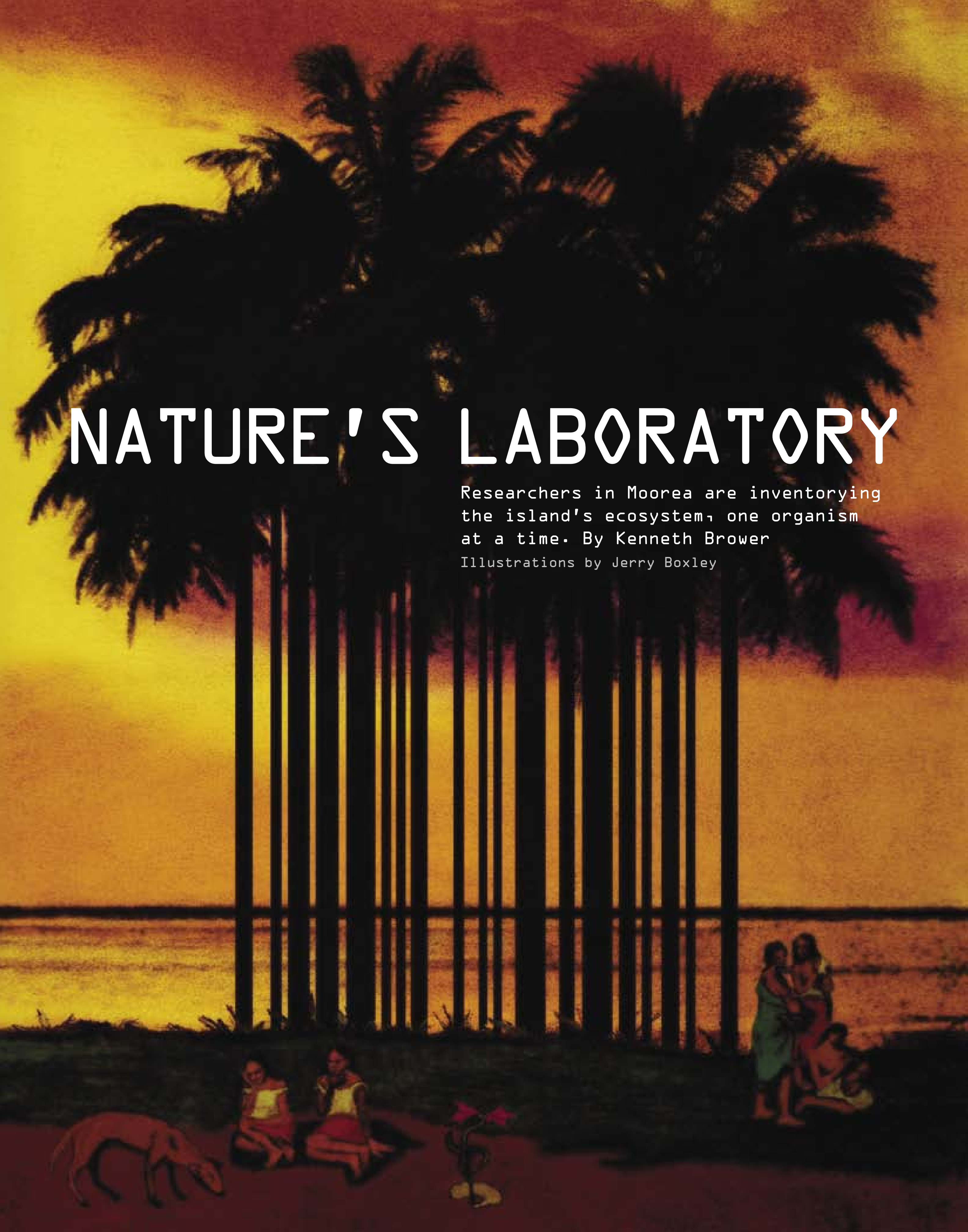
NATURE'S LABORATORY

Researchers in Moorea are inventorying the island's ecosystem, one organism at a time. By Kenneth Brower

Illustrations by Jerry Boxley



It was not storm or shipwreck or conquest that brought the first Europeans to the South Pacific island of Moorea—it was science. In 1768, Lieutenant James Cook and his ship *Endeavor* were dispatched to the Society Islands to observe the 1769 transit of Venus across the face of the Sun. Using these observations, astronomers at the Royal Greenwich Observatory hoped to determine the basic yardstick of the universe: the astronomical unit (AU), the distance from the Earth to the Sun.

