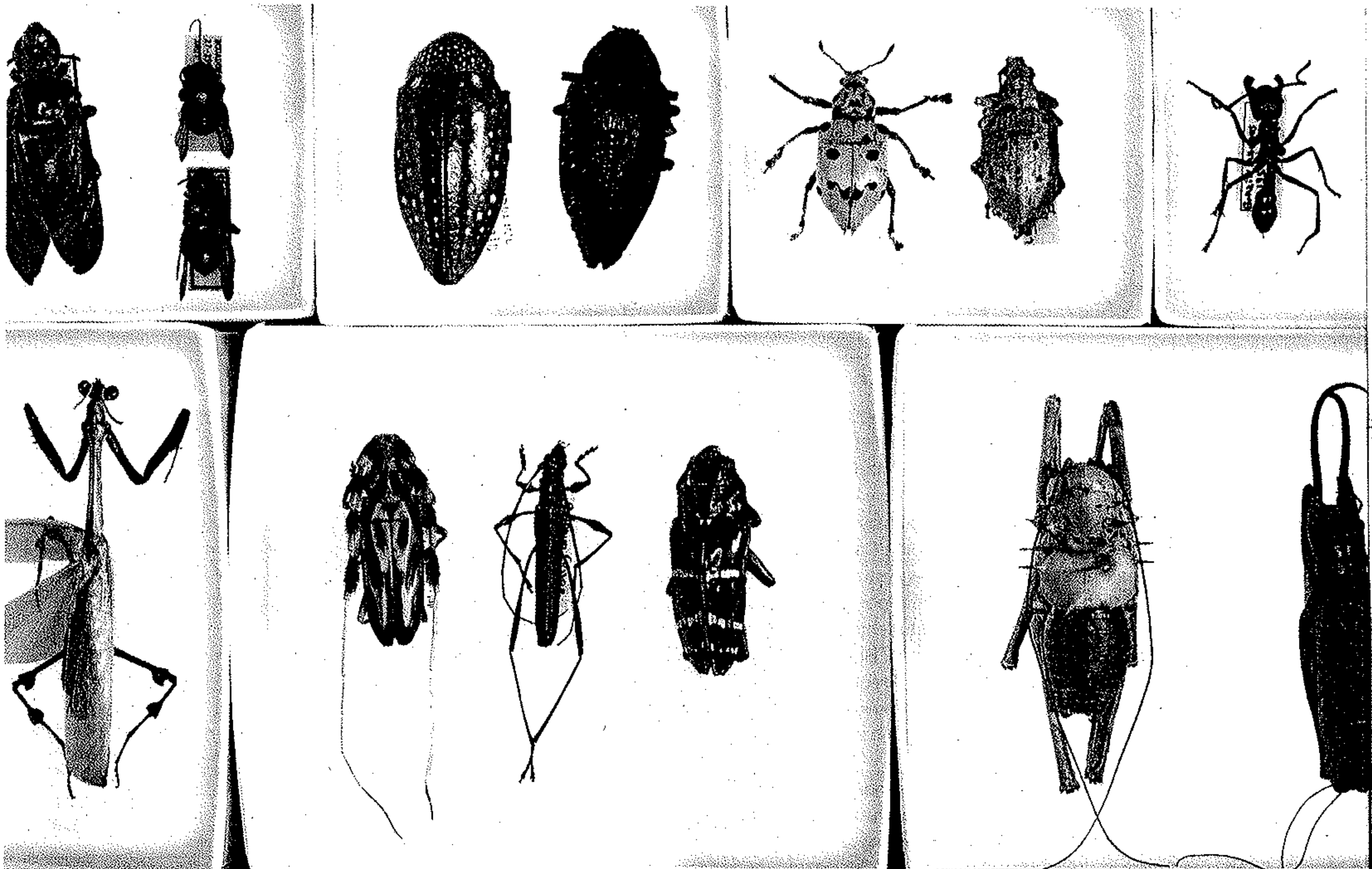
