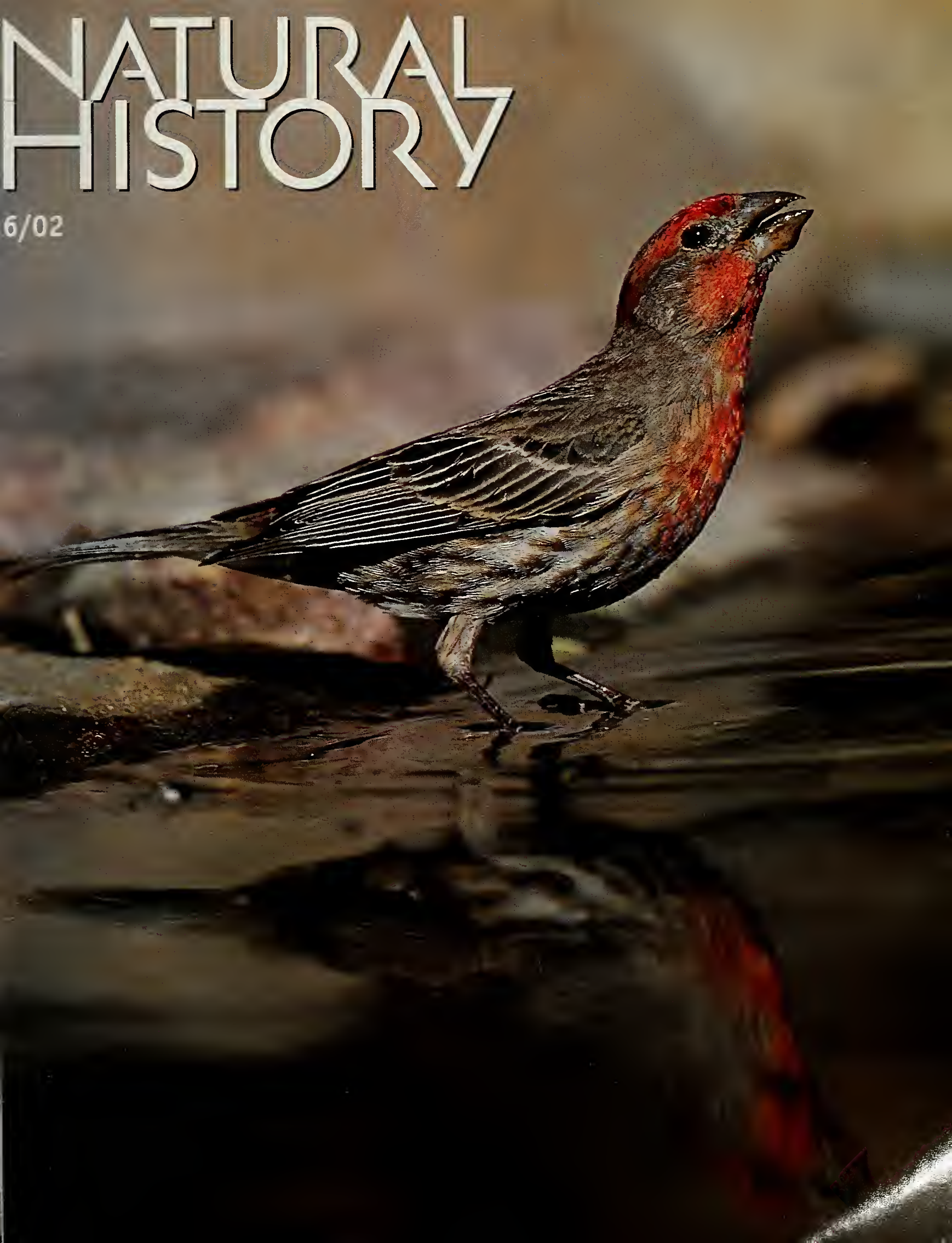
NATURAL HISTORY

6/02



NATURAL HISTORY

JUNE 2002 VOLUME 111 NUMBER 5

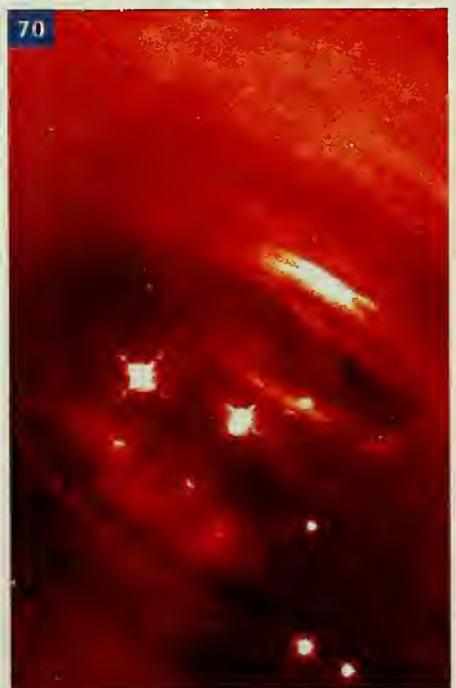
FEATURES

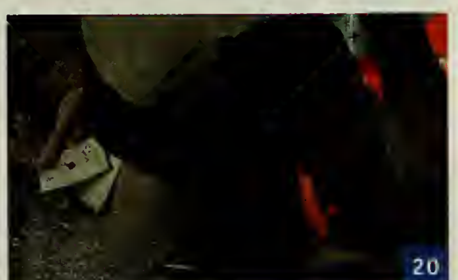
COVER In Arizona, a male house finch pauses for a drink.

STORY BEGINS ON PAGE 58

PHOTOGRAPH BY JOE MCDONALD
BRUCE COLEMAN INC.

DEPARTMENTS





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UP FRONT

Fast Forward

HOUSE FINCH. *Abundant in bottomlands, canyons, suburbs, and ranches in the West; uncommon but increasing and spreading in the East.*
—Chandler S. Robbins et al., *Birds of North America* (1966)

Field guides get such rough treatment in my household that I have to buy replacement copies every few years. Recently, when I went out and purchased yet another *Birds of North America* by Robbins, Bruun, and Zim, I discovered that after thirty-five years in print, it had been revised and updated. So far, the most dramatic difference I've noticed in the new edition is the range map for the house finch, a.k.a. *Carpodacus mexicanus*. In the old book (originally published in 1966), this small bird was described as "uncommon but increasing" in the East, where its local range was denoted on a tiny map by a purple spot somewhat above the midpoint of the U.S. Atlantic coast. The new edition says the house finch is "becoming common" in the East, and the new range map is purple from Maine to Florida. In other words, a bird once known mainly in Mexico and the Far West is now a familiar sight east of the Mississippi.


GERALD D. TANG

Such a rapid expansion of range is unprecedented for a native vertebrate (though invaders from Europe, such as the house sparrow and the Norway rat, have managed similar feats). For nature lovers, the house finch explosion has been quite a bit of fun. They're pretty birds, great songsters—delivering what to my ear is a deeper, huskier version of a goldfinch's melody—and therefore welcome additions to the backyard fauna. To some evolutionary biologists, however, the expansion represented something else: a scientific opportunity. Ornithologists Alexander V. Badyaev and Geoffrey E. Hill saw in the rapid spread of the house finch a chance to gather empirical evidence on adaptation in progress ("Avian Quick-Change Artists," page 58).

By carefully observing house finches at the northern and southern extremes of their new range, Badyaev and Hill found not only that measurable physical differences had already appeared between the populations but also that the male and female birds seemed to respond differently to the same environmental pressures. The big surprise was the finding that females play a major role in producing optimally adapted young.

The painting of a house finch in the revised edition of *Birds of North America* is the same as the one in my original field guide, despite the alterations to the later text and map. But if Badyaev and Hill are right, the birds that I first learned to recognize thirty years ago in the dry hills of central California and the birds that now sing from my eleventh-floor window ledge in Manhattan may be evolving in different directions.—*Ellen Goldensohn*

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LETTERS

Of Mice and Men

In "A Mouse's Tale" (4/02), Steven N. Austad writes: "It is more than a simple oddity that laboratory mice have smaller eyes and brains . . . larger bodies . . . weaker muscles and chromosomes, and longer telomeres than their wild relatives."

Indeed, it is not the least bit odd. As a result of spending the past fifteen years in warrens of office cubicles (not entirely unlike cheese mazes), I can attest that my eyes are smaller, my muscles weaker, my body larger. I should not be surprised to learn that my brain and telomeres had atrophied. Did the mice also go bald, by any chance?

Jeff Laite
Brooklyn, New York

Joist Gigantism

That's one helluva floor joist described in "Twister!" ("Biomechanics," 4/02). Two-foot by eight-foot? It would take quite a forest of redwoods to frame a house like that. I use joists with a two-inch-by-eight-inch cross section—that is, the ubiquitous 2 x 8.

Rick Berger
via e-mail

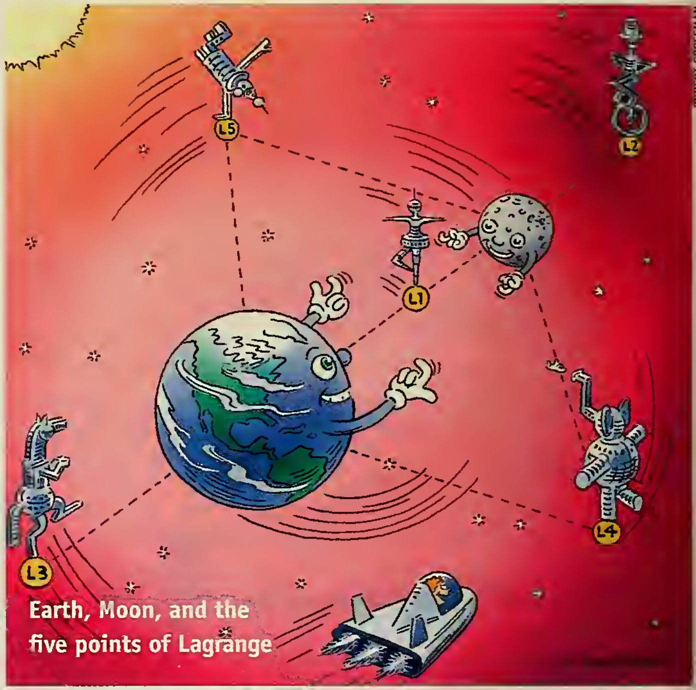
APOLOGY: The editor responsible for the error is now taking a course in carpentry.

Picture Imperfect

Neil deGrasse Tyson ("Universe," 4/02) writes: "The second and third Lagrangian points (L2 and L3) also lie on the Earth-Moon line, but L2 lies far beyond the Moon, while L3 lies far beyond Earth in the opposite direction." But in the illustration accompanying the article, the positions of L2 and L3 appear to be reversed. Which is correct, the text or the illustration?

David L. Thompson
Ann Arbor, Michigan

THE EDITORS REPLY: The text is right. The illustration had been corrected to match it, but an earlier version was printed by mistake. The picture at right is accurate.



Earth, Moon, and the five points of Lagrange

ID vs. Evolution, Continued

I am surprised that Michael J. Behe ("Intelligent Design?" 4/02) cited the blood-clotting system as an example of intelligent design. I see it as a prime counterexample.

First, clotting is *not* irreducibly complex. People lacking one of various clotting factors can survive to reproductive age. Second, the clotting system can be improved upon. Trauma patients benefit from low doses of exogenous heparin, and older people benefit from taking aspirin to inhibit platelet aggregation. Truly intelligent design would have equipped the body to provide sufficient heparin and to down-regulate platelet prostaglandin production as a person ages. Third, multiple layers of control are exactly what one would expect to result from evolution by mutation and selection. Each layer of control incrementally improves the system. I suspect that most examples of intelligent design look more like products of mutation and selection to those who study them in detail.

Allen A. Smith
Miami Shores, Florida

Thank you for the excellent presentation. The weak intelligent-design arguments were satisfactorily dispatched, and Ian Tattersall ("Endpaper") explained the lack of relationship between science and religion very well. As a secularist, I am fed up with the way the current marriage of religion and politics is forcing religious opinions down the collective public throat. I want my grandchildren to have the benefit of a good science education, not religious indoctrination. I wish copies of this issue of *Natural History* could be sent to every school board in the country.

Ann J. Phillips
via e-mail

The pieces by authors Behe, Dembski, and Wells consisted mostly of unsubstantiated claims and flawed analogies. In contrast, the counterarguments offered specific scientific results as supporting evidence. I can only speculate that the intelligent-design writers were misinformed, or at least not told that rebuttals would be published as well.

Jeffrey D. Lee
New York, New York

EDITORS' NOTE: The three intelligent-design writers were aware that their essays would be answered by evolutionists.

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

No kings. No magicians. No ladies of the lake. No singing swords.

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Patrick Henry

Thomas Jefferson

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CONTRIBUTORS

Robert S. White ("The Ice Above, the Fire Below," page 42), left, is a professor of geophysics at the University of Cambridge and leads a research group investigating volcanism and rifting in a variety of geological environments. In recent years, their work has involved terrestrial investigations (in Iceland, the Faeroe Islands, India, East Africa, and New Zealand) as well as surveys at sea (in the Indian Ocean and the Sea of Marmara and on the Mid-Atlantic Ridge and the rifted continental margins of Europe). During his twenty-seven-year career, photographer **Ragnar Th. Sigurdsson** has amassed an archive of 130,000 images, many related to the geology of his native Iceland. He has also repeatedly been drawn to the Faeroe Islands, Greenland, and Canada's far northwest.

Botanist **Rob Nicholson** ("A Beautiful Hand," page 50) became intrigued by the works of landscape artist Frederic E. Church after visiting the Hudson River school wing of the Wadsworth Atheneum Museum of Art in Hartford, Connecticut. Astonished by the accurate detail that only a close inspection of the canvases reveals, he has since sought out Church's work throughout the country. Nicholson has written other articles for *Natural History,* most recently on the angel's-trumpet trees of South America ("Flowers of Evil," 2/02). He is the conservatory manager of the Botanic Garden of Smith College, where the greenhouses contain 3,000 non-hardy plants from around the world. Founded in the late nineteenth century, it is one of the oldest continuously operating conservatories in the United States (see www.smith.edu/garden/).

Alexander V. Badyaev ("Avian Quick-Change Artists," page 58) knows just when his interest in finches began. As a child growing up in Moscow, he was given a pair of European goldfinches that his parents had bought at an open-air market. By the time Badyaev, right, was a university freshman, he was keeping and observing more than fifty finch species, and he eventually conducted a seven-year study of finch breeding biology in the Himalaya and in the Pamir region of central Asia. Badyaev has studied house finches since 1994 and is now an assistant professor of ecology and evolutionary biology at the University of Arizona, Tucson. **Geoffrey E. Hill** has studied sexual selection in house finches since 1987. A professor of biological sciences at Auburn University in Auburn, Alabama, Hill works primarily on the evolution of colorful plumage—in particular, the carotenoid-based reds and yellows of house finches and, most recently, blue coloration in other songbirds. Due out this summer from Oxford University Press is his book *A Red Bird in a Brown Bag: The Function and Evolution of Colorful Plumage in the House Finch.*

On their first joint photographic assignment in the mid-1970s, husband-and-wife team **John Eastcott** and **Yva Momatiuk** ("The Natural Moment," page 80) lived for several months with a group of semi-nomadic Canadian Inuit. During the ensuing quarter century, they have covered the gamut of wildlife and cultural subjects and have published their work in such magazines as *National Geographic, Smithsonian,* and *Audubon.* Although they have traveled widely, Momatiuk and Eastcott say they still find themselves particularly drawn to "the vast northern expanses of land where human communities are small and scattered." On the Alaskan tundra, they came nose to nose with the young arctic fox featured this month and were able to observe its hunting for about an hour and a half.

AT THE MUSEUM

Cold Storage

The Ambrose Monell Collection of tissue samples—held in nitrogen-cooled freezer vats in the Museum's basement—promises to be a world-class library of molecular biodiversity.

By Henry S. F. Cooper Jr.

PHOTOGRAPHS BY DENIS FINNIN; AMNH

Robert H. Hanner in the lab

For years, thousands of samples of organic tissue—bits of beetles, liver cells of birds, vials of elephant blood, skins of snakes, various other ingredients for a sorcerer's brew—were stashed away in freezers all over the Museum. Only a few researchers knew what was in a particular freezer, and no one had any idea of the total inventory of the Museum's tissue collection.

All this laid-back, informal treatment of specimens came to an end with the opening, last year, of the Ambrose Monell Collection for Molecular and Microbial Research. Housed in a series of four windowless, battleship-gray rooms, the collection is a repository for all of the Museum's stray bits and pieces of tissue, plus a great many more samples that the frozen-tissue laboratory hopes to acquire. As researchers apply the techniques of molecular biology to an ever widening suite of fields (genetics, taxonomy, conservation), the demand for tissues of a vast array of organisms from every corner of the animal kingdom continually increases. With room ultimately for more than a million samples (including some plant specimens), the Monell Collection is the largest cryogenic storage facility to be established within a museum anywhere in the world. Visitors from the Smithsonian, the British Museum, the Field Museum, and other institutions are touring the premises with an eye to the sincerest form of flattery: emulation.

The samples (6,000 have been processed thus far) are kept on removable racks in an array of large cryogenic containers known as Cryovats. Unlike conventional freezers, these are fueled by liquid nitrogen, which generates a vapor that maintains the very, very cold temperatures (no higher than -150° C) needed to keep tissues from degrading. Each of the cauldronlike vats is vacuum insulated in the manner of a thermos bottle; when a technician opens a lid, clouds of nitrogen vapor pour out as frothily as from any witch's cauldron.

The curatorial associate in charge of the Monnell Collection, Robert H. Hanner, requires the technicians to wear aprons, gloves, and masks. "You have to watch out for the nitrogen," he told me as we toured the laboratory. "It's heavier than air, so if there's a leak, it displaces the oxygen around you. Because it's colorless, tasteless, and odorless, you have no way of knowing if you're walking into an oxygen-

depleted environment. You get a little giddy, and maybe you pass out and fall to the floor. Your corneas can freeze." To my relief, he showed me a meter that monitors the oxygen level. If the level falls below 19.5 percent, an alarm will go off—but so far, no alarm.

In 1992, after Hanner graduated from Eastern Michigan University, he spent a year at the Museum as an intern in Rob DeSalle's Molecular Systematics Laboratory. There he got his first taste of applying the tools of molecular biology to systematics and phylogenetic research. Hanner brought some of these techniques with him to the University of Oregon, where he studied evolutionary relationships among a variety of arthropod lineages, earning his Ph.D. in December 1997. A month later, he was back at DeSalle's laboratory. Both men saw the need for a centralized tissue bank, and while DeSalle and AMNH administrators found the funding, Hanner worked out the details of using cryogenics to process and store the samples.

Because much of the work in coming years will consist of processing and inventorying samples, I asked Hanner to take me through the routine. First of all, since DNA degrades quickly, he uses the freshest possible tissue. To avoid contaminating a specimen—as well as being contaminated by microbes *from* the specimen—the gloved, masked, and white-coated Hanner uses a "biological safety cabinet" for preliminary preparations. The air pressure inside this glass-enclosed chamber is lower than the pressure outside, so air is sucked downward through a slit along the sill, which prevents dangerous aerosols from escaping.

Hanner begins by taking samples from a specimen and putting each one in a separate vial. Then he labels, weighs, and indexes them, places them on a rack, and puts the rack in the Cryovat. The indexing is, of course, essential, because a sample without a provenance is useless. Each will be related to its source—what Hanner calls a voucher specimen—which could be a living animal supplied by the Wildlife Conservation Society (WCS) or a freeze-dried carcass from AMNH's Department of Mammalogy. Besides Hanner, the laboratory employs a full-time collection manager, three part-time technicians, and several interns, all of whom help manage the collection's database. (The technicians also keep track of how often a sample is thawed; like meat in a freezer, the samples degrade with repeated defrosting.) This database will contain, whenever possible, digital images of voucher specimens and of the animals' environments, including the Global Positioning System coordinates of where they were found. Small animals, such as mosquitoes, are frozen whole—the sample and the voucher specimen being one and the same. In the case of larger animals, a given specimen might be represented by a dozen samples, taken from a dozen different organs or tissues. Having a precise identification of these samples is essential for doing experiments, and part of Hanner's job involves convincing the research community of the importance of properly identifying voucher specimens.

Small animals are frozen whole, but a given specimen of a larger animal might be represented by samples taken from a dozen different organs or tissues.

The Monell Collection operates a little like a bank, soliciting and accepting deposits and granting loans (sample loans to researchers must be approved by peer review). Unlike a bank, however, the only payment the lab requires is for mailing out the samples, which usually are not returned, because they can't be used again. The uses of the collection's tissues in research are as broad as the intersections between molecular biology, genetics, and natural history. Systematists will be able to define species: Are these two wildly different-looking beetles separate species, or are they the male and female of the same one? Geneticists will be able to track the same set of genes across a variety of species—say, the genes for backbones in vertebrates. Researchers at the National Institutes of Health might want to compare certain human genes with those of gorillas, and because the tissues of this endangered species are difficult to come by, the lab will get them from captive animals, through the WCS. Though Hanner does not see cloning as a major research function of the lab, he and his colleagues may allow the WCS to store gametes (reproductive cells) of endangered species in the Cryovats for purposes of captive breeding.

Already, several researchers—including Rob DeSalle, who is sequencing genes from several hundred species of fruit flies—have deposited or withdrawn samples. And Hanner hopes one day to return to researching molecular evolution in arthropods, becoming himself a customer of the Monell.

Henry S. F. Cooper Jr., a former staff writer for the New Yorker, *has been visiting the Museum since he was four years old, when his father sat him in a cavity of the Willamette meteorite.*

MUSEUM EVENTS IN JUNE

"BASEBALL AS AMERICA"

Lecture 6/4: "Baseball on the Moon." Physicist Peter Brancazio, Brooklyn College. Kaufmann Theater, 7:00 P.M.

Panel 6/11: "New York Stories: Willie, Mickey, or Duke?" Moderator: Marty Appel, author of *Now Pitching for the Yankees*. Panelists: Robert Creamer, *Sports Illustrated;* Maury Allen, baseball biographer: Ira Berkow, *New York Times*. Kaufmann Theater, 7:00 P.M.

AMNH BOOK CLUB

Monthly meeting 6/9: *Salt: A World History*, by Mark Kurlansky. Details at (212) 769-5200. Portrait Room, 3:00 P.M.

INSIDE AND OUTSIDE THE MUSEUM

Children's workshop 6/2: "Dinosaur Expedition." For ages 9–10. Museum instructor Lisa Breslof. 10:30 A.M.–1:30 P.M.

University Without Walls 6/3–6/27 (telephone courses): "Sharks: Denizens of the Deep"; "Myths of Masks and Symbols"; and "Seeds of Change." Advance registration required. Details from DOROT at (212) 769-2850 or toll-free at (877) 819-9147.

Identification Day 6/8: Bring in your curios, natural and cultural objects, and baseball treasures. Museum scientists and Joshua Leland Evans, of Leland's sports auction house, will help you learn more about them. Note: no appraisals; no identification of gemstones. Details at (212) 769-5176. Hall of Birds of the World and Leonhardt People Center, 1:00–4:30 P.M.

