The Insect Apocalypse Is Here

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Sune Boye Riis was on a bike ride with his youngest son, enjoying the sun slanting over the fields and woodlands near their home north of Copenhagen, when it suddenly occurred to him that something about the experience was amiss. Specifically, something was *missing*.

It was summer. He was out in the country, moving fast. But strangely, he wasn't eating any bugs.

For a moment, Riis was transported to his childhood on the Danish island of Lolland, in the Baltic Sea. Back then, summer bike rides meant closing his mouth to cruise through thick clouds of insects, but inevitably he swallowed some anyway. When his parents took him driving, he remembered, the car's windshield was frequently so smeared with insect carcasses that you almost couldn't see through it. But all that seemed distant now. He couldn't recall the last time he needed to wash bugs from his windshield; he even wondered, vaguely, whether car manufacturers had invented some fancy new coating to keep off insects. But this absence, he now realized with some alarm, seemed to be all around him. Where had all those insects gone? And when? And why hadn't he noticed?

Riis watched his son, flying through the beautiful day, not eating bugs, and was struck by the melancholy thought that his son's childhood would lack this particular bug-eating experience of his own. It was, he granted, an odd thing to feel nostalgic about. But he couldn't shake a feeling of loss. "I guess it's pretty human to think that everything was better when you were a kid," he said. "Maybe I didn't like it when I was on my bike and I ate all the bugs, but looking back on it, I think it's something everybody should experience."

I met Riis, a lanky high school science and math teacher, on a hot day in June. He was anxious about not having yet written his address for the school's graduation ceremony that evening, but first, he had a job to do. From his garage, he retrieved a large insect net, drove to a nearby intersection and stopped to strap the net to the car's roof. Made of white mesh, the net ran the length of his car and was held up by a tent pole at the front, tapering to a small, removable bag in back. Drivers whizzing past twisted their heads to stare. Riis eyed his parking spot nervously as he adjusted the straps of the contraption. "This is not 100 percent legal," he said, "but I guess, for the sake of science."

Riis had not been able to stop thinking about the missing bugs. The more he learned, the more his nostalgia gave way to worry. Insects are the vital pollinators and recyclers of ecosystems and the base of food webs everywhere. Riis was not alone in noticing their decline. In the United States, scientists recently found the population of monarch butterflies fell by 90 percent in the last 20 years, a loss of 900 million individuals; the rusty-patched bumblebee, which once lived in 28 states, dropped by 87 percent over the same period. With other, less-studied insect species, one butterfly researcher told me, "all we can do is wave our arms and say, 'It's not here anymore!' " Still, the most disquieting thing wasn't the disappearance of certain species of insects; it was the deeper worry, shared by Riis and many others, that a whole insect world might be quietly going missing, a loss of abundance that could alter the planet in unknowable ways. "We notice the losses," says David Wagner, an entomologist at the University of Connecticut. "It's the diminishment that we don't see."

Because insects are legion, inconspicuous and hard to meaningfully track, the fear that there might be far fewer than before was more felt than documented. People noticed it by canals or in backyards or under streetlights at night — familiar places that had become unfamiliarly empty. The feeling was so common that entomologists developed a shorthand for it, named for the way many people first began to notice that they weren't seeing as many bugs. They called it the windshield phenomenon.

To test what had been primarily a loose suspicion of wrongness, Riis and 200 other Danes were spending the month of June roaming their country's back roads in their outfitted cars. They were part of a study conducted by the Natural History Museum of Denmark, a joint effort of the University of Copenhagen, Aarhus University and North Carolina State University. The nets would stand in for windshields as Riis and the other volunteers drove through various habitats — urban areas, forests, agricultural tracts, uncultivated open land and wetlands — hoping to quantify the disorienting sense that, as one of the study's designers put it, "something from the past is missing from the present."

When the investigators began planning the study in 2016, they weren't sure if anyone would sign up. But by the time the nets were ready, a paper by an obscure German entomological society had brought the problem of insect decline into sharp focus. The German study found that, measured simply by weight, the overall abundance of flying insects in German nature reserves had decreased by 75 percent over just 27 years. If you looked at midsummer population peaks, the drop was 82 percent.

Riis learned about the study from a group of his students in one of their class projects. They must have made some kind of mistake in their citation, he thought. But they hadn't. The study would quickly become, according to the website Altmetric, the sixth-most-discussed scientific paper of 2017. Headlines around the world warned of an "insect Armageddon."

Within days of announcing the insect-collection project, the Natural History Museum of Denmark was turning away eager volunteers by the dozens. It seemed there were people like Riis everywhere, people who had noticed a change but didn't know what to make of it. How could something as fundamental as the bugs in the sky just disappear? And what would become of the world without them?