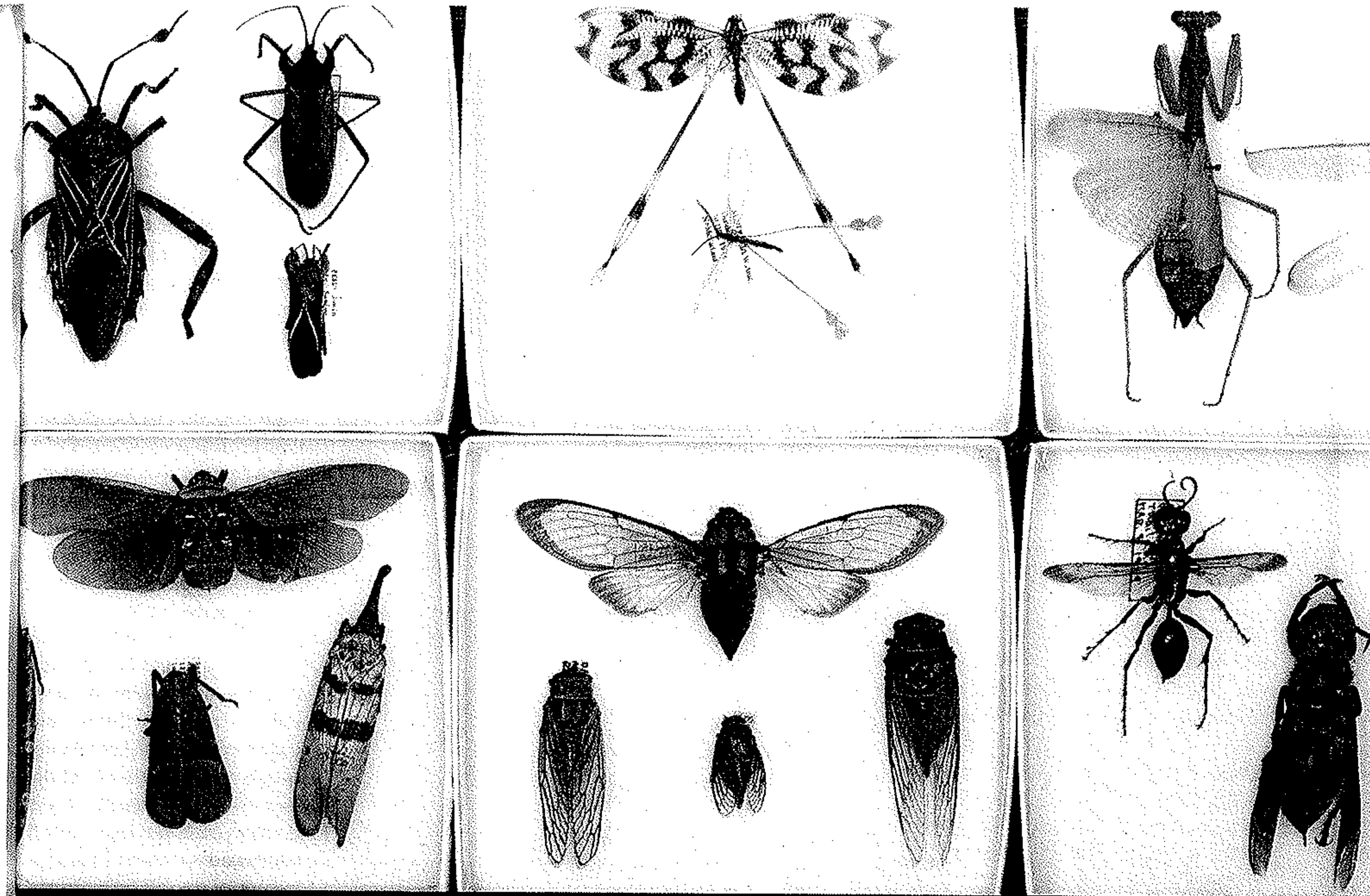