Cook built a fort and observatory at the northern tip of Tahiti and then sent botanist Joseph Banks and a couple of crewmen, along with several Tahitians, rowing overnight across the nine-mile channel to the neighbor island of Moorea. There they were to establish a second observatory. Banks and his countrymen, Gore and Monkhouse, were likely the first white men to set foot on Moorea.

Two hundred thirty-eight orbits of Earth and three transits of Venus later, science has returned to Moorea in search of another, much smaller yardstick. This time, they are searching for a snippet of mitochondrial DNA called *cytochrome oxidase 1* (CO1). It seems to be shared by most animal species, is inherited maternally, and mutates rapidly—all traits that make it a convenient marker to distinguish species.

This quick, cheap, and fairly reliable method—"barcoding" it has come to be called—is the backbone of the Moorea Biocode Project. Undertaken by the Richard B. Gump South Pacific Research Station, a Berkeley facility on Moorea, in collaboration with a nearby French facility, CRIOBE (Le Centre de Recherches Insulaires et Observatoire de l'Environnement), the wildly ambitious Biocode survey aims to catalog all nonmicrobial life on the island.

Beneath the desire simply to know what's there lies the hope that such a comprehensive inventory will help biologists understand this single island ecosystem—and by extension, provide hints at what is happening to the planetary ecosystem. Without good baseline studies, we have no way to quantify what we're losing and so are handicapped in efforts to avert the losses. At stake is the very fabric of the planetary ecosystem on which our survival depends.

GUMP STATION SITS ON COOK BAY of Moorea's north shore beneath peaks impossibly steep to be so green, like a painted backdrop for a movie. The station's dock adjoins a wet lab, beyond which a shoreline dormitory houses students from Berkeley's departments of Integrative Biology (IB) and Environmental Science, Policy, and Management (ESPM), who come every autumn to conduct two months of fieldwork. In scrub hibiscus forest on the lower slopes of Mount Rotui is a row of A-frame bungalows for visiting scientists.

The heart of the station is a two-story lab building. Upstairs are offices, a library/conference room, and the Molecular Lab, the DNA distillery where the raw material of Moorea's biota gets reduced to its essences. Aimee Ellison '07, who runs the lab, first came to Moorea in 2006 with the Berkeley class, and has returned to the island with the Biocode Project. She prepares every specimen collected on the island, extracts its DNA, and ships one-fourth of the extracted DNA off to the Smithsonian for sequencing. The remaining three-fourths she archives in a Gump Station freezer at –80°.

On the first floor of the building is a muddy-boots lab ("Dirt Lab" is stenciled on the glass door), then a more hygienic National Science Foundation lab, and then one marked "Biocode Lab" and illustrated by the project's logo, a gecko crawling across a barcode. Here, one afternoon last October, Brent Mishler of Berkeley sat at a workbench, using forceps to tease liverworts out of a clump of moss. To his left lay a row of plastic bags packed with mosses. Their yellow-green shade, combined with Mishler's cheerful manner, Ken Kesey build, and graying Jerry Garcia beard, seemed to suggest illegal agriculture. In fact Mishler is a legitimate character—an IB professor and the director of both the Jepson Herbarium and the University Herbarium at Berkeley. The contents of his plastic bags were actually just bryophytes, with zero street value. Since 1994—the year after he left Duke for Berkeley—Mishler has been traveling to Moorea with the IB class and does double duty as co-leader of the terrestrial botany research effort for the Biocode Project.

