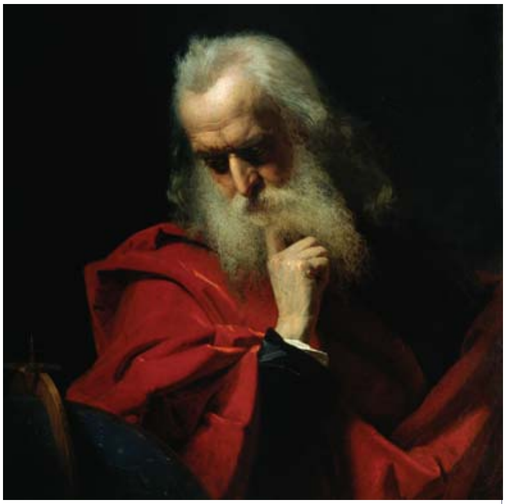

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In This Issue

Marguerite Holloway

Marguerite Holloway captures the innovative thinking behind **Daniel Janzen** and **Winnie Hallwachs'** grand vision of "bioliteracy" (Democratizing Taxonomy, p. 14). The renowned husband-and-wife team, who helped establish the Area de Conservación Guanacaste in Costa Rica, believes passionately that greater access to knowledge and technology will transform the future of conservation. Holloway is an assistant professor at the Graduate School of Journalism at Columbia University and codirects the Earth and Environmental Science Journalism program. She has written about environmental and other issues for such publications as *Discover, Natural History*, *The New York Times,* and *Scientific American*, where she is a contributing editor.

Daniel Janzen

Acclaimed science writer **Alan Burdick** raises the issue of perceptual bias in the way we go about researching and tackling invasive species (How Do You Measure What You Can't See?, p. 5). Burdick writes for *The New York Times Magazine*, *Harper's*, *GQ*, *Natural History*, and *Discover*, where he is a senior editor. His writing appeared in *2003 Best American Science and Nature Writing*. *Out of Eden* was recently named a finalist for the 2005 National Book Award and was a winner of the 2005 National Outdoor Book Award in the natural history literature category.

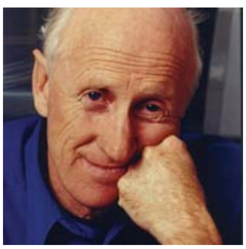
Winnie Hallwachs

Pulitzer Prize-winning journalist and author **Katherine Ellison** calls **Ross Gelbspan** an impassioned "Cassandra" when it comes to climate change (Get Real, p. 28). Gelbspan is a retired editor and reporter with *The Philadelphia Bulletin*, *The Washington Post,* and *The Boston Globe*. In 1998 he published *The Heat Is On: The Climate Crisis, the Cover-Up, the Prescription*. His latest book, *Boiling Point*, was reviewed by former Vice President Al Gore in the *Sunday New York Times Book Review* in 2005.

Alan Burdick

Ross Gelbspan

Environmental Heresies (p. 22) is a candid and provocative conversation with biologist, innovator, and entrepreneur **Stewart Brand**. An icon of the environmental and counterculture movements of the 1960s, Brand created and edited *The Whole Earth Catalog* (1968-1985); the 1972 issue of the *Catalog* sold 1.5 million copies and won a National Book Award. In 1988, he became a cofounder of the Global Business Network. Since then, he has cofounded The Long Now Foundation and the All Species Foundation. He has been a long-time trustee of the Santa Fe Insititute and occasionally advises Ecotrust. His most recent books are *How Buildings Learn* (1994) and *The Clock of the Long Now* (1999). In 1994, Brand was featured on the cover of *The Los Angeles Times Magazine*: ". . . by the time Brand's ideas spread, he's usually on to something else. He's so far ahead of the curve, it is easy to forget that he's often been there first."



Stewart Brand

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Imagine a portable DNA barcode scanner that could transform people's relationship with nature. Could such futuristic technology be to biodiversity what the printing press was to literacy?