Games 6/8: Participate in or watch demonstrations, workshops, and other activities (including a day-long "pro" game of Strat-O-Matic). Leonhardt People Center and Calder Lab, 1:00–4:30 P.M.

Workshops 6/6, 6/20: Introductory talk and instruction provides a basic understanding of genomics and DNA sequencing procedures. Calder Lab, 6:00–9:00 P.M.

Children's workshop 6/9: "Crime Lab Investigation." For ages 8–9. Museum instructor Lisa Breslof. 10:30 A.M.–1:30 P.M.

Field trip 6/11: "Up the Hudson River Toward the Tappan Zee." Sidney Horenstein, Museum coordinator of environmental programs. 6:00–9:00 P.M.

Panel discussion 6/12 (Reports From the Field series): "Lines in the Water: Nature and Culture at Lake Titicaca." Author and environmentalist Benjamin Orlove and Museum scientists Craig Morris and Melanie Stiassny. Linder Theater, 7:00 P.M.

Field trip 6/18: "Down the Hudson River Into the Bay." Sidney Horenstein. 6:00–9:00 P.M.

Other expeditions: Inwood Hill and Henry Hudson Bridge; birds of Jamaica Bay; Thacher State Park and Mohonk Preserve.

Information and reservations for all programs: (212) 769-5200.

ACOMA PUEBLO POTTERY

Lecture 6/3: "Acoma Pottery." AMNH anthropology curators David Hurst Thomas and Peter Whiteley. Kaufmann Theater, 7:00 P.M.

Workshops 6/4, 6/5: Basics of Acoma pottery, with Emma and Dolores Lewis. Held at YMCA, 5 W. 63rd St., 7:00–10:00 P.M.

Film 6/6: *Daughters of the Anasazi*. Documentary on Acoma potter Lucy Lewis and her daughters. Discussion with Emma and Dolores Lewis and AMNH anthropologist Lori Pendleton. Kaufmann Theater, 7:00 P.M.

Three-day workshop and lectures 6/7–6/9: More techniques of Acoma pottery, with Emma and Dolores Lewis. YMCA, 5 W. 63rd St., 10:00 A.M.–5:00 P.M.

Information and reservations: (212) 769-5200.

ASTRONOMY & COSMOLOGY

Lecture 6/3 (Frontiers in Astrophysics series): "Einstein's Biggest Blunder? The Case for Cosmic 'Antigravity.'" Astronomer Alex Filippenko, University of California, Berkeley. Space Theater, Hayden Planetarium, 7:30 P.M.

Isaac Asimov Memorial Panel Debate 6/10: "The Search for Life in the Universe." LeFrak Theater, 7:30 P.M.

July's Celestial Highlights 6/25: Joe Rao, meteorologist and *Natural History* columnist. Space Theater, Hayden Planetarium, 6:30 P.M.

Planetarium information: (212) 769-5200 or www.amnh.org/hayden/.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5200 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

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IMAX FILMS

"The Best of IMAX" festival 6/2–6/23: *Grand Canyon: The Hidden Secrets; To Fly!;* and *Shackleton's Antarctic Adventure*.

Regular IMAX screenings resume 6/24: *Kilimanjaro: To the Roof of Africa* and *Bears*.

The 950-seat Samuel J. and Ethel LeFrak Theater, first constructed in 1900, reopens 6/2 after an $8 million renovation funded by the Samuel J. and Ethel LeFrak Charitable Foundation.

SAMPLINGS

By Stéphan Reebs

WOOLLY ANCESTRY

Few animals are better emblems of South America than the quartet formed by the llama, the alpaca, the vicuña, and the guanaco. Both the llama and the alpaca are domesticated forms long believed to be descended from the guanaco, a wild camelid. But a new genetic analysis, done by Miranda Kadwell, of the Institute of Zoology in London, and colleagues from both Great Britain and South America, suggests that the alpaca may be more closely related to the vicuña, also a wild species.

Alpaca-llama hybrids above Machu Picchu, Peru

GEORGE HOLTON; PHOTO RESEARCHERS, INC.

As much as 90 percent of South America's native domestic livestock was lost during the century following the Spanish conquest. Since then, alpacas and llamas have been extensively hybridized. To make sense of the consequently complex genetic picture, the researchers combined a number of DNA markers. Analysis of mitochondrial DNA, which is inherited only from the mother, supported the traditional view of a guanaco-alpaca lineage. However, several other genetic markers—ones that are passed along by both the mother and the father, and thus may give a more reliable and complete picture of the hybridization history—pointed to the vicuña as the probable ancestor of the alpaca.

Untangling the history of these animals would be of more than purely academic interest. Both the domesticated alpaca and the wild vicuña are exploited for their fleece. Unprocessed vicuña fleece is extremely fine and can fetch about $200 a pound, making it the most expensive natural fiber in the world and an important source of income for rural people. By contrast, after years of alpaca-llama hybridization, the fleece of alpacas has lost its fineness and sells for less than $10 a pound. If the alpaca is indeed a descendant of the vicuña, geneticists might be able to identify pure-bred alpacas and guide new breeding programs to improve the quality of alpaca fleece. ("Genetic Analysis Reveals the Wild Ancestors of the Llama and the Alpaca," *Proceedings of the Royal Society of London* B 268, 2001)

STICKY SITUATION

When sleeping, Spix's disk-winged bat does not hang upside down by its toes, as do many other bats. Instead, this inhabitant of lowland forests from Mexico to Brazil tucks itself inside a furled young *Heliconia* leaf. In addition to being tubelike, young *Heliconia* leaves are smooth and point upward. Scientists had long assumed that the bat manages to hold on to the leaf by using four disk-shaped structures—one on each wrist and ankle—as suction cups. To test this idea experimentally, Daniel K. Riskin and M. Brock Fenton, of York University in Toronto, caught some disk-winged as well as some diskless bats in Costa Rica and compared their ability to hang on to different types of materials positioned at various angles.

Spix's disk-winged bats in *Heliconia* leaf; disk (inset)

PHOTOS BY MERLIN D. TUTTLE; BAT CONSERVATION INT'L

Suction cups can maintain a vacuum on solid and smooth surfaces but not on porous or rough ones. As predicted, the disk-winged bats slid helplessly down sandpaper and perforated aluminum, while the diskless bats held on to the bumps and holes with their claws. On smooth Plexiglas or solid aluminum, however, the Spixes had no problem holding tight, even when they were completely upside down, while bats of the other species lost their grip at angles greater than 45°.

Two anatomical twists are worth mentioning. Sweat glands keep the disks' undersurfaces moist, which helps preserve a vacuum seal and contributes further to their sticking power. Moreover, beneath each disk is a tendon that is linked to a muscle whose action controls the vacuum, both creating it and, when the bat wants to come unstuck, undoing it. ("Sticking Ability in Spix's Disk-Winged Bat, *Thyroptera tricolor* [Microchiroptera: Thyropteridae]," *Canadian Journal of Zoology* 79, 2001)

OLD PARTNERS Organisms preserved in amber (hardened resin from trees) are prized by paleontologists because of the fine details they retain. Such specimens are not rare, but gaining access to them without damaging them can be tricky. It was therefore with trepidation that David Grimaldi, of the American Museum of Natural History, recently broke open several pieces of amber to reach eight primitive termites that had been trapped within the resin 15–20 million years ago, in what is now the Dominican Republic. After dissecting the termites, he gave their guts to Andrew Wier, of the University of Massachusetts, Amherst, to examine under an electron microscope. Grimaldi and Wier were part of a team that was hoping to find the preserved remains of tiny wood-digesting organisms and then to determine how similar they were to microorganisms that live today in the hindguts of *Mastotermes darwiniensis*, the only surviving cousin of the amber prisoners.


Termite in amber

J. BECKETT; AMNH

The researchers were not disappointed. The gut sections revealed not only bits of wood but also numerous protists and bacteria, including large spirochetes. The amazing preservation meant that cell walls, even nuclei and tubules inside cells, were clearly visible. The fossil microbes were strikingly like the modern-day gut residents that break down the wood eaten by *M. darwiniensis*—a sign of remarkable stability in the evolutionary story of this ancient partnership. ("Spirochete and Protist Symbionts of a Termite *[Mastotermes electrodominicus]* in Miocene Amber," *Proceedings of the National Academy of Sciences* 99:3, 2002)

DELAYED ACTION Some years, the number of long-legged wading birds nesting in Florida's Everglades—white ibis, snowy egret, tricolored heron, and the like—shoots up to about four times its normal level. Peter C. Frederick, of the University of Florida, and John C. Ogden, of the South Florida Water Management District, noticed such an increase in 1992 after three years of severe drought. Intrigued, the two biologists decided to examine a thirty-eight-year record of weather and nesting data from the Everglades. They found that high concentrations of breeding birds usually appeared one to two years after a drought.

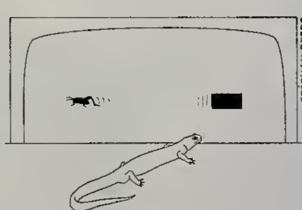
Frederick and Ogden propose two explanations for this pattern. First, dry spells often trigger fires, which release ash and other organic goodies into the otherwise nutrient-poor Everglades environment. When reflooding takes place, these resources are taken up by vegetation and help build abundant fish and invertebrate communities on which the birds can feed. Second, while all fish populations take a hit in their rapidly shrinking world during a drought, the smaller, omnivorous species may bounce back explosively afterward; the mosquito fish, for example, can breed every three months. Larger fishes that normally prey on smaller ones take longer to rebuild their numbers. For a while, the birds can feast on the bounty of small fish and breed in high numbers. These hypotheses must now be tested—finally, perhaps, a reason to look forward to the next dry summer. ("Pulsed Breeding of Long-Legged Wading Birds and the Importance of Infrequent Severe Drought Conditions in the Florida Everglades," *Wetlands* 21:4, 2001)


Egrets in the Everglades

JEFF LEPORE; PHOTO RESEARCHERS, INC

EXPERIMENT OF THE MONTH

In a study of how the terrestrial salamander *Plethodon jordani* detects and evaluates prey, German researchers Niklas Schülert and Ursula Dicke, of the University of Bremen, placed several of the amphibians in front of a monitor and presented them with footage of crickets and cricket-shaped rectangles on the move. They used computer programs to change the size and speed of the moving images. At first, the salamanders saw two different images in the middle of the screen. Both images then moved off in different directions, and the scientists noted which way the salamanders turned their heads or bodies.


Salamander viewing "prey" on computer screen

STÉPHAN REEBS

Schülert and Dicke found that a simple rectangle of about the same size, and moving at the same speed, as a real cricket held the salamanders' attention better than did a more realistic image of a small or slow-moving cricket. Apparently, the exact shape of prey need not be encoded in a salamander's brain; rather, size and speed are the paramount stimuli. In this regard, salamanders are not very different from the typical moviegoer—that is, if the computer-generated special effects of Hollywood productions are anything to go by. ("The Effect of Stimulus Features on the Visual Orienting Behaviour of the Salamander *Plethodon jordani*," *Journal of Experimental Biology* 205, 2002)

Stéphan Reebs is a professor of biology at the Université de Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild *(Cornell University Press).*

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FINDINGS


THE CHEAT, BY GEORGES DE LA TOUR (1635). PHOTO: ERICH LESSING; ART RESOURCE, NY.

Cheaters and Chumps

Game theorists offer a surprising insight into the evolution of fair play.

By Robert M. Sapolsky

Since well before the time of Dostoyevsky, people have thought about crime, punishment, and their interconnections. Why punish society's miscreants? To change, reform, or rehabilitate them? To deter potential wrongdoers? To make the victims and punishers feel better? Research by Ernst Fehr and Simon Gächter, published in the January 10, 2002, issue of the eminent science journal *Nature,* shows an unappealing aspect of social behavior in action, as well as the unexpected good that can come of it.

Whether you are a diplomat or a negotiator, an economist or a war strategist or just an ordinary person navigating the shoals of everyday life, sometimes you have to decide whether to behave cooperatively with other individuals, be they partners, competitors, or outright opponents. The same necessity arises among certain social animals in the wild. Just to pick one example, classic work by Gerald Wilkinson, of the University of Maryland, has shown that female vampire bats are continually confronted with strategic choices. After drinking the blood of prey species (such as cattle), the females fly back to large communal nests, where they feed the baby bats by disgorging the blood into their mouths. The females must choose: Do they feed only their own young, their own plus those of close relatives, or everyone's? And should the decision depend on what all the other bats are doing?

These questions of altruism, reciprocity, and competition are grist for the mill in game theory, a branch of mathematics applied to human behavior. Participants in game-theory experiments play pared-down games, with varying degrees of communication among the players, and are given differing rewards for differing outcomes. Players must decide when to cooperate and when—to use a highly technical game-theory term—to "cheat." Game

theory gets taught in all sorts of academic programs. And it turns out that social animals, even without M.B.A.'s, have often evolved strategies for deciding when to cooperate and when to cheat. According to Joan E. Strassmann, of Rice University, even social bacteria have evolved optimal strategies for stabbing each other in the back.

Suppose you have an ongoing game, a round-robin tournament that involves two participants playing against each other in each round. The rules of the game are such that if both cooperate with each other, they both get a reward. And if both cheat, they both do poorly. On the other hand, if one cheats and the other cooperates, the cheater gets the biggest possible reward, and the cooperator loses big-time. Another condition is that the players in the tournament can't communicate with one another and therefore cannot work out some sort of collective strategy. Given these constraints, the only logical course is to avoid being a sucker and to cheat every time. Now suppose some players nonetheless figure out methods of cooperating. If enough of them do so—and especially if the cooperators can somehow quickly find one another—cooperation would soon become the better strategy. To use the jargon of evolutionary biologists who think about such things, it would drive noncooperation into extinction.

Get cooperation going among a group of individuals, and the group is eventually going to be in great shape. But whoever starts that trend (the first to spontaneously introduce cooperation) is going to be mathematically disadvantaged forever after. This might be termed the what-a-chump scenario. In an every-bacterium-for-himself world, when one addled soul does something spontaneously cooperative, all the other bacteria in the colony chortle, "What a chump!" and go back to competing—now one point ahead of that utopian dreamer. In this situation, a random act of altruism doesn't pay.

Yet systems of reciprocal altruism do emerge in various social species, even among us humans. Thus, the central question in game theory is: What circumstances bias a system toward cooperation?

One well-studied factor that biases toward cooperation is genetic relatedness. Familial ties are the driving force behind a large proportion of cooperative behaviors in animals. For example, individuals of some social insect species display such an outlandishly high degree of cooperation and altruism that most of them forgo the chance to reproduce and instead aid another individual (the queen) to do so. The late W. D. Hamilton, one of the giants of science, revolutionized thinking in evolutionary biology by explaining such cooperation in terms of the astoundingly high degree of relatedness among an insect colony's members. And a similar logic runs through the multitudinous, if less extreme, examples of cooperation among relatives in plenty of other social species, such as packs of wild dogs that are all sisters and cousins and that regurgitate food for one another's pups.

Many animals—and even some bacteria—have evolved strategies for deciding when to cooperate and when to stab one another in the back.

Another way to jump-start cooperation is to make the players *feel* related. This fostering of pseudokinship is a human specialty. All sorts of psychological studies have shown that when you arbitrarily divide a bunch of people into competing groups (the way kids in summer camp are stuck into, say, the red team and the blue team), even when you make sure they understand that their grouping is arbitrary, they'll soon begin to perceive shared and commendable traits among themselves and a distinct lack of them on the other side. The military exploits this tendency to the extreme, keeping recruits in cohesive units from basic training to frontline battle and making them feel so much like siblings that they're more likely to perform the ultimate cooperative act. And the flip side, pseudospeciation, is exploited in those circumstances as well: making the members of the other side seem so different, so unrelated, so un-human, that killing them barely counts.

One more way of facilitating cooperation in game-theory experiments is to have participants play repeated rounds with the same individuals. By introducing this prospect of a future, you introduce the potential for payback, for someone to be retaliated against by the person she cheated in a previous round. This is what deters cheaters. It's why reciprocity rarely occurs in species without cohesive social groups: no brine shrimp will lend another shrimp five dollars if, by next Tuesday, when the loan is to be repaid, the debtor will be long gone. And this is why reciprocity also demands a lot of social intelligence—if you can't tell one brine shrimp from another, it doesn't do you any good if the debtor will actually still be around next Tuesday. Zoologist Robin Dunbar, based at University College London, has shown that among the social primates, the bigger the social group (that is, the more individuals you have to keep track of), the larger the relative size of the brain. Of related interest is the finding that vampire bats, which wind up feeding one another's babies in a complex system involving vigilance against cheaters, have among the largest brains of any bat species.

An additional factor that biases toward cooperation in games is "open book" play—that is, a player facing someone in one round of a game has access to the history of that opponent's gaming behavior. In this scenario, the same individuals needn't play against each other repeatedly in order to pro-

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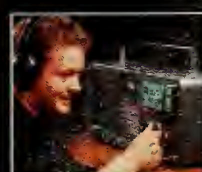

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duce cooperation. Instead, in what game theorists call sequential altruism, cooperation comes from the introduction of reputation. This becomes a pay-it-forward scenario, in which A is altruistic to B, who is then altruistic to C, and so on.

So game theory shows that at least three things facilitate the emergence of cooperation: playing with relatives or pseudorelatives, repeated rounds with the same individual, and open-book play. And this is where Fehr and Gächter's new study, a "public goods experiment," comes in. The authors set up a game in which all the rules seemed to be stacked against the emergence of cooperation. In a "one-shot, perfect-stranger" design, two individuals played each round, and while there were many rounds to the game, no one ever played against the same person twice. Moreover, all interactions were anonymous: no chance of getting to know cheaters by their reputations.

Here's the game. Each player of the pair begins with a set amount of money, say $5. Each puts any part or all of that $5 into a mutual pot, without knowing how much the other player is investing. Then a dollar is added to the pot, and the sum is split evenly between the two. So if both put in $5, they each wind up with $5.50 ($5 + $5 + $1, divided by 2). But suppose the first player puts in $5 and the second holds back, putting in only $4? The first player gets $5 at the end ($5 + $4 + $1, divided by 2), while the cheater gets $6 ($5 + $4 + $1, divided by 2—plus that $1 that was held back). Suppose the second player is a complete creep and puts in nothing. The first player has a loss, getting $3 ($5 + $0 + $1, divided by 2), while the second player gets $8 ($5 + $0 + $1, divided by 2—plus the $5 held back). The cheater always prospers.

But here's the key element in the game: Players make their investment decisions anonymously, but once the decisions are made, they find out the results and discover whether the other player cheated. At this point, a wronged player can punish the cheater. You can fine the cheater by taking away some money, as long as you're willing to give up the same amount yourself. In other words, you can punish a cheater if you're willing to pay for the opportunity.

The first interesting finding is that cooperation—which in the narrowly defined realm of this particular game means simply the steady absence of cheating—emerges even with the one-shot, perfect-stranger design. Cheaters stop cheating when punished.

People who have been cheated jump at the chance to punish the cheater, even if it means incurring a cost to themselves.

Now comes the really interesting part. The authors showed that everyone jumps at the chance to punish the cheater, even when it means that the punisher will incur a cost. And remember the one-shot, perfect-stranger design: punishing brings no benefit to the punisher. Because the two players never play together again, there's no possibility that punishment will teach the cheater not to mess with you. And because of the anonymous design, the opportunity to punish doesn't warn other players about the cheater. Embedded in the open-book setting, by contrast, is an incentive to pay for the chance to conspicuously punish: you hope that other players do the same, thereby putting the mark of Cain on an untrustworthy future opponent. And various social animals will pay a great deal, in terms of energy expenditure and risk of injury, to punish open-book cheaters (one way to encourage this in an open-book world is to use the approach of certain military academies whose honor codes punish those who fail to punish cheaters). But here the act of punishing is as anonymous as was the act of cheating.

In Fehr and Gächter's game, no good can come to the punisher from being punitive, but people avidly do it anyway. Why? Simply out of the desire for revenge. The authors show that the more flagrant the cheaters are (in terms of how disproportionately they have held back their contributions), the more others will pay to punish them. This is true even of newly recruited players, unsavvy about any of the game's subtleties.

Think about how weird this is. If people were willing to be spontaneously cooperative even if it meant a cost to themselves, this would catapult us into a system of stable cooperation in which everyone profits. Think peace, harmony, Lennon's "Imagine" playing as the credits roll. But people aren't willing to do this. Establish instead a setting in which people can incur costs to themselves by punishing cheaters, in which the punishing doesn't bring them any direct benefit or lead to any direct civic good—and they jump at the chance. And then, indirectly, an atmosphere of stable cooperation just happens to emerge from a rather negative emotion: desire for revenge. And this finding is particularly interesting, given how many of our societal unpleasantries—perpetrated by the jerk who cuts you off in traffic on the crowded freeway, the geek who concocts the next fifteen-minutes-of-fame computer virus—are one-shot, perfect-stranger interactions.

People will pay for the chance to punish, but not to do good. If I were a Vulcan researching social behavior on Earth, this would seem to be an irrational mess. But for a social primate, it makes perfect, if ironic, sense. Social good emerges as the mathematical outcome of a not particularly attractive social trait. I guess you just have to take what you can get.

Robert Sapolsky is a professor of biology and neurology at Stanford University and author of A Primate's Memoir *(Scribner, 2001).*

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Hollywood Nights

ROBERT GROSSMAN

When it comes to astronomical accuracy in the movies, nobody's getting any Oscars.

By Neil deGrasse Tyson

Few things are more annoying to avid moviegoers than seeing a film with rude hyperliterate friends who can't resist making comments about why the book was better. These people babble on about how the characters in the novel were more fully developed or how the original story line was more meaningful. In my opinion, they should just stay home and leave the rest of us to enjoy the film.

With this anti-intellectual attitude, I ought to be mute every time I detect scientific ignorance in a movie's story or set design. But I am not. On selected occasions, I can be more annoying to my fellow moviegoers than the bookworms are. Over the years, I have collected egregious errors from Hollywood's attempts to portray or engage the cosmos, and I can no longer keep them to myself.

My list, by the way, does not consist of bloopers. A blooper is a mistake that the producers or continuity editors happened to miss but would normally have caught and fixed. My list includes only movie astro-errors that were willingly introduced and indicate a profound lack of attention to easily verifiable detail. I would further assert that none of the writers, producers, or directors in question passed Astronomy 101 in college.

Let's start at the bottom.

At the end of the 1979 Disney film *The Black Hole,* which has a place on many people's ten-worst-movies list (including mine), an H. G. Wellsian spaceship loses control of its engines and plunges into a black hole. What more could special-effects artists ask for?

Let's see how well they did.

Was there any attempt to portray the extreme time dilation near the black hole's event horizon, with the universe around the doomed crew evolving rapidly over billions of years while the crew members themselves aged only a few ticks of a clock? No. Were the craft and its crew ripped apart by the ever-increasing tidal forces of gravity as they approached the singularity—something a real black hole would do to them? No. One scene did show a

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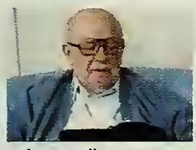

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swirling disk-shaped nebula surrounding the black hole. Good. Black holes do this sort of thing with gas that falls toward them. But did elongated jets of matter and energy spew forth from each side of the disk? No. Lastly, did the ship travel through the black hole and get spit out into another time? Into another part of the universe? Into another universe altogether? No, no, and no. Instead of working with these cinematically fertile and cutting-edge ideas, the filmmakers depicted the black hole's innards as a dark cave filled with fiery stalagmites and stalactites, as though we were touring the hot and smoky basement of Carlsbad Caverns.