Claude Elisabeth Payri from the University of New Caledonia (Nouméa) sat on the opposite side of the lab bench. Her forehead still showed the impression of her dive mask, and her auburn hair was wet. She was patiently unraveling what she called a "double": two intertwined strands of marine algae of different species. Much of the work at the Biocode Lab involves this kind of painstaking segregation; it's imperative that the DNA of only one species be analyzed at a time.

For some moments I watched her work, and then cleared my throat to propose that maybe, occasionally, despite her meticulous care with the forceps, an impure sample must get through? At this, Payri looked up. "That's why it's dangerous to have only one marker," she said. Mishler, overhearing, laughed an appreciative laugh.

"Do you agree?" asked Payri, ducking to peer under the intervening shelves.

Does he ever! Mishler believes that barcoding, in its reliance on a single genetic marker, is madness. "It doesn't allow for the fact that organisms *vary,*" he says. "The members of a species are not like cans of Campbell soup. Each individual is uniquely different."

Hard-core barcoders, he says, claim that eventually there will be no need for taxonomists—a cheap little machine will allow any 10-year-old to feed in toe of frog or wool of bat and get an instant readout identifying the species. Mishler scoffs at the notion. Biological investigators, he says, must have some idea of what they are looking for: Squads of machine-toting 10-year-olds would just sample the common species repeatedly and miss all the rare ones.

But Mishler insists he is happy with the Biocode Project's process on Moorea. "It's really just an old-fashioned biotic survey that Darwin and Wallace would have embraced, only updated with automated technology and IT."

SEVERAL BUDDHAS LINE THE PATH to Gump House, where station director Neil Davies resides. All are weathered and slightly askew—together with the overspreading banyan roots, they give the place the look of a jungle ruin. The Buddhas are indeed vestiges of another era, left behind by Richard Gump, the San Francisco department-store magnate who donated this land to science.

The station director is a fit, boyish Englishman of 39. He grew up in a working-class family in Oxford and graduated from that stellar university. Davies was not drawn to biology by some lizard on a rock or bird on a branch. Rather, he was captured by the books of naturalist Gerald Durrell, particularly those set on the island of Corfu.

Then in 2002, two years into his job as director at Gump Station, Davies was aboard Craig Ventner's yacht. Ventner, the wildcat gene-sequencer, had just published the first drafts of the human genome and had sailed to Moorea to sample marine microbes. "Well, ecosystems on islands have often been studied as models. 'Natural laboratories,' they're often called. I'm a population geneticist by training, and genome sequencing is one of the most exciting advances in science in the last couple of decades," Davies explains.

Aboard Ventner's yacht, these elements came together, and Davies had his aha! moment: *Wouldn't it be great to do the genome of Moorea?* And so began the Biocode Project.

He soon settled on barcoding as the route to an abridged version of that goal, and he remains fixed on it. The rebellion of Brent Mishler and other barcode apostates seems not to have discouraged Davies. "In the end, I think, the differences between us have been exaggerated," he says. "In barcoding we want to create a standard around something that's relatively simple." But he acknowledges that one gene will not ultimately be enough to capture an eco-

system. "With plants, CO1 doesn't work, whereas with animals and insects, it works very well. The barcode community recognizes that in different groups it will have to be a different gene."

CLAUDE PAYRI AND HER TEAM OF algologists planned to collect specimens on the outer reef slope off Cook Bay, but a big swell was rolling in from the northwest. Heading instead downwind to the northeastern tip of Moorea, in the lee of two low reef islets, the French team pulled on their wetsuits. Payri was assisted by two colleagues from Nouméa: her husband, Jean-Louis Menou, who is an expert on echinoderms, and her student Lydiane Mattio, a specialist on *Sargassum.* On a 75-minute dive, the three worked their way up the reef slope, collecting algae in net bags, which they passed up to the boat.