Anyone who has returned to a childhood haunt to find that everything somehow got smaller knows that humans are not great at remembering the past accurately. This is especially true when it comes to changes to the natural world. It is impossible to maintain a fixed perspective, as Heraclitus observed 2,500 years ago: It is not the same river, but we are also not the same people.

A 1995 study, by Peter H. Kahn and Batya Friedman, of the way some children in Houston experienced pollution summed up our blindness this way: "With each generation, the amount of environmental degradation increases, but each generation takes that amount as the norm." In decades of photos of fishermen holding up their catch in the Florida Keys, the marine biologist Loren McClenachan found a perfect illustration of this phenomenon, which is often called "shifting baseline syndrome." The fish got smaller and smaller, to the point where the prize catches were dwarfed by fish that in years past were piled up and ignored. But the smiles on the fishermen's faces stayed the same size. The world never feels fallen, because we grow accustomed to the fall.

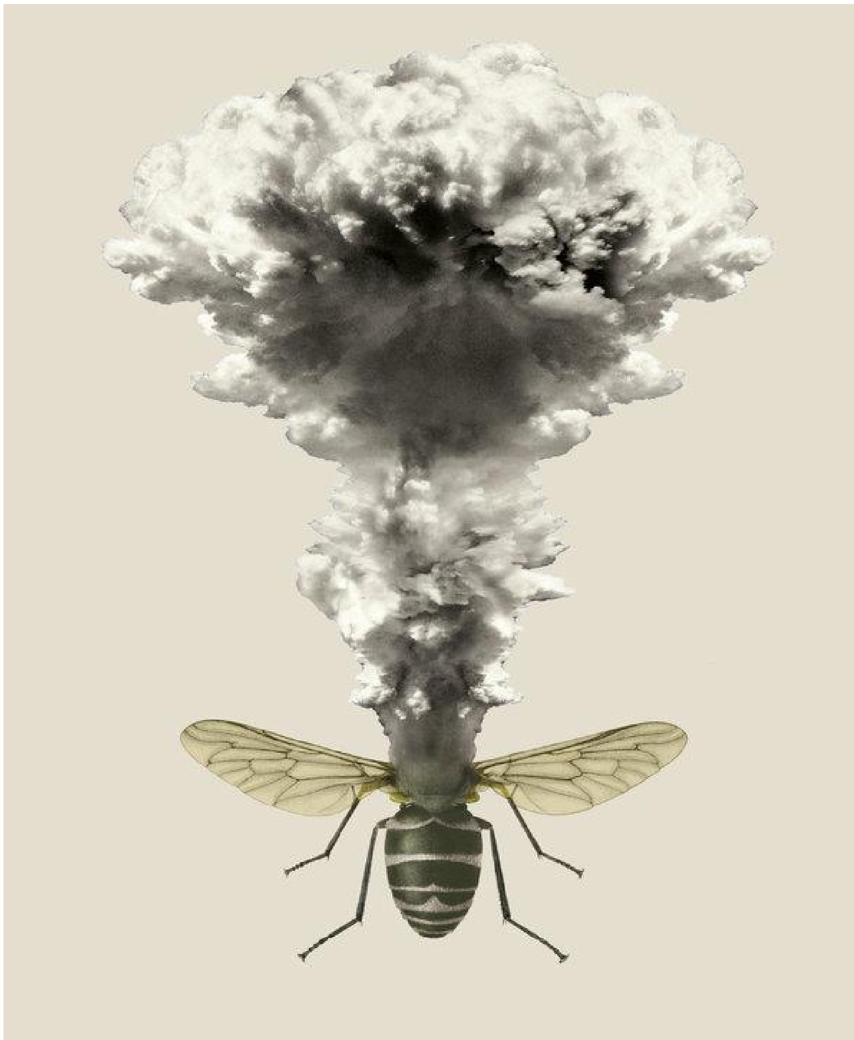
By one measure, bugs are the wildlife we know best, the nondomesticated animals whose lives intersect most intimately with our own: spiders in the shower, ants at the picnic, ticks buried in the skin. We sometimes feel that we know them rather too well. In another sense, though, they are one of our planet's greatest mysteries, a reminder of how little we know about what's happening in the world around us.

We've named and described a million species of insects, a stupefying array of thrips and firebrats and antlions and caddis flies and froghoppers and other enormous families of bugs that most of us can't even name. (Technically, the word "bug" applies only to the order Hemiptera, also known as true bugs, species that have tubelike mouths for piercing and sucking — and there are as many as 80,000 named varieties of those.) The ones we think we do know well, we don't: There are 12,000 types of ants, nearly 20,000 varieties of bees, almost 400,000 species of beetles, so many that the geneticist J.B.S. Haldane reportedly quipped that God must have an inordinate fondness for them. A bit of healthy soil a foot square and two inches deep might easily be home to 200 unique species of mites, each, presumably, with a subtly different job to do. And yet entomologists estimate that all this amazing, absurd and understudied variety represents perhaps only 20 percent of the actual diversity of insects on our planet — that there are millions and millions of species that are entirely unknown to science.

