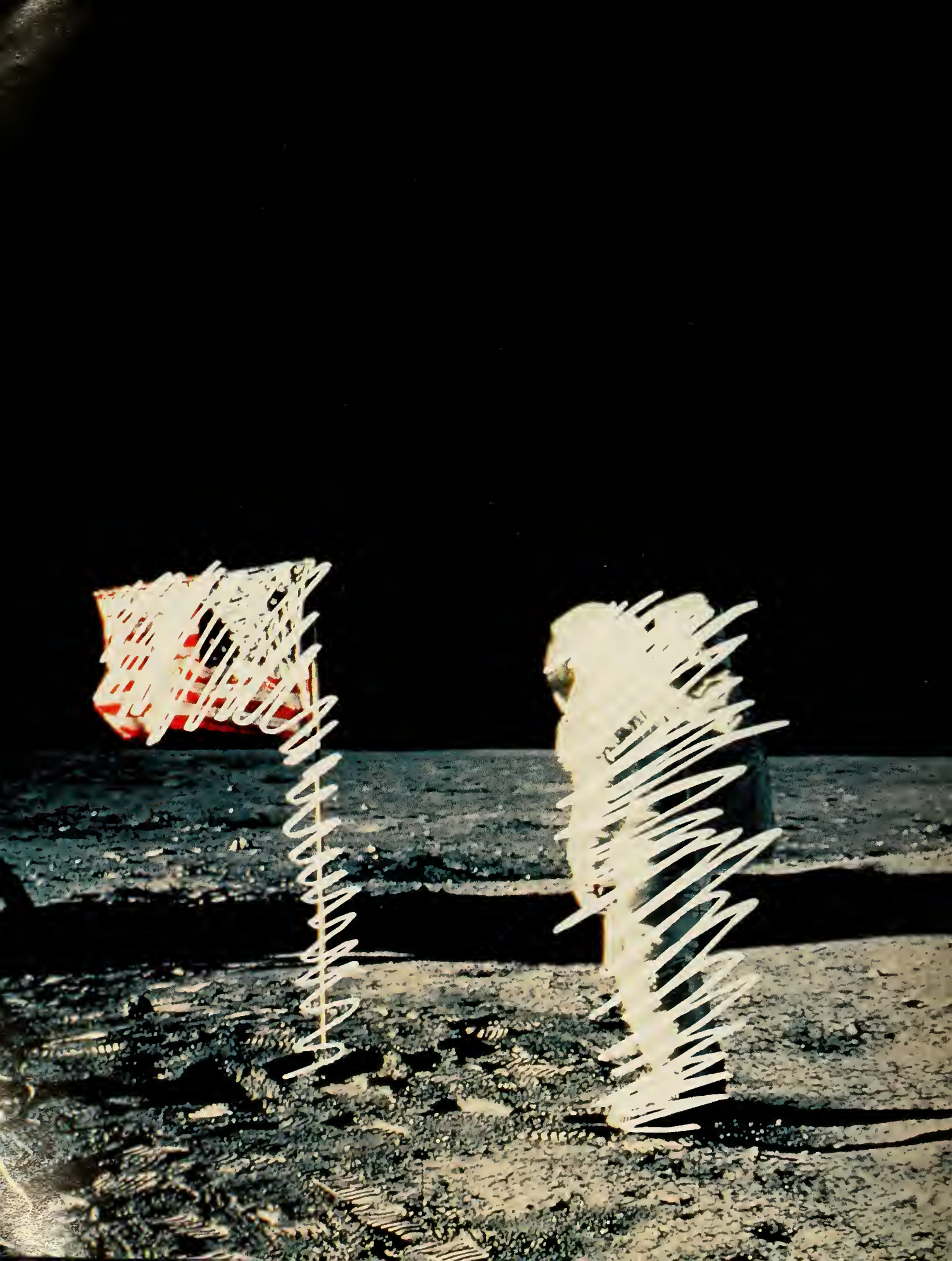


NATURAL HISTORY

9/01







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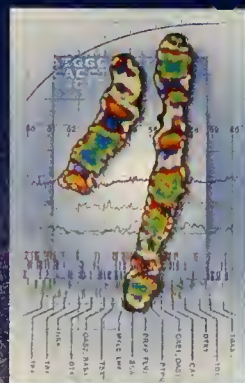
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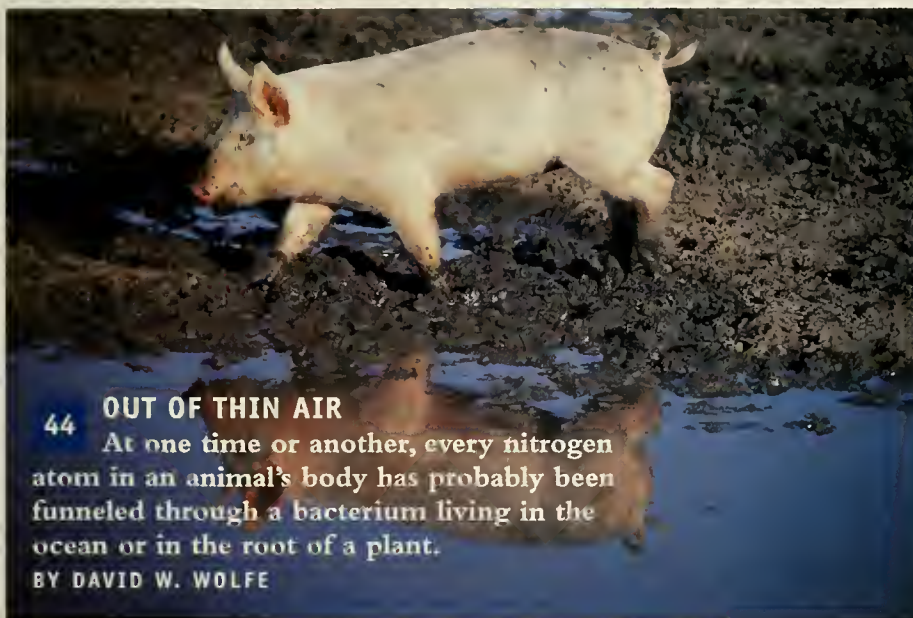
NATURAL HISTORY

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VOLUME 110

NUMBER 7

FEATURES



44 OUT OF THIN AIR

At one time or another, every nitrogen atom in an animal's body has probably been funneled through a bacterium living in the ocean or in the root of a plant.

BY DAVID W. WOLFE



54 THREADS OF OKINAWAN HISTORY

In Japan's Ryukyu archipelago, locally woven textiles connect the present with the past.

BY AMANDA MAYER STINCHECUM



62 GHOST STORIES FROM THE ICE AGE

Certain plants remind us that mastodons, camels, and ground sloths once chomped their way across America.

STORY BY CONNIE BARLOW

ILLUSTRATIONS BY

MICHAEL ROTHMAN

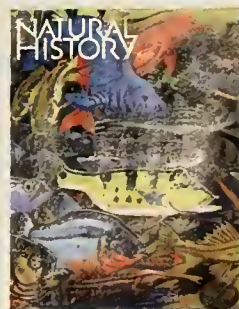


36 FRESHWATER RICHES OF THE AMAZON

When it comes to fish biodiversity, one river beats them all.

STORY BY JOHN LUNDBERG

PAINTING BY RAY TROLL



COVER

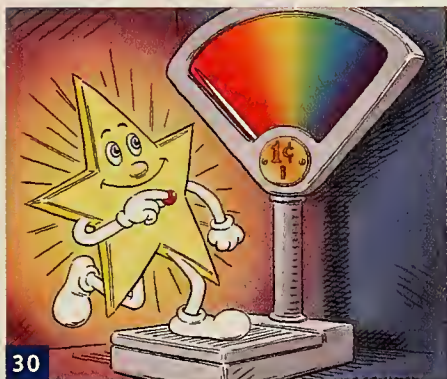
So far, scientists have identified more than two thousand species of fish in the Amazon River.

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PAINTING BY
RAY TROLL

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A lighthouse on a cliff at sunset, with the ocean in the foreground and a colorful sky in shades of purple and pink.

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UP FRONT

The Long View

Living on the paved island known as Manhattan, some of my encounters with nature necessarily take place on sidewalks. I once followed a giant silk moth for several blocks along Amsterdam Avenue in broad daylight. On a spring morning several years ago, I saw a tiny ovenbird that was walking north on Park Avenue, probably exhausted by its migratory flight from South America. And I routinely glimpse house mice frolicking in the median strip along upper Broadway after dark.

But most of my observations of plants and animals (not counting carpet beetles, silverfish, and cockroaches) take place in public parks and gardens. A favorite stroll in Riverside Park takes me past a row of honey locust trees. Long ago, I noticed that their trunks (beginning about eight feet above the ground) were encircled with three- to five-inch-long, needlelike thorns.

I'd never given the thorns a thought, however, until Connie Barlow, a writer and independent scholar of evolution, came to the magazine's office

to propose a story on "anachronistic fruits." Barlow explained the intriguing idea that many puzzling features of North American plants—the huge pit of the avocado, the indigestible flesh of the Osage orange, the outrageous thorns of the honey locust—evolved as either enticements to or defenses against large animals that are now extinct.

In 1925, excavations for an apartment building in northern Manhattan turned up a lower jaw, some teeth, and one limb bone

from *Mammuth americanum*, the American mastodon. For millions of years, until about 10,000 years ago, these elephants doubtless walked where I now walk in Riverside Park, and their appetite for the honey locust's seed pods may have had a role in the evolution of the tree's ferocious thorns.

Thinking about nature in evolutionary terms—a point of view that's common in the pages of a natural history magazine but rare in other venues—gives one a marvelously long view and some unusual insights into why things are the way they are. Once upon a time, ground sloths or camels or even ancestral rhinoceroses may have inhabited your part of the country. Reading Barlow's "Ghost Stories From the Ice Age" (page 62) makes one think about such things.—Ellen Goldensohn



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CONTRIBUTORS

Ichthyologist **John Lundberg** ("Freshwater Riches of the Amazon," page 36) began studying the fishes of South America's Orinoco River in 1974 and those of the Amazon River in 1990. His pioneering surveys of the fish life of deep river channels have turned up many new species, including catfishes and electric fishes with unusual lifestyles. Lundberg, left, says his "innate attraction to fossils" has led him to



broaden his focus; he uses insights from paleontology, geology, and biogeography in his work on tropical fish diversity. Formerly a professor at Duke University and the University of Arizona, Lundberg is now curator of ichthyology at the Academy of Natural Sciences in Philadelphia and holds adjunct professorships at the University of Pennsylvania and Drexel University. After an autumn 1997 trip down the Amazon with a boatful of friends and scientists, artist **Ray Troll** was inspired to produce his most ambitious work to date: a mural-sized canvas that took a year to complete and that portrays about 120 species—furred, feathered, but mostly finned. Troll lives in Ketchikan, Alaska, but travels frequently in the service of art and fish. He and writer Brad Matsen have produced various books on their adventures with fish, both fossil and modern. Troll is currently completing a book on sharks. For an out-of-the-ordinary fish-viewing experience, look at www.trollart.com.



David W. Wolfe ("Out of Thin Air," page 44) reports that inspiration for his recent book, *Tales From the Underground: A Natural History of Subterranean Life* (Perseus Books, 2001), often came while poking around in the dirt on daily hikes with his dog in upstate New York. But Wolfe's interest in the soil has its roots in central New Mexico, where he spent many childhood hours uncovering subterranean ant colonies in the dusty mesas near his home. Once his parents gave him a microscope, he says, "there was no turning back." An associate professor of plant ecology in the Department of Horticulture at Cornell University, Wolfe now gets paid for digging in the dirt. His current research subjects include a common root fungus that helps plants take up nitrogen more efficiently, methods for reducing the use of synthetic nitrogen fertilizers on farms, and the effects of elevated levels of atmospheric CO₂ on symbiotic nitrogen fixation in legumes. When he needs a break from the soil, Wolfe grabs his scuba gear and heads for the water. "Surface life," he says, "just seems so ordinary compared with these environments."



An independent scholar and freelance writer, **Amanda Mayer Stinchecum** ("Threads of Okinawan History," page 54) has researched the craft and history of textiles in the Ryukyu Islands for more than fifteen years, most recently as a Japan Foundation Fellow engaged in fieldwork on Taketomi, an island near the southwestern end of Okinawa Prefecture. Her particular interests include the ikat technique of creating dyed patterns as well as the methods of identifying plant fibers used in premodern cloths. Based in Brooklyn, New York, Stinchecum (shown here in 1985 examining fiber banana plants with *Mainichi* newspaper photographer Azuma Yasuo) has spent long periods in Japan. She was able to draw on her experience of the changing seasons there to write two previous *Natural History* articles: "Enduring Cold the Japanese Way" (October 1981) and "Cool Illusions in the Land of the Rising Sun" (August 1993).

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Connie Barlow ("Ghost Stories From the Ice Age," page 62), a science writer and amateur naturalist who was raised in Detroit, has spent much of her adult life living near wilderness areas in Alaska and New Mexico. She says that while working on her most recent book, *The Ghosts of Evolution* (Basic Books, 2001), she began to see "ghosts" everywhere—evidence of the lost mammalian megafauna of North America. With paleoecologist Paul Martin, she is promoting the reintroduction of elephants to grasslands in the U.S. Southwest, where the proliferation of shrubs

is a problem. They believe the presence of these proboscideans would restore the balance that existed in Pleistocene times between grazers and large browsers. Barlow has long been interested in the implications of evolution for philosophy, ethics, and the understanding of humanity's role in the cosmos, as well as in the expression of the epic of evolution through art, literature, and celebratory events. She is the editor of *Evolution Extended: Biological Debates on the Meaning of Life* (MIT Press, 1994). **Michael Rothman**, who sketched the ghost species for Barlow's piece, has participated in expeditions to



Western Samoa, French Guiana, and the Amazon River in Brazil (among other destinations), where he painted and photographed plants and animals. He has worked on several fossil reconstruction projects and has also illustrated fifteen science books for young readers. Rothman's artwork can be seen at zoos in Atlanta, Detroit, and Philadelphia. His natural-science illustrations have appeared in such publications as the *New York Times* and *Scientific American*, and he regularly illustrates articles for *Natural History* (see "Bats, Bees, and Brazil Nut Trees," April 2000, and "Undertakers of the Deep," November 1999).



Hiroshi Ogawa ("The Natural Moment," page 84) still lives in the small town in Japan's Ibaraki Prefecture where he was born in 1947. As a child, he says, "insects became my toys and my friends." Upon graduating from junior high school, Ogawa joined his father's roofing business. His passion for the past twenty-three years, however, has been photographing the insects of his native countryside. Self-taught in macrophotography and entomology, Ogawa specializes in documenting the social life of ants, wasps, and

bees. His photographs have appeared in textbooks and encyclopedias, and one was featured on the March 2001 cover of *Natural History*. He has published more than thirty children's books; among those available in English are *Wasps* (text by Sylvia Johnson; Lerner Publications, 1984) and *The Potter Wasp* (edited by Kathleen Pohl; Raintree Publishers, 1986). Ogawa still climbs on roofs occasionally to photograph insects.



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LETTERS

Family Resemblance?

The artist Alexis Rockman (cover, 6/01) must have taken inspiration from the work of Giuseppe Arcimboldo (1527–93), whose masterful conglomerations of ordinary objects, living and inanimate, are marvels. Had

Arcimboldo been a contemporary of seventeenth-century scientist Robert Hooke or microscopist Antonie van Leeuwenhoek, he might have created a work similar to Rockman's.

*Paul E. Hargraves
Narragansett, Rhode Island*

Rockman may have been influenced by seventeenth-century images composed of seashells, sometimes with other marine forms and imaginary items. I enclose one of six such arrangements from Filippo Buonanni's 1681 work on mollusks.

*Richard E. Petit
North Myrtle Beach,
South Carolina*

ALEXIS ROCKMAN REPLIES: I did have Giuseppe Arcimboldo in mind when I created the June cover, a "portrait" composed of bacteria and mitochondria. But while Arcimboldo employed familiar vegetable forms in his paintings, I used lesser-known organic elements that are actually found in the human body.

Now Hear This

In "The Lobster's Violin" ("Biomechanics," 6/01), Adam Summers describes the lobster's unusual means of sound

production. He also compares the mechanism with that of insects that use friction (stridulation) to create sound. He cites both crickets and cicadas. However, cicadas produce their sounds—the loudest of any insects—not by stridulation but by vibrating membranes, or tymbals, located on their abdomens. The pulses making up the cicada's sounds are analogous to the clicking that results when a rounded tin can lid is pushed in with a finger and then released—that is, two clicks per in-and-out cycle.

*Jerome Rovner
Athens, Ohio*

ADAM SUMMERS REPLIES: Jerome Rovner is correct, although the cicada's is a percussive, rather than a "stick-and-slip," sound.

It won't work if the cuticle is soft.

Taste Test

One sunny July day in northern Wisconsin, my wife, daughter, and I were packing up our camping gear, which was soggy from a deluge the night before. When we paused and looked around, we beheld a surrealistic scene: down the dirt road were thousands, maybe tens of thousands, of butterflies. I believe they were mostly Harris's checkerspots and wood nymphs, or the like, but there were also the occasional monarchs, swallowtails, and mourning cloaks.

Many rose from the wet, bare patches of gravel left where the snowplow had dug down a little too deep the previous winter. But when it came to density of butterflies per inch, nothing beat out coyote scats. As we drove the few miles of bad road, we passed by lots of droppings, and every time we did, a heavy cloud of butterflies greeted us. I thought of them years later when I was covered in sweat during a cabin-building spree, and a couple of wood nymphs kept landing on my nose for a drink. Phil Schappert's "Butterfly Buffet" (7/01–8/01) made me wonder how I measured up as a meal. Was I tasty, or just a poor substitute for coyote waste?

*Daniel Ryskamp
Kalamazoo, Michigan*

In Texas for a period of time, whenever my brother would go out into his yard, a butterfly would repeatedly zoom at his head. The purpose of this strange activity later became clear to me. I had parked in my damp, unpaved driveway in Connecticut, and when I got out, a butterfly gave me the same treatment. Suspecting what was wanted, I moved the car. The insect landed on the mud where the vehicle had been and began to sip.

*Fowler F. White
via e-mail*

Natural History's e-mail address is nhmag@amnh.org.

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THE EVOLUTIONARY FRONT

Tuning In

At the genetic level, the signs of natural selection are surprisingly subtle.

By *Carl Zimmer*

More knowledge doesn't necessarily translate into less confusion. In 1953, when James Watson and Francis Crick discovered the double-helix structure of DNA, biologists were poised for all the pieces of evolutionary theory to fall quickly into place. Darwin had shown how natural selection could transform anatomy and patterns of behavior, and now scientists looked forward to detecting the fingerprints of natural selection at the molecular level. But it turned out that natural selection was not the only force that could significantly alter DNA, and no one knew how to identify the source of any given change. It has taken decades to figure out a way.

This predicament took many biologists by surprise, because once the structure of DNA was understood, they thought they had a good handle on how natural selection works. Researchers determined that a gene consists of a stretch of DNA—a sequence of molecules called nucleotides that serves as a blueprint for the synthesis of a protein. If the nucleotide sequence somehow mutates, it may produce a different protein. The new protein may turn out to be so defective that the individuals who inherit the mutation die or become infertile; either way, such harmful mutations may end up being almost completely weeded out of a species. But some mutations may give their owners a reproductive edge, and before long those mutations will become widespread—even universal—in a spe-

cies. In the course of thousands and millions of years, a series of such beneficial changes could thus rework the genome of a species.

By the 1960s, however, researchers had realized that this was far from the whole story of evolution. Richard Lewontin, of Harvard University, and his colleagues collected fruit fly proteins and tallied the many variant forms of each. (The technology for sequencing the actual nucleotides was still two decades away.) They studied a selection of proteins in a single population of flies and found that fully 30 percent of the molecules existed in more than one form. If natural selection was weeding out mutations, then it was an awfully careless gardener.

Lewontin's research, and similar results from other scientists, led the Japanese biologist Motoo Kimura to launch a full-blown assault on the standard picture of how nucleotides evolve. Yes, he argued, some mutations were harmful and some were advantageous. But between those two extremes was a huge range of mutations that had no effect at all. Over the generations, these neutral mutations, as they came to be known, might become more common solely as a result of random fluctuations

(a process called neutral evolution). Kimura predicted that most variation in DNA would turn out to be produced by neutral evolution and not by natural selection.

The irony was inescapable: scientists finally had a chance to tune in to evolution on its most basic level, but the signal of natural selection seemed to be swamped by the static of neutral evolution. If your radio can't pick up a clear signal, however, maybe what you need to do is build a better radio. And biologists set out to do just that. By the 1970s, researchers had realized that there was a way—at least in theory—to isolate the signal of natural selection, thanks to the way cells build proteins.

A cell makes a copy of a gene's sequence and then ships this code out to a protein-building factory called a ribosome. There the genetic code acts as a guide for building a protein out of a set of molecules called amino acids. But a



JAMES MARSH

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Inset: Alaska Native in Kotzebue.

gene's nucleotides don't correspond to the sequence of amino acids in the protein in a one-to-one fashion. Before adding an amino acid to the end of a protein under construction, ribosomes have to read three nucleotides in a row. And in many cases, different trios of nucleotides can direct a ribosome to add the same amino acid. For example, if the nucleotide guanine appears three times in a row, a ribosome adds the amino acid glycine to the protein it is building. But it will add glycine even if the genetic sequence reads "guanine-guanine-thymine."

So imagine that a gene whose sequence includes three guanines mutates, with the third guanine turning into thymine.

Even though the gene has changed, it still calls for the same old glycine. The new protein will not just be similar to the old one; it will be identical. Geneticists call these kinds of mutations "silent substitutions," as opposed to "replacement substitutions," which actually change the structure of a protein.

