

# BARO

# OF



# LIFE

Photographs by ANDREW TINGLE

# GOODIE



A SMALL  
GROUP OF  
INSECT  
RESEARCHERS  
HAVE  
INVENTED A  
DEVICE TO  
IDENTIFY  
EVERY  
CREATURE  
ON EARTH.  
SO WHY DO  
OTHER  
BIOLOGISTS  
HATE  
THE IDEA?

# THE UTOPIAN LEPIDOPTERIST HOLDS A PIN IN EACH HAND.

His style is ambidextrous and probably unique. He catches two forewings of a dead moth simultaneously and pins them to his drying board, and then, in a continuous sweep, he does the same with the hind wings. He repeats these motions again and again, like a conductor with tiny batons. Outside, it is hot and bright. Inside, it is hot and dark. The lepidopterist, whose name is Dan Janzen, has been working here in this Costa Rican forest for more than 40 years. He is married to his research partner, Winnie Hallwachs, and the two of them occupy a small house with a roof of corrugated metal whose eaves cast deep shade. During the day they work under artificial light. At night bats flit through the gaps at the top of the wall, do hairpin turns in the air, and exit again without slowing. The utopian lepidopterist's aim is to put names on all the moths and butterflies in the forest. He wants to know more than just the names, of course; he wants to know who lives where and who eats whom and to unravel the mysteries of the ecosystem. But his first question is always the most basic one. This moth, here on the drying board: What is it called?

All over the world, farmers, port inspectors, game wardens, exterminators, building contractors, and, of course, professional biologists are staring at some form of plant or animal life and wondering helplessly what it is. Matching living things to their names is so notoriously difficult that the problem itself has been given a name: *the taxonomic impediment*. With insects, the taxonomic impediment is severe. Insects are the glue that holds the web of land-based life together; they are pollinators, soil aerators, and a major source of food. Most of them are as mysterious as extraterrestrials. More than 90 percent of insects, tens of millions of species, have never been described. As every type of information in the world is being encoded into standard formats, accessible on the Web and searchable from anywhere, plant and animal names stand out as a stubborn exception. That's because the quest for a name begins with a specimen, and a specimen is made of atoms, not bits. There is no hole in a computer into which you can drop a bug.

The utopian lepidopterist moves his hands in little semicircles, and another dust-colored insect lies flat, positioned for eternity. All around him are dead moths, wings folded softly on thorax. More will arrive tomorrow; and the next day, more still. He eats at his desk, oblivious to the food in front of him. His needles flash again. He thinks mainly about his project. There may be no person in the world faster at spreading moths. Nonetheless, at this rate, his project will fail.

**ON** the campus of the University of Guelph, in Canada, surrounded by neat embankments of snow, is a two-story building that contains an automatic animal-identifying machine. Its inventor, Paul Hebert, is 61 years old, strongly built, with blue eyes and white hair. He says he came up with the idea for the machine in a grocery store. Walking down an aisle of packaged goods in 1998, he indulged in a moment of awe: Here, in a short row of numerals, was the entire retail universe, billions of individual products, identifiable by a tiny machine-readable barcode. If it works for cans of food, Hebert thought, why not for bugs? Why not for everything?

Hebert is an evolutionary biologist and an expert on water fleas. He has been obsessed with insects since childhood. On his left hand is a scar he got running with a glass bug jar as a toddler. At 12, he began performing operations on caterpillars, experimenting with their endocrine system in a quest to produce dwarfs and giants. He won a scholarship to study at University of Cambridge, and in 1974 he began making collecting expeditions to New Guinea. He went up into the cloud forest and caught 50,000 moths and butterflies, and neatly tagged each one with date and elevation. By his count, there were 4,100 different species.





From his lab in Costa Rica, Dan Janzen (previous spread) collects moth specimens for genetic barcoding.