With so much abundance, it very likely never occurred to most entomologists of the past that their multitudinous subjects might dwindle away. As they poured themselves into studies of the life cycles and taxonomies of the species that fascinated them, few thought to measure or record something as boring as their number. Besides, tracking quantity is slow, tedious and unglamorous work: setting and checking traps, waiting years or decades for your data to be meaningful, grappling with blunt baseline questions instead of more sophisticated ones. And who would pay for it? Most academic funding is short-term, but when what you're interested in is invisible, generational change, says Dave Goulson, an entomologist at the University of Sussex, "a three-year monitoring program is no good to anybody." This is especially true of insect populations, which are naturally variable, with wide, trend-obscuring fluctuations from one year to the next.

When entomologists began noticing and investigating insect declines, they lamented the absence of solid information from the past in which to ground their experiences of the present. "We see a hundred of something, and we think we're fine," Wagner says, "but what if there were 100,000 two generations ago?" Rob Dunn, an ecologist at North Carolina State University who helped design the net experiment in Denmark, recently searched for studies showing the effect of pesticide spraying on the quantity of insects living in nearby forests. He was surprised to find that no such studies existed. “We ignored really basic questions,” he said. “It feels like we’ve dropped the ball in some giant collective way.”

Image



If entomologists lacked data, what they did have were some very worrying clues. Along with the impression that they were seeing fewer bugs in their own jars and nets while out doing experiments — a windshield phenomenon specific to the sorts of people who have bug jars and nets — there were documented downward slides of well-studied bugs, including various kinds of bees, moths, butterflies and beetles. In Britain, as many as 30 to 60 percent of species were found to have diminishing ranges. Larger trends were harder to pin down, though a 2014 review in Science tried to quantify these declines by synthesizing the findings of existing studies and found that a majority of monitored species were declining, on average by 45 percent.

Entomologists also knew that climate change and the overall degradation of global habitat are bad news for biodiversity in general, and that insects are dealing with the particular challenges posed by herbicides and pesticides, along with the effects of losing meadows, forests and even weedy patches to the relentless expansion of human spaces. There were studies of other, better-understood species that suggested that the insects associated with them might be declining, too. People who studied fish found that the fish had fewer mayflies to eat. Ornithologists kept finding that birds that rely on insects for food were in trouble: eight in 10 partridges gone from French farmlands; 50 and 80 percent drops, respectively, for nightingales and turtledoves. Half of all farmland birds in Europe disappeared in just three decades. At first, many scientists assumed the familiar culprit of habitat destruction was at work, but then they began to wonder if the birds might simply be starving. In Denmark, an ornithologist named Anders Tottrup was the one who came up with the idea of turning cars into insect trackers for the windshield-effect study after he noticed that rollers, little owls, Eurasian hobbies and bee-eaters — all birds that subsist on large insects such as beetles and dragonflies — had abruptly disappeared from the landscape.

The signs were certainly alarming, but they were also just signs, not enough to justify grand pronouncements about the health of insects as a whole or about what might be driving a widespread, cross-species decline. “There are no quantitative data on insects, so this is just a hypothesis,” Hans de Kroon, an ecologist at Radboud University in the Netherlands, explained to me — not the sort of language that sends people to the barricades.

Then came the German study. Scientists are still cautious about what the findings might imply about other regions of the world. But the study brought forth exactly the kind of longitudinal data they had been seeking, and it wasn’t specific to just one type of insect. The numbers were stark, indicating a vast impoverishment of an entire insect universe, even in protected areas where insects ought to be under less stress. The speed and scale of the drop were shocking even to entomologists who were already anxious about bees or fireflies or the cleanliness of car windshields.

The results were surprising in another way too. The long-term details about insect abundance, the kind that no one really thought existed, hadn’t appeared in a particularly prestigious journal and didn’t come from university-affiliated scientists, but from a small society of insect enthusiasts based in the modest German city Krefeld.

Krefeld sits a half-hour drive outside Düsseldorf, near the western bank of the Rhine. It’s a city of brick houses and bright flower gardens and a *stadtwald* — a municipal forest and park — where paddle boats float on a lake, umbrellas shade a beer garden and (I couldn’t help noticing) the afternoon light through the trees illuminates small swarms of dancing insects.