A comparison of the numbers of silent and replacement substitutions acquired by a gene should reveal whether it has experienced natural selection. Genes mutate randomly—both at sites where silent mutations occur and at replacement sites. If they are evolving neutrally, both kinds of mutations are equally likely to become universal. In other words, if 1 percent of the silent sites change in a million years, so will 1 percent of the replacement sites. But natural selection favors certain replacement mutations and makes them spread faster than neutral evolution can. Mutations that change a protein to some superior version will accumulate more quickly than will silent substitutions. If, say, 1 percent of the silent sites in a gene change in 10 million years, natural selection might in fact change 5 percent of the replacement sites.

In theory, then, it should be simple

to check a gene for natural selection. All you'd have to do is tally the fraction of replacement sites that have mutated and compare that with the fraction of silent sites. If the ratio is one to one, the gene has evolved neutrally. If the ratio is higher, natural selection has been at work. And the higher the ratio, the more intense the natural selection.

While simple in concept, this evolutionary "radio" was actually staggeringly hard to build. For one thing, re-

Yes, some mutations are harmful and some are advantageous. But between these two extremes is a huge range of mutations that have no effect at all.

searchers can't go back millions of years to read a gene's ancestral sequence, nor can they know the precise history of mutations that led up to its current form. But biologists can make some inferences by comparing the genes of closely related animals. Imagine, for example, that a certain gene for red blood cells is identical in every ape but that the human version of the gene differs at the 123rd position. It would be a safe bet that the human gene started off like the others and later mutated at position 123. But the evidence from real genes is rarely so clean, and thus some uncertainty inevitably creeps in.

Making matters fuzzier, until only a few years ago biologists had relatively few genetic sequences available to analyze. Like a political poll of your four best friends, studies of these genes were usually not statistically significant. Another problem was that the models of evolution used by biologists for detecting natural selection assumed that mutations were random, which is not entirely true. For example, the chemical nature of DNA makes certain nucleotides more likely to mutate into certain other ones. With so much uncertainty in their methods, biologists

attempting to tune in to natural selection couldn't be sure they weren't getting a false signal.

Not until the mid-1990s were researchers able to sidestep these uncertainties. By then, genetic data banks had begun to swell with sequences, and computers were becoming outrageously fast. Taking advantage of both trends, researchers began analyzing DNA using powerful statistical equations. One of the most widely used methods is called maximum likelihood.

Although there's some head-spinning math behind the procedure, it basically works this way: First, pick a group of related species you want to study. Then compare various chunks of their DNA

to determine their relationships and build their evolutionary tree. Now choose a gene whose history you want to track along the branches of the tree.

Ziheng Yang, of University College London, and his colleagues have led the way in this approach. They program computers to look at every possible series of mutations that could have yielded the existing variants of a gene from a common ancestor. By sorting through the billions of possible scenarios and calculating the effects of different degrees of natural selection, the computer finds the level of natural selection that offers the maximum likelihood of having produced the actual gene sequences.

Other researchers are using methods such as Yang's to analyze hundreds of genes from numerous species, including humans. Many of these genes indeed turn out to be evolving neutrally, just as Kimura predicted they would. But some glow with natural selection's fire. The genes for some of the immune-system proteins that recognize invading pathogens have been adapting particularly quickly. Known as the major histocompatibility complex (MHC), these proteins are found within each cell, and their job is to lock

on to fragments of viruses and other parasites within the cell and bring them to the cell's surface. Special immune-system cells passing by can recognize the fragments so displayed and force the infected cell to self-destruct. It turns out that some genes that build MHC proteins have acquired four times more replacement mutations than silent ones.

Scientists can tune in even more precisely to natural selection—determining not just whether a gene has been affected by it but which of its individual nucleotides has. Using the maximum likelihood method, for instance, Yang examines each site in a gene and tries to predict its nucleotide on the basis of the rest of the gene's sequence as well as the sequence of the gene in related species. The computer makes a series of predictions based on different assumptions about the level of natural selection acting on the site and then picks the level that works best.

Apparently, only a few nucleotides in MHC genes have been strongly affected by natural selection. If you look at their positions, they seem to be scattered randomly here and there within the gene. But the hidden order becomes apparent once you take account of the actual shape of MHC proteins. All the amino acids altered by natural selection are found at a cleft in the proteins—the place where they actually make contact with the pathogens.

Researchers had anticipated exactly these results, basing their prediction on the struggle between hosts and parasites. If a pathogen evolves a new structure, an old MHC protein may be less capable of grabbing onto it, making it harder for the host to fight off the disease. As a result, natural selection should favor animals with new MHC proteins that offer a better grip. Not surprisingly, researchers have also found signs of intense natural selection in the genes that construct the surface proteins of bacteria and viruses. The changes in their structure enable the pathogens to evade recognition by the immune system.

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Through studying these hot spots of adaptation in disease genes, scientists may be able to make new vaccines to keep up with their evolution.

When scientists began to tune in to natural selection, they also expected to hear a loud signal coming from the genes involved in sex. Biologists knew from studies on a wide range of animals that males compete with other males to fertilize eggs and that females choose potential mates based on the males' appearance and, perhaps, even on their sperm. Last year Gerald Wyckoff, Wen Wang, and Chung-I Wu, of the University of Chicago, discovered that a few genes that help build sperm in humans were undergoing rapid selection. And last February, Willie Swanson and his colleagues at Cornell University teamed up with Ziheng Yang; together they detected equally strong selection at work on genes that build the proteins on the surface of human egg cells. As was the case with the MHC, they found that natural selection was at work on only a few nucleotides—specifically, the ones that build part of the protein that makes contact with the head of a fertilizing sperm.

These biologists have only pointed to the regions where natural selection is taking place; they don't yet know exactly what adaptive pressures are driving it. One

possibility is that receptors on the eggs enable them to choose certain sperm for fertilization. As male genes for the surface of sperm adapt to these receptors, the female genes for eggs evolve into new forms.

When we think of what changes in our ancestors gave rise to *Homo sapiens*, the genetics of fertilization and head colds may not pop to the top of the list. The only reason that genes involved in sex and sickness were the first to reveal evidence of natural selection is simply that biologists turned to them first. Researchers are now looking for evidence

of natural selection in other kinds of genes. One of the most surprising results of this search came in August 2000 from Gavin Huttley, a geneticist at Australian National University. Huttley has discovered that a gene called *BRCA1* has experienced strong natural selection over the past few million years.

BRCA1 has been in the news in recent years because it sometimes mutates into a form that has been linked to several types of cancer, such as breast and prostate cancers. Normally, the gene plays vital roles in the development of embryos and the repair of damaged DNA. Huttley compared the *BRCA1* gene in humans with those in other apes and discovered that it experienced intense natural selection in our ancestors. It's possible, he concludes, that the cancers *BRCA1* can cause when it mutates are a price we pay for having become human.

Other genes may have evolved in important ways, too, but natural selection may have affected only a few key mutations, making them hard to detect. Wyckoff, Wu, and their University of Chicago colleague Justin Fay

In humans, the *BRCA1* gene can mutate into a form linked to cancer. This risk may be a price we pay for having evolved separately from the apes.

predict that many such genes will be discovered. In the July 2001 issue of *Genetics*, they reported on a survey they had made of several hundred genes sequenced during the Human Genome Project. Rather than analyzing individual genes, they pooled all of them together and compared them with the same sequences in other primates. By analyzing so much data at once, they hoped to pick up faint signals of natural selection that they might otherwise have missed in any single gene. The scientists were not disappointed. In the 30 million years since our ancestors

split from those of the Old World monkeys, more than a third of the changes in our amino acids have been the result of natural selection. Wyckoff, Wu, and Fay calculate that, on average, one of these adaptive changes happened every eighty years or so.

Natural selection is widespread in the human genome; now biologists just have to figure out exactly which genes have experienced it. Not surprisingly, researchers such as Wyckoff and his coworkers (notably graduate student Steve Dorns, who works at the laboratory of Bruce Lahn, of the University of Chicago and Howard Hughes Medical Institute) are examining the genes that help build and operate the human brain. After all, the human brain is in some ways very different from those of apes. The most obvious difference is size: relative to body weight, a human brain is twice as big as a chimp brain.

The initial results are telling—but not what you might expect. In the few brain-related genes that scientists have closely studied in primates, silent substitutions far outnumber replacement substitutions. This sort of ratio is the sign of a third kind of evolution, known as purifying selection. Some particularly intricate parts of the body cannot tolerate even a little tinkering with their structure, so any change to the proteins involved gets ruthlessly weeded out. The primate brain may be one such delicately constructed organ.

Ancestral humans somehow overcame this resistance to change and acquired a few precious mutations that made them (and us) particularly clever. But finding a way to detect those crucial changes may prove to be one of our greatest mental challenges.

Science writer Carl Zimmer is the author of Evolution: The Triumph of an Idea (HarperCollins, 2001). His book Parasite Rex has just been published in paperback.

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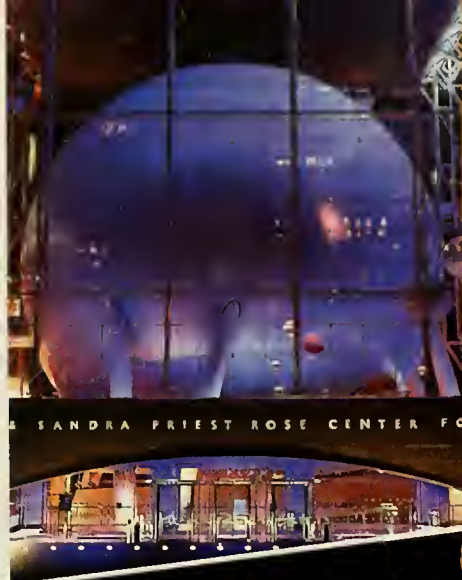
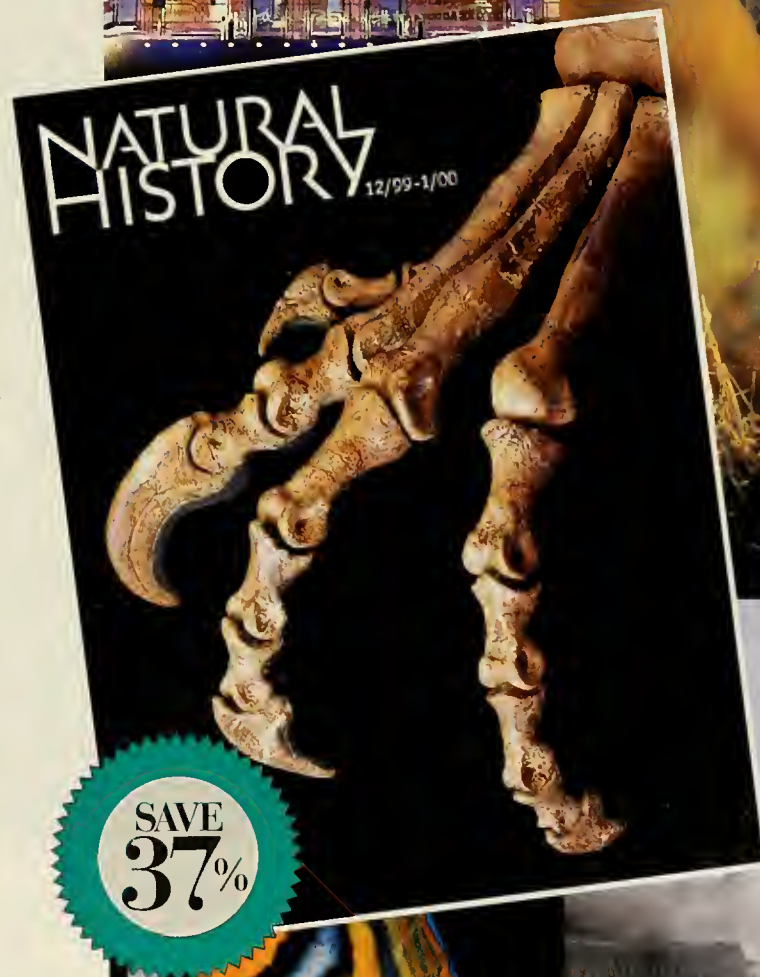
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THIS LAND

Channeling in California

Native vegetation is rebounding on Santa Catalina Island.

By Robert H. Muhlenbrock

Prickly pear at Little Harbor

A dense fog hung over the Gulf of Santa Catalina as my wife, Beverly, and I boarded a high-speed boat at Dana Point, not far from the famous Mission San Juan Capistrano, southeast of Los Angeles. It took just an hour and a half to cross the thirty-five miles that separated the mainland from our destination, Santa Catalina Island. Covering seventy-six square miles, Santa Catalina is one of southern California's eight Channel Islands. Five others—San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara—constitute Channel

Islands National Park. The remaining two are San Nicolas and San Clemente.

The Channel Islands (often called the Santa Barbara Islands) began emerging above sea level about 5 million years ago as volcanic, igneous, sedimentary, and metamorphic rocks were uplifted by tectonic forces associated with the San Andreas Fault. Some, including Santa Catalina, were also overlain by lava flows. During the last glaciation, when sea levels were roughly 400 feet lower, a few of the islands were connected to each other,

but all of them have always been isolated from the mainland. As a result, each hosts a variety of endemic plants and animals—that is, species or subspecies found only there.

Santa Catalina is twenty-two miles long and ranges in width from half a mile, at an isthmus, to eight miles. It is essentially a mountain ridge, the highest point being 2,097-foot Mount Orizaba. Along the coast, precipitous cliffs up to 1,400 feet high are interspersed with coves and bays leading into deep, V-shaped canyons. Most of the beaches in the coves are

covered with cobblestones, while a few are sandy. Summers are warm and dry; most of the annual rainfall of twelve or more inches falls during the winter. Although the Santa Ana winds that blow from the mainland in winter are often violent, temperatures remain mild.

The original vegetation of Santa Catalina Island has been altered by human activity, particularly through the introduction, more than a century ago, of sheep, goats, and cattle, followed by mule deer, wild pigs, and bison. After years of intense grazing, existing chaparral and coastal scrub communities were largely replaced by nonnative grasses. During the last half of the twentieth century, however, efforts were made to control feral goats and pigs and to remove some of the cattle and bison (only a small herd of bison now remains as a tourist attraction). Today, 88 percent of the island is

owned by the Santa Catalina Island Conservancy, which was formed in 1972, and the original vegetation is gradually being renewed.

The habitats include oak woodland, riparian woodland, chaparral, coastal scrub, bluff faces, maritime desert scrub, grasslands, and marshy areas and ponds. About 640 plant species have been recorded on Santa Catalina, nearly two-thirds of them native. Most of the native plants can also be found in the Santa Monica Mountains on the mainland, but several are restricted to the Channel

Islands or just to Santa Catalina. Some of the rarest plants live on steep rocky cliffs that have been inaccessible to the island's feral goats.

A California quail and a Bewick's wren are among four bird subspecies found only on Santa Catalina. Native mammals include five endemic subspecies, the largest of which is a Channel Island fox. There are also

various endemic invertebrates, including two snails, several butterflies and moths, a few beetles, a cricket, and a walking stick.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

HABITATS

Oak woodland develops best in moist, protected canyons and valleys with deep alluvial soils. Island oak, canyon oak, and scrub oak are common, along with Catalina cherry, elderberry, and summer holly (actually a member of the heath family). The rare Catalina ironwood is found in Toyon Canyon and in a few other canyons. Wildflowers include miner's lettuce, lacepod, a buttercup, and the showy fiesta flower (a member of the same family as waterleaf). Among the ferns are California polypody, maidenhair fern, and golden-back fern.

Riparian woodland, with black cottonwood and Fremont cottonwood as the major trees, grows along the streams of canyon floors. Red willow, arroyo willow, elderberry, and McDonald oak are present in the tree and shrub layers. Low-growing shrubs include wild rose, California blackberry, and snowberry. Wild honeysuckle, wild grape, redroot (a type of wild cucumber), and coral vine climb over the vegetation. Purple vervain is one of the few colorful wildflowers.

Chaparral is found on north- and east-facing slopes on the side of the island facing the mainland and also in arroyos

(dry gullies that carry water after a rain) on the Pacific slopes. One of the best of these sparsely vegetated, shrubby habitats is found on the western slopes of Black Jack Mountain. Among the shrubby species are a tree poppy, three kinds of sumacs (lemonade, laurel sumac, and sugar sumac), chamise, island buckthorn, mountain mahogany, Christmas berry (toyon), pitcher sage, wild apple (which is not an apple, despite the similar appearance of the fruit), and Santa Catalina and white lilacs (not really lilacs but relatives of the New Jersey tea of the eastern United States). An uncommon endemic on the slopes of Black Jack Mountain is Greene's rockrose. Of the few wildflowers,



STEPHEN P. PARKER, PHOTO RESEARCHERS, INC.

figwort and everlasting appear to be the most common.

Coastal scrub appears on some of the canyon slopes where the soil is extremely thin and rocky. A good



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headlands, such as the southwestern side of Indian Head Point, that are exposed to prevailing westerly winds blowing in from the Pacific. Velvet cactus, prickly pear, *Bergerocactus emoryi*, and cholla are widespread, often joined by box thorn, a prickly shrub in the nightshade family. Other common plants are brittlebush, California sagebrush, several wildflowers in the aster family, and a wild four-o'clock.

Grassland areas have begun to see the return of some native species, including feather love grass and two kinds of needlegrass. In early spring,

the grasslands are often covered with the shiny yellow heads of goldfields. Other wildflowers interspersed among the grasses are tidy tips, red maids, Indian paintbrush, owl's clover, shooting-star, larkspur, golden star, mariposa lily, and johnny-jump-up.

Freshwater marsh and aquatic plants can be seen throughout the year in Cottonwood Canyon and Bulrush Canyon. Among them are scouring rushes, brass-buttons, yerba mansa, watercress, camphorweed, two kinds of cattails, and a variety of sedges and rushes.

place to observe this open habitat is above the beach at Little Harbor, on the island's west side. California sagebrush dominates, although prickly pear, lemonade, laurel sumac, deerbrush, white sage, and black sage are common. St.-Catherine's-lace has huge clusters of white flowers on a stem that may reach twelve feet tall. A species of tree mallow attains a similar height.

Bluff face plants include the fleshy-stemmed sea dahlia; alabaster plant, a species with fleshy leaves; dusty-miller, with its gray leaves and stems; bush snapdragon; sticky monkey-flower; and snake's-head, a tall perennial in the aster family. Two species of live-forever (a succulent) grow from crevices in the steep cliffs.

Maritime desert scrub is the most arid of the island's habitats. It occurs on



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IN SUM

FOWL CALLS Most of us think we're familiar with the sounds of the domestic chicken, *Gallus gallus domesticus*, but not all fowl calls are created equal. One distinctive sound, uttered by females only after egg laying and predictably named the postoviposition cackle, has long been something of a mystery to scientists.

Since the loud cackle can alert potential predators to a freshly laid egg, evolutionary bi-



ROBERT MAYER: ANIMALS

ologists assume that the call must have a benefit outweighing the risk. Some have suggested that hens cackle to announce to roosters their renewed receptivity to mating.

Biologists Tommaso Pizzari and Tim Birkhead, of the University of Sheffield in England, tested this hypothesis in a free-range population of *G.g. domesticus* that was fully habituated to humans. Besides observing the chickens' cackling-related behavior, the researchers exposed the roosters to tape recordings that alternated hens' postoviposition cackles with "contentment" calls.

Contrary to expectation, cackling was observed after only about 15 percent of egg laying episodes, and just one-third of the hens ever burst into cackles after laying. Moreover, females that cackled were no more likely to mate than were those that did not. During the tape-playing experiments, most males ignored both calls; the few that paid attention to the recordings were equally interested in both types of calls.

Pizzari and Birkhead concluded that cackling after egg laying does not signal female receptivity. Indeed, they suggest, exactly the opposite may be occurring: females may be signaling their lack of receptivity in order to avoid male harassment, which sometimes re-

sults in lethal injuries to the hens. An alternative explanation leaves males out of the equation altogether: females may cackle to communicate with one another, perhaps to synchronize egg laying. ("For Whom Does the Hen Cackle? The Function of Postoviposition Cackling," *Animal Behaviour* 61, 2001)—Kirsten L. Weir

EAGLES VS. TRAINS Thanks to cleaner air and water, ample food supplies, reclaimed habitats, and release/monitoring programs, the U.S. bald eagle population has soared since the bird was listed as a national endangered species a quarter century ago. In New York State alone—where an aggressive restoration program operates—the number of fledged young rose from fifteen in 1990 to seventy-one in 2000.

Many of the birds, which feed mainly on fish, winter or nest in the lower Hudson River valley. But this habitat has its perils, including passenger trains traveling at up to 125 miles an hour on the New York City–Montreal line. The high-speed trains make little noise and move faster than anything an eagle would encounter in its natural environment.

Ward B. Stone, of the New York State Department of Environmental Conservation, and colleagues examined ten eagles struck and killed by high-speed trains between 1986 and 2000. Most of these collisions occurred on the rail line between New York City and Albany, and nine of the ten eagles killed were immatures. Less wary and agile than adults, young eagles are more likely to scavenge and thus to be attracted to the ample supply of dead animals on the tracks.

Some observers have suggested that carion on train tracks actually aids overall eagle survival by providing fledglings with a ready food supply. But Stone and colleagues conclude that, with several new nesting territories nearby, the trains' net effect on the eagle population "is most likely to be decidedly negative." ("Bald Eagles Killed by Trains in New York State," *Short Communications* 35:1, 2001)—Heather Van Doren

WASP BITES WASP Many types of colonial insects share information via body contact. One of the more mysterious forms of such

contact is known as social biting, and species that engage in the practice don't necessarily restrict themselves to dainty nibbles. *Polybia occidentalis* wasps, for example, go at a nest mate's body with degrees of intensity that range from mildly chewing to mauling the victim and lifting it right into the air.

But exactly what message does such chomping send? To find out, Sean O'Donnell, of the University of Washington, Seattle, studied female *P. occidentalis* workers at a field site in Costa Rica. He first investigated whether sexual competition was involved; other studies have shown that female workers in some species, possibly responding to chemical cues, police one another's reproductive status by attacking those females with well-developed ovaries. (Evolutionary theory suggests that the group's best interests are served if the queen is the sole breeder.)



SEAN O'DONNELL

The researcher observed marked females to determine how often and how badly they bit or were bitten. He compared these stats with their size, their degree of ovary development, and the frequency of their departures for the foraging field.