UNCLA

For three centuries, scientists have divided living things into tidy species. But the real world seems more slippery: a continuum in which one variety of life flows seamlessly into the next.

By Richard Conniff

When scientists concluded in 2007 that the giraffe—long regarded as a single species, *Giraffa camelopardalis*—should in fact be classified as six or more species, the news worried schoolchildren and conservationists alike. The finding, based largely on genetic evidence, suggested that these graceful, long-necked animals were in trouble. Lumped together as a single species, the giraffe seemed relatively healthy, with a population of up to 110,000 individuals scattered across sub-Saharan Africa. But split apart into at least six separate groups,



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some of the most beloved animals on earth suddenly looked "hyper-endangered," as one researcher put it. The study was unsettling on a more basic level, too. The idea that an animal so well known and so big—the giraffe is the tallest animal on earth—could have so many cryptic species hiding beneath its familiar dappled flesh seemed to call into question the notion of species itself.

The concept of species is among the most familiar scientific ideas in our lives. We celebrate (or bemoan) the human species, get excited about the discovery of new species, obsess over the fate of endangered ones, and shout at one another about the book called *On the Origin of Species.* The word derives from the Latin *specere,* "to look at" or "to behold." What we behold, in the conventional view of natural history, is a comforting and lovely sense of order. In a drawer at a museum, the butterflies, dragonflies, beetles, and other insects stand discretely apart, like jewels, each neatly labeled on its mounting pin.

The real world, by contrast, can seem like a seething mess, with one species smudging uncertainly into another. "Fuzzy species are common," says Rutgers University geneticist Jody Hey. Taxonomists, the scientists who specialize in classification, frequently disagree about how to determine where one species ends and another begins. Ask the big question—"So what is a species, anyway?"—and you discover there is no universally accepted definition. Instead, some 20-odd concepts and interpretations vie for eminence.

A group of insects are mounted classically in this collection, each one apparently belonging to a single, cohesive species. But are those divisions truly meaningful?

THE PUFFERFISH DECEPTION

One evening in March 2007, a couple in Chicago sat down to a soup made from "monkfish" exported by a Chinese company. Their faces started to burn soon after they ate. The wife had to be hospitalized and needed rehabilitation to walk again. Customers at Korean restaurants in California and New Jersey also fell ill. The monkfish, it turned out, was actually pufferfish, and depending on the species, a single pufferfish can contain enough toxin to kill 30 people. It was a blunt reminder that species distinctions we cannot readily see, or even taste, can have serious consequences.

Investigators from the Food and Drug Administration could not at first identify the species either. Then a leading authority on pufferfish, Keiichi Matsuura of the National Museum of Science and Nature in Tokyo, looked at photos of the shipment and identified the culprit as *Lagocephalus lunaris.* Most pufferfish carry toxin in their organs, which generally get discarded; in *L. lunaris,* the toxin is in the flesh. According to Matsuura, fishermen in Thailand catch this fish side by side with two other pufferfish species, one only mildly poisonous, the other not at all. The three species look alike, so they sometimes get tossed together.

Matsuura identified the fish on the basis of morphological differences too obscure for anyone but an expert to discern: the pattern of prickles on their backs. Consumers are unlikely to benefit from this kind of expertise when eating out, and fish markets and restaurants are notorious for being clueless about the species they sell. In one study, genetic evidence showed that the "Mediterranean red mullet" marketed in the Northeast was actually Caribbean spotted goatfish. It makes you wonder: "Couldn't they just look more closely?" one might ask. But when it comes to species distinctions, looking is often not enough. R. C.

The notion of biological species dates back at least to Carolus Linnaeus, the Swedish botanist who invented the system of classification in 1735. A compulsive organizer, he divided life on earth into distinct entities with fixed forms given to them by God. Even at the time, other naturalists saw shades of gray, with one species often separated from another only by barely perceptible nuances.

In the mid-19th century Charles Darwin made these nuances the basis for his theory of evolution by natural selection. He saw that the normal variations among individuals within a species tended to become more significant among separate populations of the same species, and even more so among separate varieties, as each moved down its own evolutionary path. The natural world was a continuum, he concluded, with isolated populations perpetually in the process of becoming species in their own right. The evolutionary perspective meant acknowledging the species designation as "arbitrarily given, for the sake of convenience, to a set of individuals closely resembling each other," Darwin wrote.

