
FACT: Content
THE SIXTH EXTINCTION? A Reporter at Large

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The town of El Valle de Anton, in central Panama, sits in the middle of a volcanic crater formed about a million years ago. The crater is almost four miles across, but when the weather is clear you can see the jagged hills that surround the town, like the walls of a ruined tower. El Valle has one main street, a police station, and an open-air market that offers, in addition to the usual hats and embroidery, what must be the world's largest selection of golden-frog figurines. There are golden frogs sitting on leaves and--more difficult to understand--golden frogs holding cell phones. There are golden frogs wearing frilly skirts, and golden frogs striking dance poses, and ashtrays featuring golden frogs smoking cigarettes through a holder, after the fashion of F.D.R. The golden frog, which is bright yellow with dark-brown splotches, is endemic to the area around El Valle.

It is considered a lucky symbol in Panama--its image is often printed on lottery tickets--though it could just as easily serve as an emblem of disaster.

In the early nineteen-nineties, an American graduate student named Karen Lips established a research site about two hundred miles west of El Valle, in the Talamanca Mountains, just over the border in Costa Rica. Lips was planning to study the local frogs, some of which, she later discovered, had never been identified. In order to get to the site, she had to drive two hours from the nearest town--the last part of the trip required tire chains--and then hike for an hour through the rain forest.

Lips spent two years living in the mountains. "It was a wonderland," she recalled recently. Once she had collected enough data, she left to work on her dissertation. She returned a few months later, and though nothing seemed to have changed, she could hardly find any frogs. Lips couldn't figure out what was happening. She collected all the dead frogs that she came across--there were only a half dozen or so--and sent their bodies to a veterinary pathologist in the United States. The pathologist was also baffled: the specimens, she told Lips, showed no signs of any known disease.

A few years went by. Lips finished her dissertation and got a teaching job. Since the frogs at her old site had pretty much disappeared, she decided that she needed to find a new location to do research. She picked another isolated spot in the rain forest, this time in western Panama. Initially, the frogs there seemed healthy. But, before long, Lips began to find corpses lying in the streams and moribund animals sitting on the banks. Sometimes she would pick up a frog and it would die in her hands. She sent some specimens to a second pathologist in the U.S., and, once again, the pathologist had no idea what was wrong.

Whatever was killing Lips's frogs continued to move, like a wave, east across Panama. By 2002, most frogs in the streams around Santa Fe, a town in the province of Veraguas, had been wiped out. By 2004, the frogs in the national park of El Cope, in the province of Coclé, had all but disappeared. At that point, golden frogs were still relatively common around El Valle; a creek not far from the town was nicknamed Thousand Frog Stream. Then, in 2006, the wave hit.

Of the many species that have existed on earth--estimates run as high as fifty billion--more than ninety-nine per cent have disappeared. In the light of this, it is sometimes joked that all of life today amounts to little more than a rounding error.

Records of the missing can be found everywhere in the world, often in forms that are difficult to overlook. And yet extinction has been a much contested concept. Throughout the eighteenth century, even as extraordinary fossils were being unearthed and put on exhibit, the prevailing view was that species were fixed, created by God for all eternity. If the bones of a strange creature were found, it must mean that that creature was out there somewhere.

"Such is the economy of nature," Thomas Jefferson wrote, "that no instance can be produced, of her having permitted any one race of her animals to become extinct; of her having formed any link in her great work so weak as to be broken." When, as President, he dispatched Meriwether Lewis and William Clark to the Northwest, Jefferson hoped that they would come upon live mastodons roaming the region.

The French naturalist Georges Cuvier was more skeptical. In 1812, he published an essay on the "Revolutions on the Surface of the Globe," in which he asked, "How can we believe that the immense mastodons, the gigantic megatheriums, whose bones have been found in the earth in the two Americas, still live on this continent?" Cuvier had conducted studies of the fossils found in gypsum mines in Paris, and was convinced that many organisms once common to the area no longer existed. These he referred to as *especies perdues*, or lost species. Cuvier had no way of knowing how much time had elapsed in forming the fossil record. But, as the record indicated that Paris had, at various points, been under water, he concluded that the *especies perdues* had been swept away by sudden cataclysms.

"Life on this earth has often been disturbed by dreadful events," he wrote. "Innumerable living creatures have been victims of these catastrophes." Cuvier's essay was translated into English in 1813 and published with an introduction by the Scottish naturalist Robert Jameson, who interpreted it as proof of Noah's flood. It went through five editions in English and six in French before Cuvier's death, in 1832.

Charles Darwin was well acquainted with Cuvier's ideas and the theological spin they had been given. (He had studied natural history with Jameson at the University of Edinburgh.) In his theory of natural selection, Darwin embraced extinction; it was, he realized, essential that some species should die out as new ones were created. But he believed that this happened only slowly. Indeed, he claimed that it took place more gradually even than speciation: "The complete extinction of the species of a group is generally a slower process than their production." In "On the Origin of Species," published in the fall of 1859, Darwin heaped scorn on the catastrophist approach:

So profound is our ignorance, and so high our presumption, that we marvel when we hear of the extinction of an organic being; and as we do not see the cause, we invoke cataclysms to desolate the world.

By the start of the twentieth century, this view had become dominant, and to be a scientist meant to see extinction as Darwin did. But Darwin, it turns out, was wrong.

Over the past half-billion years, there have been at least twenty mass extinctions, when the diversity of life on earth has suddenly and dramatically contracted. Five of these--the so-called Big Five--were so devastating that they are usually put in their own category. The first took place during the late Ordovician period, nearly four hundred and fifty million years ago, when life was still confined mainly to water. Geological records indicate that more than eighty per cent of marine species died out. The fifth occurred at the end of the Cretaceous period, sixty-five million years ago. The end-Cretaceous event exterminated not just the dinosaurs but seventy-five per cent of all species on earth.