O'Donnell found that female workers' biting behavior was not related to body size or degree of ovary development, so reproductive competition couldn't explain it. Foragers (usually the older wasps) were bitten more often than the younger wasps designated to work only in or on the nest. And bitten foragers were more likely to leave the nest immediately in search of food and supplies. O'Donnell concluded that biting encourages wasps to do their jobs, but the factors that determine a worker's social standing—that is, whether it is more likely to be the biter or the bitten—remain a mystery. ("Worker Biting Interactions and Task Performance in a Swarm-Founding Eusocial Wasp," *Behavioral Ecology* 12, 2001)—Kirsten L. Weir

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IN THE FIELD

Salt of the Earth

Tiny mineral crystals can have huge effects on arid landscapes.

By Peter J. Marchand

Badwater Basin, Death Valley, California. Squinting across the shimmering expanse of pure white salt, I was unprepared for what I saw. Etched into the surface of that mirror-flat basin was a netlike pattern of polygons bearing a remarkable resemblance to the ones I'd just seen in the frost-shaped landscape of northwestern Alaska. For a moment I imagined that the glittering white was snow and that the raised ridges defining the large polygons were ice wedges growing in cracked, frozen earth. I lifted my hat and wiped my brow, recalling stories of cruel delusion suffered by pioneers crossing the Mojave Desert in the searing heat. But the scene before me was no mirage.

That two such disparate environments, at opposite ends of the climatic spectrum, should produce similar features surprised me at first. Yet patterned ground resembling that of northern polar regions can be seen in deserts as far afield as Egypt, Iran, China, Mongolia, and Peru. In the United States, such features show up sporadically in arid lands from New Mexico to Idaho. Nor is the resemblance superficial, for in both hot and cold climates the patterning results from the same fundamental process—the repeated expansion and contraction of the ground, often accompanied by the shifting and sorting of rocks. In the Arctic, extreme cold and freezing water are the principal agents, cracking the frozen earth beneath the surface and constantly churning, lifting, and moving the soil. In deserts, extreme

heat and the crystallization of salts dissolved by percolating rainwater accomplish the same task.

Many streams in the world's arid and semiarid regions run only intermittently and empty into broad, undrained basins known as playas, where they deposit their sediment and dissolved minerals. As the water evaporates, a thick crust of salt crystals builds up on the surface. But salt formation is not limited to floodwater basins. Wherever salts are present in water, even in the moist soil beneath stones, they crystallize during dry spells. As these crystals grow, they exert considerable force, sometimes even raising stones on pedestals of salt. Crystals can also form within the minute pores of rocks exposed to saline water; straining against their confines, they may eventually break the rock apart. (I have seen evidence of this same destructive force in old fence posts driven into moist saline soils. Slowly, the salty water is drawn up through the wood, but as soon as it reaches ground level—where the wood is exposed to air and sunlight—the water evaporates and salt crystals form, shattering the post.)

Salt crystals generate additional stresses in fractured rock as they undergo daily cycles of heating and cooling. Warming by several degrees during the day, the crystals may expand at a faster rate than the minerals in the rock that contains them. Wedged into small cracks in granite, for instance, they may generate pressures of up to thirty pounds per square inch. And if they

are dehydrated, they may enlarge even more as they attract water from the cool night air. Unlike dewdrops, which often sit on the surface of an object, water that attaches to salt actually becomes part of its crystalline structure and increases its volume. Like wet plaster of paris hardening in a glass jar, salt crystals that have incorporated water can also expand to crack their container. (Various forms of hydrated and anhydrous calcium sulfate, the key constituent of plaster of paris, are common throughout the deserts of the world.) All this activity can move rocks the way frost does when it shatters, heaves, and sorts the pieces into patterns.

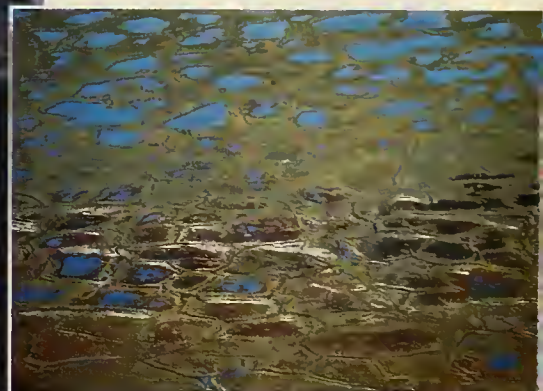
Like ice in the Arctic, though, salt rarely acts alone in the formation of patterned ground features. In a playa such as Badwater Basin, fine silt and clay deposited by infrequent floodwaters also play a central role in the process. As soil dries beneath the salt veneer, it shrinks and cracks—like a mud puddle after rain—creating fissures sometimes two to three feet deep and forming the dominant polygonal pattern. But even as the surface becomes parched and hardened, groundwater—along with its dissolved salt—continues to be drawn upward through the fine-grained soil by capillary action. Upon reaching the open fissures, the water evaporates, salt crystals build up on the fissures' walls, and ramparts rise above the circumscribed polygons, clearly defining each one. In time, accumulating salts widen and accentuate the fissures in much the



JOHN CARBONE/CORBIS OUTLINE; BRUCE COLEMAN, INC. INSET: ART WOLFE

Left: Accumulated salts highlight cracks in the floor of Death Valley, California. Similar polygonal shapes can be seen in an aerial view of Alaska's coastal plain (inset).

the circles of bare soil. And like frost boils in the Arctic, many of these circles were marked by rocks thrust upward, broken into layers, and split apart—by salt crystals rather than by freezing water. On steeper inclines, the stones were displaced primarily toward the downslope edge of the mound, and the same process of sorting had led to the formation of small, stone-banked steps or terraces. Some steps even appeared to have crept



same manner that slow additions of freezing water gradually increase the width of ice wedges bordering Arctic polygons.

As I hiked up the gently sloping flanks of Badwater Basin's salt pan, I encountered still more patterns in the ground. Low mounds of silty soil pocked the stony desert pavement like so many frost-heaved "boils" in an

Arctic coastal plain. Despite Death Valley's extreme dryness, pockets of clay had swelled with moisture during the last rainfall, bulging upward to form these low mounds. Each time this process repeats itself, stones on the surface of the mound move a little, nudged by salt and pulled by gravity toward the edges of the dome, where they eventually come to rest, outlining

imperceptibly downward. en masse, just as lobes of soil on Arctic hillsides ooze slowly downhill over the frozen subsoil.

This was as clever a trick of nature as I had ever witnessed—a near-perfect duplication of an Arctic landscape pattern in one of the hottest places on earth.

Peter Marchand is a research ecologist at the Catamount Institute, situated on the north slope of Pike's Peak in Woodland Park, Colorado.

UNIVERSE

Over the Rainbow

The astrophysicist's pot of gold lies along the entire spectrum.

By Neil deGrasse Tyson

Whenever cartoonists draw biologists, chemists, or engineers, the characters typically wear protective white lab coats with assorted pens and pencils poking out of the breast pockets. Astrophysicists use plenty of pens and pencils, but we never wear lab

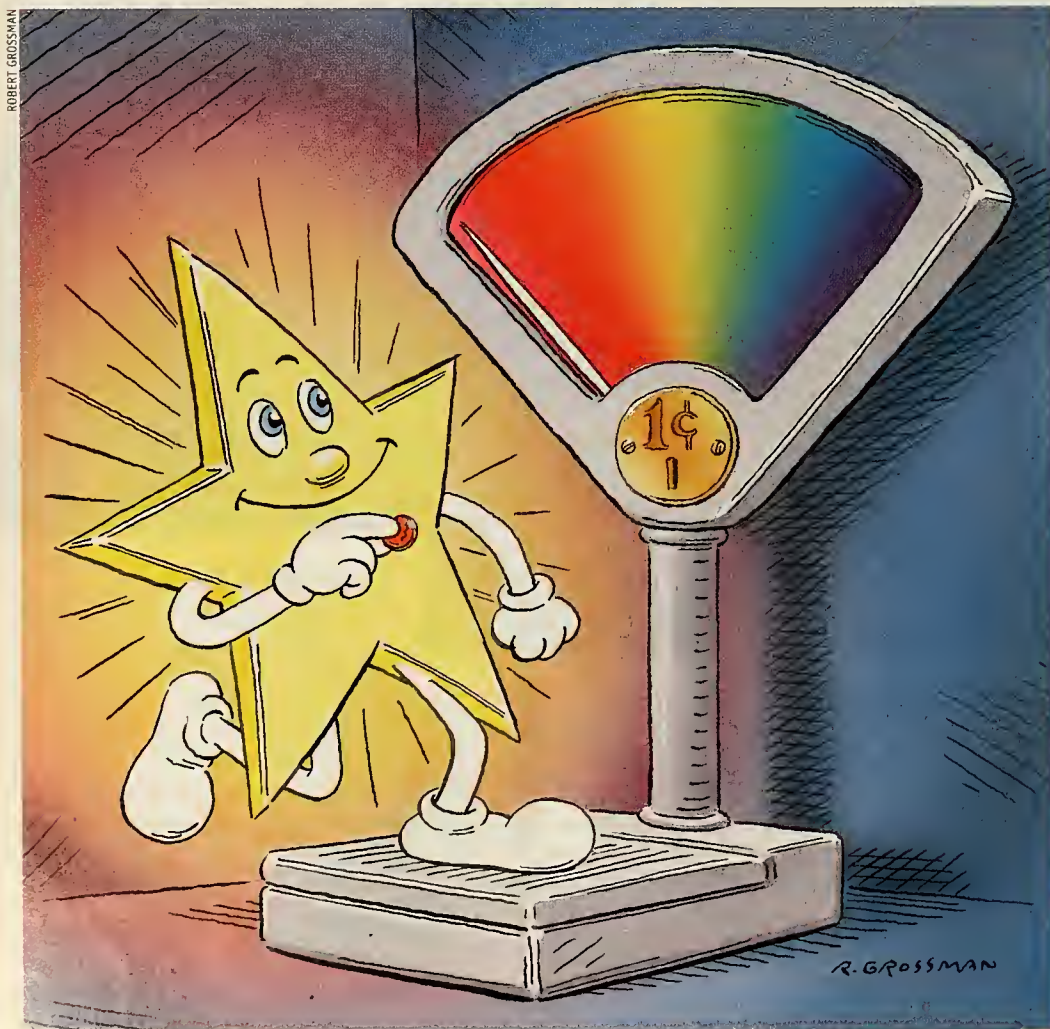
coats unless we are building something to launch into space. Our primary laboratory is the cosmos, and unless you run into some bad luck and get hit by a meteorite, you are not at risk of getting your clothes sullied or singed. Therein lies the challenge. How do you study something that cannot possibly get

your clothes dirty? How do astrophysicists manage to learn anything about either the universe or its contents when all the objects to be studied are light-years away?

Fortunately, the light emanating from a star reveals much more to us than the star's position or brightness.

The light also serves as a sensitive probe of the star's atoms, which lead busy lives. Their little electrons continually absorb and emit light. And if the environment is hot enough, collisions between atoms can jar loose some or all of their electrons, scattering light to and fro. Each type of atom leaves its unique fingerprint on the light being studied, implicating the responsible chemical elements or molecules.

In 1666, Isaac Newton used a prism to disperse white light and produce the now familiar spectrum of seven colors—red, orange, yellow, green, blue, indigo, and violet—that he himself named. (Feel free to call them Roy G. Biv.) Other people had played with prisms before. What Newton did next, however, had no precedent. He passed the emergent spectrum of colors back through another prism and recovered the pure



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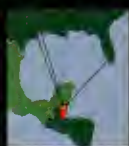
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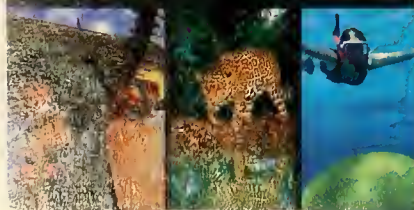
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white he had started with. This simple exercise demonstrated a remarkable property of light that has no counterpart on the artist's palette—where these same colors of paint, when mixed, leave you with a sludge-colored glob. Further, Newton tried to disperse each of the spectrum's seven colors, but he found them to be pure. The human eye has no capacity to do what prisms do.

found in the spectra of many stars—including Capella, one of the brightest in the nighttime sky.

By the mid-1800s, German chemists Gustav Kirchhoff and Robert Bunsen (of "Bunsen burner" fame) were making a cottage industry of burning stuff and passing the light through a spectroscope, an optical device with a built-in prism. They mapped the pat-

Were it not for science's ability to analyze light by breaking it up into its component colors, we would know next to nothing about the universe.

Another window to the universe lay undiscovered before us.

A careful inspection of the Sun's spectrum using precision optics and techniques unavailable in Newton's day reveals not only Roy G. Biv but also narrow segments within the spectrum where color is absent. These "lines" through the light were discovered in 1802 by British physician and chemist William Hyde Wollaston, who naively (though sensibly) suggested that they were naturally occurring boundaries between the colors.

Despite their seven distinct names and the presence of dark lines, spectral colors change gradually from one into the next. Soon the efforts of German physicist and optician Joseph von Fraunhofer produced a more complete discussion and interpretation. Fraunhofer, who devoted his career to the quantitative analysis of spectra and to the construction of optical devices that generate them, is often referred to as the father of modern spectroscopy, but I might make the additional claim that he was the father of astrophysics. Between 1814 and 1817, he discovered that when passed through a prism, the light of certain flames produced patterns of lines that resembled what he had found in the Sun's spectrum, which in turn resembled lines

terns made by known elements and discovered many new ones, including rubidium and cesium. Each element left its own pattern of lines—its own calling card—in the spectrum being studied. So fertile was this enterprise that the second most abundant element in the universe, helium, was discovered in the spectrum of the Sun before it was discovered on Earth. The element's name reflects this history, with its prefix derived from *helios*, "the Sun."

A detailed and accurate explanation of the role played by atoms and their electrons in the formation of spectral lines would not emerge until the era of quantum mechanics, a half century after Kirchhoff and Bunsen. But the conceptual leap had already been made: just as Newton's equations for gravity connected the realm of laboratory physics to the solar system, Fraunhofer connected the realm of laboratory chemistry to the cosmos. He set the stage for others to identify the chemical elements that filled the universe and to determine the conditions of temperature and pressure influencing their spectral patterns.

Among the more boneheaded statements ever made by philosophers, armchair or otherwise, we find the following 1835 proclamation by French logical positivist Auguste Comte:

On the subject of stars, all investigations which are not ultimately reducible to simple visual observations are . . . necessarily denied to us. . . . We shall never be able by any means to study their chemical composition. . . . I regard any notion concerning the true mean temperature of the various stars as forever denied to us.

Quotes like that can make you afraid to say anything in print.

Just seven years later, in 1842, Austrian physicist Christian Doppler proposed what became known as the Doppler effect, which is the change in the frequency of waves emitted by an object in motion. One can think of a moving object, whether a car or a star, as stretching the waves in its "wake" (reducing their frequency) and compressing the waves in front of it (increasing their frequency). The faster the object moves, the more the waves in front of it are compressed and the more those behind it are stretched. This simple relationship between wave speed and wave frequency has profound implications. If you know the natural frequency at which light or sound waves are emitted by an object, but you note a different value when the object is moving, the difference between the two frequencies is a direct indication of the object's speed toward or away from you. In an 1842 paper, Doppler made this prescient statement:

It is almost to be accepted with certainty that this [effect] will in the not too distant future offer astronomers a welcome means to determine the movements . . . of such stars which . . . until this moment hardly presented the hope of such measurements and determinations.

The idea works for sound waves, for light waves, and, in fact, for waves of any origin (although Doppler would surely be surprised to learn that his discovery would one day be used in mi-

crowave-based radar "guns" wielded by police officers to extract money from people who drive automobiles above a speed limit set by law). By 1845, Doppler was "conducting" experiments in which musicians played tunes on flatbed railway trains while people with perfect pitch wrote down the changing notes they heard as the trains approached and then receded.

During the late 1800s, the widespread use of spectroscopes, coupled with the relatively new science of photography, enabled the field of astronomy to be reborn as the discipline of astrophysics. One of the preeminent research publications in my field, the *Astrophysical Journal*, was founded in 1895, and until 1962 it bore the subtitle *An International Review of Spectroscopy and Astronomical Physics*. Even today, nearly every paper reporting observations of the universe gives either an analysis of spectra or is heavily influenced by spectroscopic data obtained by others. Since much more light is needed to generate the spectrum of an object than to take its snapshot, the biggest telescopes in the world, such as the twin 10-meter Keck telescopes in Hawaii, each with nearly twenty times the light-gathering power of the Hubble Space Telescope, are tasked primarily with obtaining spectra.

Were it not for science's ability to analyze light by breaking it up into its component colors, we would know next to nothing about the universe. Astrophysics educators thus face a pedagogical challenge of the highest rank. We deduce nearly all our scientific information about the structure, formation, and evolution of objects in the universe by studying spectra, but the analysis of a spectrum is removed by several levels of abstraction from the thing being studied. In some cases, analogies and metaphors can help link complex, somewhat abstract ideas to simpler, more tangible ones. The biologist might describe the shape of the DNA molecule as two coils connected

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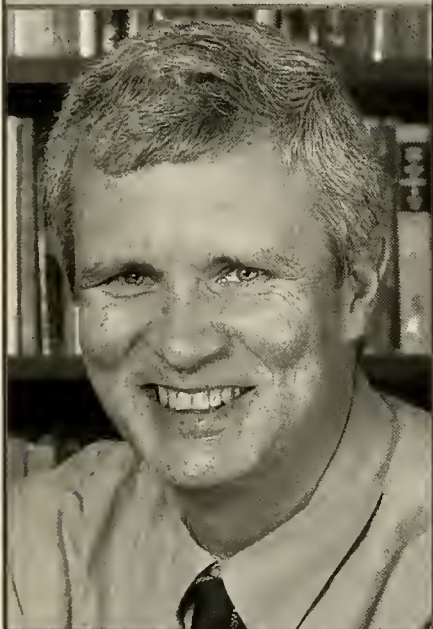
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to each other the way rungs on a ladder connect the ladder's sides. I can picture a coil. I can picture two coils. I can picture rungs on a ladder. I can therefore picture the molecule's shape. Each part of the description sits only one level of abstraction removed from

bones, tools, fossils, memorabilia, and so forth. All these are Level 0 specimens, requiring little or no cognitive investment from viewers before they can process the explanation of what the item is. But astrophysicists have a problem: they cannot place cosmic speci-

Photographs can show us that dying high-mass stars explode. But X-ray and visible-light spectra show us that heavy elements spew from these stars, enriching the galaxy.

the molecule itself. And they come together nicely to make a vivid image in the mind. However easy or hard the science is, one can now at least talk about this molecule.

But to explain to an audience how we know the speed of a receding star requires five nested levels of abstraction:

Level 0: Star

Level 1: Picture of a star

Level 2: Light from the picture of a star

Level 3: Spectrum from the light from the picture of a star

Level 4: Patterns of lines in the spectrum from the light from the picture of a star

Level 5: Shifts in the patterns of lines in the spectrum from the light from the picture of a star

Going from Level 0 to Level 1 is a trivial step we all take every time we get pictures back from the photo processor. But by the time a scientist's explanation reaches Level 5, the audience is either befuddled or fast asleep. The public hardly ever hears about the role of spectra in cosmic discovery because the concept is just too far removed from the objects themselves to be explained efficiently. When creating exhibits for natural history museums, or for any museum where real things matter, what designers typically seek are objects and artifacts suitable for display—rocks,

mens on display because most of them would vaporize the museum.

Most astrophysics exhibits are therefore conceived in Level 1, leading principally to displays of pictures—some quite gorgeous. The most famous telescope in modern times is, of course, the Hubble, known to the public primarily through the beautiful, full-color, high-resolution images it has produced of objects in the universe. The problem here is that after viewing such exhibits, you wax poetic about the beauty of the universe yet are no closer than before to understanding how it all works. To really know the universe requires forays into Levels 3, 4, and 5. While much good science has come from the Hubble telescope (including the most reliable measure to date for the expansion rate of the universe), you would never know from media accounts that the foundation of our cosmic knowledge continues to flow primarily from the analysis of spectra and not from looking at pretty pictures.

I want people to wax poetic not only after exposure to Levels 0 and 1 but up to and including exposure to Level 5, which admittedly requires a greater intellectual investment on the part of the student and (perhaps especially) on the part of the educator.

For example:

It's one thing to see a beautiful color picture, taken in visible light, of a neb-

ula in our own Milky Way Galaxy. But it's another thing to know from its radio-wave spectrum that the nebula also harbors newly formed stars of very high mass within its cloud layers. This gas cloud is a stellar nursery, regenerating the light of the universe.

It's one thing to know that high-mass stars explode every now and again. Photographs can show us this. But the X-ray and visible-light spectra of these dying stars reveal a cache of heavy elements that enrich the galaxy and can be directly linked to the constituent elements of life on Earth. Not only do we live among the stars, the stars live within us.

It's one thing to look at a poster of a pretty spiral galaxy far beyond our own. But it's another thing to know from Doppler shifts in its spectral features that this particular galaxy is rotating at 200 kilometers per second—from which, using Newton's laws of gravity, we infer the presence in it of 100 billion stars. And by the way, the Doppler shifting also tells us that the galaxy is receding at one-tenth the speed of light.

It's one thing to look at nearby stars that resemble the Sun in luminosity and temperature. But it's another thing to use hypersensitive Doppler measurements of a star's motion to infer the existence of planets in orbit around them. At press time, our catalog of extrasolar planets nears 100 entries.

It's one thing to observe the light from a quasar at the edge of the universe. But it's another thing entirely to analyze the quasar's spectrum and deduce from that analysis the structure of the invisible universe—the gas clouds and other obstructions that lie along the quasar's path and take a bite out of its spectrum.

Fortunately for the magnetohydrodynamicists among us, atomic structure changes slightly under the influence of a magnetic field. Where can this change be seen? In the slightly altered spectral patterns caused by these magnetically afflicted atoms.

And armed with Einstein's relativistic version of the Doppler formula, we deduce the expansion rate of the entire universe from the spectra of countless galaxies, near and far, and thus infer the age and fate of the cosmos.

