

# NATURAL HISTORY

A black and white photograph of a lemur, likely a nocturnal species, perched on a tree branch. The lemur has dark fur and its eyes are glowing with a bright red or orange light, a common effect in night photography of animals. The background is a blurred forest scene with various leaves and branches.

6/05

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**LEMURS**





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# NATURAL HISTORY

JUNE 2005

VOLUME 114

NUMBER 5



## FEATURES



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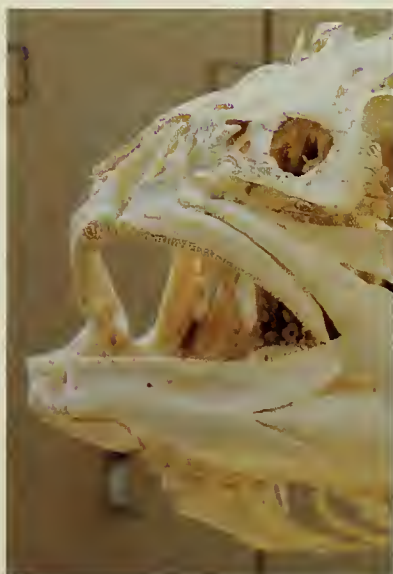
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SHARON T. POCHRON  
AND PATRICIA C. WRIGHT

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PHOTOGRAPHS BY  
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LUIS AND MONIKA ESPINASA

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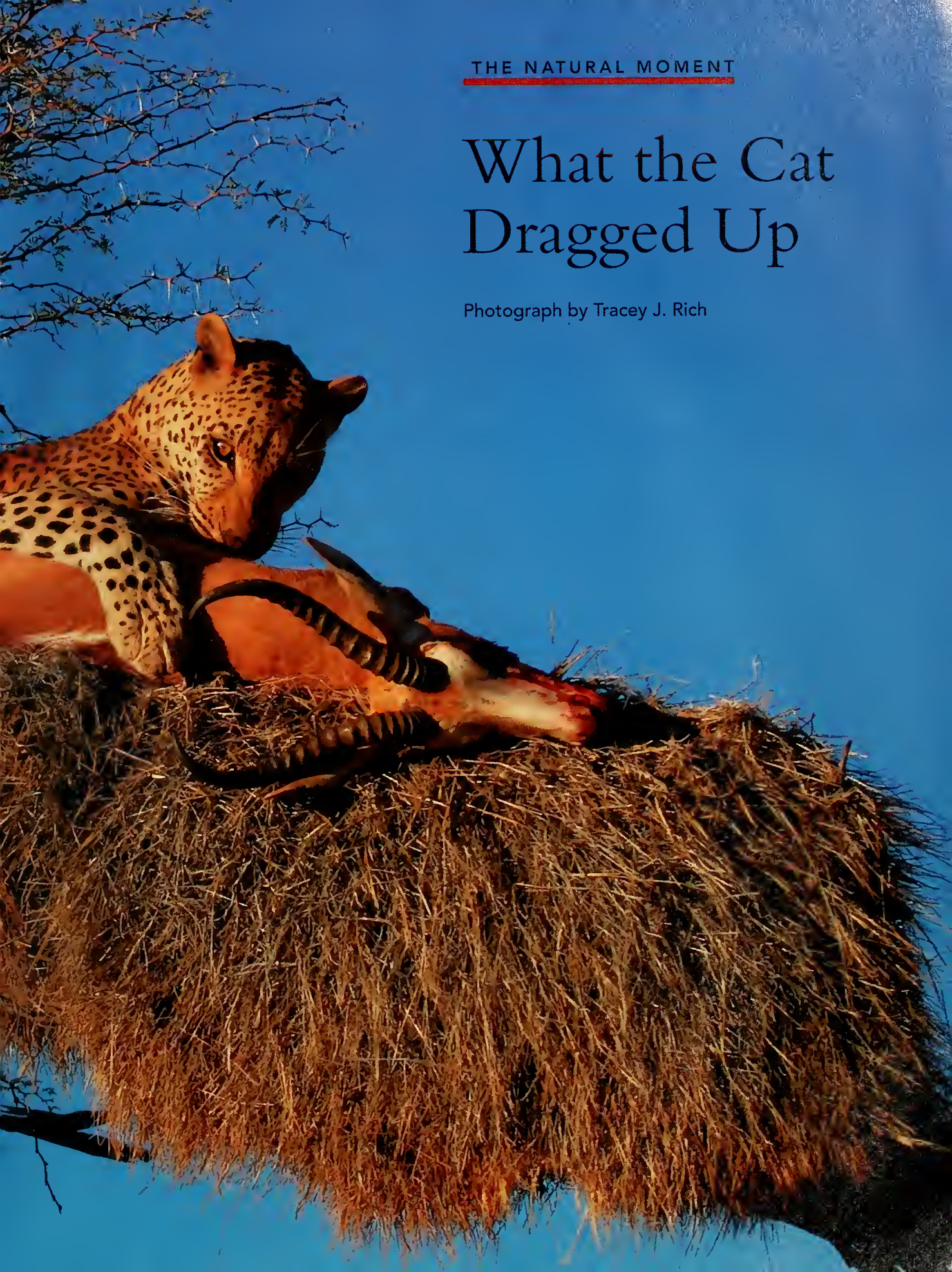




THE NATURAL MOMENT

# What the Cat Dragged Up

Photograph by Tracey J. Rich





◀ See preceding two pages



Cats have a knack for looking coolly graceful, whether hunting, killing, or absently tearing flesh from a fresh catch. Photographer Tracey J. Rich first spied this leopard in southern Namibia, as it was nimbly dragging a springbok antelope carcass—weighing at least sixty pounds—toward her on the ground. Then, as Rich gawked, the leopard gripped its catch by the neck and, without too much effort, lugged it twenty feet straight up an acacia tree.

Leopards (*Panthera pardus*) often trundle their bulky prey into trees for safekeeping from competitors such as hyenas, lions, and wild dogs. But Rich saw no other animals nearby on the plains, except for herself and her two human companions. The acacia was not well protected from the sun or from vultures, either. Perhaps the main attraction was an enormous weaverbird nest in the treetop, just the thing for a leopard to lounge on. A community of sociable weaverbirds (*Philetainus socius*) had created the billowy thatching, but they apparently abandoned the roost sometime before the big cat arrived.

Content in its aerie, the leopard gave Rich an “odd look” now and then—a signal that it hadn’t forgotten its audience. But for the most part, she says, “It played with the dead springbok, licked it, and occasionally took a few mouthfuls.”

—Erin Espelie

## Observing, Skeptically

The first time I ever visited a “wild” cave was decades ago, in the karst-rich country of the southern Appalachians. Caves in their natural state bear little resemblance to commercial caverns: no freight elevators or tastefully lighted stalactites, no café and gift shop at the main entrance. The entrance to my first cave was a pit, 160 feet deep; to enter, my guides and I tied a rope to a tree, dropped the other end to the bottom, and rappelled down. The adventure got even better. We scrunched into a crack in the floor of the pit, belly-crawling a few dozen feet through a tight little passage. But then we emerged, rewarded for our efforts, into an immense room at the base of a deafening waterfall, cascading from a darkness too high for our headlamps to penetrate.

Charles Darwin, as far as I know, never crawled around in caves; his weakness as an explorer was isolated volcanic islands. But there’s no question he would have been fascinated by Luis and Monika Espinasa’s story on page 44, “Why Do Cave Fish Lose Their Eyes?” Darwin posed the same question, and was not able to answer it to his own satisfaction. Subtle observations of the bones in the fishes’ eye sockets, and the genes in the fishes’ cells, may finally resolve the conundrum.

• • •

Lynn Margulis is another close observer of nature, but she is also a scholarly explorer and a fiercely independent thinker. Remarkably, nearly four years after the anthrax attacks of 2001, the life history of the anthrax disease agent remains an open scientific question. Where, Margulis pointedly asks, is the anthrax bacterium in nature?

The usual response is, it’s the spore of a soil bacterium, lying in wait to infect an animal. But the bacterium doesn’t grow, or develop, or infect anything in the soil; describing it as a “soil bacterium,” as Margulis deadpans in her article “Jointed Threads” (page 28), is not very “useful.” In fact, the label is more likely just a placeholder covering for scientific ignorance.

Margulis and her coworkers have now added a surprising piece to the anthrax puzzle: *Bacillus*, the genus to which anthrax belongs, has a stage in its life history as a threadlike collection of cells, growing benignly on the intestinal walls of many animals.

What light will this work shed on the anthrax bacillus? It’s impossible to say. But you would think, given the threat of anthrax spores as a biological weapon, that a basic understanding of their life cycle in nature would not be a place to skimp in the nation’s budget.

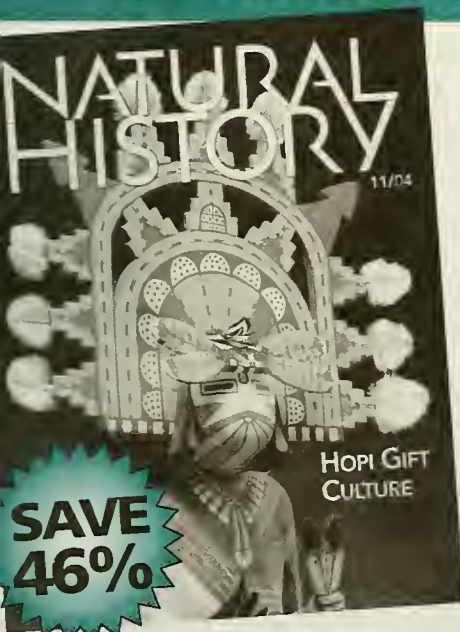
• • •

If you’re a graduate this month, or know one, you’re liable to be reminded, portentously, that life is an adventure in learning. I don’t disagree. But my word to the graduates this commencement season is, Look to Darwin, or the Espinasas, or Margulis for examples of lives to emulate. Be skeptical. Challenge dogma. Ask: “How do you know?” See—and think—for yourself. And if you’re exploring a cave, make sure you’re observing closely enough to keep track of where you came from.

—PETER BROWN



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# NATURAL HISTORY

THE WONDERS OF NATURE AT YOUR FINGERTIPS



## CONTRIBUTORS



A family-wide passion for picture taking spurred **TRACEY J. RICH** ("The Natural Moment," page 6) to take up wildlife photography herself. She's been snapping photos, she says, "since she can remember." In the field, she draws on her doctoral study in behavioral ecology at the University of Nottingham in England.

A Distinguished University Professor in the department of geosciences at the University of Massachusetts-Amherst, **LYNN MARGULIS** ("Jointed Threads," page 28) has long worked on the origin of nucleated cells. Margulis is a member of the National Academy of Sciences. In 1999 she was one of twelve recipients of National Medal of Science. She thanks James di Properzio, Celeste Asikainen, Abe Gomel, and A.I. Tauber, who made important contributions to the research and preparation of this article.



**SHARON T. POCHRON** ("Dance of the Sexes," page 34) earned her doctorate for fieldwork studying baboons, but when she began observing Milne-Edwards's sifakas, she quickly realized that little about baboon behavior would apply to her new subjects. Pochron, upper left, is an assistant research professor at the Institute for the Conservation of Tropical Environments (ICTE), at Stony Brook University in New York. Her co-author, **PATRICIA C. WRIGHT**, lower left, a professor of anthropology at Stony Brook University, is ICTE's executive director and the international coordinator for the Ranomafana National Park Project in Madagascar. The park was established in 1991, largely through her efforts.



Australian-born artist **JUSTINE COOPER** ("Behind Closed Doors," page 40) remembers exploring secret places ever since she was five, when she discovered her parents' collection of color-coded bones (her parents are veterinarians). Her photographs behind the scenes at the American Museum of Natural History, from which this month's portfolio is selected, are on display at the Kashya Hildebrand art gallery in New York City, through June 4.



**LUIS** and **MONIKA ESPINASA** ("Why Do Cave Fish Lose Their Eyes?" page 44) met while attending a graduate course at the American Museum. On one of their first dates, a flash flood trapped them inside a cave for eighteen hours. Since then, the couple has jointly discovered and described several new species of cave organisms. Luis is an associate professor of biology at Shenandoah University in Winchester, Virginia, where he specializes in the evolution of blindness in cave fish. Monika teaches biology at the same institution, and at Lord Fairfax Community College in Middletown, Virginia.



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*Natural History* (ISSN 0028-0712) is published monthly, except for combined issues in July/August and December/January, by Natural History Magazine, Inc., in affiliation with the American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024. E-mail: [nhmag@naturalhistorymag.com](mailto:nhmag@naturalhistorymag.com). *Natural History Magazine, Inc.* is solely responsible for editorial content and publishing practices. Subscriptions: \$30.00 a year, for Canada and all other countries; \$40.00 a year. Periodicals postage paid at New York, NY, and at additional mailing offices. Canada Publications Mail No. 40030827. Copyright © 2005 by Natural History Magazine, Inc. All rights reserved. No part of this periodical may be reproduced without written consent of Natural History. If you would like to contact us regarding your subscription or to enter a new subscription, please write to us at Natural History, P.O. Box 5000, Harlan, IA 51593-0257. Postmaster: Send address changes to *Natural History*, P.O. Box 5000, Harlan, IA 51537-5000. Printed in the U.S.A.



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**Pushing Capacity**

In his article "Collapse" [4/05], Jared Diamond chooses the population that inhabits the highlands of New Guinea as an example of a society that has solved its environmental problems. Unfortunately, the pioneer-

the eve of first contact, according to Enga elders, the population was growing rapidly, its growth was accompanied by runaway competition, demands on land and production were ever accelerating, and warfare was rampant. It is like-



Oh, dear! I'm almost out of madagascar.

ing work of James B. Watson, an anthropologist at the University of Washington in Seattle, has shown that the favorable picture of New Guinea described by early explorers was not a long-established one, but rather just a snapshot taken during a period of rapid change.

For much of New Guinea's prehistory, populations in the highlands depended on hunting and gathering, supplemented by agriculture. Around 350 years ago, sweet-potato vines arrived from Indonesia, making it possible for the first time to store surplus food in the form of livestock: pigs. Our studies of precolonial traditions among the Enga in New Guinea show that once they could produce a surplus, change was rapid. On

ly that highland societies were headed for collapse.

*Polly Wiessner  
University of Utah  
Salt Lake City, Utah  
Akiu Timu  
Enga Cultural Centre  
Wabag, Enga Province,  
Papua New Guinea*

Jared Diamond states that one of the causes of collapse at Copán "was a failure of the Mayan kings and nobles to address problems within their control." But the archaeological evidence indicates to me that the Mayan rulers were well aware of many of the environmental problems they faced in the second half of the eighth century A.D., and that they took a number of steps in response. For example, they undertook massive building and

sculptural programs to glorify the gods (and themselves), which displaced farmers into nonfood-producing labor in the cities. That put added stresses on their cities.

Where Mr. Diamond sees no action, I see definite actions that in hindsight probably were not the best.

*Jeremy A. Sabloff  
University of Pennsylvania  
Museum  
Philadelphia, Pennsylvania*

**Pick of the Crop**

The book *Mendel in the Kitchen: A Scientist's View of Genetically Modified Foods*, reviewed by Laurence A. Marshall ["Bookshelf," 3/05], suggests that if only people understood the science behind genetically modified (GM) food crops, they would embrace the new technology. As a molecular biologist, I understand the science, and I am very much opposed to GM crops in their present form.

Nina Fedoroff and Nancy Marie Brown are incorrect to imply that GM technology is the same as standard plant breeding. Introducing foreign material into plant DNA is neither "predictable" nor "precise." The procedures of cell culture and transformation used in producing GM crops cause many random mutations and chromosomal rearrangements. Mutations that cause subtle but significant changes in plant metabolism need not be lethal to the plant; but consuming such a plant could lead to serious health problems.

If GM technology is as safe as Ms. Fedoroff and

Ms. Brown claim it is, why are the biotechnology producers so opposed to mandatory safety testing and labeling?

*Pamela Maher  
La Jolla, California*

**NINA FEDOROFF REPLIES:**

In our book Nancy Marie Brown and I address all of the issues Pamela Maher raises. Most gene insertions have little or no effect on the plant, but the cell-culture procedures used in transforming some plants are indeed mutagenic. Cell-culture procedures, chemical mutagens, and radiation all have been applied in what people now refer to as traditional, or conventional, plant breeding for the better part of a century. Thousands of new and valuable varieties of food plants, including the familiar Rio Red grapefruit, have been developed through such mutagenic procedures.

Such plants undoubtedly carry genetic changes other than the ones underlying the selected traits. Unexpected health problems due to those genetic changes are rare, though not unheard of. When breeders select for such traits as improved insect resistance, for example, they can inadvertently produce plants with a higher content of toxic compounds than plants naturally produce to defend themselves against pests. Yet traditional plant breeders are not required to do safety testing of new food crops.

For crops derived via molecular techniques, however, the requirements for compositional analysis, as



well as for toxicity and allergenicity testing, are rigorous. Hence it is more likely in the case of GM crops that such problems will be caught before food-stuffs come to market. To my knowledge, companies that produce GM foods are not opposed to such testing.

Mandatory labeling is a different issue. It requires that the GM crops be harvested, stored, shipped, and handled separately, all of which translates into higher costs. If the crops look the same as non-GM crops, identifying them requires expensive molecular testing. Mandatory labeling would drive up food costs, but offer no health benefits, and it would disproportionately affect the poorest consumers.

### In the Sticks

J. David Henry's article on the boreal forest ["Northern Exposure," 2/05] perpetrates the misconception that taiga and boreal forest are one and the same. In fact, however, not all boreal forest is taiga, and not all taiga occurs in the boreal forest. Taiga (Russian for "forest of little sticks") specifically refers to a forested area dominated by stunted coniferous trees such as black spruce or lodgepole pine (as in the photograph on page 29 of Mr. Henry's article). Taiga often lies between forest and treeless tundra. In the boreal forest, taiga generally occurs in wet areas in which permafrost is close to the surface, and thus inhibits drain-

age and root development.

The boreal forest also includes dry northern forest, as pictured on pages 28 and 30. There you will find aspen, white spruce, and other commercially valuable trees. But that forest is not taiga, and unlike the taiga, dry northern forest faces substantial threat from overexploitation.

Confusing the terms "taiga" and "boreal forest" may worsen the threat. Protecting vast areas of taiga as a "feel good" measure will not help preserve the exploitable dry northern forest.

*Mark Crispin  
Bainbridge Island, Washington*

J. DAVID HENRY REPLIES:  
Among North American

ecologists, the term "taiga" is used in several different ways. Mark Crispin describes one of them, but a consistent use of the word has not yet emerged. "Taiga" is an old and well-established Russian word for the predominantly coniferous forest that covers most of Siberia and western Russia. Russians and most Europeans use the word "taiga" to refer to the entire boreal forest. I follow this established usage.

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Endangered U.S. species that are on the upswing: (from top) yellow-shouldered blackbird, green sea turtle, bighorn sheep

## Report Card

The Endangered Species Act of 1973 is dear to the hearts of most American environmentalists. Vital to its framework is the listing of animal and plant species whose numbers are so depleted that the survival of the species itself is put at risk. Associated with each listing are guidelines for the species' recovery. Now that the act has been in place for three decades, it's fair to ask whether the lot of the species under its protection has significantly improved.

Yes, say Martin F.J. Taylor, a conservation biologist at the National Parks Association of Queensland in Australia, and two colleagues. Looking at federal census data for nearly 1,100 species, the investigators found some obvious—and some not-so-obvious—trends. The longer a jeopardized species was listed as endangered (and was thus eligible for the act's protections), the greater the chances that its numbers eventually increased. Species whose recovery plans were customized and whose habitats were protected by being designated as critical were more likely to be improving than species

protected only by umbrella recovery plans, covering multiple species, or whose habitats remained unprotected.

Not everything is coming up roses, though. The pace of new listings has steadily slowed since the mid-1990s, despite the accelerating intensity of the threats. The designation of critical habitats, too, slowed to a crawl between 1986 and 2000. Rarely have recovery plans been fully followed. Even under the best conditions, no more than a quarter of the species improved in numbers, and about 40 percent declined. Only thirteen of 1,370 species listed as endangered since the act was passed have recovered enough to be delisted.