Some people may think of these scenes as expressions of the director's poetic or artistic license, which allows him to invent whimsical cosmic imagery without regard to the real universe. But given how lame the scenes were, it's more likely to have been an expression of the director's scientific ignorance.

Is it from license or ignorance that nearly every Moon ever painted by artists is either a crescent or full? During half of any month, the Moon is another shape. And if you paint a full Moon in the spot where the Moon of another phase should have been, you unwittingly alter the time of night for the depicted scene. I remember one famous painting in which a full Moon is high in the sky while children are playing in the streets and supper is being prepared in the surrounding cottages. Either the townspeople eat dinner at midnight or the artist was without a clue. When the 1989 movie *New York Stories* was being filmed, Francis Ford Coppola's cinematographer called my office to ask when and where the full Moon could best be seen rising over the Manhattan skyline. When I instead offered him the first-quarter Moon or the waxing gibbous Moon, he was unimpressed. Only the full Moon would do.

Although I rant, there's no doubt that creative contributions from the world's artists would be poorer in the absence of artistic license. Among other losses, we would have neither impressionism nor cubism. But what distinguishes good artistic license from bad is whether or not the artist is well informed before the creativity begins. Perhaps Mark Twain said it best: "First get your facts; then you can distort them at your leisure."

For the 1997 blockbuster movie *Titanic*, director and producer James

Any amateur astronomer watching James Cameron's Titanic *would spot the fake sky immediately.*

Cameron invested heavily not only in special effects but in recreating the ship's luxurious interiors. From the wall sconces to the patterns on the china and silverware, no detail was too small to attract the attention of Mr. Cameron, who made sure to reference recently salvaged artifacts from the sunken ship lying more than two miles under the surface of the sea. Furthermore, he carefully researched the history of fashion and social mores to ensure that his characters dressed and behaved in ways generally consistent with life in the year 1912. Aware that only three of the vessel's four engines were used on that maiden voyage from Southampton, England, to New York City, Cameron correctly showed smoke spewing from only three stacks. We have accurate records of the date and time the ship sank, the weather conditions, and the longitude and latitude of the site: Cameron captured these elements, too.

With all this attention to detail, you'd think this director would have paid a bit more attention to the stars and constellations visible on that fateful night.

He didn't.

In the movie, the Hollywood stars above the *Titanic* bear no correspondence whatsoever to any constellations in the real sky. Worse yet, as the heroine hums a tune while bobbing on a slab of wood in the freezing waters of the North Atlantic, she stares straight up: stars on the right are the mirror image of stars on the left. How lazy can you be? To get an accurate sky would not have required a major adjustment to the film's budget.

What's odd is that hardly any moviegoers would know whether or not Cameron captured his china and silverware patterns accurately. Yet any amateur astronomer could spot the fake sky instantly. And anybody can go out and choose one of a dozen programs for the home computer that display the real sky for any time of day, any day of the year, any year of the millennium, and any spot on Earth.

On one occasion, however, Cameron exercised artistic license commendably. After the *Titanic* sinks, you see countless people (dead and alive) floating in the water. Of course, on this moonless night in the middle of the ocean, you would barely have seen your hand in front of your face. Cameron needed to illuminate the scene so that the viewer could follow the rest of the story. The lighting is soft and sensible, with no obvious shadows to disclose a light source and further embarrass the director.

The only time I ever bothered to compose a letter complaining about a cosmic mistake was after I saw the 1991 romantic comedy *L.A. Story*, written and co-produced by Steve Martin. In this film, he uses the Moon to track time by showing its phase progressing from crescent to full. No big deal. The Moon just hangs there in the sky from night to night. I applaud Mr. Martin's effort to engage the universe in his plotline. However, when viewed from any location north of Earth's equator (Los Angeles qualifies), the real Moon's illuminated surface grows from right to left until it's full. Steve Martin's Hollywood moon grows backward.

My letter to Mr. Martin was polite and respectful, written on the assumption that he would want to know the cosmic truth. Alas, I received no reply, but then again, I was only in graduate school at the time and lacked a weighty letterhead to grab his attention.

In the 1984 mermaid fantasy *Splash*, Daryl Hannah has only six days on dry land with Tom Hanks before having to return to the ocean depths. The director, Ron Howard, tracked these six days using the growing phases of the Moon. Like Steve Martin's moon, this one grows backward. But by that point in the film, I had already bought into the premise that Tom Hanks could fall in love with a buxom fish, so how could I rightly complain about the Moon?

The 1983 macho test-pilot epic *The Right Stuff* had plenty of the wrong stuff. In my favorite transgression, Chuck Yeager, the first person to fly faster than the speed of sound, is shown climbing past 80,000 feet, setting another altitude and speed record. As he ascends supersonically, you see puffy white altocumulus clouds whizzing by. This scene must really irk meteorologists. Forget that it's supposed to take place over the Mojave Desert, where clouds of any species are rare, but no altocumulus cloud anywhere in Earth's real atmosphere would be caught dead above 20,000 feet.

In the film Contact, *a pivotal line delivered by Jodie Foster contains an embarrassing astro-gaffe.*

But without those visual effects, I suppose the viewer would have no sense of how fast the plane is moving. So I understand the motive. But the film's director, Philip Kaufman, was not without choices: other kinds of clouds, such as cirrocumulus and the especially beautiful noctilucent clouds, do exist at very high altitudes, as any intro meteorology course will teach you.

The 1997 film *Contact* contains an especially embarrassing astro-gaffe. Inspired by Carl Sagan's 1983 novel of the same name, *Contact* explores what we might do when making contact with intelligent extraterrestrial life. The heroine is an astrophysicist alien-hunter played by Jodie Foster. One of her pivotal lines, recited while she establishes her love interest in ex-priest Matthew McConaughey, contains mathematically impossible information. As the two of them sit in front of the largest radio telescope in the world, Jodie says with passion: "Out there, just in our galaxy alone, there are 400 billion stars. If only one out of a million of those had planets, and if just one out of a million of those had life, and if just one out of a million of those had intelligent life, there would be literally millions of civilizations out there." Wrong. According to her numbers, that leaves 0.0000004 planets with intelligent life on them, which is a figure somewhat lower than "millions." No doubt "one in a million" sounds better on-screen than "one in ten," but you can't fake math.

Ms. Foster's recitation is not a gratuitous mathematical reference. It is an explicit nod to the famous Drake equation, named for astrophysicist Frank Drake, who first estimated the likelihood of finding intelligent life in our galaxy, basing his estimate on a sequence of factors starting with the galaxy's total number of stars. For this reason, this is one of the most important scenes in the film.

Whom do we blame for the flub?

Not the screenwriters, even though their words were spoken verbatim. I blame Jodie. As the lead actress, she is the last line of defense against errors that might have crept into the screenplay. She must bear some responsibility. Not only that, last I checked, she was a graduate of Yale University. Surely they teach arithmetic there.

During the 1970s and 1980s, the popular television soap opera *One Life to Live* showed the Sun rising while the show opened and setting as the credits rolled at the end. Unfortunately, their sunrise was a sunset shown in reverse. Nobody took the time to notice that on every day of the year in the Northern Hemisphere, the rising Sun moves at an angle up and to the right of the spot on the horizon where it first appears. But when the soap-opera sun rose, it angled to the left. The producers obviously filmed a sunset and played it in reverse for the show's beginning. They were either too sleepy to wake up early and film the sunrise, or the sunrise was filmed in the Southern Hemisphere—after which the camera crew ran to the

Northern Hemisphere to shoot the sunset. Had the producers called their local astrophysicist, they might have been advised to film the sunset in a mirror before running it backward. This would have taken care of everybody's needs.

Of course, inexcusable astro-illiteracy extends beyond television, film, and fine art. The famous star-studded ceiling of New York City's Grand Central Terminal rises high above the countless busy commuters. I would remain silent if the original designers had no pretense of portraying an authentic sky. But the ceiling's half-acre canvas contains among its 2,500 stars a half-dozen real constellations, each traced in its classical splendor, along with the Milky Way, just where you're supposed to find it. Leaving aside the sky's greenish color, which greatly resembles that of Sears household appliances from the 1950s, the sky is backward.

Yes, backward.

This was common practice during the Renaissance, when the same craftsmen made both celestial spheres and Earth globes. When viewing the sky, you stood in a mythical place "outside" the universe, looking down, imagining Earth as the globe's center. The approach works well when you look down on spheres smaller than you but fails miserably when you look up at half-acre ceilings. And amid the backwardness, for reasons I have yet to divine, the stars of Orion face forward, with Betelgeuse and Rigel correctly oriented.

Astrophysics is surely not the only science trod upon by underinformed artists. Naturalists have probably logged more gripes than we have. I can hear them now: "That's the wrong whale song for the species of whale they showed in the film." "Those igneous rocks do not belong in that sedimentary terrain." "The sounds made by those geese are from a species that flies nowhere near that location." "They would have us believe it's the middle of the winter, yet that oak tree still has all its leaves."

In my next life, one thing I plan to do is open a school for artistic science, where creative people could be accredited for their knowledge of the natural world. Upon graduating, they would be allowed to distort nature only in informed ways that advance their artistic needs. At the end of a movie, as the credits roll by, the director, producer, set designer, cinematographer, and whoever else is accredited would proudly list their membership in SCI-PAL, the Society for Credible Inclusion of Poetic and Artistic License.

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

THE EVOLUTIONARY FRONT

The Rise and Fall of the Nas

We have 900 genes for smelling, but almost two-thirds of them are broken.

By Carl Zimmer

JAMES MARSH

Smell, above all other senses, is our link with history. It takes just a sniff of certain odors—the ozone tang of rain falling on blacktop or the crisp sting of frying onions—to instantly hurl us back decades. And our sense of smell has a history of its own, reaching back more than 500 million years. Until recently, however, scientists have had relatively little evidence on which to base a reconstruction of its evolution. They've only been able to compare the olfactory senses of living vertebrates or turn up the occasional fossil nose. But now historians of smell have been delivered a trove of new evidence, thanks to progress in deciphering the human genome and the genomes of other animals. The genes that enable us to smell reveal an epic story—the rise of an extraordinarily sophisticated sense organ and its subsequent decline in power.

It wasn't even so long ago that scientists learned how our sense of smell actually works. Air flowing into your nose carries with it a swarm of complex organic molecules that get trapped in the mucus-rich lining of the nose's inner recesses. Millions of nerve endings project into the mucus, and the molecules bump into them like driftwood floating through a kelp forest. Each neuron is studded with a dozen or so identical receptors, all made by the same gene and all bearing the same structure. Altogether there are several hundred different types of receptors. Each type is like a unique lock, and certain molecules inhaled into the nose can fit into them like a key. Once this happens, a receptor triggers a series of chemical reactions within its neuron, ultimately producing an electrical signal that hurtles along the length of the neuron and into the brain.

Each neuron bears only one type of receptor, but that same type can be found on other neurons—thousands of them—scattered across the interior of the nose. The neurons thread their way through tiny holes in the skull and attach to microscopic clumps of neurons at the front of the brain. In a remarkable feat of biological wiring, the thousands of neurons bearing the same type of receptor all converge on a single

al Empire

clump. The hundreds of clumps that receive signals from the different kinds of olfactory neurons act like a sort of odor map: each aroma lights up a distinct pattern of clumps, which the brain interprets to produce our perceptions of smell.

Exactly how the neurons manage to sort themselves out so precisely, no one is prepared to say. Yet these trails get blazed over and over again during our lifetime. Olfactory neurons survive only sixty days, and as they die, special cells in the nose lining mature into new olfactory neurons, which produce receptors of their own. Each of these new neurons sends out an axon that extends through a hole in the skull and somehow manages to find its correct clump in the brain.

The first scientists to discover genes for olfactory receptors were Richard Axel, of Columbia University, and Linda Buck, of Harvard, who found eighteen of them in rats in 1991. Each of the genes produces a protein that is shaped like a string folded into a distinctive series of seven loops. Axel and Buck decoded the sequences of nucleotides that make up the genes, and researchers around the world then began to search for other olfactory genes with similar sequences. They soon found many more, in rats, humans, frogs, catfish—in fact, in every other vertebrate they examined. The olfactory receptors all share a distinctive structure, but they are not identical. Their differences enable them to grab differently shaped molecules, thus allowing the perception of different odors.

The data gathered by scientists eventually pointed to a remarkable evolutionary history. The genes that make olfactory receptors in living vertebrates have all descended from a single ancient gene carried by some common ancestor. The evidence also shows that the evolution of olfactory genes has repeatedly involved two kinds of events: accidental duplication of a gene in its entirety, and subsequent mutations that introduce slight differences between the two copies. As the genes changed and multiplied, they grew into a family. And as early species of vertebrates gave rise to new ones, they passed on their olfactory genes, which continued to evolve.

The evidence for this evolution can be found in the olfactory genes carried by different vertebrates. Closely related species, such as chimpanzees and humans, always have slightly different sets of olfactory genes. Yet their sets of genes are much more similar to each other than they are to those carried by more distant relatives. By comparing the DNA sequences of olfactory genes, scientists have been able to organize them into an evolutionary tree and to trace the connection between new genes and the emergence of new lineages of vertebrates.

Humans are not the only mammals whose genetic machinery for smelling has fallen apart.

These comparisons suggest that the common ancestor of living vertebrates—a primitive fish that lived about 530 million years ago—used a tiny collection of olfactory receptors for smelling. Lampreys, which are jawless fish that belong to the oldest living lineage of vertebrates, use only a handful of olfactory receptor genes. What's more, those genes belong to the oldest lineages of olfactory receptor genes. Apparently, by the time jawed fishes evolved, the repertoire of olfactory receptor genes had become much more complex. All living jawed fishes studied so far have about a hundred genes for smelling.

Instead of pulling air through a nose, as we do, fish let water circulate through a nasal cavity above their mouth. And living underwater, they are most sensitive to molecules that dissolve easily in water and can thus be swept into their nasal cavities. When a branch of vertebrates came on land 360 million years ago, they encountered a new environment of scents, and their old olfactory receptors were not well adapted to perceiving insoluble molecules wafting through the air. Through mutation and natural selection, one branch of olfactory genes in these vertebrates diversified into a giant new family that may well have been more effective at detecting the airborne chemicals.

Living frogs may preserve something of this ancient transition. On land, a frog sucks in air and detects odors with the receptors at the rear of its nose. But when a frog dives, a flap seals off the back half of the nose from the water, while a special set of olfactory sensory neurons housed in the front of the nose allows the animal to smell underwater. It turns out that the receptors in the front are all made by the most primitive, fishlike genes in the frog's olfactory collection; those in the rear are formed by the new class of genes shared by every land vertebrate.

Though all living land vertebrates come equipped with a big battery of olfactory receptor genes, mammals have become exquisitely adept at smelling. Predatory mammals such as dogs and wolves use their noses to track prey for miles, while deer, rats, and other mammalian prey can sniff danger in a millionth of a gram of urine. Smell guides our appetite: the smell of ripe fruit appeals to us, while the smell of rotting meat drives us away. Males and females judge one another on the basis of their scents, and smell is also crucial in the bonding between mother and infant.

In the past few years, as scientists have worked on sequencing entire genomes, the search for olfactory receptors has shifted into overdrive. Instead of using molecular probes to grope for actual fragments of DNA, scientists can now search for patterns in online databases and find dozens of olfactory genes at a time. Researchers have published drafts of genomes not only for humans but also for many laboratory favorites, such as fruit flies and yeast. For scientists who study smell, the most valuable genome has been that of the mouse, which shares with humans a common ancestor that lived about 100 million years ago. A comparison of the mouse's olfactory genes with ours shows we've taken very different paths since we parted ways.

Researchers now estimate that a mouse has 1,500 genes for olfactory receptors. That means a tremendous portion of the mouse genome—about one in every twenty of its 30,000 genes—is connected to smell. But only about 1,200 of these genes actually seem to work. The remaining 300 are marred by mutations that have most likely rendered them useless. These mutations act like bugs in software, causing the neuron's protein-building machinery to come to a screeching halt when it tries to read the damaged genes. Known as pseudogenes, these ruined stretches of DNA are an inevitable by-product of the fast-paced evolution of smell in mammals. And unless other mutations delete these pseudogenes from the genome, they simply linger, passed down from parent to offspring.

Mice and their fellow rodents have been pushing the boundaries of olfaction for millions of years. Meanwhile, our own olfactory universe has been shrinking. Researchers have carried out preliminary surveys of olfactory receptor genes in apes, and they've found that 40 percent of the known olfactory receptor genes in gibbons and orangutans are pseudogenes. In gorillas and chimpanzees, our closest living relatives, the proportion climbs to 50 percent. And among humans, the numbers become even more embarrassing. Current estimates put the total number of our olfactory receptor genes at 900, and of those genes, only 320 or so work. In other words, almost two-thirds of our olfactory genes are broken.

When it comes to smell, our primate ancestors have been getting by with less for millions of years. Apes, which emerged about 20 million years ago, apparently came to rely more on vision and less on smell. The shift may have had something to do with changes in diet and perhaps even in social structure. Whatever the reason, as noses became less crucial to ape survival, the evolution of olfactory receptor genes into pseudogenes became less harmful. The decay accelerated with the rise of hominids 5 million years ago. It's possible that as ancestral humans began hunting and digging up tubers, they relied more on sharp eyes than on sharp noses. Perhaps even the rise of language helped reduce their need to use a vocabulary of scents.

Smell is probably becoming less important in our increasingly industrialized world.

The decay of our genome hasn't been random, however. The common ancestor of mice and humans bequeathed to both our lineages the same major families of olfactory receptor genes. In humans, most of these genes no longer work, but we still have a few functioning survivors in each gene family. Evolution has pruned back our olfactory tree, it seems, rather than ripping it out. The evidence from our genome hints that, like mice, we can still perceive a broad *range* of smells. We just do a much worse job at making fine distinctions between them.

Humans are not the only mammals that have let their genetic machinery for smelling fall apart. Dolphins, for example, descend from a hoofed mammal that adapted to life in the ocean about 50 million years ago. Along the way, the dolphin nose was modified into a blowhole. In addition, a dolphin can create vibrations by pushing air back and forth through flaps in the nasal cavity. These vibrations pass out of the animal's head and into the surrounding water, where they bounce off fish and other nearby objects. With exquisitely sensitive ears, the dolphin can hear these echoes and turn them into three-dimensional images in its brain.

Given that dolphins keep their blowholes sealed underwater and that their nasal cavities have turned into sound generators, anatomists have long speculated that these animals lost their original sense of smell. (Dolphins can detect chemicals in water, but the evidence suggests that they use their tongue rather than their nose.) Recently, a team of German researchers decided to carry out a preliminary survey of the genes for olfactory receptors in the striped dolphin. They discovered thirteen, but among those genes they could not find a single one that actually worked. For dolphins, the sense of smell appears to live on only as a genetic ghost.

Our own species probably won't go quite so far, but the future of our nose looks dim. In an increasingly industrialized world, smell is probably even less important than it was in the past, so olfactory pseudogenes may become even more common. We may be on our way to living with the bare minimum number of genes for smelling.

The fact that we lug around 580 defunct genes may seem bizarre, particularly when you consider that their close cousins continue to work in other mammals. But neither our DNA nor our bodies are perfectly designed. In the early 1800s, when Charles Darwin was learning his biology, most English naturalists believed that God created every species of animal and plant individually to perfectly fit its particular habitat. Darwin considered this absurd. Who would intentionally give ostriches tiny useless wings? Why should eyes begin to grow on fish living in caves and then degenerate into useless tissue? Why do we humans carry vestigial tailbones inside our bodies?

Darwin watched naturalists struggling to find explanations that could reconcile perfect design and imperfect anatomy. British anatomist Richard Owen, for example, abandoned the idea that vestigial organs were perfectly designed. Instead, he claimed that God produced a series of new designs over time, each of which was based on an "archetype"—a kind of transcendental blueprint. Ostriches had wings because God based them on the body plan for birds. Similarly, geologist John MacCulloch suggested that God pursued each plan until its potential was exhausted. "What bosch!!" Darwin wrote in a notebook. "The designs of an omnipotent creator, exhausted and abandoned. Such is Man's philosophy, when he argues about his Creator!"

In vestigial structures, Darwin saw compelling evidence that species had evolved. Blind cave fish, for example, descended from sighted fish that lived in neighboring rivers. "On the view of descent with modification," he wrote in the *Origin of Species,* "we may conclude that the existence of organs in a rudimentary, imperfect, and useless condition, or quite aborted, far from presenting a strange difficulty, as they assuredly do on the ordinary doctrine of creation, might even have been anticipated, and can be accounted for by the laws of inheritance."

Darwin didn't need to put his theories through contortions to account for flightless birds and cave fish. Vestigial organs were exactly the sort of thing you'd expect to emerge as life-forms adapted gradually to their surroundings. And today, as scientists discover hundreds of vestigial genes that have lurked in our genome for millions of years, the reality of evolution is now, more than ever, as plain as the nose on Darwin's face.

Science writer Carl Zimmer is the author of Evolution: The Triumph of an Idea *(HarperCollins, 2001) and* Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures *(Free Press, 2000; Touchstone Books, 2001).*

IN THE FIELD

Jamming Cicadas

After years underground, these insects emerge on cue and sing in concert.

By Peter J. Marchand

Folklore has it that cicadas singing on a summer morning portend a hot day. If true, then this particular June day had the makings of a scorcher.

When I first stepped out of my house in Arizona's White Mountains, only a single cicada was singing. Within two hours the air was ringing with the metallic buzz of hundreds of males. The chorus steadily crescendoed as more and more insects joined in, singing and flying, singing and flying. By noon it seemed that every branch among the junipers and piñon pines surrounding my home was occupied by an adult cicada. The ground beneath the trees looked like a battlefield, pockmarked with half-inch-diameter emergence holes and littered with molted skins, the last vestige of the cicadas' subterranean existence. For an insect that spends better than 95 percent of its life below ground, this would be the final hurrah: a single, frantic mating effort that would last no more than a few days.

I was witnessing the emergence of annual cicadas, which, despite their name, spend up to seven years underground before coming to the surface to mate, lay eggs, and die. As impressive as the numbers of annual cicadas can be, however, their emergence pales in comparison with that of periodical cicadas (genus *Magicicada*) found in the eastern United States. Populations of the latter, after remaining below ground

DOUG WECHSLER; ANIMALS ANIMALS

In a suburban backyard, newly emergent 17-year cicadas meet potential mates.