One could make a compelling argument that astrophysicists know more about the universe than marine biologists know about the ocean floor or geologists know about the center of Earth. Far from leading an existence as

powerless stargazers, we are armed to the teeth with the tools and techniques of spectroscopy, enabling us *Homo sapiens* to stay firmly planted on Earth yet finally to touch the stars—without burning our fingers—and claim to know them as never before.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.



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Freshwater Riches *of the* Amazon

Story by John Lundberg ~ Painting by Ray Troll

*To find the reasons for
a river's abundance,
a scientist goes fishing
in deep time.*



Home to more than two thousand freshwater fish species, the Amazon, ichthyologically speaking, is the hottest big river on the planet. Some of its inhabitants are familiar: cardinal tetras, discus, angel cichlids, and armored “pleco” catfish inhabit home aquariums; trophy-sized peacock bass and goliath catfishes beckon sporting anglers; giant-sized tambaqui and pirarucú are prime food fishes for residents of the region; and piranhas, electric eels, and river stingrays contribute to tales of tropical danger. But any notion that science has achieved a complete inventory of the Amazon’s, or the world’s,

fishes is utterly dispelled by ongoing discoveries. Each year since 1960, more than 35 tropical American species of fishes, including catfishes, characins, electric fishes, killifishes, and cichlids, have been newly described and named. During the past decade the pace has quickened, with more than 50 fishes coming to scientific light annually. By contrast, the Congo River of Africa has about 700 fish species in total, and the well-studied Mississippi-Missouri of North America, a relatively scant 375.

I had surveyed the fishes of the Orinoco River system of Venezuela and Colombia for many years before my first visit to the Amazon in 1990. For an

ABOUT THE ARTIST

In 1997, artist and fish aficionado Ray Troll traveled 1,000 miles of the Amazon. The river’s diversity inspired a seven-by-fifteen-foot painting of 120 species.

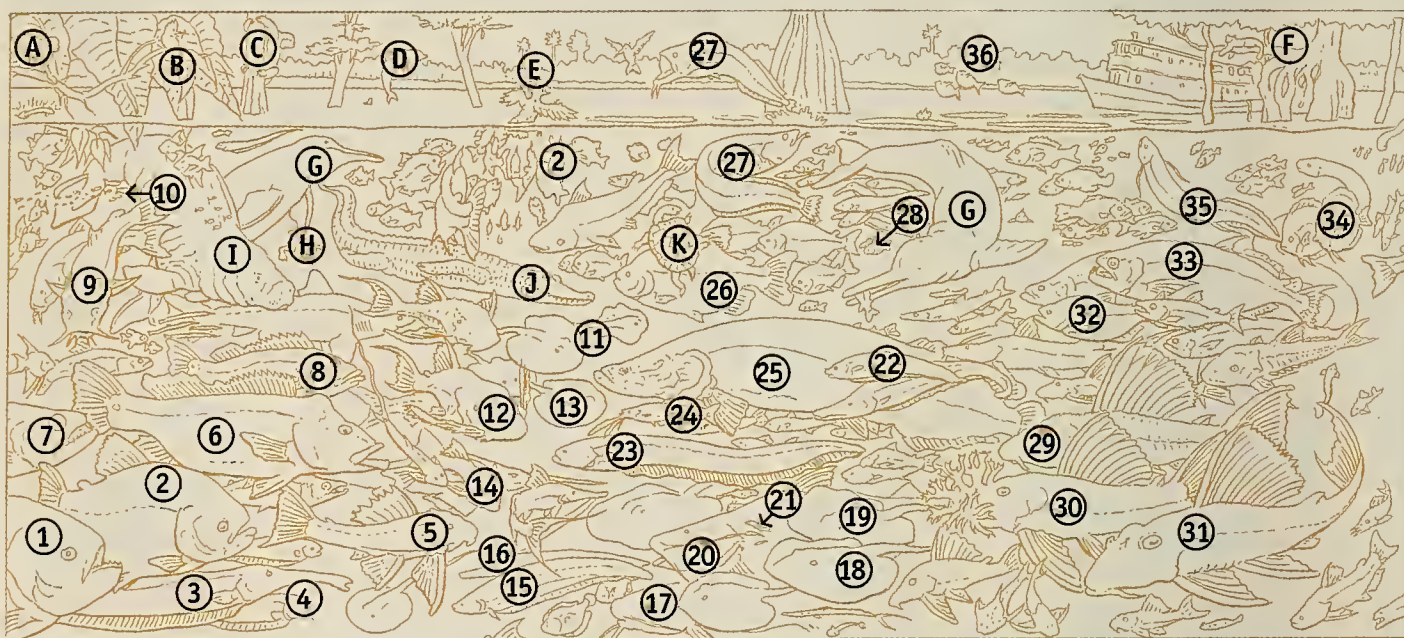
ichthyologist, the Amazon represents a pinnacle of diversity, but I also wanted to investigate the history and origins of the river's many fish species. Biogeography is the science that seeks to document and explain patterns of diversity and regional differences in species abundance, so I delved into the ancient geography of South America to find out just why the Amazon has so many fishes.

Two broad, global patterns of biogeography help explain Amazon fish diversity, but they don't tell the whole story. Size matters, and the Amazon River basin is a large, watery place, covering more than 2.5 million square miles, or 30 percent of the South American continent. In terms of water vol-

ume, no other river on earth comes close to it. In the rainy season, the Amazon discharges 3–6 million cubic feet of water per second into the Atlantic and accounts for 20 percent of the worldwide flow

Size is at best a partial explanation for the Amazon's bounty.

of freshwater into the oceans. So we might expect the vast basin, or watershed—consisting of the main stem of the Amazon and its thousands of tribu-



FISH . . .

1. Black piranha, *Serrasalmus rhombeus*
2. Red-bellied piranha, *Pygocentrus nattereri*
3. Thin-nosed tube-snout knifefish, *Sternarchorhynchus oxyrhynchus*
4. *Sternarchogiton* sp.
5. Dark-spotted armored catfish, *Pterygoplichthys* sp.
6. Speckled peacock bass, *Cichla temensis*
7. Freshwater dogfish, *Rhaphiodon vulpinus*
8. Peacock bass, *Cichla ocellaris*
9. Pirarara (red-tailed) catfish, *Phractocephalus hemioliapterus*
10. Cardinal tetra, *Paracheiradon axelrodi*
11. Motoro, *Potamotrygon* sp.

12. Royal pleco, *Panaque nigrolineatus*
13. Reticulated stingray, *Potamotrygon reticulatus*
14. Common pleco, *Hypostomus* sp.
15. Duke's channel knifefish, *Magasternarchus ducis*
16. Tamandua tube-snout knifefish, *Orthosternarchus tamandua*
17. Black piraiba catfish, *Brachyplatystoma* sp.
18. Tiger stingray, *Potamotrygon* sp.
19. Faulkner's stingray, *Potamotrygon faulkneri*
20. Piraiba catfish, *Brachyplatystoma filamentosum*
21. Candirú catfish, *Vandellia plazaii*
22. Tooth-lip knifefish, *Oedemognathus exodon*
23. Electric eel, *Electrophorus electricus*

aries—to contain many fish species. Yet the Orinoco, with a watershed area of less than half a million square miles, boasts at least 1,000 species, and even smaller rivers of the Guianas teem with hundreds of species. Size, then, is at best a partial explanation for the fish-rich Amazon.

A second general pattern, which holds true for tropical America's birds, reptiles, amphibians, mammals, insects, marine fishes, invertebrates, and plants—that is, most organisms—is known as the latitudinal diversity gradient. Long recognized but never fully explained, this is the trend for life to be more diverse in tropical, low-latitude regions. It is a fact of geography that near the equator, the earth receives more energy from the sun. Temperature and day length are more seasonally stable (although in many cases rainfall is not). Under these conditions, vegetation abounds and, in turn, can support many animals of many species, including some that have extremely specialized lifestyles and exist only in small populations. The Amazon is full of gastronomic specialists. *Hypophthalmus*, for example, eats tiny zooplankton; other fish eat snails (*Megalodoras uranoscopus*), the scales of other fish (*Catoprion*), the tails of other fish (*Magostemarchus*), chunks of flesh and fins (piranhas), fruits and seeds (tambaqui), wood (*Panaque*), or blood and gills (candirú catfish). (One species of candirú catfish, which is attracted to the flow of water from the gills of its prey, has become notorious for its unfortunate tendency to mistake a stream of urine for gill flow and to enter human urethras.)

While river systems both large and small in the northeastern two-thirds of the continent appear to



Adapted for life in turbid waters, the Amazon river dolphin has extremely small eyes. It uses its finely tuned echolocation skills to detect prey.

exemplify the tendency of low latitudes to be species rich, other South American rivers do not. Fish diversity falls off precipitously in the watersheds north and west of the Andes. These rivers and tributaries are flanked by some of the richest land and marine communities, but by South American standards, they have relatively few freshwater fishes. For example, the Magdalena River and Lake Maracaibo in the northwest each host only about 150 species.

While heat, sunlight, and ample food can help maintain tropical diversity, they do not explain how great diversity arose in the first place. The bounty of the Amazon can be accounted for only if we consider time as well as space. Biogeographical pat-

24. *Hypophthalmus fimbriatus*

25. Pirarucú, *Arapaima gigas*

26. Tambaqui, *Colossoma macropomum*

27. Arowana, *Osteoglossum bicirrhosum*

28. Harald Schultz's cory, *Corydoras haraldschultzi*

29. *Hypostomus* sp.

30. Polka-dot bristlenose catfish, *Ancistrus lineolatus*

31. Goldy pleco, *Scobiancistrus aureatus*

32. Elongate piranha, *Serrasalmus elongatus*

33. Pirandirá vampirefish, *Hydrolycus scomberoides*

34. Heckel discus, *Symphysodon discus*

35. American lungfish, *Lepidosiren paradoxa*

36. Hatchetfish, *Thoracocharax stellatus*

... AND FRIENDS

A. Squirrel monkey, *Saimiri sciureus*

B. Green kingfisher, *Chloroceryle americana*

C. Three-toed sloth, *Bradypus tridactylus*

D. Tucuxi dolphin, *Sotalia fluviatilis*

E. Hoatzin, *Opisthocomus hoazin*

F. Jaguar, *Panthera onca*

G. Amazon river dolphin, *Inia geoffrensis*

H. Surinam toad, *Pipa pipa*

I. Amazonian manatee, *Trichechus inunguis*

J. Spectacled caiman, *Caiman crocodilus*

K. Yellow-spotted Amazon turtle, *Podocnemis unifilis*



Wired for life in the deep: *Orthosternarchus*, a nearly blind electric fish, and *Magosternarchus*, an electric tail-eating species (long blue-gray and red fishes at lower right). A nonelectric, armored catfish swims above a ray (left).

The Amazon and its tributaries are not only vast but also fast moving, deep, and dark. In the clearer tributaries an observer may peer down to a depth of several yards, but in most of this silt-laden river system, light does not penetrate even three feet. One of the main challenges faced by ichthyologists hoping to discover and document the fish species in very big South American rivers is to devise ways to survey less accessible parts of the channels. My colleagues and I found that from large boats or even motorized canoes, we could trawl depths of a few to more than 150 feet by casting a weighted net with a wide mouth and very fine mesh. In the process, we lost plenty of equipment as our gear snagged on submerged trees and rocks in water that was moving six or more feet per second.

So far on our Amazon collecting trips, we have netted some 240 species of fish, some of them with surpassingly strange lifestyles. Especially well adapted to low or nonexistent light levels are several new species of electric fishes and catfishes. Many, such as the electric fish *Orthosternarchus* and the catfish *Bathycetopsis*, are blind or have only tiny vestigial eyes; some lack pigment. One transparent catfish, *Micromyzon*, has thick bones and armor plating but is among the tiniest of freshwater fish: an adult specimen carrying eggs measured just one-third of an inch long. Electric fishes of deep waters are able to navigate and locate prey using electric impulses.

terns, particularly those of fishes, are rooted deep in the past. As denizens of rivers, streams, and lakes, the largest groups of endemic, or native, freshwater fishes in South America are relatively confined. Unlike many other creatures, they can neither move through coastal saltwater nor traverse land barriers. Where they are and how they move about depend on changes of continental proportions that have taken place at a geologically slow pace.

One controversial theory that seeks to explain tropical America's biodiversity holds that climatic shifts starting about 2 million years ago and continuing through the Pleistocene Epoch, or until about ten thousand years ago, caused the repeated fragmentation and merging of tropical rainforests. Such shifts provided multiple opportunities for birds, butterflies, and plants to diverge and eventually be-

Dark New World

Each species has its own distinct patterns of electric discharges that it uses to communicate, much like birds use song. One electric fish bears a fleshy protrusion above its chin; we can only guess what that feature might be used for.

Some catfishes provide abundant food for the people living in the Amazon River basin and are often caught as adults in shallow water near river banks. But they appear to spend their juvenile stage floating and feeding near the surface of the river's central channels. Understanding such lifestyles is important for managing the harvest of food fish in the Amazon.

Two of the strangest creatures in this new realm are a pair of related electric fish species that we named *Magosternarchus raptor* and *M. ducis*. About ten inches long, these fishes make a living by feeding on the tails of other species of electric fish. We found this out when their stomachs proved to contain nothing but fish tails. Their victims can conveniently regenerate the nibbled appendage, renewing their own posteriors and the food source of the tail eaters. (We suspect that *Magosternarchus* may also dine on the tails of its own kind.) While we expect the Amazon and other big tropical rivers around the world to reveal more secrets in the future, some spots in these rivers run forbiddingly deep—up to 300 feet in the Amazon near Manaus, Brazil—and this may be deep enough to preserve some riverine mysteries.—J. L.



Left: Millions of years ago, the major river systems of South America flowed north-south.



As the Andes rose, Lake Maracaibo and the Magdalena River were isolated in the northwest, and the Orinoco and Amazon Rivers took 90° turns and began to flow into the Atlantic, left and detail above.

come new species. But in the case of fishes, a time frame of 2 million years is just yesterday. Long before the Pleistocene, the Amazon teemed with species that are closely related to fishes alive today in the river. We need, then, to consider phenomena much older than 2 million years as we search for clues to the diversification and biogeography of Amazon fishes.

As early as the middle Miocene, about 15 million years ago, the tropical American fish fauna was

For fishes, 2 million years ago is just yesterday.

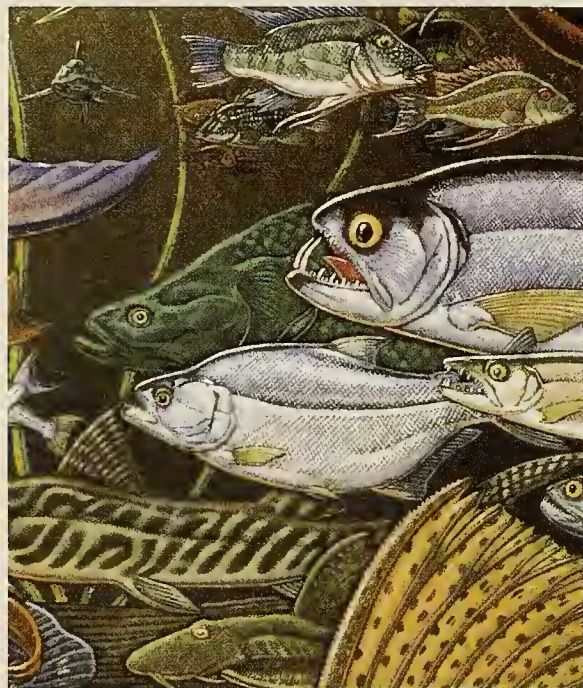
essentially like today's. It included many living groups: stingrays, lungfish, pirarucú, piranha, go-liath catfishes, some electric fishes, and cichlids. A primatologist friend and colleague once showed me a fossil of a 13-million-year-old fish he had excavated in Colombia. He had no idea what kind of fish he had found and was struck by its particularly large teeth. He was surprised when I was able to identify the fossil; the specimen looked just like a living fish I knew well, the tambaqui. Although no longer found in the rivers of central Colombia, the tambaqui, which feeds on seeds and fruits that fall from trees in the seasonally flooded forests, thrives today in the Amazon. Similarities between ancient and modern fishes crop up even further back in time. One well-preserved fossil fish about 59 million years old looks like, and is indeed related to, the *Corydoras* catfish popular today in the aquarium trade. And some fossil catfishes, lungfishes, and

characins date back to the Late Cretaceous, 70 million years ago.

Today, 93 percent of South American freshwater drains into the Atlantic, but this was not always the case. The stage on which the present pattern of rivers took shape was the continent itself. The players, South America's major physical features, included two huge slabs of stable continental crust, known as the Guyana and Brazilian Shields; the dynamic Andes mountain range; and the vast lowlands that lay between the shields and the mountains. About 90 million years ago, South America and Africa (both of which had earlier been part of the southern supercontinent of Gondwana) separated from each other. As South America, which comprised a continental plate, moved west, it crashed against an oceanic plate moving east. The collision caused the land along the west coast of South America to rise up, and the first stage of Andean mountain building began. During their long history, the Andes underwent several phases of uplift and subsidence. As the mountains grew, adjacent land to the east and north buckled, forming a

troughlike basin running north and south. At times the basin was filled with sediment; at wetter intervals it contained large lakes, was periodically inundated by shallow ocean waters, and channeled major rivers in a north-south direction. Taken together, the formation of Andean and other land barriers, the shifting courses of rivers, and sporadic incursions of ocean waters would have produced many opportunities for fish species to evolve as some populations were isolated from others and began to adapt to new conditions.

A toothy pirandirá vampirefish and smaller elongate piranha, right. Opposite page: Representing the world's biggest freshwater food fish, a pirarucú swims just below a tambaquí, as arowanas leap at the water's surface.



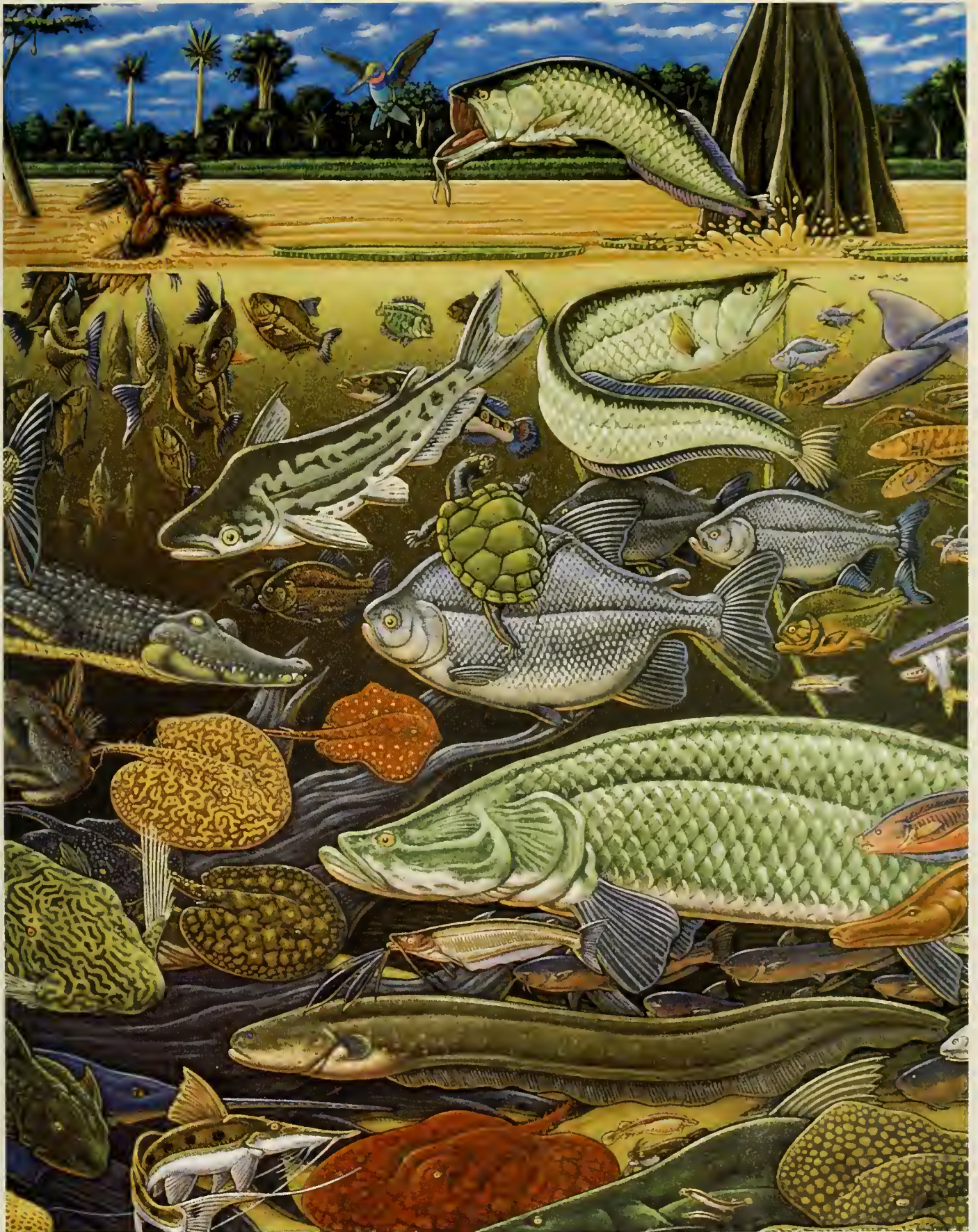
Long before the end of the Miocene, a great river, consisting of what are today the western Amazon and the Orinoco, flowed north through the lowland basin and into the Caribbean. About 10 million years ago, the rise of the eastern Andes created the Magdalena River basin in Colombia. Uplift continued until, by 8 million years ago, the mouth of the north-flowing Amazon-Orinoco was dammed. The river could no longer reach the Caribbean Sea. This major event in the geographical history of South America split the Orinoco and Amazon and reoriented their course from north-south to west-east. The Amazon began to flow into the Atlantic, as it does today. Over time, new rivers appeared in the north, and 3.5 million years ago the elevation of the Isthmus of Panama formed a bridge between the American continents.