The significance of mass extinctions goes beyond the sheer number of organisms involved. In contrast to ordinary, or so-called background, extinctions, which claim species that, for one reason or another, have become unfit, mass extinctions strike down the fit and the unfit at once. For example, brachiopods, which look like clams but have an entirely different anatomy, dominated the ocean floor for hundreds of millions of years. In the third of the Big Five extinctions--the end-Permian--the hugely successful brachiopods were nearly wiped out, along with trilobites, blastoids, and eurypterids. (In the end-Permian event, more than ninety per cent of marine species and seventy per cent of terrestrial species vanished; the event is sometimes referred to as "the mother of mass extinctions" or "the great dying.")

Once a mass extinction occurs, it takes millions of years for life to recover, and when it does it generally has a new cast of characters; following the end-Cretaceous event, mammals rose up (or crept out) to replace the departed dinosaurs. In this way, mass extinctions, though missing from the original theory of evolution, have played a determining role in evolution's course; as Richard Leakey has put it, such events "restructure the biosphere" and so "create the pattern of life." It is now generally agreed among biologists that another mass extinction is under way. Though it's difficult to put a precise figure on the losses, it is estimated that, if current trends continue, by the end of this century as many as half of earth's species will be gone.

The El Valle Amphibian Conservation Center, known by the acronym EVACC (pronounced "e-vac"), is a short walk from the market where the golden-frog figurines are sold. It consists of a single building about the size of an average suburban house. The place is filled, floor to ceiling, with tanks. There are tall tanks for species that, like the Rabb's fringe-limbed tree frog, live in the forest canopy, and short tanks for species that, like the big-headed robber frog, live on the forest floor. Tanks of horned marsupial frogs, which carry their eggs in a pouch, sit next to tanks of casque-headed frogs, which carry their eggs on their backs.

The director of EVACC is a herpetologist named Edgardo Griffith. Griffith is tall and broad-shouldered, with a round face and a wide smile. He wears a silver ring in each ear and has a large tattoo of a toad's skeleton on his left shin. Griffith grew up in Panama City, and fell in love with amphibians one day in college when a

friend invited him to go frog hunting. He collected most of the frogs at EVACC--there are nearly six hundred--in a rush, just as corpses were beginning to show up around El Valle. At that point, the center was little more than a hole in the ground, and so the frogs had to spend several months in temporary tanks at a local hotel. "We got a very good rate," Griffith assured me. While the amphibians were living in rented rooms, Griffith and his wife, a former Peace Corps volunteer, would go out into a nearby field to catch crickets for their dinner. Now EVACC raises bugs for the frogs in what looks like an oversized rabbit hutch.

EVACC is financed largely by the Houston Zoo, which initially pledged twenty thousand dollars to the project and has ended up spending ten times that amount. The tiny center, though, is not an outpost of the zoo. It might be thought of as a preserve, except that, instead of protecting the amphibians in their natural habitat, the center's aim is to isolate them from it. In this way, EVACC represents an ark built for a modern-day deluge. Its goal is to maintain twenty-five males and twenty-five females of each species--just enough for a breeding population.

The first time I visited, Griffith pointed out various tanks containing frogs that have essentially disappeared from the wild. These include the Panamanian golden frog, which, in addition to its extraordinary coloring, is known for its unusual method of communication; the frogs signal to one another using a kind of semaphore. Griffith said that he expected between a third and a half of all Panama's amphibians to be gone within the next five years. Some species, he said, will probably vanish without anyone's realizing it: "Unfortunately, we are losing all these amphibians before we even know that they exist."

Griffith still goes out collecting for EVACC. Since there are hardly any frogs to be found around El Valle, he has to travel farther afield, across the Panama Canal, to the eastern half of the country.

One day this winter, I set out with him on one of his expeditions, along with two American zookeepers who were also visiting EVACC. The four of us spent a night in a town called Cerro Azul and, at dawn the next morning, drove in a truck to the ranger station at the entrance to Chagres National Park. Griffith was hoping to find females of two species that EVACC is short of. He pulled out his collecting permit and presented it to the sleepy officials manning the station. Some underfed dogs came out to sniff around.

Beyond the ranger station, the road turned into a series of craters connected by ruts. Griffith put Jimi Hendrix on the truck's CD player, and we bounced along to the throbbing beat. (When the driving got particularly gruesome, he would turn down the volume.) Frog collecting requires a lot of supplies, so Griffith had hired two men to help with the carrying. At the very last cluster of houses, in the village of Los Angeles, they materialized out of the mist. We bounced on until the truck couldn't go any farther; then we all got out and started walking.

The trail wound its way through the rain forest in a slather of red mud. Every few hundred yards, the main path was crossed by a narrower one; these paths had been made by leaf-cutter ants, making millions--perhaps billions--of trips to bring bits of greenery back to their colonies. (The colonies, which look like mounds of sawdust, can cover an area the size of a suburban back yard.) One of the Americans, Chris Bednarski, from the Houston Zoo, warned me to avoid the soldier ants, which will leave their jaws in your shin even after they're dead. "Those'll really mess you up," he observed. The other American, John Chastain, from the Toledo Zoo, was carrying a long hook, for use against venomous snakes. "Fortunately, the ones that can really mess you up are pretty rare," Bednarski said. Howler monkeys screamed in the distance. Someone pointed out jaguar prints in the soft ground.

After about five hours, we emerged into a small clearing. While we were setting up camp, a blue morpho butterfly flitted by, its wings the color of the sky.