While they decompressed, Payri wanted to use the time to collect in the shallow water near the two reef islets. Both were covered in a feathery forest of casuarinas, and separated by a shallow tidal channel, its white-sand bottom dotted with coral heads. Here in the warm shallows, amid tourist snorkelers wearing swim trunks and bikinis, the French algologists in black wetsuits with sheathe knives strapped to their ankles looked like Navy Seals invading a beach picnic.

Following in my facemask and fins, I watched Payri and Mattio carve specimens from coral heads, tuck them in Ziploc bags, and then swim to the next coral head. There are an estimated 600–700 species of fish in Moorea, and to date the Biocode Project has collected mitochondrial DNA from 450 of them. Among them is the Picassofish, a triggerfish with a prognathous snout and an astonishing color pattern. When I got back to Gump Station, I looked the fish up in the database. Its CO1 nucleotide sequence reads

ACCCTATACCTAATTTTCGGTG
CTTGAGCTGGGATAGTAGGCAC
AGCCTTAAGCTTGCTAATCCG
GGAGAACTGAGCCAACCCGGCG
CTCTCTTAGGCGATGACCAGATT

TACAATGTCATCGITACAGCACA
TGCTTTCGTTATAATTTTCTTTA
TAGTAATACCAATCATAATTGGT
GGTTTCGGAAACTGACTAATCCA
TTAATGATCGGAGCCCCCGACAT
AGCATTCCCCCGAATGAACAACA
TGAGCTTCTGACTTCTACCGCCT
TCACTTCTACTTCTTCTTGCCTC
CTCAAGCGTAGAAGCCGGTGCTG
GAACCGGATGAACAGTGTACCCC
CCTCTCGCAGGCAACCTGGCCCA
CGCGGGGGCCTCTGTTGACC
TCACTATCTTCTCACTCCACCAG
GTATCTCATCAATTCTAGGGGCT
ATTAATTTCATTACAACAATTAT
TAATATGAAACCCCCCGCCAT
TTCTCAATACCAAACACCCCT
GTTTGTTTGAGCAGTTCTGAT
TACAGCAGTCCTTCTCCTCTTA
TCTCTCCCAGTCCTAGCTGCTG
GAATTACAATACTACTAACT
GATCGAAATTTAAACACCACAT
TCTTCGACCCTGCTGGAGGTGG
GGACCCGATCCTTTATCAACA
CTTA

On the one hand, I found this deeply unsatisfying. As Mishler might point out, it is such reductive shorthand for a creature as lovely as the Picassofish. On the other hand, it isn't really simple—copying this code was the trickiest passage I have ever typed. In some stretches—CCCCCCGCC, for example—the letters were hard to count, causing my eyes to cross and blur. The exercise left me full of admiration for life, which manages to copy such instructions correctly almost every time.

IN ONE OF THE GUMP STATION'S LAND ROVERS, the project's two mycologists set off for Afareaitu Falls to collect fungi, and I went along. Sarah Bergemann, an associate professor of mycology from Middle Tennessee State University, was at the wheel. Her colleague, Todd Osmundson, a postdoctoral researcher from Berkeley, rode shotgun and navigated. En route to the trailhead, we passed native women whose faces and bright-colored smocks gave me a sense of déjà vu—Gauguin paintings come to life.

The path to the waterfall switchbacked through a jungle of Tahitian chestnuts and hibiscus trees. The understory smelled like a good place for fungi, but nobody knew for sure. ("There's no literature in Polynesia on fungi," Osmundson had told me.) At the first bend, we came upon a ladder of polypores (shelf fungi) climbing a dead tree. "*Ganoderma,*" said Bergemann. "It's a common wood-decaying pathogen." Osmundson held his GPS high overhead, recorded the coordinates in his notebook, and then broke off some samples.

A few yards up the trail, Bergemann knelt to harvest a cluster of small mushrooms with slender, pale stalks and cinnamon-colored caps. "*Galerina,*" Osmundson said. "The same toxin as death caps. Fortunately, nobody eats it because it's so small."

