INTRODUCTION

A couple of years ago, University of Tennessee entomologist Stylianos Chatzimanolis borrowed a box of unclassified beetles from the Natural History Museum in London. Taxonomists do this all the time; they borrow material from other natural history collections the way someone might borrow a book from a library. The beetles Chatzimanolis borrowed were unknown—unsorted. They'd been collected in the past by field biologists but never formally described.

When the box arrived in Chattanooga, Tennessee, Chatzimanolis found twenty or so beetle specimens pinned inside it. But one of the beetles was not like the others. First, it looked much older. Long-bodied, with a segmented, sinuous abdomen, it was a rove beetle—but an unusually large specimen with a wide iridescent green head.

The beetle had been collected in Argentina in 1832. As Chatzimanolis began to look more closely at the specimen—and at its yellowed handwritten label—he realized it had been collected by a young Charles Darwin during the voyage of the *Beagle*. Somehow it had never been described. It was stored away unnamed, then it had disappeared without a trace into the vast beetle collection in London.

Finally, after its 180 years in storage, Chatzimanolis gave the beetle a name. It is so unlike any known species of rove beetle that he had to erect an entirely new genus to contain it. He named it *Darwinilus sedarisi*.[1]

The beetle is named now, but the central question remains: Does it matter? Is there any need to name it at all? The specimen had waited for 180 years. Why name it now? In fact, it matters a great deal.

A single species is the irreducible component of all the biodiversity on Earth. For centuries scientists have been trying to describe, classify, and order the natural world. When a new species is named, an array of other work suddenly becomes possible. By studying a newly named species alongside its closest relatives, biologists gain a deeper understanding of the evolutionary processes that shaped it. Ecologists are given a window into the workings of infinitely complex ecosystems. Conservationists gain insights into how to manage environments to maintain its population numbers. But for all this to be possible we first need to know it exists.

We can think of Earth's biodiversity as a symphony, with each species represented by a single musical note. By itself, a single note means nothing—it is stripped of meaning. But over time notes accumulate and begin to intermingle. Notes become motifs, which become themes. Themes repeat and slowly build to become movements—rich musical passages that have become more than the sum of their parts. But what if the sheet music is incomplete? Currently we have named an estimated one-fifth of all species on Earth. Imagine what Beethoven's Ninth Symphony might sound like if an orchestra played only every fifth note and left silent gaps between them. What happens to the themes and the slowly gathering refrains? How can we begin to understand Earth's biodiversity in all its richness without knowing even half of its components?

Museums and biorepositories worldwide are filled with unknown species. By some estimates, 75 percent of newly described mammal species are already part of a natural history collection somewhere in the world. It's true for all other orders too: for parasitic worms and for frogs, fishes, corals, and flies; for crabs, moths, and lichens and bryophytes. In 2012 researchers discovered an unknown species of egg-eating sea snake at the Natural History Museum in Copenhagen.[2] Collected in the late 1800s, the snake was subsequently named *Aipysurus mosaicus*, for the mosaic-like pattern made by its brown and cream-colored scales. A long time ago it had been misidentified as a closely related species, labeled as such, then stored in a jar for more than a century. But it was different, and markedly so—different enough that a sharp-eyed herpetologist immediately noticed.

The authors of a 2010 *Proceedings of the National Academy of Science* study estimate that of the seventy thousand or so species of flowering plants waiting to be described, about half have already been collected.[3] They are stored without names in herbaria. It's not difficult to imagine how this might happen. The encyclopedic Department of Entomology at the National Museum of Natural History in Washington, DC, alone contains about thirty million insect specimens. There is far too much material for taxonomists and curators to assess, identify, and name.

Even when a specimen is examined, it's often misidentified and wrongly named. In a November 2015 article in *Current Biology*, researchers assessed the accuracy of collections in herbaria in twenty-one countries.[4] Essentially, more than half of all the specimens they examined had been given the wrong name: collections are filled with errors. This is a huge problem. How useful is a collection if the labels on the specimens are wrong? What if half the specimens aren't what we think they are? Between 1970 and 2000 the number of tropical plant specimens in herbaria doubled, but most of the recently collected material was mislabeled. And in plenty of cases specimens are not identified at all. A faded handwritten label on the specimen might bear the tantalizing annotation "novel species?" Or simply "nov. sp.?"