That evening, after the sun set, we strapped on headlamps and clambered down to a nearby stream. Many amphibians are nocturnal, and the only way to see them is to go looking in the dark, an exercise that's as tricky as it sounds. I kept slipping, and violating Rule No. 1 of rain-forest safety: never grab onto something if you don't know what it is. After one of my falls, Bednarski showed me a tarantula the size of my fist that he had found on a nearby tree.

One technique for finding amphibians at night is to shine a light into the forest and look for the reflecting glow of their eyes. The first amphibian sighted this way was a San Jose Cochran frog, perched on top of a leaf. San Jose Cochran frogs are part of a larger family known as "glass frogs," so named because their translucent skin reveals the outline of their internal organs. This particular glass frog was green, with tiny yellow dots. Griffith pulled a pair of surgical gloves out of his pack. He stood entirely still and then, with a heronlike gesture, darted to scoop up the frog. With his free hand, he took what looked like the end of a Q-tip and swabbed the frog's belly. Finally, he put the Q-tip in a little plastic vial, placed the frog back on the leaf, and pulled out his camera. The frog stared into the lens impassively.

We continued to grope through the blackness. Someone spotted a La Loma robber frog, which is an orangey-red, like the forest floor; someone else spotted a Warzewitsch frog, which is bright green and shaped like a leaf. With every frog, Griffith went through the same routine--snatching it up, swabbing its

belly, photographing it. Finally, we came upon a pair of Panamanian robber frogs locked in amplexus--the amphibian version of sex. Griffith left these two alone.

One of the frogs that Griffith was hoping to catch, the horned marsupial frog, has a distinctive call that's been likened to the sound of a champagne bottle being uncorked. As we sloshed along, the call seemed to be emanating from several directions at once. Sometimes it sounded as if it were right nearby, but then, as we approached, it would fall silent. Griffith began imitating the call, making a cork-popping sound with his lips. Eventually, he decided that the rest of us were scaring the frogs with our splashing. He waded ahead, while we stood in the middle of the stream, trying not to move. When Griffith gestured us over, we found him standing in front of a large yellow frog with long toes and an owlish face. It was sitting on a tree limb, just above eye level. Griffith grabbed the frog and turned it over. Where a female marsupial frog would have a pouch, this one had none. Griffith swabbed it, photographed it, and put it back in the tree.

"You are a beautiful boy," he told the frog.

Amphibians are among the planet's great survivors. The ancestors of today's frogs and toads crawled out of the water some four hundred million years ago, and by two hundred and fifty million years ago the earliest representatives of what became the modern amphibian clades--one includes frogs and toads, a second newts and salamanders--had evolved. This means that amphibians have been around not just longer than mammals, say, or birds; they have been around since before there were dinosaurs. Most amphibians--the word comes from the Greek meaning "double life"--are still closely tied to the aquatic realm from which they emerged. (The ancient Egyptians thought that frogs were produced by the coupling of land and water during the annual flooding of the Nile.) Their eggs, which have no shells, must be kept moist in order to develop. There are frogs that lay their eggs in streams, frogs that lay them in temporary pools, frogs that lay them underground, and frogs that lay them in nests that they construct out of foam. In addition to frogs that carry their eggs on their backs and in pouches, there are frogs that carry them in their vocal sacs, and, until recently, at least, there were frogs that carried their eggs in their stomachs and gave birth through their mouths. Amphibians emerged at a time when all the land on earth was part of one large mass; they have since adapted to conditions on every continent except Antarctica. Worldwide, more than six thousand species have been identified, and while the greatest number are found in the tropical rain forests, there are amphibians that, like the sandhill frog of Australia, can live in the desert, and also amphibians that, like the wood frog, can live above the Arctic Circle. Several common North American frogs, including spring peepers, are able to survive the winter frozen solid.

When, about two decades ago, researchers first noticed that something odd was happening to amphibians, the evidence didn't seem to make sense. David Wake is a biologist at the University of California at Berkeley. In the early nineteen-eighties, his students began returning from frog-collecting trips in the Sierra Nevada empty-handed. Wake remembered from his own student days that frogs in the Sierras had been difficult to avoid. "You'd be walking through meadows, and you'd inadvertently step on them," he told me. "They were just everywhere." Wake assumed that his students were going to the wrong spots, or that they just didn't know how to look. Then a postdoc with several years of experience collecting amphibians told him that he couldn't find any, either. "I said, 'O.K., I'll go up with you and we'll go out to some proven places,'" Wake recalled. "And I took him out to this proven place and we found, like, two toads."

Around the same time, other researchers, in other parts of the world, reported similar difficulties. In the late nineteen-eighties, a herpetologist named Marty Crump went to Costa Rica to study golden toads; she was forced to change her project because, from one year to the next, the toad essentially vanished. (The golden toad, now regarded as extinct, was actually orange; it is not to be confused with the Panamanian golden frog, which is technically also a toad.) Probably simultaneously, in central Costa Rica the populations of twenty species of frogs and toads suddenly crashed. In Ecuador, the jambato toad, a familiar visitor to back-yard gardens, disappeared in a matter of years. And in northeastern Australia biologists noticed that more than a dozen amphibian species, including the southern day frog, one of the more common in the region, were experiencing drastic declines.

But, as the number of examples increased, the evidence only seemed to grow more confounding. Though amphibians in some remote and--relatively speaking--pristine spots seemed to be collapsing, those in other, more obviously disturbed habitats seemed to be doing fine. Meanwhile, in many parts of the world there weren't good data on amphibian populations to begin with, so it was hard to determine what represented terminal descent and what might be just a temporary dip.

"It was very controversial to say that amphibians were disappearing," Andrew Blaustein, a zoology professor at Oregon State University, recalls. Blaustein, who was studying the mating behavior of frogs and toads in the Cascade Mountains, had observed that some long-standing populations simply weren't there anymore. "The debate was whether or not there really was an amphibian population problem, because some people were saying it was just natural variation." At the point that Karen Lips went to look for her first research site, she purposefully tried to steer clear of the controversy.