A couple of hours of collecting brought us to the base of Afareaitu Falls. In the wet season, this tall waterfall roars, but today it just splashed down the sheer black basalt. Bergemann and Osmundson sat and drank from their water bottles in the cool, moist microclimate. Meanwhile, they took inventory of their specimens. I had seen them collected, one fungus at a time; yet here, together, the plastic cases became portable galleries celebrating the strange beauty of the fungi and their dizzying diversity. Again and again on Moorea I would have this same impression: The science of the Biocode Project was always verging on art.

THE BIOCODE PROJECT WAS OPERATING at full capacity in October 2008, for the first time in its short history. In this period of feverish output, the laboratory perpetually looked like the aftermath of a fraternity party. Disposable cups covered all the workbench surfaces, each one holding an inch or two of what appeared to be unfinished vodka, but was in fact just seawater. At the bottom of each cup, like the worm in tequila, an invertebrate swam or crawled, while at the top floated a slip of paper identifying the collection site.

One afternoon the invertebrate team processed a site designated "MIB-7." Four cups held tiny, exquisite reef shrimp, each a different species. In a fifth cup, a small reef crab lay on her back, gripping the MIB-7 label, holding it overhead in one claw, as if greeting someone named MIB-7 at the airport. Then, 40 minutes later, she and all her companion shrimp had been processed—photographed and logged into the database, with a leg or claw confiscated for DNA sequencing—and the team was filling the cups with a new batch of reef shrimp, every one of them different from those that had gone before.

Jonathan Geller, Ph.D. '88, called me over into his domain, the marine plankton. Professor Geller studies marine invertebrates at San Jose State University and the Moss Landing Marine Laboratories. He sat at his microscope, processing, one milliliter at a time, some zooplankton collected that morning outside the reef. "That's a pteropod, a sea butterfly," he said, pointing to the microscope monitor. On clear, gelatinous "wings"—the lobes of its two outsized parapodia—the pteropod flapped slowly and majestically across the screen.

From Geller's plankton, it was but a step sideways to the realm of George Hecht, the ostracode specialist. He sucked up an eyedropper full of wet sand he had collected on the back-reef, squirted it into a small black bowl, and set the bowl on the stage of his microscope. Encircling the bowl's rim with his thumbs and index fingers, as if warming his hands around a cup of coffee, he made the tiniest clockwise rotations of the bowl—a slow turning that continually brought new areas of magnified sand into the bright inner circle of the beam.

Hecht's hands are large—he was forced to hold his three outer fingers daintily out to the sides, like a prizefighter at a tea party. "I can do three hours at a stretch before my eyes begin to cross," he said. "I used to do this eight hours a day at the Smithsonian."

For a while I watched Geller and Hecht, seated at adjacent microscopes, as they labored at this Lilliputian end of Moorea's ecosystem. Moorea had been chosen for its relatively simple ecosystem, yet even here the cataloging of everything alive was only a goal, never a possibility—as the researchers themselves were quick to admit. The microscopy in this lab was like astronomy, forever revealing a cosmos receding more rapidly from us.

And so it went. The Biocode philosophy was to cheat sleep now and crash sometime later on the mainland, and the researchers worked late into every night. The men were sometimes rank from the day's exertions in the field, and stubbled with two or three days' of beard. The women were neater and more fragrant but equally weary. They all labored to the irregular pulse of camera strobes as they documented specimens.

The euphoria of running on fumes and camaraderie gave way, in the wee hours, to pure fatigue, yet exhaustion never stopped the researchers from kibitzing. The truism about modern science—that its practitioners grow ever more narrowly specialized and isolated—was temporarily suspended. Everyone was winging it a bit; the scope of the mission required each scientist to work outside their core expertise.

Barcoding is new science, but this kind of scientific enterprise is not. The Challenger Expedition, the Great Barrier Reef Expedition, and all the other great biotic surveys of history were animated by this same collegial, interdisciplinary spirit. True, the barcode method is reductive shorthand—that is the whole point—yet the effort to gather these codes is expansive, even heroic. ◼

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