Nevertheless, only twenty-two listed species have become extinct, whereas without the protections afforded by the act, 227 species would likely have become extinct. And for about \$150 million, the listings of endangered species and the habitats that shelter them could be brought up to date. (*Bioscience* 55:360–67, 2005)

—Stéphan Reebbs

## Rock of Ages

If you want to know how long a rock has been exposed to the sky, measure its neon-21. Cosmic rays—energetic particles that originate in distant stars and galaxies—are constantly smashing into the atoms that make up various minerals in exposed rock. When they do, they produce neon-21, a stable isotope of that noble gas. The more of

the isotope you find in a rock, the longer the rock has been lying on the surface of the Earth.

A team of geologists led by Tibor J. Dunai of Vrije University in Amsterdam measured the neon-21 in quartz from an abandoned river terrace in the Atacama Desert in northern Chile. Currently the area gets

no runoff from rainfall or rivers, and apparently the rocks on its surface have lain exposed and undisturbed for a very long time: 23 million years, according to Dunai and his colleagues. Undisturbed means uneroded, making that corner of the Atacama the oldest unaltered landscape on Earth. (*Geology* 33:321–24, 2005)

—S.R.

Earth's most unchanged surfaces lie in the Atacama Desert.



## Preservation Halls

Wood rots readily, and so even though it's been used for construction around the world and through the ages, almost every wooden building ever made has eventually disappeared. But Heather McKillop, an anthropologist at Louisiana State University in Baton Rouge, and a team of snorkelers recently discovered an important exception: a group of twenty-three hardwood and palm-wood buildings that are still partly intact after some 1,400 years. Embedded in mangrove peat on the floor of a huge lagoon off the coast of Belize, they are the first ancient wooden buildings ever found in the Maya's homeland.

The wood in the buildings dates to between A.D. 600 and 900, when grand Mayan cities such as Palenque and Tikal flourished in the area. At the time, the lagoon's buildings were on dry land; a subsequent rise in sea level transformed the site into mangrove forest. The mangroves' waterlogged roots decayed into peat, and the peat's acidity and lack of oxygen kept the wood from rotting.

What went on in all those buildings, and at some twenty other nearby sites discovered by the snorkelers, was salt making on a grand scale. Local entrepreneurs apparently boiled seawater or brine (seawater made saltier by being poured through salt-saturated soil) in standardized ceramic pots, packed the salt residue into their canoes, and paddled upriver to the inland, salt-deprived cities of the Yucatán Peninsula. Other desirable goods—seafood, stingray spines for ritual bloodletting, conch shells for use as horns—were transported inland from other sites.

In addition to hundreds of wooden posts, which demarcated both exterior walls and interior rooms, ceramics were found in great abundance in the lagoon. One large wooden paddle buried in the peat has also been recovered—the first one ever found, though identical paddles are depicted in ancient Mayan art. (*Proceedings of the National Academy of Sciences* 102: 5630–34, 2005) —S.R.

## Soup's On

Knowing whether you're hungry or sated should be a classic case of gut intuition. Yet a recent study of eating habits showed that people don't pay much attention to the gut: they rely instead on their eyes to assess whether they've eaten their fill.

Brian Wansink, a food-marketing psychologist at Cornell University in Ithaca, New York, and two colleagues set out to determine whether people can be tricked into eating more than they intend to (yes, they can) and whether, once tricked, they have a good idea of how much they actually ate (no, they don't).

At lunchtime in a university cafeteria, the investigators seated volunteers in groups of four at a modified table, set with four eighteen-ounce soup bowls. Two bowls were ordinary, but two were covertly connected by a hose to a vat of soup, and very slowly refilled as the volunteers ate. Those spooning their soup from the ordinary bowls ate, and correctly thought they had eaten, slightly more than eight ounces. The deceived diners ate nearly fifteen ounces, on

average, but thought they had eaten less than ten.

In both groups, similar proportions of the volunteers claimed they knew how much



they had eaten. Most of them estimated their intake from the height of the soup in the bowl, and described their fullness after the meal in similar terms. Apparently—the adage notwithstanding—the eyes are really smaller than the stomach. (*Obesity Research* 13:93–100, 2005) —T.J. Kelleher

## Beyond DNA?

A basic tenet of modern biology is that only genes—long sequences of DNA—carry the information needed for building an organism. Henceforth, however, that tenet may have to appear with an asterisk. Susan J. Lolle, Robert E. Pruitt, and two other botanists at Purdue University in West Lafayette, Indiana, have discovered that the DNA path of inheritance may not be the only one.

Lolle, Pruitt, and their colleagues chanced on their finding while working with a gene that occurs in *Arabidopsis thaliana*, a plant often used to explore genetic questions. Like you and me and most other sexually reproducing organisms, *Arabidopsis* has two copies, or alleles, of each of its genes (even though it happens to be self-fertilizing). And when both alleles of its gene *HOTHEAD* are mutant, the

plant's organs are grossly deformed. According to biology 101, that's a common circumstance with a clear implication: when both parents (or one self-fertilizing parent)

express a recessive mutation, their progeny must show the mutation, too.

So it came as a shock to the investigators that mutant *Arabidopsis* gave rise to some nonmutant progeny. There was no evidence that the mutant alleles were simply mutating back to normal, or that some other gene was normalizing the offspring. What

gives? Perhaps, the biologists suggest, some heritable RNA—bearing the ancestral instructions for normality—lurks within the reproductive cells, ready to insert its instructions where it meets mutated DNA. (*Nature* 434:505–509, 2005)

—S.R.



*Arabidopsis thaliana*



## SAMPLINGS

### Wave in the Water

Here's a conundrum: even in the purest of ultrapurified water, microorganisms live and even multiply. Does the water retain trace amounts of nutrients? Do the microorganisms somehow manufacture their own food? Do they cannibalize one another?

Dissatisfied with those explanations, Victor A. Gusev of the Sobolev Institute of Mathematics in Novosibirsk, Russia, and Dirk Schulze-Makuch of Washington State University in Pullman came up with another one. Gusev, a biophysicist, and Schulze-Makuch, a geobiologist, propose that low-frequency electromagnetic waves from the Sun and Earth—specifically radio waves, a form of ra-



diation that's less energetic than visible light—may provide the necessary energy.

To test their hypothesis, the investigators grew cultures of *Escherichia coli* bacteria in superdistilled water. They shielded some of the cultures from all electromagnetic waves by placing them in an airtight metal chamber, and permitted only low-frequency waves to reach the other cultures. The results were unequivocal: nearly all the bacterial populations deprived of radiation died out within a week, whereas nearly all the populations exposed to radiation survived.

The investigators' explanation is that free protons, generated by the continual dissociation of water molecules under ordinary conditions, are excited by naturally occurring electromagnetic waves. The protons accumulate enough kinetic energy that by the time they reach the bacteria's cell membrane, they can form high-energy chemical bonds—in other words, usable energy. (*Naturwissenschaften* 92:115–20, 2005)

—Graciela Flores



Female beewolf toting honeybee

### An Ounce of Prevention

Beewolf wasp mothers leave little to chance. They build a separate underground protective cell for each of their eggs and provision each cell with a few paralyzed live honeybees so that the larvae will find dinner ready when they hatch. Martin Kaltenpoth, a biologist at the University of Würzburg in Germany, and his colleagues recently discovered that beewolf moms also swab the cells with disinfectant.

Specialized glands in the wasp's antennae host bacteria of the genus *Streptomyces*—normally soil-dwelling bacteria that produce antibiotic and antifungal compounds such as streptomycin and

tetracycline. As mom readies her brood cells, her antennae secrete lots of bacteria-laden white glop, which she smears inside each cell. Then she lays an egg and closes up the chamber. Several months later the larvae hatch. They touch and seemingly ingest some of the glop, and then start spinning their cocoons—inadvertently infusing the threads with the *Streptomyces* and their medicine.

And that's a good thing for the larvae. A brood cell can get hot and steamy—a perfect setting for fungal and bacterial infections. Dinner—and the diner—could readily decay. Kaltenpoth and his colleagues found that when deprived of glop, only one of fifteen larvae survived long enough to emerge from the cocoon—compared with fifteen of eighteen from a batch of undeprived larvae. The biologists propose that symbiotic, antibiotic-producing soil bacteria such as *Streptomyces* may have joined forces with numerous species of arthropods, and may have helped make the soil a hospitable place for a nest. (*Current Biology* 15: 475–79, 2005)

—G.F.

### Strike, Counterstrike

Poison can be a formidable weapon—particularly if it's 10,000 times more lethal than cyanide. Tetrodotoxin, the substance in pufferfish organs that may be Japanese cuisine's biggest thrill, turns up in other animals, too—among them the rough-skinned newt. This newt, a resident of the American West, has the stuff in its skin, which acts as an excellent deterrent to predators.

But some populations of garter snakes eat the newt willingly. How is that possible? Shana L. Geffeney, a biologist at Utah State University in Logan, and several colleagues say just a few key mutations in one garter-snake gene are enough to do the trick. Tetrodotoxin kills by paralyzing its victims. It worms its way into a hole in a protein expressed in the membrane of muscle cells that control contraction. There the poison blocks the movement of sodium into the cells. If the sodium can't move, the muscles can't con-

tract. In the poison-tolerant snakes, however, the protein differs from the one in vulnerable snakes by only a few amino acids. That's enough to thwart the tetrodotoxin and keep the muscles going—until either prey or predator evolves a new weapon. (*Nature* 434:759–63, 2005)

—S.R.



Some garter snakes survive a dinner of supertoxic newt.



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# Fueling Up

*To travel from the Earth to the sky requires propulsion. Propulsion requires energy. Energy requires fuel.*

By Neil deGrasse Tyson

In daily life you rarely need to think about propulsion, at least the kind that gets you off the ground and keeps you aloft. You can get around just fine without booster rockets—simply by walking, running, rollerblading, taking a bus, or driving a car. All those activities depend on friction between you (or your vehicle) and Earth's surface.

When you walk or run, friction between your feet and the ground enables you to push forward. When you drive, friction between the rubber wheels and the pavement enables the car to move forward. But try to run or drive on slick ice, where there's hardly any friction, and you'll slip and slide and generally embarrass yourself as you go nowhere fast.

For motion that doesn't engage Earth's surface, you'll need a vehicle equipped with an engine stoked with massive quantities of fuel. Within the atmosphere, you could use a propeller-driven engine or a jet engine, both fed by fuel that burns the free supply of oxygen provided by the air. But if you're hankering to cross the air-



Artist's conception of spacecraft designs by the German rocket engineer Werner von Braun (detail of illustration by Walter Molino, cover of the Sunday supplement to the Italian newspaper *Corriere della Sera*, May 9, 1954)

less vacuum of space, leave the props and jets at home and look for a propulsion mechanism that requires no friction and no chemical help from the air.

One way to get a vehicle to leave our planet is to point its nose upward, aim its engine nozzles downward, and

swiftly sacrifice a goodly amount of the vehicle's total mass. Release that mass in one direction, and the vehicle recoils in the other. Therein lies the soul of propulsion. The mass released by a spacecraft is hot, spent fuel, which produces fiery, high-pressure gusts of exhaust that channel out the vehicle's hindquarters, enabling the spacecraft to ascend.

Propulsion exploits Isaac Newton's third law of motion, one of the universal laws of physics: for every action, there is an equal and opposite reaction. Hollywood, you may have noticed, rarely obeys that law. In classic Westerns, the gunslinger stands flat-footed, barely moving a muscle as he shoots his rifle. Meanwhile, the ornery outlaw that he hits sails backward off his feet, landing butt first in the feeding

trough—clearly a mismatch between action and reaction. Superman exhibits the opposite effect: he doesn't recoil even slightly as bullets bounce off his chest. Arnold Schwarzenegger's character the Terminator was truer to Newton than most: every time a shotgun



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Space shuttle Columbia lifts off, October 20, 1995

blast hit the cybernetic menace, he recoiled—a bit.

Spacecraft, however, can't pick and choose their action shots. If they don't obey Newton's third law, they'll never get off the ground.

**R**ealizable dreams of space exploration took off in the 1920s, when the American physicist and inventor Robert H. Goddard got a small liquid-fueled rocket engine off the ground for nearly three seconds. The rocket rose to an altitude of forty feet and landed 180 feet from its launch site.

But Goddard was hardly alone in his quest. Several decades earlier, around the turn of the twentieth century, a Russian physicist named Konstantin Eduardovich Tsiolkovsky, who earned his living as a provincial high school teacher, had already set forth some of the basic concepts of space travel and rocket propulsion. Tsiolkovsky conceived of, among other things, multi-

ple rocket stages that would drop away as the fuel in them was used up, reducing the weight of the remaining load and thus maximizing the capacity of the remaining fuel to accelerate the craft. He also came up with the so-called rocket equation, which tells you just how much fuel you'll need (assuming you won't be stopping at any filling stations en route) for your journey through space.

Nearly half a century after Tsiolkovsky's investigations came the forerunner of modern spacecraft, Nazi Germany's V-2 rocket—"V" for *Vergeltungswaffen*, or "Vengeance Weapon." The V-2 was conceived and designed for war, and was first used in combat in 1944, principally to terrorize London. The brainchild of Wernher von Braun and hundreds of other scientists and engineers working with the Nazis, the V-2 was the first ballistic missile and the first rocket to target cities that lay beyond its own horizon. Capable of

reaching a top speed of about 3,500 miles an hour, the V-2 could go a few hundred miles before plummeting back to Earth's surface in a deadly free fall from the edge of space.

To achieve a full orbit of Earth, however, a spacecraft must travel five times faster than the V-2, a feat that, for a rocket of the same mass as the V-2, requires no less than twenty-five times the V-2's energy. And to escape from Earth orbit altogether, and head out toward the Moon, Mars, or beyond, the craft must reach 25,000 miles an hour. That's what the Apollo missions did in the 1960s and 1970s to get to the Moon—a trip requiring at least another factor of two in energy.

And that represents a phenomenal amount of fuel.

Because of Tsiolkovsky's unforgiving rocket equation, the biggest problem facing any craft heading into space is the need to boost "excess" mass in the form of fuel—most of which is the fuel required for transporting the fuel it will burn later in the journey. And the spacecraft's weight problems grow exponentially. The multistage vehicle was invented to soften this problem. In such a vehicle, a relatively small payload—such as the Apollo spacecraft, an Explorer satellite, or the space shuttle—gets launched by huge, powerful rockets that drop away sequentially or in sections when their fuel supplies become exhausted. Why tow an empty fuel tank when you can just dump it and possibly reuse it on another flight?

Take the Saturn V, a three-stage rocket that launched the Apollo astronauts toward the Moon. Designed by von Braun (among others), it could almost be described as a giant fuel tank. The Saturn V and its human cargo stood thirty-six stories tall, yet the three astronauts returned to Earth in an itty-bitty, one-story capsule. The first stage dropped away about ten minutes after liftoff, once the vehicle had been boosted off the ground and was moving at about 9,000 feet per second (more than 6,000 miles per hour). Stage two dropped away about ten minutes later, once the vehicle was moving at about



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23,000 feet per second (almost 16,000 miles per hour). Stage three had a more complicated life, performing several episodes of fuel burning: the first to accelerate the vehicle into Earth orbit, the next to get it out of Earth orbit and head it toward the Moon, and a couple more to slow the craft down so that it could pull into lunar orbit. At each stage, the craft got progressively smaller and lighter, which means that the remaining fuel could do more with less.

Since 1981, NASA has used the space shuttle for missions in “low-Earth orbit”—a few hundred miles above our planet. The shuttle has three main parts: a stubby, airplane-like “orbiter” that holds the crew, the payload, and the three main engines; an im-

rubber pincers on the hand brake squeeze the wheel rim; on a car, the brake pads squeeze against the wheels’ rotors, slowing the rotation of the four rubber tires. In those cases, stopping requires no fuel. To slow down and stop in space, however, you must turn your rocket nozzles backward, so that they point in the direction of motion, and ignite the fuel you’ve dragged all that distance. Then you sit back and watch your speed drop as your vehicle recoils in reverse.

To return to Earth after your cosmic excursion, rather than using fuel to slow down you could do what the space shuttle does: glide back to Earth unpowered, and exploit the fact that our planet has an atmosphere, a source

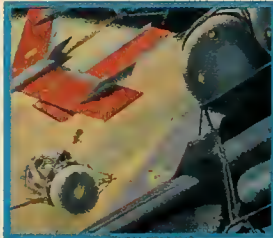
space shuttle were cremated in midair on the morning of February 1, 2003, as their orbiter tumbled out of control and broke apart during reentry. They met their deaths because a chunk of foam insulation had come loose from the shuttle’s huge fuel tank during the launch and had pierced a hole in the shield covering the left wing. That hole exposed the orbiter’s aluminum dermis, causing it to warp and melt in the rush of superheated air.

Here’s a safer idea for the return trip: Why not put a filling station in Earth orbit? When it’s time for the shuttle to come home, you attach a new set of tanks and fire them at full throttle, backward. The shuttle slows to a crawl, drops into Earth’s atmosphere, and just flies home like an airplane. No friction. No shock waves. No heat shields.

But how much fuel would that take? Exactly as much fuel as it took to get the thing up there to begin with. And how might all that fuel reach the orbiting filling station that could service the shuttle’s needs? Presumably it would be launched there, atop some other skyscraper-high rocket.

Think about it. If you wanted to drive from New York to California and back again, and there were no gas stations along the way, you’d have to drag along a fuel tank as big as a tanker truck. But then you’d need an engine strong enough to pull a tanker, so you’d need to buy a much bigger engine. Then you’d need even more fuel to drive the car. Tsiolkovsky’s rocket equation eats your lunch every time.

In any case, slowing down or landing isn’t only about returning to Earth. It’s also about exploration. Instead of just passing the far-flung planets in fleeting “flybys,” a mode that characterized an entire generation of NASA space probes, the spacecraft ought to spend some time getting to know those distant worlds. But it takes extra fuel to slow down and pull into orbit. *Voyager 2*, for instance—launched in August 1977—has spent its entire life coasting. After gravity assists from both Jupiter and then Saturn (the poor man’s



*The biggest problem facing any spacecraft is the need to boost the fuel required to transport the fuel it will burn later in the journey.*

mense external fuel tank that holds more than half a million gallons of self-combustible liquid; and two “solid rocket boosters,” whose two million pounds of rubbery aluminum fuel generate 85 percent of the thrust needed to get the giant off the ground. On the launchpad the shuttle weighs four and a half million pounds. Two minutes after the launch, the boosters have finished their work and drop away into the ocean, to be fished out of the water and reused. Six minutes later, just before the shuttle reaches orbital speed, the now-empty external tank drops off and disintegrates as it reenters Earth’s atmosphere. By the time the shuttle reaches orbit, 90 percent of its launch mass has been left behind.

Now that you’re launched, how about slowing down, landing gently, and one day returning home? Fact is, in empty space, slowing down takes as much fuel as speeding up.

Familiar, earthbound ways to slow down require friction. On a bicycle, the

of friction. Instead of using all that fuel to slow down the craft before reentry, you could let the atmosphere slow it down for you.

One complication, though, is that the craft is traveling much faster during its home stretch than it was during its launch. It’s dropping out of an 18,000-mile-an-hour orbit and plunging toward Earth’s surface—so heat and friction are much bigger problems at the end of the journey than at the beginning. One solution is to sheathe the leading surface of the craft in a heat shield, which deals with the swiftly accumulating heat through ablation or dissipation. In ablation, the preferred method for the cone-shaped Apollo-era capsules, the heat is carried away by shock waves in the air and a continuously peeling supply of vaporized material on the capsule’s bottom. For the space shuttle and its famous tiles, dissipation is the method of choice.