Near the center of the old city, a paper sign, not much larger than a business card, identifies the stolid headquarters of the society whose research caused so much commotion. When it was founded, in 1905, the society operated out of another building, one that was destroyed when Britain bombed the city during World War II. (By the time the bombs fell, members had moved their precious records and collections of insects, some of which dated back to the 1860s, to an underground bunker.) Nowadays, the society uses more than 6,000 square feet of an old three-story school as storage space. Ask for a tour of the collections, and you will hear such sentences as “This whole room is Lepidoptera,” referring to a former classroom stuffed with what I at first took to be shelves of books but which are in fact innumerable wooden frames containing pinned butterflies and moths; and, in an even larger room, “every bumblebee here was collected before the Second World War, 1880 to 1930”; and, upon opening a drawer full of sweat bees, “It’s a new collection, 30 years only.”

On the shelves that do hold books, I counted 31 clearly well-loved volumes in the series “Beetles of Middle Europe.” A 395-page book that cataloged specimens of spider wasps — where they were collected; where they were stored — of the western Palearctic said “1948-2008” on the cover. I asked my guide, a society member named Martin Sorg, who was one of the lead authors of the paper, whether those dates reflected when the specimens were collected. “No,” Sorg replied, “that was the time the author needed for this work.”

Sorg, who rolls his own cigarettes and wears John Lennon glasses and whose gray hair grows long past his shoulders, is not a freewheeling type when it comes to his insect work. And his insect work is really all he wants to talk about. “We think details about nature and biodiversity declines are important, not details about life histories of entomologists,” Sorg explained after he and Werner Stenmans, a society member whose name appeared alongside Sorg’s on the 2017 paper, dismissed my questions about their day jobs. Leery of an article that focused on him as a person, Sorg also didn’t want to talk about what drew him to entomology as a child or even what it was about certain types of wasps that had made him want to devote so much of his life to studying them. “We normally give life histories when someone is dead,” he said.

There was a reason for the wariness. Society members dislike seeing themselves described, over and over in news stories, as “amateurs.” It’s a framing that reflects, they believe, a too-narrow understanding of what it means to be an expert or even a scientist — what it means to be a student of the natural world.

Amateurs have long provided much of the patchy knowledge we have about nature. Those bee and butterfly studies? Most depend on mass mobilizations of volunteers willing to walk transects and count insects, every two weeks or every year, year after year. The scary numbers about bird declines were gathered this way, too, though because birds can be hard to spot, volunteers often must learn to identify them by their sounds. Britain, which has a particularly strong tradition of amateur naturalism, has the best-studied bugs in the world. As technologically advanced as we are, the natural world is still a very big and complex place, and the best way to learn what’s going on is for a lot of people to spend a lot of time observing it. The Latin root of the word “amateur” is, after all, the word “lover.”

Some of these citizen-scientists are true beginners clutching field guides; others, driven by their own passion and following in a long tradition of “amateur” naturalism, are far from novices. Think of Victorians with their butterfly nets and curiosity cabinets; of Vladimir Nabokov, whose theories about the evolution of Polyommatus blue butterflies were ignored until proved correct by DNA testing more than 30 years after his death; of young Charles Darwin, cutting his classes at Cambridge to collect beetles at Wicken Fen and once putting a live beetle in his mouth because his hands were already full of other bugs.

The Krefeld society is volunteer-run, and many members have other jobs in unrelated fields, but they also have an enormous depth of knowledge about insects, accumulated through years of what other people might consider obsessive attention. Some study the ecology or evolutionary taxonomy of their favorite species or map their populations or breed them to study their life histories. All hone their identification skills across species by amassing their own collections of carefully pinned and labeled insects like those that fill the society's storage rooms. Sorg estimated that of the society's 63 members, a third are university-trained in subjects such as biology or earth science. Another third, he said, are "highly specialized and highly qualified but they never visited the university," while the remaining third are actual amateurs who are still in the process of becoming "real" entomologists: "Some of them may also have a degree from the university, but in our view, they are beginners."

The society members' projects often involved setting up what are called malaise traps, nets that look like tents and drive insects flying by into bottles of ethanol. Because of the scientific standards of the society, members followed certain procedures: They always employed identical traps, sewn from a template they first used in 1982. (Sorg showed me the original rolled-up craft paper with great solemnity.) They always put them in the same places. (Before GPS, that meant a painstaking process of triangulating with surveying equipment. "We are not sure about a few centimeters," Sorg granted.) They saved everything they caught, regardless of what the main purpose of the experiment was. (The society bought so much ethanol that it attracted the attention of a narcotics unit.)

Those bottles of insects were gathered into thousands of boxes, which are now crammed into what were once offices in the upper reaches of the school. When the society members, like entomologists elsewhere, began to notice that they were seeing fewer insects, they had something against which to measure their worries.

"We don't throw away anything, we store everything," Sorg explained. "That gives us today the possibility to go back in time."