Scientists have been arguing ever since about where to draw the line. For years taxonomists tended to follow the "biological species" concept. As articulated in the 1940s by ornithologist and evolutionary thinker Ernst Mayr, it defines a species as a population of organisms that interbreed and live in reproductive isolation—that is, they do not normally breed with similar populations.

But nothing in nature is as simple as this sounds. Among its other drawbacks, this definition excludes the vast majority of organisms on earth. Bacteria, for instance, do not interbreed at all; they reproduce asexually—and also swap genes in ways that can blur the distinction between species. Even some sexual species would not qualify, according to Richard Mayden, an ichthyologist and evolutionary theorist at Saint Louis University. For instance, certain fish species produce no males, but the females must have sex to trigger parthenogenic development of unfertilized eggs; the female therefore "mates" with males of other species. It's not exactly virgin birth, but since the males don't fertilize the eggs, it isn't interbreeding, either. Strict followers of the biological species concept might also have to classify some dog breeds as separate species, Hey suggests, because a Chihuahua cannot jump high enough to make puppies with a mastiff.

A more general problem, according to critics of the biological species concept, is that it does not really help scientists figure out where one species ends and another begins. Determining whether different populations of a species are interbreeding is difficult at best, especially for scientists looking at specimens in a museum. Figuring out the sex lives of fossil species is nearly impossible.

Influenced by his work with fossils, George Gaylord Simpson, one of the great paleontologists of the 20th century, proposed his "evolutionary species" concept in 1951. It defines a species as a lineage—individuals descended from a common ancestor—that maintains a distinct identity and follows a common evolutionary path through time. The addition of a time line suited scientists limited to working with fossils, often of extinct species. Simpson's concept was also broad enough to accommodate asexual and parthenogenic species. But in terms of providing an obvious criterion for recognizing a species, it was not much of an improvement.

Tantalized by these efforts, a small army of evolutionary thinkers fanned out, beginning in the 1960s, on a quest for what Hey calls "the big one," the magic formula that would somehow address all the murky complications of the natural world and "lay the species problem to rest." What they ended up with was more like an alphabet soup: The "phenetic" concept defines species mainly according to observable differences in physiological traits. The "genetic" concept

PREVIOUS PAGES: ROBERT BENSSON/AURORA (2) THIS PAGE: FRED BAVENDAM/MINDEN PICTURES puts more emphasis on DNA. The "ecological" concept focuses on ecological niches or adaptive zones. And the "phylogenetic" concept combines descent with "diagnosable" differences in physical traits. But all these concepts suffer from arbitrary cutoff points, arguable assumptions, and cases in which they flat out do not work. One formidable critic, until his death at 101 in 2005, was Mayr, who clung to the biological species concept. He derided rivals as "armchair taxonomists" and asserted that some of them had "never personally analyzed any species populations or studied species in nature."

The failure to pin down the term "species" continues to vex many evolutionary biologists today. Physicists have the atom. Molecular biologists have DNA. Some evolutionary biologists worry that failing to define their fundamental unit of study with the same precision leaves them open to criticism that they are doing something less than hard science. In Colorado, for instance, state and federal fisheries experts were recently spending hundreds of thousands of dollars a year over five years to restore populations of a threatened subspecies of trout, the greenback cutthroat. Then in 2007, genetic analysis suggested that most of the fish being protected belong to a much more common subspecies, the Colorado River cutthroat trout. Even conservationists could not tell the difference just by looking.

If biologists cannot define it and sometimes do not know it when they see it, is the idea of species real? In many cases, especially among insects, separate species can appear identical except for minute differences in their genitalia. Because they can have such a direct influence on reproductive success, genitalia evolve more quickly and in more bizarre ways than any other animal trait. And since they may determine whether two individuals can interbreed, genitalia often provide a reliable guide to species identity. "Pull out the genitalia," says Maxi Polihronakis, a beetle taxonomist at the Santa Barbara Museum of Natural History, "and often everything becomes clear."

Or not. One difficulty with using any morphological trait is that there are not enough experts in the world with a working knowledge of the differences that distinguish closely related species, whether it is the pattern of bristles on the genitalia of *Anopheles* mosquitoes, say, or the dorsal prickles in the pufferfish genus *Lagocephalus*. And even that expertise does not guarantee that the morphological differences will yield absolute answers. The question is always where to draw the line: Are the differences just a matter of normal variation among individuals within a species? Or do they suggest that individuals or varieties belong to separate species?