Unfortunately, as we all now know, heat shields are hardly invulnerable. The seven astronauts of the *Columbia*



propulsion mechanism), *Voyager 2* flew past Uranus in January 1986 and past Neptune in August 1989. For a spacecraft to spend a dozen years reaching a planet and then spend only a few hours collecting data on it is like waiting two days in line to see a rock concert that lasts six seconds. Flybys are better than nothing, but they fall far short of what a scientist really wants to do.

**O**n Earth, a fill-up at the local gas station has become a pricey activity of late. Plenty of smart scientists have spent plenty of years inventing and developing alternative fuels that might one day see widespread use. And plenty of other smart scientists are doing the same for the world of propulsion.

The most common forms of fuel for spacecraft are chemical substances: ethanol, hydrogen, oxygen, monomethyl hydrazine, powdered aluminum. But unlike airplanes, which burn fuel by drawing oxygen through their engines, spacecraft have no such luxury; they must bring the whole chemical equation along with them. So they carry not only the fuel but an oxidizer as well, kept separate until valves bring them together. The ignited, high-temperature mixture then creates high-pressure exhaust, all in the service of Newton's third law of motion.

Bummer. Even ignoring the free "lift" a plane gets from air rushing over its specially shaped wings, pound for pound, any craft whose agenda is to leave the atmosphere must carry a much heavier fuel load than does an airplane. The V-2's fuel was ethanol and water; the Saturn V's fuel was kerosene for the first stage and liquid hydrogen for the second stage. Both rockets used liquid oxygen as the oxidizer. The space shuttle's main engine, which must work above the atmosphere, uses 385,000 gallons of liquid hydrogen and 143,000 gallons of liquid oxygen.

Wouldn't it be nice if the fuel itself carried more punch than it does? If you weigh 150 pounds and you want to launch yourself into space, you'll need 150 pounds of thrust under your feet (or spewed forth from a jet pack) just to

weigh nothing. To actually launch yourself, anything more than 150 pounds of thrust will do, depending on your tolerance for acceleration. But wait. You'll need even more thrust than that to account for the weight of the unburned fuel you're carrying. Add more thrust than that, and you'll accelerate skyward.

**T**he space mavens' perennial goal is to find a fuel source that packs astronomical levels of energy into the smallest possible volumes. Because chemical fuels use chemical energy, there's a limit to how much thrust they can provide, and that limit comes from the stored binding energies within molecules. So, given those limitations, physicists and engineers have been looking into innovative alternatives.

After a vehicle rises beyond Earth's atmosphere, propulsion need not come from burning vast quantities of chemical fuel. In deep space, the propellant can be small amounts of ionized xenon gas, accelerated to enormous speeds within a new kind of engine. A vehicle equipped with a reflective sail can be pushed along by the gentle pressure of the Sun's rays, or even by a laser stationed on Earth or on an orbiting platform. And within ten years or so, a perfected, safe nuclear reactor will make nuclear propulsion possible—the rocket designer's dream engine. The energy it generates will be orders of magnitude more than chemical fuels can produce.

While we're getting carried away with ourselves, making the impossible possible, what we really want is the antimatter rocket. Better yet, we'd like to arrive at a new understanding of the universe, to enable journeys that exploit shortcuts in the fabric of space and time. When that happens, the sky will no longer be the limit.

[This is part one of a two-part article.]

*Astrophysicist NEIL DEGRASSE TYSON is the director of the Hayden Planetarium at the American Museum of Natural History. His latest book, co-authored with Donald Goldsmith, is Origins: Fourteen Billion Years of Cosmic Evolution (W.W. Norton, 2004).*

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# Life in Death Valley

*A tide of blossoms, in the wake of heavy storms, has grown into a big attraction.*

**D**eadly rains brought floods and mudslides to Southern California this past year, but the rains have offered amends: a profusion of spring wildflowers. In Death Valley National Park the bloom has been particularly spectacular. The predominant flower, a yellow beauty called desert sunflower, dressed up what is, more commonly, a relatively barren valley floor. The flowers created a kind of golden alluvium, marking where courses of rainwater had surged down the mountains just months before. The floral wash converged into a giant pool on the basin's floor—a sight to behold [see photograph at upper right].

Death Valley usually gets, at most, two inches of rain a year. From June 2004 until June 2005 about six and a half inches fell, reviving dormant flower seeds and leaving small lakes—where desert pupfish are having a boom year—in place of dry, salty flats. The flowers in turn have lured tourists in record numbers. Cars, RVs, and motorcycles will probably continue to line the roads through early June.

Yet visitors who venture into some of the sparser flower patches may be the most rewarded. There, among dry shrubs and rocks, are the more unusual buds. The chia, for instance, has exquisite flowers that look like mini-orchids unfolding from a pointed purple sphere. The desert five-spot has delicate petals that blow open in a breeze to reveal five blushing circles inside. [See photographs at lower right.]

The rain also brought with it a parasite known as toothed dodder [see photograph at left]. Its orange tendrils creep across the ground until they find a plant. Then the dodder snakes around its new host, grows into a large stringy mass, and ultimately chokes and kills its lifeline. Yet even the toothed dodder adds a bright color to this year's striking and unusual spring palette in Death Valley.

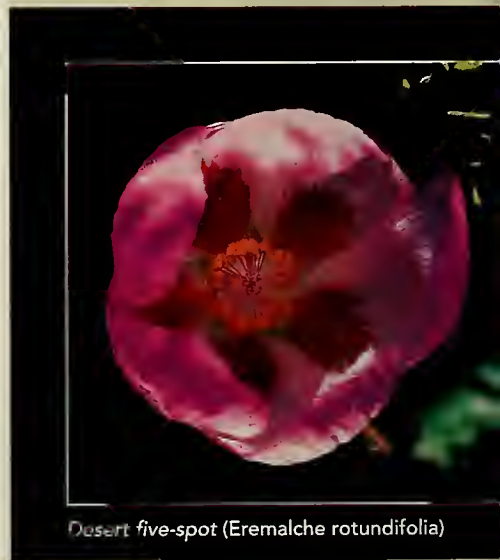
—Erin Espelie



Toothed dodder (*Cuscuta denticulata*), wrapped around desert lupine (*Lupinus sparsiflorus*)



Desert sunflower (*Geraea canescens*)



Desert five-spot (*Eremalche rotundifolia*)





Desert chicory (*Rafinesquia neomexicana*)



Chia (*Salvia columbariae*)



Scarlet locoweed (*Astragalus coccineus*)



# Snap!

*How can the Venus flytrap indulge its taste for insect flesh?  
The secret is the cunning construction of its leaves.*

By Adam Summers ~ Illustrations by Ian Worpole

**A**lthough plants are firmly rooted in the ground, they do move: sunflowers track the Sun across the sky; daffodils turn their floral faces away from the wind as it blows. Most plant motion is either quite slow (the sunflower), or driven by external factors (the wind on the daffodil). Herbal hustle caused by internal forces is uncommon. That's no surprise, really: plants have neither nerves nor muscles, nor do they have other obvious mechanisms for generating force rapidly.

Yet despite the lack of muscle, several plant lineages have independently evolved some capacity for rapid movement. The trigger plants of Australia, for instance, slap a dab of pollen on visiting bees. More morbidly, the Venus flytrap slams two halves of a leaf shut on nutritious insects. Recently, investigators discovered that the flytrap owes its quick grasp to a "bistable configuration" of its leaves, whereby small movements can trigger much larger ones.

**T**he Venus flytrap (*Dionaea muscipula*) is native to verdant, boggy coastal plains of North and South Carolina. Bogs are more acidic and have fewer nutrients than most plants can tolerate, and so it's no coincidence that several bog plants supplement their root-gathered nutrition with insect snacks. That makes a bog into a minefield for winged and walking arthropods. Bladderworts, pitcher plants, and sundews all in-



*Venus flytrap catches insects with a modified leaf. In the initial state (left), the two halves of the leaf curve away from each other. But a landing insect triggers the two halves to rotate slowly toward each other, making their convex curvature unstable. Suddenly, in about a tenth of a second, the curvature of the two halves becomes concave (right), the leaves snap shut, and the insect is trapped.*

dulge their carnivorous tastes. Among those refugees from the Little Shop of Insect Horrors, though, the flytrap has a uniquely dynamic method for catching prey.

The flytrap features a set of inch-long, heart-shaped capture leaves, each fringed with trigger hairs and bisected by a deep fold. Any insect unwary enough to bend a single hair is a goner. The two halves of the leaf snap shut along its fold in just 100 milliseconds, swiftly enveloping the animal. The trigger hairs become the bars of a prison. In the ensuing few hours the trap seals itself airtight, and digestive glands in the leaf secrete enzymes that reduce the insect to a dry husk.

Botanists discovered the Venus flytrap several hundred years ago, and

its behavior has fascinated people ever since. It may come as a surprise, then, that until recently no one knew how a flytrap, unthinking and without muscles, could move fast enough to capture flies. The mystery prompted Yoël Forterre, a physicist at the University of Provence in Marseille, France, and his colleagues to take up the case.

To improve visibility, the team began by daubing flytrap leaves with dots of paint that glows under ultraviolet light. Then they shot videos of the leaves closing, at 400 frames per second (a somewhat smaller video file, showing the action at 125 frames per second is available online at [www.nature.com/nature/journal/v433/n7024/supinfo/nature03185.html](http://www.nature.com/nature/journal/v433/n7024/supinfo/nature03185.html)).



Watching the videos in slow motion, and tracing the path of each painted dot in three dimensions, the investigators discovered that what appears to be a quick, fluid snap of the two halves of the leaf is actually a three-phase process.

In its initial, open configuration, the capture leaf looks like a paper-back book that has been splayed open by breaking its binding, and further insulted by bending its spine into an arc. The two halves of the leaf also curve away from each other; if you were to see them from the hapless insect's point of view, they would appear to be convex, with the center of each leaf toward you and the edges curving away.

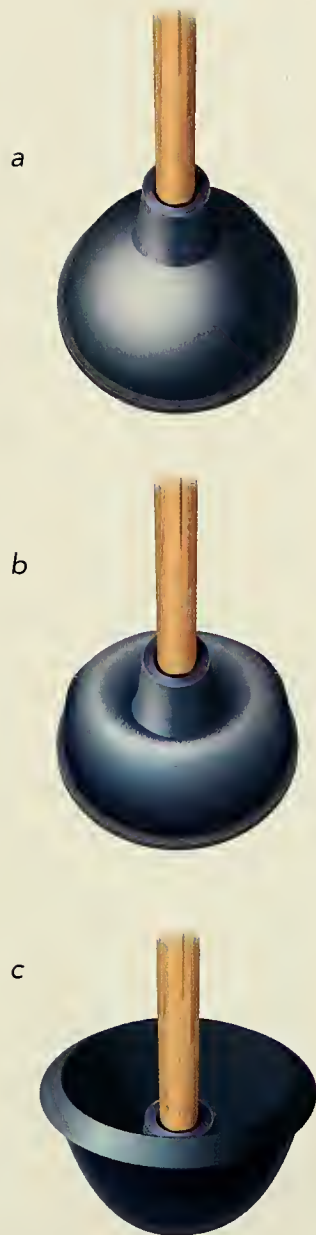
The first phase of the leaf closure begins when a trigger hair is disturbed. The capture leaf begins to close slowly for half a second or more, reducing the "gape" of the leaf by a few hundredths of an inch. As it does so, the spine straightens slightly, its curvature resisting the closure like a spring. The leaf halves retain their convex curvature even as they rotate slightly toward each other.

Suddenly the leaf crosses a critical threshold, and the second phase begins. The two halves buckle outward, into a new, concave configuration (again, from the insect's point of view), and the leaves snap shut.

During the third phase the leaf slowly continues to close. That process can last a long time; the trap keeps closing for hours and remains closed for days.

Because both the open, convex configuration and the closed, concave one resist any rotation of the leaf halves about the spine, both configurations are stable. The leaf is therefore bistable.

To get a better picture of the idea, think about the shape of a toilet plunger, or plumber's helper. Stored next to the toilet, a plunger is in a stable, concave configuration. When you use it on a clogged toilet, as long as you don't push too hard, the plunger



*"Bistable configuration" of a toilet plunger is a good analog to the basic working feature of half the leaf of a Venus flytrap. A plunger (a) can remain in its open configuration despite some pushing (b). If the plunger is pushed far enough, however, its curvature suddenly becomes reversed (c).*

is stable enough to spring back to its resting state. Push too hard, though, and the rim of the plunger will snap back along the handle, and the whole thing will buckle into a convex shape [see illustration above]. Then, unfortunately, you must flip it back by hand. Much the same effect drives the sud-

den closure of the flytrap. The closing pushes the structure to the edge of stability slowly enough that the hapless insect never notices. Then suddenly, in becomes out, out becomes in, and the prey is neatly trapped.

Earlier botanists had proposed that the flytrap, lacking muscles, relied on cellular water pumps called vacuoles to drive the leaf closure. That hypothesis had been met with some skepticism, because the change in leaf shape seemed to require that a large volume of fluid move rapidly from one place to another. Water-powered movement can drive slow motions, such as that of a sunflower tracking the Sun. But no one could see how cells could gain volume fast enough to close the flytrap.

Forterre and his colleagues, however, have demonstrated that fast pumping isn't needed. Just a small change in the shape of the leaf cells—which needn't be powered by a flow rate any higher than that of the water in and out of sunflower cells—can cause the trap to snap quickly. Pushed to the point of instability, the leaf halves are forced to buckle into a new shape. The continuing slow rotation of the leaf halves in the third phase is also consistent with a slow flow rate of water into the leaf cells.

The pretty yet creepy Venus flytrap illustrates a principle applicable to a variety of self-assembling structures. Take my self-erecting shelter for the beach. In its storage configuration it looks like several flat discs of nylon fabric. But when I grab one layer and shake it, the fiberglass supports suddenly reconfigure, and a two-person hut stands ready for use. The Venus flytrap makes me wonder how hard it would be to add low-force actuators to my sunshade—for rapid repacking or, with an unsuspecting person sitting inside, simply for entertainment.

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# Jointed Threads

*Joseph Leidy was the first to describe symbiotic bacteria growing together in long strings in animal intestines. Microbiological analyses now link the bacteria with anthrax.*

By Lynn Margulis



Joseph Leidy (1823–91), a Philadelphia naturalist, was well known in his day for independent, broad-ranging, and meticulous biological and geological studies. His scientifically accurate contributions remain widely known, even though his name is largely neglected by historians of science.

Anthrax, once upon a time, was a marginal disease in people, afflicting shepherders and few others. Most people who contracted it at all got the cutaneous form of the disease, which forms black scabs on the skin that look like anthracite coal (hence the name “anthrax”). But in autumn 2001, around the time of the terrorist attacks on New York and Washington, deadly anthrax spores began to be spread in letters mailed to news organizations and prominent government officials. Several people inhaled the spores and died from the much more deadly pulmonary form of the disease. Fear of the anthrax contagion was rampant. The very idea that small quantities of white powder in envelopes could be anthrax spores has changed post office practices to such a degree that they have adversely affected many citizens’ daily routines, including my own.

Anthrax spores became infamous as a potential weapon during the Second World War, when the British test-fired anthrax bombs on the Scottish island of Gruinard. The bacterium’s infectious spores spread across the island’s 520 acres and left Gruinard uninhabitable for nearly fifty years. Not until the late

1980s was the island decontaminated. The cleanup required four years of effort by a large crew, wielding almost 300 tons of formaldehyde—a sobering testament to the durability, both temporal and chemical, of anthrax spores.

What is still unknown, even after the island’s cleanup, is the bacterium’s ecology. Is anthrax just a kind of bacterial sit-and-wait predator, which bides its time until a sheepshearer cuts himself or a letter handler inhales a cloud of spore-laden dust? The anthrax bacterium is readily grown in laboratory culture. But where is it in nature?

*The anthrax bacterium is readily grown in laboratory culture. But where is it in nature?*

Our eclectic reading habits have helped my students and me disentangle one strand of the anthrax story. We recently discovered that a common laboratory bacterium, identical in all but the most trifling ways with the organism that causes anthrax, lives deep inside the intestines of many healthy animals. But the scientific story of anthrax does not begin with our work, or with the terrorist attacks of 2001,

or even with the episode on Gruinard. It begins in the field, on the ties of railroad tracks in the part of New Jersey that borders Pennsylvania, in middle of the nineteenth century. The central figure of the story is a Philadelphia naturalist named Joseph Leidy, once famous but now largely forgotten. Leidy was the first to observe our laboratory bacterium in its natural habitat, living in the intestines of animals.

Leidy’s scientific legacy affects everyone, yet he enjoys almost no posthumous reputation. A nineteenth-century polymath, who was initially trained as a physician, Leidy became one of his era’s greatest naturalists. He identified the nematode in undercooked pork that is responsible for trichinosis, a debilitating and sometimes deadly muscle disease. He described and named some 400 new species of North American animals, plants, and mushrooms and other fungi. He was the father of modern vertebrate paleontology in North America. He properly interpreted certain fossil remains found in the West as belonging to dinosaurs. Leidy worked tirelessly on the reconstruction of the history of the Earth’s surface by inves-



tigating metamorphic rocks and eroded minerals. He even discovered a thriving diversity of microscopic life adhering to fish scales, after he had admonished his fishmonger in the Philadelphia open market to neither damage nor remove them.

Exceedingly broad in his choices of nature's gifts to investigate, Leidy published some 400 scientific papers during a fifty-year career. All the papers are single-authored—not because he was uncooperative (there is much evidence of his generosity toward his scientific colleagues as well as his students), but because he was consistently ahead of his colleagues. As Leonard Warren makes clear in his recent biography, *Joseph Leidy: The Last Man Who Knew Everything*, the main reason the history of science overlooks his accomplishments relates to the breadth of his interests. Leidy's science could never be assigned to a single discipline. Yet his writings never generalize. Leidy stays so close to his own data that to those today who are looking to the past for overarching theories or gen-

eral principles, he seems to deal only with trivia.

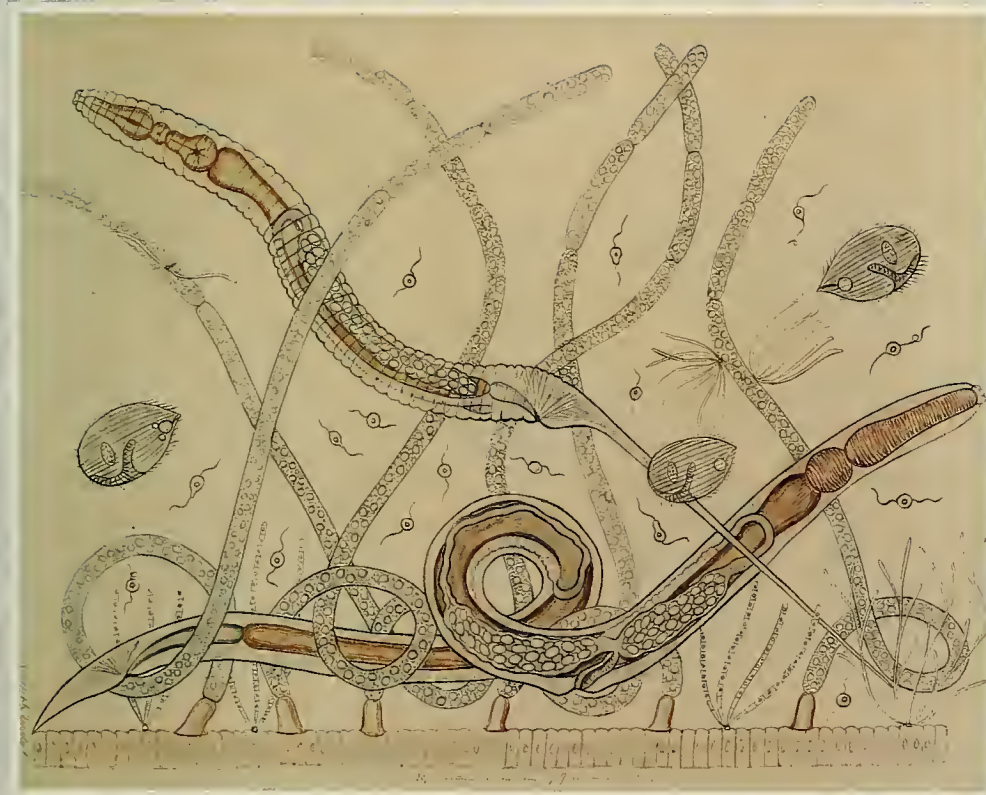
Today's neglect, however, contrasts sharply with the fame he achieved during his lifetime as a scientist, particularly in his native Philadelphia. A larger-than-life statue of him stands outside the city's Academy of Natural Sciences, and the building housing the biology department at the University of Pennsylvania bears his name. Several mountains in the western United States are also named for him. And he helped President Lincoln found the National Academy of Sciences.