## BARCODES WORK FOR CANS OF SOUP. WHY NOT BUGS?

Except that they weren't really species. "They were operational taxonomic units," he says. "You aren't allowed to call them species until you know what they are." Hebert went to the Natural History Museum in London and began to check his specimens against its large reference collection. He naively thought he knew something about moths. He understood their anatomy, he possessed a microscope, he could speed through the professional literature. He was almost never stumped by anything he found in Canada. He had studied at Cambridge for three years and had quickly found his bearings among the moths of the British Isles. But the tropical moths were different. There was too much diversity, too many dead insects in the drawers. After several years, he admitted defeat. He had failed to identify two-thirds of his specimens. "It was like forgetting how to read," Hebert says. "It was like being struck dumb. I had to face how far I was

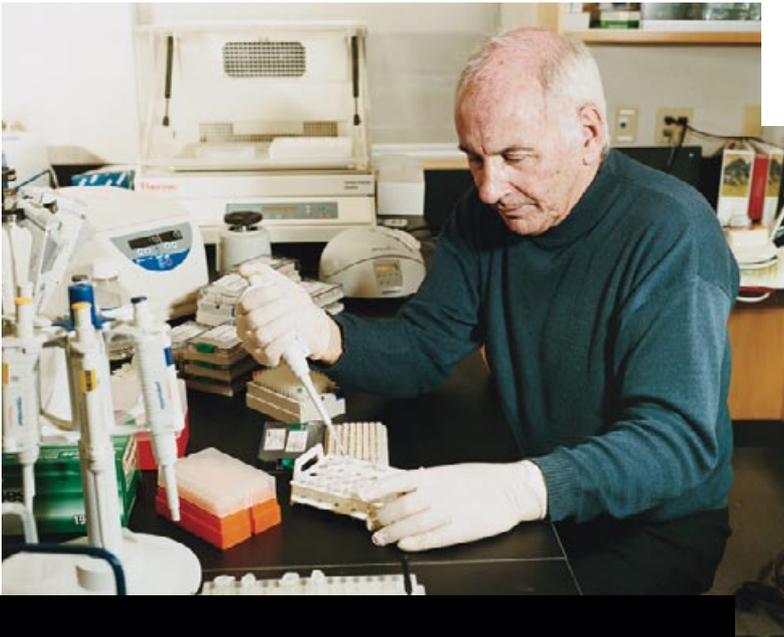
from attaining what I wanted, how *inadequate* my ability was."

Hebert started anew with water fleas. Water fleas, he told himself, were the kind of insect a person could get his mind around. There are only about 200 species of water fleas. By the time Hebert had his flash of inspiration in the grocery store, he was running a lab at the University of Guelph with a small coterie of graduate students, a budget of about \$120,000 per year, and the ability to answer just about any question on water fleas.

He understood, of course, that animals already carry a numerical code in their genome. Anybody who has watched a crime show knows that DNA can be used to identify organisms down to the level of the single individual. But the genome is impractical for mass identification of species. Commercial barcodes have just a handful of digits; animal genomes run to billions of letters. Sequencing was neither

easy, fast, nor cheap. “Students would go off to study variation in a few hundred specimens and disappear for a year,” Hebert recalls. Still, there were some common shortcuts. In the 1990s, researchers had begun using easily sequenced fragments of mitochondrial genes to quickly sort their specimens into groups. Mitochondrial genes are inherited maternally. They are not scrambled by recombination, and mitochondrial variation offers rough clues about evolutionary history. Insect people were using the back end of a mitochondrial gene known as CO1 to help identify specimens, marine invertebrate people liked the front end, and vertebrate zoologists used a different mitochondrial gene altogether. Hebert’s idea was that, out of a hodgepodge of related techniques, he could build a simple, universal identification system—assuming, that is, the same small piece of mitochondrial DNA worked reliably for all the animals in the world.

tifications to be incorrect, the extreme difficulty of telling many animals apart in various life stages, the small number of species identified in the past 250 years, the vast number of unidentified species still remaining, and, perhaps most damning of all, the fact that even when an expert has identified a group of animals and done the identification correctly and produced a guide, the guide itself is so complex that mistakes are common. As a remedy, Hebert set out his own method of identifying animals through a small, standard sequence of DNA; he shared his data about Canadian moths, and he added some additional data gleaned from GenBank, a publicly accessible repository of gene sequences. At the end of the paper, he asked for money. “We believe that a CO1 database can be developed within 20 years for 5–10 million animal species on the planet for approximately \$1 billion,” he wrote.



Paul Hebert has set up a genetic barcoding factory in his lab in Guelph, Canada.

Taxonomists were outraged. “Have you heard of the blind-10-year-old problem?” asks Jesse Ausubel, a program officer with the Alfred P. Sloan Foundation, which funded two small meetings of well-known scientists to discuss Hebert’s idea in 2003.