This is all made possible by how little we know about the natural world that thrums and vibrates all around us. We have barely scratched its surface. By most estimates, there are about ten million species on the planet, but we have named fewer than two million of them. The rest of Earth's biodiversity remains unknown. We exist within enormous sprawling, complicated ecosystems populated by thousands of interconnected species, but we don't fully understand how they interact or what role each plays. We can't know what really happens to that ecosystem if one of the species in it—an unremarkable-looking beetle, for instance, or a bat, or a frog, or an orchid—is removed forever. Most likely the ecosystem will continue to function. It will compensate and adapt in some unseen way. But how? And what does that tell us about the species that are left?

Most of the life on Earth, in other words, is still a mystery to us—undescribed and underexplored. Once it is named, a humble beetle doesn't perform its ecological role any differently. Nothing changes. But how can we hope to understand the complexity of life if we can't even identify its participants? How can we protect an animal we haven't named?

For centuries, natural history collections—and the intrepid collectors who built them—have helped us understand the biodiversity around us. Currently, taxonomists and biologists describe about eighteen thousand new species every year. Novel species are named every day. This includes extinct fossilized species and microscopic organisms like bacteria and viruses. First a holotype is identified—a single specimen that is used to describe and define the entire species. A new branch sprouts on the Tree of Life—an irreducible component of Earth's mostly still unknown biodiversity. Although eighteen thousand new species every year might sound like a lot, it represents an astonishingly small fraction of the world's total.

In fact, we are surrounded by unnamed species. At best, says Quentin Wheeler, a taxonomist and the president of the State University of New York College of Environmental Science and Forestry, we know perhaps one in four living insect species. We discover new species everywhere, from city backyards to remote rainforests and deep-sea environments. In September 2016 researchers at the University of Rochester in New York named *Lenomyrmex hoelldobleri*, a new species of tropical ant.[5] It was described from a single tiny specimen that had been flushed—already dead—from the stomach of a bright orange frog called the diablito, or little devil frog (*Oophaga sylvatica*). The ant lives in the Ecuadoran rainforest. Since there is only one sample and it came from a frog's stomach, no one knows precisely where it lives. Shark researcher David Ebert has named ten new species of shark from specimens he found for sale in just one Taiwanese fish market.[6] In thousands of other instances, though, biologists have already collected the novel specimens. The holotypes sit in collections, unidentified.

When you visit a large, established collection like the Field Museum of Natural History in Chicago or the California Academy of Natural Sciences—or museums in Leiden, or London, or Paris, or São Paulo—it is impossible to get a sense of the immense size and breadth of the collection that sits just beyond the public spaces. The bat collection at the American Museum of Natural History alone—just a small part of a much larger and more comprehensive mammal collection—includes more than 250,000 specimens. It continues to grow every year. Field biologists working in remote places capture bat specimens, then prepare them, label them with locality data, and accession them into the collection. Scientists from across the world travel to New York to measure and compare the specimens, like a vast reference library of biological material. Or they borrow specimens from the museum, the way Chatzimanolis borrowed beetles from the Natural History Museum in London, where coleopterist Max Barclay oversees an enormous beetle collection that encompasses about ten million individual beetles. More than a thousand new beetle species are described each year from that collection alone. In the United States, natural history collections contain an estimated one billion specimens. The entomology collection at the Bishop Museum in Honolulu, Hawaii, contains fourteen million specimens, including type specimens of thirty-six mosquito species. The Duke University herbarium includes more than 160,000 specimens of moss. The herpetology collection at the California Academy of Sciences in San Francisco has more than 300,000 cataloged specimens from 175 countries. At the Smithsonian Institution, the oldest botanical specimens date back to 1504.

The time that passes between the collection and description of a specimen is known as its shelf life or dwell time. According to a *Current Biology* article, the average shelf life across all orders of organisms is about twenty-one years.[7] Naming and describing species is a painstaking process that can take a long time.

Occasionally, though, the dwell time becomes much longer and turns into deep time. The specimens sit dormant for fifty or seventy-five years—sometimes a century or longer still. They wait in basements and storage cabinets. They sit in drawers or in jars of fixative. Their labels slowly turn yellow and fade. The person who collected them dies. But they still wait. Outside, on the street, where time still has its usual weight, the world changes. There are wars and there are scientific advances. The borders of the country where a specimen was collected are redrawn, then redrawn again, but in the collections the specimens remain unchanged. In most cases several million other specimens surround them, making them even more difficult to find.

A single specimen of an unknown species of spider might sit unidentified in a flask along with fifty examples of a known and commonly found species. In some small way, it is profoundly different from the others. It has something important to tell us about the ecosystem it came from and the processes that made it, but it has become almost impossible to find. It could remain undiscovered forever.

Then one day a graduate student who has become an expert in a particular genus of spiders takes the lid off the jar and sees something unexpected inside—something different.