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By Marguerite Holloway

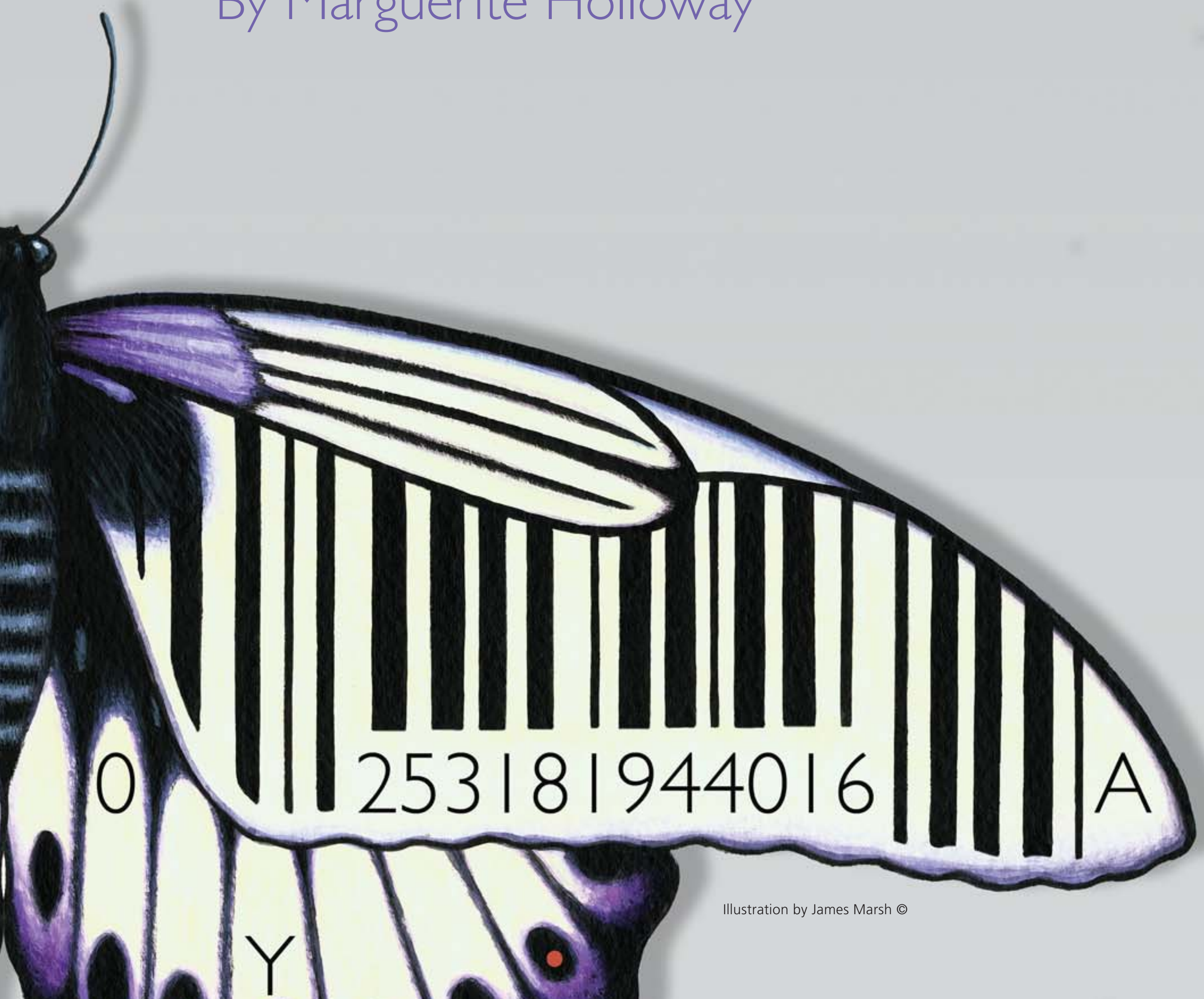


Illustration by James Marsh ©

With 16 butterflies hidden in a briefcase, biologists Daniel Janzen and Winnie Hallwachs arrived for a meeting at the Banbury Center of Cold Spring Harbor Laboratory in New York in March 2003. Some were dark-chocolate brown with white bands and patches of shimmering azure, others mocha with cream or black with orange lines—eight different pairs of skipper butterflies common to Costa Rica, where Janzen and Hallwachs had collected them. Each pair identical to the unpracticed eye. Identical even to the practiced eye.

Janzen and Hallwachs gave the butterflies to Paul Hebert, a molecular geneticist at the University of Guelph in Ontario and a featured speaker at the Banbury meeting. In the 1990s, Hebert and his colleagues had found a way to take a snippet of DNA from a single gene common to all animals and to read it as one would an ID tag.