As rivers appeared, disappeared, and changed course, their communities of fishes went along for

the ride. The ranges of various species expanded, merged, or were disrupted. The geological upheavals that divided rivers and river basins provided opportunities for speciation when fish populations were isolated. The results are the species that today are found only in those systems. However, fossils from the regions now occupied by the Magdalena River and Lake Maracaibo show they once contained fishes no longer found there but that still inhabit the Amazon. These include lungfish, *Arapaima*, tambaquí, piranha, *Hydrolycus*, and goliath and pirarara catfishes. Although the fossil record documents such localized extinctions of living fish groups, we have no evidence of widespread extinctions and only two or three cases in the past 65 million years in which an Amazon fish species was completely extinguished.

The biodiversity equation is balanced by speciation on one side and extinction on the other. Low extinction rates are part of the formula for fish-species richness in the Amazon basin and eastern South America. But in other regions of the world, freshwater fishes also provide textbook examples of rapid species formation. Chief among these examples are the African cichlids, which, in a geologically brief period (perhaps less than 100,000 years), evolved into hundreds of species that now live in the same body of water. In contrast, we have no evidence for any unusually high rates of speciation among fishes in South America. Given enough time and low extinction rates, a normal tempo of speciation gave rise to the Amazon's array.

Since the day I recognized my colleague's fossil as almost identical to a modern fish, I have discovered several other examples of this phenomenon, and I am still struck by the great antiquity of many of the living tropical American fish species. By comparison, the history of other groups, such as mammals, has been fast paced and marked by high turnover. Tropical American mammal species have immigrated, emigrated, evolved, and gone extinct with a rapidity that makes Amazon fishes look frozen in time. Fish like the tambaquí—whose fossil and modern jaws and teeth reveal unmistakable similarities—have, except in the restless edges of their ranges, changed little over the past 15 million years. As continents separated and connected, as the Andes grew and rivers took right-angle turns, the tambaquí persisted in its specialized diet of fruits and seeds. This fish and many modern-day finned icons of the Amazon recount a long and enlightening chapter of the story of life on earth. □



Out of Thin Air



A very special group of microbes tap into the atmosphere's huge storehouse of nitrogen and make it available to the rest of us.

By David W. Wolfe

Lightning and some bacteria that live in the roots of certain plants, such as lupines, opposite page, share the rare ability to "fix" nitrogen gas, turning it into a form that plants and animals can use.

Take a deep breath. Most of what is filling your lungs is not oxygen but nitrogen, in the form of N_2 gas. Every cubic yard of the air around us, in fact, is about 80 percent N_2 . On the face of it, this abundance would appear to be an unqualified blessing, for nitrogen is an essential ingredient of life—a key component of amino and nucleic acids, the basic building blocks of proteins and our genes. There is a catch, however. This immense supply might as well be on Jupiter or Mars as far as most living things are concerned. No animal, plant, fungus, or protist has mastered the chemical art of converting the abundant gaseous form of nitrogen into a biologically useful one. In fact, if N_2 were the only nitrogen available, most species would quickly go extinct—like sailors dying of thirst while adrift on a

life raft at sea. Fortunately, within the dark and hidden realm that is the ground beneath our feet—a realm generally ignored by us oversized, sunlight- and oxygen-dependent "surface chauvinists"—live a handful of bacterial species that can metabolize N_2 and thereby bring this nitrogen into the food chain.

Earth's first microbes, which emerged about 3.5 billion years ago, had no such ability. N_2 became available to them only when it was transformed into nitrate (NO_3 , nitrogen combined with oxygen) during lightning strikes and meteor impacts. At that time, the energy and heat generated by these random events were the only forces in nature capable of breaking the powerful chemical bond that holds the two atoms of N_2 together. This sprinkling of nitrate from the heavens had some inherent



Alders host nitrogen-fixing bacteria in the genus *Frankia*, which nourish the trees and help maintain healthy nitrogen levels in the soil.

limitations with regard to supporting life on earth, however. For one thing, nitrate is easily washed away by rain and often winds up in groundwater, rivers, and ultimately the oceans before any terrestrial organisms can make use of it. For another, once photosynthesis evolved (perhaps 3 billion years ago), the number of living things on earth expanded rapidly, creating a demand for usable nitrogen that exceeded this meager supply.

Enter a unique group of bacteria that "invented" a way to convert, or fix, N_2 gas into ammonia (NH_3 , another usable form of nitrogen, this

time in combination with hydrogen) without the intense heat and pandemonium that come with lightning bolts and meteor bombardment. When these bacteria die and decompose, or are consumed by other organisms, the nitrogen they managed to incorporate into their cells becomes available to the rest of us. Essentially all the nitrogen contained within the proteins and genes of plants, animals, and humans has, at one time or another, been funneled through these nitrogen-fixing microbes.

A single pinch of garden soil may contain 10,000 bacterial species, but probably no more than



100 to 200 species of free-living nitrogen fixers exist worldwide. Many of these are members of an ancient group of self-sufficient organisms known as cyanobacteria, which can fix both carbon (through photosynthesis) and nitrogen. Cyanobacteria are vitally important as "primary producers" at the base of the food chain in the oceans. On land, the most common and important nitrogen-fixing bacteria are those that live symbiotically within the roots of plants, providing their hosts with nitrogen and receiving in return the products of photosynthesis (carbon-laden, energy-rich sugars).

With 99 percent of soil organisms not yet named or studied, we still have much to learn about subterranean symbioses and the nitrogen cycle. Scientists frequently turn up new nitrogen-fixing microbes, some of which form partnerships with animals rather than plants. For example, bacteria living in the intestinal glands of a wood-boring mollusk known as the shipworm provide the animal with as much as one-third of its nitrogen. And recently, researchers identified a nitrogen-fixing spirochete bacterium that lives in the gut of termites.

All of the world's nitrogen fixers, whether free-living or symbiotic, rely on the same enzyme—nitrogenase—to do the job. Nitrogenase is a giant among enzymes, both in the literal sense (it is a huge and complex molecule) and in its significance for earth's biochemistry. Those of us who tend to fret about nature's fragile balance find it a bit disconcerting to learn that our planet's entire supply of nitrogenase could fit into a single large bucket. Lose

Below: A nodule on the root of a pea plant.

Bottom: Nodules clustered on the root of a soybean plant. Symbiotic bacteria housed within the nodules provide the plant with usable nitrogen.



ART WOLFE



SEM BY JEREMY BURGESS'S P.L.; PHOTO RESEARCHERS, INC.

The planet's entire supply of nitrogenase—the enzyme on which all nitrogen fixers depend—could fit into a single large bucket.

this, and life as we know it would come to a screeching halt.

Modern molecular techniques have identified more than twenty bacterial genes involved in the manufacture and control of nitrogenase, while X-ray crystallography and other techniques have revealed the enzyme's structure: long, twisted chains of atoms, arranged like spaghetti, or a ball of yarn after a cat has been playing with it. Nitrogenase actually consists of two huge proteins that physically separate and reunite eight times in the course of 1.2 seconds as they work to break the bond between the two nitrogen atoms and convert one molecule of N_2 into two molecules of ammonia. Most chemical reactions occur in millionths of a second; a duration of 1.2 seconds is almost



DAN GURAUCH; PHOTO RESEARCHERS, INC.

Legumes—including soybeans, below, acacias, lupines, and clovers—open up their roots to nitrogen-fixing bacteria in the genus *Rhizobium*.



RICHARD HAMILTON SMITH

unheard-of, and it reflects how difficult nitrogen fixation is and how much energy must be expended to accomplish it. Nitrogen-fixing bacteria that can team up with plants or animals have the advantage of using the energy-rich sugars they receive from their hosts to help defray some of these manufacturing costs.

Only a century ago did biologists discover that some plant species allow nitrogen-fixing bacteria to invade their root systems and that the nitrogen supplied by this symbiosis eventually becomes available to entire plant and animal communities. Two obscure German agricultural scientists, Hermann Hellriegel and Hermann Wilfarth, uncovered the phenomenon in the mid-1880s while conducting a series of routine greenhouse experiments to determine the fertilizer needs of various crops. Their curiosity got the better of them when they noticed that, unlike other crops, plants in the legume family—

young Dutch scientist named Martinus Biejerinck isolated bacteria belonging to the genus *Rhizobium* growing within the small nodules visible on the roots of legume plants.

We now know a great deal about how nitrogen fixing in legumes works. Essential to the process is the ability to screen the tens of thousands of bacteria in the soil, picking out the few “good guys”—*Rhizobium* bacteria—that are allowed to penetrate the roots. In the course of many millions of years, the host plants have evolved defense mechanisms against bacterial infection. Overriding these defenses requires some complex underground chemical communication, orchestrated by genes in both the plants and the nitrogen-fixing bacteria.

The plant takes the first step in establishing friendly relations. When it reaches a particular stage of development and when environmental cues are just right, certain of the plant’s genes turn on, inducing the roots to produce and exude compounds called flavonoids. The flavonoids attract rhizobial bacteria and also activate several of their genes.

Once this chemical handshake has taken place, the rhizobia begin to produce complex sugars and enzymes that cause the tiny root hairs of the plant to curl and allow the bacteria to enter. The rhizobia then wend their way into the root until they encounter special host cells, in which they set up shop. From this point on, the bacteria and the plant—members of two separate kingdoms—share the know-how and labor needed to construct what is essentially a new organ: a fully operational nitrogen-fixing root nodule. The plant does most of the work, while the rhizobia direct matters by sending out a sequence of chemical signals that turn various plant genes on and off. One important step is the creation of a semipermeable membrane around the

German chemist Fritz Haber was the first human to fix nitrogen synthetically without blowing up his laboratory in the process.

beans, peas, alfalfa, lupines, vetch—thrived even in nitrogen-deficient soils.

In a definitive experiment, Hellriegel and Wilfarth showed that peas grown in steam-sterilized soil developed yellow leaves and other symptoms of nitrogen deficiency. This proved that something *living* in the soil was providing the legumes with nitrogen and suggested that some type of symbiosis might be involved. A few years later, in 1888, a

Fritz Haber’s Reversal of Fortune

During World War I, Fritz Haber, “the man who fixed nitrogen,” was asked to spearhead the German effort to develop chemical weapons. Haber agreed, rationalizing that the threat of such weapons would shorten the war and result in less suffering overall. Other scientists were appalled. When Haber was awarded the Nobel Prize in Chemistry in 1918 for his work on nitrogen fixation, Frenchmen who had been offered awards that year declined them in protest, calling him “morally unfit for the honor.”

Shunned and misunderstood outside Germany, Haber maintained an active laboratory in his beloved homeland until the

Nazis took power in the 1930s. Max Planck, a high-ranking German physicist, reputedly tried to defend Haber and other Jewish scientists during a conversation with Hitler. The Führer is said to have replied, “If the dismissal of Jewish scientists means the annihilation of contemporary German science, then we shall do without science for a few years.”

Haber fled Germany in 1933. Because of his World War I activities, however, he was unwelcome in much of Europe. Within one year of exile, on January 29, 1934, he died in his sleep of a heart attack in Basel, Switzerland.—D. W.

developing nodule; this membrane will allow the selective exchange of ammonia, sugars, and other nutrients between bacteria and plant. Soon the bacteria get down to the business of fixing nitrogen that enters the nodule from air spaces in the surrounding soil.

Each type of nitrogen-fixing bacterium must also devise a mechanism for shielding nitrogenase from oxygen, because exposure to oxygen destroys this all-important enzyme. Rhizobia on a pea plant, for example, signal the plant to synthesize leghemoglobin, a large molecule that has an even higher affinity for oxygen than does the hemoglobin of our blood. The leghemoglobin binds to any stray oxygen entering the nodule from air spaces and prevents it from reacting with the nitrogenase. (Like hemoglobin, leghemoglobin contains iron and turns deep red when oxygenated. In the field, scientists check for active nodules by cutting into one or two and looking for the characteristic pinkish to blood-red color of the fluids inside.)

Thousands of years ago—long before scientists understood all these details—the value of rotating legumes with other crops was recognized. The Roman poet Virgil (70–19 B.C.) recommended rotation with legumes in part 1 of *The Georgics*, his ode to workers of the land:

Sow in the golden grain where previously
You raised a crop of beans that gaily shook
Within their pods, or a tiny brood of vetch,
Or the slender stems and rustling undergrowth
Of bitter lupine. . . .

.....
Thus will the land find rest in its change of crop,
And earth left unploughed show you gratitude.

Legumes continue to be of tremendous importance in agriculture, both as high-protein foods for animals and people and as “green manure” for the soil. Today, seeds of legumes sold to farmers are routinely inoculated with strains of *Rhizobium* selected for maximum nitrogen-fixing ability. Leguminous trees—including mesquite in the Mojave Desert, acacias in semideserts and savannas, and several tropical hardwoods—play an important role in maintaining nitrogen levels in the soils of some natural ecosystems. In some forests of Scandinavia, the Pacific Northwest, and other temperate regions, nitrogen-fixing bacteria in the genus *Frankia* dominate, providing nitrogen through their association with alder, bayberry, and other tree and shrub species.

A modern nitrogen-fertilizer factory in Louisiana, bottom, uses a process invented nearly a century ago by Fritz Haber, below.



SCIENCE PHOTO LIBRARY; PHOTO RESEARCHERS, INC.



BRIAN MILLER; EARTH SCENES

Nitrogen runoff from farms, lawns, and golf courses can stimulate massive blooms of algae and turn a pristine body of water into a fishless, green, mucky mess.

Just as nitrogen fixation is energetically costly for the bacteria, it is also expensive for the plant. Symbiotic nitrogen-fixing bacteria often burn up about 20 percent of the carbohydrates produced by their hosts. Preliminary results obtained by my research group at Cornell University and by others suggest some intriguing possibilities for the future. As rising levels of atmospheric carbon dioxide (associated with the burning of fossil fuels) stimulate photosynthesis, legumes will be able to generate more carbohydrates and thus support more root bacteria, perhaps gaining thereby a competitive advantage over other plants. This could be beneficial for legume

crops, but it would also undoubtedly alter the mixture of species in natural plant communities and encourage the growth of leguminous weeds (such as kudzu in the southeastern United States and clovers competing with cash crops or lawn grasses).

Another area of current research is focused on the mechanisms that nature has worked out to shut down nitrogen fixation when it is not needed. We now know that some of the plant and bacterial genes controlling nodule formation and nitrogenase synthesis are turned off when large amounts of ammonia are already present in the soil.

As vital a process as nitrogen fixation is, it sup-



plies only 10 to 20 percent of the current annual nitrogen requirement for life on earth. The rest comes from recycling nitrogen that has already been fixed. Here, too, soil organisms play a major role.

Early on, as our planet's food chain began to evolve, a huge cast of soil creatures, collectively known as decomposers, evolved the capacity to obtain their nitrogen by consuming dead microbes, plants, or animals. Nitrogen is also recycled by a group of soil bacteria that use the hydrogen atoms of ammonia as an energy source, converting ammonia to nitrate in the process. Yet another group of bacteria, known as denitrifiers, feed on the nitrate for the oxygen it contains, rather than as a nitrogen source. They use the oxygen atoms as a substitute for pure oxygen and produce N_2 gas as a waste byproduct of respiration. Denitrification thus replenishes the atmosphere with N_2 and closes the loop of the nitrogen cycle.

Unfortunately, humans are now interfering with this cycle in a serious way. The rapid increase in the population of our species over the past few centuries has resulted in the need for a great deal of fixed nitrogen. To feed our crops, we initially relied on recycled nitrogen in the form of manure, but at the beginning of the twentieth century, scientists warned that unless another source of nitrogen fertilizer was found, food shortages were imminent. With World War I looming, nitrogen was also in demand for the production of trinitrotoluene (TNT) and other explosives.

So, during the first decade of the last century, the race was on to figure out how to do what the subterranean nitrogen fixers had been doing for billions of years: make a usable form of nitrogen out of N_2 gas. In the early 1900s, Germany had some of the most sophisticated chemistry laboratories in the world. Fritz Haber, an ambitious and gifted young scientist working at one of these facilities, was attracted to the problem and ultimately became the first human to fix nitrogen. Or, to be more precise, Haber was the first to do it without blowing up his laboratory—and with a yield of ammonia that made the process practical for commercial production. In 1909 he began a collaboration with an industrial engineer named Carl Bosch, and by 1910 the first nitrogen factory was up and running. The feared nitrogen crisis had been avoided.

Today, nearly a century later, the Haber process remains the only economically viable method for producing synthetic nitrogen fertilizer. Unfortunately, the process requires large amounts of energy,

temperatures of about 930°F (500°C), and pressures of several hundred atmospheres (several hundred times the air pressure at sea level). Constructing a nitrogen-fertilizer plant thus costs hundreds of millions of dollars. The holy grail of today's nitrogen chemists is a biotechnology alternative—vats of nitrogenase churning out cheap fertilizer—but that goal remains elusive.

Despite the expense of the Haber process, the demand for fertilizer is so great that the amount of nitrogen fixed industrially in this way has been doubling about every six years since Haber first introduced his method. More than 90 percent of the fer-

Below: Like all animals, grizzly bears get their nitrogen by consuming other organisms.
Bottom: Large amounts of fertilizer are used to grow food for animals destined for the slaughterhouse.

THOMAS MANGELSEN; MINDEN PICTURES



In most countries where incomes are rising, meat consumption is increasing too—as is the inefficient use of nitrogen fertilizers.

PAUL FUSCO; MAGNUM PHOTOS, INC.



Below: Nitrogen enters waterways in the manure of pigs and other farm animals.

Opposite page: Planting alfalfa, a legume, is one way to add nitrogen to the soil without applying fertilizers.

tilizer needs in the United States are met by man-made nitrogen fertilizer. The majority of this is used to grow crops to feed livestock rather than humans. Nutritionists and agricultural scientists have known for many years that meat is a much less efficient way to meet our dietary nitrogen (and thus protein) needs than is the direct consumption of fruits, grains, and vegetables. Despite this, in most countries where incomes are rising, meat consumption is increasing too—as is the inefficient use of nitrogen fertilizers.

Researchers estimate that at least one-third of the human population is currently being fed, directly or

Mexico; during some years, this creates a “dead zone” of several thousand square miles.

Recently, scientists discovered that atmospheric concentrations of nitrous oxide (N_2O), a gaseous by-product of the microbial denitrification process, have increased from about 290 to 310 parts per billion in the past fifty years, paralleling the human-caused increase of nitrogen on the land. Even in trace amounts, nitrous oxide can cause acid rain, contribute to the deterioration of the stratospheric ozone shield that protects us from ultraviolet radiation, and act as a very potent greenhouse gas—300 times more potent than carbon dioxide.

In response to growing environmental concern, many farmers have begun working with agricultural scientists to improve both the precision of nitrogen fertilizer application and the efficiency with which crop plants take up the nitrogen. Some farmers are adopting methods to “spoon-feed” fertilizer to their crops slowly, as the crops develop, rather than dump one huge application on the soil just before planting. One new technology, already being tested in some areas, is the use of global positioning satellites (GPSs) to create high-resolution “nutrient maps” of farm soils. As a farmer passes through his or her fields on a tractor, the GPS information is fed into the tractor’s computer, and the amount of fertilizer applied, foot by foot, is automatically adjusted. Other research focuses on the genetic improvement of legumes and their nitrogen-fixing bacterial partners. The use of legumes as rotation crops is once again gaining favor. And some farmers include “trap crops” in their rotations—plants such as cereal rye and sudangrass, which have deep, prolific rooting systems that are able to take up nitrate before it leaches into groundwater. Finally, geneticists are hoping to reduce the nitrogen requirements of some of our planet’s important food crops. My own research program includes a collaborative project with plant breeder Margaret Smith, also at Cornell, to develop varieties of corn that use nitrogen more efficiently.

Can the same human ingenuity that led to a process for fixing nitrogen help us find solutions to the problems we created by tampering with the nitrogen cycle? We know that our nitrogen-fixing activities of the past century have significantly increased the earth’s capacity to support life, but we also know that if we want to sustain this life as well as protect our natural environment, we will need to come up with better, more efficient ways to manage the nitrogen we fix. □



RICHARD HAMILTON SMITH

The demand for fertilizer is so great that the amount of nitrogen fixed industrially has been doubling about every six years.

indirectly, with the help of the Haber process. Globally, more nitrogen is fixed by humans through this method than by all the naturally occurring microbial fixers in the soil. Yet only about one-third to one-half of the nitrogen we pour onto our farms, lawns, gardens, and golf courses each year is actually taken up by plants. Much of the rest, in the form of nitrate, leaks into groundwater, estuaries, and the oceans. A high level of nitrate in drinking water is toxic, especially to infants. Added to natural bodies of water, nitrate stimulates massive blooms of algae that clog the waterways, reduce clarity, and use up so much oxygen that few other aquatic species can survive alongside them. Nitrate from farmlands and factories in the central United States is currently draining through the Mississippi River and into the Gulf of



Threads of Okinawa

ISHIGAKI MUNICIPAL YAEYAMA MUSEUM



Three weavers interpret their region's heritage.

By Amanda Mayer Stinchecum

Above: From the early seventeenth to the twentieth century, ramie cloth was made in the Yaeyama Islands as tax payment. Below: Ramie cloth made by contemporary weaver Arakaki Sachiko.

Stretching from the island of Kyūshū southwest to Taiwan, the Ryukyu archipelago consists of about two hundred islands, some volcanic, the rest formations of coral. The majority make up Japan's southernmost prefecture, Okinawa. Typhoons regularly pummel this subtropical region, impartially buffeting old wooden houses and new buildings of stucco, glass, and poured concrete. Rain and salt spray drench sugarcane fields, rice paddies, jungle, and city streets. The soil is generally thin and poor, and on many islands the water table is too low for wet rice cultivation. More than 90 percent of the more than 1.3 million inhabitants are concentrated on the main island (also called Okinawa). Relying principally on income from U.S. military bases, government subsidies, and tourism, the prefecture is Japan's poorest. But the women boast the highest average life expectancy in the nation and the world.