"I didn't want to work on amphibian decline," she told me. "There were endless debates about whether this was a function of randomness or a true pattern. And the last thing you want to do is get involved when you

don't know what's going on."

But the debate was not to be avoided. Even amphibians that had never seen a pond or a forest started dying. Blue poison-dart frogs, which are native to Suriname, had been raised at the National Zoo, in Washington, D.C., for several generations. Then, suddenly, the zoo's tank-bred frogs were nearly wiped out.

It is difficult to say when, exactly, the current extinction event--sometimes called the sixth extinction--began. What might be thought of as its opening phase appears to have started about fifty thousand years ago. At that time, Australia was home to a fantastic assortment of enormous animals; these included a wombatlike creature the size of a hippo, a land tortoise nearly as big as a VW Beetle, and the giant short-faced kangaroo, which grew to be ten feet tall. Then all of the continent's largest animals disappeared. Every species of marsupial weighing more than two hundred pounds--there were nineteen of them--vanished, as did three species of giant reptiles and a flightless bird with stumpy legs known as *Genyornis newtoni*.

This die-off roughly coincided with the arrival of the first people on the continent, probably from Southeast Asia. Australia is a big place, and there couldn't have been very many early settlers. For a long time, the coincidence was discounted. Yet, thanks to recent work by geologists and paleontologists, a clear global pattern has emerged. About eleven thousand years ago, three-quarters of North America's largest animals--among them mastodons, mammoths, giant beavers, short-faced bears, and sabre-toothed tigers--began to go extinct. This is right around the time the first humans are believed to have wandered onto the continent across the Bering land bridge. In relatively short order, the first humans settled South America as well. Subsequently, more than thirty species of South American "megamammals," including elephant-size ground sloths and rhino-like creatures known as toxodons, died out.

And what goes for Australia and the Americas also goes for many other parts of the world. Humans settled Madagascar around two thousand years ago; the island subsequently lost all mammals weighing more than twenty pounds, including pygmy hippos and giant lemurs. "Substantial losses have occurred throughout near time," Ross MacPhee, a curator at the American Museum of Natural History, in New York, and an expert on extinctions of the recent geological past, has written. "In the majority of cases, these losses occurred when, and only when, people began to expand across areas that had never before experienced their presence." The Maori arrived in New Zealand around eight hundred years ago. They encountered eleven species of moas--huge ostrichlike creatures without wings. Within a few centuries--and possibly within a single century--all eleven moa species were gone. While these "first contact" extinctions were most pronounced among large animals, they were not confined to them. Humans discovered the Hawaiian Islands around fifteen hundred years ago; soon afterward, ninety per cent of Hawaii's native bird species disappeared.

"We expect extinction after people arrive on an island," David Steadman, the curator of ornithology at the Florida Museum of Natural History, has written. "Survival is the exception."

Why was first contact with humans so catastrophic? Some of the animals may have been hunted to death; thousands of moa bones have been found at Maori archeological sites, and man-made artifacts have been uncovered near mammoth and mastodon remains at more than a dozen sites in North America. Hunting, however, seems insufficient to account for so many losses across so many different taxa in so many parts of the globe. A few years ago, researchers analyzed hundreds of bits of emu and *Genyornis newtoni* eggshell, some dating from long before the first people arrived in Australia and some from after. They found that around forty-five thousand years ago, rather abruptly, emus went from eating all sorts of plants to relying mainly on shrubs. The researchers hypothesized that Australia's early settlers periodically set the countryside on fire--perhaps to flush out prey--a practice that would have reduced the variety of plant life. Those animals which, like emus, could cope with a changed landscape survived, while those which, like *Genyornis*, could not died out.

When Australia was first settled, there were maybe half a million people on earth. There are now more than six and a half billion, and it is expected that within the next three years the number will reach seven billion.

Human impacts on the planet have increased proportionately. Farming, logging, and building have transformed between a third and a half of the world's land surface, and even these figures probably understate the effect, since land not being actively exploited may still be fragmented. Most of the world's major waterways have been diverted or dammed or otherwise manipulated--in the United States, only two per cent of rivers run unimpeded--and people now use half the world's readily accessible freshwater runoff. Chemical plants fix more atmospheric nitrogen than all natural terrestrial processes combined, and fisheries remove more than a third of the primary production of the temperate coastal waters of the oceans. Through global trade and international travel, humans have transported countless species into ecosystems that are not prepared for them. We have pumped enough carbon dioxide into the air to alter the climate and to change the chemistry of the oceans.

Amphibians are affected by many--perhaps most--of these disruptions. Habitat destruction is a major factor in their decline, and agricultural chemicals seem to be causing a rash of frog deformities. But the main culprit in the wavelike series of crashes, it's now believed, is a fungus. Ironically, this fungus, which belongs to a group known as chytrids (pronounced "kit-rids"), appears to have been spread by doctors.

Chytrid fungi are older even than amphibians--the first species evolved more than six hundred million years ago--and even more widespread. In a manner of speaking, they can be found--they are microscopic--just about everywhere, from the tops of trees to deep underground. Generally, chytrid fungi feed off dead plants; there are also species that live on algae, species that live on roots, and species that live in the guts of cows, where they help break down cellulose. Until two pathologists, Don Nichols and Allan Pessier, identified a weird microorganism growing on dead frogs from the National Zoo, chytrids had never been known to attack vertebrates. Indeed, the new chytrid was so unusual that an entire genus had to be created to accommodate it. It was named *Batrachochytrium dendrobatidis*--*batrachos* is Greek for "frog"--or Bd for short.