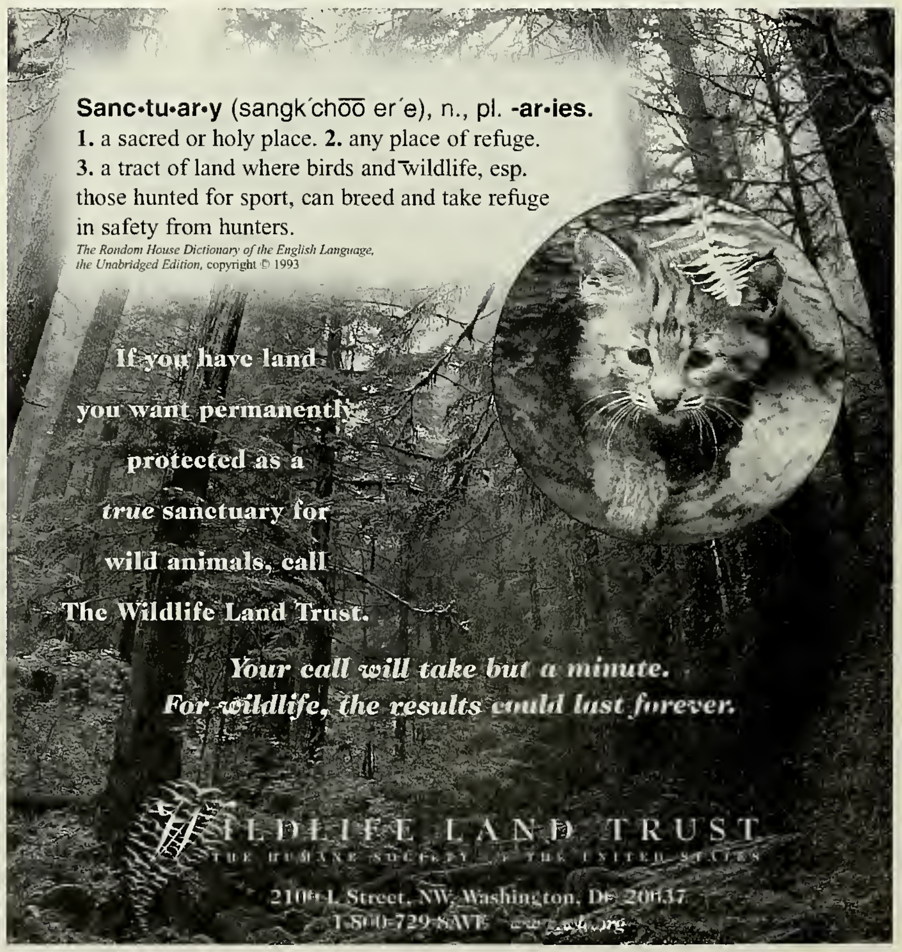
for a full thirteen or seventeen years, appear synchronously in almost unimaginable numbers—up to 150 per square yard, or nearly three-quarters of a million per acre—and produce a mating chorus that is nothing short of deafening.

Periodical cicadas are among the longest-lived insects presently known. The seven species of *Magicicada* are distributed among fifteen discrete populations, or "broods," all found east

CHRIS SIMON

Periodical cicadas are handsomely colored.

of the Great Plains. Four of these species require thirteen years to complete their life cycles; the remaining three species need seventeen. In most years, there is an emergence event of science-fiction proportions somewhere in the eastern states, usually involving more than one species of periodical cicada. This year, thirteen-year cicadas will appear in Louisiana, Mississippi, Arkansas, Tennessee, Kentucky, Missouri, and Illinois, and seventeen-year cicadas will show up in Ohio, Pennsylvania, and West Virginia.



E.R. DEGGINGER; COLOR PIC, INC.

The name of the game: adults have just days to mate and reproduce before they die.

The clockwork appearance of periodical cicadas in late May to mid-June has long fascinated, and perplexed, entomologists. Cicadas live all but their last days feeding on the sap of tree roots located a few inches to a couple of feet below ground. There the nymphs are buffered from the environmental cues, such as changes in temperature and hours of daylight, that provide most plants and animals with a means of keeping a biological calendar. But researchers Richard Karban, Carrie Black, and Steven Weinbaum, of the University of California, Davis, believe they have discovered how periodical cicadas time their emergence. They suspected that these cicadas might receive their cues indirectly by monitoring the annual flowering cycles of their host trees. (Flowering temporarily alters the quantity or quality of nutrients available to the feeding nymphs.) So Karban and his colleagues reared seventeen-year cicadas on the roots of a variety of peach that they induced to flower twice during the nymphs' fifteenth year. The cicadas emerged the following summer, one year ahead of schedule.

But why are these insects bound by such a rigid calendar in the first place? The answer probably has much to do with predator avoidance. During a mass emergence of periodical cicadas, almost any animal, from raccoons to raptors, will prey on them. But with the cicadas' appearance only once every thirteen or seventeen years in different parts of the country, predators are unable to predict just when or where they will next turn up. And any predators that do happen upon the superabundance of emerging cicadas can satiate their appetites and still leave the vast majority of the insects alive and free to reproduce.

The simultaneous emergence of more than one species of periodical cicada creates an interesting mating challenge. Females must be able to recognize their own kind, by sound, amid hordes of individuals—including willing males of the wrong species—and a drone so loud that even cicadas have trouble hearing. Chris Simon and her research associates David Marshall and John Cooley at the University of Connecticut have recently deciphered some of the subtleties of mate recognition by recording sonograms of different species that had been identified in the laboratory by their DNA. Similar though their mating signals may sound to us, each species vibrates its sound-producing tymbals at a slightly different frequency. Where one species, recently discovered by Marshall and Cooley, overlaps in territory with another having a similar call note, the frequency of the first species' song is adjusted upward by about 0.3 kilohertz. The female, demonstrating remarkable discrimination of mating signals, can then pick the males of her species out of the crowd.

But the acoustical sophistication of periodical cicadas doesn't end there. Marshall and Cooley have discovered that upon recognizing an appropriate mate, a female signals her receptiveness with a flick of her wings, synchronized with the final downward slur of the male's song—apparently the only part of a mating song that the female can identify against the background of a million-voice chorus. Detecting the precisely timed wing flick, the male then courts the female with a complex repertoire of additional mating songs. In the intense competition for mates, males can also obscure the signals of potential competitors. Should an interloper alight close to a courting pair, the first suitor will jam the interloper's song

with a buzz timed to mask its ending slur. Rendered invisible behind an acoustic curtain, the interloper moves on, unnoticed by the female.

Two weeks after the emergence near my house began, I stood under the trees in silence. The frenetic voices of mating cicadas had fallen quiet. Before the adults perished, millions of eggs had been deposited on the branches of the junipers and piñon pines, tucked safely into slits cut by the ovipositing females. Another generation would soon hatch, fall to the ground as ant-sized nymphs, and burrow quickly beneath the surface to begin their extended subterranean existence.

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

KENNETH M. HIGHFILL; PHOTO RESEARCHERS, INC.

Seventeen-year cicada, Kansas

THIS LAND

Where Forests Meet

The Black Hills are a crossroads of vegetation.

By Robert H. Mohlenbrock

Home to such well-known landmarks as Mount Rushmore, Devils Tower, and the Crazy Horse Memorial, the Black Hills straddle the border between South Dakota and Wyoming. The modern name for these mountains reflects one bestowed by the native Lakota, for whom this is sacred land: Paha Sapa (hills of black). The range does look dark from a distance, because 95 percent of its tree cover consists of ponderosa pine, which has deep green needles.

A hundred and fifty million years ago, when dinosaurs roamed the earth, this region was relatively flat and the climate was tropical or subtropical. Instead of ponderosa pines, the dominant plants were cycads, which resemble tree ferns. Between 150 and 100 million years ago, the cycads were joined by figs, sassafras, oaks, and willows, as well as such evergreen plants as sequoias and palms. Then, about 60 million years ago, the terrain began to be uplifted, blocking the eastward flow of warm air from the Pacific. As the region became cooler and drier, temperate species gradually began to replace the tropical plants, and eventually some of the evergreens were replaced by deciduous trees (most of them migrants from the East).

As the Cascade Range and the Rocky Mountains rose up in the West, beginning about 30 million years ago, the Black Hills region became cold and arid. Coniferous forests developed, and grasslands appeared in the driest areas along their periphery. Following the last ice age, which ended about 12,000 years ago, northern forest species such as white spruce and paper birch migrated south into the region. Because several habitats—Rocky Mountain, Great Plains, northeastern deciduous forest, and northern forest—seem to meet here, the Black Hills boast an unusual collection of trees, ferns, and wildflowers. According to Wyoming botanist Robert Dorn, 30 percent of the 1,260 species now found in the Black Hills originated in the Great Plains, 25 percent (including ponderosa pine) in the Rockies, 5 percent in deciduous forests, and 1 percent in northern forests. (The remaining species generally have widespread distribution.)

Spearfish Canyon, South Dakota

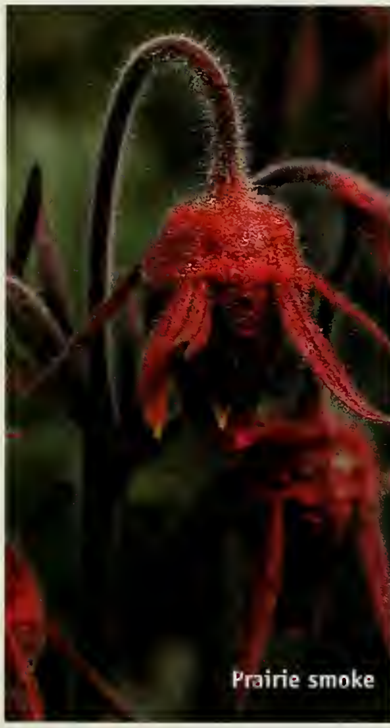
PHILLIP HENRY

The range's uninhabited areas fall mainly within Black Hills National Forest, most of which lies in South Dakota. One of the best introductions to the region is to drive U.S. Highway Alt 14, a National Scenic Byway that passes through Spearfish Canyon. Exposed on the canyon walls are various types of shale and limestone, while the streams in the canyon bottom are lined with lush vegetation. The byway includes a number of "interpretive stops" where visitors can park and learn about particular habitats. For hikers, a good way to sample a cross section of vegetation is to follow the trail that begins at the Spearfish Canyon Resort and leads to Roughlock Falls.

JOE LEMONNIER

For visitor information, contact:
Supervisor's Office
Black Hills National Forest
Highway 385N, RR2, Box 200
Custer, South Dakota 57730
(605) 673-9200
www.fs.fed.us/r2/blackhills/

Ponderosa pine forest. Beneath the pines are several distinct communities of understory plants. On exposed, rocky, south-facing slopes, particularly in the southern Black Hills, the major species are little bluestem, yucca, sagebrush, sand lily, and various gramas and needlegrasses. Juniper, Oregon grape, buffalo berry, and blue wild rye dominate at about 7,000 feet on a centrally located limestone plateau. In the northern part of the region, in relatively moist areas between 4,000 and 5,000 feet, the pines are joined by bur oak, and the understory contains chokecherry, Oregon grape, and melic grass. Plants with a western flavor—mountain mahogany, skunkbush, and American black currant—appear at the western edge of the Black Hills.



PHILLIP HENRY

Prairie smoke

Rocky Mountain juniper forest. On some dry, rocky exposures in the southern Black Hills, the principal tree is Rocky Mountain juniper. The understory includes several prairie grasses as well as the shrubby skunkbush.

Deciduous forest. In waterside habitats in the eastern mountains, box elder and green ash grow with American elm, eastern cottonwood, red-osier dogwood, and Bebb willow. Wildflowers here include water parsnip, fringed loosestrife, and hedge nettle. In the northeastern foothills, on relatively dry slopes, bur oak dominates above an understory of hop hornbeam, smooth sumac, coralberry, and poison ivy. Among the wildflowers are a red columbine, aster, figwort, wild sarsaparilla, fleabane, and avens. In the northwest, particularly in the wake of natural forest fires or controlled burns, quaking aspen and paper birch take over. Common in the understory are chokecherry, beaked hazelnut, a wild rose, red baneberry, thimbleberry, and bracken.

Meadows and grasslands. The foothills harbor several treeless habitats. The wetter areas support meadows containing Missouri goldenrod, false toadflax, golden-glow, Indian paintbrush, Mariposa lily, death camas, and prairie smoke. Grasslands are found in drier zones. At the southern edge of the hills is a bunchgrass community of little bluestem, while elsewhere, particularly along the western edge, grow short prairie grasses—the most prominent being various bluegrasses, buffalo grass, and wheat grass—as well as prickly pears. Rabbitbrush and three kinds of sagebrushes give the lowlands to the west and south a distinctly Wild West appearance.

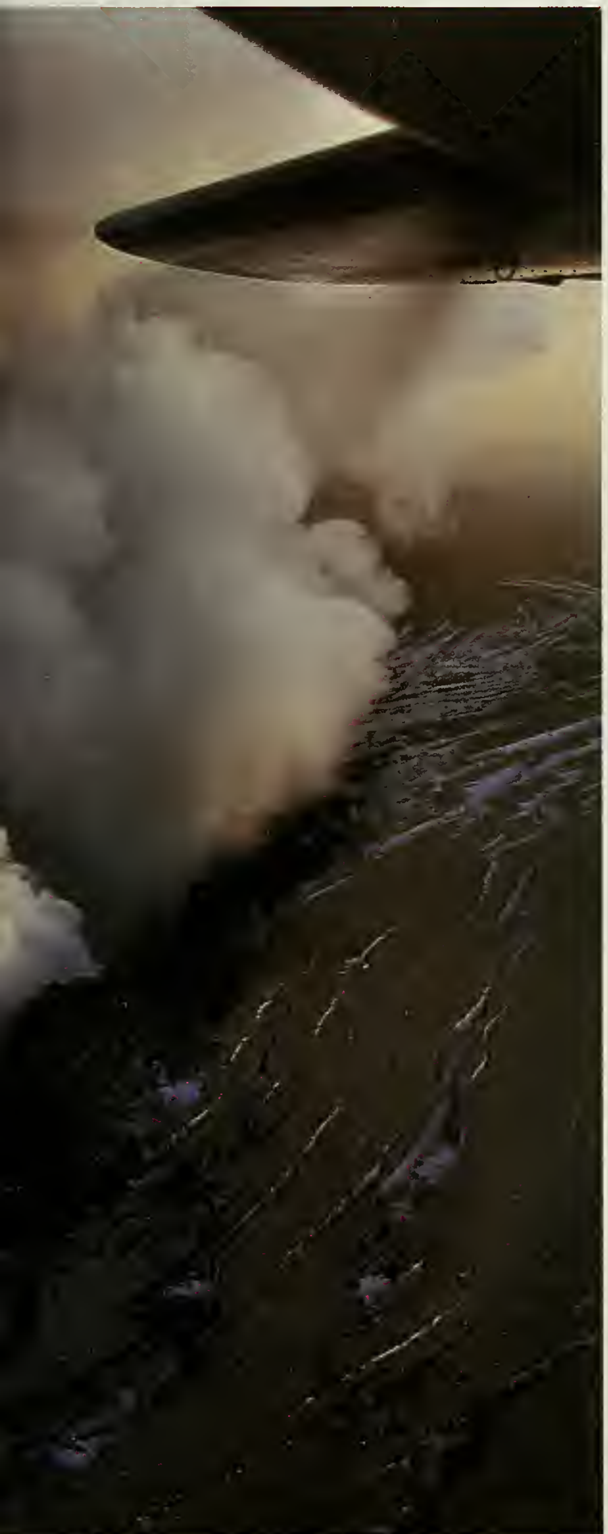
Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

The Ice Above, the

Fire Below

Story by Robert S. White
Photographs by Ragnar Th. Sigurdsson

Iceland is still being shaped by the geological interaction of opposites.



In southeastern Iceland, some 4,500 feet above sea level, lies Vatnajökull—the largest temperate-zone ice cap in Europe. On the last day of September 1996, the ground beneath the glacier began to shake. The trembling indicated that a volcanic eruption, destined to be among the biggest recorded in twentieth-century Iceland, had started beneath the ice.

Vatnajökull, 3,200 frozen square miles overlying Iceland's most active volcanic region, sits, as does the rest of the island, above a mantle plume—a column of hot rock that rises from the depths of Earth and feeds volcanoes with lava. Although it is paradoxical that Iceland's hottest region boasts its biggest ice cap, it is no coincidence: the ice sheet is huge and permanent precisely because lava flowing from the mantle plume has built the mountains so high. Iceland is made of such paradoxes. Its mountains and valleys are sculpted primarily through the interplay of the mantle's molten rock, which builds volcanoes, and the glaciers' solid water, which ferociously erodes the landscape. During an eruption of any of the island's ice-covered volcanoes, upwelling lava meets hundreds of feet of ice, producing trillions of gallons of meltwater and confronting Icelanders with a three-pronged pestilence of fire, flood, and ice.

In 1998 I journeyed to Iceland at the behest of Bryndís Brandsdóttir, a seismologist at the Science Institute of the University of Iceland with an immense knowledge of Icelandic earthquakes and volcanoes, and of Magnús Tumi Gudmundsson, a geophysicist at the same institute and president of the Icelandic Glaciological Society. They had asked me to accompany them on a seismic survey of Earth's crust beneath Vatnajökull. The intention was to pursue the causes and effects of Iceland's fiery

Part of Iceland's Vatnajökull glacier collapsed during a 1996 volcanic eruption, adding billows of steam to the ash and gases that rose 30,000 feet into the air.

Beside the 1996 eruption site, an observation plane looks like a speck. The lava here ate through 1,500 feet of ice in just thirty hours.

belches by mapping the sources of molten rock that feed the eruptions and by examining the rocks that the eruptions had left behind.

Iceland's convulsions are of more than parochial interest. Volcanic eruptions under ice provide a glimpse into the deep history of Earth. A controversial geological theory known as "snowball Earth" posits that glaciers completely encased the planet at least once in the past, and that buried volcanoes, by ejecting greenhouse gases through the ice and into the atmosphere, were what eventually rescued Earth from being a permanent wintry waste. During the less drastic but still major ice ages that have periodically covered Earth since then, many other volcanoes were similarly buried. Studying active eruptions beneath the ice allows us to understand how distant ice ages shaped some of the geological features we observe on Earth today.

Iceland's awesome volcanic power comes from the confluence of two processes: tectonic volcanism and the action of a mantle plume. This island nation lies exactly on a mid-ocean ridge running down the center of the Atlantic. A global network of such ridges—37,000 miles of mountain ranges that are almost entirely underwater—has resulted from the drifting apart of tectonic plates. The ensuing gap, flanked by strings of volcanoes, continually spews molten rock that becomes new crust. The volcanic activity of underwater mountains dwarfs the output of large terrestrial volcanoes such as Mount Saint Helens, Vesuvius, and Mount Pinatubo. We are scarcely aware of it, but every year about three

cubic miles of molten rock erupts underwater: an average of 1,600 tons of magma every single second of every day, enough to fill an Olympic swimming pool twenty times a minute.

Although the mantle plume lying below Iceland is not molten, up to 30 percent of it melts while it approaches the surface, because its melting temperature drops as the plume rises and the pressure on it decreases (much as the boiling point of water drops when atmospheric pressure decreases). Solid, upwelling mantle rock begins to melt when it is still sixty miles beneath the surface, and as it rises, the pressure drops further and the rate of melting increases, generating huge volumes of molten rock that bleed upward to feed the volcanoes at the surface. Several dozen active mantle plumes exist at various places across the globe—under volcanoes such as the Hawaiian Islands in the North Pacific, Réunion and Mauritius in the Indian Ocean, and the Canaries and the Azores in the North Atlantic—but only Iceland's mantle plume lies directly beneath a mid-ocean ridge. This plume can well up closer to the surface than plumes elsewhere are able to, so it melts far more copiously than its counterparts in other areas of the world. Ultimately, the combination of tectonic volcanism and mantle plume generates four times more molten rock beneath Iceland than is generated beneath any other section of the mid-ocean ridges. Pushed by the underlying mantle plume and the thickened crust created by the enormous fires, the land is thrust well above sea level and capped by ice.

By ejecting greenhouse gases through the ice, volcanoes may have rescued Earth from being a permanent wintry waste.

And the Vatnajökull ice sheet itself, born on volcanic heights, actually serves to reduce volcanic activity. The pressure of its weight inhibits melting of the upwelling rock—the reverse of the very principle that causes Iceland's mantle plume to exacerbate local eruptions. Indeed, during the last ice age, the island was entirely blanketed by ice, and the rate of volcanic eruptions decreased markedly. When the ice melted, which it did quickly, the sudden reduction in weight caused a thirtyfold increase in volcanic activity, creating the numerous volcanic

A depression, below, shows the subglacial path of meltwater produced by the 1996 eruption. After the flood swept out, the ice collapsed.

The flood burst forth from underneath Vatnajökull at Skeidarárjökull, creating the heart-shaped opening in the foreground, and swept across the flats to the sea.

The aurora borealis, the Moon, and Öræfajökull, Iceland's highest point, loom over the site of the 1996 flood.

mountains that now dominate the landscape.

The collision of fire and ice at Vatnajökull led our expedition to explore the crust of the 1996 eruption in an area that came to be called Gjálp, after a Nordic giantess. That eruption lasted thirteen days and built a three- to four-mile-long ridge of volcanic rock from lava erupting through a fissure buried by the ice. The molten rock, at a temperature of 2,000° F, ate its way up through 1,500 feet of ice in just thirty hours, breaking through to send a plume of ash, hot gases, and superheated steam 30,000 feet into the air. More than a trillion gallons of meltwater were created during the eruption, which released the energetic equivalent of about 15,000 tons of high explosives (or the atomic bomb dropped on Hiroshima) every minute for ten days. Yet the 1996 event produced only one-twentieth the lava generated by a 1783 eruption in the

same region of Iceland (the largest eruption on Earth in historic times).

The melted ice flowed into a subglacial lake at the bottom of a three-mile-wide caldera known as Grímsvötn, which lies under the ice cap. Held in on one side by just a dam of ice, the water rose at sixty feet per day, compared with a normal rate of sixty feet per year. A torrential flood called a jökulhlaup by Icelanders (and now by the rest of the world) finally came shortly after dawn on November 5, 1996, when the rising water, lifting the overlying cap like an ice cube in a cold beverage, began to flow south toward the sea.

The flood was the largest in sixty years; the water, heated to 40°–50° F, rapidly eroded the gla-

The rising water, lifting the overlying cap like an ice cube in a cold beverage, began to flow south toward the sea.

cier under which it was flowing, cutting large channels through the ice. Maximum flood rates reached 1.6 million cubic feet per second. Where the water broke through the edge of the glacier, the jökulhlaup was powerful enough to break off lumps of ice thirty feet high, weighing up to a thousand tons, and to sweep them across the adjacent plain. On the sand flats of Skeidarársandur, the flood washed away sections of the only road around the island, including a large bridge, as well as power transmission cables. Since the Icelanders were expecting such an event, however, no one was hurt.

By the time of my visit two years later, the Grímsvötn caldera held only a hundred feet of water, the ice was healing over the rift in the center of Vatnajökull caused by the eruption, and the Gjálp erup-

tive pile could be investigated in detail. Gjálp turned out to be composed almost entirely of the volcanic rock called hyaloclastite—generated as the molten lava hit the ice, whereupon it was quenched and fragmented. As the lava melted its way upward, ice flowed toward the fissure from all sides, forcing the new volcanic pile to become very steep. The 1996 eruption ceased soon after the lava broke through the surface of the ice sheet. The resulting hyaloclastite is weak for a rock; it will probably be eroded away in a matter of only a few thousand years. However, elsewhere in Iceland, in areas now free of

The flat top of 10,000-year-old Herdubreid corresponds to the height (about 3,000 feet) of the ice that formerly surrounded the mountain.