During World War II, Allied bombing of the main island, culminating in the 1945 invasion of Okinawa, reduced the prefecture's capital city of Naha to rubble and destroyed most of the smaller towns and villages. An estimated 150,000 civilians died. Twenty-seven years of U.S. occupation followed before the territory reverted to Japanese sovereignty. Even now, some 25,000 American military personnel, along with their dependents, live and

work on bases that occupy one-fifth of the main island. Fueling resentment against both the Japanese and the U.S. governments for acting without the consent of the Okinawans, this military presence creates bad feelings that are naturally exacerbated when servicemen commit crimes against local civilians. More than 4,700 incidents have been reported since 1972, with rapes of young girls and women



awan History

being among the most serious. Accidents that have resulted from military maneuvers—including 39 air crashes since 1972—are another cause of outrage.

Although Okinawans have not turned to the kind of violent nationalism that has arisen among some ethnic groups in Eastern Europe, South Asia, Southeast Asia, or Africa, they do assert their own identity, distinct from that of mainland Japan. Lin-

guists recognize five separate languages within the archipelago, related to but different from Japanese. The indigenous religion, presided over primarily by women, incorporates elements of shamanism and animism. Aspects of household and village organization (particularly the prominent role played by women), together with Okinawan music, dance, literature, architecture, ceramics, textiles, and food,



AMANDA MAYER STINGHECUM

On the island of Taketomi, in the Yaeyama Islands, women wait their turn to perform during their village's most important religious festival, Tanedori. Wearing robes of fiber banana cloth held in place with ropes of twisted straw (work clothes worn by village women until after World War II), they will enact the role of the hardworking farm-woman.



Arakaki Sachiko, above, has revived the ikat technique for patterning ramie cloth in the Yaeyama Islands. Right: The cloth is laid in the sea for bleaching and to help set the dye. Below: Fine ramie cloth from the nineteenth century.



form a multifaceted and fluid but unique heritage. Among these, cloth and clothing in particular have come to embody Okinawan ethnicity, both for the people of the islands and for others beyond their coastal reefs.

Records of local textiles go back to the Ming dynasty (1368–1644), when China extended its cultural and economic hegemony to the Ryukyu Islands, legitimating three kings of the main island in exchange for their submission to the Ming emperor. In 1372 the first Ryukyuan emissaries reached Nanjing, where they presented their tribute payment of local products: sulfur, horses, and ramie cloth, a fabric woven from the bast fibers of an indigenous plant in the nettle family.

Under this benign arrangement, the kingdom of Ryukyu (unified in 1429 under the court at Shuri, now part of the city of Naha) became a thriving entrepôt for trade between Japan, Korea, China, Siam, Sumatra, Malacca, and other Asian states. But in 1609, forces from Satsuma, a Japanese feudal domain in southern Kyūshū, invaded the islands and took the king hostage. Ryukyu's autonomy survived in name only. Two years later, Satsuma de-

manded its own annual tribute, including some 75,000 bushels of rice and 19,000 rolls of cloth (each roll was about thirteen yards long and sixteen inches wide—enough to make one kimono). Sixteen thousand of these rolls were ramie; the remaining 3,000 were *bashōfu*, made of fibers taken from the leafstalks of the *ito bashō*, or fiber banana plant, a relative of the edible banana. These crisp, breathable fabrics are highly valued even today for kimonos worn during Japan's hot, humid summers.

To meet Satsuma's demands, the Shuri monarchy levied taxes on the Ryukyuan people. Most of these taxes were payable in grain. But on Kume Island (west of the main island) and in the Outer Islands (the island groups of Miyako and Yaeyama, at the southwestern end of the archipelago), these took the form of a poll tax. More than half were to be paid in cloth, mainly ramie. Local officials strictly—and sometimes cruelly—controlled all aspects of production. Although in principle both men and women bore the burden of grain and cloth payments, in practice yarn making, dyeing, and weaving were allotted to women, on the basis of skill and age. This system continued even after 1879, when Japan's Meiji government forced Ryukyu to submit to Japanese sovereignty, abolished the Ryukyuan monarchy, and annexed the islands to create Okinawa Prefecture. (The poll tax was finally eliminated in 1904.)

Known as Yaeyama *jōfu* (fine cloth), the finest ramie weaves came from the Outer Islands. Despite the hardships and humiliations under which they labored, the women of this area expressed through songs the joy, close to awe, they felt toward the act of making a beautiful piece of cloth as an offering to the king. (In fact, the cloth was presented to the local administrative office.)

This feeling—that dyeing and weaving, and the resultant cloth, are sacred offerings—permeates the work of Arakaki Sachiko, a contemporary weaver on Ishigaki Island.

Though born and raised in the town of Ishigaki, the administrative center of the Yaeyama Islands, **Arakaki Sachiko** grew up unaware of the fine textiles made by her ancestors. On a trip to Tokyo in the early 1970s, however, she visited the Japan Folk Craft Museum and discovered the vibrant colors and patterns of ramie cloth made during the era of the poll tax.

The bold yet delicate designs resulted from the ikat technique, a painstaking method of resist dye-

ing in which selected segments along lengths of yarn are tightly bound to prevent the dye from penetrating. When these yarns are woven together on the loom, the combination of dyed and undyed segments creates patterns whose outlines are more or less blurred according to the skill and intent of the weaver. In the Yaeyama Islands, true ikat was abandoned in the early twentieth century in favor of a quicker and cheaper method—applying a thickened, dark red-brown dye directly to the yarns—that resulted in a more uniform, hard-edged pattern.

After studying in Naha, Arakaki returned to Ishigaki and single-handedly recreated the old ikat method of making Yaeyama *jōfu*. She also revived

Ryukyuan royalty wore robes of dyed fiber-banana cloth.

the rich palette of colors: the blues of indigo, a vivid yellow from the *fukugi* tree, the pinks and reds of sappanwood and safflower. Eventually she received a commission to reproduce, for display at the Ishigaki Municipal Yaeyama Museum and the Japan Folk Craft Museum, two sets of the very robes in the Tokyo collection that had originally inspired her work. She says the luxury of working for the first time exclusively with handmade yarn—scarce and costly—taught her “the blessedness of the yarn itself.”

The project proved to be a test of fire. Using plant dyes, which are notoriously unpredictable, Arakaki labored to duplicate the bold patterns and vivid colors of the originals—a task much more difficult than improvising. On more than one occasion, she had to start over from the undyed yarn when she couldn't correct a weaving or dyeing error.

Given a new sense of her own potential, Arakaki has since experimented with fresh combinations of colors derived from plants, nearly all from Okinawa—brilliant greens, velvety grays, golden ochres, pinks and reds, every shade of indigo blue. In June 1995 she exhibited her work in Tokyo at Wakō, a department store known for refined, very Japanese taste. This solo show provided a rare opportunity for an Okinawan artist to reach a discerning mainland audience. The experience challenged Arakaki to raise her work to a still higher artistic level.

Okinavans believe clothing envelops the spirit, preventing its escape from the body. Arakaki's labor is an act of consecration, embracing her own spirit.

The airy membranes she weaves, fashioned into the loose robes of the islands, protect the soul of the wearer.

The earliest detailed descriptions of Ryukyuan cloth and clothing date from the fifteenth century. Shipwrecked Koreans who washed up on the shores of Yonaguni, the westernmost of the Yaeyama Islands, reported that the islanders—all commoners—cultivated, wove, and wore only ramie. Silk and cotton production was introduced into the Ryukyus from China in the sixteenth century, but the use of these fabrics was long restricted to the elite classes. As the demand for ramie for tribute, tax, and trade increased, the monarchy forbade commoners to wear this fabric as well. Clothing made from *bashōfu* (fiber banana cloth) took its place. Eventually women, children, and men of all classes—kings and queens, court officials and landowners, and the poorest farmers and fisherfolk—all adopted *bashōfu*.

Robes of fiber banana cloth dyed brilliant yellow and scarlet, some of them ikat-patterned, were worn by Ryukyuan royalty. The glossy blue-black, green, or ivory garments of court officials were so fine and lustrous that the untutored eye now mistakes them for silk. *Bashōfu* garments worn by the court and aristocracy were made in the capital, Shuri. Commoners wore coarser robes the color of dried grass, plain or with brown stripes or checks; they were forbidden to wear ikat. Even today, although nearly all Okinavans wear Western-style clothing, they often don *bashōfu* garments for local festivals and other celebrations.

The fiber banana familiar in the Ryukyus has

Arakaki uses local plant products, including gardenia fruits and annatto, to dye her ramie cloth.



TAKUMI KENGO

Taira Toshiko, top right, separates the layers of a fiber banana stalk—the first step in making yarn. Below right: A scarlet robe of fiber banana cloth (*bashōfu*), patterned with a geometric float weave, made for Ryukyuan royalty during the nineteenth century. Bottom right: A member of the *bashōfu* cooperative in Kijoka boils strips of fiber banana with ash lye. This softens the pulpy part, which is then scraped off. The resultant ribbons of cellulosic fiber will be split into yarn.



AMANDA MAYER STITCHCOM



TREASURES FROM THE SHO FAMILY INHERITANCE, NAHA

sometimes been regarded as a separate species or variety (*Musa liukiuensis* or *M. x sapientum* var. *liukiuensis*), but it is probably best classified as *M. balbisiana* and most likely was introduced from Southeast Asia. Throughout the Ryukyus, this treelike plant, with its large, pliant leaves shredded by the wind, creates pools of shade next to tile-roofed wooden houses and forms windbreaks around cultivated fields. It does not grow wild, however—a sign that it is not truly indigenous. Exactly when and how the fiber banana reached the islands remains a mystery; its cultivation is not mentioned in historical documents until 1546.

Following Japan's annexation of Okinawa, fiber banana cloth became fashionable for summer kimonos on the mainland, and it was produced in vil-

lages throughout the prefecture. Kijoka, in the northern part of Okinawa Island, shared in this work. The ikat technique was introduced into Kijoka in the late nineteenth century. *Bashōfu* developed far beyond the simple cloth that had been the earlier heritage of Ryukyuan village life. Because many of the men left the village in the early decades of the last century to do construction work in Naha, women became the primary practitioners of the art. By the early 1940s, hundreds of kimono lengths of golden-brown cloth with rich brown and deep indigo motifs were being sold at Mitsukoshi, an elegant department store in Tokyo.

As Japan intensified its war effort, Okinawa's weaving enterprise ground to a halt. Volunteers from Kijoka joined many other Okinawans at an aircraft factory in the mainland Japanese town of Kurashiki, midway between Osaka and Hiroshima. Kijoka weaver **Taira Toshiko** went along. At the war's end, uncertain of Okinawa's fate, Taira remained in Kurashiki for another year. There she came to the attention of Tonomura Kichinosuke, a weaver and folk-craft proponent who later founded the Kurashiki Folk Craft Museum. He urged her to return to Kijoka and preserve the legacy of Ryukyuan *bashōfu*.

Taira followed his advice, and the workshop she



established in Kijoka in 1962 has flourished under her quiet direction. Taira was instrumental as well in the founding of a *bashōfu* cooperative in Kijoka. In 1999 the Japanese government designated her a Living National Treasure for both her textile art and her leadership in reviving Kijoka's *bashōfu* in-

In 1999, Taira Toshiko was named a Living National Treasure.

dustry. Weavers on several of the Yaeyama Islands have also carried on local traditions of making and using fiber banana cloth. Some have incorporated the yarns into innovative silk and cotton textiles.

Including 100 yarn makers, about 150 people participate in the textile cooperative. To produce the yarn, the women cut down the mature plants and strip off layers from the sheathlike leafstalks, sorting them into piles to be made into fine, medium, and coarse cloth. They soften the fiber by cooking it with lye. The most demanding part of the yarn-making process—splitting the gleaming ribbons of fiber into fine strands, then tying the strands end to end to form a continuous yarn—is performed by some of the oldest members of the village, nimble-fingered women whose dimmed eyesight prevents them from doing the actual weav-

ing of the intricate ikat patterns. Kinjō Nabe, who died recently at age 106, continued to make yarn until shortly before her death.

The average age of the women in Taira's own workshop is about 60, while the apprentice weavers working nearby in the Kijoka textile cooperative's hall are considerably younger—a healthy sign for the future of the craft. Taira spends most of her time with the apprentices, walking from loom to loom and occasionally making a gentle suggestion to a weaver intently bent over her work. Extremely shy and increasingly frail, she leaves most of the administrative responsibilities to her able and articulate mainland-born daughter-in-law, Mieko.

Even with a drastic decline in the number of

Below: *Bashōfu* woven for fine summer kimonos by Taira Toshiko and the women of her workshop. The subtle warp-and-weft ikat pattern was dyed blue and brown with indigo and the woody stalks of *teichi*, a member of the rose family.



The main islands of Okinawa Prefecture



Makishi Tamiko, above, works in silk, sometimes incorporating other fibers to vary the texture. Scarves and shawls, below, reflect her contemporary aesthetic.

Japanese women who wear kimonos, the cooperative sells all the cloth it produces—about 270 rolls a year. A roll from Taira's own workshop sells in Tokyo for upwards of \$15,000—"to some," according to Mieko, "because it is made by a Living National Treasure, but to a few because they really love it." Mieko also observes that if it weren't for souvenir items—neckties, wallets, decorative mats—this modern cottage industry, like so many others in Japan, would be dying out.

A few years ago, Taira made a special collection dyed in the vivid reds, yellows, and greens of the Ryukyuan court. But she prefers the modest style traditional in Kijoka, in which the blue and brown of local vegetable dyes complement the natural golden color of the fiber. Taira has rescued, nurtured, and refined this cloth. Today it is an emblem of Okinawa itself.

In fact and sensibility, **Makishi Tamiko** is a weaver whose world is entirely urban. Her father, Nakasone Seizen, collected, reconstructed, and interpreted Okinawa's languages and ancient poetry. One of Okinawa's most cherished scholars, he remains a great influence on her work. Like many Okinawans, Makishi fled her home in the capital to

displaying the work of independent weavers on Okinawa's main island. In the past five years, her solo shows in small galleries throughout Japan—often with installations designed by her husband, painter Makishi Tsutomu—have gained her quite a following.

Some weavers in Okinawa actively seek ways to adapt their textiles to contemporary clothing, but

One cocoon can yield a silk filament 1,500 yards long.

Makishi is reluctant to do so. Handmade fabrics are both costly and fragile. The wearer faces the possible discoloration or fading of natural dyes, laundering problems, the weakening of the delicate fibers because they've been pierced by sewing-machine needles—as well as the prospect of spending \$2,000 or \$3,000 to commission an outfit subject to the whims of fashion. More significant for Makishi, creating Western-style clothes necessitates cutting into the natural borders of the woven rectangle, a destructive act minimized in the making of traditional Japanese clothing. To avoid this, while ensuring that her fabrics will be worn, Makishi has decided to concentrate on shawls and scarves.

Once a weaver of silk for kimonos, Makishi has stayed with silk. But instead of using the inelastic, characterless, machine-reeled silk yarn produced by mainland factories, whenever she can get fresh cocoons she reels her own silk, pulling out a number of fragile filaments to form a glistening thread (from one cocoon, agile fingers can entice a single filament 1,500 yards long). Sometimes Makishi inserts fiber banana or ramie yarn into the silk web, skillfully weaving in a crisp line or two, or she crosses silk warps with crinkly ramie wefts to make a new texture, choosing with deliberation the hue and material of each thread.

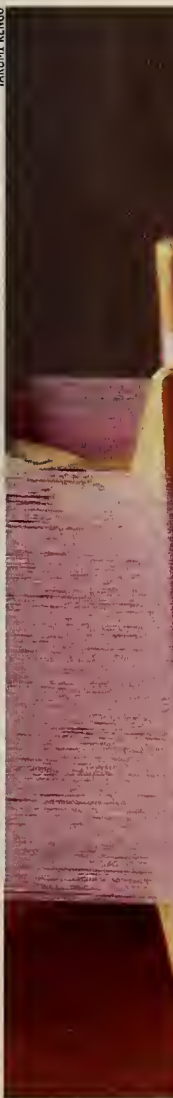
Makishi's subtle colors and textures evoke the subdued grays, tans, and dark blues of kimonos



escape Allied bombing, spending the war years in her father's home village of Nakijin. Otherwise she has lived her whole life in cities—first Naha, then Tokyo (where she attended art school), and now Urasoe, adjacent to Naha.

A profoundly private person, Makishi has nevertheless played a leading role in encouraging and

TAKUMI KENGO



worn by the women and men in her family during and after the war. One of her prized possessions, a man's golden-tan-and-white striped summer kimono of fiber banana and cotton, belonged to a favorite uncle—something of a dandy, she says. Very occasionally, Makishi will dye an entire shawl a single, startlingly intense color, but her palette tends toward white, beige, brown, gray, and sometimes yellow or indigo blue, worked into delicate shadings of stripes, checks, or wide bands. These may be shot through with a single line of light blue (from the *kusagi* berries she grows on her terrace) or some other contrasting hue, so inconspicuous that it might go unnoticed except when the wearer turns her head and sees it for the first time, from a few inches away, in the shawl that lies on her own shoulder.

For the past few years, Makishi has been working with carbon ink (so-called India ink or Chinese ink), dyeing skeins of lustrous silk yarns pale silver,

glossy charcoal, and every shade in between. Calligraphers and painters know that some carbon ink has a bluish tinge, some is brown, some a more neutral gray. Makishi exploits this infinite rainbow. Her use of ink—the essential substance of the scholar's work in East Asian cultures, more than just a means of recording words—is a conscious tribute to her father's memory.

Light as clouds, translucent as fog, or gleaming like a sheet of silver or copper leaf, Makishi's weavings are completely contemporary. Her work is, above all, a representation of her inner life. "From the time the umbilical cord is cut and tied, human beings begin the search for the thread that ties their lives together," she has written of her own connection to fashioning cloth. Her art incorporates the old ways of yarn production and dyeing, of reeling and degumming silk, into a new tradition of her own making. □

Spools of silk yarn, below, display some of the colors Makishi Tamiko has obtained from vegetable dyes. Makishi's current work utilizes a variety of carbon inks, from which she coaxes purple, brown, and bluish tones as well as shades of gray from silver to charcoal.



Ghost Stories From the Ice Age

Some plants are haunted by large mammals from another era.

Story by Connie Barlow ~ Illustrations by Michael Rothman

In the shadows along the trail," wrote paleo-ecologist Paul Martin in 1992, "I keep an eye out for ghosts, the beasts of the Ice Age. What is the purpose of the thorns on the mesquites in my backyard in Tucson? Why do they and honey locusts have sugary pods so attractive to livestock? Whose foot is devil's claw intended to intercept? Such musings add magic to a walk and may help to liberate us from tunnel vision, the hubris of the present, the misleading notion that nature is self-evident."

A mere 13,000 years ago, near the end of the Pleistocene Epoch (which began 1.6 million years ago), fruiting plants of the Western Hemisphere that had long relied on big animals to distribute their seeds suddenly lost these allies. Although some scientists believe diseases or climatic change may have been factors, a growing body of evidence supports Paul Martin's hypothesis, first advanced in the 1960s, that newly arriving humans equipped with formidable stone-tipped spears were responsible for wiping out the large Pleistocene mammals that had roamed forests, deserts, and plains. Within a thousand years of the first evidence of this hunting culture in the Americas, the mastodons and mammoths, tall camels, giant armadillos, and ground sloths—and the giant bears, cats, and wolves that stalked them—had all disappeared.

These extinct American herbivores once dispersed the seeds of such big-fruited plants as honey locust, Kentucky coffee tree, and Osage orange, all of which produce fruits that no native animal today

regards as food. Now the seeds either rot with the pulp or sprout too close to the parent tree. Avocado trees yield fruit with an outlandishly large pit that no native gullet can accommodate. In addition to bearing these "anachronistic" fruits, some trees display defenses that are equally out of step with current conditions. Mesquite, hawthorn, and honey locust protect their trunks or lower branches with long, sturdy thorns that now seem unnecessary.



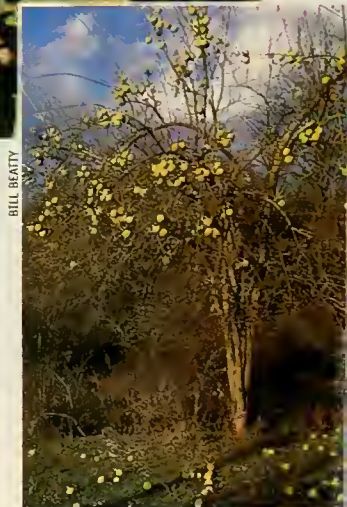
How have these fruiting plants managed to survive for 13,000 years without their dispersal partners? An individual plant can keep sending up root suckers that allow it to persist for hundreds, even thousands of years. Another way is by entering into new partnerships: humans now plant seeds and saplings in widely scattered locations. Yet these plants still proclaim, by the very structure of their fruits, seed coats, and armaments, that they are adapted for life in a vanished world.



ALVIN E. STANTON/ NATIONAL AUDUBON SOCIETY PHOTO RESEARCHES, INC.

OSAGE ORANGE (*Maclura pomifera*) could have been more accurately named American breadfruit; the color and fibrous texture of this New World fruit closely resembles its tropical Asian counterpart. The fruit is, however, shunned by humans and all mammals native to North America, where the tree was once common in woodland meadows and at prairie edges. After losing its dispersal partners, which presumably were large herbivores, Osage orange became increasingly rare.

The hard, fibrous spheres, above, frustrate deer and cattle, which lack upper incisors. By the time Europeans arrived, the tree's range was confined to just a few river valleys in what is now eastern Texas. Ranch horses there do consume the fruit after it has fallen, which suggests that early native horses of the Pleistocene, opposite page, may also have eaten it.