Genetic analysis might sound like the perfect tool for resolving these messy complications. The term "DNA bar coding" suggests that the process is as straightforward as using a laser scanner to separate chicken noodle soup from beef barley in the supermarket checkout line. And it is, in fact, quick and cheap. A gene sequencing machine followed by analysis can produce bar coding results on a batch of specimens in several hours at $10 apiece. But bar coding is seldom conclusive when it comes to designating a new species.

Bar coding typically involves sequencing a few short segments of animal DNA from the mitochondria, the mini-organs that produce energy within every cell. Mitochondrial DNA has a fast mutation rate and hence is a quick-and-dirty indicator of a possible species difference. But since this DNA is inherited only from the maternal line, it does not go through the normal genetic process of division and recombination. That means traits are not steadily diluted to the point of insignificance. If two species have mixed in the past, the genetic evidence of that indiscretion may linger like an archaeological record for 10,000 years or more. That persistence can give the misleading impression that these species still interbreed today. Bar coding suggests, for instance, that savanna elephants and forest elephants belong to the same species, *Loxodonta africana*. DNA from the cell nucleus, which includes both maternal and paternal lines, tells a different story: The two types of elephants are in fact separate species, leading recently to a proposed relisting of the forest elephant as *Loxodonta cyclotis*.

Even so, DNA bar coding is turning taxonomy on its head, suggesting that valid species can exist in the absence of any morphological difference whatsoever. In Costa Rica's Area de Conservacion Guanacaste, a group of researchers have collected some 450,000 caterpillars over three decades and reared them in captivity. Among other things, they were interested in parasitoid insects whose reproductive strategy is to find a caterpillar and lay an egg on or in it. The egg produces a larva that develops by devouring the caterpillar's innards, eventually bursting out, *Alien*-style, to become an adult fly or wasp. Recently the researchers used bar coding to take a closer look at 16 species of parasitoid flies known to scientists for more than a century. Hidden within each of the 16 was evidence of four or five cryptic species that looked identical even to experts but that were nonetheless separated from one another by an average genetic distance of about 4 percent. (By comparison, humans and chimpanzees differ genetically by about 2 percent.)

The scientists then went back and looked at the caterpillars from which the flies were reared. It turned out that the genetically different individuals were ecologically and behaviorally different, too. Researchers had assumed that the original 16 species were all generalists parasitizing any caterpillar that happened to be in the wrong place at the wrong time. But at least 64 of the 73 new species were actually specialists, each focusing its deadly attentions on just one or two caterpillar species.