“Taxonomy is partly connoisseurship,” Ausubel says. “But if you can use a chemical test to identify species, then a blind 10-year-old can do it.” Some non-taxonomists objected as well. J. Craig Venter, famous for his work on sequencing the human genome, argued that Hebert’s suggestion was uninteresting. The so-called barcode region amounted to just 650 base pairs, less than a ten-millionth of the genome. Why be satisfied with something like that when the cost of whole genome sequencing was rapidly falling? But for Hebert, the triviality of sequencing a little fragment was exactly the point. “It’s seven orders of magnitude smaller!” he says. “It’s always going to be cheaper. If you can get whole genomes for \$10, you will get barcodes for pennies.”

Hebert proposed a barcoding factory: Capture

## MORE THAN 90 PERCENT OF INSECT

To test this assumption, Hebert needed a large, easily accessible collection of already identified specimens. Water fleas wouldn’t work—there weren’t enough different kinds of them. So Hebert did something he hadn’t done in years: He hung a sheet illuminated by a fluorescent light in his backyard and started catching moths. He collected more than a thousand specimens and identified them using traditional methods. It wasn’t very hard; these were the Canadian moths he’d known since he was a kid. He sequenced a fragment of CO1 from each bug, and sure enough, every moth was sorted to the right group. His success rate was 100 percent.

In January 2003, Hebert published a paper in *Proceedings of the Royal Society* in which he claimed his technique could solve the taxonomic impediment. “Although much biological research depends on species diagnoses,” Hebert wrote, “taxonomic expertise is collapsing.” He went on to complain of the dwindling number of qualified taxonomists, the tendency of expert iden-

## SPECIES HAVE NEVER BEEN NAMED.

a bunch of bugs, remove a leg from each, sequence a bit of DNA, and produce a chart that shows which bugs clump together as a single species. If a sample of that species has already been identified, then the factory can provide a name. Along with legs from bugs, the factory can accept other material that contains DNA—feathers from birds, or bits of mollusk, or samples from a pallet of frozen fish. Once the method is proven and the standard is accepted, such a factory could even be miniaturized. It could be taken out to the field, put in the back of a van.

Bacteria and viruses don’t have mitochondria, but most other life does. The CO1 gene is nearly universal. If it worked on the animals he tested so far, it should work on everything. But as Hebert pressed his case among his peers, he realized that he was on shaky ground. Scientists who had spent their whole careers doing molec-



ular genetics doubted that his good luck with a few groups would carry over to the whole diversity of life. The only thing that could possibly answer such skepticism would be more evidence, but more evidence was exactly what he couldn't get. Hebert had already burned through his lab budget doing sequencing. He had shed his grad students and was down to a single postdoc. He was thinking about mortgaging his house. "OK, I'm saying I have the solution to identifying all animal life, but I've got only a few hundred species to prove it," he recalls. "That's not going to be convincing to any scientist." Hebert knew he needed to conduct a proper test, preferably with a large group of hard-to-tell-apart insects. Tropical lepidoptera, for instance, are some of the most difficult cases in the animal kingdom. But the specimens would have to be newly collected, because it was too hard to extract DNA from old tissue. And Hebert would have to identify the specimens twice, once with a barcode and once with conventional taxonomy to see if the two results matched. Although the work was slow, he could handle the genetic sequencing in his lab. But the traditional taxonomic identification—this was impossible. This was the *taxonomic impediment*. This was the very problem he had run away from a quarter of a century before.

**DAN** Janzen and Paul Hebert met in 2003, at the first meeting funded by the Sloan Foundation. Janzen, after hearing Hebert's bold claims, informed the startled inventor that he was thinking too small. A barcode factory was a pretty good idea, but to rescue field biology, they needed more. Why didn't they work on a machine that was the size of a comb—a species tricorder.

"You've raised the bar," Hebert said.

The two men had been in contact before, though Janzen had forgotten. In 1978, he sent Hebert a note saying that he'd heard he had been working in New Guinea and had put together a good collection of butterflies and moths—but there had been no publications. What was he doing with his specimens? Janzen, at the time, was already on his way to becoming one of the most important biologists of his generation. In the mid '60s, he had published a paper on the coevolution of ants and acacia trees that became a classic of evolutionary biology; later, he would do the same thing for wasps and figs. He is a MacArthur Fellow and a winner of the Crafoord Prize. Hebert was forced to write back and admit that he'd given up. "I'm not doing this anymore," he replied.

