


NATURAL HISTORY



6/03

PATTERNS IN NATURE



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FEATURES

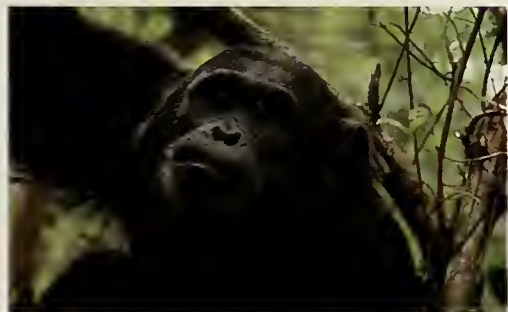


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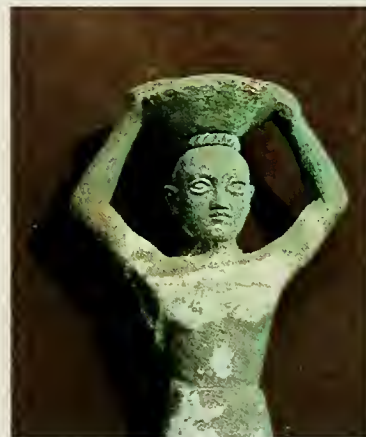
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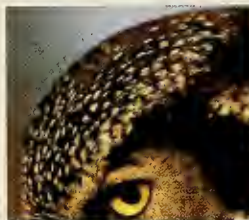
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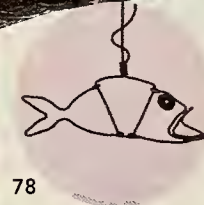


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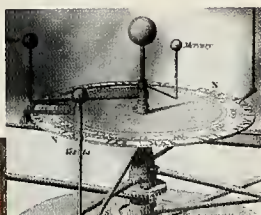
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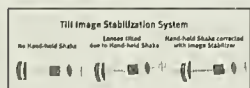
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THE NATURAL MOMENT

Pretty in Pink

Photograph by Gary Noel Ross





◀ See preceding pages



Like most other katydid species, the western round-winged katydid (*Amblycorypha parvipennis*) is normally green. But throughout its range, from South Dakota to central Texas, both pink and yellow variants occasionally pop up. My pink lady—for this was a female—was still a wingless juvenile when I came across her one early June morning in western Missouri's Wah' Kon-Tah Prairie. To get better acquainted with this rarity, I placed her in a terrarium.

Then I began to worry—the insect wouldn't feed on the greens I offered her, all prairie grasses and leaves that should have appealed to a katydid. But then, observing that her color was well matched by the pale purple coneflower, I offered her a bloom. She immediately began to nibble on the petals.

After a few days I tried an experiment to see if she got her pink pigment from the flowers: I started her on a diet of yellow blooms. But even though she feasted on yellow for the rest of her two-month confinement, I found no hint of jaundice. Apparently the color was in her nature, not her nurture. Ongoing research on related species, by David A. Nickle, an entomologist with the USDA's Agricultural Research Service, and others, is untangling how katydid color variation is genetically determined.

Why a pink (or yellow) katydid? My guess is that the variants, adapted to feeding on diverse kinds of flowers, help a katydid species enlarge its niche. The color camouflage is simply a tool the insects need to survive.

—Gary Noel Ross

Front-Page News

For more than a decade I've been pointing out to anyone who would listen that science and nature are big news. Disease organisms are news—think of AIDS, or anthrax, or SARS. Space exploration is news. The crisis in biodiversity is news. Environmental degradation, earthquake prediction, energy resources, the Iceman, and genetically modified crops are all news. You can't be current on the events of the day without being on top of what's happening in science.

Seldom have we at *Natural History* more keenly felt this observation than we have this month. In Baghdad looters rushed into the National Museum, plundering priceless archaeological artifacts. We decided to cover the disaster primarily by showing some of the artifacts—and leaving the reader to contemplate the fact that some of them may never be seen again. We also invited David Keys, a freelance reporter who specializes in archaeology, to pull together the main threads of the story so far. Finally, John Malcolm Russell, an expert in Near East archaeology who wrote "Robbing the Archaeological Cradle" for the February 2001 issue of *Natural History*, has graciously allowed us to reprint excerpts from his still all-too-relevant article. All three elements are collected under the title "Lost Time" (page 42).