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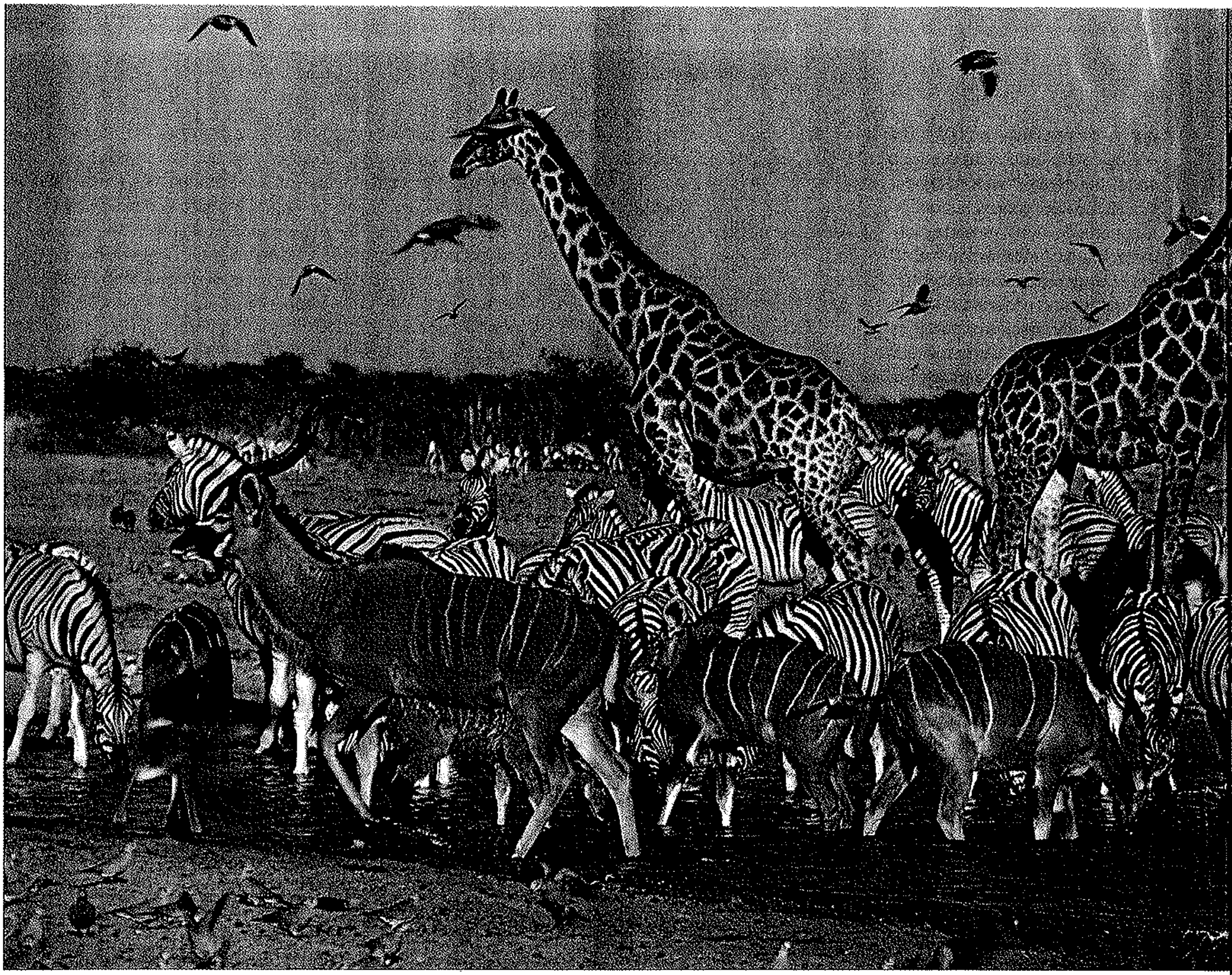
That distinction is important in understanding how an ecosystem works, according to University of Pennsylvania conservation biologist Dan Janzen, a leader of the Guanacaste research team. It is also the sort of evidence that biologists, Janzen included, have traditionally missed. "To me a species is a very real thing," he says. But separating species based on "how they look to a six-foot-tall diurnal mammal" may not have much relevance to the creatures themselves. DNA bar coding alerts scientists that they need to figure out "what is actually there, rather than what we perceive as humans." The key difference between species may be a matter of scent, seasonal timing, vocalization, auditory targeting of a particular prey, or some other trait. Such invisible distinctions may leave no trace in a museum specimen drawer, but they can make a life-or-death, sex-or-solitude difference in the wild, and not just for the species themselves.

For instance, bar coding studies in malaria zones around the world are splitting *Anopheles* mosquitoes into multiple cryptic species, all of them identical to human eyes. Why should we care? Because some of those species cause disease, while others are harmless. A detailed picture of invisible differences helps public health workers target limited funds more effectively. The result is that children



now live who, just a year or two ago, probably would have died.

On the other hand, the proliferation of new species also complicates life for conservationists, not least because it opens the door to environmental skeptics. An editorial in *The Economist* not long ago suggested that the scientific currency is "being subtly debauched by over-eager taxonomists." The magazine wondered if organisms were simply being "rebranded" to help conservation. Some biologists share that concern, particularly about certain primates that have recently been split off into separate species. They fear that unwarranted "species inflation" could jeopardize the credibility of their work. Taxonomists could become "like expert witnesses," says Kent Redford of the Wildlife Conservation Society Institute. "You know, 'You tell me if you want them to be separate species, and I'll tell you what philosophy of species designation I'm going to use to give you the answer you want.'"