Nichols and Pessier sent samples from the infected frogs to a mycologist at the University of Maine, Joyce Longcore, who managed to culture the Bd fungus. They then exposed healthy blue poison-dart frogs to it. Within three weeks, the animals sickened and died.

The discovery of Bd explained many of the data that had previously seemed so puzzling. Chytrid fungi generate microscopic spores that disperse in water; these could have been carried along by streams, or in the runoff after a rainstorm, producing what in Central America showed up as an eastward-moving scourge. In the case of zoos, the spores could have been brought in on other frogs or on tracked-in soil. Bd seemed to be able to live on just about any frog or toad, but not all amphibians are as susceptible to it, which would account for why some populations succumbed while others appeared to be unaffected.

Rick Speare is an Australian pathologist who identified Bd right around the same time that the National Zoo team did. From the pattern of decline, Speare suspected that Bd had been spread by an amphibian that had been moved around the globe. One of the few species that met this condition was *Xenopus laevis*, commonly known as the African clawed frog. In the early nineteen-thirties, a British zoologist named Lancelot Hogben discovered that female *Xenopus laevis*, when injected with certain types of human hormones, laid eggs. His discovery became the basis for a new kind of pregnancy test and, starting in the late nineteen-thirties, thousands of African clawed frogs were exported out of Cape Town. In the nineteen-forties and fifties, it was not uncommon for obstetricians to keep tanks full of the frogs in their offices.

To test his hypothesis, Speare began collecting samples from live African clawed frogs and also from specimens preserved in museums. He found that specimens dating back to the nineteen-thirties were indeed already carrying the fungus. He also found that live African clawed frogs were widely infected with Bd, but seemed to suffer no ill effects from it. In 2004, he co-authored an influential paper that argued that the transmission route for the fungus began in southern Africa and ran through clinics and hospitals around the world.

"Let's say people were raising African clawed frogs in aquariums, and they just popped the water out," Speare told me. "In most cases when they did that, no frogs got infected, but then, on that hundredth time, one local frog might have been infected. Or people might have said, 'I'm sick of this frog, I'm going to let it go.' And certainly there are populations of African clawed frogs established in a number of countries around the world, to illustrate that that actually did occur."

At this point, Bd appears to be, for all intents and purposes, unstoppable. It can be killed by bleach--Clorox is among the donors to EVACC--but it is impossible to disinfect an entire rain forest. Sometime in the last year or so, the fungus jumped the Panama Canal. (When Edgardo Griffith swabbed the frogs on our trip, he was collecting samples that would eventually be analyzed for it.) It also seems to be heading into Panama from the opposite direction, out of Colombia. It has spread through the highlands of South America, down the eastern coast of Australia, and into New Zealand, and has been detected in Italy, Spain, and France. In the U.S., it appears to have radiated from several points, not so much in a wavelike pattern as in a series of ripples.

In the fossil record, mass extinctions stand out, so sharply that the very language scientists use to describe the earth's history derives from them. In 1840, the British geologist John Phillips divided life into three chapters: the Paleozoic (from the Greek for "ancient life"), the Mesozoic ("middle life"), and the Cenozoic ("new life"). Phillips fixed as the dividing point between the first and second eras what would now be called the end-Permian extinction, and between the second and the third the end-Cretaceous event. The fossils from these eras were so different that Phillips thought they represented three distinct episodes of creation.

Darwin's resistance to catastrophism meant that he couldn't accept what the fossils seemed to be saying. Drawing on the work of the eminent geologist Charles Lyell, a good friend of his, Darwin maintained that the apparent discontinuities in the history of life were really just gaps in the archive. In "On the Origin of Species," he argued:

With respect to the apparently sudden extermination of whole families or orders, as of Trilobites at the close of the palaeozoic period and of Ammonites at the close of the secondary period, we must remember what has been already said on the probable wide intervals of time between our consecutive formations; and in

these intervals there may have been much slow extermination.

All the way into the nineteen-sixties, paleontologists continued to give talks with titles like "The Incompleteness of the Fossil Record." And this view might have persisted even longer had it not been for a remarkable, largely inadvertent discovery made in the following decade.

In the mid-nineteen-seventies, Walter Alvarez, a geologist at the Lamont Doherty Earth Observatory, in New York, was studying the earth's polarity. It had recently been learned that the orientation of the planet's magnetic field reverses, so that every so often, in effect, south becomes north and then vice versa. Alvarez and some colleagues had found that a certain formation of pinkish limestone in Italy, known as the scaglia rossa, recorded these occasional reversals. The limestone also contained the fossilized remains of millions of tiny sea creatures called foraminifera. In the course of several trips to Italy, Alvarez became interested in a thin layer of clay in the limestone that seemed to have been laid down around the end of the Cretaceous. Below the layer, certain species of foraminifera--or forams, for short--were preserved. In the clay layer there were no forams. Above the layer, the earlier species disappeared and new forams appeared. Having been taught the uniformitarian view, Alvarez wasn't sure what to make of what he was seeing, because the change, he later recalled, certainly "looked very abrupt."

Alvarez decided to try to find out how long it had taken for the clay layer to be deposited. In 1977, he took a post at the University of California at Berkeley, where his father, the Nobel Prize-winning physicist Luis Alvarez, was also teaching. The older Alvarez suggested using the element iridium to answer the question.

Iridium is extremely rare on the surface of the earth, but more plentiful in meteorites, which, in the form of microscopic grains of cosmic dust, are constantly raining down on the planet. The Alverezes reasoned that, if the clay layer had taken a significant amount of time to deposit, it would contain detectable levels of iridium, and if it had been deposited in a short time it wouldn't. They enlisted two other scientists, Frank Asaro and Helen Michel, to run the tests, and gave them samples of the clay. Nine months later, they got a phone call. There was something seriously wrong. Much too much iridium was showing up in the samples. Walter Alvarez flew to Denmark to take samples of another layer of exposed clay from the end of the Cretaceous. When they were tested, these samples, too, were way out of line.