In spite of Leidy's wide-ranging interests and activities, he was never away from his first scientific passion for long: the study of the microcosm. Warren conveys Leidy's boundless curiosity for the microworld by quoting a characteristic remark: "How can life be tiresome," Leidy asked, "so long as there is still a new rhizopod [amoeba] undescribed?" Leidy certainly never tired. The archives of the Academy of Natural Sciences in Philadelphia hold the delicate, accurate, even lovingly ren-

dered drawings of the microcosm that he made throughout his career.

One of Leidy's pleasures was to take long walks across the Delaware River from Philadelphia to New Jersey, where he would explore what were then isolated and bucolic landscapes along the railroad tracks. Next to the rail beds, Leidy observed with customary curiosity, were discarded ties beset with "white ants," as termites were then called. By contrast, he noted, in sound and sturdy ties the insects were seldom present. Leidy long wondered what the insects ate, because termites also occurred so often in teeming numbers in rotting logs and fences, where no obvious sources of food were present.

Leidy punctured the guts of the insects and examined the contents under his microscope. Amid liquid brown matter in the hindgut, he found the pieces of wood the insects had eaten. But his greatest astonishment came when he looked closely at the brown liquid: "[It was] swarming with myri-



Life within the intestine of the millipede *Julus marginatus* is depicted in a chart drawn by Leidy in 1888. The wall of the arthropod's intestine is shown along the bottom of the image as a horizontal row of epithelial cells (each cell is twelve micrometers high). Two nematodes, packed with eggs, are prominently depicted in partial longitudinal section. The four filamentous growths that look like small, leafless shrubs rooted in the intestinal wall are *Arthromitus*, as described by Leidy. Some of the segments, or cells, that make up the threadlike filaments of *Arthromitus* have mature spores inside them. The most mature spores, ready for release (one per cell) into the arthropod's intestine, are on the tips of the filaments. The branched *Arthromitus* at the far right lacks spores. Leidy's original chart measures six and a half by ten feet.



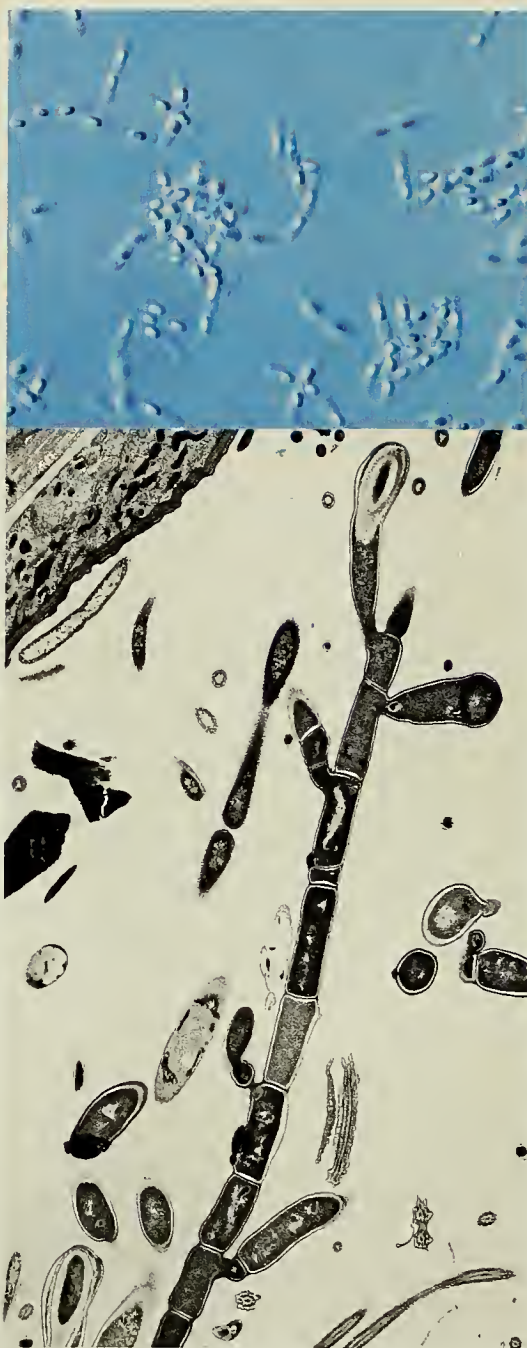
ads of parasites . . . wonderful in number, variety, and form." Watching this scene under the microscope, he later wrote, reminded him of "the turning out of a multitude of persons from the door of a crowded meeting-house."

The episode came to be one of Leidy's most abiding microbial discoveries. The myriad citizens in Leidy's jostling crowds turned out to be symbionts that are omnipresent in healthy termites. Leidy later discovered similar microorganisms in wood-eating cockroaches. In 1850 he introduced those intestinal inhabitants to the world of science, in a paper titled "On the existence of entophyta in healthy animals as a natural condition." Among the "entophyta" (literally "plants [living] inside") that Leidy discovered in the termite was a bacterium that, more than a century later, became the subject of our study.

A large teaching chart, completed by Leidy in 1888, shows the life-forms within the intestine of *Julus marginatus*, a millipede; the arthropod plays host, as Leidy by then had realized, to some of the same microorganisms as the New Jersey termites do [see illustration on preceding page]. In fact, as he recorded on the chart, he discovered bundles of long filaments, which he dubbed "jointed threads," in the intestines of a number of arthropods.

Leidy went on to depict and describe the development and propagation of shiny spherical bodies, or spores, along many of the filaments. He noted that mature spores are released into the digestive tract, and he suspected that from there they move through the intestines by peristalsis. It is now known that they are defecated into the soil, where they survive because of their high resistance to desiccation and heat.

But though the spores from the cells that make up Leidy's jointed threads spend part of their life his-



Arthromitus cells (blue micrograph at top), grown in laboratory culture from spores, are indistinguishable from rod-shaped bacteria in the genus *Bacillus*. The genus includes the bacterium that causes the disease anthrax. The Arthromitus cells are each about four micrometers long; inside them are spherical spores that, when mature, measure one to two micrometers across. An Arthromitus filament (electron micrograph above) is segmented; the high-power magnification of the electron microscope, unavailable to Leidy, shows that each segment is a single cell. Because such filamentous multicellular growth patterns are lost in laboratory culture, the segments in this image look quite different from the cells of cultured Arthromitus (top), and the difference shows why microbiologists fail to recognize Arthromitus as a stage in the life history of *Bacillus*.

tory in the soil, it is not useful to describe them as soil bacteria, because they do not grow in soil. To reach the next stage in their life cycle, they must be carried, ingested, or blown into some wet environment abundant with food: a clump of decaying vegetation in a farm pond, perhaps, or the intestine of another animal, or a petri dish of nutrient agar in a laboratory. If the spores reach such nutritious surroundings, they germinate; then, seizing the day, they grow and multiply quickly for as long as they are surrounded by enough air, food, and water to continue.

Leidy recognized from the outset that the spores of jointed-thread entophytes that occur in healthy organisms might be related to contagion. As he observed,

Contagious diseases and some others might have their origin and reproductive character through the agency of cryptogamic spores, which from their minuteness and lightness are so easily conveyed from place to place through the atmosphere by means of the gentlest zephyr.

The word *cryptogamic* (from the Greek *crypto-*, "hidden," plus *gamein*, "to marry") in Leidy's time referred to an archaic grouping of seedless plants (such as ferns and mosses), as well as to algae and bacteria (regarded as plants that lack flowers). Only two great groups, or "kingdoms," of living beings were recognized. If an organism was not an animal, it had to be a plant.

Given that dichotomous classification, it should be no surprise that Leidy described his jointed threads in the language of botany. The organisms tended to be "rooted" to the epithelium, or inside surface layer of cells, of the animal's intestine. Less frequently, they were rooted to one of the other intestinal inhabitants. They did not swim. They developed shiny spheres that he suspected



were “plant spores.” Clearly, then, the jointed thread was a plant. (Such a classification does not mean that Leidy failed to recognize his jointed threads as bacteria. It was just that they—and for that matter, all bacteria—were clearly not animals, and so they had to be plants.)

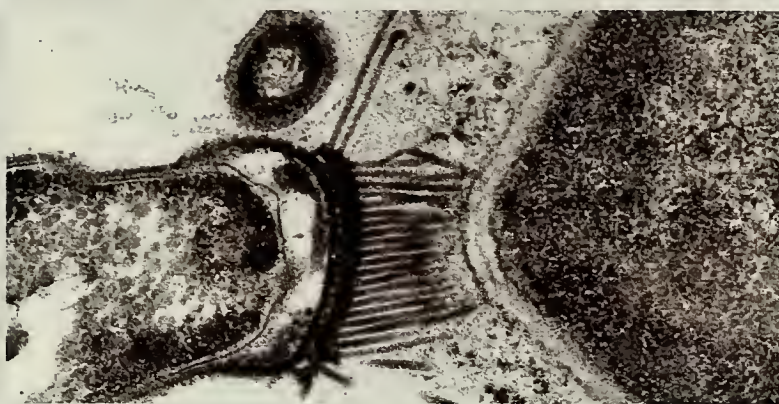
From various termite species, Leidy identified a series of related but distinguishable jointed threads, which he named *Arthromitus cristatus*. He classified the jointed threads from the common cockroach as a second species, *A. intestinalis*. After Leidy’s detailed scientific articles and drawings were published, such jointed threads were also discovered in the intestines of many other animals, including ducks and dogs. Jointed threads, it turns out, are “plants” inside intestines everywhere.

A century and a half after Leidy, my colleagues and I have often followed in his footsteps in our studies of the microbial communities in termites, wood-eating cockroaches, and a few other arthropods. On occasion, I have collected termites in Arizona south of Tucson, and was fortunate to examine what lives inside the Sonoran desert termite (*Pterotermes occidentis*). We keep termites in the laboratory, and we have often observed, with variations, just what Leidy depicted in his illustrations. We have even seen the same branching filaments that Leidy drew but did not name.

We were not the first, however, to reconfirm Leidy’s findings. In the 1940s, the protozoologist Harold Kirby prepared beautiful, permanent stained slides for the microscopic study of symbionts in the guts of termites. Kirby’s interest was in wood nymphs—protists that lack mitochondria, swim vigorous-

ly, and digest hefty wood fragments—but his slides include the same straight and branched *Arthromitus*-like filaments that Leidy’s drawings portray. Sixty years after Kirby, we, too, saw the filaments.

One nontermite host of *Arthromitus* that my colleagues and I examined in depth was the common sow bug, *Porcellio scaber*. Sow bugs form hordes in the warm, smelly monkey house where golden lion tamarins (*Leontopithecus rosalia*), native to Brazil, live at the EcoTarium in Worcester, Massachusetts. The sow bugs love to feed and breed under rocks and in other dark



Spore attachment fibers, the thin filaments at the center of the image in this electron micrograph, attach *Arthromitus* (left) to another microorganism, just as they usually connect the bacterium to the cells lining the gut walls of insects. Such fibers, characteristic of the *Arthromitus* in the Sonoran desert termite, tend not to be observed in laboratory cultures. The image, made by Bjorn Afzelius of Stockholm University, is magnified 52,000 diameters.

crannies where the monkeys scamper in that steamy enclosure. Jeremy Jorgensen, then a graduate student at the University of Massachusetts–Amherst, isolated *Arthromitus* from the sow bugs’ intestines with ease. Jorgensen’s simple but effective method of isolating the spores was simply to boil the intestinal contents of sow bugs continuously for at least twenty minutes. Among all the other intestinal bacteria, only *Arthromitus* spores survived the boiling.

Jorgensen also found *Arthromitus* filaments in the intestines of the tamarins. He figured out how the bacteria got there when he saw the sow bugs crawling over the tamarins’ food and defecating on it with abandon. The cycle of *Arthromitus* propagation was not

complete, however. How did the bacteria get into the sow bugs? Jorgensen, learning from the keeper of the monkey house that the noisy little primates simply did not produce feces any time after 8 A.M., visited the monkey house at dawn. Promptly as the sun rose, all the tamarins—with surprising synchronicity—dropped their feces at once. Jorgensen watched in amazement as sow bugs, thousands of them, emerged as one from their hiding places to ingest the tamarin poop almost instantly. Here was the completion of the life cycle: the “soil” bacteria enter the intestines of the insects and the mammals by the same route—their mouths.

Meanwhile, our work with the *Arthromitus* bacterium that occurs in termites continued. With the help of Frederick A. Rainey, a microbiologist at Louisiana State University in Baton Rouge, we sequenced the gene for the bacterium’s ribosomal RNA, and compared the sequences with other published ones. We measured many bacterial traits of *Arthromitus*, and we studied it with the electron microscope. Those data, along with the ribosomal RNA sequence, confirmed that *Arthromitus* is equivalent to a large, familiar, rod-shaped bacterium that is easily grown in the microbiologist’s laboratory: a harmless spore-forming microorganism known as *Bacillus cereus*.

Recognizing that *Bacillus cereus* is *Arthromitus* may be of interest to microbiologists, but the interest these days transcends the boundaries of the field. The genus *Bacillus* includes the anthrax bacterium, *B. anthracis*. No one had realized that *Bacillus*, the organism so commonly cultured and often considered a pest or contaminant in the laboratory, is essentially the same



organism to which Leidy had given the name *Arthromitus* in the wild. The rod-shaped bacteria cultured on an agar petri dish look quite different from the shiny spores and the cells that make up “jointed threads” in their native habitat—the digestive systems of healthy animals. Leidy’s work on *Arthromitus* is not so well known today, but modern science, and the rest of us, ignore it at our peril.

Part of the difficulty in making this connection, oddly enough, arose from the fact that, since 1980, practices with laboratory bacteria have been codified. The professional microbiologist may not describe and name a bacterium simply because it appears in nature—say, within an animal, on a plant or mushroom, or as a coating of hundreds on wood-nymph protists. According to the international rules of bacterial nomenclature, a microorganism must be described and named only in “pure culture.” In other words, the microorganism must be described as it lives and grows in a test tube, all by itself. Furthermore, two different pure-culture samples of bacteria must be banked in at least two different international culture collections.

The irony of those rules is that several features of the bacteria in the wild—their habit of assembling into filaments; their shorter, swimming filaments that pursue a docking site on the lining of the animal’s intestine; and the spore-attachment fibers [see image on preceding page]—tend not to form outside an animal’s intestine. Those accoutrements of symbiotic life are dispensable, and dispensed with, under laboratory conditions, as *Arthromitus*, the jointed thread that lives “in healthy animals as a natural condition,” becomes *Bacillus*, the test-tube bacterium in the service of microbiology.

The causative agent of anthrax, *B. anthracis*, differs from *B. cereus* (and, equivalently, test-tube *Arthromitus*) in one crucial respect: *B. anthracis*

is armed. *B. anthracis* is *B. cereus* with two or three additional plasmids: lengths of DNA formed into tight rings. The relation of *B. cereus* to *B. anthracis* is similar to that between a *Homo sapiens* by himself and a *Homo sapiens* with an inherited gun. Like the gun, the plasmids may be passed from parent to offspring. Their ammunition



Sow bug (also known as a wood louse or roly-poly) is a kind of land crustacean that lives in damp, warm places, especially under rocks and in logs. Sow bugs were collected from a monkey house by Jeremy Jorgensen. Their intestines, as well as those of the monkeys, were replete with *Arthromitus*. This false-color electron micrograph is magnified about nine diameters.

is simply the genes that code for a terrible toxin and for a coating that protects the bacterium carrying the toxin from the host’s immune system.

David J. Ellar of the University of Cambridge is an expert on the huge genus *Bacillus*. In addition to *B. cereus* and *B. anthracis*, many other members of the genus exist: oxygen-breathing, heat-resistant spore-formers. A large number of those walled, rod-shaped bacteria regularly associate with insects, mammals, or agricultural plants. Ellar heads a *Bacillus* genome project intent on obtaining a full sequence of bacilli other than *B. anthracis* to compare with that dangerous one.

After my student colleagues, including Jorgensen, Michael Dolan, Rita Kolchinsky, and Andrew Wier, identified *Arthromitus* with *Bacillus*, Ellar asked me to provide him with a sample of *Arthromitus* newly isolated from an in-

sect intestine. He wanted to examine the genome of a bacillus that had never been tamed by laboratory life. Unfortunately, a lack of research funding and other assistance made it impossible to oblige him, but we had a lively conversation. Ellar remembered once observing a culture of bacilli that had just been acquired for his collection. Examining the culture through a microscope, he had been perplexed by the little fibers he had seen growing on the spores.

After he read our *Arthromitus* papers, Ellar realized that in one new culture the spores had retained their attachment fibers, typical of wild *Arthromitus*. The culture probably had not been in the laboratory for long. I asked him where he had found the new strain. He looked through his extensive records and called back excitedly a few weeks later. The bacillus with the tiny fibers had been collected in the Pasoh forest of Malaysia. And yes, it came from a termite mound.

Leidy’s meticulous observation of live organisms, Kirby’s equally keen empiricism, and our comparative work have made it clear that *Bacillus anthracis*, the anthrax culprit, comes from a long line of symbionts in animal intestines. Those symbionts are filaments that live inside people, sheep, and various members of barnyard and wild animal communities. Without its two extra plasmids, the bacterium is harmless. It grows on mushy food both inside and outside the intestine. And when conditions deteriorate, it forms remarkably tolerant propagules—tough, even boilproof, shiny, spores by the millions that waft on air. If we are to be afraid of anthrax, as indeed we must be, we need to condemn those who would deliberately culture a bacillus that is armed with the dangerous plasmids that enable it to be a pathogen, a freak of nature, rather than a law-abiding citizen of the intestinal microcosm. □





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# Dance of the Sexes

*A lemur needs some unusual traits to survive in Madagascar's unpredictable environment.*

By Sharon T. Pochron and Patricia C. Wright

The group of lemurs, known as Milne-Edwards's sifakas, was small—an adult male, an adult female, and two large offspring. With only four animals, distinguishing them should have been easy. “That’s the male,” said Georges Rakotonirina, pointing. Rakotonirina was the lead field technician, a native of Madagascar who had been studying the sifakas with one of us (Wright) since 1986. “And that’s the female.” The novice among us (Pochron), new to the study in 2000, stared at the dark forms up in the tree and blinked. They all looked the same.

“Look,” said Rakotonirina. “They’re eating *vahia-banikondro*.”

“What?” Pochron thought to herself. “How can he tell from down here what they’re eating? And can I possibly learn to pronounce and spell . . . whatever it is?” Hearing chattering in the forest canopy, Pochron then asked aloud, “What bird is that?”

Rakotonirina laughed. “That’s the sifaka,” he said. “It means he wants to stop fighting.” Pochron knew then and there she had some catching up to do, notwithstanding her previous experience studying baboons in Tanzania. But like Wright and many others whose first encounter with lemurs was life-changing, she was hooked.

The lemurs of Madagascar are the surviving members of a lineage that has been genetically isolated from the rest of the primate family for at least 65 million years. The island became separated from the African mainland 160 million years ago, and from the Indian landmass 80 million years ago. The ancestors of lemurs probably colonized the island by rafting there on drifting vegetation. Until relatively recently, lemurs lived in a separate world. Meanwhile, primates elsewhere

evolved into monkeys, apes, and humans.