As we go to press, another breaking news story has touched us closely. We have learned to our dismay that Subhankar Banerjee, the photographer of "Arctic Covenant" in our April 2003 issue, has become caught in the continuing political cross fire over oil drilling in the Arctic National Wildlife Refuge (ANWR). Banerjee's photographs documented the wildlife and flora of the refuge against the stunning backdrop of mountains and floodplain.

On March 19 Senator Barbara Boxer, a California Democrat, held up Banerjee's book—from which our portfolio was excerpted—on the floor of the U.S. Senate. Advocates of drilling, particularly Senator Ted Stevens, a Republican from Alaska, had portrayed the region as a barren land, devoid of wildlife for all but a few months a year. Boxer challenged that view, citing the book.

The reaction was virtually immediate. According to *The New York Times*, Banerjee's photographs, which were scheduled for display in the main-level rotunda at the Smithsonian Institution's National Museum of Natural History in Washington, D.C., were moved to a far less prominent gallery there. Captions for the photographs were shortened from discursive to telegraphic. A letter from Lawrence M. Small, the head of the Smithsonian, responding to a request for an explanation by Illinois Democratic Senator Richard J. Durbin, maintained that the earlier captions "might have been construed as advocacy" for ANWR, and were therefore excluded as a matter of Smithsonian policy.

The entire episode reflects the personalizing and retributive nature of contemporary political discourse. According to the *Times*, Stevens had told his Senate colleagues: "People who vote against [the drilling] are voting against me. I will not forget it." Stevens serves on the Senate oversight subcommittee for the Smithsonian, as does Durbin, and so the Smithsonian can hardly be blamed for fretting about its political support. Stevens's office denies putting any pressure on the museum. But self-censorship—if that's what it is—is still a slap in the face of free expression, and a repugnant consequence of the struggle to survive in a climate of intimidation.

—PETER BROWN

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CONTRIBUTORS



GARY NOEL ROSS ("The Natural Moment," page 6) was cataloging the butterflies in Missouri's Wah' Kon-Tah Prairie when he flushed out a katydid whose color seemed as outlandish as the Pink Panther's. Although based in Baton Rouge, Louisiana, Ross was then serving as "lepidopterist in residence" at the 7.5-square-mile prairie. Formerly a professor of biology at Southern University in Baton Rouge, Ross is director of butterfly festivals for the North American Butterfly Association.

To learn more about the complexity of nature, **SCOTT CAMAZINE** ("Patterns in Nature," page 34) became a biologist, a physician, and a photographer. His recent research has largely been devoted to the study of honey bee societies. Camazine was fascinated by the natural world as a child, and eventually became obsessed with the question of how complex patterns emerge and are maintained in nature, the subject of his article in this month's issue. (See his home page at <http://www.scottcamazine.com/>.) He is a co-author of *Self-Organization in Biological Systems*, published in 2001 by Princeton University Press.



Having spent several years observing the hunting behavior of chimpanzees in Gombe National Park, Tanzania, **CRAIG STANFORD** ("Close Encounters," page 46) decided to study the relations between chimpanzees and gorillas in Uganda's Bwindi Impenetrable National Park. Initiated in 1996, his Bwindi Impenetrable Great Ape Project (www.rcf.usc.edu/~stanford/bigape.html) examines how much the two species overlap in their use of the habitat's resources as well as the implications of that overlap for conservation initiatives and for the interpretation of ancient hominid adaptation. Stanford is a professor of anthropology and biological sciences at the University of Southern California in Los Angeles, and co-director of the university's Jane Goodall Research Center. His book on early human evolution, *Upright: The Evolutionary Key to Becoming Human*, is slated for publication by Houghton Mifflin later this year.

Astronomer **FULVIO MELIA** ("Peering at the Edge of Time," page 52), an Australian expatriate living in Arizona, wants to put Einstein's general theory of relativity to the ultimate test—by exposing it to the intense gravity of our galaxy's central, supermassive black hole. A professor of astronomy at the University of Arizona in Tucson, and an associate editor of *Astrophysical Journal Letters*, Melia also brings his love for the beauty of the night sky to his writing for a general audience. When he's not looking up, he enjoys history, fast cars, and Australian Rules football. His article in this issue is adapted from his book *The Black Hole at the Center of Our Galaxy*, which is being published by Princeton University Press.