In 2013, Krefeld entomologists confirmed that the total number of insects caught in one nature reserve was nearly 80 percent lower than the same spot in 1989. They had sampled other sites, analyzed old data sets and found similar declines: Where 30 years earlier, they often needed a liter bottle for a week of trapping, now a half-liter bottle usually sufficed. But it would have taken even highly trained entomologists years of painstaking work to identify all the insects in the bottles. So the society used a standardized method for weighing insects in alcohol, which told a powerful story simply by showing how much the overall mass of insects dropped over time. "A decline of this mixture," Sorg said, "is a very different thing than the decline of only a few species."

The society collaborated with de Kroon and other scientists at Radboud University in the Netherlands, who did a trend analysis of the data that Krefeld provided, controlling for things like the effects of nearby plants, weather and forest cover on fluctuations in insect populations. The final study looked at 63 nature preserves, representing almost 17,000 sampling days, and found consistent declines in every kind of habitat they sampled. This suggested, the authors wrote, “that it is not only the vulnerable species but the flying-insect community as a whole that has been decimated over the last few decades.”

For some scientists, the study created a moment of reckoning. “Scientists thought this data was too boring,” Dunn says. “But these people found it beautiful, and they loved it. They were the ones paying attention to Earth for all the rest of us.”

The current worldwide loss of biodiversity is popularly known as the sixth extinction: the sixth time in world history that a large number of species have disappeared in unusually rapid succession, caused this time not by asteroids or ice ages but by humans. When we think about losing biodiversity, we tend to think of the last northern white rhinos protected by armed guards, of polar bears on dwindling ice floes. Extinction is a visceral tragedy, universally understood: There is no coming back from it. The guilt of letting a unique species vanish is eternal.

But extinction is not the only tragedy through which we’re living. What about the species that still exist, but as a shadow of what they once were? In “The Once and Future World,” the journalist J.B. MacKinnon cites records from recent centuries that hint at what has only just been lost: “In the North Atlantic, a school of cod stalls a tall ship in midocean; off Sydney, Australia, a ship’s captain sails from noon until sunset through pods of sperm whales as far as the eye can see. … Pacific pioneers complain to the authorities that splashing salmon threaten to swamp their canoes.” There were reports of lions in the south of France, walruses at the mouth of the Thames, flocks of birds that took three days to fly overhead, as many as 100 blue whales in the Southern Ocean for every one that’s there now. “These are not sights from some ancient age of fire and ice,” MacKinnon writes. “We are talking about things seen by human eyes, recalled in human memory.”

What we’re losing is not just the *diversity* part of biodiversity, but the *bio* part: life in sheer quantity. While I was writing this article, scientists learned that the world’s largest king penguin colony shrank by 88 percent in 35 years, that more than 97 percent of the bluefin tuna that once lived in the ocean are gone. The number of Sophie the Giraffe toys sold in France in a single year is nine times the number of all the giraffes that still live in Africa.

Finding reassurance in the survival of a few symbolic standard-bearers ignores the value of abundance, of a natural world that thrives on richness and complexity and interaction. Tigers still exist, for example, but that doesn’t change the fact that 93 percent of the land where they used to live is now tigerless. This matters for more than romantic reasons: Large animals, especially top predators like tigers, connect ecosystems to one another and move energy and resources among them simply by walking and eating and defecating and dying. (In the deep ocean, sunken whale carcasses form the basis of entire ecosystems in nutrient-poor places.) One result of their loss is what's known as trophic cascade, the unraveling of an ecosystem's fabric as prey populations boom and crash and the various levels of the food web no longer keep each other in check. These places are emptier, impoverished in a thousand subtle ways.

Scientists have begun to speak of functional extinction (as opposed to the more familiar kind, numerical extinction). Functionally extinct animals and plants are still present but no longer prevalent enough to affect how an ecosystem works. Some phrase this as the extinction not of a species but of all its former interactions with its environment — an extinction of seed dispersal and predation and pollination and all the other ecological functions an animal once had, which can be devastating even if some individuals still persist. The more interactions are lost, the more disordered the ecosystem becomes. A 2013 paper in Nature, which modeled both natural and computer-generated food webs, suggested that a loss of even 30 percent of a species' abundance can be so destabilizing that other species start going fully, numerically extinct — in fact, 80 percent of the time it was a secondarily affected creature that was the first to disappear. A famous real-world example of this type of cascade concerns sea otters. When they were nearly wiped out in the northern Pacific, their prey, sea urchins, ballooned in number and decimated kelp forests, turning a rich environment into a barren one and also possibly contributing to numerical extinctions, notably of the Steller's sea cow.

Conservationists tend to focus on rare and endangered species, but it is common ones, because of their abundance, that power the living systems of our planet. Most species are not common, but within many animal groups most individuals — some 80 percent of them — belong to common species. Like the slow approach of twilight, their declines can be hard to see. White-rumped vultures were nearly gone from India before there was widespread awareness of their disappearance. Describing this phenomenon in the journal BioScience, Kevin Gaston, a professor of biodiversity and conservation at the University of Exeter, wrote: "Humans seem innately better able to detect the complete loss of an environmental feature than its progressive change."