The Alvarez hypothesis, as it became known, was that everything--the clay layer from the scaglia rossa, the clay from Denmark, the spike in iridium, the shift in the fossils--could be explained by a single event. In 1980, the Alverezes and their colleagues proposed that a six-mile-wide asteroid had slammed into the earth, killing off not only the forams but the dinosaurs and all the other organisms that went extinct at the end of the Cretaceous. "I can remember working very hard to make that 1980 paper just as solid as it could possibly be," Walter Alvarez recalled recently. Nevertheless, the idea was greeted with incredulity.

"The arrogance of those people is simply unbelievable," one paleontologist told the Times.

"Unseen bolides dropping into an unseen sea are not for me," another declared.

Over the next decade, evidence in favor of an enormous impact kept accumulating. Geologists looking at rocks from the end of the Cretaceous in Montana found tiny mineral grains that seemed to have suffered a violent shock. (Such "shocked quartz" is typically found in the immediate vicinity of meteorite craters.) Other geologists, looking in other parts of the world, found small, glasslike spheres of the sort believed to form when molten-rock droplets splash up into the atmosphere. In 1990, a crater large enough to have been formed by the enormous asteroid that the Alverezes were proposing was found, buried underneath the Yucatan. In 1991, that crater was dated, and discovered to have been formed at precisely the time the dinosaurs died off.

"Those eleven years seemed long at the time, but looking back they seem very brief," Walter Alvarez told me. "Just think about it for a moment. Here you have a challenge to a uniformitarian viewpoint that basically every geologist and paleontologist had been trained in, as had their professors and their professors' professors, all the way back to Lyell. And what you saw was people looking at the evidence. And they gradually did come to change their minds."

Today, it's generally accepted that the asteroid that plowed into the Yucatan led, in very short order, to a mass extinction, but scientists are still uncertain exactly how the process unfolded. One theory holds that the impact raised a cloud of dust that blocked the sun, preventing photosynthesis and causing widespread starvation. According to another theory, the impact kicked up a plume of vaporized rock travelling with so much force that it broke through the atmosphere. The particles in the plume then recondensed, generating, as they fell back to earth, enough thermal energy to, in effect, broil the surface of the planet.

Whatever the mechanism, the Alverezes' discovery wreaked havoc with the uniformitarian idea of extinction. The fossil record, it turned out, was marked by discontinuities because the history of life was marked by discontinuities.

In the nineteenth century, and then again during the Second World War, the Adirondacks were a major source of iron ore. As a result, the mountains are now riddled with abandoned mines. On a gray day this winter, I went to visit one of the mines (I was asked not to say which) with a wildlife biologist named Al Hicks. Hicks, who is fifty-four, is tall and outgoing, with a barrel chest and ruddy cheeks. He works at the headquarters of the New York State Department of Environmental Conservation, in Albany, and we met in a parking lot not far from his office. From there, we drove almost due north.

Along the way, Hicks explained how, in early 2007, he started to get a lot of strange calls about bats. Sometimes the call would be about a dead bat that had been brought inside by somebody's dog. Sometimes it was about a live--or half-alive--bat flapping around on the driveway. This was in the middle of winter, when any bat in the Northeast should have been hanging by its feet in a state of torpor. Hicks found the calls bizarre, but, beyond that, he didn't know what to make of them. Then, in March, 2007, some colleagues went to do a routine census of hibernating bats in a cave west of Albany. After the survey, they, too, phoned in.

"They said, 'Holy shit, there's dead bats everywhere,'" Hicks recalled. He instructed them to bring some carcasses back to the office, which they did. They also shot photographs of live bats hanging from the cave's ceiling. When Hicks examined the photographs, he saw that the animals looked as if they had been dunked, nose first, in talcum powder. This was something he had never run across before, and he began sending the photographs to all the bat specialists he could think of. None of them could explain it, either.

"We were thinking, Oh, boy, we hope this just goes away," he told me. "It was like the Bush Administration. And, like the Bush Administration, it just wouldn't go away." In the winter of 2008, bats with the white powdery substance were found in thirty-three hibernating spots. Meanwhile, bats kept dying. In some hibernacula, populations plunged by as much as ninety-seven per cent.

That winter, officials at the National Wildlife Health Center, in Madison, Wisconsin, began to look into the situation. They were able to culture the white substance, which was found to be a never before identified fungus that grows only at cold temperatures. The condition became known as white-nose syndrome, or W.N.S. White nose seemed to be spreading fast; by March, 2008, it had been found on bats in three more states--Vermont, Massachusetts, and Connecticut--and the mortality rate was running above seventy-five per cent. This past winter, white nose was found to have spread to bats in five more states: New Jersey, New Hampshire, Virginia, West Virginia, and Pennsylvania.

In a paper published recently in *Science*, Hicks and several co-authors observed that "parallels can be drawn between the threat posed by W.N.S. and that from chytridiomycosis, a lethal fungal skin infection that has recently caused precipitous global amphibian population declines."

When we arrived at the base of a mountain not far from Lake Champlain, more than a dozen people were standing around in the cold, waiting for us. Most, like Hicks, were from the D.E.C., and had come to help conduct a bat census. In addition, there was a pair of biologists from the U.S. Fish and Wildlife Service and a local novelist who was thinking of incorporating a subplot about white nose into his next book. Everyone put on snowshoes, except for the novelist, who hadn't brought any, and began tromping up the slope toward the mine entrance.