BILL BEATTY

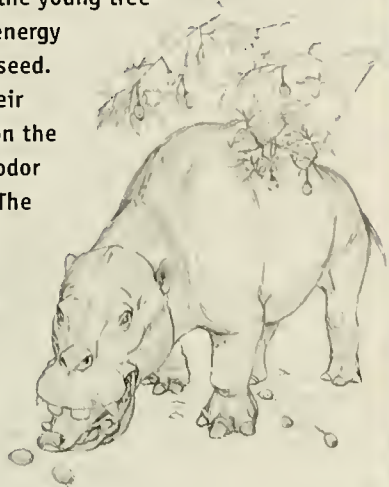


A **MASTODON** plucks pods from a honey locust tree, below. For more than 20 million years, the honey locust (*Gleditsia triacanthos*) lured big beasts to disperse its tough, tooth-resistant seeds by embedding them in sweet, protein-rich pods. Native to the central United States, this tree of the forest edge also sported ferocious thorns on its trunk and lower branches, left, preventing the elephants from stripping bark—and thus killing the tree—while they browsed for seed pods. No contemporary seed dispersers can

reach the pods, and today the thorns are probably superfluous. We now plant this sturdy, drought-resistant tree along urban sidewalks and in suburban parking lots. The fallen pods can be a nuisance to pedestrians, though, and the sharp thorns are dangerous, so domesticated varieties tend to be male (podless) and thornless. Among older plantings in city parks, however, one can find female trees with pods, their trunks heavily armed with mastodon-proof thorns.



WILD AVOCADOS produce nutritious, energy-rich fruit, right, with one very large and dense seed that contains bitter poisons. This small tree (*Persea americana*) lives in shady tropical forests. During its first few months of growth, while seeking out shafts of sunlight, the young tree depends upon the energy stored in the huge seed. Adult trees drop their drab-colored fruit on the ground, where the odor attracts mammals. The largest living fruit-eaters of tropical America are several species of tapir, which eat around the seed or spit it out. Thirteen thousand years ago, however, the hippopotamus-like *Toxodon*, above, would have swallowed whole avocado seeds and defecated them in other parts of the forest.

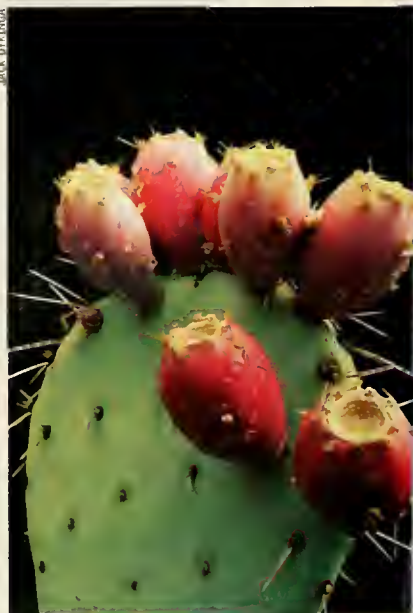


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AN AMERICAN CAMEL of the Pleistocene finds cactus fruit easy to reach, right. The camel clan originated in western North America before spreading into Eurasia and Africa. Equipped with long legs and neck, *Camelops* would have been an ideal dispersal partner for tall species of prickly pear (*Opuntia*) in the deserts of North America. Today the fruit of these cacti, far right, is plucked by nonnative livestock or, once it withers and falls, eaten by scavenging coyotes and foxes. The small, tough seeds survive in their dung and soon sprout.



JACK DRYNKA

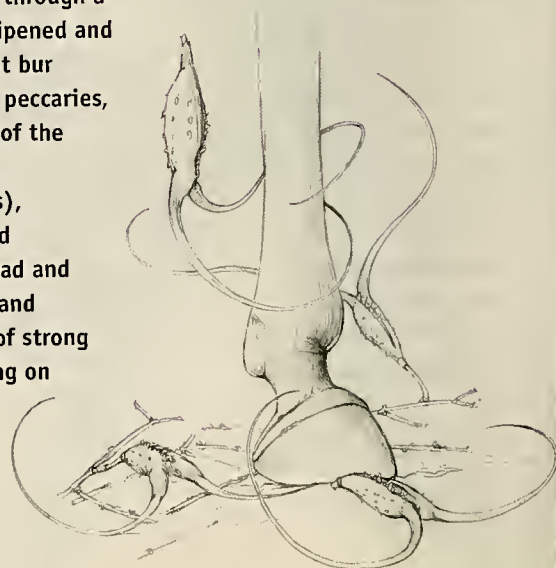




DEVIL'S CLAW (*Proboscidea*) grips the hoof, right, of an extinct American horse. In this re-creation, the animal has walked through a patch of devil's claw, or unicorn plant, after the fruit has ripened and split open and the leaves have died back. Because the giant bur cannot attach to the slender limbs of deer, pronghorn, and peccaries, the plant's range probably diminished after the extinction of the large Pleistocene mammals. Following the introduction of domesticated horses and cattle (and, later, of farm tractors), however, devil's claw rebounded, and it is now a widespread agricultural pest. The hard fruit, left, is shaped like the head and trunk of an elephant. As it ripens, its green skin blackens and dries; eventually the "trunk" pops open to become a pair of strong but flexible pointed tongues. Some seeds drop from the casing on contact with the disperser. The remainder are released when the swollen part of the woody bur has been trampled or crushed.



STEPHEN TRIMBLE



Thirteen thousand years ago, some big-fruited plants of the Western Hemisphere suddenly lost the animal allies that helped disperse their seeds.

GOURD-BEARING VINES (*Cucurbita*), left, precursors of domesticated squashes and pumpkins, are found in dry washes and along roadsides in Mexico and the U.S. Southwest. Today they are spread by floodwaters and also carried on tire treads and in the blades of road graders. During the Pleistocene, the desert-dwelling Shasta ground sloth (*Nothratheriops shastensis*) would have eaten the ripe gourds in autumn, below. Because the pulp is bitter (probably a defense against marauding insects), any animals eating large quantities of wild *Cucurbita* fruit may have had to consume clay to adsorb the toxins.



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AT THE MUSEUM

The Art of Worship

For millions of Hindus in India, religion interweaves private worship, public ritual, and ephemeral art.

Story and photographs by Stephen P. Huyler



Completing the morning's
kolam in Tamil Nadu

It is dark as Padmasini Ramachandran steps between the sleeping bodies of her children and opens her front door. Just as she does every morning, she pours water from a small brass pot into her hand and sprinkles it over the dirt beneath her feet, making it firm enough to draw on. Bending straight from her waist, she takes a large pinch of rice flour from a little metal bowl and quickly drops it onto the

ground, followed by another and another, all evenly spaced, until she has created a diamond-shaped grid of white dots about five feet long on each side. Then, with further pinches of flour, she deftly draws thin white lines between the dots—some straight, some curved—rapidly transforming this patch of earth into the petals, leaves, stamens, and stem of a lotus blossom. Because it is a special festival day hon-

oring the gods, Ramachandran fills in her picture with colored powders before going inside to awaken her family and prepare breakfast.

In front of each doorway, all the way down the block and beyond, other women are creating *kolams* (known as *rangoli* or *rangavalli* in other parts of India)—decorations intended to protect home and family from evil and to encourage good fortune. Every day,

following a centuries-old tradition, women in more than a million homes in this southern Indian state of Tamil Nadu draw a fresh *kolam*. They pride themselves on never repeating a design.

Each drawing is ephemeral. As the day begins and family members come out of the house and into the street, they walk over the *kolam*, smudging the design. Bicycles, scooters, bullock carts, cars, and buses all rapidly eradicate the artwork; within an hour, all traces of it are gone. To an outsider, the women's efforts might seem to be a frustrating waste of time, but to the artist they represent a moment of creativity, solace, and spirituality.

Most of India's billion citizens are Hindus, members of a religion of remarkable diversity. Hinduism is polytheistic, and although its adherents may believe in an all-encompassing, indivisible being—similar in many ways to the god of Christians, Jews, and Muslims—they also believe that the many aspects

of the divine may be viewed and worshiped through particular gods and goddesses that embody different aspects of the cosmos. Just as creation has innumerable facets, so Hinduism has innumerable deities, and the personalization of gods and goddesses makes possible an intimate relationship with the divine.

Hinduism is the world's third largest religion, involving one in every seven human beings. Unique among all major religions in that it does not proselytize, Hinduism also does not profess one right way, one set of beliefs, or one correct system of ethics. Young Hindus grow up learning to follow the tenets and customs of their parents but are encouraged to decide for themselves which primary gods or goddesses they find inspiring. This right of personal choice of deity means that although young adults continue to practice many family rituals, they also conduct their own private worship in whatever manner seems most beneficial to them.

The exhibition *Meeting God: Elements of Hindu Devotion* opens in Gallery 77 on September 8, 2001, and runs through February 24, 2002.



Praying to the rising sun in Uttar Pradesh

Beliefs may be individual, but rituals tend to be observed in common with large portions of the population. Ramachandran rises each morning to create her beautiful *kolam* just as her mother, grandmother, and great-grandmother did before her. Yet within the confines of this age-old ritual is the



Fulfilling a vow to Surya, the sun god, in Bihar

expression of her own personality, her individual creative communication with the divine. Similarly, throughout India, Hindus begin each day with rituals of devotion. Countless millions pray to the rising sun, considered masculine, while standing in or pouring water, viewed as feminine. In acknowl-

edging the two, they also acknowledge the One, for in Hinduism the supreme deity is the absolute complement of opposites—dark and light, wrong and right, good and evil. By beginning each day in such ways, Hindus attune themselves with the universe and validate their place within it.

For thirty years, Stephen P. Huyler, a cultural anthropologist and photographer, has conducted field research in India on sacred art and rituals. He has worked extensively with museums exhibiting Hindu art; the exhibition "Meeting God: Elements of Hindu Devotion" is based on Huyler's book of the same name (Yale University Press, 1999).

MUSEUM EVENTS

SEPTEMBER 4, 5, AND 6

Central Park field trips: A series of eight bird walks led by Museum naturalists. Tuesdays (beginning September 4, with Stephen C. Quinn), Wednesdays (beginning September 5, with Joseph DiCostanzo), and Thursdays (beginning September 6, with Harold Feinberg).

SEPTEMBER 12 AND 22

Urban forest walking tours: Central Park (September 12, 8:30–11:00 A.M.) and Palisades National Natural Landmark (September 22, 10:00 A.M.–1:00 P.M.). William Schiller, Museum botany lecturer.

SEPTEMBER 19

Lecture: "Wildlife of India." Naturalists Hashim Tyabji and Toby Sinclair. 7:00 P.M., Kaufmann Theater.

SEPTEMBER 22

Field trip: "New York City Historic Sites and Their Geological Settings." Geologist Sidney S. Horenstein, coordinator for Museum environmental programs. 9:00 A.M.–5:00 P.M.

SEPTEMBER 28

Lecture: "The Story of the Man Who Made the Map That Changed the World." Author and BBC broadcaster Simon Winchester. 7:00 P.M., Kaufmann Theater.

SEPTEMBER 30

Free daylong program: "Reflections

of Our Spirit," in conjunction with the exhibition "Meeting God: Elements of Hindu Devotion." Lectures on religious architecture and on traditional arts with religious symbolism; performances of music and dance; Indian food. 11:00 A.M.–5:30 P.M., Kaufmann and Linder Theaters and Leonhardt People Center. For details, call (212) 769-5315.

DURING SEPTEMBER

Additional field trips, walking tours, and workshops for children and adults, both inside and outside the Museum. For more information, call (212) 769-5200.

Planetarium courses: "How to Choose a Telescope"; "Stars, Constellations, and Legends"; and many

others. For complete course descriptions, visit www.amnh.org/hayden.

Films at the IMAX Theater: *Lost Worlds: Life in the Balance* (biodiversity and the need for conservation); *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition); and *Bears* (natural history of the grizzly, polar bear, and various other species).

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.



Pooja stahl (prayer area), Raaga Entertainment Superstore, Jackson Heights, Queens (from an exhibition of photographs by Steve McCurry of Hindu, Sikh, and Jain shrines in the New York metropolitan area). Gallery 77 Annex, September 8, 2001, through February 24, 2002.

STEVE MCCURRY

MUSEUM FRIENDS SUPPORT SCIENCE EDUCATION AND INCREASE THEIR RETIREMENT INCOME

Looking back on his career as an executive at Simon and Schuster, Jason Berger says, "One of my proudest achievements was the distribution of Little Golden Books to supermarkets and pharmacies across the country, where they found their way into the hands of millions of young children who otherwise might have had little exposure to children's literature."

Several years ago, their wish to support science education prompted Jason and his wife Susanna to include the American Museum of Natural History in their wills. Then, last year, they discovered charitable gift annuities.

A gift annuity is a way to support the Museum and provide a lifetime annuity to one or two people aged 55 or older. When appreciated stock is used to fund the plan, there can be substantial capital gains tax savings.

According to Susanna, "Because we can give and receive income for life, this is an ideal way for us to provide now part of the gift we want the Museum to have in the future. In fact, we like gift annuities so much, we plan to do one every year!"



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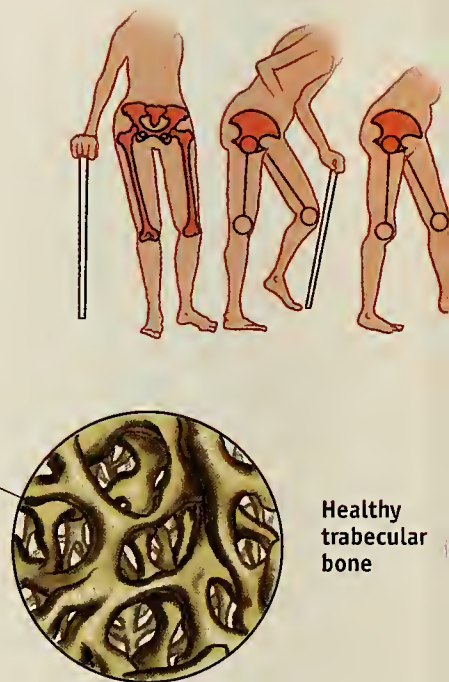
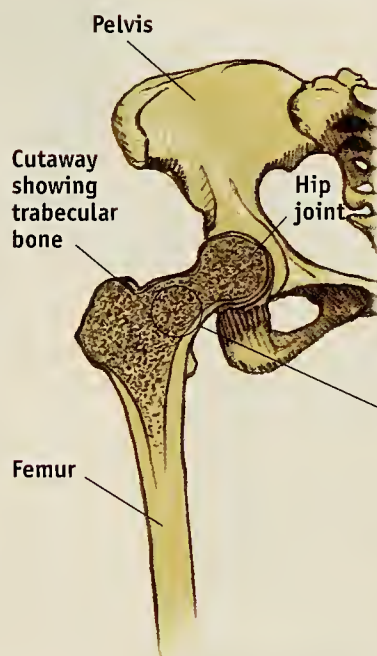
Struttin' Your Stuff

A filigree of slender, mineral-rich struts gives bone much of its strength.

By Adam Summers

At about thirty years of age, the human skeleton is as heavy and strong as it will ever get. Then comes the downhill slide that for many people ends in osteoporosis (severe bone loss), crushed vertebrae, and fractured hips and wrists. But through studies of the internal architecture of bones and the ways they can fail, orthopedic biomechanics is setting a course for preventive measures and new treatments.

A typical bone consists of a hard outer shell surrounding a cavity filled with soft marrow tissue. Made of what is called cortical bone, the outer shell is remarkably thin. In the thighbone, or femur, for example—the longest, strongest bone in your body, running from the hip to the knee—the shell's thickness ranges from just two to eight millimeters. For most of the femur's length, the cavity is filled with fatty yellow marrow. At both ends, however, the last few inches of cavity are occupied by a meshwork of thin, mineralized struts called trabecular



bone. The pores of this bone are filled with red marrow, which produces blood cells. Surprisingly, this bony filigree, which may fill in 30 percent of the open space, is responsible for most of the bone's overall strength.

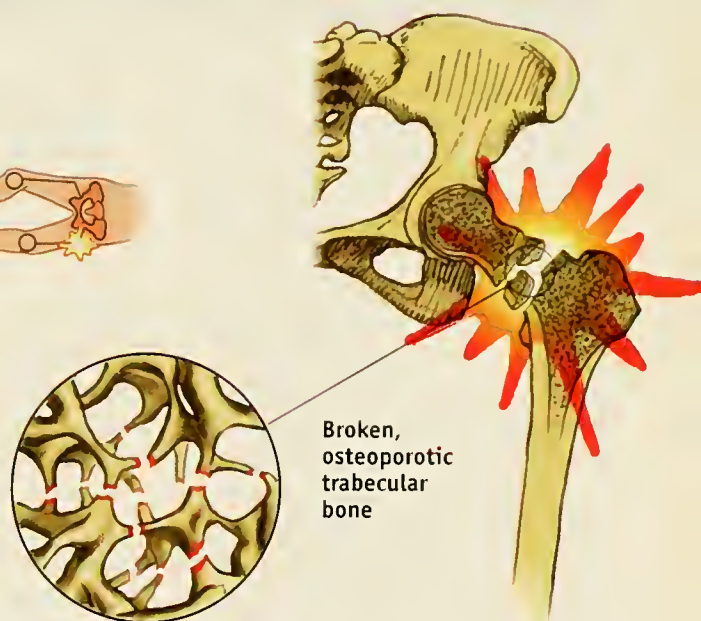
The struts of trabecular bone are only about half as thick as pencil lead; their structural importance comes from their orientation and interconnections. The beauty of the arrangement of trabecular bone was noted in 1866 by a Swiss engineer, Karl Cullman, who happened upon the bisected head of a femur in a colleague's lab. "Why, that's my crane!" he is said to have exclaimed, and indeed, the pattern of struts in the bone would have looked remarkably like the pattern of girders in the heavy-duty crane Cullman had just designed for a loading dock. Further investigations of bones ranging from heels and wrists to vertebrae have revealed that struts tend to follow the lines of stress to which the bones are normally

subjected. For example, most of the struts in the human heel are oriented so that they dissipate the impact associated with walking, while the orientation of the struts in the wing of a vulture counteracts the bones' tendency to bend during flapping.

Our bones develop from soft cartilage. Evidence of these cartilaginous beginnings can be seen in the soft spot in the center of a baby's skull or in the way a child tends to bounce where an adult would break—or at least hurt mightily. Most of our cartilage is gradually replaced by bone, which becomes more and more mineralized (and thus heavier) until reaching a peak in early middle age. Then, for reasons probably having to do with changing hormone levels, the rest of the body starts to extract calcium stored in the bones. (Our bodies use calcium as a signaling ion. Every time a muscle contracts, for example, huge numbers of calcium ions move through cell membranes. As we age, our bodies become less



HOW TO BREAK A HIP With age, the meshwork of struts at the ends of bones becomes thinner and more porous. In the human hip, struts positioned to bear the weight of normal walking remain strong longer than non-load-bearing struts. Impact from another direction—during a fall, for instance—can cause sudden failure.



efficient at maintaining a constant level of calcium in the system and must mobilize it from the bones.) This natural process is especially rapid in postmenopausal women, leading in many cases to significant reductions in bone density and eventually to osteoporosis. An elderly woman with advanced osteoporosis might have just 50 percent of the bone mass she had in her early thirties.

We lose trabecular bone twice as fast as cortical bone. Recently, Tony Keaveny, a bioengineer at the University of California, Berkeley, uncovered an interesting wrinkle in trabecular bone loss. It turns out that not all struts are created—or rather, lost—equally. The most durable are those positioned to withstand the loads to which a bone is most often subjected. This helps explain why a hip that is still strong enough to carry the burden of everyday movements is far less able to withstand the stress of a fall.

Once enough bone mass has been

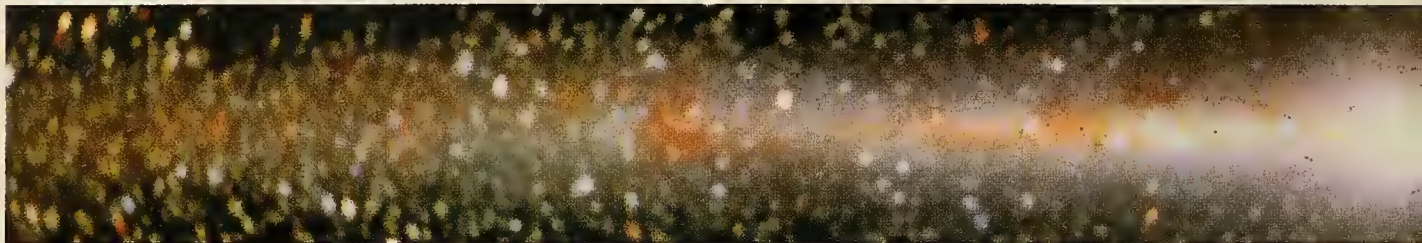
lost, however, all trabecular struts—regardless of their orientation—are prone to failure. Keaveny has pioneered an unusual method for determining just how failure happens. With a high-resolution CAT scanner, he makes a computer model—accurate down to 0.015 inch—of a section of trabecular bone. Using a supercomputer, he “pushes on the model bone until it breaks.” These simulations have led him to conclude that when trabecular bone is subjected to stress from the usual directions, failure (breakage) is primarily due to crushing. On the other hand, stresses that come from other directions force the struts to bend, reducing their effectiveness.

How might these insights aid efforts to repair bones weakened by mineral loss? Keaveny points out that while replacing an entire osteoporotic bone is impractical, strengthening or augmenting its trabecular struts might be possible. In their tissue-culture facility, he and his colleagues start with a sterile block of trabecular

bone—the scaffolding—which they submerge in a solution of nutrients, osteoblasts (bone-building cells), and various growth factors. For the next several weeks to months, the researchers monitor the tissue culture with CAT scans and, if all goes well, track the development of new, mineralized material. Computer simulations can test how much strength the new growth has added. This combination of engineering, tissue culture, and basic biology has raised the possibility that one day, an injection of cells and growth factors may stimulate old bones to thicken their thinning struts.

Meanwhile, research shows that exercise helps make bones stronger and denser. So, baby boomers, to keep osteoporosis at bay, take the stairs, not the elevator, and keep lifting those weights.

Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine.



We know what that whitish blur across the night sky is: the Milky Way. And we know what the Milky Way is: our galaxy. Now if only we knew exactly what a galaxy is.

As one of the most prominent features in the sky, especially on a moonless night, the Milky Way was a subject of speculation for several millennia. Ancient astronomers wondered if it was something unlike everything else up there. A giant cloud, perhaps? Only after Galileo used one of the first telescopes to resolve the seeming spill across the heavens into a “congeries of innumerable stars” did observers know for sure what it was: more of the same.