At the 2003 meeting, Janzen and Hebert made a deal. Hebert would provide discount barcode analysis for around \$2 each. Janzen would use his unparalleled field research operation to test whether barcoding worked, and he would create a prototype system to inventory animal life. Each barcode would link to a reference specimen, with collection notes, scientific name where possible, and detailed ecological data. Nobody in the world had access to as many fresh, annotated specimens of tropical moths as Janzen did. For decades, he had been hacking his way through the taxonomic impediment.

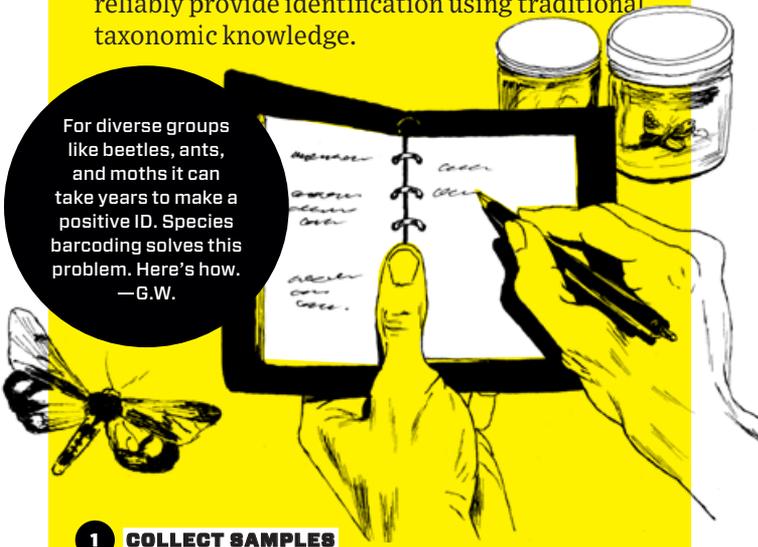
Janzen also began to advocate for Hebert's barcode project in every venue he could, taking advantage of his status to advance a vision that made Hebert's claims seem modest by contrast. In an editorial for *Philosophical Transactions of the Royal Society*, he wrote:

*The space ship lands. He steps out. He points it around. It says*

## HOW TO IDENTIFY A SPECIES

For many groups of animals and plants, there are only a handful of people in the world who can reliably provide identification using traditional taxonomic knowledge.

For diverse groups like beetles, ants, and moths it can take years to make a positive ID. Species barcoding solves this problem. Here's how. —G.W.



### 1 COLLECT SAMPLES

It's not necessary to take the whole animal. A piece of feather, a leg of an insect, or some bits of flesh will do.

### 2 DOCUMENT THE FACTS

Where was it found? When? What was the context? Take a picture and add a geocode. This information can be linked to the barcode, creating an ever-expanding trove of biological data.

### 3 EXTRACT DNA

At the barcoding lab, the tissue will be processed using detergent and a protease to break down cell walls and extract DNA.

### 4 READ THE DNA

The sequence of nucleic acids in the barcode region—only about 650 base pairs—is about one-ten-millionth of the whole genome. Using standard tools of molecular biology, this bit of genetic code can be amplified and read for less than \$10, with a turnaround time ranging from a few hours to a few days.

### 5 GET RESULTS

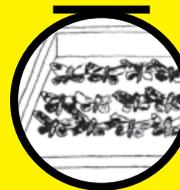
Match the sequence of the barcode region to sequences that have already been collected. There are three categories of results that can emerge:

#### MAKE POSITIVE ID



If the sequence results in a close match to a named specimen, the search is done.

#### ASSIGN TO GROUP



Match it within a large group of specimens that likely belong to the same species, although no link to a valid scientific name has yet been made.

#### ADD TO DATABASE



Even if the barcode doesn't match anything in the database, it could be matched to observations gathered from around the world.