In addition to extinction (the complete loss of a species) and extirpation (a localized extinction), scientists now speak of defaunation: the loss of individuals, the loss of abundance, the loss of a place's absolute animalness. In a 2014 article in Science, researchers argued that the word should become as familiar, and influential, as the concept of deforestation. In 2017 another paper reported that major population and range losses extended even to species considered to be at low risk for extinction. They predicted "negative cascading consequences on ecosystem functioning and services vital to sustaining civilization" and the authors offered another term for the widespread loss of the world's wild fauna: "biological annihilation."

It is estimated that, since 1970, Earth's various populations of wild land animals have lost, on average, 60 percent of their members. Zeroing in on the category we most relate to, mammals, scientists believe that for every six wild creatures that once ate and burrowed and raised young, only one remains. What we have instead is ourselves. A study published this year in the Proceedings of the National Academy of Sciences found that if you look at the world's mammals by weight, 96 percent of that biomass is humans and livestock; just 4 percent is wild animals.

We've begun to talk about living in the Anthropocene, a world shaped by humans. But E.O. Wilson, the naturalist and prophet of environmental degradation, has suggested another name: the Eremocine, the age of loneliness.

Wilson began his career as a taxonomic entomologist, studying ants. Insects — about as far as you can get from charismatic megafauna — are not what we're usually imagining when we talk about biodiversity. Yet they are, in Wilson's words, "the little things that run the natural world." He means it literally. Insects are a case study in the invisible importance of the common.

Scientists have tried to calculate the benefits that insects provide simply by going about their business in large numbers. Trillions of bugs flitting from flower to flower pollinate some three-quarters of our food crops, a service worth as much as $500 billion every year. (This doesn't count the 80 percent of wild flowering plants, the foundation blocks of life everywhere, that rely on insects for pollination.) If monetary calculations like that sound strange, consider the Maoxian Valley in China, where shortages of insect pollinators have led farmers to hire human workers, at a cost of up to $19 per worker per day, to replace bees. Each person covers five to 10 trees a day, pollinating apple blossoms by hand.

By eating and being eaten, insects turn plants into protein and power the growth of all the uncountable species — including freshwater fish and a majority of birds — that rely on them for food, not to mention all the creatures that eat those creatures. We worry about saving the grizzly bear, says the insect ecologist Scott Hoffman Black, but where is the grizzly without the bee that pollinates the berries it eats or the flies that sustain baby salmon? Where, for that matter, are we?

Bugs are vital to the decomposition that keeps nutrients cycling, soil healthy, plants growing and ecosystems running. This role is mostly invisible, until suddenly it's not. After introducing cattle to Australia at the turn of the 19th century, settlers soon found themselves overwhelmed by the problem of their feces: For some reason, cow pies there were taking months or even years to decompose. Cows refused to eat near the stink, requiring more and more land for grazing, and so many flies bred in the piles that the country became famous for the funny hats that stockmen wore to keep them at bay. It wasn't until 1951 that a visiting entomologist realized what was wrong: The local insects, evolved to eat the more fibrous waste of marsupials, couldn't handle cow excrement. For the next 25 years, the importation, quarantine and release of dozens of species of dung beetles became a national priority. And that was just one unfilled niche. (In the United States, dung beetles save ranchers an estimated $380 million a year.) We simply don't know everything that insects do. Only about 2 percent of invertebrate species have been studied enough for us to estimate whether they are in danger of extinction, never mind what dangers that extinction might pose.

When asked to imagine what would happen if insects were to disappear completely, scientists find words like chaos, collapse, Armageddon. Wagner, the University of Connecticut entomologist, describes a flowerless world with silent forests, a world of dung and old leaves and rotting carcasses accumulating in cities and roadsides, a world of "collapse or decay and erosion and loss that would spread through ecosystems" — spiraling from predators to plants. E.O. Wilson has written of an insect-free world, a place where most plants and land animals become extinct; where fungi explodes, for a while, thriving on death and rot; and where "the human species survives, able to fall back on wind-pollinated grains and marine fishing" despite mass starvation and resource wars. "Clinging to survival in a devastated world, and trapped in an ecological dark age," he adds, "the survivors would offer prayers for the return of weeds and bugs."