That ancient genetic split is surely one reason lemurs often boast such unusual traits, compared with humanity’s closer primate relatives. For example, dwarf lemurs store up fat in their tails and then draw on it while hibernating; in contrast, no monkey or ape hibernates. Members of one lemur family, the indriids, maintain an upright, kangaroolike posture as they leap from one tree trunk and cling to another; monkeys, however, are quadrupedal, like squirrels. All lemurs have toothcombs—a set of teeth ideally shaped for grooming; monkey and ape teeth are shaped for biting and chewing.

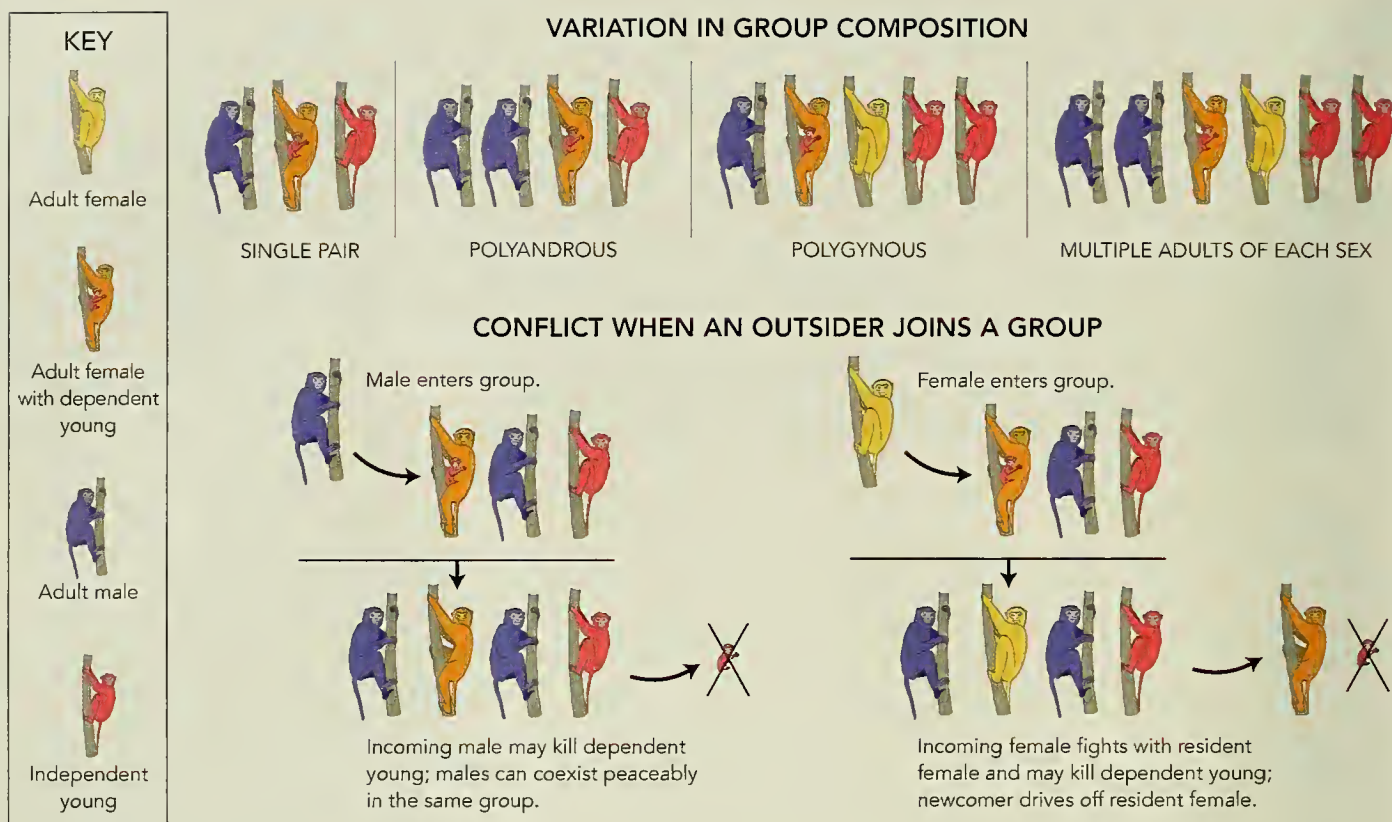
Especially surprising to evolutionary biologists, in most groups of lemurs, females are dominant over males. In some lemur species female dominance becomes manifest only in conflicts over food; in other species it emerges in all social settings. Yet in monkeys and apes—indeed, in mammals generally—female dominance is rare. What has led to such an unusual social characteristic among lemurs, with its far-reaching implications?

*Milne-Edwards's sifaka, one of the lemur species of Madagascar, lives in trees, mainly on a diet of fruits, leaves, and seeds. The species has been the subject of a long-term study by the authors.*



Female mammals that do dominate males are usually well equipped physically to do so. Female spotted hyenas are often bigger than males. Female





Composition of groups of Milne-Edwards's sifakas varies widely, and may shift from year to year within a single group, as shown in this schematic diagram. Groups range in size from two to nine individuals; as juveniles mature, many leave to join other groups. When an outsider tries to join a group, fighting may ensue, particularly between adult females.

reindeer rule over males during the short season when males have shed their antlers prior to growing new ones and the females have not yet shed theirs. Female golden hamsters call the shots when they are fatter than males.

But female lemurs are not usually larger than males, nor do they have any special weapons for enforcing dominance, such as bigger teeth. Members of the two sexes are virtually monomorphic, or similar, when it comes to physical strength. How do females manage to get their way without the brawn to back up a threat? We and our colleagues do not yet have a definitive answer to that question, but after eighteen years studying one indriid species, we have some inklings.

The center of our universe is the Milne-Edwards's sifaka (*Propithecus edwardsi*). Until recently it was considered a subspecies of the diademed sifaka, but geneticists have now determined that it is a separate species. Weighing in at about thirteen pounds and looking like something out of the Muppet studio, the animal lives throughout Ranomafana National

Park, a 170-square-mile emerald forest set in cloud-covered mountains, and in adjacent regions [see map on preceding page]. It has orange eyes and woolly, water-resistant fur (a useful trait in a rainforest), which is colored dark brown to black except for two large, white patches on the animal's back. The females have a lemony, maple-syrupy smell; the males, which have more glands for scent marking, smell muskier.

Active by day, Milne-Edwards's sifakas prefer to hang out some forty feet up in the trees, and they travel, as do other indriids, by leaping from one tree trunk to the next. Adults are mainly leaf eaters, but they also rely heavily on fruits and seeds.

Females and males do not often come into conflict, but when they do, the females win about 95 percent of the time. Apparently males are letting females win such altercations. What are they giving up by submitting? The answer may be calories. Adult females, for instance, appear to eat more seeds than adult males do. The difference is most pronounced during the mating season. Seeds are generally high in fat, and storing up fat is good preparation for a female on her way to becoming reproductively active. When you see males and females fighting, you will probably find tempting seeds nearby.

If males are allowing females to enjoy more seeds, what are they getting in return? The answers that



jump to mind are: sex and offspring. And that would make sense in evolutionary terms. Unfortunately for the theory, the annual estrus cycle of the female lasts only ten hours, and in that short period she may mate with several males. None of those mating males is likely to know whose baby the female is having. If he allows a female to take his food, and she uses it to raise another male's offspring, he has not helped himself at all. So why would he allow her to win extra calories? Nature is hardly known for its generosity. In our years of field observations seeking answers to this question, we have found ourselves bumping into some other unusual and fascinating lemur traits. Our goal, then, is to find a coherent explanation that makes sense of it all: with apologies to the high-energy physicists, our holy grail is a kind of grand unified theory of the lemur.

**M**ilne-Edwards's sifakas usually occur in small groups ranging from two to nine individuals. Typically, the groups include three adults (either two males and one female, or vice versa), infants, and older offspring. A female may come into her brief period of estrus at any time during the mating season, which runs from late November through mid-January. The babies are born in May, June, and July. A female gives birth to only one baby at a time, and nurses it attentively until the next mating season, if it survives until then. The cycle puts weaning at a propitious time, when food is most likely to be abundant. A mother that has nursed a baby that long is apt to skip a year before breeding again, most likely because it takes a while to store up enough fat.

Within a group of sifakas life is reasonably peaceful: members spend a lot more time grooming each other than they do squabbling. Males within a group get along most of the year. During the mating season, though, fights between males can be among the most aggressive in this species. There is little question that the fights are about sex, and the fact that fighters sometimes suffer injuries to their testicles

may be no accident. You can tell that a threatening look, a swipe, or a bite has had an effect if you hear the intended target emit birdlike chatter, the equivalent of, "Stop picking on me! I'll leave now!"

Since the males are clearly competing with each other for access to fertile females, it is puzzling that males have not evolved to be larger than the females (or to have bigger teeth or other such endowments). According to classic behavioral ecology, when males compete, the larger or stronger males usually prevail. The larger males thus have more offspring, and those offspring carry the genes associated with being large. After several generations the repeated selection for large males should lead to males that are larger than the females. When the males and females of a species differ in such physical characteristics, the species is said to be sexually dimorphic.

Most large mammal species are sexually dimorphic. Monomorphism, where it is found, typically occurs in monogamous species, in which a single male and female pair up to raise their offspring together. To succeed evolutionarily, monogamy has to be a two-way street. The male has the genetic incentive to help feed, carry, and protect the young of a particular female only if the monogamous bond assures him the young are his. If the female needs a devoted mate to help raise her young, she has a genetic incentive of her own—to avoid mating with a male that beats up other males, because, despite winning the "right" to take many "wives," he cannot offer parental care to all his offspring. When male fighting is suppressed by such female preferences, so too is sexual dimorphism. Some lemurs such as in-

*According to evolutionary theory, a male will assist a female—for example, by ceding disputed food to her—only if his action will increase the likelihood of perpetuating his own genes. At least one of the three social conditions outlined in the schematic diagram below must hold if males in future generations are to inherit his "altruistic" behavior. Males and females are represented by the shapes shown in the key in the diagram on the opposite page.*

Male assists a female that bears his offspring.



Their offspring carries half his genes.

Male assists his sister.



Her offspring carries, on average, a fourth of his genes.

Male assists a female that mates with him and several other males.



Her offspring may carry half his genes—or none at all.



dris (*Indri indri*) fit that pattern: they are monomorphic and monogamous [for a comparison of the indri with the diademed sifaka, see "Scent Wars," by Joyce A. Powzyk, April 2002].

Paradoxically, though, most lemur species do not behave like indris: they mate promiscuously, and males provide little or no care for infants, which may or may not be theirs. In short, they look like monogamous species, but they act like nonmonogamous ones. The Milne-Edwards's sifaka fits that pattern, too. But how can it be a stable arrangement?

Our observations offer part of the solution to the puzzle. First, no male, even if he is stronger than other males, can prevent a female from mating promiscuously. Nor does a larger male have the advantage of producing more sperm, because during the breeding season the testicles of all the males are roughly the same size. Thus the ejaculate of a heavy male cannot, as has been observed in some mammalian

*When a male joins a group of sifakas, he may kill any babies, a measure that speeds up his chance of fathering offspring.*

and avian species, overwhelm the ejaculate of a light male: if they both mate with a particular female, each has an equal chance to father her offspring.

Aside from the competition between males over females, serious fighting may also erupt when a new adult animal joins a group. Such transitions in group membership shed additional light on the roles of males and females—and, in particular, the dominance of females—within lemur groups.

Milne-Edwards's sifaka groups are far less predictable in composition than those of monkey and ape species. A baboon troop, for instance, characteristically includes many adult males and females. Gorilla groups are generally polygynous, consisting of one silverback male, his harem of several adult females, their young, and one or more subordinate males. By contrast, sifaka groups can be polyandrous (one female and two or more males) or polygynous (one male and two or more females). They can include multiple males and multiple females—or just one adult pair [see illustration on page 36].

Not only do all such combinations turn up with roughly equal frequency, but a group may change in composition from one year to the next. A new member is most likely to join a group from August until October, just before the mating season. If a new male seeks to join a group, all the animals may coexist peacefully. Sometimes, though, the resident male

and the newcomer fight, and one is driven away. And sometimes a female prefers the new male, and she may help force the old male to leave.

For any dependent offspring in the group, an incoming male poses great danger: he is likely to kill them, a measure that is evolutionarily adaptive because it speeds up his chance to father offspring. Such behavior is well documented in primates.

When an adult female tries to join a group, friction with the resident female seems inevitable. The two sometimes bite, slap, and chase each other. The resident female generally leaves, probably an indication that the incoming female has shrewdly judged her chances before attempting to gain entry. Just as males do, an incoming female may kill any dependent young. In other primates, at least, it is less common—and less easily explained as adaptive behavior—for the female to kill the young than it is for the male. The murderous action of the incoming female seems to hasten the departure of the resident female. When two adult females live together peaceably in a group, we suspect that they are closely related. Genetic studies currently under way should clarify this.

To investigate why the sifaka's social arrangements vary so widely, we compared sifaka survivorship and fertility patterns with those of some other primates. For example, tamarins and marmosets, both New World monkeys, suffer high mortality in their early years; sensibly, then, they reach sexual maturity and begin reproducing at an early age. By contrast, many Old World monkeys, such as baboons and macaques, live longer, start to reproduce later, and have more time between babies.

The mortality pattern of the Milne-Edwards's sifaka closely resembles that of the tamarins and marmosets: many die in their first few years of life. In fertility, however, Milne-Edwards's sifakas resemble baboons and macaques: the sifakas that do survive reach sexual maturity fairly late (about three and a half years for females, and four and a half years for males), and they reproduce at a slow rate over a span approaching thirty years. It is almost as if sifakas have deliberately chosen the most difficult of all the primate patterns ever observed: high mortality coupled with slow reproduction. By the end of her life, a female tamarin or marmoset will have three or four daughters; a baboon or macaque will have two or three. But by the end of her lifespan, a female sifaka will rarely have more than one daughter that survives to reproduce. The constraints on reproduction may be responsible for encouraging the sifakas' highly flexible group structures.

The sifaka's lifespan is unusual for a mammal its size. On average, the larger the species, the longer it lives.



As we noted earlier, Milne-Edwards's sifakas weigh about thirteen pounds, yet they live nearly thirty years in the wild. Such longevity may have evolved in response to unpredictable environmental conditions. After all, a longer life gives the animals a better chance of reproducing during the years when conditions are most favorable. It is hard to imagine that food could ever be scarce in a place such as Ranomafana National Park, where greenery covers every surface. Yet the availability of food varies seasonally, with the rain. Furthermore, Madagascar is prone to cyclones and droughts, which can also lead to shortages.

Perhaps here too is part of the solution to our original question about lemurs: why are females the dominant sex? The behavioral pattern, in which males cede food to females, appears essential for balancing female and male reproductive needs. For females, fertility, pregnancy, and nursing all depend on sufficient body weight. Weight is less important for males, because their reproductive role is limited to copulation and, as we mentioned earlier, during the breeding season, the testes of small-bodied males are the same size as those of larger-bodied males. If the males did grow larger overall, Madagascar's unpredictable environment might prove fatal to them. In sum, neither having a small body size nor relinquishing high-calorie foods to females seems to compromise the fertility of males.

In the past few years we have considered a number of ways to account for these observations. Because the females mate promiscuously, perhaps each male simply defers to all females, on the grounds that there is always some chance that one of them will bear his offspring. Or a male may yield food to a female only when he has some good reasons for thinking he will sire her offspring. Or a male may defer to a close female relative (mother, sister, daughter), whose offspring would indirectly share some of his genes. Or maybe the reality is some combination of all those factors [see illustration on page 37].

One way to learn more about what is going on is to test offspring for paternity. Toni Lyn Morelli, one of Wright's graduate students, has been sampling blood of these sifakas and analyzing it genetically. In a species where the average number of adults in a group is three, however, discerning a statistically significant pattern may take some time. And—who knows?—the results may lead us to some new lemur mystery. □

*Milne-Edwards's sifakas, like other lemurs in the indriid family, usually cling to trees in an upright position and leap from one trunk to another in this posture, instead of jumping in a four-footed, squirrel-like fashion, as arboreal monkeys do.*







## Behind Closed Doors

*Wielding a vintage camera, a photographer explores the storerooms and back-room cabinets of a great natural history museum.*

Photographs by Justine Cooper

Many of us have gleefully rummaged through a grandparent's attic with an eye for lost treasure. The objects we found often brought the past to life. Now imagine an attic with more than five acres of floor space, crammed with treasures dating to millions of years in the past and replete with "crawl spaces" high enough for dinosaurs and mammoths to stand upright.

Beginning in 2003 the artist Justine Cooper was granted access to one of the great "attics" of the world: behind the scenes at the American Museum of Natural History in New York. The museum is the repository for a staggering 32 million-plus specimens and other objects, distributed throughout a mazelike warren of twenty-five buildings, with as many as eleven floors. Most items are stored in metal cabinets, some with multiple drawers, others adapted to the odd shapes of their occupants. But specimens also reside in glass



Mold of polyester resin and silicone, of a *Homo ergaster* female, upper photograph, appears to flee Justine Cooper's camera in this view of an anthropology store-room in the American Museum of Natural History in New York City. Drawer of luna moths, lower photograph, sparkles with variations among the individuals.





*Clockwise from above right: a corridor of storage cabinets in the department of herpetology; a line of yellow honeycreepers in a collection drawer; common horn sharks from waters off the coast of California, preserved in alcohol; and a row of elephant skulls, collected in the nineteenth century, each weighing about 150 pounds.*







*Clockwise from upper left on these two pages: taxidermied polar bear specimen awaits its turn outside a freezer, where it will get antivermin treatment; Australian grouper skeleton dominates a storage room in the ichthyology department; racks and trophy heads of various ungulates populate a room in the mammalogy department; a drawer in the entomology department holds some of the galls collected by the zoologist (and pioneer in the social study of human sexuality) Alfred C. Kinsey.*

jars of ethanol, in nitrogen-cooled stainless steel tanks, in freezer chambers—and even in the open, in offices and along corridors. (At any one time, less than 1 percent of the collection is on display in the public areas.)

Cooper appropriated an item that was itself part of the collection, a 1910 Korona View camera, to recapture the treasures of the museum's storerooms and back-room cabinets. With it, she could offer the modern public at least a vicarious view of the museum's hidden wonders.

For more than a year Cooper visited every department of the museum and shot more than a hun-





dred images. Each image, focused razor-sharp, was recorded in detail on a four-by-five-inch negative.

Cooper was drawn again and again to the drawers upon drawers of insects, which comprise more than 45 percent of all the items in the museum's collection. In addition to millions of insects pinned in drawers and millions more preserved in alcohol, the museum boasts an important research collection of insects fossilized in amber. Among the many naturalists whose collections made their way to the museum is that of the American zoologist Alfred C. Kinsey, best known for his pioneering studies of human sexuality; here resides his unparalleled trove of more than 5 million wasps and galls. Particularly fascinating for Cooper was that each grouping—luna moths pinned in neat rows, elephant skulls all in a line, a jumble of sharks in a jar of alcohol—was a constant reminder of nature's endless variation.

Unlike your typical grandparents' cherished keepsakes, the items in the museum's collection—as in the collection of any natural history museum—were not stashed behind the scenes because they had outlived their usefulness. Quite the contrary. They serve as a library of life and nature from which humanity learns ever more about our world.

—Mary Knight





# Why Do Cave Fish Lose Their Eyes?

*A Darwinian mystery unfolds in the dark.*

By Luis and Monika Espinasa

Sometimes, when we lead students or beginning cave explorers into their first “wild” cave, we turn out all our lights at our first rest stop. For many people, the experience of total darkness is stunning, and even a bit overwhelming. Wave a hand in front of your face, and you see nothing. Yet other senses seem to come alive. If the cave is wet, you can hear the drip, drip, drip of water across the chamber. You can smell the earth and damp air as the cave “breathes.” As you grope for the comforting switch on your electric headlamp—or the flint lighter of your

The loss or degradation of a trait through time is known as regressive evolution. But why is loss so fascinating, and so important to understand? Textbooks tend to focus instead on “constructive” evolution and the development of new or modified structures. A student of biology is bound to learn about the development of such novelties as legs in amphibians, hair and mammary glands in mammals, and the large, complex brain in higher primates. What the student probably does not realize is that for every new development, in all likelihood, something was sacrificed. The gills, scales, and tails that were lost by the ancestors of amphibians, mammals, and higher primates are just a few cases in point.