The discovery of valid new species divisions can also present conservationists with major new headaches. Individual species that had seemed relatively healthy can suddenly look endangered when split up into multiple separate ones. Protected areas that once seemed adequate may not include what turns out to be essential habitat. But when genetic, morphological, and behavioral differences all point to a new species, says David Brown, the geneticist whose study argued for dividing giraffes into six species, that is not rebranding. It is science.

Brown says his research team did not know what to expect when it began its study. In zoos, the different giraffe types now being proposed as separate species did the one thing that has traditionally defined animals as a single species: They bred together and produced what seemed like viable offspring. As a result, past taxonomists had categorized the variants as subspecies at best, meaning that although they bred together, they were morphologically or geographically distinct. It seemed likely that they would interbreed in the wild, too. The genetic evidence in Brown's study showed otherwise. Even neighboring giraffe types almost never interbreed. Some populations that look identical to us turn out to have been going their separate ways for up to 1.5 million years.

One possible explanation for these divisions has to do with climate. Masai giraffes, living just south of the equator, give birth during the dry season from December to March, meaning their offspring are ready to wean just as the wet season arrives and produces new foliage to browse on. North of the equator, where reticulated giraffes live, the dry season starts in July. A hybrid of the two species with a blended reproductive cycle might do fine in a zoo. But in the wild, predators kill 50 to 70 percent of young giraffes in the first year of life. Being born in the right season, so there is plenty of browse to support fast growth, can be critical to a young giraffe's survival. The species difference that seems

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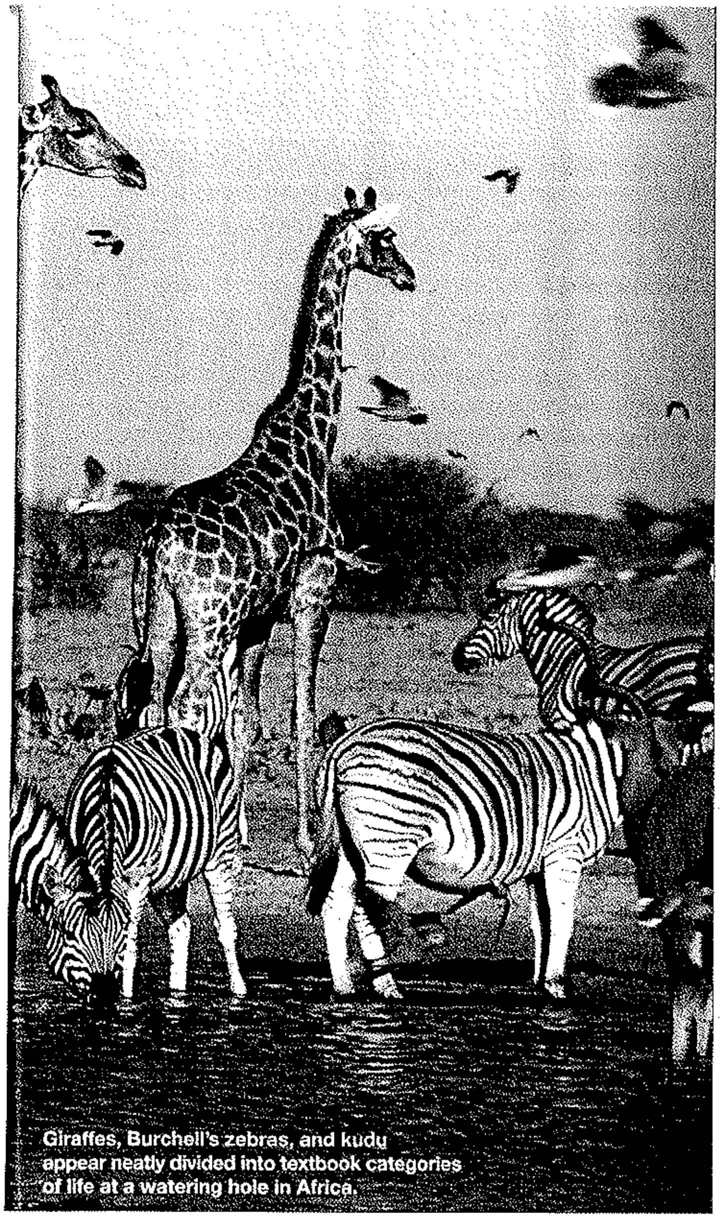

Giraffes, Burchell's zebras, and kudu appear neatly divided into textbook categories of life at a watering hole in Africa.

like an imperceptible nuance to us is anything but to them.