But the crux of the windshield phenomenon, the reason that the creeping suspicion of change is so *creepy*, is that insects wouldn't have to disappear altogether for us to find ourselves missing them for reasons far beyond nostalgia. In October, an entomologist sent me an email with the subject line, "Holy [expletive]!" and an attachment: a study just out from Proceedings of the National Academy of Sciences that he labeled, "Krefeld comes to Puerto Rico." The study included data from the 1970s and from the early 2010s, when a tropical ecologist named Brad Lister returned to the rain forest where he had studied lizards — and, crucially, their prey — 40 years earlier. Lister set out sticky traps and swept nets across foliage in the same places he had in the 1970s, but this time he and his co-author, Andres Garcia, caught much, much less: 10 to 60 times less arthropod biomass than before. (It's easy to read that number as 60 percent less, but it's sixtyfold less: Where once he caught 473 milligrams of bugs, Lister was now catching just eight milligrams.) "It was, you know, devastating," Lister told me. But even scarier were the ways the losses were already moving through the ecosystem, with serious declines in the numbers of lizards, birds and frogs. The paper reported "a bottom-up trophic cascade and consequent collapse of the forest food web." Lister's inbox quickly filled with messages from other scientists, especially people who study soil invertebrates, telling him they were seeing similarly frightening declines. Even after his dire findings, Lister found the losses shocking: "I didn't even know about the earthworm crisis!"

The strange thing, Lister said, is that, as staggering as they are, all the declines he documented would still be basically invisible to the average person walking through the Luquillo rain forest. On his last visit, the forest still felt "timeless" and "phantasmagorical," with "cascading waterfalls and carpets of flowers." You would have to be an expert to notice what was missing. But he expects the losses to push the forest toward a tipping point, after which "there is a sudden and dramatic loss of the rain-forest system," and the changes will become obvious to anyone. The place he loves will become unrecognizable.

The insects in the forest that Lister studied haven't been contending with pesticides or habitat loss, the two problems to which the Krefeld paper pointed. Instead, Lister chalks up their decline to climate change, which has already increased temperatures in Luquillo by two degrees Celsius since Lister first sampled there. Previous research suggested that tropical bugs will be unusually sensitive to temperature changes; in November, scientists who subjected laboratory beetles to a heat wave reported that the increased temperatures made them significantly less fertile. Other scientists wonder if it might be climate-induced drought or possibly invasive rats or simply "death by a thousand cuts" — a confluence of many kinds of changes to the places where insects once thrived.

Like other species, insects are responding to what Chris Thomas, an insect ecologist at the University of York, has called "the transformation of the world": not just a changing climate but also the widespread conversion, via urbanization, agricultural intensification and so on, of natural spaces into human ones, with fewer and fewer resources "left over" for nonhuman creatures to live on. What resources remain are often contaminated. Hans de Kroon characterizes the life of many modern insects as trying to survive from one dwindling oasis to the next but with "a desert in between, and at worst it's a poisonous desert." Of particular concern are neonicotinoids, neurotoxins that were thought to affect only treated crops but turned out to accumulate in the landscape and to be consumed by all kinds of nontargeted bugs. People talk about the "loss" of bees to colony collapse disorder, and that appears to be the right word: Affected hives aren't full of dead bees, but simply mysteriously empty. A leading theory is that exposure to neurotoxins leaves bees unable to find their way home. Even hives exposed to low levels of neonicotinoids have been shown to collect less pollen and produce fewer eggs and far fewer queens. Some recent studies found bees doing better in cities than in the supposed countryside.

The diversity of insects means that some will manage to make do in new environments, some will thrive (abundance cuts both ways: agricultural monocultures, places where only one kind of plant grows, allow some pests to reach population levels they would never achieve in nature) and some, searching for food and shelter in a world nothing like the one they were meant for, will fail. While we need much more data to better understand the reasons or mechanisms behind the ups and downs, Thomas says, "the average across all species is still a decline."

Since the Krefeld study came out, researchers have begun searching for other forgotten repositories of information that might offer windows into the past. Some of the Radboud researchers have analyzed long-term data, belonging to Dutch entomological societies, about beetles and moths in certain reserves; they found significant drops (72 percent, 54 percent) that mirrored the Krefeld ones. Roel van Klink, a researcher at the German Center for Integrative Biodiversity Research, told me that before Krefeld, he, like most entomologists, had never been interested in biomass. Now he is looking for historical data sets — many of which began as studies of agricultural pests, like a decades-long study of grasshoppers in Kansas — that could help create a more thorough picture of what's happening to creatures that are at once abundant and imperiled. So far he has found forgotten data from 140 old data sets for 1,500 locations that could be resampled.

In the United States, one of the few long-term data sets about insect abundance comes from the work of Arthur Shapiro, an entomologist at the University of California, Davis. In 1972, he began walking transects in the Central Valley and the Sierras, counting butterflies. He planned to do a study on how short-term weather variations affected butterfly populations. But the longer he sampled, the more valuable his data became, offering a signal through the noise of seasonal ups and downs. “And so here I am in Year 46,” he said, nearly half a century of spending five days a week, from late spring to the end of autumn, observing butterflies. In that time he has watched overall numbers decline and seen some species that used to be everywhere — even species that “everyone regarded as a junk species” only a few decades ago — all but disappear. Shapiro believes that Krefeld-level declines are likely to be happening all over the globe. “But, of course, I don’t cover the entire globe,” he added. “I cover I-80.”