In that stretch of one gene, they claimed, lay a world of difference that could distinguish a lizard from a leopard or one lepidopteran from another. Classical taxonomy, which relies on morphology, behavior, and genetics, can be time-consuming; and sequencing an animal's entire genome, which is rarely done, can be expensive. Here, as Hebert saw it, was a rapid, cheap way to identify a specimen, to know what species it belonged to: a barcode for biodiversity. The Alfred P. Sloan Foundation funded the Banbury meeting so that Hebert and others could present the technique as a way to speed up specimen identification and so that taxonomists and biologists could discuss whether the process could, or should, work to that end.

By many accounts, it was not a pleasant meeting. Some taxonomists thought Hebert's idea too simplistic. They were—and many remain—skeptical that a part of a gene could accurately serve as ID. "What we realized we were seeing in front of us was a very strong antagonism," Janzen recalls.

But Janzen and Hallwachs were thrilled. Where many saw limitations, they saw transformations. They saw a revolutionary technology that could change the way conservation is done. As biologists working in the tropics, where potentially millions of species remain unidentified, the husband-and-wife team had collected tens of thousands of specimens now stacked up in their offices at the University of Pennsylvania and lined up in museums, waiting to make their slow way through the taxonomic process. Janzen and Hallwachs desperately wanted a fast, inexpensive way to identify a known species or verify that one was unknown. But they also imagined the technology creating something much greater than a series of biodiversity inventories.

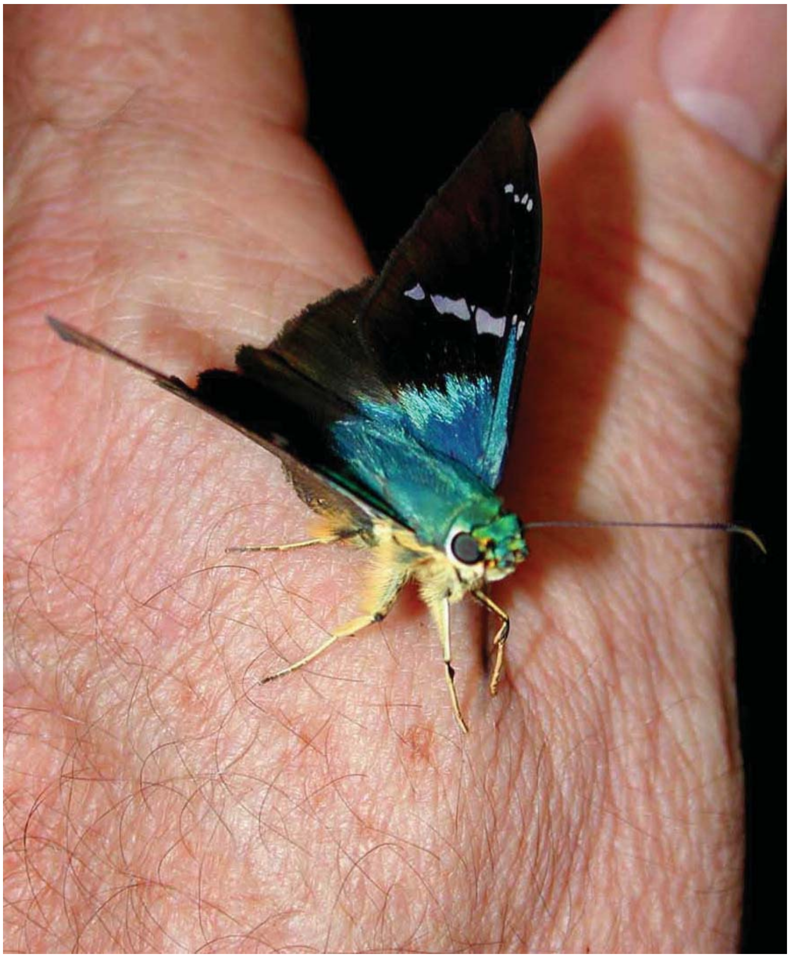
"We got to 3:00 in the afternoon on the second day, and by this time the room was full of roosters; the only way you could get anywhere was by turning into one," says Janzen, who has never been mistaken for a wallflower. "I pulled my comb out of my back pocket and said, 'What I want is something this size that will give me one sequence and one name in one minute for one penny.' And Paul Hebert looked at me across the room and said, 'You have raised the bar.'"