*“friendly - unfriendly - edible - poisonous - dangerous - living - inanimate.” On the next sweep it says “Quercus oleoides - Homo sapiens - Spondias mombin - Solanum nigrum - Crotalus durissus - Morpho peleides - serpentine. This has been in my head since reading science fiction in 9th grade a half a century ago... Imagine a world where every child’s backpack, every farmer’s pocket, every doctor’s office, and every biologist’s belt has a gadget the size of a cell phone. For free. Pop off a leg, pluck a tuft of hair, pinch a piece of leaf, swat a mosquito, and stick it in on a tuft of toilet tissue. One minute later the screen says *Periplaneta americana*, *Canis familiaris*, *Quercus virginiana*, or *West Nile Virus* in *Culex pipiens*. A chip the size of your thumbnail could carry 30 million species-specific gene sequences and brief collaterals. Push the collateral information button once, the screen offers basic natural history and images for that species—or species complex—for your point on the globe. Push it twice, and you are in dialogue with central for more complex queries. Or, the gadget, through your cell-phone uplink, says “this DNA sequence not previously recorded for your zone, do you wish to provide collateral information in return for 100 identification credits?” Imagine what maps of biodiversity would look like if they could be generated from the sequence identification requests of millions of users.*

The barcoder, for Janzen, is more than just a scientific tool. It is an instrument to revolutionize ecological research, turning it from a specialized occu-

pation into a global collaboration. And he had an idea of where to find support for this kind of dream. Janzen introduced Hebert to his contacts at the Gordon and Betty Moore Foundation, who encouraged him to put in for a small grant, perhaps \$2 million. “Two million?” Hebert remembers thinking. “We’re married if you give me \$2 million.” It gave him the money, and the Canadian government followed up with \$30 million. Hebert got a new building with a big room full of sequencing machines, along with technicians to run them. The Canadian press picked up the story, mixed it with a bit of national pride, and announced that a scientist in Guelph was on track to put barcodes on all the animals in the world.

**AT** this point, a number of biologists began to feel distinctly annoyed. The claim that organisms could be barcoded was absurd. A can of soup can be barcoded, because it is a particular instance of an *original* can of soup. The soup had an author, who tasted it and pronounced it good. The same cannot be said of living things. There is no archetype for an animal, no original form that all particular examples of a wolf or a human or a housefly must somehow be expected to match. There is only reproduction. There is only inheritance



## TO SOME TAXONOMISTS, THE IDEA OF A BARCODE FOR EACH

with variation. There is only evolution. A species is a cluster of genotypes, none of them identical, even within the same brood. Implicit in the word *barcoding* is the notion that the creatures of Earth comprise a mosaic of stable kinds. This made Hebert’s critics laugh, because it is a common idea about species among the uneducated. It predates Darwin by thousands of years.

“We’re not accusing Hebert of being a creationist, just of acting like one,” says Brent Mishler. Mishler is an expert on moss. He is stocky and thickly bearded, with a gentle demeanor and immense knowledge. We stand and talk amid the tall cabinets of the Jepson Herbarium at UC Berkeley, where he is director. The cabinets contain the dried and pressed remnants of more than 2 million plants, one of the largest collections in the Americas. Mishler’s herbarium will identify a plant for you, if you send it in by mail. Although the official cost is \$75 per hour, the staff will almost always try to identify your specimens for free because the herbarium is meant to serve scholars and the public. But it is simply impossible to comply with everybody’s wishes, especially if the wish is for life to have conveniently ordered ranks, like an illustrated children’s book. Mishler is not a conservative. He knows that species names are a swamp of confusion and that the very idea of what counts as a species is a





Dan Janzen and Winnie Hallwachs foresee a tricorder-type device that can identify species on the fly.

topic of energetic debate. Hebert's automatic animal identifying machine is wrong, according to Mishler, not because it challenges conventional wisdom but because it's backward looking. "The Linnaean hierarchy is an outmoded remnant of a pre-evolutionary worldview," Mishler says. "People *want* to think of things as members of mutually exclusive, hierarchically organized categories. It is probably hardwired into human beings, but it is not true, and it is the source of tremendous problems in the world. George Bush does this kind of thing all the time." Mishler has a soft expression and a thoughtful tone, but he is very unhappy with Paul Hebert.

"Honestly, I never thought it would get this much steam," says Kipling Will, one of Mishler's colleagues. Will is associate director of the Essig Museum of Entomology. He is an expert on beetles. "My first reaction was that it was silly," Will says. "I don't get any grant money for bitching, but I thought, 'People are going to read this, so it deserves a critique.'"