So why do cave fish lose their eyes? We ask the reader to stop for a moment and ponder this riddle. Whenever we pose the question to our students in introductory biology classes, one of them invariably responds: “It’s obvious, isn’t it? Caves are dark. Cave fish don’t use their eyes because they can’t see in the dark.”

Oops, wrong. That would be a Lamarckian answer. Poor Lamarck! The French naturalist Jean Baptiste Pierre Antoine de Monet Lamarck, a pioneer of evolutionary thinking in the late eighteenth and early nineteenth centuries, is often ridiculed for his theories of use and disuse and his belief in the inheritance of acquired characteristics. In academia, being called a Lamarckian is less than flattering. But if you, like our students, came to a Lamarckian conclusion, you’re in very good company. The question of eyelessness in cave fish is, and was, so challenging that it baffled even Darwin. The co-founder of the theory of evolution by natural selection gave an explanation that was, in the end, remarkably Lamarckian. Even

*In evolution, “use it or lose it” does not apply.*

carbide lamp—your spatial sense, or proprioception, becomes keen and alert. If you leave the lights off for a few minutes, you might even begin to “see” how, with patience, you could learn a lot about your surroundings—and perhaps move about (if there are no deep pits nearby!) without the sense of sight at all.

Many species, of course, have lived in the total darkness of the underground for millennia, functioning perfectly well without vision. In fact, scores of troglomorphic (cave-living) animals as diverse as crustaceans, insects, salamanders, and spiders have lost their eyes in the process. More than a hundred species of fish living permanently in caves around the world are blind or have some degree of eye degeneration. To a biologist, those facts are fascinating—and deeply perplexing. With eyes and without eyes, a fish can see no more than you can in the perpetual darkness of a cave. But why lose them? What’s more, since so many species of cave-dwelling fish, not at all closely related, have lost their eyes, the phenomenon seems to be neither an accident of evolution nor an isolated event.

*Underground environment of a cave is often a place of abundant freshwater and nearly constant temperatures, but little or no light. Around the world more than one hundred species of fish have adapted to life in the cave environment, often in quite subtle ways. Underground waterfalls such as the one in the photograph are quite common in caves; this one is located in Gaping Gill Cave, in North Yorkshire, England.*







today, the question has no definitive answer—though several fascinating lines of research suggest a genuinely Darwinian resolution is within sight. But the complexity and sophistication of the efforts that have

rates of survival and reproduction skewed the giraffe population toward animals with elongated necks. The key to the mechanism of Darwinian evolution is natural selection.

“We desperately need our exercise and beauty treatments, so we can have bodies like Brad Pitt and Salma Hayek,” we joke with our students. “We’re certain they will greatly enhance our fitness. Yet regardless of our needs and all our efforts, our children have not inherited those characteristics. Please,” we urge the students, “see if you can come up with a Darwinian mechanism to explain why cave fish lose their eyes—one that involves natural selection.”

So how did Darwin slip into Lamarckism? Cave organisms are ideal models to support Darwin’s idea of natural selection. In the dark, organisms with the more acute sensory organs should survive and reproduce preferentially. Hence, with time, the population should evolve such characteristics as longer antennae, longer legs, and additional organs rich in sensory receptors—just as, in fact, they do. Nevertheless, Darwin was stumped over just how the

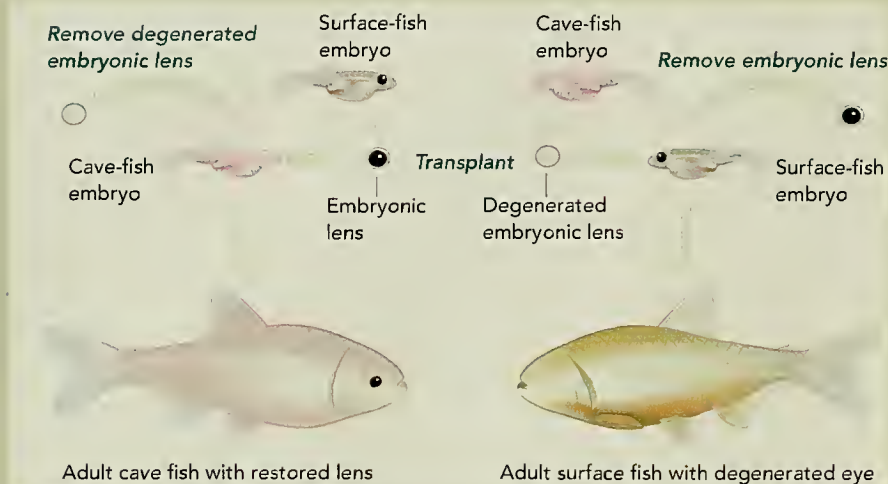
same kind of mechanism could work for regressive evolution. Reluctantly, he invoked disuse:

By the time that an animal had reached, after numberless generations, the deepest recesses, disuse will on this view have more or less perfectly obliterated its eyes, and natural selection will often have effected other changes, such as an increase in the length of the antennae or palpi, as a compensation for blindness.

But that conclusion irked Darwin. He continued, no doubt in frustration, and fell back on a Lamarckian explanation: “It appears probable that disuse has been the main agent in rendering organs rudimentary. It would at first lead by slow steps to the more and more complete reduction of a part, . . . as in the case of the eyes of animals inhabiting dark caverns.” Although Darwin found that conclusion unsatisfactory, in the end, he admitted defeat:

It is scarcely possible that disuse can go on producing any further effect after the organ has once been rendered functionless. Some additional explanation is here requisite which I cannot give.

Can biologists today do any better? In a cave, what advantage, if any, does a fish without eyes have over a fish with eyes? Our students typically



*Lens-transplant experiment by William R. Jeffery and his colleagues, carried out with cave and surface varieties of the tetra fish (*Astyanax mexicanus*), showed that despite the degeneration of the eyes in the cave fish, most of the genes involved in eye formation remain fully functional. The diagram outlines the primary experimental steps of the twin transplant. Two months after the transplants the corneas, irises, and lenses of the cave-fish eyes were restored, and the surface fish had highly degenerated eyes.*

been needed to reach this resolution show how, at times, a simple question can open up penetrating new leads into the labyrinth of evolutionary theory.

When biology textbooks describe the mechanism Lamarck proposed for evolution, they unfailingly invoke his explanation of neck length in giraffes: Giraffes have long necks, Lamarck maintained, because their forebears were continually stretching to reach the highest leaves in trees. The desire to reach higher leaves led to longer necks, and later on, the giraffes’ offspring inherited that physical trait. Similarly, Lamarck believed, unused organs shrivel until they disappear. In short, use it or lose it.

Darwin told the story quite differently. A Darwinian explanation assumes that neck length has always varied among the individuals in a giraffe population. In the past, the giraffes with the longest necks reached the highest leaves, which were more abundant, and may have held more nutrients than the lower leaves, but were inaccessible to shorter-necked giraffes. Overall, then, the longest-necked animals were the best-fed members of the population. Better nutrition translated into longer or healthier lives, and so longer-necked giraffes produced more offspring than shorter-necked giraffes. With time, differential



bring up efficiency and the idea of conserving energy. Maybe blind fish do not have to waste valuable energy on making useless eyes.

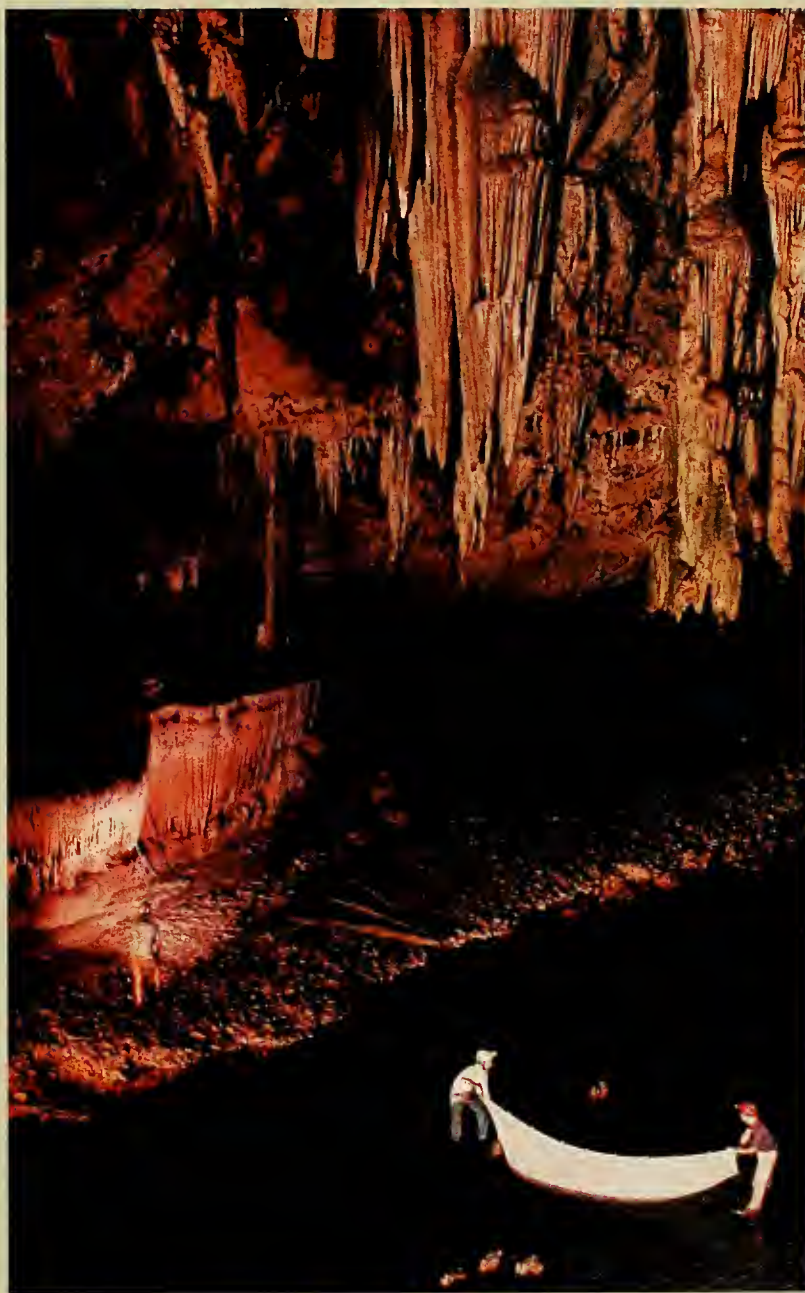
Yet that explanation won't work either. The energy needed to make an eyeball, which is basically a globule of protein that encapsulates some water, is probably much less than what is needed to make the plug of fat and bone that covers the same space in blind cave fish. As every dieter knows, there are more calories in a gram of fat than in a gram of protein, and even more calories in fat than in water. Growing a complex structure such as the vertebrate eye seems to require less energy than growing a fatty plug over a degenerated eye. Complexity is not always synonymous with energy expenditure.

Biologists today endorse two principal but competing hypotheses to account for the evolution of degenerated eyes. The first hypothesis assumes that the loss of eyes somehow enhances the efficiency of neural processing or reshapes the fish's morphology and physiology to better suit a life of total darkness. As a consequence, natural selection drives the regressive evolution.

The second hypothesis is that genes controlling the development of unnecessary structures become effectively neutral. Once the genes neither enhance nor hinder the organism's survival, the forces of natural selection that once maintained those genes in good working order no longer operate. The genes accumulate mutations that impair their function, and so the unnecessary structures governed by the genes degenerate. That view is summed up in the phrase "neutral-mutation theory."

Biologists favoring the first hypothesis face the problem of having to come up with an advantage for losing one's eyes. One of the best ways to address this kind of puzzle is to look for instances of pleiotropy, a known and common phenomenon of genetics. Pleiotropic effects are the multiple, often seemingly unrelated characters caused by a single gene.

One of the best-documented cases of pleiotropy is the gene associated with sickle-cell disease. In the red blood cells of people carrying the gene, mutant hemoglobin molecules stick together to form rodlike bundles that deform the red blood cells into the shape of a sickle. People with sickle cells often suffer chronic anemia, extreme pain, and organ damage. At the same time, however, the parasite that causes malaria cannot thrive inside red blood cells that carry the altered hemoglobin, and so people with the



Cave fish are netted for further study from a cave in northern Thailand by one of the authors (Luis Espinasa) and the cave biologist Richard L. Borowsky of New York University.

mutant gene show enhanced resistance to malaria. The malaria resistance conferred by the sickle-cell gene is a pleiotropic effect. In spite of its harmful effects, the gene persists among human populations in parts of Africa with a high incidence of malaria. Similarly, if the genes that control eye degeneration in cave fish also control other, unrelated structures that could confer an advantage to fish living in darkness, pleiotropy could explain the loss of eyes.



What about the second hypothesis, neutral-mutation theory? Mutations occur in all living organisms and in all genes. Natural selection, though, exercises quality control over genes. If a fish living in a surface stream suffers a mutation harming its vision, it is more likely than its sighted fishmates to die of hunger or to be eaten by predators. The decreased fitness often leads to early death or a low rate of reproduction, thus eliminating the harmful mutation.

According to the neutral-mutation theory, however, if a genetic mutation leads to blindness of an eyed fish living in a cave, the fish will have no advantage or disadvantage over other eyed fish in the cave. The mutation will simply remain in the population. As more and more such mutations accumulate, the entire population will become blind.

A new generation of molecular and developmental biologists have been tackling the issues raised by such questions for several years. Horst Wilkens of the Zoological Institute and Zoological Museum of the University of Hamburg in Germany and Richard L. Borowsky of New York University have been working with both cave and surface varieties of the tetra fish, *Astyanax mexicanus*. They have mapped the genes in both cave and surface fish that control eye size, pigment loss, and condition factor (a polite term for “fatness”). Caves, in general, are food-poor environments, and cave fish have evolved a highly efficient metabolism that enables them to survive on fewer calories than their surface counterparts need.

The gene mapping showed that at least three genes, on three distinct chromosomes, affect eye development, though the exact roles of the genes are still unknown. Borowsky and Wilkens also discovered that one of those genes is closely linked to a gene that regulates metabolic rate (it is even possible, though unproved, that both eye development and metabolism are affected by one gene). Because of the linkage, it is possible that a genetic mutation that improves me-

tabolism could also harm eye development, or be linked to a gene that does. The linkage therefore provides a clue that pleiotropic (or pleiotropic-like) effects might account for the regressive evolution of cave-fish eyes.

A second group of investigators, led by William R. Jeffery, a biologist at the University of Maryland in College Park, has taken great strides in unraveling the history of blindness in *Astyanax*. In 2000, workers in Jeffery's laboratory transplanted an embryonic surface-fish lens into the optic cup, or eye socket, of a cave-fish embryo, and, conversely, transplanted a cave-fish lens into a surface-fish embryo [see illustration on page 46]. Two months later, the surface fish with a transplanted cave-fish lens had a highly degenerated eye. At the same time, the cave fish previously doomed to eyelessness possessed a large eye with a restored cornea, iris, and lens. Because cells that make up different parts of the eye come from different embryonic tissues, the transplanted lens must have activated genes in the cave fish's own cells.

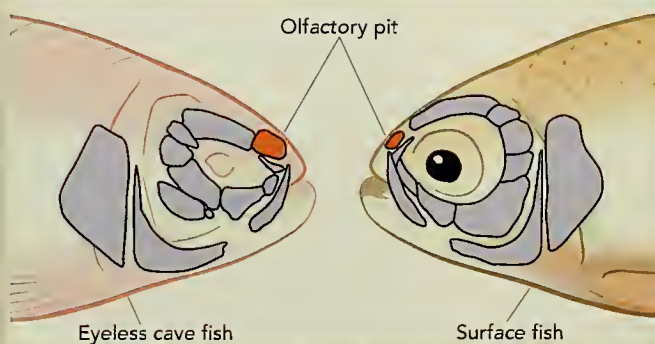
The significance of their finding cannot be overemphasized. For one thing, it gives no boost to the neutral-mutation theory of blindness in cave fish. Recall that, according to the theory, all genes not being expressed—that is, used as a template for making proteins in the cell—should be accumulating mutations and degenerating. But Jeffery's research showed that, even after tens of thousands of years of

evolution in caves, most *Astyanax* genes that play a role in eye formation remain perfectly functional.

Blindness in *Astyanax* seems to be caused instead by mutations in a small number of master switches that control other genes and proteins necessary to the development of the eye. Jeffery and his colleagues have isolated one of those master-control genes, a gene known as *Hedgehog*, or *Hh*, whose

modified expression leads to blindness in cave fish.

Not all the possible pleiotropic effects of *Hh* in cave fish are known, but suggestive scenarios abound. The *Hh* gene controls not only the size of the eyes, but also the development of teeth, taste buds, the an-



Configuration of the bones surrounding the eye socket of the tetra fish (*A. mexicanus*) depends on the presence or absence of eyes. According to work by one of the authors (Luis Espinasa), in the cave variety of the fish, where no eye is present, the olfactory pit is 13 percent wider than it is in the surface fish, thereby enlarging the area available to sensors for smell. The size differences of the olfactory pits of the two fish in the diagram have been exaggerated for clarity.





Eyelessness is the common trait of a wide range of cave-adapted animals. The painting, by John B. Sibbick, portrays a representative sample, though not all to the same scale. They are (clockwise from upper left): an olm, or proteus (*Proteus anguinus*), an underground freshwater amphibian, which grows as long as twelve inches; a one-half-inch-long water louse (*Cirolanides texensis*); a tetra fish (*A. mexicanus*), which grows to about four and a half inches long; and a Texas blind salamander (*Eurycea rathbuni*), which grows to about five inches long.

terior part of the brain, and other craniofacial structures. Most intriguingly, *Hh* has an inverse effect on the development of eyes and taste buds: the smaller the eyes, the more taste buds are produced, which undoubtedly lead to an enhanced sense of taste.

Collectively, we have worked with blind cave organisms for more than eighteen years, and one of us (Luis Espinasa) was working with blind cave fish in Jeffery's laboratory shortly after the publication of the momentous work on lens transplants. At the time, Espinasa's research was focusing on the bones surrounding the eye socket in cave *Astyanax* and how the bones are modified by the presence or absence of eyes. He noted that when a fish develops without eyes, the bones are shifted into the empty socket space, deforming the entire skull. Part of this deformation includes the bones of the nose. The width of the olfactory pit in blind fish increases on average by 13 percent, thus enlarging the surface of the olfactory epithelium, where the chemical receptors are lodged [see illustration on opposite page].

Could the larger size enhance the blind fish's sense of smell? It is very likely, and we view the trade-off as a beautiful example of a pleiotropic effect. A mutation causes eye loss in cave fish, which consequently deforms the skull. In turn, the deformation enhances olfaction. Natural selection is not acting on cave-fish eyes; it is acting instead to increase the fish's sense of smell.

Olfaction is probably not the end of the story; other effects have surely been at work in the evolution of the blind cave fish of the world. According to one of our favorite theories, there is a kind of pleiotropic trade-off of neurological con-

nections in the brain. After all, the neurons of many non-troglobitic organisms, such as cats and mice, have a certain inherent plasticity, which may depend on age. In newborn kittens, for instance, neurons of the visual cortex are activated and connected to both eyes. As development progresses, however, some neurons become sequestered, forming networks that can process information only from either the right eye or the left eye. If one eye is removed, or simply covered with an eye patch, more neurons join the network of the eye being used. In short, more neurons are applied to the most frequently used networks, making the brain more efficient.

Could something similar be happening in cave fish? Electrodes inserted into the visual cortex of eyeless cave fish show that their "visual" neurons actively respond to tactile stimuli, not visual ones. Do eyeless fish in caves develop a more efficient neural network than eyed fish living in the dark? We think the answer is yes, because functional eyes in darkness do not stop sending information to the brain: "I detect no light. I detect no light. I still detect no light." If there are no receptors, however, the neurons can be fully recruited and sequestered by other systems, making the brain as a whole work more efficiently.