Janzen and Hallwachs have a long-running reputation for creative thinking. The vision that emerged from this meeting and from later ones, and that the two researchers and others are now promoting, is no exception. An inexpensive, portable DNA barcode scanner could transform people's relationship with nature, they argue. Any curious person could take the leg of a beetle or an ant or, eventually, a bit of leaf or bark, pop it into a device smaller than a GPS unit, "scan" its barcode, get a species name, Google that name, learn about the organism, and develop a connection to it.

Janzen and Hallwachs argue that such a gadget would be to biodiversity what the printing press was to literacy. "All you have to do is show people that there is a book and teach them how to read enough so they can pronounce the words. And they will go on and read it themselves. Not all of them will, of course not. But enough," Janzen says. "If you can't read, what is a library? Just a stack of nice firewood and that is all it is."

Bioliteracy, as Janzen and Hallwachs conceive it, is crucial to saving nature. Enough talk of losing it all, they say; enough doom and gloom, enough going to hell in a handbasket. "We have to move to what people *do* care about,

Opposite: Curator Wojciech Pulawski and Collections Manager Norman Penny in the California Academy of Sciences' entomology collections. Photo by Dong Lin



Photos by Daniel Janzen

Above: In the Area de Conservación Guanacaste in Costa Rica, DNA barcoding has revealed that this butterfly species—known for 250 years as *Astraptes fulgerator*—is in fact ten species. The adults look identical, but the caterpillars have significantly divergent color patterns correlated with different food sources. Shown here are the ringed caterpillar eating *Trigonia* (*Trigoniaceae*) and the spotted caterpillar eating *Hampea appendiculata* (*Malvaceae*).

something that gives them a return," Janzen says. "If you can't know what the objects are that are walking in your backyard or your house or your kitchen, or when you go into a park or to the ocean, then there is no reason to keep them."

Janzen and Hallwachs want biological knowledge to extend beyond experts, to move out of the hands of the one person in the world who can identify a certain spider, to reach everyone. They see a handheld barcode device—which doesn't exist yet—democratizing information, bolstering bioliteracy, making gardeners of us all.

THEY HAVE STARTED THE REVOLUTION in their own garden: the 156,000-hectare reserve, Area de Conservación Guanacaste, in northwestern Costa Rica. Janzen and Hallwachs helped establish the reserve in the 1980s and 1990s through creative, now-famous means described in many articles and in William Allen's book *Green Phoenix* (1). For several decades, the two have sought to find every species of butterfly and moth living in the area and have run into some severe challenges. A butterfly called *Astraptes fulgerator* posed a problem that Janzen, Hallwachs, and their collaborator, entomologist John Burns of the Smithsonian Institution, couldn't solve in classical ways. The caterpillars of this one species differ in appearance and eat different plants. Yet the adults are indistinguishable. Even their genitalia, the morphological feature which distinguishes many moth and butterfly species, are the same.

And that is why sixteen butterflies went to Cold Spring Harbor Laboratory and then to Guelph. Those 16 butterflies emerged as 16 different species when Hebert looked at their barcodes. So Janzen and Hallwachs thought Hebert might solve the mystery of *A. fulgerator*. Hebert sequenced the relevant stretch of the single identifying gene in nearly 500 of these butterflies. Called cytochrome *c* oxidase 1, or

CO1 for short, the gene is located in the mitochondrial DNA of all animals (except for a few protists) and is part of the cell's respiratory machinery. Mitochondrial DNA is inherited from the mother's side and mutates more rapidly than nuclear DNA. For this reason, Hebert had suspected that recent differences between species would show up more clearly here than in nuclear DNA. (At present, plants can't be barcoded, although several research groups are close. John Kress and colleagues at the Smithsonian Institution, for instance, have located two sequences that might soon serve as rapid identification for flowering plants.)

Soon, as Janzen and the team described in a 2004 paper in *Proceedings of the National Academy of Sciences* (2), *A. fulgerator* was not one but ten species. "That just blew everyone's mind away, including ours," Janzen says. Other researchers are finding similar richness. Hebert, Mark Stoeckle of The Rockefeller University in New York, and collaborators discovered that 260 North American bird species were, according to their CO1 signatures, actually 264 species. At this rate, estimates of 10 to 50 million species on the planet—fewer than 2 million of which have been identified—might prove conservative. Such exuberant branching may pose a problem for conservationists in the U.S., where a fight to protect one species might be more challenging if that one species were suddenly three.