The snow was icy and the going slow, so it took almost half an hour to reach an outlook over the Champlain Valley. While we were waiting for the novelist to catch up--apparently, he was having trouble hiking through the three-foot-deep drifts--the conversation turned to the potential dangers of entering an abandoned mine. These, I was told, included getting crushed by falling rocks, being poisoned by a gas leak, and plunging over a sheer drop of a hundred feet or more.

After another fifteen minutes or so, we reached the mine entrance--essentially, a large hole cut into the hillside. The stones in front of the entrance were white with bird droppings, and the snow was covered with paw prints. Evidently, ravens and coyotes had discovered that the spot was an easy place to pick up dinner.

"Well, shit," Hicks said. Bats were fluttering in and out of the mine, and in some cases crawling on the ground. Hicks went to catch one; it was so lethargic that he grabbed it on the first try. He held it between his thumb and forefinger, snapped its neck, and placed it in a ziplock bag.

"Short survey today," he announced.

At this point, it's not known exactly how the syndrome kills bats. What is known is that bats with the syndrome often wake up from their torpor and fly around, which leads them to die either of starvation or of the cold or to get picked off by predators.

We unstrapped our snowshoes and put on helmets. Hicks handed out headlamps--we were supposed to carry at least one extra--and packages of batteries; then we filed into the mine, down a long, sloping tunnel. Shattered beams littered the ground, and bats flew up at us through the gloom. Hicks cautioned everyone to stay alert. "There's places that if you take a step you won't be stepping back," he warned. The tunnel twisted

along, sometimes opening up into concert-hall-size chambers with side tunnels leading out of them.

Over the years, the various sections of the mine had acquired names; when we reached something called the Don Thomas section, we split up into groups to start the survey. The process consisted of photographing as many bats as possible. (Later on, back in Albany, someone would have to count all the bats in the pictures.) I went with Hicks, who was carrying an enormous camera, and one of the biologists from the Fish and Wildlife Service, who had a laser pointer. The biologist would aim the pointer at a cluster of bats hanging from the ceiling. Hicks would then snap a photograph. Most of the bats were little brown bats; these are the most common bats in the U.S. and the ones you are most likely to see flying around on a summer night. There were also Indiana bats, which are on the federal endangered-species list, and small-footed bats, which, at the rate things are going, are likely to end up there. As we moved along, we kept disturbing the bats, which squeaked and started to rustle around, like half-asleep children.

Since white nose grows only in the cold, it's odd to find it living on mammals, which, except when they're hibernating (or dead), maintain a high body temperature. It has been hypothesized that the fungus normally subsists by breaking down organic matter in a chilly place, and that it was transported into bat hibernacula, where it began to break down bats. When news of white nose began to get around, a spelunker sent Hicks photographs that he had shot in Howe's Cave, in central New York. The photographs, which had been taken in 2006, showed bats with clear signs of white nose and are the earliest known record of the syndrome. Howe's Cave is connected to Howe's Caverns, a popular tourist destination.

"It's kind of interesting that the first record we have of this fungus is photographs from a commercial cave in New York that gets about two hundred thousand visits a year," Hicks told me.

Despite the name, white nose is not confined to bats' noses; as we worked our way along, people kept finding bats with freckles of fungus on their wings and ears. Several of these were dispatched, for study purposes, with a thumb and forefinger. Each dead bat was sexed--males can be identified by their tiny penises--and placed in a ziplock bag.

At about 7 P.M., we came to a huge, rusty winch, which, when the mine was operational, had been used to haul ore to the surface. By this point, we were almost down at the bottom of the mountain, except that we were on the inside of it. Below, the path disappeared into a pool of water, like the River Styx. It was impossible to go any further, and we began working our way back up.

Bats, like virtually all other creatures alive today, are masters of adaptation descended from lucky survivors. The earliest bat fossil that has been found dates from fifty-three million years ago, which is to say twelve million years after the impact that ended the Cretaceous. It belongs to an animal that had wings and could fly but had not yet developed the specialized inner ear that, in modern bats, allows for echolocation. Worldwide, there are now more than a thousand bat species, which together make up nearly a fifth of all species of mammals. Most feed on insects; there are also bats that live off fruit, bats that eat fish--they use echolocation to detect minute ripples in the water--and a small but highly celebrated group that consumes blood. Bats are great colonizers--Darwin noted that even New Zealand, which has no other native mammals, has its own bats--and they can be found as far north as Alaska and as far south as Tierra del Fuego.

In the time that bats have evolved and spread, the world has changed a great deal. Fifty-three million years ago, at the start of the Eocene, the planet was very warm, and tropical palms grew at the latitude of London. The climate cooled, the Antarctic ice sheet began to form, and, eventually, about two million years ago, a period of recurring glaciations began. As recently as fifteen thousand years ago, the Adirondacks were buried under ice.

One of the puzzles of mass extinction is why, at certain junctures, the resourcefulness of life seems to falter. Powerful as the Alvarez hypothesis proved to be, it explains only a single mass extinction.

"I think that, after the evidence became pretty strong for the impact at the end of the Cretaceous, those of us who were working on this naively expected that we would go out and find evidence of impacts coinciding with the other events," Walter Alvarez told me. "And, of course, it's turned out to be much more complicated. We're seeing right now that a mass extinction can be caused by human beings. So it's clear that we do not have a general theory of mass extinction."

Andrew Knoll, a paleontologist at Harvard, has spent most of his career studying the evolution of early life. (Among the many samples he keeps in his office are fossils of microorganisms that lived 2.8 billion years ago.) He has also written about more recent events, like the end-Permian extinction, which took place two hundred and fifty million years ago, and the current extinction event.