There is evidence that blind people develop above-average abilities in specific tasks related to hearing or to touching. There is also anecdotal evidence that sighted people have keener nonvisual senses when they cannot see—remember how the nonvisual senses seem to come alive in a cave when the lights go out? Would blind people reorganize their neural networks better than eyed people, if both groups began living in the dark or inside a cave? That is a question our students, and readers, will have to ponder. □



*The Fly in the Cathedral:  
How a Group of Cambridge  
Scientists Won the International  
Race to Split the Atom*  
by Brian Cathcart  
Farrar, Straus and Giroux, 2005;  
\$25.00

For a man who admits he never took a class in physics, Brian Cathcart certainly knows how to turn great science into arresting drama. The scene is the Cavendish Laboratory in Cambridge, England, in the late 1920s. Scientists, just beginning to unlock the secrets of the atom, had been astonished almost two decades earlier by the discovery that matter is mostly empty space; orbiting the nucleus of each atom, like a system of miniature moons, is a cloud of electrons, particles with negative electric charge.

The seminal figure who had first proposed the existence of a dense atomic nucleus was Ernest Rutherford, an inventive, New Zealand-born physicist. In 1909, while at the University of Manchester, he devised a plan to bombard gold atoms with alpha particles, or positively charged bits of matter emitted by the radioactive element radium, and then watch what happened to the alpha particles after they penetrated the material: How often did they hit something solid, and how often did they pass straight through? Day after day, a student in Rutherford's laboratory stared through his eyepiece, tallying the faint flashes of light that signaled the arrival of an alpha particle recoiling off something very dense in the gold atoms—the nuclei.

By the late 1920s, most of the mass of the atom was known to reside in the positively charged nucleus at its center, a kernel a hundred thousand times smaller than the atom itself. It had been tough going to probe this far into the atom, yet the success of the efforts, it seemed, only deepened the mystery:

Was the nucleus a single particle or, like a nested Russian doll, was it only the threshold of further nanoworlds within?

Rutherford knew that alpha particles, which readily pierced the atom's cloud of electrons, didn't have enough energy to penetrate and pry apart the nucleus. Since the probe particles bore a positive charge, just like the nucleus, the probe and the nucleus repelled each other. What was needed, Rutherford realized, was a way of accelerating the



Trio that first split the atom: Ernest T.S. Walton (left), Ernest Rutherford (center), and John D. Cockcroft, May 1932

particles to ultrahigh speeds, so that they would slam through the electric barrier that walled off the nucleus from like-charged intruders.

Rutherford assigned the task to two young Cavendish Laboratory physicists, Ernest T.S. Walton and John D. Cockcroft—the heroes of Cathcart's story. Although atoms are minuscule, Rutherford's protégés knew that any device that could shoot particles into an atomic nucleus had to be physically huge: the charged particles would have to be propelled by special guns powered not by black powder but by millions of volts of electricity. As their research progressed, Cockcroft and Walton's laboratory began to fill up with industrial-strength transformers and pumps that might have looked more at home in a Manchester mill than on the venerable Cambridge campus.

Cathcart's drama is leavened by colorful characters popping in and out of the narrative, most notably the Rus-

sian-born American physicist George Gamow. A practical joker and raconteur, Gamow not only played Falstaff to the Cavendish crew, but he also made the crucial calculations of the voltage needed to crack the nucleus. And the team's race for scientific glory had all the usual obstacles: equipment breakdowns, blind alleys, competition from other groups of physicists. The struggle reached its climax in April 1932, when, after several years of repeated experiments, high-voltage protons from Cockcroft and Walton's accelerator penetrated the nuclei of lithium atoms, splitting the nuclei in two. "The Atom Split," the newspapers proclaimed—and the rest is history.

Cockcroft and Walton won the 1951 Nobel Prize in physics, a recognition not only of a great leap in understanding nature, but also of a fundamental change in the research enterprise. Gone are the days when you could investigate the atom on a tabletop. The mysteries of the atomic nucleus are now being explored by accelerators that encircle areas as large as Swiss cantons, with annual worldwide budgets of many billions of dollars. In nature, it turns out, the smaller the subject, the harder and costlier it is to study.

*Earthquakes in Human History:  
The Far-Reaching Effects  
of Seismic Disruptions*  
by Jelle Zeilinger de Boer  
and Donald Theodore Sanders  
Princeton University Press, 2005;  
\$24.95

What's shakin'? The question might have made a snappy title for this book, instantly drawing the reader's attention to the human side of earthquakes. Tremors in the earth, after all, change not only the landscape but also the course of human affairs. From ancient times—for example, in



the biblical account of the fall of the walls of Jericho and the subsequent rise of the Israelite nation—geologic, social, economic, and even political changes have followed close in the wake of tectonic disaster.

To be sure, earthquakes are no longer feared as the retribution of an angry god; geologists know they are side effects of Earth's crustal readjustments. Yet as last year's devastating tsunami in the Indian Ocean tragically demonstrated, earthquakes still strike without warning. Their effects can still level towns, sweep communities away, and benumb survivors with their display of nature's utterly random violence. The effects of tremors lasting only minutes often dwarf those of almost all other natural disasters, leaving scars on the



Earthquake in Los Angeles, 1933, as depicted by Vittorio Pisani for the Roman weekly, *La Tribuna Illustrata*

landscape and the population that can last for centuries.

Geologist Jelle Zeilinga de Boer and science writer Donald Theodore Sanders drive that point home with well-chosen evidence from notable seismic upheavals of the past. Some of the most impressive documentation comes from the Lisbon earthquake, which rocked the Portuguese city at midmorning on November 1, 1755.

Worshippers, crowded into churches for celebrations for All Saints' Day, were crushed by collapsing stone walls and roofs.

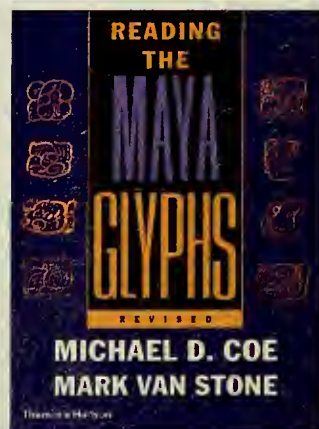
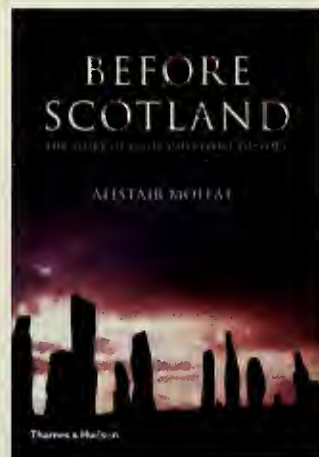
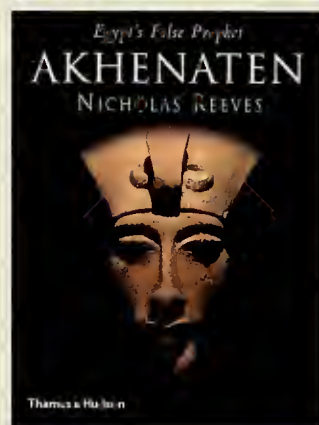
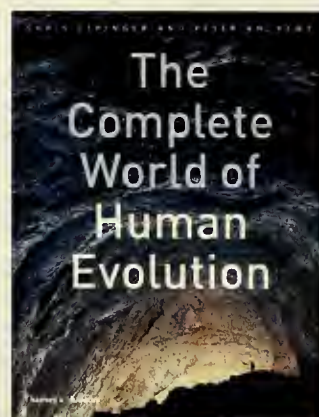
One eyewitness account, relayed to the British geologist Charles Lyell, told how hundreds of people fled for refuge to a new marble quay at the harbor. Suddenly the entire structure, built on the unconsolidated sediments of the Tagus River estuary, sank into the sea, as if swallowed up by the devil himself. Tsunamis, some as high as twenty feet, swept through harbors all along the Portuguese coast, sinking ships and submerging coastal villages.

At the time of the earthquake, Lisbon was one of the richest cities in the world. The temblor left it battered and impoverished, knocking Portugal permanently into the second tier of European nations. Libraries that housed naval charts and other documents from the great Portuguese voyages of discovery were lost, along with priceless works of art. Religious zealots battled civic authorities for control of the hearts, minds, and purses of the survivors; only slowly were order and stability restored. Elsewhere in Europe the pitiful devastation fueled the skepticism of Enlightenment thinkers about the omnipotence and justness of God. In Voltaire's satire *Candide*, Pangloss, the inimitable optimist, views the Lisbon devastation and declares:

For all this is a manifestation of the rightness of things, since if there is a volcano at Lisbon it could not be anywhere else. For it is impossible for things not to be where they are, because everything is for the best.

De Boer and Sanders spend time, in passing, on some of the technical details about the geologic faults and tectonic movements that were ultimately responsible for the quakes they focus

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on. But the best parts of their book are the stories, big and small, of people and institutions affected by the great seismic disruptions. It's a fascinating field, seismology: part science, part history, part sociology, and, alas, part prophecy. There are, of course, some things we can do to improve our chances of survival—such as building better warning systems for tsunamis. When the next big one hits somewhere, though, as it surely will, it's almost certain that the best place to be, will be anywhere else.

*Birdsong: A Natural History*  
by Don Stap  
Scribner, 2005; \$24.00

Among some birds, life is an opera; among others, life is a cabaret. Eastern towhees, with a repertoire of fewer than a dozen songs, present daytime recitals of well-practiced favorites. Their performances include frequent encores, presumably lasting until the singers tire and the birds move on to the next tune. By contrast, the male marsh wren is a seasoned crooner that plays up to his mostly female listeners with a repertoire of more than a hundred songs. He performs them one after another in rapid succession, without repeating a number. Most versatile of all is the brown thrasher, a singer's singer, which knows as many as 2,000 songs.

Birdsong, one of the most familiar and pleasing of natural phenomena, remains, for the most part, one of the most enigmatic as well. Although ornithologists have amassed vast recorded archives of glides, twitters, and warbles, little is known of the origin and function of avian musicianship. Because most of the singers are male, and because birdsong tends to peak in the spring mating season, singing probably helps to stake out good territory and—just as it does among people—to attract the opposite sex. Ornithologists also know something about how birdsong is produced. The sound comes from an organ called the syrinx, a little chamber of muscle, membrane, and cartilage, which vibrates

when air is forced through it. In nearly every group of birds, different parts of the syrinx vibrate independently, enabling a bird, in effect, to sing a duet with itself. Moreover, avian hearing and perception can be remarkably acute. In one series of experiments, pigeons were able to discriminate reliably between compositions by Bach and Stravinsky.



*Song contestants: Chipping sparrow, left, sings only one song, but the marsh wren can perform more than two hundred.*

But the most remarkable and puzzling aspect of birdsong is that many birds learn their songs from other birds—at least among the 4,500 species in a large suborder called oscines, or songbirds, a group that includes chickadees, jays, orioles, thrushes, and warblers. Other kinds of birds, such as chickens, ducks, and hawks, tend to make calls that are genetically wired in. But if you're a singing bird rather than a squawking or quacking one, chances are you learned your song from your father, uncle, or neighbor. There are, consequently, "dialects" of birdsong: variations on timing, pitch, and pronunciation evident in distinct local populations. Black-capped chickadees in mainland New England (and in most of the U.S.) sing a two-note song that sounds like "hey! sweetie." But out on Martha's Vineyard, an island off the coast of Massachusetts, the same species sings its song with many specific variations—ranging from "sweetie, hey!" to "sosweetie-sweetie"—depending on its nesting location.

Don Stap, a professor of English at the University of Central Florida in

Orlando, may not have professional credentials in animal acoustics, but he's a seasoned birder who has already published a book (*A Parrot Without a Name*) based on fieldwork by prominent ornithologists. He provides both a lucid overview of the major research findings about birdsong, and a running narrative about the daily lives of two ornitholo-

gists, Gregory F. Budney of Cornell University, in Ithaca, New York, and Donald E. Kroodsmma, of the University of Massachusetts-Amherst. Much of the time, they just sit around listening—in the velvet fog of early morning in the Sierras, for instance, or in the dank mist of a Central American rainforest. But even to a tin-eared nonbirder like me, Stap's descriptions make the work sound exciting.

Stap has a gift for depicting exotic places. But the puzzle of birdsong by itself is an engaging one: Just what are the birds saying to one another, anyway? If their songs are learned, how did the tunes originate? And how do the songs change over time? In this digital age, a CD or DVD attached to the book might have added a useful dimension to an otherwise boffo performance. Even without audio-visual aids, though, Stap's fine book is—how shall I sum it up—a tweet!

LAURENCE A. MARSCHALL, author of *The Supernova Story*, is W.K.T. Salm Professor of Physics at Gettysburg College in Pennsylvania. He is the 2005 winner of the Education prize of the American Astronomical Society.



## The Talking Web

By Robert Anderson

Recently I read aloud to my children from "*Surely You're Joking, Mr. Feynman!*," recorded and edited by Ralph Leighton, a friend of the Nobel prize-winning physicist Richard P. Feynman. The kids' favorite part (and, I suspect, everyone else's, too) was Feynman's retelling of his adventures as a safecracker. With a little math, a little psychology, and the persistence of, well, a scientist, Feynman managed to break into safes when he worked on the Manhattan Project, demonstrating that classified information about the atomic bomb was far from secure, after all.

A search of the Web for more stories about Feynman led me to the Vega Science Trust ([www.vega.org.uk](http://www.vega.org.uk)), a U.K.-based organization that broadcasts free, high-quality science programs over the Internet. There I found archival video recordings from a series of physics lectures Feynman gave in New Zealand at the University of Auckland in 1979.

But Feynman is just the beginning of what the Vega Trust has to offer. On the "Science Programmes" page, the "Face2Face" link takes you to an archive of recordings by famous scientists. In the gray menu box on the "Science Programmes" page, you'll find a link to even more such recordings, listed "By Scientist" or "By Subject." Many of the talks—such as "The Origin of Life," by the recently deceased evolutionary biologist John Maynard Smith—were delivered at the Royal Institution of Great Britain in London, where the tradition of making science accessible to the public goes back two centuries. Consult the "A-Z" link, in the gray menu box, to see the full catalog of downloadable science videos.

If, like me, you get hooked on watching scientists talk on video, there's no end to the fascinating bounty on the Internet. At the site of The Royal Society in London, for instance, you can watch and listen as David R. Scott, the

commander of the Apollo 15 mission to the Moon, explains the "Challenges facing the human exploration of Mars" (go to [www.royalsoc.ac.uk/page.asp?id=2406](http://www.royalsoc.ac.uk/page.asp?id=2406)). The "Video Library" offers more selections in a column on the left. Among the other attractions available at the "Video Library" is an unusual discussion about "Beauty in science and literature," by a poet and novelist, Ben Okri, and a neuroscientist, Nancy J. Rothwell.

A number of other institutions make science lectures available to the public on the Web. One is Harvard University, at the "harvard@home" site ([athome.harvard.edu](http://athome.harvard.edu)). Click on "program list" in the red banner menu at the top, and scroll down to view the selections. I made a beeline for a talk by one of my favorite thinkers, the biologist Edward O. Wilson; he explains his ideas about the ways our genetic and cultural evolution are intertwined. At Cornell University, I found three lectures on quantum theory given in 1999 by the late Hans Bethe ([bethe.cornell.edu](http://bethe.cornell.edu)). What makes Bethe's talks so special—and so accessible to the general public—is that he prepared them for a particular audience: his neighbors in a retirement community near the university campus, in Ithaca, New York.

True to its eclectic reputation, the Exploratorium in San Francisco ([www.exploratorium.edu/](http://www.exploratorium.edu/)) offers a wide range of unusual topics in its audio and video lecture series. In the menu at the upper right of the home page, under "Webcasts," click on "Archive" to access "Live@Exploratorium." You'll find nearly a decade's worth of lectures. One segment I particularly enjoyed comes from a series of talks and panel discussions on memory, presented in 1998 (click on "1996-8" on the banner menu). Choose "Memory Lectures" from the scroll-down list, and then click on the selection by the neuroscientist Robert M. Sapolsky—his talk is called "Stress and Memory: Forget It!"

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

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# Peekaboo Planet

*A decade after first finding exoplanets, astronomers may now be seeing them.*

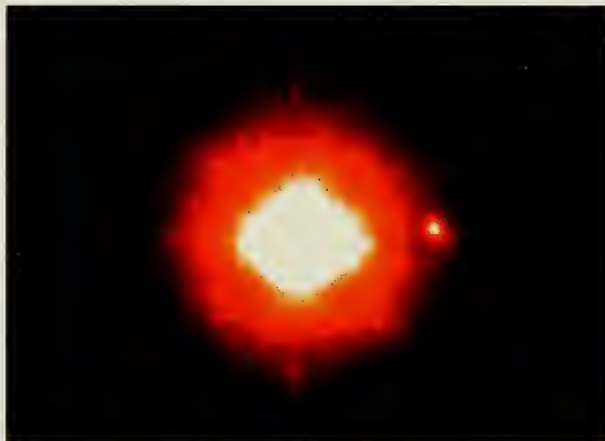
By Charles Liu

In little more than a decade, the number of planets discovered outside our solar system has grown from zero to nearly 200. Ask what an individual “exoplanet” looks like, though, and we astronomers still can’t tell you for sure. That’s because astronomers have observed exoplanets only indirectly—either by watching their gravitational effects on the stars they orbit, or by measuring periodic dips in starlight as the planets pass in front of the stars they orbit. Until now, directly detecting the light of exoplanets was beyond our scientific reach.

Happily, the key words here are “until now.” In the past few months, at least three groups of investigators have drawn on new technology and human creativity to “see,” with infrared eyes, the light of what appear to be three exoplanets, orbiting their respective stars.

The technology behind this breakthrough is also the basis for infrared night-vision goggles, which sense the heat that objects radiate as infrared light, then translate the infrared into visible light. Infrared cameras are the astronomer’s heat-vision spectacles. Objects warmer than their background emit more infrared light than the background does, and so they show up as relatively bright. Mounted on a telescope, the infrared camera makes an ideal instrument for exoplanet paparazzi angling to capture the perfect picture of a distant planet’s light.

Perhaps the most spectacular example of an infrared telescopic camera is NASA’s Spitzer Space Telescope—an orbiting observatory of unprecedented sensitivity, dedicated to taking



*Infrared photograph of the star GQ Lupi (center) reveals a point of light (dot at right), thought to be an orbiting planet.*

the measure of the infrared cosmos. Two of the three groups I mentioned above relied on it to gather their exoplanetary data. The first, led by Drake Deming of NASA’s Goddard Space Flight Center in Greenbelt, Maryland, targeted the exoplanet called HD 209458b, 150 light-years from Earth; the second, led by David Charbonneau of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, singled out TrES-1, about 500 light-years away.

The groups chose their targets carefully, to have the best chance of spotting their quarry in the infrared. Both exoplanets are gas giants more than 200

times the mass of Earth (for comparison, the mass of Jupiter, which is also a gas giant, is equal to 320 Earth masses). The orbits of both are known to high precision, and the orbital plane of each one is edge-on as seen from Earth: from our point of view, both exoplanets pass directly in front of, then behind, their parent star. Finally, both exoplanets orbit close to the parent star—at only about a tenth the radius of Mercury’s orbit around the Sun—close enough that intervals between occultations of one object by the other are not long.

Neither HD 209458b nor TrES-1 can be imaged distinctly. Each one is so close to its parent star that the light it emits is overwhelmed by the stars’ light. But the atmospheres of both exoplanets absorb huge amounts of heat from their stars, raising the planets’ surface temperatures to a scorching 1,500 degrees Fahrenheit. At that temperature, the astronomers calculated, both planets would glow so brightly with infrared radiation that when each passed behind its sun, the absence of infrared emissions might be noticeable.