But in other places, the explosion of knowledge is a boon to conservationists. Brian Fisher of the California Academy of Sciences and his team typically collect 1 million ants a year, ship them to 140 collaborators, and then wait: "We have nothing to show for it, except for a few new species." So two years ago, Fisher began sending ants from Madagascar to Hebert's lab. Until now, botanists, mammalogists, and ornithologists have been the ones most able to influence conservation management decisions through rapid biodiversity surveys. Thanks to the CO1 barcode, Fisher says, entomologists are now in the game. In Madagascar, he contends, entomological variation can be as good a guide to conservation planning as bird diversity can.

And in Mauritius, where Fisher also collects, a CO1 barcode sequence just saved the last one-hectare habitat of a newly discovered endemic ant (*Discothyrea berlita*), one of nine ant species found nowhere but on the island. This January, the Mauritius Forest Service was about to remove all nonnative plants in a small patch of forest, a move Fisher says would have eliminated the ant. He sent a local nongovernmental organization a reprint of a paper describing the new ant and its vulnerability. Within days the Mauritius Forest Service changed course. "They had me rewrite a long management plan," he says. The native ant remains safe in its bower of invasive and native vegetation. Ironically, the mix of plants protects this tiny forest and its endemic ant from destructive exotic ant species better than an invasive-weeding management plan can.

Fisher, Janzen, and Hallwachs are careful to emphasize that, powerful as CO1 is, it can't stand alone. Without traditional taxonomy, a CO1 sequence can be like an unfinished sentence. If Fisher sees something unclear in CO1—perhaps he can't parse species because they hybridized or recently speciated—he will check nuclear genes for the full picture. Muddiness in CO1 excites him because it reveals a conundrum to be unraveled.

> Janzen and Hallwachs anticipate that barcodes for **all the species in the world** could end up on a fingernail-sized chip.

As researchers and Hebert sequence specimens, they register the CO1 barcode in GenBank, a database of DNA sequences in the public domain. The sequences are flagged with information about the voucher specimen, taxonomic identification, and location. Without a library of taxonomically verified CO1 barcodes from field studies, museums, and zoos, a handheld device will be useless and short-lived. That's why Janzen and Hallwachs' vision doesn't entail just the instrument. A teenager placing an ant into a barcoder needs an "ant chip" to put into that device (Janzen and Hallwachs anticipate that CO1 codes for all the species in the world could end up on a fingernail-sized chip). Or the teen needs to connect via wireless to a CO1 sequence library where the ant's code can be matched. Only then will a name for that ant emerge—a name that can serve as the hook with which to pull in knowledge.

All this may not be far off. Researchers in medicine, agriculture, natural resource management, and defense have a pressing need to quickly identify infectious agents, pests, invasive species, and illegal products made from endangered plants and animals. Inspectors without expertise could quickly identify a questionable insect egg on fruit, larvae in ballast water, or a slab of bushmeat. "Barcoding can be done by someone who has no training, and that is really the power of it," notes Stoeckle of Rockefeller University. "You can take advantage of all the knowledge that is out there and allow an untrained person to identify something."

Even to the trained eye, some things are impossible to tell apart—fish flesh, for example. The U.S. Food and Drug Administration is setting up a barcode library for 100 fish species because there is so much fraud and illegal fishing, says David Schindel, executive secretary of the Consortium for the Barcode of Life, a partnership of more than 110 organizations headquartered at the Smithsonian Institution. A recent study published in *Nature* showed that fish marketed as "red snapper" represented as many as 22 species (3). If consumers could test their own meals, barcode activism might eventually flourish. Given all the federal and industry activity, Schindel predicts that tabletop barcode devices are two years off, portable versions five years off.

On a clear, cold January morning, I meet with Janzen and Hallwachs at the University of Pennsylvania to talk about barcoding and the future of conservation. They are leaving for Costa Rica the following day; Janzen teaches only four months a year, and the couple spends the rest of its time—as much as possible—in the Area de Conservación Guanacaste.

Janzen sits behind his desk, a gray eminence in gray fleece and gray glasses, his gray beard tamer than it was in the 1980s, when writers and biologists described him as a wild man. Less hirsute perhaps, but no less energetic. He becomes the bard of barcode, recounting a tale of coincidence and fate much as I imagine the Greek poets did.