Steam rises from hot spots in the half-frozen Grímsvötn lake.

ice, there are similar, very steep-sided mountains composed primarily of hyaloclastite rock that has been preserved for about 10,000 years, since the end of the Ice Age. One of the island's classic volcanic mountains, Herdubreid—sixty miles northeast of Grímsvötn—rises 3,000 feet above the surrounding plain, which is itself composed of lava flows. The rock in Herdubreid endures because at this mountain's creation, the lava not only penetrated the ice but lasted long enough to pour out lava flows on top of the hyaloclastite pile once the rock had broken through the ice surface. Much tougher than the rock at Gjálp, these lava flows had not been quenched by the glacier, and they formed a flat top that is resistant to erosion and protects the steep-sided but weak material beneath it. Dotting Iceland are still other beautiful, steep, flat-topped mountains like Herdubreid, formed at the end of the last glaciation in much the same way as was Gjálp. The height of the flat top provides a good indication of how thick the ice was at the time of the eruption that formed the mountain.

Although my Icelandic colleagues and I went to Vatnajökull in the summer of 1998, during what we thought was a quiet time, the volcanoes had a surprise in store for us. We had deployed a network of fifty seismic detectors over the ice cap and were still working at

We felt the effects of molten rock being injected into a magma chamber 10,000 feet below us.

the site when an earthquake swarm of several hundred small tremors occurred right beneath our feet. Many months later, after Raimon Alfaro, a graduate student at the University of Cambridge, analyzed the data, we realized we might have experienced the effects of a batch of molten rock being injected into a magma chamber some 10,000 feet below us. Fortunately for my colleagues and me, instead of erupting to the surface straightaway, it paused underground for half a year. But six months later, shortly before Christmas 1998, the accumulated pressure within the magma chamber forced the molten rock up through the faults and cracks around the sides of Grímsvötn and started another large eruption just six miles south of Gjálp. No researchers were on the ice at this time (deep in an Icelandic winter), so no injuries resulted from the eruption. Even the Glaciological Society's base hut, anchored to the rock right on Grímsvötn's rim, survived—albeit blanketed by ash.

Studies of the earlier ash falls in the Vatnajökull region show that some eighty eruptions have occurred in this area over the past 800 years. They appear to come in bursts, at intervals of 130 to 140 years. It may be that changes in pressure caused by an eruption in one spot trigger another eruption nearby and that this sequence continues until the accumulated molten rock has been bled from the subterranean magma chambers. The never-ending extension of the tectonic plate boundary that passes right through this region drives ongoing melting of the rock beneath Iceland, refilling the magma chambers and subsequently leading to a new phase of eruptions. Thus, the beginning of the twenty-first century may well witness another period of high volcanic activity beneath Vatnajökull, with the attendant production of destructive jökulhlaups. Doubtless there will be more unexpected discoveries. The raw forces unleashed in these eruptions and floods are so vast that it is unlikely they can be controlled in the foreseeable future, but they can and will be better understood. We must hope that, as a result, Icelanders will continue to live safely in the domain of these rumbling giants. □

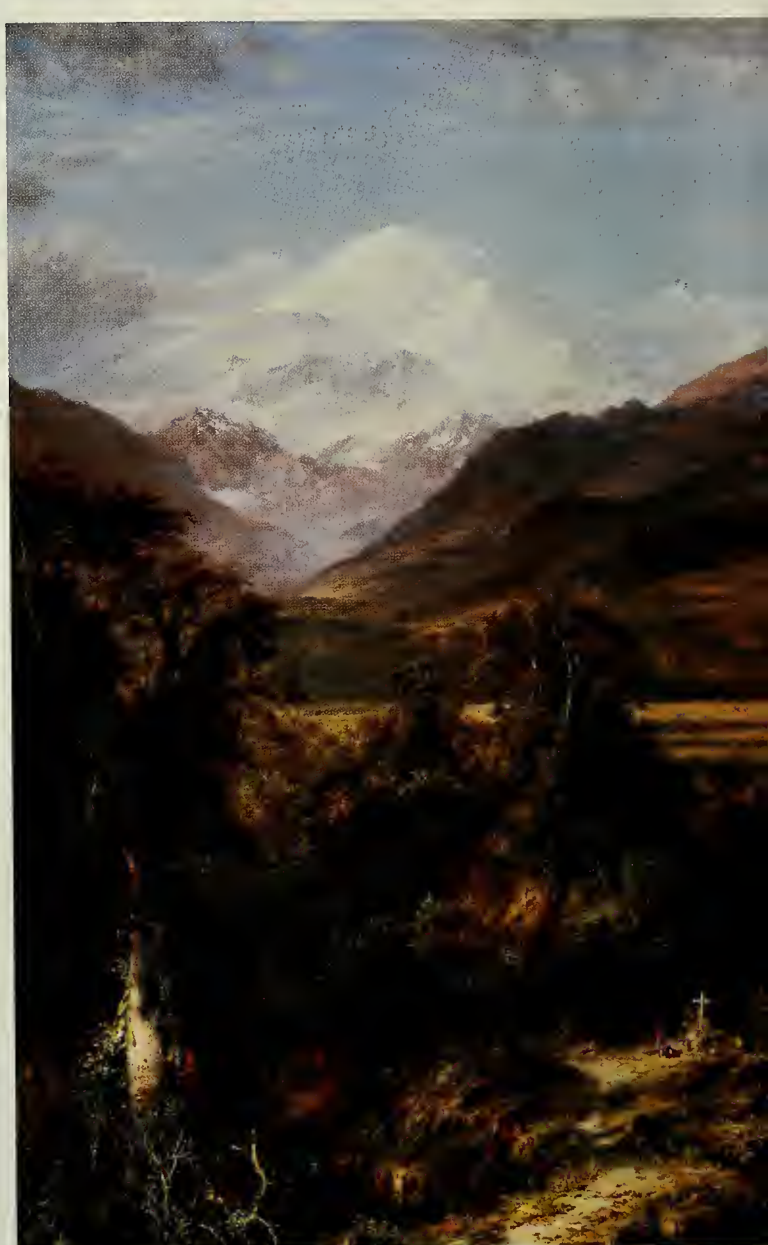
Clouds from the 1998 eruption

We know intuitively when an artist has rendered a human body poorly, when the proportions are wrong or a line is off. But few people are perturbed by an improperly painted plant or tree (which is why vegetation is a great confidence builder for art students). Yet each species has a genetic code that programs its branching patterns, the shape and distribution of its leaves, the way damaged parts heal. A great landscape artist understands the regularities (and irregularities) of growth and decay and is able to convey them precisely. One who did so was the American master Frederic E. Church (1826–1900), a painter well read in both science and art theory. As a botanist who has traveled in some of the same regions that Church did, I am particularly captivated by the fidelity to nature displayed in his canvases, even though their main intent, theme, or symbolism may lie elsewhere.

Born in Hartford to a long-established tribe of Connecticut Yankees, Church was a student of the Romantic landscape artist Thomas Cole, one of the founders of the Hudson River school. By the age of twenty-four, Church had already been elected to the National Academy of Design, on the strength

Through his scientifically detailed canvases, Frederic E. Church transported the Tropics to the temperate zone.

OLANA STATE HISTORIC SITE, NEW YORK STATE OFFICE OF PARKS, RECREATION AND HISTORIC PRESERVATION



A Beautiful Hand

of his painting *West Rock, New Haven.* From his home base in New York City, he traveled to areas of natural beauty—Virginia, Kentucky, Vermont, the Berkshire Hills of Massachusetts, the White Mountains of New Hampshire, the wilds of Maine—to sketch and gather ideas. His careful observation of the details of nature is evident in his early work, and the practiced eye can easily distinguish his spruces from his hemlocks. But it was in the Tropics that Church met, and mastered, his greatest challenge: conveying the mystique of the region's flora and geography to those who would never directly experience its beauty.

The nineteenth century was a time of exploration and analysis, as scientists cataloged nature's species and sought to decipher her riddles. Information about the Tropics was conveyed, through lectures or the printed word, by the few who had pen-

***The Heart of the Andes,* below, shows Church's attention to botanical detail. Far left: A photograph of the artist by Mathew Brady.**

By Rob Nicholson

COOPER-HEWITT, NATIONAL DESIGN MUSEUM, SMITHSONIAN INSTITUTION. PHOTO: KEN PELKA

In 1865, in the mountains of Jamaica, Church made an oil sketch of what he called "wild" sugarcane, but this crop species was actually brought to the West Indies by Columbus in 1493. Church's sketches guided him when he worked on large canvases in his New York City studio.

etrated "the torrid zone." Only with the popularization of lithography and, later, photography could science begin to offer a glimpse of this world to the masses. (I even think back to my own childhood, when my impressions of the Tropics were shaped mostly by Johnny Weismuller as Tarzan, pushing through rented foliage on a Hollywood lot.)

We know when an artist has rendered a human body poorly, but few of us notice improperly painted trees.

Until his fame was eclipsed by Darwin's, perhaps the preeminent scientist of the nineteenth century was Alexander von Humboldt (1769–1859), a German who traveled extensively in South America and Mexico. His observations on the distribution of vegetation were to form the basis of the science of phytogeography, and his books, such as *Cosmos: A Sketch of a Physical Description of the Universe* (published in five volumes beginning in 1845), were widely read and discussed. Unlike Darwin, von Humboldt viewed nature as an expression of divine order—an order that could be revealed through the work of the landscape artist. Church must have devoured passages of *Cosmos* as if its author were speaking directly to him:

> *Are we not justified in hoping that landscape painting will flourish with a new and hitherto unknown brilliancy when artists of merit shall more frequently pass the narrow limits of the Mediterranean, and when they shall be enabled, far in the interior of continents, in the humid mountain valleys of the tropical world, to seize, with the genuine freshness of a pure and youthful spirit, on the true image of the varied forms of nature?*

COOPER-HEWITT, NATIONAL DESIGN MUSEUM, SMITHSONIAN INSTITUTION. PHOTO: JOHN PARNELL

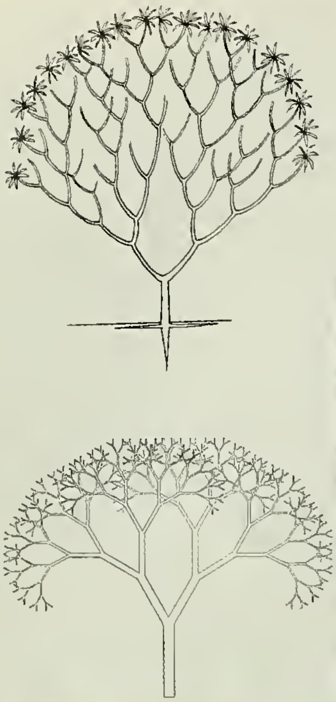
Von Humboldt even suggested strategies for how to proceed with the collection of visual data:

Colored sketches, taken directly from nature, are the only means by which the artist, on his return, may reproduce the character of distant regions in more elaborately finished pictures; and this object will be the more fully attained where the painter has, at the same time, drawn or painted directly from nature a large number of separate studies of the foliage of trees; of leafy, flowering, or fruit-bearing stems; of prostrate trunks, overgrown with Pothos and Orchideæ; of rocks and of portions of the shore, and the soil of the forest. The possession of such correctly-drawn and well-proportioned sketches will enable the artist to dispense with all the deceptive aid of hothouse forms and so-called botanical delineations.

To a temperate-world New Englander who had already surveyed the forests of the eastern United States, von Humboldt's call must have sounded like a summons to Eden. And although Church was on his way to being considered America's foremost landscape painter, others were competing with him in his usual territory. What better way to stay ahead of the pack than to head to the Tropics? In 1853 Church ventured to South America, putting ashore at Barranquilla, New Granada (now Colombia),

Another of Church's sketches from Jamaica features a tree fern, a plant whose pattern of growth resembles that of some palms. In 1978, botanists Hallé, Oldeman, and Tomlinson defined nearly two dozen models of tree growth. The tree fern relates to their Corner's Model, one example of which is given below *(Oenocarpus distichus)*.

DRAWINGS ON PP. 53, 54 (TOP), AND 57 FROM *TROPICAL TREES AND FORESTS: AN ARCHITECTURAL ANALYSIS*, BY F. HALLÉ, R.A.A. OLDEMAN, P.B. TOMLINSON.



SKETCH BY A CLERK OF THE WORKS; IN JOHN RUSKIN, *MODERN PAINTERS*, 1860

and then proceeding by steamer up the Magdalena River into the interior.

Over the course of the next five months, Church and his traveling companion, Cyrus Field (a boyhood friend and Massachusetts paper merchant who later was instrumental in the laying of the first Atlantic cable), retraced von Humboldt's route. They journeyed from the lowland tropical forests on the northern Caribbean coast to the cold, high grasslands of the Andes and down to the lowland forests of Ecuador on the Pacific coast, losing themselves, at times literally and at times artistically, in the views of "unparalleled magnificence." Church experienced the thrill of finding beauty and power that few knew existed, and as an artist he must have felt as though he were interpreting these views and organisms for the first time. Von Humboldt had implored artists to reveal the hidden spirituality in nature, and Church, raised by staunchly Christian parents, was receptive to illuminating the works of an omnipotent and loving God on canvas. His art was forever changed.

Church sketched as he went, accumulating images for more elaborate depiction later on canvas. Collections of these sketches are in the Smithsonian Institution's Cooper-Hewitt, National Design Museum, in New York City, and at Olana State Historic Site (Church's home), in Hudson, New York. To spend a few days with this body of work is like studying the field notes of a Darwin or a Wallace and can be more illuminating than the finished paintings that came out of the artist's Manhattan studio. They have the immediacy of a first impression, and through Church's marginal notes you can hear his eyes at work: "Beautiful soft masses of lightish yellow green foliage of a velvety appearance—Appears at times like a tree at others like a vine clustering among the darker masses of a tree."

NATIONAL ACADEMY OF DESIGN, NEW YORK, BEQUEST OF JAMES A. SUYDAM, 1865, NO. 232P

He would place numbers on certain details, listing the corresponding colors in the margins.

Church tried to cope with the overwhelming diversity of the tropical flora by seizing on New England reference points ("This tree grows in many

To spend a few days with Church's sketches is like studying the field notes of a Darwin or a Wallace.

beautiful forms often resembling the Elm, with a multiplicity of branches which are more irregular than the Elm"). He was also familiar with the admonitions of John Ruskin, an English artist, art critic, and social commentator whose work *Modern Painters* was published in five volumes between 1843 and 1860. In volume one, Ruskin devoted a chapter to analyzing depictions of trees in various

European paintings. "These laws respecting vegetation," he wrote, "are far more imperative than those which were stated respecting water, that the greatest artist cannot violate them without danger, because they are laws resulting from organic structure, which it is always painful to see interrupted."

Ruskin's fifth volume, published after Church had undertaken two trips to South America, includes a remarkable analysis of tree growth that surely influenced the artist as he worked on his canvases:

> *So far as you can watch a tree, it is produced throughout by repetitions of the same process, which repetitions, however, are arbitrarily directed so as to produce one effect at one time, and another at another time. . . . It is the knowledge of the mode in which such change may take place which forms the true natural history of trees. . . . I find there is quite an infinite interest in watching the different ways in which trees part their sprays . . . but a volume, instead of a chapter or two, and quite a little gallery of plates, would be needed to illustrate the various grace of this division.*

More than a century passed before biologists began to systematically elucidate the architecture of trees, their structure and patterns of growth. In a landmark book, *Tropical Trees and Forests: An Architectural Analysis*, published in 1978, Francis Hallé, Roelof Oldeman, and Philip Tomlinson presented twenty-three "architectural models" of possible tree growth, each named for a botanist and defined by some combination of growth characters (trunk formation, branching pattern, position of flowers, rhythmic versus constant growth, and so on). Their models, for each of which they provide representative portraits, encompass all known trees. One of their illustrations of Leeuwenberg's Model is a near-perfect match for a plate in Ruskin's fifth volume that was used to illustrate branching patterns. Between these two publications lie Church's paintings. One of his landscapes of Colombia, done in 1854, shows a tree in detail on the river's edge—an elegant depiction of this same growth pattern.

With the benefit of von Humboldt's grand synthesis and broad vision, as well as of Ruskin's visual

Scene on the Magdalene (La Magdalena), **opposite page, bottom, includes a tree at the river's edge whose growth pattern corresponds to Leeuwenberg's Model, top. Church would have been familiar with a similar model, center, published by John Ruskin in 1860.**

OLANA STATE HISTORIC SITE/NEW YORK STATE OFFICE OF PARKS, RECREATION AND HISTORIC PRESERVATION

Above: During the 1880s and 1890s, Church (seated at far right) and his wife, Isabel (standing beside him), wintered in Mexico.

acuity and mania for details done right, Church's mental and visual talents were primed for the task ahead. Hundreds of pencil and oil sketches flowed from his tropical voyages to Colombia (1853), Ecuador (1853, 1857), and Jamaica (1865); the result was more than two dozen major tropical canvases completed between 1859 and 1883. A number of them highlight geological subjects, notably the volcanoes of Ecuador, but I am most drawn to those in which the flora runs rampant.

The best known of Church's landscapes hangs in the Metropolitan Museum of Art in New York

City. Unveiled in 1859, *The Heart of the Andes* was inspired by his second trip. More than fifty-four square feet in size, the massive canvas traveled around the country as an exhibition that tens of thousands paid to see. Detailing various life zones, from the lush tropical lowlands to the barren mountainsides, it could serve as an illustration of von Humboldt's theories on plant distribution relative to altitude. *The Heart of the Andes* astonishes in its level of detail and accuracy, displaying a type of photorealism a century ahead of its time.

Audiences were advised to bring opera glasses to view the canvas, surveying the painting as if searching a vista. (I have tried this, and it does delete peripheral clutter and allow one to swim through the painting hunting for new life-forms.) I can recognize species of passionflowers, cannas, ipomeas, *Xanthosoma*, and tree ferns. Within this tropical collage can be found organisms native to Ecuador but also some exotics from other countries. A quetzal sits upon a branch, yet this species of trogon is not found outside the Mexican and Central American cloud forests. Did Church crib it from a book on birds, such as John Gould's *Monograph of the Trogonidae, or Family of Trogons* (1835–38)?

Visitors love to explore the painting; if nothing else, it is a work about the joy of discovering life in all its variety and, from that, drawing conclusions about some greater power. To a biologist, the painting speaks of process, change, diversity, and interconnection. Yet Church apparently never embraced the concept of evolution, remaining loyal to the God of his Yankee forebears.

COOPER-HEWITT, NATIONAL DESIGN MUSEUM, SMITHSONIAN INSTITUTION

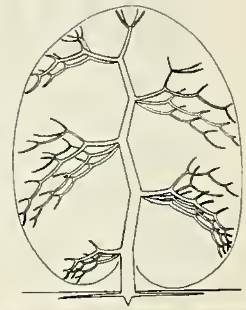
Church's sketch of a silver thatch palm, right, dates from 1865. A similar tree figures prominently in his 1877 composition *Morning in the Tropics*, far right. The branching form of the leafless tree on the painting's right-hand side suggests a match to Koriba's Model, illustrated top right.

The majority of Church's tropical canvases incorporate a volcano or a mountain as a distant focal point. His *Vale of Saint Thomas, Jamaica* is a particularly fine yet poignant example. The artist traveled to Jamaica in 1865 to recuperate after he had lost his first two children to diphtheria. He sketched tirelessly, immersing himself in work as a form of

Audiences were advised to bring opera glasses and to view the huge canvas as if searching a vista.

NATIONAL GALLERY OF ART, WASHINGTON D.C. GIFT OF AVALON FOUNDATION, 1965.14.1. (PA). PHOTO: RICHARD CARAFELLI therapy. The tree ferns he sketched appeared two years later in grand scale on this canvas. In the foreground, on a ridge crest, stand two large specimens of *Cyathea arborea*. Midcanvas, a small mountain cuts the horizon line; between the tree ferns and the mountain flows a river. In the roiling storm of an evening's shower, two distant palms on the mountain crest reach up into a patch of soft lemon light. Is the work symbolic of Church and his wife on one shore and their two children, who have "crossed over," on the other?

My favorite canvas is the edenic *Morning in the Tropics* that now hangs in the National Gallery of Art in Washington, D.C. Painted in 1877, it was one of the last of his tropical canvases, a vision of paradise unspoiled, with only a wisp of a hut and a lone canoeist to suggest human presence. It is a luxuriant depiction of competition: from the tops of the trees down to the river's edge, the canvas crackles with jostling leaves angling toward the morning sun. A finely rendered tree in the foreground—a silver thatch palm, *Coccothrinax argentata*—pins the locale in the Caribbean, probably Jamaica. The lines of the trees are cast upon the water, and the sun's glare is reflected through the haze. Atmosphere and river meld together, the boundary between the clouds and the treetops blurs, and all life becomes one transmuting flow. □

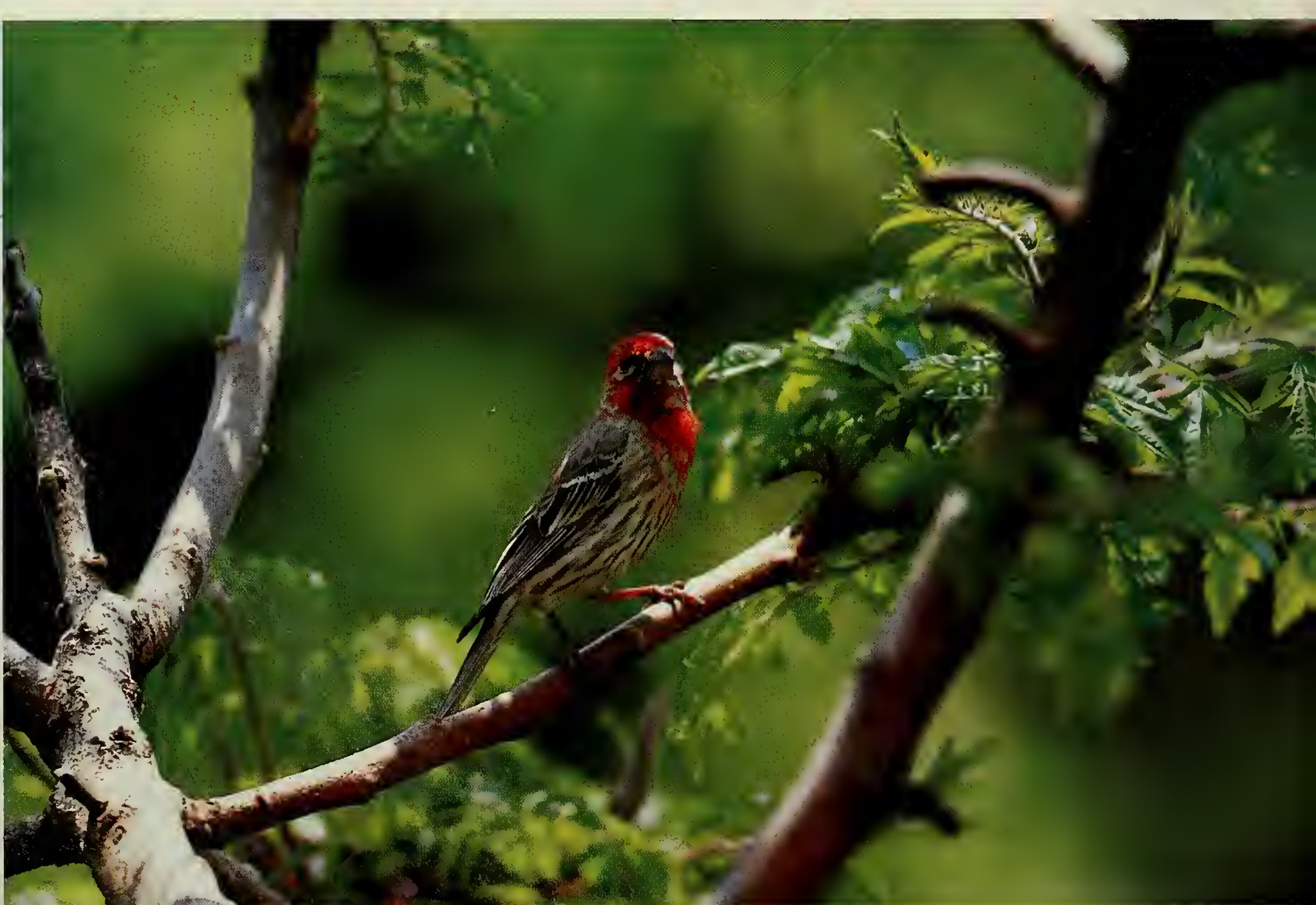


Exemplars of rapid adaptation, house finches show that mothers know best.

