat flying insects, such as larks, swallows, and swifts, are in steep decline. Habitat loss certainly plays a role, Nocera says, “but the obvious factor that ties them all together is their diet.”

Some intriguing, although indirect, clues come from a rare ecological treasure: decades' worth of stratified bird droppings. Nocera and his colleagues have been probing disused chimneys across Canada in which chimney swifts have built their nests for generations. From the droppings, he and his colleagues can reconstruct the diets of the birds, which eat almost exclusively insects caught on the wing.

The layers revealed a striking change in the birds' diets in the 1940s, around the time DDT was introduced. The proportion of beetle remains dropped off, suggesting the birds were

eating smaller insects—and getting fewer calories per catch. The proportion of beetle parts increased slightly again after DDT was banned in the 1970s but never reached its earlier levels. The lack of direct data on insect populations is frustrating, Nocera says. “It’s all correlative. We know that insect populations could have changed to create the population decline we have now. But we don’t have the data, and we never will, because we can’t go back in time.”

Sorg and Wägele agree. “We deeply regret that we did not set up more traps 20 or 30 years ago,” Sorg says. He and other Krefeld society members are now working with Wägele’s group to develop what they wish they had had earlier: a system of automated monitoring stations they hope will combine audio recordings, camera traps, pollen and spore filters, and automated insect traps into a “biodiversity weather station” (see illustration, above). Instead of tedious manual analysis, they hope to use automated sequencing and genetic barcoding to analyze the insect samples. Such data could help pinpoint what is causing the decline—and where efforts to reverse it might work best.

Paying attention to what E. O. Wilson calls “the little things that run the world” is worthwhile, Sorg says. “We won’t exterminate all insects. That’s nonsense. Vertebrates would die out first. But we can cause massive damage to biodiversity—damage that harms us.”