Hallwachs interjects, answering unanswered questions, correcting him, providing dates and finer detail—it is the system they have worked out over decades of collaboration. "Now let me be clear," Janzen says at some point. "I say it in jest, but it is true. I talk, she thinks." Hallwachs is tall and slender, with long brown hair and a gentle voice. "Daniel, my friend," she says emphatically during one conversation when they disagree. And then to me, "I strongly think Dan is wrong."

They may differ about a point of mitochondrial genetics, but about barcoding and bioliteracy they are in complete agreement. Innovation and democratization have been at the root of their work in Costa Rica. They have

Opposite: Brian Fisher with an ant collection at the California Academy of Sciences. Photo by Dong Lin catalyzed the unprecedented and as-yet-unreplicated by working with many people to endow a national park that can cover its costs with the interest income. They didn't set aside a pristine area, an untouched gem, as most conservationists seek to do. They bought denuded, grazed, and farmed land right along with primary forest; they experimented with restoration. They trained residents as field biologists and to run the conservation area. They established an education program for children and adults.

Innovation and democratization underlie their belief in a handheld barcoder. The instrument could make knowledge about the natural world available to everyone, they say. This knowledge, this bioliteracy, is crucial to the future of nature as garden, in Janzen and Hallwachs' view. There is no place humans have not or will not soon alter or put to their own uses. A garden needs savvy gardeners and tools. The barcode is one of those tools.

> A name can confer familiarity, recognition—it gives something a place in the world, a history, it makes it real.

The technology wouldn't replace field guides. "You can't get a piece of evidence when it is flying away, or when taking a sample might destroy the animal," Hallwachs says. "But the barcoder would solve problems of scale when there is too much information: like 13,000 species of plants in Costa Rica and 1,000 species of shrimp in the sea." And it won't replace education programs any more than teaching people to read did. But it might open up the natural world to people in a new way. A name can confer familiarity, recognition. You cannot dismiss people readily when you know their name—it gives them a place in the world, a history, it makes them real. Janzen and Hallwachs are saying the same holds for the organisms all around us.

As I listen, I wonder whether naming can transform people's relationship to nature. I think of my mother, who loves birds but can't recall their names most of the time. She loves them no less, travels no shorter distances, wakes up no later, makes no fewer donations because she doesn't know what to call the lovely creature she just caught a glimpse of. For her, a name would be nice, but she is already committed to birds.

Then I wonder whether someone who is not already in love with the out-of-doors and animals and plants would even pick up a barcoder. It seems that innate curiosity or love or obsession—like Janzen's, like Hallwachs'—would already have to be there, and if it is already there, wouldn't those people already be committed to conservation? How would the barcoder change people who have no interest?

I ask Janzen and Hallwachs about this. A barcode device would intrigue or attract many people not already in the fold, they say. And it would allow those with curiosity to go deeper. Janzen gives the examples of a boy picking a butterfly wing off a car radiator and a mother seeking to find out whether the caterpillar that stung her daughter was harmful. Their curiosity could be satisfied immediately, and they might even become interested in the natural history of the creature they crossed paths with—at the very moment that they crossed paths. "If there is a way of incorporating wild biodiversity into their lives, it will be through knowing what it is. If you don't know what it is, you will destroy it," Janzen says. "How are you ever going to get people to see the wild world as anything other than an object to be pushed away or chopped up unless they come to have some personal relationship with it?" ❧

1. Allen, W. 2001. *Green Phoenix: Restoring the Tropical Forests of Guanacaste, Costa Rica*. Oxford University Press, New York.

2. Hebert, P. et al. 2004. Ten species in one: DNA barcoding reveals cryptic species in the neotropical skipper butterfly *Astraptes fulgerator*. *Proceedings of the National Academy of Sciences* 101(41):14812-14817.

3. Marko P. et al. 2004. Fisheries: Mislabelling of a depleted reef fish. *Nature* 430:309-310.

Marguerite Holloway is a science writer based in New York City. She has written about environmental and other issues for such publications as *Discover*, *Natural History*, *The New York Times* and *Scientific American*, where she is a contributing editor. Holloway is an assistant professor at the Graduate School of Journalism at Columbia University and codirects the Earth and Environmental Science Journalism program.