Avian Quick-Change Artists

By Alexander V. Badyaev and Geoffrey E. Hill

LEFT: GERALD D. TANG; RIGHT: JOHANN SCHUMACHER DESIGN



Adaptation to the environment is the cornerstone of Darwinian natural selection. Among the most conspicuous consequences of this process are changes in the size and shape of animals in response to climate. Nearly 200 years ago, long before the publication of Darwin's *Origin of Species,* zoologists recognized that in wide-ranging species, individuals that inhabit the colder parts of the range tend to be larger and to have shorter limbs and appendages (black bears and white-tailed deer, for example, show this trend in North America). When one is considering species that have had stable ranges over thousands of years, such changes in body size and shape can be assumed to have evolved very slowly, by incremental stages, over many thousands of generations. Biologists only rarely have a chance to witness the pace of such changes when a population of vertebrates spreads into a very new environment. Over the past few years, however, we have documented rapid and adaptive changes in the size and shape of one vertebrate species—the house finch—and we have discovered a fascinating and unanticipated mechanism that allows this bird to adjust quickly to local environments.

House finches were originally found only in western North America. When northern Europeans first settled on the East Coast and the Spanish colonized the Southwest, these sparrowlike birds ranged from Oregon and Wyoming to southern Mexico and east to the foothills of the Rocky Mountains. Originally birds of open savannas, canyons, and deserts, house finches avoided both forested and treeless regions; the Great Plains and the dense forests of the Pacific Northwest were unsuitable habitat for them. Eventually, unbroken woodlands were felled to make way for farms and cities, and in the process, huge new areas suitable to house finches emerged. In response, they expanded their range, eventually spreading to British Columbia and western Montana by the 1980s. In the eastern United States, humans lent a hand in establishing house finch populations (see "Hollywood, Honolulu, and Hoboken," page 61). Today the song of the house finch can be heard from Ontario to Hawaii and from Florida to Oaxaca. House finches have not just colonized these new areas but have thrived, becoming among our most familiar year-round backyard birds. Their total number in North America was recently estimated at more than a billion birds, a significant portion of which live east of the Mississippi.

Native to the United States and Mexico, house finches are now equally at home year-round in the North and East. A male enjoys spring in Illinois, opposite page, while another braves winter in New York, above.

As they spread across the continent, house finches faced an array of diverse new climates and habitats. Consider the differences in temperature and humidity between California's coastal oak savanna (part of the species' historical range), the Hawaiian Islands (from suburban Honolulu to 6,000 feet up the slopes of Mauna Loa on the big island of Hawaii), southern

The close match between house finch appearance and environment has come about in a mere fifteen years in some cases.

Michigan, Long Island in New York State, the Rocky Mountains of western Montana, and southern Alabama. These sites range from tropical to cold-temperate, from arid to extremely humid, from high elevation to sea level, from windy to calm, and from having extreme seasonal changes to virtually no seasons at all.

Given the wide range of environments to which the house finch is now exposed, we wondered if the birds that had settled in different areas had become different in physical appearance. We chose seven populations for which we knew the history of colonization, and we measured the size and shape of individual birds. Surprisingly, given the brief time since some of the populations had diverged and had settled in their new environments, we found substantial—up to 10 percent—differences in the size and shape of individuals among populations. Moreover, the patterns of variation were complex. It was not simply that birds in the North were big and birds in the South were small. Within most populations, males and females differ in size and shape, that is, they are sexually dimorphic. We found, however, that male and female house finches were changing seemingly independently, resulting in differing degrees of dimorphism from population to population. In some populations, the males had longer tarsi (lower legs), whereas in others, the females had longer tarsi. The same held for body mass and bill size. And most surprisingly, house finch populations separated for only decades were as different as finch populations that we knew had been separated for hundreds or thousands of years.

CALVIN LARSEN; PHOTO RESEARCHERS, INC.

A male house finch (left) makes an overture to a prospective mate, who will appraise several suitors before she accepts an offer. Males and females pair up after meeting in winter flocks.

Once we had documented that rapid change had occurred in the sizes and shapes of males and females, we wanted to find out what environmental pressures were responsible. Choosing two populations that live and breed at the climatic extremes of the species' range—hot, humid lowlands in Auburn, Alabama, and cold, arid mountains in Missoula, Montana—we monitored thousands of finches (color-banded so that we could distinguish individuals) for six years.

Our investigation required more than simply catching and measuring birds. We needed to follow individuals all year to gather data on how certain aspects of size and shape correlated with survival, success in attracting mates, and the number of young produced (fecundity). We found that populations differed in which one of these three factors had the greatest impact on the birds' size and shape. In Montana, for example, higher fecundity was most strongly affected by body size, whereas in Alabama it was survival that was strongly impacted by body size. The reasons for these differences are unknown, but it may be that the Montana population is still expanding rapidly, making fecundity particularly important, while in the warm, wet climate of Alabama, avoiding parasites and diseases may be the key to success (see "Backyard Epidemic," page 62). We also found that the specific size of a trait could be beneficial in one context but not necessarily in another. For instance, in Montana, males with longer wings were more successful in attracting mates. Conversely, smaller males survived better than large males in both populations, but the effect of size on survival was much greater in Alabama.

The key finding from our geographical studies was this: males and females display a size and shape that is the most beneficial for survival and reproduction in their local environments. In a population where females with shorter tails have higher survival and fecundity, females have shorter tails than do females from other populations; in populations where males with deeper bills have higher survival and fecundity, males have deeper bills compared with those of other populations, and so forth. And this close match between the physical appearance of males and females and their environments has come about in a mere fifteen years for some populations.

But we are left with a number of basic questions: What is the mechanism for the remarkable divergence among finch populations? Does the match between birds and their environments represent a genetically based change or simply a plasticity in physical traits that the house finches possess, enabling them to accommodate environmental variation? Especially puzzling is the divergence between the sexes: How do males and females end up looking so very different from each other in different environments when the sexes are virtually genetically identical?

The most straightforward mechanism by which populations of house finches could have achieved such divergence is that, in each population, the finches physically unsuited to the rigors of the new environment were removed from the population by dying or by failing to produce young. The progeny of survivors then inherited beneficial physical traits; the physical appearance of individuals changed over generations; and the population divergence evolved over time. Because we knew the strength of natural selection in our two study populations and the degree of genetic variation in their physical traits, we could calculate the number of generations necessary to accumulate the differences we were seeing. We found that if the population differences indeed represent evolutionary change (that is, genetically based changes in physical traits across generations) in response to distinct selection pressures, then hundreds of years would be needed to produce such divergence. Yet we knew that the populations became established in their environments only in the last few decades, so the adaptive changes must have occurred very recently.

We found that the main limitation for rapid evolutionary change in response to the different environments of Montana and Alabama is that males and females are nearly identical in the genes that code for size and shape. This means that any evolutionary change in size or shape in one sex will be accompanied by an identical change in the other sex. Because the sexes play different roles in reproduction, natural selection often favors different physical appearance in males and females within and among populations. However, the shared genes

ALEXANDER V. BADYAEV

Birds in the hand: Montana juveniles are ready for weighing and measuring.

Hollywood, Honolulu, and Hoboken

Throughout the nineteenth and into the early twentieth century, house finches were popular cage birds in the United States (as they still are in parts of Mexico). The birds were shipped, probably as pets, to Hawaii in the mid-nineteenth century, and some of these translocated finches established wild breeding populations that soon spread to all the major Hawaiian Islands. Many house finches were also imported to East Coast cities, including Boston and New York, where they were marketed as "Hollywood" finches. After the Migratory Bird Treaty Act was signed into law in 1918, the shipment of house finches as pets became illegal, but the trade apparently continued unabated for decades. In the summer of 1939, however, law enforcement agents began to crack down on the illegal sale of Hollywood finches in New York City. To avoid fines, some pet store owners simply released their stock of house finches onto the streets of the city. Contrary to expectations, many of the released birds survived. Through the 1940s and 1950s, a small breeding population hung on in the immediate vicinity of New York City. By the early 1960s, the eastern population had begun to grow and spread, and by the late 1980s, house finches had settled in across the eastern United States and southern Canada.—*A.V.B.*

strongly limit the ability of one sex to evolve local adaptations independently of the other sex, at least over short periods of time. Yet the sexes differ in timing and rate of growth; thus, selection on growth itself can be very effective in accomplishing rapid changes in sexual size dimorphism in adults. So we turned our attention to processes that can alter the way the sexes grow.

A female feeds a chick, above. The adaptive growth of embryos and hatchlings is engineered by mothers.

The series of changes that occur in an animal as it proceeds from a single fertilized egg to a fully developed adult involves the massive replication and differentiation of cells and tissues. Different parts of the body have to be created and enlarged in precisely the right sequence relative to other parts of the body, or serious problems arise. Minute changes in growth can lead to large changes in adults. At the same time, mistakes in development are typically lethal, so in most birds the rate and timing of growth are not easily modified by the environment.

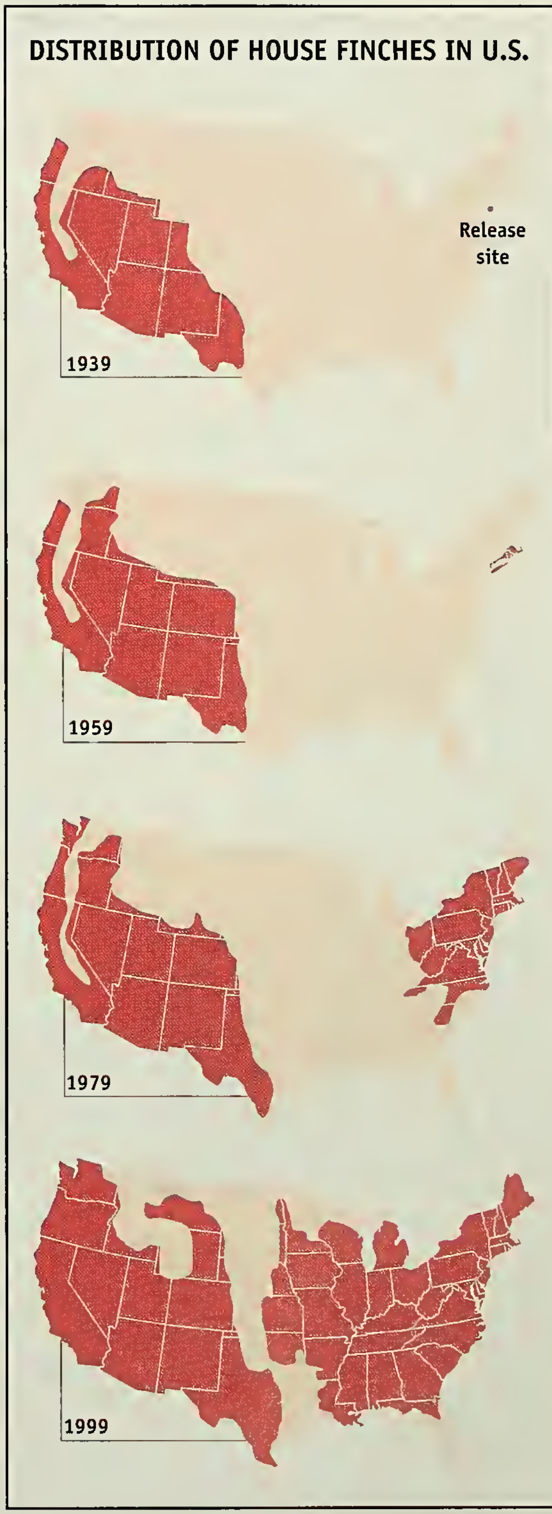
It seems house finches have somehow circumvented this problem. After measuring the growth of hundreds of nestlings in both populations, we found that each population's timing and rate of growth are highly distinctive and that these growth patterns produce the size and shape best suited to the particular environment of each population. Given that the environments of Montana and Alabama are so distinct, it is not surprising that the growth patterns of the two populations turned out to be different. They were, in fact, opposite. In general, females tended to grow faster in Montana, while males tended to grow faster in Alabama. Correspondingly, in Montana, adult females were larger than males, whereas in Alabama, males were

Backyard Epidemic

Birds colonizing a new area are exposed not only to different temperatures, humidity, and food availability but also to new sets of pathogens. After getting a foothold in the vicinity of New York City, the eastern population of house finches began to grow at an exponential rate. In 1994, in the midst of the finches' explosive population growth and expansion, an observant birdwatcher in Maryland noticed that some house finches at his bird feeder had grossly swollen eyes. When some of these sick birds died in his yard, he sent the remains to experts on avian pathology, who determined that the finches were infected with the bacterium *Mycoplasma gallisepticum*. This pathogen, which causes a well-known poultry disease, had never before been found in songbirds. Apparently, house finches feeding around poultry barns in Maryland had contracted a mutant strain of *M. gallisepticum* that was able to survive and reproduce in their bodies and that led to upper respiratory and eye infections. The pathogen spread through moisture droplets. Bird feeders, so common in the East, became transmission centers as infected birds left droplets that were then picked up by other house finches.

From 1994 to 1996, epidemics of *M. gallisepticum* spread north, west, and south from the Maryland point of origin. More than 100 million birds—half the house finches in eastern North America—perished. The eastern house finch population is no longer growing but appears to be stable. Moreover, it is showing signs of developing some resistance to the disease. If exposed to the pathogen, the finches in the western population would be highly vulnerable. At present, only the scarcity of finches in the Great Plains has prevented transmission of the disease to the West.—*A.V.B.*

PATTI MURRAY; ANIMALS ANIMALS



MYRA KLOCKENBRINK

Quick to come to feeders, above, house finches savor a variety of seeds and fruit.

larger than females. The finding that modifications of growth patterns were responsible for the rapid changes in finch morphology between distinct environments left us with another mystery. How had the growth of male and female finches been modified to match their local environments so perfectly?

To find out, we had to start at the first stage of growth: the egg. House finch females lay one egg per day until a clutch, typically five eggs, is complete. Embryos in the eggs do not begin to develop until their mother warms them through incubation. This allows the female to control when the eggs hatch. She can synchronize hatching by waiting until the last egg is laid before she begins the twelve-day incubation, or she can stagger hatching by beginning incubation before the last egg is laid. House finch females typically begin incubating two or three days before the last egg is laid, giving early-laid eggs a developmental head start over later-laid eggs. Because the entire brood of young house finches spends a total of fifteen days in the nest after the hatching of the first egg, this means that compared with last-hatched chicks, chicks from first-laid eggs can get up to five more days' (up to 33 percent more) post-hatch time in the nest, during which they are cared for and fed by parents. Not surprisingly, chicks from the first and

In Montana, females tend to produce daughters in first-laid eggs and sons in last-laid eggs. In Alabama, the pattern is the opposite.

the last couple of eggs in a clutch grow very differently and fledge at different sizes.

Amazingly, female finches utilize this simple and predictable relationship between hatching order and chick growth to produce offspring that match the local environment. In Montana, where small males and large females do best, breeding females tend to produce daughters in first-laid eggs and sons in last-laid eggs. Conversely, in Alabama, where large males are favored, the first-laid eggs are usually sons, and the last-laid eggs daughters. Moreover, in both populations, sex and hatching order greatly influence growth rate and size at fledging. For example, in Montana, males from first-laid eggs grow fastest and are larger at fledging than are males that hatch from subsequent eggs, whereas last-laid females grow the fastest and are larger than other females at fledging. The patterns are opposite in Alabama. Because size at fledging often determines the survival of young birds, it seems that breeding females speed up the growth of nestlings that would otherwise be at a disadvantage due to their hatching order.

Size affects survival, and females seem to speed up the growth of nestlings that would be at a disadvantage due to their hatching order.

ALEXANDER V. BADYAEV

The effect of hatching order on size and growth can be dramatic. The chicks above are brothers that hatched just one day apart. Right: Male and nestlings in the Sonoran Desert.

This strategy has an enormous impact on the eventual size and shape of adults in the population. By "designing" young to fit the environment by modifying their growth and sex in relation to their egg-laying order, mothers improve the chances that offspring will survive. By our estimates, 10 to 20 percent more offspring survive to adulthood than would survive if male-female hatching order were random. This could make the difference between house finches successfully colonizing a region or going extinct when faced with a novel environment, and it may be a primary reason that house finches have been able to spread into an array of environments over such a short time.

Our next step with the Alabama and Montana finches was to devise an experiment to help answer the latest set of questions that arose. Just how does place in the laying order determine growth rate and final body size? Does something in the eggs themselves produce the difference, or is the critical factor sibling competition or differences in the parental care that nestlings receive as they grow? We were able to rule out some explanations with a simple egg-switching experiment in which we exchanged eggs among the nests and modified their original hatching order. For example, we wanted to know what would happen if we took a fifth-laid egg from one nest and put it into the second-laid-egg's place in a foster nest. By switching eggs and then observing the growth of the exchanged nestlings, we found that the original laying order influenced the growth and final size of nestlings much more than the hatching order in the foster nest. That is, the nestling from a fifth-laid egg grew up to look like a fifth nestling even when it hatched in the second position in a foster nest. So, whatever makes early- and late-laid eggs grow differently is already present when the egg is laid. Interestingly, we recently found that females modify the size of eggs in relation to both the gender of an embryo and the laying order, so that the more rapidly growing nestlings hatch from the larger eggs.

Thus, we discovered what may be one of the main mechanisms underlying both the rapid divergence in physical traits among populations and the successful colonization of novel environments by house finches. As tends to be the case in scientific investigations of complex phenomena, however, we have simply replaced one set of questions with another, perhaps more challenging, set. It remains unknown how females modify the sex and growth of nestlings and especially how they make modifications so their young are well suited to the local environment. The resolution of how females achieve these feats will be the focus of future studies, and it promises to keep us busy with this common yet amazing songbird for years to come. □

NATURALIST AT LARGE

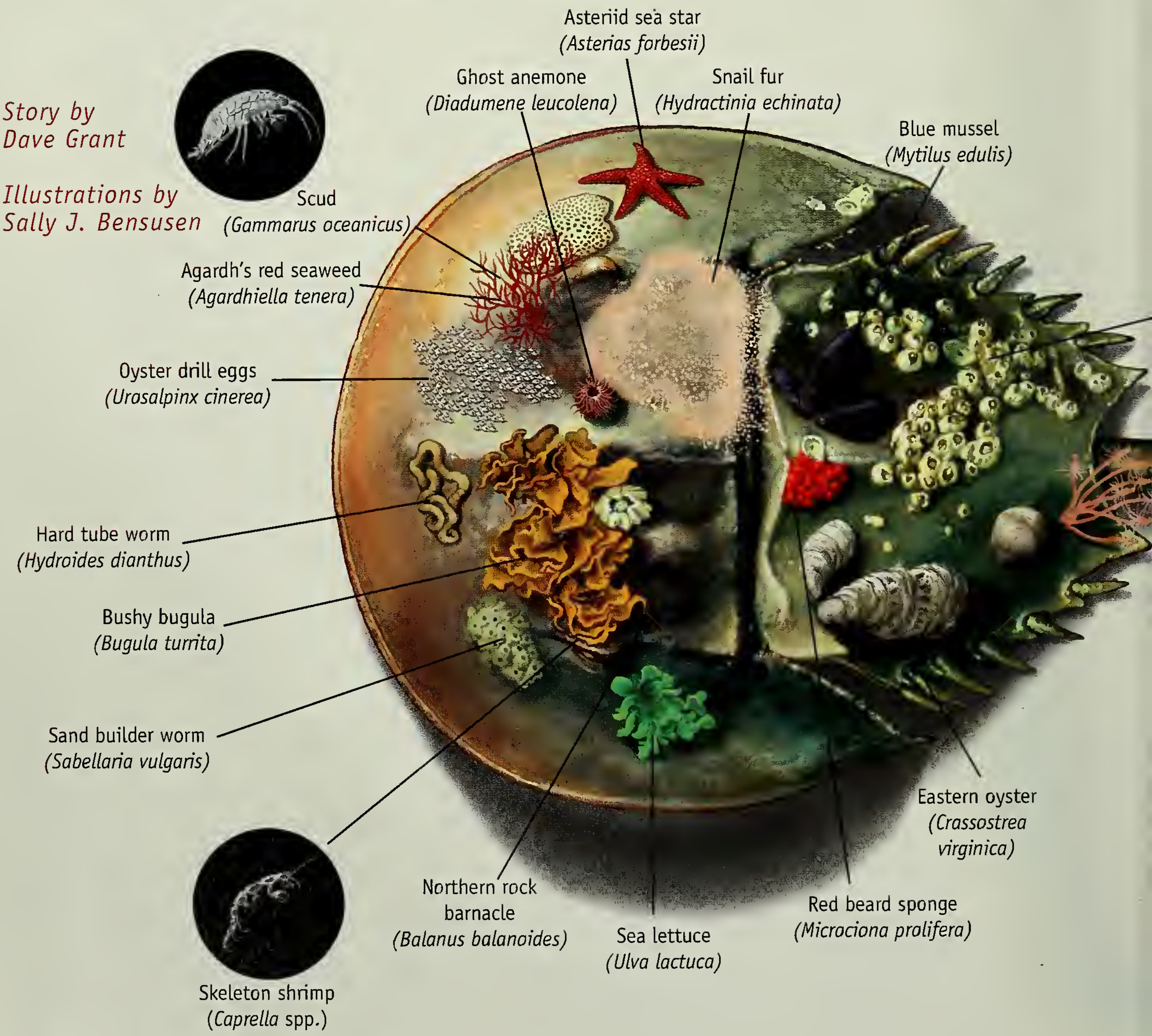
Hitchin' a Ride

Scuds, shrimps, and sponges are among the creatures that cling to the horseshoe crab.

From a bayside beach named for its most famous inhabitant, my dive partners and I stagger into the murky waters of New Jersey's Horseshoe Cove with scuba tanks strapped to our backs. Young, olive-colored horseshoe crabs glide away effortlessly as we approach, while the sluggish, dark, heavily encrusted older crabs hunker down in the sand a few yards offshore. As we watch them, the only sound I can hear is the gurgling of

Story by Dave Grant

Illustrations by Sally J. Bensusen



my exhaled breath as it bubbles up to the surface.