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A Long Jump

The first literary mention of the ancient Greek athletic event known as the long jump, whose biomechanics are discussed in Adam Summers's column "Throwing Yourself into It" [4/03], is in book VIII of the *Odyssey*. Homer presents it as an after-dinner contest performed for Odysseus, but makes no mention of the use of *halteres*, or weights, by the jumpers.

Mr. Summers asserts that the competitive long jump was a standing event; on the contrary, it seems to have been a running jump. That interpretation arises in part from the fact that an-

standing long jump, but probably not for the competitive event. Several literary sources recount long jumps exceeding fifty feet.

The first Olympic victor in the long jump was Lampis of Sparta, who in 708 B.C. won the pentathlon—a contest consisting of five separate events, including the long jump. The earliest vase paintings that depict jumping with weights date from the sixth century, and the oldest surviving weights from about 600 B.C. So one might ask whether and how Lampis and other early long jumpers actually used weights. Philostratos, a third-century A.D. sophist,

shoulders and hands, athletes probably would have used them as dumbbells are used today—as training weights.

David Gilman Romano
University of Pennsylvania
Philadelphia, Pennsylvania

ADAM SUMMERS REPLIES: Both standing and running long jumps may have been ancient Olympic events. The jump shown on many vases certainly appears to be a standing long jump, because the arms are moving together. In a running long jump the arms are out of phase, one behind and the other in front. It's difficult to envision a biomechanical benefit for *halteres* in that kind of jump.

In reference to the fifty-foot jumps, some scholars believe those figures result from combining the outcomes of several standing long jumps.

Biologists have adopted the term "*halteres*" to refer to the rear vestigial "wings," or balancers, in dipterans (two-winged flies, mosquitoes, gnats, and so on). Curiously, in the fruit fly, a single gene mutation is capable of making the *halteres* revert to a second set of wings, thus anatomically removing the mutated flies from the order Diptera.

Frank Sturtevant
Sarasota, Florida

Entomophilia

I enjoyed Le Anh Tu Packard's article about the giant water bug known in Vietnam as the *ca tuong* ["Bug Juice," 3/03]. The insect is a food delicacy not

only in Vietnam but also throughout Southeast Asia. In Thailand—where, according to the English entomologist William S. Bristowe, writing in 1932, "it reaches the tables of princes in Bangkok"—it is known as *malaeng da na*. Although artificial bug flavoring is now available, the Thais still prefer the real thing.

More information about this delectable insect is available in chapters 24 and 25 of my online book "The Human Use of Insects as a Food Resource" (www.food-insects.com).
Gene R. DeFoliart
University of Wisconsin—Madison
Madison, Wisconsin

Surf and Turf

I read with great interest Robert S. Semeniuk's article "How Bears Feed Salmon to the Forest" [4/03], on the work of Thomas E. Reimchen in investigating marine-derived nutrients in forest ecosystems. Fisheries biologists have long regarded Pacific salmon as "keystone species" because of their ability to transport vast amounts of oceanic nutrients far inland during spawning migrations. Reimchen's research adds complexity to the existing paradigm by delineating the second stage of the "nutrient pump": large carnivores transporting huge numbers of salmon carcasses into the terrestrial environment. Marine-derived nutrients thus get distributed over a far greater area than they would be otherwise. Hence bears, being an integral part



"So, what do ornithologists do to relax?"

cient Greek has words for the jumper's takeoff board (*bater*) and his earthen landing pit (*skamma*), neither of which should have been necessary for a standing jump. *Halteres* may have been used at times for the

tells us that *halteres*—a "sure guide for the hands and for bringing the feet cleanly to the ground"—were invented by the pentathletes themselves; judging by his comment that *halteres* were good for the

of the nutrient pump, are critical to the health of the Pacific Northwest's coastal ecosystems.

Kenneth I. Ashley
University of British Columbia
Vancouver, British Columbia

Democracy in Space

Neil deGrasse Tyson's cogent essay "Reaching for the Stars" [4/03] correctly identifies what might be called the "categorical imperatives" that have universally governed human forays into the immense and the unknown: defense, commerce, and spiritual or temporal power. But he doesn't explicitly mention a pertinent feature of the history of grandiose projects, a feature common to Chinese emperors, Iberian royalty,

and Egyptian pharaohs responsible for the wonders of past ages: they were all autocrats who did not require the permission of their governed to launch their initiatives.