With that in mind, both groups aimed the Spitzer Telescope at the two distant solar systems before, during, and after each object was passing behind its parent star. Deming’s group measured the infrared emission of the HD 209458b system at a wavelength of 24 microns; Charbonneau’s group did the same for the TrES-1 system at 4.5 and 8.0 microns. (For comparison, the infrared emission of a healthy human body peaks at about 9.3 microns.) Both groups detected a dimming of the infrared emissions from the exoplanetary systems when the planets were eclipsed by their stars. The dimming was very slight, less than 0.3 percent, but, small as it was, it stood out clearly in the exquisitely precise data from the Spitzer Telescope.

The third group of investigators, led by Ralph Neuhauser of the Astro-



physical Institute of the University of Jena, Germany, stuck to a ground-based observing strategy. From Earth's surface, infrared astronomers must contend with the obscuring effects of the atmosphere, which not only blurs and distorts astronomical images but also blocks out all but a narrow band of infrared wavelengths. The trade-off is that ground-based infrared telescopes can be much larger than the ones flown into space. Moreover, computer-controlled optics enable those telescopes to adapt to atmospheric distortions, canceling out much of the blurring.

With the 8.2-meter Yepun Telescope at Cerro Paranal, Chile, Neuhäuser and his colleagues made high-resolution pictures at two infrared wave bands of the star GQ Lupi, 450 light-years from Earth. Next to the star they detected a small companion object. Recognizing it in archived images of the star made by the Hubble Space Telescope six years ago, the team was able to calculate that

it is separated from, and is possibly orbiting, GQ Lupi at a distance of about 10 billion miles—about a hundred times the distance between Earth and the Sun. Then, comparing the companion's infrared emission spectrum with spectra calculated from models of gas giants, they concluded that the companion is most likely two to three times as massive as Jupiter.

If Neuhäuser's interpretation is confirmed, the companion to GQ Lupi would be the first gas giant to be directly imaged in orbit about a sunlike star. But that is still a big "if." Neuhäuser's observations are being compared with models of relatively old gas giants. GQ Lupi, however, is just an infant by stellar standards, only one or two million years old [see "Star Baby," by Charles Liu, December 2003/January 2004]. The current understanding of infant stars—and their planets—is in its infancy itself. Assuming the companion formed during the same period as its parent star, various competing models

predict that its mass could be between one and forty-two times the mass of Jupiter. The upper end of that range takes the companion out of the giant-planet class and into the realm of brown dwarf stars. So, even though Neuhäuser and his coworkers are fairly sure GQ Lupi's companion is a planet, they also acknowledge the possibility that it's not. What would make their result definitive? More images, of course—and more models, too.

The scientific progress made by these observations is incremental, but they are powerful confirmations of the recent achievements of exoplanetary astronomers. The images also pose new questions and open new avenues of inquiry. Perhaps best of all, they triumphantly provide, for us picture-hungry humans, something fascinating to look at.

*CHARLES LIU is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.*

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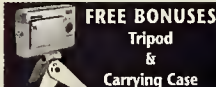
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June saves some of the best for last: three planets converge in the sky to form a planetary trio, a dazzler for sky gazers late in the month. A trio is a conjunction so close that the three planets fit inside a circle no more than five degrees across. **Venus** (magnitude  $-3.9$ ), **Mercury** (magnitude  $-0.2$ ), and **Saturn** (magnitude  $0.2$ ) are all readily visible within the prescribed circle, low in the west-northwestern sky, for about an hour after sunset from the 23rd until the 29th. Their relative positions, which change from night to night, should be fascinating to watch. Individual conjunctions include Venus and Saturn (separated by just 1.3 degrees) on the 25th, Mercury and Saturn (1.4 degrees) on the 26th, and Mercury and Venus (a mere 0.1 degree) on the 27th.

**Mercury** reaches superior conjunction, opposite Earth in its solar orbit, on the 3rd and passes from the morning to the evening sky. By about the 14th it should

be visible glimmering through the twilight just above the west-northwestern horizon about forty-five minutes after sunset. In the final week of June, as noted earlier, Venus and Saturn join Mercury in the sky.

**Venus** remains just above the west-northwestern horizon after sunset all month. The planet is so bright that it can be spotted even through the dimming glow of twilight, about forty-five minutes after sunset. Venus itself sets about ninety minutes after the Sun. Look early, soon after sunset and preferably with binoculars. On the 7th, Venus appears far to the upper left of a wire-thin crescent Moon, just one day past new. The following evening, the Moon is much easier to see, hovering well above Venus.

**Mars** rises around 2 A.M. on the 1st and about 1 A.M. on the 30th. It begins the month 111 million miles from Earth,

shining at magnitude 0.3. By the end of June Mars is 18 million miles closer and 45 percent brighter than it is at the beginning, shining at magnitude  $-0.1$ ; the planet is just a trifle brighter than the star Arcturus, the bear guard, in the constellation Boötes, the herdsman. Not only are Mars and Arcturus nearly equal in brightness, but they also have a similar shade of yellow-orange. On the 29th Mars appears to the right of the Moon, which is just past last quarter.

**Jupiter** is among the first objects to appear as the sky darkens, shining high in the south-southwest. On the 1st the planet stands slightly more than fifteen degrees to the upper right of Spica, the brightest star in the constellation Virgo, the virgin. The giant planet lingers in these parts throughout the month, passing just 1.5 degrees to the south of Porrima on the 30th. On the 16th Jupiter appears to the upper left of the waxing gibbous Moon.

**Saturn**, at magnitude 0.2, is 6.5 degrees below and to the left of Pollux, in the constellation Gemini, the twins. The planet sets three hours after the Sun at the beginning of the month and two hours after the Sun at month's end. On the evening of the 9th, a lovely crescent Moon passes between Saturn and Pollux; Saturn appears to the lower left of the Moon, and Pollux appears to the Moon's upper right. Toward the end of the month Saturn becomes a bit more difficult to see in the bright twilight, just as it forms the trio with Venus and Mercury noted earlier.

The **Moon** wanes to new on the 6th at 5:55 P.M. Our satellite waxes to first quarter on the 14th at 9:22 P.M. and to full on the 22nd at 12:14 A.M. It wanes to last quarter on the 28th at 2:23 P.M.

The **solstice** occurs on the 21st at 2:46 A.M. Summer officially begins in the Northern Hemisphere, and winter in the Southern Hemisphere.

*All times are given in eastern daylight time.*

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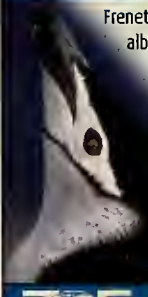
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## Dinosaurs: Ancient Fossils, New Discoveries

Now through January 8, 2006

**T**his groundbreaking exhibition presents the most up-to-date look at how scientists are reinterpreting many of the most persistent and puzzling mysteries of the dinosaurs: what they looked like, how they behaved, and how they moved, as well as the complex and hotly debated theories of why—or even whether—they became extinct.

### T. REX WALKS IN PLACE

According to the latest research, *Tyrannosaurus rex* was not the speed demon depicted in *Jurassic Park*, and in fact, probably didn't run at all in pursuit of its prey—it walked. So how did this stalker walk? Just like the robotic six-foot-long scale model of a *T. rex* skeleton in the exhibition *Dinosaurs: Ancient Fossils, New Discoveries* at the American Museum of Natural History.

Based on a fossil in the Museum's collection, the polyurethane model illustrates the walk cycle of these carnivorous beasts. Hall Train Studios in Toronto combined mechanical design

with state-of-the-art animation expertise to create the model for the exhibition. A single motor powers a dense array of aluminum and plastic gears, cams, and levers that move vertical supporting rods up, down, and sideways in research-dictated paths. The overall effect is a marvel of paleontological art—the most scientifically accurate model ever built of a dinosaur walking.

The biggest hurdle was re-creating the movement of the animal's feet. A total of 50 mechanical parts were required in each of the animal's littlest toes to make them flex in the subtle, curling pattern scientists have de-

scribed. From there, the mechanics of the knees (just six gears needed to produce the roll/glide needed here), pelvis, head, and tail movements fell into place more easily.

"Making this model was the most challenging project of my life because it required coaxing machine parts into conveying movements that are organic and fluid," said Hall Train, a designer and animator who specializes in natural history projects. Train's work certainly paid off: the result of his toiling culminates in a surprisingly lifelike simulation of a *T. rex* on the move.

### ART AND SCIENCE BRING MESOZOIC FOREST TO LIFE

A 700-square-foot diorama of an ancient forest, the biggest and most detailed recreation of a prehistoric environment ever constructed, is the centerpiece of the new exhibition, *Dinosaurs: Ancient Fossils, New Discoveries*, at the American Museum of Natural History.

There are no glass walls in this evoca-



This intricate mechanical model of a *T. rex* in motion will amaze visitors with its lifelike gait.





An exhibition preparator puts the finishing touches on this large-scale diorama of a prehistoric forest.

tive diorama, so visitors feel as though they are immersed in a prehistoric “lost world” never before viewed by humans. They will come face to face with more than 100 full-size models depicting the wide range of amazing creatures that lived there.

As it turns out, the prehistoric forests of what is now Liaoning Province in northeastern China looked a great deal like modern-day New Jersey. Most of the plants and trees growing in China 130 million years ago are very similar to modern pines, ferns, and cedars that grow abundantly today in the New Jersey Pine Barrens, according to paleobotanist Kirk R. Johnson of the Denver Museum of Nature & Science. In fact, much of the initial sketching and research took place in the real-life environment of the Pine Barrens.

Not just an artistic flight of fancy, the creatures and backgrounds in the Liaoning Forest diorama are the result of an extraordinary collaboration of art

and science, partnering sculptors and painters in the Museum’s Department of Exhibition with renowned paleontologists. A team of artists spent weeks painting the 68-foot-long background mural, while Museum sculptors immersed themselves in the latest scientific reports on the Liaoning fossil finds before meticulously sculpting the life-size, fleshed-out models of creatures that populate the forest. This collaboration has led to an astounding feat: an intricately designed, scientifically accurate re-creation of a prehistoric world.

*Dinosaurs: Ancient Fossils, New Discoveries* and its accompanying education and public programs are made possible by Bank of America.

This exhibition is organized by the American Museum of Natural History, New York ([www.amnh.org](http://www.amnh.org)), in collaboration with the Houston Museum of Natural Science; California Academy of Sciences, San Francisco; The Field Museum, Chicago; and North Carolina Museum of Natural Sciences, Raleigh.

Major funding has also been provided by the Lila Wallace-Reader’s Digest Endowment Fund.

## PEOPLE AT THE AMNH

Denis Finnin  
Director, Photography Studio



Denis Finnin

Denis Finnin first stepped foot inside the unfamiliar walls of the Museum for a job interview. Now, 16 years later, he knows every nook and cranny.

“The role of the Photo Studio is multifaceted,” Denis explains. “We work with most departments in the Museum, photographing pieces for scientific departments, Museum events, and behind-the-scenes activities. Our images are used for presentations, marketing, and in exhibitions.” Denis has played an integral role in documenting the construction and rehabilitation of many of the Museum’s halls and additions, including the renovation of the fossil halls ten years ago, and more recently, the Rose Center. His work has also sent him on trips across the globe. He recalls the two weeks he spent in Indonesia, where he documented the collection of sulfur specimens from the crater of a volcano for the Gottesman Hall of Planet Earth, as a highlight of his career here at the Museum.

When he’s not behind the camera, Denis enjoys outdoor activities, like camping and hiking with his wife and son. His love for the outdoors led him to become an avid cyclist, and he commutes to the Museum by bicycle as often as possible—even through the winter.



# Museum Events

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## EXHIBITIONS

**Totems to Turquoise: Native North American Jewelry Arts of the Northwest and Southwest**  
Through July 10, 2005

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Andean women often weave outdoors.

**Exploring Bolivia's Biodiversity**  
Through August 8, 2005

These lush photographs of Bolivia take viewers on a journey through the mountain landscapes of the Andes to the dense lowland tropical forests of the Amazon and the dry forests of the Chaco. Captions in English and Spanish.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.



Image taken by the NASA Transition Region and Coronal Explorer (TRACE) telescope

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2:00–3:00 p.m. and 4:00–5:00 p.m.

Join the Andean music, dance, and theater troupe Rupai for a traditional summer solstice performance.

## LECTURES

**Searching for Our Distant Ancestors in Asia**

Thursday, 6/2, 7:00–8:30 p.m.

Chris Beard explains how his discoveries of 45-million-year-old fossils in China shed new light on primate evolution.

**Earthquakes and Tsunamis: Can They Happen Here?**

Thursday, 6/30, 6:30 p.m.

Michael E. Wyssession discusses how earthquakes and tsunamis threaten not just the "other side" of the world, but also many parts of the United States, including New York City.

## WORKSHOP

**Make It, Wear It:**

**Beaded Jewelry Workshop**

Three Thursdays, 6/9–6/23,

7:00–9:00 p.m.

Participants will create their own unique beaded jewelry using traditional South African techniques.

## FAMILY AND

### CHILDREN'S PROGRAMS

**The Dinosaurs of Waterhouse Hawkins**

Saturday, 6/11, 12:00 noon–1:00 p.m. and 2:00–3:00 p.m.

Brian Selznick's performance magically depicts the life of the extraordinary 19th-century artist who built the world's first life-size models of dinosaurs.

**Visit the Space Station!**

Saturday, 6/11, 11:00 a.m.–12:30 p.m. (Ages 4–5, each child with one adult) or 1:30–3:00 p.m. (Ages 6–7, each child with one adult)

Kids fascinated by astronauts

will see what a day might be like living, working, and playing aboard the International Space Station.

**Melanie in Manhattan**

Sunday, 6/12, 2:00–3:30 p.m.

(Recommended for children ages 8–12)

Carol Weston reads from her latest book, in which Melanie Martin explores the Museum, from the dinosaur halls to the stars of the Hayden Planetarium.

**Dr. Nebula's Laboratory: Dino Adventure**

Sunday, 6/26, 2:00–3:00 p.m.

Science theater for the whole family: on a paleontology adventure, Scooter will uncover the mysteries of the dinosaurs.

## SUMMER

### ADVENTURE CAMPS

**Monkey Business:**

**Primatology**

Monday–Friday, 6/20–6/24,

9:00 a.m.–4:00 p.m. (For children entering grades 2 or 3)

## STARRY NIGHTS Live Jazz

ROSE CENTER  
FOR EARTH AND SPACE

Friday, June 6  
6:00 and 7:30 p.m.

Ravi Coltrane  
Quartet

Starry Nights is made possible, in part, by Constellation NewEnergy.

## Robotics

Monday–Friday, 6/20–6/24,  
9:00 a.m.–4:00 p.m. (For chil-  
dren entering grades 6 or 7)

## Dinosaur Detectives

Tuesday–Thursday,  
6/28–6/30, 9:00 a.m.–  
3:00 p.m. (For children  
entering grades 2 or 3)

## DINOSAUR SUNDAYS

Take all three and earn  
a certificate!

## Dinosaur Trackways

Sunday, 6/5, 11:00 a.m.–  
12:30 p.m. (Ages 4–6, each  
child with one adult) or  
1:30–3:00 p.m. (Ages 7–10)  
Participants will learn what  
dinosaur trackways can and  
can't reveal about dinosaur  
behavior.

## Digging for Dinos

Sunday, 6/12, 11:00 a.m.–  
12:30 p.m. (Ages 4–6, each  
child with one adult) or  
1:30–3:00 p.m. (Ages 7–10)  
Children will become junior  
paleontologists and learn how  
scientists conduct fieldwork in  
their quest for fossils.

## Build Your Own Dinosaur

Sunday, 6/26, 11:00 a.m.–  
12:30 p.m. (Ages 4–6, each  
child with one adult) or  
1:30–3:00 p.m. (Ages 7–10)  
The anatomical similarities  
between dinosaurs and birds  
come to life by constructing  
dinosaur models with creative  
materials!

*Dinosaurs: Ancient Fossils, New Discover-  
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public programs are made possible by  
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Major funding has also been provided  
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## HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME  
*Virtual Universe*

*At Home in the Milky Way*  
Tuesday, 6/7, 6:30–7:30 p.m.

*This Just In . . .*

*June's Hot Topics*  
Tuesday, 6/21, 6:30–7:30 p.m.

*Celestial Highlights*  
*Star Hopping*

Tuesday, 6/28, 6:30–7:30 p.m.

## INFORMATION

Call 212-769-5100 or visit [www.amnh.org](http://www.amnh.org).

## TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m.,  
or visit [www.amnh.org](http://www.amnh.org). A service charge may apply.  
All programs are subject to change.

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## PLANETARIUM SHOWS

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*Are We Alone?*

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*Passport to the Universe*

Narrated by Tom Hanks

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# Balanophagy

By William Bryant Logan

[Balanophagy, "acorn eating," from the Greek *balanos*, "acorn" + *phagein*, "to eat"]

Oaks have been cut down without a thought around the world for the past 3,000 years, but they are not forgotten as a source of foodstuff everywhere, or by everyone. My own culinary adventures with the acorn began with a walk I took in the heart of New York City's Little Korea, on Thirty-second Street in midtown Manhattan. In the biggest Korean market in the city, when I asked whether there were any foods made from acorns, I drew a mystified look from the sales girl. I rummaged around in my change pocket, where I usually keep at least one acorn. Sure enough, there was a red-oak acorn. I drew it out and held it up. "This," I said.

Immediately, the girl broke into smiles and laughter; the acorn was obviously as familiar to her as a rice grain, though not by the name "acorn." She led me to a shelf full of one-pound packages of acorn-starch flour, and then to the cold case, where she showed me a tofu-like square of acorn jelly.

The first prepared oak food I ate was the acorn jelly. It was a lovely chocolate-brown color. It hit the tongue with a slimy slipperiness, like the feel of a slug, but fortunately it began to dissolve almost immediately. It was lighter in texture than *Jell-O*, and the sensation of it, after the first shock, was pleasant. The only real trouble was the taste. One writer called the flavor "insipid." But "absent" might be nearer the mark. There is a definite presence and texture to the stuff, satisfying on the tongue, and palatable going down the throat. But flavor? Tap water is tastier.

I tried frying it in olive oil. That was better. I sliced it thin, grated scallions over it, added sesame oil and rice vinegar. That was delicious. What I eventually discovered by repeated experiment was

the last sensation it produced when I ate it: a pleasant feeling, in the pit of my stomach, of being full.

More experiments were called for. I pulled out a cookbook called *Acorns and Eat 'em*, by Suellen Ocean.



Suellen lives in the northern mountains of California, where good acorns are plentiful. She is the sort of person

who, if you called her an unregenerate hippie, might proudly nod assent.

I made Suellen's acorn pancakes, using the acorn flour. They tasted fine; a little chewy perhaps. The acorns added no flavor, but again they gave me that odd feeling of being able to satisfy my hunger very quickly. I felt that I could eat acorns on a regular basis, so long as I varied the flavorings. That pleasant sensation of being full was strangely rewarding, though I might not value it as highly as those who have often gone hungry in their lives.

It occurred to me that the acorn might well have been the foundation of all the stews and hot pots that are still the mainstays of cuisines throughout the temperate world. If the acorn was once a staple food, it would have called out to be flavored, spiced, varied, and embellished. And if, as a number of anthropologists now think, the culminating state of hunter-gatherer culture was one in which everything from seeds and nuts to fleshy fruits, meats, fish, shellfish, turtles, insects, and berries were consumed, it would have been natural to develop a cookery based not on roasted or boiled meats but on mixed stews.

The first time I saw a map with the legend "World Oak Distribution," I was startled. The map showed clearly that the distribution of oak trees is coterminous with the locations of the settled civilizations of Asia, Europe, and North America. It is interesting to think that where there are or have been the cities and cultures that shaped the modern world, there are or have been oaks.

*WILLIAM BRYANT LOGAN, a certified arborist and award-winning writer, lives and gardens in Brooklyn, New York. This essay is adapted from his forthcoming book *Oak: The Frame of Civilization*, which is being published next month by W.W. Norton & Company, Inc.*



# WHAT YOU THOUGHT YOU KNEW IS HISTORY



Photo: R. Mickens/AMNH

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