Will's office is a few minutes' walk from the Jepson Herbarium, in the old core of the Berkeley campus. The Essig Museum has long served the needs of agriculture. Before bugs were interesting to evolutionary theorists, they were pests, and

ing that barcoding would be useful, at best, only in groups of animals that were already well understood. This undercut Hebert's key claim, for if barcodes depended on expert taxonomy, how could they be the solution to the taxonomic impediment? Other taxonomists joined the protest. Late last year, the prestigious journal *Evolutionary Biology* published an article by Marcelo R. de Carvalho, an expert on sharks, and coauthored by 29 other taxonomists from museums and universities around the world, warning that programs to automate the identification of species were bound to come to grief. Such schemes, Carvalho wrote, were delivered by "end users" of taxonomy who were "not familiar with the complexity of its hypotheses and its identity as a real, successful, and independent science."

And yet, all the while, Hebert's barcode database continued to grow. Ecologists joined the game, and marine biologists, and more foundations came through to fund the barcoding of specific groups. The Smithsonian Institution launched a global consortium, which held an international conference in Taipei. The barcoders treat their critics in the manner of Copernican astronomers brushing off niggling Ptolemaic complaints. "It's pretty frustrating," Will says.

**I'M** in a bar near an overdeveloped Costa Rican beach with the utopian lepidopterist. Janzen is working hard to persuade a local real estate speculator—a balding gringo with sunburned cheeks and a Gulf Coast accent—to give up a very large piece of land. With his khaki shirt, oversize digital camera, and uncombed white hair, Janzen looks like an innocent biologist. But in these parts, he is a power player of the first order, and, ten minutes later, the deal is done; \$2 million for 2,471 acres. Janzen will add the land to a biological reserve—Area de Conservación Guanacaste, known as ACG—that

## SPECIES IS

## LAUGHABLE. IT REPRESENTS A PRE-EVOLUTIONARY WORLDVIEW.

one of the reasons we wanted to know about them was so we could kill them. Will accepts that people need fast, accurate answers from taxonomy, but he warns that urgent utilitarian demands create pressure for shortcuts and attract superficial thinkers eager for a quick fix. "You cannot resolve these questions by looking at a single character, such as a short section of mitochondrial DNA," Will says, "unless you *already know* that character works in the particular group you are concerned about. And for most of what we're dealing with, you do not know that." Will reaches behind him and brings out a box. "Here are some beetles," he says. "These are a bunch of little black things. A lot of them are probably the only specimen that's ever been collected—or maybe ever will be—because habitats are destroyed and species go extinct. How are you going to get an identification by barcoding these?" If you pulled a leg off one of these beetles and sent it to Guelph, you wouldn't get a name, because no name yet exists. The barcoding project, Will says, is based on a fantasy.

Will never meant to turn his opposition into a crusade. But the overconfidence of the barcoders bothered him. Eventually, he coauthored a lengthy technical attack in *Journal of Heredity* argu-

takes up about 610 square miles and runs from up near the Nicaraguan border down almost to the city of Liberia, as well as a good distance into the sea. When the speculator's land becomes part of the conservation area, Janzen will start cataloging it, collecting specimens of all the lepidoptera he and his colleagues can find, pulling off their legs and sending them to Guelph. As hard as Will works to debunk Hebert's claims, Janzen works harder to register barcodes. He is trying, through sheer accumulation of insects, to impose the automatic animal identifying machine upon the world.

The first time he talked with Hebert, Janzen asked where Hebert was getting his specimens. "He told me he was using a personal butterfly collection," Janzen says. "That resonated, because *this* is a personal butterfly collection." We are standing behind his little house in a rough, open pavilion strung with ropes. Beneath the ropes hang hundreds of plastic bags full of leaves, and inside every bag there is a caterpillar, a pupa, a moth, or some flies or wasps that have managed to parasitize the caterpillar, eat the pupa, and emerge into the middle of this scientific experiment. Like the insects in the neighboring bags, the destiny of these parasites is to be frozen, dried,

identified, barcoded, and shipped to a museum for reference. Here, and in 10 other caterpillar-rearing stations in the forest, Janzen, Hallwachs, and their many local collaborators have solved taxonomic mysteries that go back hundreds of years. “Some of these moths have had names forever, and their caterpillars, too, and they’ve never been recognized as the same species,” Janzen says.