Natural history collections are in danger, and many are struggling to survive.[8] In recent years a lot of institutions have seen drastic reductions in funding. The number of taxonomists working in collections has declined too. Much of the taxonomic work is now undertaken by evolutionary biologists, and they also are underfunded. The curators, vital custodians who oversee the care and organization of the collections, are disappearing as well. For instance, in 2001 the Field Museum had thirty-nine curators. Today there are twenty-one. The National Museum of Natural History in Washington, DC, has seen a loss of curators from a high of 122 in 1993 to a current low of 81: about a quarter. In the past, many larger institutions had a team of curators working in each discipline: three or four mammalogists, a couple of ichthyologists. There might have been several entomologists, each with a deep and informed interest in a single, highly specialized tribe of insects. Frequently these experts have been replaced by one overburdened collections manager. At some institutions, even collections managers are in short supply. The Field Museum currently lacks managers for several important collections: paleobotany, mycology, anthropology, and mammalogy.

Imagine a library filled with rare and important books but with no librarians to care for them.

Sometimes a natural history collection disappears altogether. At a smaller institution, or in an academic department, an expert in a particular taxon will retire or die and leave behind thousands of specimens. Occasionally those orphaned collections are adopted by larger institutions—enfolded into an established collection. But sometimes they're not.

With the advent of new technologies, many institutions have begun digitizing their collections, an ongoing process that will allow researchers worldwide to access specimens remotely.[9] Funded by the National Science Foundation, Integrated Digitized Biocollections—or iDigBio—is part of an ongoing global effort. The results are amazing. The iDigBio website includes links to more than seventy-two million records detailing individual specimens, housed in repositories across the world. There are collection data for everything from lichens and bryophytes to lowland gorillas. The Global Biodiversity Information Facility (GBIF) is another effort: a database funded by international governments that provides a single point of access to millions—currently more than half a billion—digitized records from institutions worldwide. Researchers at the Museum of Natural History in Berlin have begun digitizing its entomology collection, converting each specimen—via spherical high-resolution images—into a single incredibly detailed image that can be rotated and viewed from different angles. This means I can now sit on my couch and explore the gleaming surfaces of *Chrysis marqueti*, an iridescent green cuckoo wasp collected from the West Bank. Or, impaled on its pin in Berlin, *Hemidictya frondosa*—a butter-colored Brazilian cicada, frozen in midflight with its veined, leaflike wings outspread.

Overall, digitizing collections will increase taxonomic knowledge and help to reduce the hurdles that prevent species description. Known as the taxonomic impediment, the barriers to identification include a shortage of skilled taxonomists and curators, an insurmountable excess of undetermined material, a simple lack of interest, and constant reductions in institutional support. When the funding for projects like iDigBio stops—and it has been halted from time to time—the digitizing efforts halt too.

Either way, nothing can replace holding a specimen. The weight of the object in the hand engages the brain in ways that an image on a screen simply cannot.

For many people in the collections community, it feels as if natural history collections have been set adrift. People think natural history museums are quaint Victorian places, dimly lit and dusty—a throwback to an analog world. A cabinet filled with dead animals is no longer useful. After all, how can we learn anything from a 180-year-old beetle?

But the collections are more important now than ever. They provide an indelible taxonomic record of all life on Earth, and life on Earth is changing. According to many scientists, life is disappearing much faster than any time in recent history. By some estimates, current rates of extinction are a thousand times higher than natural background rates—much higher than previously calculated.[10] We have entered what some researchers have called the Sixth Extinction. For some species, the few specimens placed in natural history collections worldwide are the only examples that exist: living specimens are gone. Collections have multiple concrete uses. They allow researchers to understand the effects of complex processes like climate change, comparing the different species present in a particular region across time. We can use collections to pinpoint the introduction of invasive species and diseases to ecosystems. Ornithologists can track changes in bird migration patterns with collection data. Biological specimens—like the 250,000 bats at the American Museum of Natural History—might even allow epidemiologists to track the outbreak and cause of deadly zoonotic diseases like the ebola virus, which periodically erupt in human populations and then just as rapidly disappear into their animal reservoirs.

More important, the collections are repositories of human endeavor. They tell a profoundly human story. Three centuries of scientific thought can be condensed to a single unnamed longhorn beetle from Ghana or the long-vacated turriform shell of a Vietnamese land snail. The specimens come from across the world: from the bottom of the ocean; from inside volcanoes; from sub-Saharan Africa, the rainforests of Borneo, urban American backyards, and the endless brittle, frozen landscape of the Antarctic. A multitude of specimens. And there, in the collections, the mysteries await.

For a while they are lost—sometimes for centuries. But then, finally, they are found.