There are also new efforts to set up more of the kind of insect-monitoring schemes researchers wish had existed decades ago, so that our current level of fallenness, at least, is captured. One is a pilot project in Germany similar to the Danish car study. To analyze what is caught, the researchers turned to volunteer naturalists, hobbyists similar to the ones in Krefeld, with the necessary breadth of knowledge to know what they’re looking at. “These are not easy species to identify,” says Aletta Bonn, of the German Center for Integrative Biodiversity Research, who is overseeing the project. (The skills required for such work “are really extreme,” Dunn says. “These people train for decades with other amateurs to be able to identify beetles based on their genitalia.”) Bond would like to pay the volunteers for their expertise, she says, but funding hasn’t caught up to the crisis. That didn’t stop the “amateurs” from being willing to help: “They said, ‘We’re just curious what’s in there, we would like to have samples.’ ”

Goulson says that Europe’s tradition of amateur naturalism may account for why so many of the clues to the falloff in insect biodiversity originate there. (Tottrup’s design for the car net in Denmark, for example, was itself adapted from the invention of a dedicated beetle-collecting hobbyist.) As little as we know about the status of European bugs, we know significantly less about other parts of the world. “We wouldn’t know anything if it weren’t for them,” the so-called amateurs, Goulson told me. “We’d be entirely relying on the fact that there’s no bugs on the windshield.”

Thomas believes that this naturalist tradition is also why Europe is acting much faster than other places — for example, the United States — to address the decline of insects: Interest leads to tracking, which leads to awareness, which leads to concern, which leads to action. Since the Krefeld data emerged, there have been hearings about protecting insect biodiversity in the German Bundestag and the European Parliament. European Union member states voted to extend a ban on neonicotinoid pesticides and have begun to put money toward further studies of how abundance is changing, what is causing those changes and what can be done. When I knocked on the door of de Kroon’s office, at Radboud University in the Dutch city Nijmegen, he was looking at some photos from another meeting he had that day: Willem-Alexander, the king of the Netherlands, had taken a tour of the city's efforts to make its riverside a friendlier habitat for bugs.

Stemming insect declines will require much more than this, however. The European Union already had some measures in place to help pollinators — including more strictly regulating pesticides than the United States does and paying farmers to create insect habitats by leaving fields fallow and allowing for wild edges alongside cultivation — but insect populations dropped anyway. New reports call for national governments to collaborate; for more creative approaches such as integrating insect habitats into the design of roads, power lines, railroads and other infrastructure; and, as always, for more studies. The necessary changes, like the causes, may be profound. "It's just another indication that we're destroying the life-support system of the planet," Lister says of the Puerto Rico study. "Nature's resilient, but we're pushing her to such extremes that eventually it will cause a collapse of the system."

Scientists hope that insects will have a chance to embody that resilience. While tigers tend to give birth to three or four cubs at a time, a ghost moth in Australia was once recorded laying 29,100 eggs, and she still had 15,000 in her ovaries. The fecund abundance that is insects' singular trait should enable them to recover, but only if they are given the space and the opportunity to do so.

"It's a debate we need to have urgently," Goulson says. "If we lose insects, life on earth will. ..." He trailed off, pausing for what felt like a long time.

In Denmark, Sune Boye Riis's transect with his car net took him past a bit of woods, some suburban lawns, some hedges, a Christmas-tree farm. The closest thing to a meadow that we passed was a large military property, on which the grass had been allowed to grow tall and golden. Riis had received instructions not to drive too fast, so traffic backed up behind us, and some people began to honk. "Well," Riis said, "so much for science." After three miles, he turned around and drove back toward the start. His windshield stayed mockingly clean.

Riis had four friends who were also participating in the study. They had a bet going among them: Who would net the biggest bug? "I'm way behind," Riis said. "A bumblebee is in the lead." His biggest catch? "A fly. Not even a big one."

At the end of the transect, Riis stopped at another parlous roadside spot, unfastened the net and removed the small bag at its tip. Some volunteers, captivated by what the study revealed about the world around them, asked the organizers for extra specimen bags, so they could do more sampling on their own. Some even asked if they could buy the entire car-net apparatus. Riis, though, was content to peer through the mesh, inside of which he could make out a number of black specks of varying tininess.

There was also a single butterfly, white-winged and delicate. Riis thought of the bet with his friends, for which the meaning of bigness had not been defined. He wondered how it might be reckoned. What gave a creature value?

"Is it weight?" he asked, staring down at the butterfly. In the big bag, it looked small and sad and alone. "Or is it grace?"