Knoll noted that the world can change a lot without producing huge losses; ice ages, for instance, come and go. "What the geological record tells us is that it's time to worry when the rate of change is fast," he told me. In the case of the end-Permian extinction, Knoll and many other researchers believe that the trigger was a sudden burst of volcanic activity; a plume of hot mantle rock from deep in the earth sent nearly a million

cubic miles' worth of flood basalts streaming over what is now Siberia. The eruption released enormous quantities of carbon dioxide, which presumably led--then as now--to global warming, and to significant changes in ocean chemistry.

"CO₂ is a paleontologist's dream," Knoll told me. "It can kill things directly, by physiological effects, of which ocean acidification is the best known, and it can kill things by changing the climate. If it gets warmer faster than you can migrate, you're in trouble."

In the end, the most deadly aspect of human activity may simply be the pace of it. Just in the past century, CO₂ levels in the atmosphere have changed by as much--a hundred parts per million--as they normally do in a hundred-thousand-year glacial cycle. Meanwhile, the drop in ocean pH levels that has occurred over the past fifty years may well exceed anything that happened in the seas during the previous fifty million. In a single afternoon, a pathogen like Bd can move, via United or American Airlines, halfway around the world. Before man entered the picture, such a migration would have required hundreds, if not thousands, of years--if, indeed, it could have been completed at all.

Currently, a third of all amphibian species, nearly a third of reef-building corals, a quarter of all mammals, and an eighth of all birds are classified as "threatened with extinction." These estimates do not include the species that humans have already wiped out or the species for which there are insufficient data. Nor do the figures take into account the projected effects of global warming or ocean acidification. Nor, of course, can they anticipate the kinds of sudden, terrible collapses that are becoming almost routine.

I asked Knoll to compare the current situation with past extinction events. He told me that he didn't want to exaggerate recent losses, or to suggest that an extinction on the order of the end-Cretaceous or end-Permian was imminent. At the same time, he noted, when the asteroid hit the Yucatan "it was one terrible afternoon." He went on, "But it was a short-term event, and then things started getting better. Today, it's not like you have a stress and the stress is relieved and recovery starts. It gets bad and then it keeps being bad, because the stress doesn't go away. Because the stress is us."

Aeolus Cave, in Dorset, Vermont, is believed to be the largest bat hibernaculum in New England; it is estimated that, before white nose hit, more than two hundred thousand bats--some from as far away as Ontario and Rhode Island--came to spend the winter there.

In late February, I went with Hicks to visit Aeolus. In the parking lot of the local general store, we met up with officials from the Vermont Fish and Wildlife Department, who had organized the trip. The entrance to Aeolus is about a mile and a half from the nearest road, up a steep, wooded hillside. This time, we approached by snowmobile. The temperature outside was about twenty-five degrees--far too low for bats to be active--but when we got near the entrance we could, once again, see bats fluttering around. The most senior of the Vermont officials, Scott Darling, announced that we'd all have to put on latex gloves and Tyvek suits before proceeding. At first, this seemed to me to be paranoid; soon, however, I came to see the sense of it.

Aeolus is a marble cave that was created by water flow over the course of thousands of years. The entrance is a large, nearly horizontal tunnel at the bottom of a small hollow. To keep people out, the Nature Conservancy, which owns the cave, has blocked off the opening with huge iron slats, so that it looks like the gate of a medieval fortress. With a key, one of the slats can be removed; this creates a narrow gap that can be crawled (or slithered) through. Despite the cold, there was an awful smell emanating from the cave--half game farm, half garbage dump. When it was my turn, I squeezed through the gap and immediately slid on the ice, into a pile of dead bats. The scene, in the dimness, was horrific. There were giant icicles hanging from the ceiling, and from the floor large knobs of ice rose up, like polyps. The ground was covered with dead bats; some of the ice knobs, I noticed, had bats frozen into them. There were torpid bats roosting on the ceiling, and also wide-awake ones, which would take off and fly by or, sometimes, right into us.

Why bat corpses pile up in some places, while in others they get eaten or in some other way disappear, is unclear. Hicks speculated that the weather conditions at Aeolus were so harsh that the bats didn't even make it out of the cave before dropping dead. He and Darling had planned to do a count of the bats in the first chamber of the cave, known as Guano Hall, but this plan was soon abandoned, and it was decided just to collect specimens. Darling explained that the specimens would be going to the American Museum of Natural History, so that there would at least be a record of the bats that had once lived in Aeolus. "This may be one of the last opportunities," he said. In contrast to a mine, which has been around at most for a few centuries, Aeolus, he pointed out, has existed for millennia. It's likely that bats have been hibernating there, generation after generation, since the end of the last ice age.

"That's what makes this so dramatic--it's breaking the evolutionary chain," Darling said.

He and Hicks began picking dead bats off the ground. Those which were too badly decomposed were tossed back; those which were more or less intact were sexed and placed in two-quart plastic bags. I helped out by holding open the bag for females. Soon, it was full and another one was started. It struck me, as I stood there holding a bag filled with several dozen stiff, almost weightless bats, that I was watching mass

extinction in action.

Several more bags were collected. When the specimen count hit somewhere around five hundred, Darling decided that it was time to go. Hicks hung back, saying that he wanted to take some pictures. In the hours we had been slipping around the cave, the carnage had grown even more grotesque; many of the dead bats had been crushed and now there was blood oozing out of them. As I made my way up toward the entrance, Hicks called after me: "Don't step on any dead bats." It took me a moment to realize that he was joking.

There have been five great die-offs in history. This time, the cataclysm is us.

Kolbert discusses the five great mass extinctions in Earth's history, some of which resulted in the elimination of 75%-80% of all species then in existence. Some biologists think the recent fungal plagues killing off frogs, bats and other species may be the opening salvo of the sixth great die-off. And human beings are the primary cause.

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Caption: Some estimates suggest that, if current trends continue, half the world's species may disappear by the end of this century. - DAVID HUGHES

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