So far they have sent more than 77,000 insect legs to Guelph for barcoding and linked each to a complete digital record, including photographs, collection details, and collateral notes. Janzen knows these insects extremely well, but barcoding has focused his attention on distinctions that had always been impossible to sort out. “Sometimes you’ve got all these slightly different moths, and according to convention they are the same species,” he says. “The original specimen that goes with this name could be sitting in a dusty drawer in Berlin, and who knows what ecological information goes with it? Maybe none! So we send legs of all these supposedly identical insects to Paul, and sure enough, we get different barcodes. We go back to the box and sort them by barcode, and sure enough, one of the barcode clusters is big, one of them is smaller, one of them is gray, and one of them feeds on a different plant. So there goes your variation—there are four species!”

Janzen works his way slowly down the line of plastic bags, shaking them slightly, seeing if anything happened overnight. When he finds a moth, wings open, resting among the leaves, he removes the bag from the line and puts it into a freezer. “A hobbyist could do this,” he says. “A child could do it. Biology is common property. That’s the good thing, and it is also the bad thing. You need these observations, but there is no way to organize them, to connect them with the taxasphere.”

The taxasphere is Janzen’s nickname for taxonomic experts and the scientific knowledge they control. This knowledge lives in journals and monographs, in seminars, museum collections, and, least accessibly, in the brains of the taxonomists themselves. One afternoon, standing with me in the forest, Janzen points to a thin tree whose leaves have deep lobes. “Do you recognize this tree? It’s a papaya,” he says. “I don’t suppose you know how it is pollinated? If you look it up, you will see that people believe it is pollinated by moths. But this is not true.”

Later, I search the Web and find pictures of hawk moths drinking deeply from papaya flowers in full bloom. “Those are the *male* flowers,” Janzen says. The female trees have smaller flowers that are nearly odorless. Many years ago, here in Guanacaste, Janzen played host to the late Herbert Baker, one of the high priests of insect pollination. All night, Baker watched the flowers of the female papaya tree. No moths stopped in. The only visitors that drank sap from both plants were male mosquitoes. The papaya is an important crop and a popular garden plant, yet misinformation about its pollination is nearly total. Baker’s observations never left the taxasphere.

The next day, at a rearing station high on the slopes of one of the volcanoes, Janzen reaches into a plastic bag full of leaves and takes out a green caterpillar with red spots like eyes. “They are not eyes,” he says. “Caterpillars don’t have eyes.” He pokes the caterpillar and it gives a sudden turn, pointing its fake eyes toward his finger and puffing up like a miniature snake. Back in the ’80s and ’90s, Janzen proved this mimicry can work to deter predators. He had his fellow researchers sneak up on the nests of birds

that like to eat big caterpillars and wrap pipe cleaners around the necks of nestlings so they could not swallow. Later, they crept back to unwrap the pipe cleaners and retrieve the uneaten bugs. The biologists kept careful records of 65 nests. “You know what?” Janzen asks. “Not a *single* caterpillar with eye spots.”

Janzen keeps poking the caterpillar, but it no longer puffs and turns. “After you do it a few times they stop,” he says. “This caterpillar is going to turn into a moth, *Xylophanes germen*. The next time somebody finds it, how are they going to connect it with the story I just told you?” Earth, Janzen says, is like an unread book, but unread books can only entice people who are literate. “Take a kid on a field trip today and you can see that he is walking through the forest like a person who is totally blind.”

**IT** is 5 am. At the rearing barn in Costa Rica, the researchers—Hazel Cambronero, Ana Ruth Franco, and Sergio Rios Salas—are tired and quiet. We drove out the day before, carrying collecting equipment, plastic bags, and fluorescent lights, but the wind beat hard all night, making the sheet flap relentlessly against the hanging lamp. Every few seconds, the moths were startled away. The researchers gave up at dawn, and now they don’t bother with food or coffee but throw their gear into the Land Cruiser and rattle out the gate. Above them the sky is busy: Venus competes with Mercury and a waxing moon and a fruit-loop dawn. We climb back out of the Atlantic drainage, cross the Continental Divide, and descend toward the west. At a one-family village called New Zealand, we have breakfast, and the researchers begin to come to life. They were all born nearby. Franco has been working on lepidoptera here for more than a decade, since she was a teenager.