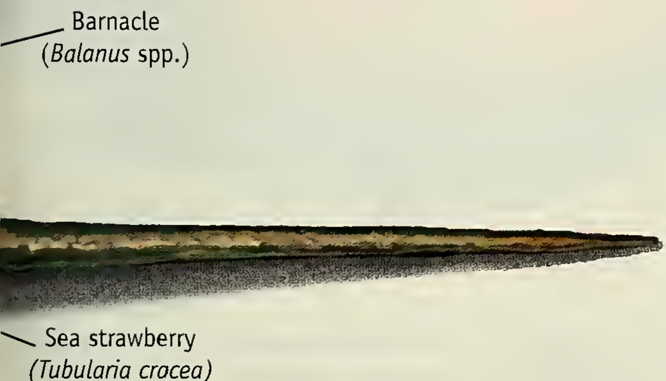
The role that *Limulus polyphemus* plays in my life has changed from nuisance to necessity over the course of two decades (coincidentally, the life span of a healthy horseshoe crab). My earliest encounters with *Limulus* on the beach were brief affairs; as a youngster, I gave the animal little thought except to poke one and then beat a hasty retreat if it moved. In college I learned that the species (not a true crab but a distant cousin of spiders) is a biological success story, having dodged whatever cosmic bullets exterminated the dinosaurs. Later, when I worked on research boats sampling fish in lower Sandy Hook Bay off the coast of New Jersey, I learned to avoid taking samples at the mouths of the Navesink and Shrewsbury Rivers in April, lest I fill the nets with migrating horseshoe crabs and incite a captain's tirade that could peel the paint off the wheelhouse walls.

In time, however, horseshoe crabs began to pique my interest instead of my ire. I started observing them to better understand their diet but soon became intrigued with the variety of hitchhikers that live on them. Since then, I have been keeping an inventory of organisms that can be found on *Limulus,* and these, rather than the crabs, have become the focus of my investigative efforts as well as my favorite tool for teaching marine biology.

Horseshoe crabs (sometimes referred to as soldier crabs) comprise four species. Three inhabit Indo-Pacific waters, and one populates the eastern shore of North America, from the Yucatán peninsula to northern Maine. The Atlantic species has survived for a quarter billion years, predating even the tectonic events that opened up the Atlantic Ocean. Although these crabs are sometimes dragged up in fishing nets from the continental shelf, in waters more than 650 feet deep, they seem to prefer spending the winter at depths of about 100 feet or less, where I've snagged them in the fall while trolling for bluefish. Every spring, vast numbers of horseshoe crabs travel twenty miles inshore to calm bays in search of sandy beaches, where they spawn in intertidal zones. The females lay up to 20,000 eggs in shallow nests dug at the high-water line during spring tides, which occur in conjunction with new and full moons. The young take a month or more to hatch, emerge from the sand, and drift among the plankton. Their vulnerable early years are spent burrowing, feeding on marine worms and shellfish, and apparently overwintering in the marshes and tidal flats of bays; I've accidentally uncovered them while digging for clams in Sandy Hook. There, as elsewhere along the eastern shore of North America, adolescents move into deeper bay waters and coastal waters for the rest of their first decade and are surprisingly hard to find until they mature and begin returning en masse to the beach to spawn each April.

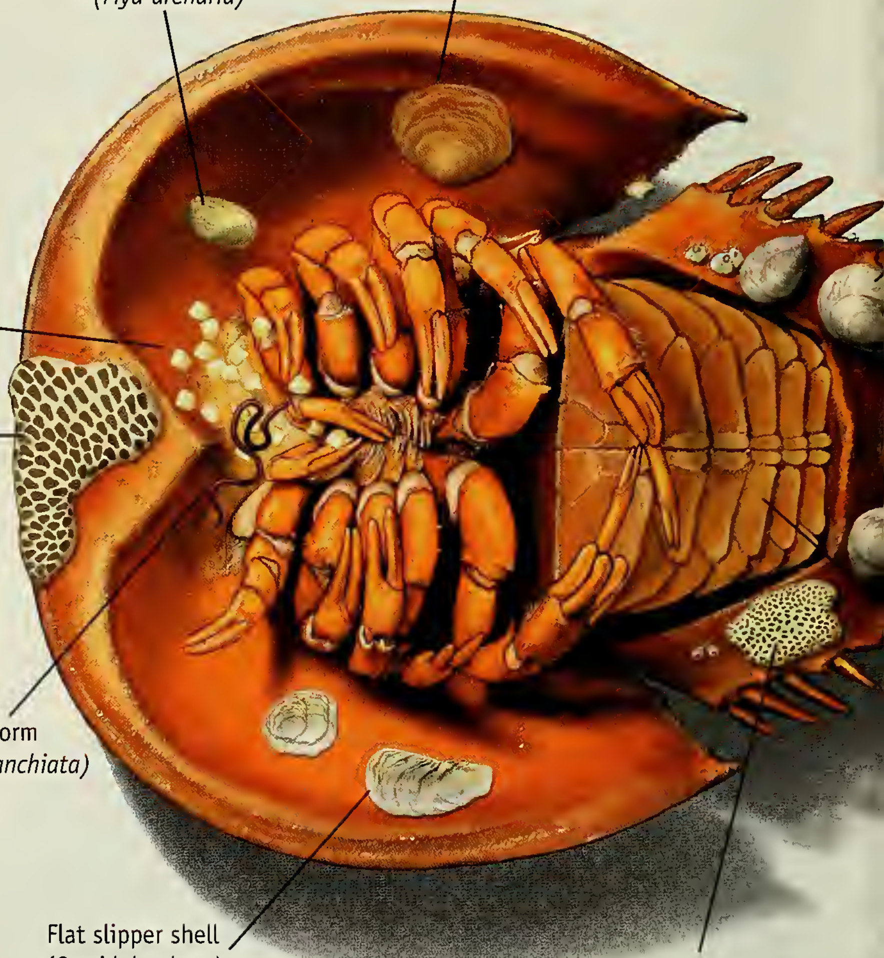
Like a rock on the seabed, a horseshoe crab is gradually hidden over time by a mantle of encrusting marine life. First to colonize the shell are bacteria, which coat submerged surfaces with a slimy film that allows other creatures to attach. Soon a zoological "five o'clock shadow" develops. My ever growing list of organisms to which the crab plays host contains more than three dozen invertebrate species representing nine phyla. The first wave of multicellular organisms that cement themselves to the crab's shell typically includes barnacles, delicate encrusting bryozoans, and tube-forming polychaete worms.

Unique confederates of the horseshoe crab are *Bdelloura* flatworms. Commonly (and perhaps confusingly) known as *Limulus* leeches, they are members of Platyhelminthes, a phylum laden with parasites and commensals; the exact relationship between the three species of *Bdelloura* and their horseshoe crab hosts is unknown. Unlike true leeches, or the nineteenth-century bdellometer (a mechanical



The horseshoe crab's hard shell is home to a bevy of invertebrates. As the crab moves, water swirls around these creatures, providing them with food and oxygen.

Mollusks often latch on to the underside of the horseshoe crab. Mussels, for example, use strong filaments to anchor themselves, often entangling the crab's legs and thereby greatly impairing its movement.



substitute for leeches), they don't draw blood. Instead they are obliged to live exclusively on the gills and legs of horseshoe crabs while feeding on bacteria and other microbial life. Flip an adult crab on its back, and you are sure to find some of these creatures.

Crabs arriving from offshore in late April often wear a crown of invertebrates that have attached as larvae and somehow avoided being worn off or smothered in the sand when their host crab burrowed. Other creatures are equally undeterred: the sand builder worm, which glues sand grains together for its home, establishes itself in thick patches along the sides of crabs as they wait, half buried in the sediment, for spring off our mid-Atlantic beaches. And high on the crabs' backs, I often find striking red beard sponges and fragile colonies of *Bugula* (a bushy bryozoan that is often dyed green and sold in florist shops as "Irish sea fern").

Old fishermen on Sandy Hook Bay tell me they do not launch their boats until after Memorial Day to avoid the spring's new crop of barnacle larvae. This helps spare them the chore of scraping barnacle colonies from their boat hulls later in the year. Young horseshoe crabs encounter the same problem but deal with it through rapid growth, frequent moltings, and burrowing. It's said that at age fifty, you have the face you deserve; for a horseshoe crab, the wear and tear of middle age begins to show at age ten, after it has molted sixteen or seventeen times. Since mature adults no longer shed their shells, they become beachheads for an even greater variety of creatures.

If a vacant space on top of a crab's shell receives enough sunlight through the shallow water, then green sea lettuce, brown popweed, and red rockweed often move in. In time, the shell community may become as diverse as that on any piling or seafloor rock, harboring colonies of plankton eaters such as sea strawberries (fragile red hydrozoans that look like long-stemmed flowers) and snail fur (fuzzy, pink, Velcro-like hydroids). More flower-shaped

animals also stake their claim here, including the beautiful striped anemone (an invader from Japanese waters) and the pale ghost anemone.

Give a horseshoe crab a good shake in a bucket of water, and you will discover which free-living predators are lurking in the community and grazing on its inhabitants. Errant polychaetes such as scale, sand, and blood worms can be nudged from hiding places. Skeleton shrimp compete for microscopic morsels with scuds—side-swimming shrimp that are among the most ubiquitous creatures in mid-Atlantic estuaries. Shake the crab harder, and you may dislodge tiny sea stars feeding on oysters and mussels, or sea urchins scavenging for seaweed and sedentary invertebrates. Baby rock or spider crabs, which use horseshoe crabs as hiding places to evade fish and cannibalistic cousins, may also be shaken loose, along with rugged little mud crabs equipped with barnacle-crushing claws. Other organisms ousted by a shake may include sand shrimps or potential food items for *Limulus,* such as juvenile soft-shelled and hard-shelled clams or tiny gem shells.

An aging horseshoe crab is gradually hidden beneath a mantle of encrusting marine life.

Where space permits, oysters and jingle shells sometimes anchor themselves to the horseshoe crab. A third mollusk—the slipper shell—habitually attaches near the crab's gills. This univalve bonds tightly to the shell and rarely moves; over time, the crab ends up with a stack of many generations of slipper shells. Though a drag to the crab, this is a bonus to the biologist attempting to estimate the age of individuals: we simply count the slipper shell stacks.

Poor *Limulus.* It must still run a gauntlet of periwinkles, oyster drills, and mud and basket snails, most of which leave egg masses that cover any undeveloped real estate on the shell. Some old crabs are really quite a sad sight by the time I encounter them near the shore at Horseshoe Cove. Worst of all, the oldest are often hindered (mussel-bound, if you'll pardon the pun) by the sinewy filaments of byssal threads that blue, ribbed, and horse mussels wrap around the crabs' gills and appendages. These hangers-on stay with the crab until the end.

Each spring, I look forward to the crabs' arrival from offshore, because they always bring along something new and interesting to show me. Over the years, I have noticed that the most lethargic are likely to have algae and various invertebrates cloaking their shells and eyes, and plenty of mussels entangling their legs and gills. Such a thorough covering on the surface of the crab may cause it more than a little inconvenience, interfering with light detection, movement, and respiration. A thick coating of tagalongs seems to presage the demise of the crab. This and a certain sluggishness are clues that they are suffering and probably won't survive another season.

I always peel off the growth from the eyes, legs, and gills of heavily infested crabs, but my efforts probably don't help them for long. They struggle on, ambling off into deeper water and vanishing beneath an ever thickening blanket of bryozoans, barnacles, and whatever else issues from Triton's wreathed horn.

Perhaps, like their human counterparts, these old soldiers never die, they just fade away.

Dave Grant is the director of the Ocean Institute of Brookdale Community College in New Jersey and a field-trip leader for the American Littoral Society at Sandy Hook. This article is adapted from his chapter in Limulus in the Limelight: A Species 350 Million Years in the Making and in Peril? *edited by John T. Tanacredi (Kluwer Academic/Plenum, 2001).*

OUT THERE

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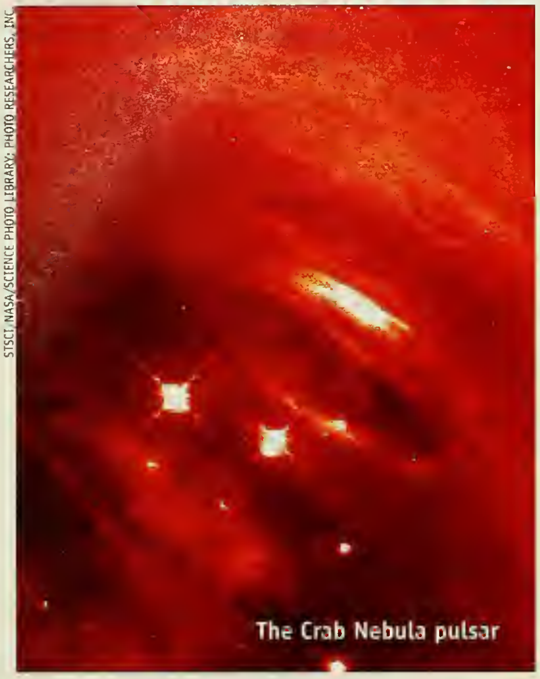


The Crab Nebula pulsar

A Pulsar on the Move

Astronomers resolve a long-standing mystery—only to reveal a new puzzle.

By Charles Liu

About once a century, somewhere in our galaxy, a star destroys itself in an explosion called a supernova. Within ten seconds, this titanic blast releases more energy than our Sun will produce in its entire 10-billion-year lifetime. Then, during the next 100,000 or more years, a glowing, gaseous remnant of the explosion expands outward from the supernova site at hundreds of miles per second, scattering the heavy elements that seed the birth of new stars and planets. The core of the exploded star, compacted by its own gravity, collapses into a superdense ball called a neutron star, ten miles across and 100 trillion times denser than lead. If the neutron star spins with a favorable orientation, it will send regular pulses of electromagnetic radiation toward Earth. We call this kind of star a pulsar.

You might expect to find a neutron star at the center of every supernova remnant. One of these, the Crab Nebula, has a pulsar at its center (spinning thirty-three times a second) and is often cited as a typical remnant, yet the vast majority either have a neutron star off-center or just don't seem to have one at all.

Astronomers are never short on ideas about how the universe works, so we of course have a plausible explanation for this apparent contradiction. Supercomputer simulations of supernovas almost never produce a perfectly symmetrical explosion; factors such as stellar spin or off-center blast waves can impart a fraction more energy on one side than on the other. The imbalance propels the neutron star away from the center of the maelstrom, pushing it outward at tremendous speeds. Within a few thousand years, it is far from the middle of the spidery supernova remnant.

Solid observational evidence now supports this theory. A team of astronomers, led by Joshua Migliazzo at the Massachusetts Institute of Technology and Bryan Gaensler at Harvard University, has just published measurements of the motion of a pulsar dubbed B1951+32, lying near one edge of a supernova remnant with an equally cryptic name, CTB 80. Using data gathered over twelve years with the Very Large Array radio telescope in New Mexico, Migliazzo and colleagues showed that the pulsar is moving across the sky, away from the center of the remnant, at a blistering pace of 0.025 arc seconds per year. Standing on Earth while watching this pulsar move across the sky is similar to standing in New York City while watching a snail in San Francisco crawl one-sixteenth of an inch per day. However, at the remnant's distance from Earth—about 7,000 light-years, or some 40,000 trillion miles—0.025 arc seconds per year translates to a minimum velocity of 550,000 miles per hour. At that speed, an astronaut could get to the Moon and back in less than an hour.

Unsatisfied with merely making a first-of-its-kind measurement, the researchers went one step further. Tracing the pulsar's trajectory backward to the center of the supernova remnant, they computed how much time its journey has taken. The dying star that birthed B1951+32 almost certainly exploded at that central location, so the question they've really asked is, How old is the pulsar? Their answer: 64,000 years, plus or minus eighteen millennia.

In human terms, this pulsar is an ancient artifact, born long before our ancestors began painting animals on cave walls. Astronomically speaking, though, it's young—too young, in fact, according to the most commonly accepted method of measuring the age of a pulsar. Under the conventional formula, this pulsar's age should be 107,000 years.

Migliazzo and his colleagues offer a simple explanation for the discrepancy. The standard formula for calculating age assumes that, as a result of supernova collapse, pulsars are born whirling at extremely high speeds—a hundred or more revolutions per second—and then slow down over time. The researchers state that if B1951+32 began spinning at thirty-seven revolutions per second, then both the standard and the new calculations would match at 64,000 years.

That sounds like an ideal solution —except that such a conclusion unseats a long-held tenet of pulsar physics: that all neutron stars begin their lives at breakneck rates of spin. Is our theoretical understanding of pulsar formation seriously flawed? Pulsar B1951+32 may now have provided the strongest challenge yet to the conventional wisdom.

The richness of Migliazzo and Gaensler's discovery shows how much we can learn from the study of traveling pulsars. Sadly, only a fraction of the thousand or so known pulsars can be analyzed this way. Many creep along so slowly that measuring their motion with current technology is a hopeless task. Others simply don't have a clear association with a supernova remnant, so we can only guess where they came from. But it's nice to know that, at least in this case, theoretical and circumstantial evidence have come together with reliable observational data to settle a long-standing puzzle—and stir up fresh debate—about the death of stars.

Charles Liu is an astrophysicist with the Hayden Planetarium. He is also affiliated with Barnard College as a research scientist in the Department of Physics and Astronomy.

THE SKY IN JUNE

By Joe Rao

Mercury appears at dawn at about midmonth, just above the east-northeastern horizon, but alas, never climbs much higher. The planet is at greatest elongation on June 21 (23° west of the Sun). It steadily brightens for the rest of the month, so the last week of June is the best time to look for it, preferably with binoculars.

Venus soars in the western evening twilight all month. More than 25° high in the west right after sunset, it does not drop below the horizon until about two and a half hours later. On June 1, Venus sits 2.5° below and to the right of Jupiter; two evenings later, they are separated by 1.5° and thereafter grow more distant. A beautiful crescent Moon hangs above and to the left of Venus on the evening of the 13th.

Mars, now a full year removed from its gloriously bright opposition of 2001, is all but gone from view. Located in Gemini, it shines at magnitude +1.7, low near the west-northwestern horizon just after sunset. By the final week of June, the combination of low altitude and bright evening twilight renders the planet invisible.

Jupiter and Venus make a bright pair in the western sky shortly after sunset early this month. The two planets are closest on June 3, when Jupiter appears one-seventh as bright as its companion. Jupiter then seems to drop rapidly away from Venus, setting earlier and becoming more deeply immersed in the evening twilight. It sits below and to the left of the crescent Moon on the 12th, likely disappearing from view by the end of the month.

Saturn arrives at solar conjunction on June 9 and is pretty much out of sight all month. Nonetheless, look for it very low near the east-northeastern horizon just before sunup during the final few days of the month, below and to the left of the somewhat brighter Mercury.

The Moon wanes to last quarter on June 2 at 8:05 P.M. New Moon falls on the 10th at 7:46 P.M., and first quarter on the 17th at 8:29 P.M. Full Moon comes on June 24 at 5:42 P.M.

An annular eclipse of the Sun occurs when the Moon is too far from Earth—and therefore appears too small in the sky—to completely block the light of the Sun, so a ring, or annulus, of sunlight remains visible around the Moon's silhouette. Such an eclipse occurs June 10 over the Pacific Ocean. Near the beginning of the track of the annular eclipse, it engulfs several islands in the Indonesian Sangihe and Talaud groups and later Saipan and Tinian, of the Northern Mariana Islands chain. Just before the end of the track, it passes less than twenty miles south of Puerto Vallarta, on the west-central coast of Mexico. Observers there can see the setting Sun appearing as a spectacular ring of fire for just over a minute. Much of the rest of western and central North America sees a partial solar eclipse in the late afternoon or at sunset.

The solstice occurs at 9:24 A.M. on June 21. Summer begins in the Northern Hemisphere; winter begins in the Southern Hemisphere.

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

BIOMECHANICS

A Weighty Matter

At nearly seven tons, Tyrannosaurus rex *would have simply been too heavy to run fast.*

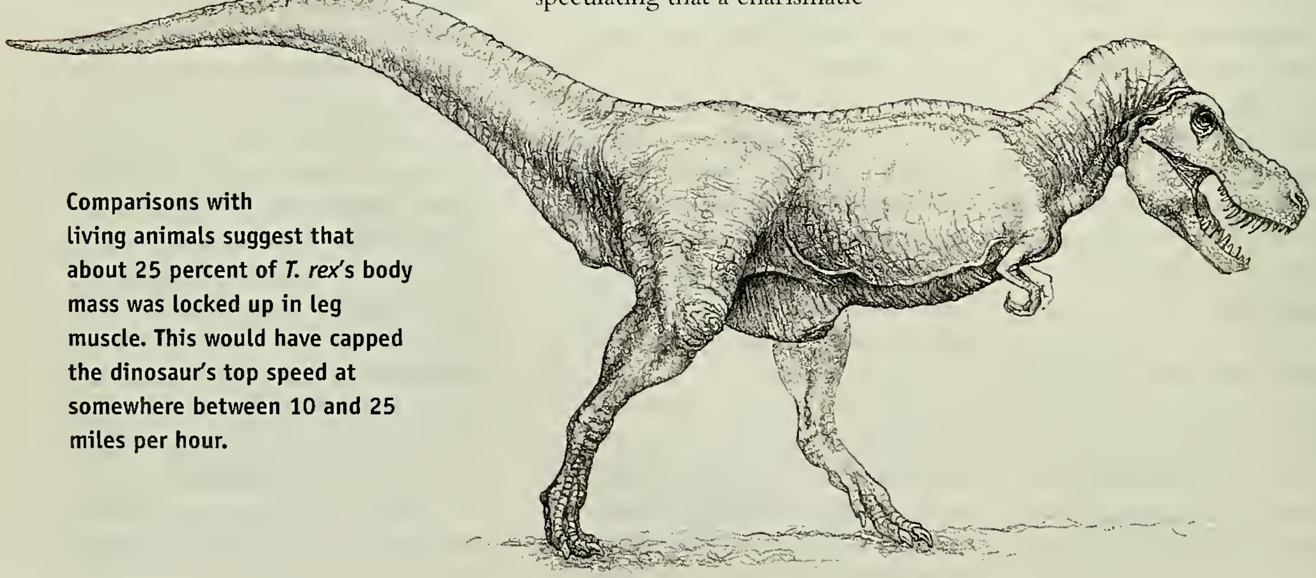
Story by Adam Summers ~ Illustrations by Sally J. Bensusen

Oblong, milk-chocolate slabs of rock, dappled with darker footprints, hang from the walls and cover trestle tables in the Pratt Museum at Amherst College. While assembling and cataloging this collection of rocks about a century and a half ago, geologist Edward Hitchcock identified more than a hundred species of animals on the basis of the size, shape, and spacing of the footprints and trails they'd left behind in the Triassic mud. Among the raindrop craters, the worm trails, and the bulldozer tracks of armored invertebrates are the three-toed prints of small dinosaurs and the deeper tracks of bigger, heavier animals.