If groups of humans were separated long enough, they could begin the march toward hidden speciation as well. A study published last year in the *American Journal of Human Genetics* used mitochondrial DNA to argue that the San Bushmen of southern Africa became isolated from other modern humans for up to 110,000 years, probably because climate change produced a great desert separating East Africa from southern Africa. That separation was long enough to begin the process of pulling away from other human populations, according to Spencer Wells, an author of the paper and director of the Genographic Project at National Geographic. No one really knows how long it would take for an isolated human population to evolve into a separate species. "What we know," Wells says, "is that humans and Neanderthals are different species, and that separation time was about 500,000 years."

Looking at species, Jody Hey says, is like looking at clouds. On a sunny day they can seem like distinct entities, with sharp boundaries separating them. On other days they pile up together in dense banks, or with wispy tendrils connecting one to another. Then we remember what damp, atmospheric things they really are. The closer we look, the more everything starts to appear like fog.

Homo sapiens, on the other hand, is a pigeonholing species. "Our brains are these massive engines for creating categories," Hey says. "We're just brilliant at identifying kinds of things. We evolved to do that." There are times when precision counts: Is that mosquito *Anopheles dirus,* which is a major vector of malaria, or *A. harrisoni,* which is not? But the practical approach in many other contexts, he suggests, may be to get comfortable with uncertainty.

"I don't necessarily care what the taxonomic rank would be of the units I'm studying," says Hey, whose current research involves cichlid fish in Lake Malawi. "I could go in and study the level of divergence in a population and never care about whether they're ranked as separate species." This is not to suggest that species are unimportant. "That would be like saying that because people disagree about where human life begins, humans don't matter," says Kevin de Queiroz, a reptile expert at the National Museum of Natural History. Nor does less concern over ranking species diminish the value of taxonomy. When a new disease like SARS threatens to become pandemic, it becomes obvious why we need experts who can track the source of the disease not just to bats in general but to Chinese horseshoe bats of the genus *Rhinolophus.*

But instead of arguing about precisely where to draw the line between species, Hey suggests, being less categorical could be more productive. Taxonomists need to stop holding out pigheadedly for "the big one," the ultimate concept that covers all species, he says. They are likely to get better results, adds de Queiroz, by applying different tools and species concepts to different groups. Morphology might be useful for mammals but not for bacteria. Genetics might work for bacteria but not for most fossils.

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Sidestepping the species argument does not mean avoiding conservation or other scientific issues, Hey emphasizes. Despite its name, even the Endangered Species Act prudently manages not to get stuck on the definition of a species. Instead, it extends protection down to the level of a "distinct population segment" differing from other segments and traveling on a separate evolutionary trajectory. If we were to delay conservation measures until we nailed down the precise taxonomic rank of a population, the population might well go extinct in the meantime.

There is plenty of precedent for acting in the face of uncertainty. Doctors may disagree about the nature of a disease, Hey notes, yet they have no problem providing essential expertise on the public health measures to control it. Meteorologists may disagree about whether a hurricane will hit with Category 4 or 5 force, yet we still listen when they warn us to evacuate.

But to E. O. Wilson, the Harvard evolutionist and taxonomist, this kind of thinking sounds woefully incomplete. It may be difficult to do taxonomy in the rapidly opening world of microorganisms, where bacteria routinely swap gene segments, he says, but the answer is not for scientists to throw up their hands. Instead, we have to get past visual observation and study more carefully how animals live. "It does not mean we are going to keep parsing until finally we have an infinite number of species. It stops once you get to a certain point and you find out what the animals themselves know. And then you realize you are close to the truth." ■