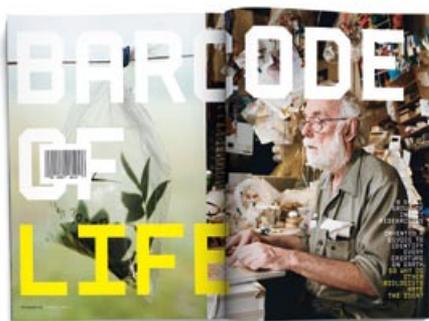
Janzen calls Cambronero, Franco, and Salas parataxonomists. They are neither university scientists who live off their research grants nor ignoramus who move through the natural world as if blind. Instead they are observers, discoverers, hunters of specimens. They are like 19th-century botanical and zoological collectors, who were part of a collaborative enterprise that spanned the globe; they traveled and corresponded, strove for credit, sold their services. Their collections and notes formed the undergrowth of biological knowledge from which the modern science emerged. Darwin in his youth was one of them. Aside from his genius, it was the key to his career.

There were standards battles even then. Joseph Hooker, the great director of Royal Botanic Gardens, Kew, attempted to get everybody to use tiny labels of precise dimensions to encourage brevity and prevent the accumulation of local detail from obscuring what he believed to be the widespread distribution of common species. Hooker wanted his collection to be the touchstone for the world, but he was premature. Nature was too diverse to be standardized by human experts using Latin words to describe salient features on little bits of paper.

In Guelph today, the barcoding factory is running at full speed. So far, Hebert’s team has analyzed nearly 375,000 specimens. In Madagascar, a well-known myrmecologist named Brian Fisher has been barcoding ants by the thousands; there is a collaboration under way to get the barcodes of all birds (they have done 30 percent in the past five years) and every species of fish as well.

Barcoding works. When a named reference specimen exists in Hebert’s database, the system can accept a bit of tissue, sequence the barcode region, and come up with a species | **CONTINUED ON PAGE 212**





## Barcode of Life

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name. Unfortunately, there are only about 47,000 barcodes that link directly to a name, because many of the barcoded specimens still lack a valid, traditional taxonomic identification. But Hebert no longer loses sleep over the taxonomic impediment. After all, the reason you want a scientific name is to connect with other research. When enough of this research is linked to barcodes, then the barcodes, not the names, will be canonical. Names will still exist, but they will be like nicknames, affectionate handles useful in writing and conversation but of fading relevance to science. Slowly, the 250-year history of Lin-

naean nomenclature will come to an end. “Each sequencer can run 500,000 sequences a year,” Hebert says. “Line them up, feed them bug bits, pay the chemistry bill, and we can easily register 1 million species in a decade. Give us a few more sequencers, more chemistry money, more bug bits, and we’ll register 100 million species in 20 years and then go swimming on a beach in Costa Rica.”

He is kidding about going swimming on the beach. The barcode simplifies a naming process that, until now, has been horribly tangled. But on the other side of this simplification is not simplicity. When even schoolchildren carry automatic animal identifying machines—well, what then? If there are 100 million barcodes, how many observations will there be? How many specimens? How many dollops of fact, semifact, and falsehood mixed together? Who will hack their way through this new tangle, even more fiendish than the old one? Beyond the taxonomic impediment, all the confusion of the natural world awaits.

Fortunately for the progress of science, a messy, almost organic growth of truth and half-truth is exactly the kind of thing that

human beings of a certain temperament find impossible to resist. Janzen, Hebert, Will, and Mishler—the barcoders and their critics alike—have been collecting facts since they were children, before they even knew what science was. In the end, barcodes are not just devices to put names on animals; they are also clever traps to catch all the people in the world whose curiosity impels them toward data as if toward light.

Among the first people caught, of course, was the inventor of barcoding himself, who long ago had given away his collection of New Guinea moths and butterflies so it wouldn’t torment his conscience. Recently, Hebert felt compelled to stop by the Canadian National Collection of Insects, Arachnids, and Nematodes. The possibility of extracting DNA from old specimens has been much on his mind. “They are still there,” he says. “Thirty years later, they are still unnamed. They are just sitting in a drawer, waiting for me to pull a leg off.” ■

Contributing editor **GARY WOLF** (gary@aether.com) wrote about futurist Ray Kurzweil in issue 16.04.