Data from trackways like these, along with detailed measurements of skeletons and computer-generated models, are giving paleontologists with a biomechanical bent new insight into the real world of *Jurassic Park*. (For the record, few of the interspecific encounters in Steven Spielberg's movie could ever have taken place, because the actual creatures lived in several geological periods: the Cretaceous as well as the Triassic and Jurassic.)

Researchers use the length and width of fossil footprints to estimate the size, including leg length, of the beast that left them. The spacing of the prints reveals whether the animal was ambling along or sprinting. Fossil trackways indicate that bipedal dinosaurs weighing up to 4,000 pounds could sprint, while larger dinosaurs could move no faster than a swift walk. Yet this evidence hasn't stopped some scientists from speculating that a charismatic megacarnivore like *Tyrannosaurus rex*, which weighed roughly 13,000 pounds, could race along at forty-five miles per hour after its prey. And they are right not to have been intimidated, for in the world of fossils, the absence of evidence is not the same as evidence of absence. However, recent research suggests why no one has found any tracks of big running dinosaurs: the largest species just didn't have the muscle power required to run fast.

A running biped bounces up and down, its center of mass dropping down as the body is supported on one bent leg and then rebounding as the leg straightens. The force with which a running foot strikes the ground has been measured for a number of species, over a broad range of body sizes, and is surprisingly consistent: at least two and a half times the body



Comparisons with living animals suggest that about 25 percent of *T. rex*'s body mass was locked up in leg muscle. This would have capped the dinosaur's top speed at somewhere between 10 and 25 miles per hour.

weight. A 200-pound human running down Central Park West in New York City thus hits the ground with about 500 pounds of force at each step. At its lowest point, the body is in a sort of equilibrium—the leg in contact with the ground is bent at the hip, knee, and ankle, with its muscles having exerted enough force to counteract the downward momentum and begin the upward, straightening acceleration.

Amazingly, a given cross-sectional area of muscle generates about the same amount of force regardless of what animal (at least what vertebrate) it comes from. This fact is very handy, because if you know the size of a muscle—whether it belongs to Arnold Schwarzenegger or a hummingbird—you can make a pretty good guess about how much force it can exert.

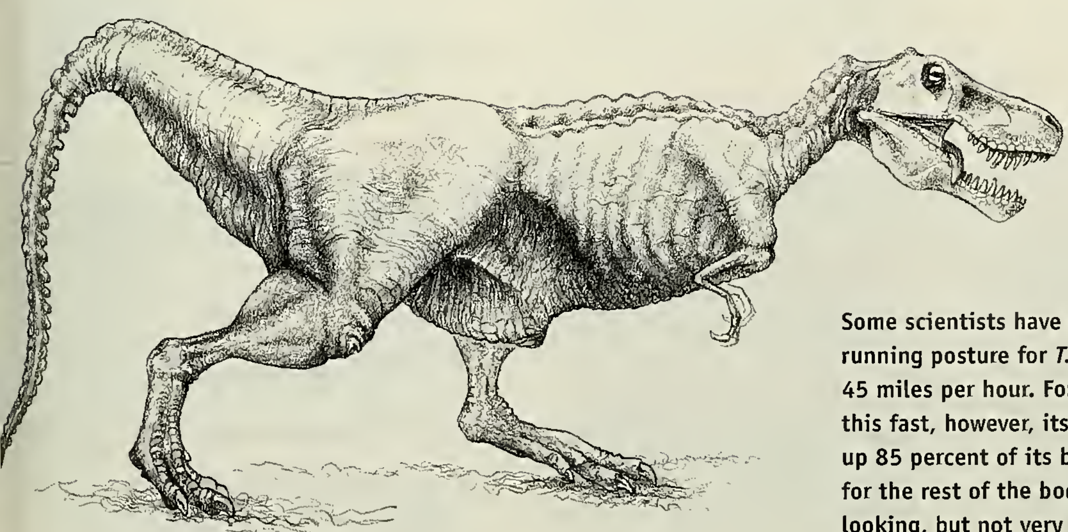
This relationship between force and cross-sectional area is at the heart of the problem, not only for *T. rex* but for every other large critter. While available muscle force increases as the square of muscle size, the weight of the muscle (and, indeed, of the whole animal) increases as the cube of its size—that is, as its volume increases. The force that a running animal must overcome is proportional to its body weight; beyond a certain weight, the animal won't have the strength to keep from crashing to the ground.

To determine the minimal amount of muscle a *Tyrannosaurus* would need to run fast, John Hutchinson and Mariano Garcia, of the University of California, Berkeley, used a two-dimensional computer model of a *T. rex* skeleton to look at the key moment in the running stride: just before the animal bounces back up. They tried out various postures, from an improbably upright one to a more scientifically fashionable crouch. Their simulations determined that the mass of the leg-straightening muscles ranged from 25 percent of body mass for the straight-legged pose to a whopping 85 percent for the crouching sprinter. To see how these percentages would compare with those of a living animal, the researchers applied the model to the chicken, which is a strong runner. They found that, according to the model, a chicken should be able to run with as little as 10 percent of its body weight tied up in leg-straightening muscles.

Living animals devote at most half their body weight to muscles, including heart, biceps, and abdominal muscles, as well as those used for walking or running. In chickens and other strong two-legged runners, about 20 percent of the body mass is in the leg straighteners—about twice as much as Hutchinson and Garcia's model says is needed. To run quickly, *Tyrannosaurus* would have required more leg muscle than any living animal has. In fact, a *T. rex* that adopted a crouched posture while running would have had to devote so much body mass to leg muscle that there would have been almost nothing left for skin and bones.

So, how quickly could a huge carnivorous dinosaur move? Given its long legs, probably more than ten miles per hour. It may even have gotten up to twenty-five—swift enough to run down most humans, but not fast enough to catch an SUV speeding through Jurassic Park.

Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine (asummers@uci.edu).



Some scientists have proposed a more crouched running posture for *T. rex,* as well as speeds of up to 45 miles per hour. For such a huge dinosaur to run this fast, however, its leg muscles would have to take up 85 percent of its body mass, with little left over for the rest of the body. The result would be a scary looking, but not very probable, creature.

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REVIEW

So Near and Yet So Far

Yes, we're primates. But how much does that tell us about our behavior?

By Meredith F. Small


KARL AMMANN

Philosophers have always been engaged in trying to understand how much of human behavior is innate—biologically determined—and how much is molded by life experience. This so-called nature/nurture debate has been transformed in recent years by an explosion of research on the human genome, behavioral genetics, and molecular biology. The answer to the philosophers' question seems to be that the behavior of all animals, including humans, reflects a dynamic interplay of genes and environment. Yet, as demonstrated by the two books reviewed here, the controversy over the influence of each force still rages.

Melvin Konner and Jonathan Marks are both anthropologists in the grand tradition, at ease discussing the complexities of biology as well as culture. Both men draw not only from their own disciplines but from their knowledge of history, sociology, and literature. But they differ dramatically in their estimate of science's ability to explain who we are. In *The Tangled Wing,* Konner celebrates science, while in *What It Means to Be 98% Chimpanzee,* Marks deplores some of the misdeeds performed in the name of this discipline, suggesting that science has been misused to support shaky social agendas. Read together, the two books provide a good recipe for human nature, seasoned with a cautionary note.

The original edition of *The Tangled Wing,* published more than two decades ago, was one of the first—and surely one of the most exhaustive—books on human behavior to hit the shelves during the heyday of sociobiology. Konner's medical training (he teaches psychiatry and neurology as well as anthropology at Emory University), combined with his anthropological fieldwork with a !Kung San population of hunter-gatherers in Botswana, provide a strong foundation for integrating the mountain of research on genetics, hormones, behavioral genetics, psychology, and ethnography and also for finding ways to explain why we are the way we are. In this extensively updated and rewritten second edition, Konner moves easily from chapters on such general topics as human sociality, adaptation, ingenuity, brain development, genes, and culture to those focused on particular aspects of human emotion and desire.

The Tangled Wing: *Biological Constraints on the Human Spirit,* by Melvin Konner (Times Books)
What It Means to Be 98% Chimpanzee: *Apes, People, and Their Genes,* by Jonathan Marks (University of California Press)

In his chapter on rage, for example, Konner describes two, almost identical murders—young men killing their girlfriends—in two very different cultures and shows how the justice system in each culture viewed the man's deed. In the United States, the act was seen as a lover's quarrel; in China, as a political act against the state. Both of the killers were overcome with jealous rage—surely a biopsychological state—yet each culture viewed the act through a different lens. Konner then looks at the brain chemistry of aggression, citing studies of rats, monkeys, and people, and suggests that changes in the level of hormones such as serotonin are clearly involved in impulses toward suicide, violence, and negativity. At the same time, anger can be molded or learned as a response to the environment and can thus play a role in altering hormone balances. Over and over, Konner depicts human nature as a complex meshing and overlapping of biology and culture. "Our species is at a

crux in its earthly history, aggressively mastering techniques that will let us guide and change our own nature," he writes. "The biological genies—whether medicines, hormones, recreational drugs, brain cells, neural circuits, clones, or genes themselves—cannot be put back into the bottle." We are responsible for "seeing to it that these new genies are servants to, not masters of, our destiny."

In *What It Means to Be 98% Chimpanzee,* Jonathan Marks (a professor at the University of North Carolina at Charlotte), begins by taking apart a statement that has become a tenet of anthropology: We share 98 percent of our DNA with chimpanzees, so we must be another kind of chimp. Not really, says this author. Yes, any fool can see the similarities in anatomy and behavior, but to link those similarities to common bits of DNA is quite difficult. To begin with, most of the DNA we share with chimps is repetitive "junk." Even when meaningful sequences are compared, Marks contends, the matches might be considered similar or dissimilar, depending on the geneticist's eye and on the kinds of comparisons being done. And the much-touted figure of 98 percent also becomes less awesome when we acknowledge that we share about 35 percent of our genome with daffodils yet do not consider ourselves part flower.

Marks explains that his book is about a "hybrid field" called molecular anthropology, which "acts as mediator between reductive genetics and holistic anthropology; between formal knowledge and ideology; between facts of nature and facts produced by authorities; between what science can do and what scientists ought to do; and most fundamentally, between human and animal." And he challenges the idea of a culturally based human nature, saying that the quest for human nature "is itself an illusion." Culture, asserts Marks, is "*programmed* into human life."

The more important crisis in molecular anthropology, he claims, is understanding the biases that scientists bring to their work, and he cites as an example *The Bell Curve: Intelligence and Class Structure in American Life,* the 1994 book by Richard J. Herrnstein and Charles Murray that categorizes people according to their "cognitive ability" (an unmeasurable innate property, according to Marks). For anthropologists to use genetics to trace the history of the human lineage is, in this author's opinion, no more free of bias than is any other scientific endeavor—the Human Genome Diversity Project (HGDP) being a case in point. In 1991 the HGDP set out to collect blood from more than 700 ethnic groups in an attempt to map the distribution of peoples. But indigenous peoples, the project discovered, were not interested in giving their blood or hearing what scientists had to say. At an HGDP symposium in 1996, in answer to a project spokesperson's statement that the goal was "to tell these people who they really are," Debra Harry, a Northern Paiute activist against "bio-colonialism," said: "I know who I really am—shall I tell you who you really are?" The cultural assumptions of the scientists came across as spectacularly naive. "Ethnic groups are categories of human invention," Marks points out. "Their boundaries are porous, their existence historically ephemeral."

Both books speak to the power of science as a tool for either understanding ourselves or fooling ourselves. We now know there is a biological basis for human nature, but apparently what we do too often with this nature is to nurture our own prejudices.

Anthropologist Meredith F. Small is the author, most recently, of Kids: How Biology and Culture Shape the Way We Raise Our Children *(Doubleday, 2001).*

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All Ears and Eyes

By Robert Anderson

The senses that allow us to perceive our world are remarkably complex. But in the past decade, biologists have begun to understand how we see, hear, smell, taste, and touch. Some of the advances are highlighted (in English and Spanish) by the Howard Hughes Medical Institute at www.hhmi.org/senses/.

Take the sense of smell. Most people would say it's done with the nose. But Gordon Shepherd, a professor of neuroscience at Yale University, tells us this is "a little like saying that we hear with our earlobes." Read through "The Mystery of Smell," and you will discover that the real work is done by about a thousand different receptors on the olfactory neurons, deep inside the nasal cavity. Or read "The Quivering Bundles That Let Us Hear," and you will learn about experiments in which the cilia of the hair cells in the inner ear "quivered to the high-pitched tones of violins, swayed to the rumblings of kettle drums, and bowed and recoiled, like tiny trees in a hurricane, to the blasts of rock-and-roll." Once you know more about these amazing structures (which do not repair themselves once damaged), you might turn that music down a few decibels.

This site sparked my interest in the senses, but it doesn't have any links to other sites for more information. So I will give you one more: BioMEDIA's "Eye to Eye" annotated Web link set (ebiomedia.com/gall/eyes/EyeAWLS.html)—a great list of sites on the biology, diversity, and evolution of eyes. Be sure to check out the "Eye to Eye Gallery" at the bottom of the page.

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

BOOKSHELF

Join naturalist Scott Weidensaul on his travels to find the Tasmanian wolf, the black-footed ferret, and the Indian forest owlet in **The Ghost With Trembling Wings:** *Science, Wishful Thinking, and the Search for Lost Species* (North Point Press). Some of these species, of course, have been elbowed out of existence by introduced ones, and the fallout has been chronicled in Yvonne Baskin's **A Plague of Rats and Rubbervines:** *The Growing Threat of Species Invasions* (Island Press). But if you'd prefer to tune out such economic and ecological bad news, Stephanie Mills recommends **Epicurean Simplicity** (Island Press). Her book is a call for living prudently (but intensely) in harmony with the natural world. In **Lewis & Clark Among the Grizzlies:** *Legend and Legacy in the American West* (Falcon/Globe Pequot Press), naturalist Paul Schullery has sifted through journals from the Corps of Discovery, 1804–1806, to document expedition members' first (and increasingly frequent) encounters with the "white" bear and to revisit a "former grizzly bear kingdom now lost under cities, ranches, and civilized landscapes."

On another important theme, evolutionary biologist Stephen Jay Gould offers a rigorously scientific, scholarly, and elegant interpretation of **The Structure of Evolutionary Theory** (Harvard University Press), including the fierce and ongoing debates that surround the topic. A masterpiece of evolution is the human eye, and in the beautifully illustrated **Vision and Art:** *The Biology of Seeing* (Abrams), neurobiologist Margaret Livingstone explains how the eye processes light. In **Body Heat:** *Temperature and Life on Earth* (Harvard University Press), biopsychologist Mark S. Blumberg explains another mechanism driven by the evolutionary process—the way animals find (or avoid) heat and regulate their temperature as efficiently as possible. Still on the subject of evolution, Steve Olson, in **Mapping Human History:** *Discovering the Past Through Our Genes* (Houghton Mifflin), argues that DNA provides "a sort of molecular parchment on which an account of our species has been written."

Among the new crop of memoirs is John Tyler Bonner's **Lives of a Biologist:** *Adventures in a Century of Extraordinary Science* (Harvard University Press), in which he chronicles an illustrious career devoted in large part to studying the life cycles of slime molds. Or check out astrophysicist Janna Levin's **How the Universe Got Its Spots:** *Diary of a Finite Time in a Finite Space* (Princeton University Press), made up of journal entries to explain (to her mother) her abstruse work on such topics as infinity, relativity, black holes, and topology.

For unusual guidebooks, try Tim Fitzharris's **National Park Photography** (AAA Publishing), filled with helpful maps indicating the best views, professional pointers on technique, and advice on taking outstanding photographs of natural wonders. In **Animals & Plants of the Ancient Maya:** *A Guide* (University of Texas Press), Victoria Schlesinger wants to "bring to life the interaction between an ancient people and their environment." Finally, for a beautifully illustrated tour of our solar system's planets, see F. W. Taylor's **The Cambridge Photographic Guide to the Planets** (Cambridge University Press).

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or through www.amnh.org.

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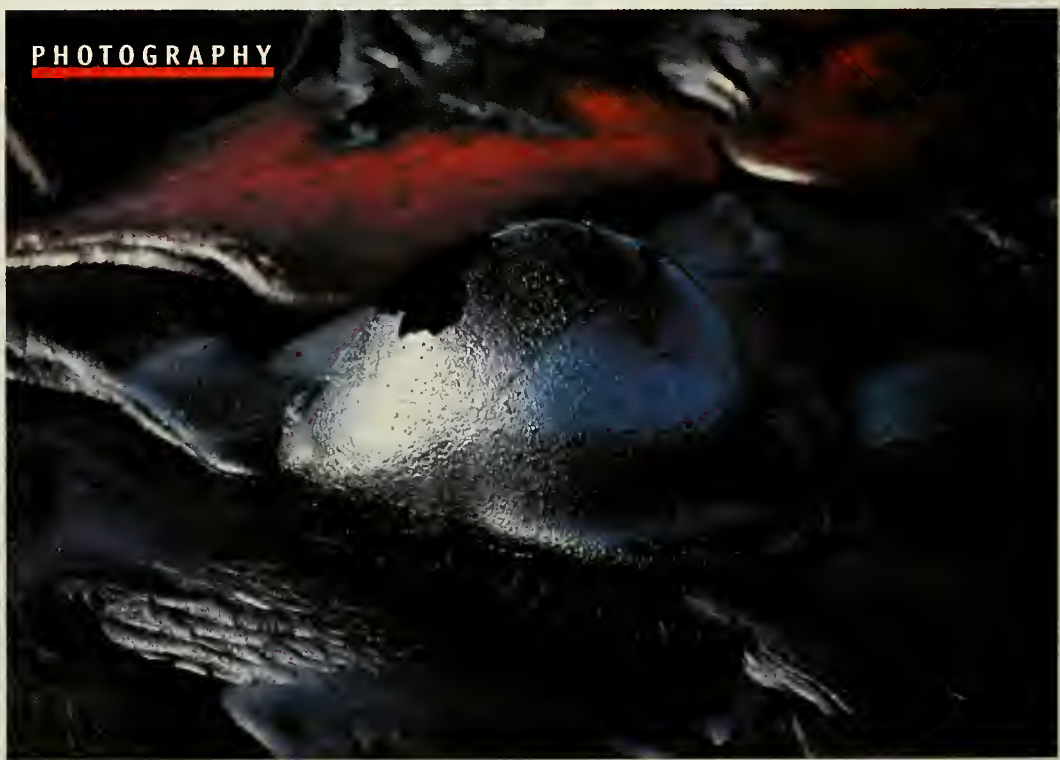

Volcanoes, *photographs by Philippe Bourseiller; text by Jacques Durieux (Abrams)*

THE NATURAL MOMENT

Trained Eye

Photograph by **Yva Momatiuk** and **John Eastcott** MINDEN PICTURES

At summer's end, a young arctic fox is learning to hunt on its own. Photographers John Eastcott and Yva Momatiuk first spied this pup as it crouched on a gravel bar at the mouth of Alaska's Sagavanirktok River, near the Beaufort Sea. It was regurgitating the indigestible remains of an earlier catch: the bones and beak of a small bird. Soon the juvenile performed a series of deliberate stalking and pouncing maneuvers. According to Momatiuk and Eastcott, it eventually caught and devoured five lemmings in "several crunchy gulps."

If the young fox is to survive the Arctic winter, it must gain weight rapidly. Adding to its standard diet of insects, berries, bird eggs, and occasional scraps of carrion, the pup increases its protein intake by hunting mice, voles, and lemmings. When the cold weather finally sets in, it may be as much as 50 percent heavier than it was in midsummer.

Winter's onset also means a change in coat. The fox's dark summer pelage will be replaced by snow-white thermal fur. Well adapted to the icy climate, arctic foxes have several other special traits, including hairy paws, pigment-protected eyes, and a long, wraparound tail.

As the sea freezes and food becomes scarce, the pup may turn to scavenging. Youngsters like this one have been known to follow polar bears in hopes of swiping some leftovers.

—*Erin M. Espelie*

ENDPAPER

Cultivated Wilderness

By Elizabeth S. Eustis

Beside an old ice pond in the suburbs of Boston, I made a wild garden. It began as a vaguely naturalistic sprinkling of spring ephemerals among the ferns, blueberries, tupelos, oaks, and white pines spontaneously flourishing on abandoned farmland. In the course of two decades, my efforts have evolved into a deliberate attempt to encourage native plants and arrest the invasion of thuggish colonizers, such as the purple loosestrife and the common reed *Phragmites australis* volunteering at the pond's edge. This has become my idea of wild gardening.

The concept of a wild garden is a reflection of its time. In the Renaissance garden, elemental forces of nature were represented by fountains, statuary, and artificial grottoes. In the seventeenth-century English garden, rectangular plots of trees planted in straight lines were called wilderness; nongeometrical garden design was an exotic notion rumored to be practiced by the Chinese.

Irregular garden designs developed in Europe alongside changing ideas of cosmic and social order. In his widely read novel *Julie: or, The New Eloise,* Jean-Jacques Rousseau, who proclaimed that freedom was the natural state of man, described a radically naturalistic garden as an "artificial wilderness . . . without order and without symmetry." Reacting against the rigid grandeur of royal gardens such as the one at Versailles, Rousseau admired a new kind of English landscape garden, with serpentine lines and open vistas of meadows, streams, and groves of unclipped trees.

LUESTHER T. MERTZ LIBRARY, NEW YORK BOTANICAL GARDEN

The "picturesque" vista of White Lodge in Richmond Park, Surrey, before its transformation by Humphry Repton in 1805

By the end of the eighteenth century, a fashion for simulated wildness in landscape design became known as "the picturesque." The foremost landscape designer of the Industrial Revolution, Humphry Repton, disparaged this "new and slovenly doctrine," declaring a limit to the desirability of having untamed land near a house. Repton substituted ornamental gardens for "the uncleanly, pathless grass of a forest, filled with troublesome animals of every kind, and some occasionally dangerous."

Prompted in part by a nineteenth-century surge of popular interest in field botany and fern collecting, English gardening writer William Robinson produced the first book on wild gardens in 1870. Robinson recommended artistically introducing plants into natural landscapes and then leaving them to their own devices—a disaster for delicate species and a bonanza for aggressive ones. We live with the results of such laissez-faire planting ideas. Barberry, knotweed, ailanthus, and the brilliant *Euonymus* known as burning bush are just some of the horticultural immigrants that continue to outcompete many of our indigenous species.

At the turn of the twenty-first century, the idea of wild gardening is changing again. When I first planted a few wildflowers, I never imagined that my pondside garden would take shape in response to new environmental pressures and ecological imbalances. But something in my approach shifted as I learned that in New England alone, approximately 200 native species will soon require active human intervention in order to survive. Vast wetlands of *Phragmites* all over this region warn me to treat its recent appearance at my pond seriously and soon. If I can't save the world, I can at least refresh my little corner of it without making things worse by planting invasives, such as the pretty little goutweed that could so easily cover that bare spot under the beech tree. My role is shifting from wild gardener to wild guardian, a new reflection of our changing need for cultivated wilderness.

Elizabeth S. Eustis is co-curator of the New York Botanical Garden's current exhibition, "Plants and Gardens Portrayed: Rare and Illustrated Books From the LuEsther T. Mertz Library" (through July 31), and president of the New England Wild Flower Society.

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