But more of the same *what*? If the Sun and planets comprised a solar system, as natural philosophers had figured out by the end of the seventeenth century (see “Celestial Events,” February 2001), did all the stars in the night sky, along with our own star, the Sun, comprise a further system of their own? And if so, what would the shape of this star system be?

In 1750, when it was still difficult not to think of the “fixed stars” as lying at some uniform distance from Earth, English philosopher Thomas Wright suggested that the Milky Way might be merely an optical effect. What if, he speculated, the seemingly dense concentration of stars was actually a standard distribution that only *looked* dense because we happened to be seeing this section of sky edge-on? Five years later, German philosopher Immanuel Kant elaborated on this possibility, suggesting that the overall stellar system might be disk

Milky Way Mystery

What you see depends on how you see it.

By Richard Panek

shaped. But not until British astronomer William Herschel began plumbing the depths of the stars in the late eighteenth century, at long last endowing the night sky with a true third dimension, did astronomy arrive at a modern model of what this system might resemble: a giant cluster roughly in the shape of a convex lens.

When we look at the Milky Way, then, what we’re seeing is the disk of our spiral galaxy. The word “galaxy” derives from the Greek *gala* (milk), and the designation “Milky Way,” in fact, can refer either to that visible stretch of stars or to the overall stellar system, in much the same way that “New York” can mean either the city or the state.

As is the case with most astronomical phenomena, galaxies reveal entirely different aspects when we examine them in wavelengths of light that our eyes can’t see—infrared or X rays, for instance. By observing infrared radiation from the central region of the Milky Way, astronomers can see through the dust and gas that obscures our visible-light view of the millions of stars in our spiral galaxy’s bulge. The contrast observed in X rays is even more extreme. As the Space Telescope Science Institute’s Megan Donahue said at a recent astronomy conference, referring to a stunning photograph of a large group of galaxies, “If we had X-ray telescopes at the turn of the century,

we wouldn’t call these ‘galaxy clusters’ but ‘gas clusters.’ The luminous matter”—hundreds of billions of stars—“is just the froth on the gas.”

If the stars are the froth on the gas, the gas, in turn, is the froth on . . . well, astronomers aren’t sure what. They’ve known since the 1970s (and some suspected as far back as the 1930s) that the gravitational interactions of galaxies indicate the presence of something they can’t detect in any band of light, from radio waves all the way to gamma radiation. “Dark matter,” they decided to call it. According to most estimates, this dark matter comprises at least 90 percent of the mass of most galaxies, including our own.

But not only don’t astronomers know what 90 percent of the mass of a galaxy such as our own is; they’re not sure where it is, either. Does dark matter permeate the Milky Way? Probably not, since astronomers don’t find evidence for it in the gravitational interactions of individual stars. Instead, they’ve posited, dark matter forms a halo around the galaxy, but whether it’s spherical or oblate, and how far it extends—or if it even exists—remain frustratingly persistent mysteries.

The best time to see the Milky Way’s galactic bulge is when the sky is very dark; around the time of the new Moon is a good bet for that. In September, the sky is darkest on the



The Milky Way's galactic bulge (based on false-color satellite data)

16th. Weather permitting, a whitish blur will be visible between the northeastern and southwestern horizons in the first hours after nightfall. As for the complete Milky

Way Galaxy, at least 90 percent of it won't be visible. But then, it never is. What's always been true of the night sky still holds, only now more than ever: it's dark up there.

Richard Panek's latest book, The Invisible Century: Einstein, Freud, and Our Search for Hidden Universes, will be published next year by Viking.

THE SKY IN SEPTEMBER

By Joe Rao

Mercury is visible—but just barely—along the western horizon. Look for it during the first half of September only 3° above the horizon, as seen about half an hour after sunset from midnorthern latitudes. After reaching greatest elongation from the Sun on the 18th, Mercury drops from sight.

Venus, the morning “star,” settles lower and lower in the east as the weeks go by, but even by month's end it's still visible for two hours before sunrise. On the morning of September 3, the planet blazes near the southern fringe of M44, the Beehive Cluster in the constellation Cancer. The big conjunction for Venus this month is with the first-magnitude star Regulus, or Alpha Leonis, in the constellation Leo. On the morning of the 15th, a very thin crescent Moon forms a striking isosceles triangle with Venus and Regulus; the bluish white star appears 5° distant from both the Moon and Venus, which appear 3° apart. On the mornings of September 20 and 21, Venus and Regulus appear closest, with the planet passing 0.7° above Regulus on the 20th and 0.8° to its left on the 21st (Venus will be 132 times brighter than the star). By the 25th, Regulus appears to pull up and away from Venus.

Mars, positioned near the top of the Teapot in the constellation Sagittarius, loiters in the south-southwestern sky at dusk throughout September. At the start of the month it sets at about 12:30 A.M. local time, and by the end, about forty-five minutes earlier. As the planet recedes from Earth, it fades from magnitude -0.9 on September 1 to -0.4 by the 30th. Although still relatively bright, Mars shines with one-sixth the luster of its dazzling mid-June showing. The first-quarter Moon passes just above it on the evening of September 24; on the 30th, Mars in turn passes half a degree north of Nunki, a magnitude +2.1 bluish white star in the Teapot's handle.

Jupiter, in the constellation Gemini, rises at about 1:30 A.M. local time in early September and at about midnight by the end of the month. The giant planet shines brightly, low in the east, its four moons visible through even a modest telescope. A fat crescent Moon passes just north of Jupiter on the morning of September 12. From parts of northwestern Canada and Alaska, the Moon will actually occult (hide) Jupiter.

Saturn rises in the east-northeast within four and a half hours after sunset on September 1 and an hour

earlier by the 30th. By dawn, it can be found high in the south, well above and to the right of Jupiter. All month, this zero-magnitude planet remains about 6° northeast of the first-magnitude star Aldebaran. On the morning of the 10th, the last-quarter Moon occults Saturn—between 1:00 and 2:00 A.M. local time in Hawaii; before sunrise on most of the U.S. West Coast (narrowly missing Seattle, however); and during the day farther east.

The Moon is full on September 2 at 5:43 P.M. and is the most distant full Moon of 2001, having arrived at apogee the previous night. Last quarter is on the 10th at 2:59 P.M. The new Moon falls on September 17 at 6:27 A.M. and first quarter is on the 24th at 5:31 A.M.

The autumnal equinox occurs at 7:04 P.M. on September 22, when the Sun, appearing to travel along the ecliptic, crosses the equator into the Southern Hemisphere. This marks the beginning of autumn in the Northern Hemisphere and spring in the Southern Hemisphere.

Unless otherwise noted, all times are given in Eastern Daylight Time.

REVIEW



MARC RIBBOUD; MAGNUM PHOTO, INC.

Delusions and Degradation

How Mao Zedong's grandiose and coercive policies wrecked China's environment

By Vaclav Smil

Exactly twenty years ago, I began writing an appraisal of China's environment. The project became possible as the country abandoned the worst Maoist orthodoxies and turned, under Deng Xiaoping's leadership, to economic and social reforms. Statistics began appearing regularly again in 1978; old scientific journals were restarted and many new ones launched. Journalistic accounts boldly probed topics whose discussion had been either strictly forbidden

or dishonestly couched in Maoist clichés during the long and painful reign of the Great Helmsman. Published in 1983, my book *The Bad Earth: Environmental Degradation in China* was met not only with a great deal of attention but also with disbelief, stemming

from the persistence of a naive Western image of China as a civilization living in harmony with its environment, or perhaps from some American and European intellectuals' residual infatuation with Maoism (or from a combination of the two). Some readers were unwilling to accept the fact that the country's environmental problems were widespread, acute, and intractable.

Mao's War Against Nature: Politics and the Environment in Revolutionary China, by Judith Shapiro (Cambridge University Press, 2001; \$18.95)

Since then, more than a dozen English-language books have detailed the worrisome state of China's environment. Western periodicals and TV programs have repeatedly reported on the consequences of the pollution and ecosystemic degradation that affect not only the country's population and economy but also the so-called global commons. Informed students of the

world's environment are now aware of China's enormous problems (China is the world's top producer of airborne sulfur dioxide and particulate matter from coal combustion, and less than one-fifth of all the country's wastewater is treated before discharge). Environmentalists are alarmed by prospects of the country's continuing desertification, massive soil erosion, and loss of mature forests, not to mention the consequences of damming the Yangtze River for the planet's largest hydroelectric project. (Surprisingly, however, greenhouse gas emissions have been falling in China, due to carbon absorption by forests planted in the 1970s.)

Most acute are the widespread shortages of water in the semiarid-to-arid region of northern China that includes Beijing and supports two-fifths of the nation's industrial and agricultural production (while relying on less than one-tenth of the country's total runoff). These shortages, intensified by the cessation of the Huang He's (Yellow River's) flow for up to five months a year during the past decade, are supposed to be solved by a vast interbasin water transfer from the Yangtze, another megaproject with worrisome environmental consequences.

In her new book about the history of China's environmental degradation during the Mao era (1949–76), Judith Shapiro—a professor of environmental politics at American University in Washington, D.C., and coauthor, with Liang Heng, of several books on China's Cultural Revolution and its aftermath—is no longer facing naive readers. But critics who question her personification of the past in the book's title—*Mao's War Against Nature*—would be wrong. Assigning the guilt to Mao is historically correct. During his emperorlike reign, decisions were not the result of careful, collective deliberations of the Communist Party leadership; rather, they were a direct reflection of the chairman's ignorance, biases, and disdain for the suffering of others. For

more than a quarter century, his decisions affected every aspect of life in China and were responsible for not only massive environmental degradation but also the political persecution and death of millions. The most monstrous consequence, however, was the worst famine in world history, with a death toll of 30 million people between 1959 and 1961.

Shapiro's historical account of these devastating decades follows, sensibly, a topical rather than chronological sequence. Her earlier publications on China deal with the country's modern history, politics, and intellectual life (her field of expertise), and she uses these filters to look at the enormous environmental changes experienced by the country during the third quarter of the twentieth century. Shapiro argues her case by combining published information (from Mao's writings, newspaper and magazine accounts, biographies, and memoirs) with vivid personal descriptions and the recollections of numerous people she interviewed while teaching and traveling in China. This combination works to illustrate the madness of Maoist policies—the irrational designs that caused such suffering and such destruction of nature.

The travails of two notable Chinese intellectuals who dared disagree with Mao, and who paid a high price for their boldness, are discussed first. Economist and demographer Ma Yin-chu called for population control at a time when Mao was extolling unlimited population growth. And China's leading hydroengineer, Huang Wanli, questioned the building of the Soviet-designed Sanmenxia, the first dam on the Huang He, whose reservoir began rapidly silting soon after the project's completion. Both men were lucky. Although their professional careers ended in 1958, they survived.

The book then turns to the Great Leap Forward, meant to elevate China to a new economic level in a matter of years. But the Maoist regime's criminally naive schemes for instant industri-

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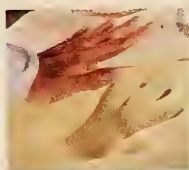
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alization—involving massive deforestation to produce charcoal for inefficient, primitive iron furnaces—brought on the neglect of farming as well as the aforementioned horrific famine.

Almost as soon as the country recovered, Mao plunged it into a new round of social convulsions in 1966, known—most inappropriately—as the Cultural Revolution. “Learning From Dazhai” was a key slogan of that period, imploring people to copy the achievements (vastly exaggerated or even entirely fictitious) of a formerly impoverished village. Widespread destruction of lakes and wetlands for the purpose of creating new cropland was one of the most unfortunate aspects of Mao’s campaigns, and a detailed description of the disastrous results takes up the book’s third chapter. The fourth deals with preparations for war with the USSR and the forcible relocation of industries (and urban youth) to the country’s interior during the late 1960s and early 1970s. The environmental consequences of these programs included the destruction of large areas of tropical forest in southern China to make way for rubber plantations and the conversion of grasslands in the north into erosion-prone cropland.

“Maoist coercive, state-sponsored experiments for social improvement came at a dangerously high price,” Shapiro writes. “The issues raised by the Mao years thus remain deeply relevant.” Both for readers interested in China’s past and for those concerned about its future, the story Shapiro tells is a valuable account of Mao’s regime—one of the last century’s most tragic episodes.

Václav Smil teaches in the University of Manitoba’s geography department. His most recent books, both published by MIT Press, are Feeding the World: A Challenge for the Twenty-First Century (2000) and Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production (2001).

nature.net

Becoming Human

By Robert Anderson

Many people dismiss evolution on the grounds that it is only a theory. Our president is of the opinion that “the jury is still out” on it, according to a *New York Times* article last year.

But consider what “theory” means, as the word is properly used in the sciences. Physicist Alan H. Cromer, in his 1993 book *Uncommon Sense: The Heretical Nature of Science*, reminds us that a theory is not to be confused with “an idea tentatively held for the purposes of argument—that we call a hypothesis. Rather, a theory is a set of logically consistent abstract principles that explain a body of concrete facts.” Evolution is firmly based on just such a logical structure and is therefore every bit as certain as the existence of atoms.

On the Internet, *Becoming Human* (www.becominghuman.org) makes a nice introduction to the theory of human evolution and to the rapidly growing number of hominid fossils that support it. The centerpiece of the site, produced by the Institute of Human Origins at Arizona State University, is an interactive documentary narrated by Donald Johanson, the discoverer of the “Lucy” hominid remains. Although designed for those with a high-speed connection, the site can be viewed in bits and pieces with slower access.

Becoming Human shows the Internet’s ability to update a site as new information surfaces. The “News and Views” section, for instance, recently posted several links to sites covering the discovery of a new species (the 3.5-million-year-old *Kenyanthropus platyops*) that challenges Lucy’s pivotal position in our lineage.

Robert Anderson is a freelance science writer living in Los Angeles.

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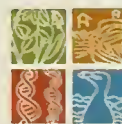


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BOOKSHELF

Wild Nights: Nature Returns to the City, by Anne Matthews (North Point Press, 2001; \$22)

Coyotes, peregrine falcons, wild turkeys, and other wildlife are now sighted in and around New York City—an amazing resurgence in “a profoundly unnatural landscape; a competitive maze; a wonder of money and art.”

Holding Back the Sea: The Struggle for America's Natural Legacy on the Gulf Coast, by Christopher Hallowell (HarperCollins, 2001; \$26)

In the Mississippi River delta—an area with more than 3 million acres of marsh and swamp—massive erosion, rising sea levels, introduced species, and other agents are destroying about twenty-five square miles of wetland a year and threatening the fish harvest, gas and oil reserves, the local residents, and even New Orleans itself.

Blue Nile: Ethiopia's River of Magic and Mystery, by Virginia Morell (National Geographic/Adventure Books, 2001; \$26)

In her account of rafting 560 miles down the Abay Wenz (“great river”)—from Lake Tana in Ethiopia to the Sudanese border—Morell interweaves the day-to-day drama of an expedition with a history of the river and portraits of its peoples.

Barren Lands: An Epic Search for Diamonds in the North American Arctic, by Kevin Krajick (Holt, 2001; \$24.95)

In 1991, in Canada's remote Northwest Territories, a small-time prospector discovered eighty-one tiny diamonds in a crater lake, precipitating “one of the greatest mining rushes in history.”

The Mummy Congress: Science, Obsession, and the Everlasting Dead, by Heather Pringle (Hyperion, 2001; \$23.95)

The Third World Congress on Mummy Studies, held in Chile in

1998, gave journalist Pringle the opportunity to observe this quirky discipline and to explore the “intimate relationship between the living and the everlasting dead.”

Making Babies: The Science of Pregnancy, by David Bainbridge (Harvard University Press, 2001; \$26)

Reproductive biologist Bainbridge investigates the coexistence of mother and fetus during the forty weeks of gestation and concludes that human pregnancy is “a triumph of the natural world, but it can have strange unforeseen effects,” from the mother's susceptibility to disease to the outcome of a male child's sexual orientation.

The Parrot Who Owns Me: The Story of a Relationship, by Joanna Burger (Villard Books, 2001; \$23.95)

A red-lored Amazon rules the roost at an ornithologist's New Jersey home. In recounting her stormy but loving relationship with Tiko (the bird is forty-six years old by the end of the book and could live to sixty or seventy), Burger provides information about the behavior of birds of every feather.

Walking on Eggs: The Astonishing Discovery of Thousands of Dinosaur Eggs in the Badlands of Patagonia, by Luis M. Chiappe and Lowell Dingus (Scribner, 2001; \$25)

Four years ago, a paleontological team led by Chiappe and Dingus discovered a dinosaur nesting ground in Argentina, covering more than a square mile and littered with vast numbers of egg fragments and intact five-inch eggs. The authors piece together the events that prevented these eggs from hatching 70 million years ago.

The Southwest Inside Out: An Illustrated Guide to the Land and Its History, by Thomas Wiewandt and Maureen Wilks (Wild Horizons, 2001; \$24.95)

Abundant photographs, historical tidbits, fascinating facts, and amusing anecdotes complement clear explanations of the natural features of North America's desert and canyon country: its dunes, rocks, cliffs, and water.

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.



Indian Country, photographs by Gwendolen Cates (Grove/Atlantic, 2001; \$44.95)

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THE NATURAL MOMENT



Dry Cleaning



Near the village of Yamato, Japan, in late spring, a paper wasp queen (*Polistes chinensis*) tends a nest she has built on a dead stalk of goldenrod. A potential queen begins her colony by searching out a patch of the species' favorite flowers, where she mates with a suitable male. Next she chooses a nest site and constructs about twenty hexagonal cells from a durable papier-mâché of chewed wood fibers mixed with saliva. After completing each cell, the queen deposits an egg in it before starting the next one. When the larvae hatch, she will feed them chewed-up caterpillars until they are ready to pupate. At that time, each larva wraps itself in a cocoon, plugs its chamber with silk, and becomes quiescent.

For the next three or four months, while the youngsters mature, the foundress cleans the nest regularly and helps keep it cool by fanning her wings. All the cell openings are angled downward, thus preventing rainwater from collecting in them and drowning the larvae. Any water that adheres after a rain must be swallowed by the queen and then regurgitated, drop by drop, over the side—an action captured in this photograph. In autumn, the larvae emerge as adult workers and begin enlarging the colony.

—Richard Milner

Photograph by Hiroshi Ogawa

ENDPAPER

Garbage Out, Garbage In

By Alan S. Kesselheim

It is my first morning of a week in paradise—the Sian Ka'an Biosphere Reserve on the east coast of Mexico's Yucatán peninsula, where a vast living coral reef bumps right up against the shore. I am here to teach a writing workshop. Before me stretches the electric-blue Caribbean. Beneath my feet, the sand of pulverized coral has the pillowy, soft texture of white flour. It takes me a while to notice the garbage.

Plastic bottles, milk cartons, sandals, strands of rope, disposable diapers, shopping bags, six-pack holders, sunglass

frames, broken Styrofoam coolers, baseball caps, plastic GIs. They bob in the surf alongside incoming coconuts, mingle with the seaweed at the high-water line, flutter in the shrubs at the back of the beach. Not what I expected to see at a UNESCO World Heritage Site.

Farther north along the coast, garbage is not allowed. From Cancún to Tulum, along a sixty-mile strip of vacation real estate known as the Mayan Riviera, much

of the beach is not only patrolled for litter each day but also manicured every morning by workers wielding rakes. In some places, the sand is refreshed periodically with truckloads brought in from elsewhere: beaches to go.

But in the protected reserve, the natural state is upheld, including our prolific, enduring detritus.

"It is literally the garbage of the world," my host, Anna Woods, tells me. A part-time resident, she runs a series of artists workshops in the reserve. Woods has found medical waste from New York City hospitals washed up, the addresses still intact on the containers. In order to reach this coast, such refuse must first be swept north and east by the

Gulf Stream to Europe, then south toward Africa and west across the Atlantic—a loop of roughly 10,000 miles. "Some of it might have gone around twice," says Woods.

She shrugs when I ask if I could pick up some of the trash. "It's a five-hour round trip on very bad roads to dispose of it at the dump outside of Tulum. Who knows how it's taken care of there."

Over the days I learn to filter out the litter, at least most of the time. I focus on the bleached shells, the hunks of intricately patterned coral, the hermit crabs dragging their homes through the sand like martyrs on a pilgrimage.

Halfway through my week, as I walk down the beach, I meet Cruz, a skinny eleven-year-old boy from a nearby *ranchito*. In a pouch made with his faded T-shirt, he carries his morning's treasure—a stash of plastic and Styrofoam knickknacks thrown up by the sea. There is not a single shell or rock or lump of coral in the mix.

Cruz has never been to a Wal-Mart. But if he is patient and alert enough, almost anything can come to him. He arranges and rearranges his coastal trove in the yard outside his house the same way my kids play with their Lego sets and plastic barn animals in our basement. His model ranches consist of assorted boxes and cartons, with twine fences, milk-carton horse stalls, and a syringe for a tiny silo. An extensive system of roads conveys cars and trucks. A surprisingly large assortment of suitable farm animals inhabit the spread, although the rancher may be a garish action figure or space alien, and his wife the nude upper half of a Barbie doll.

My last morning at the reserve, I walk the flour-sand shoreline one final time, searching for pretty shells or convoluted knobs of coral to carry home to my kids. The breeze is blowing onshore; the waves break across the reef.

I notice that I am unconsciously surveying the beach the way Cruz does, without judgment, watchful for some glimmer of surprise. I am alive to the possibility that I just might find some stunning piece of the world's refuse to cart back, a treasure in honor of Cruz.

Freelance writer Alan S. Kesselheim is a columnist for Big Sky Journal and a contributing editor for Canoe & Kayak. His latest book is The Wilderness Paddler's Handbook (McGraw-Hill, 2001).



On the beach in the Sian Ka'an Biosphere Reserve, Mexico

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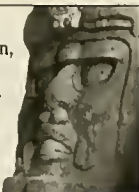
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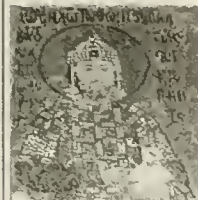
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