Today, however, proponents of space exploration must persuade not just one monarch (and perhaps a few influential advisors) to implement a stupendous dream. The United States is a democracy, in which an entire population, or at least their hundreds of elected representatives, must be persuaded. Advocates of space exploration must show that it is directly pertinent in the near term not merely to the parochial interests of a select sliver of the populace, but also to

the pragmatic concerns of the vast majority.

Robert E. Becker
Grand Rapids, Michigan

Picture Imperfect

On page 58 of the article "Vietnam's Secret Life," by Eleanor J. Sterling, Martha M. Hurley, and Raoul H. Bain [3/03], is a photograph of a single branch of the golden Vietnamese cypress, showing both needles and scales. The caption says that it is highly unusual for a mature tree to "bear both needles and scales." Yet nearly all mature redwoods (*Sequoia sempervirens*) have needles on their low foliage and scales on their upper foliage, reflecting the humidity gradients found in tall forests.

Roman Dial
Alaska Pacific University
Anchorage, Alaska

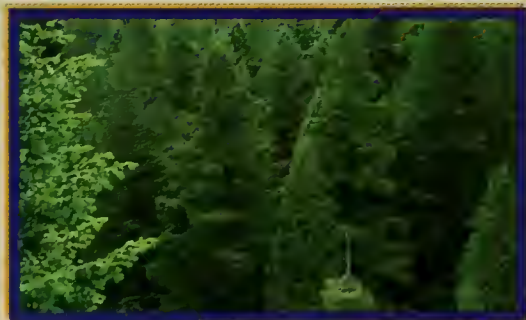
MARTHA HURLEY REPLIES:

The caption should have specified that for a mature tree to bear both needles and scales *on the same branch* is highly unusual; in fact, this trait characterizes all cypresses, and is one way to identify them.

Redwoods do bear both kinds of foliage simultaneously on the same tree, though not on the same branch; in addition, a number of related species undergo a transition between the two foliage forms as the plants mature.

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

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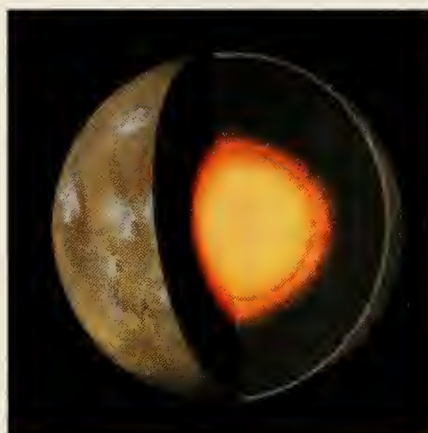
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UN-SOLID GROUND Most people probably don't give much thought to the two faint, ever-shifting double bulges that are continuously sliding across the surface of our planet. Those bulges are called solid-body tides; the larger of the two is caused by the Moon (the other by the Sun), and it's pretty subtle: about one foot high at its maximum. But if the Earth had a solid core instead of one whose outer 94 percent is liquid, the bulges would be some 30 to 40 percent smaller. The effect is the result of two phenomena: the gravitational pull of the Moon or the Sun, coupled with the relative elasticity of a planet with a partly liquid core.

Now Charles F. Yoder, a planetary scientist at the Jet Propulsion Laboratory in Pasadena, California, and his colleagues have measured solid-body tides elsewhere in the solar system. Not only have they done it with remarkable precision, but, intriguingly, they've also determined that the solid-body tides on Mars—caused by the Sun, not by a Martian satellite—are large enough to indicate that at least part of that planet's core is liquid.

Until recently, planetary geologists had no direct evidence that Mars had a solid core. But after Yoder's team analyzed three



Inside Mars

years' worth of radio signals from NASA's Mars Global Surveyor and tracked the spacecraft's orbit around Mars, their data showed a slight but continuous change in the tilt of Surveyor's orbit: a shift of about 0.001 degree a month. Early in the study, the investigators realized only a liquid core could give rise to a tidal bulge capable of having the observed gravitational effect on the spacecraft. And how much bulge is that? About a third of an inch. ("Fluid core size of Mars from detection of the solar tide," *Science* 300:299–303, April 11, 2003)

HOME, SWEET HOME On Earth, where there's water, there's usually life. But few people would expect to find life in an isolated reservoir of 4,300-year-old seawater locked inside the basalt crust that forms the bottom of the world's oceans. The water is hot—a sweltering 149 degrees Fahrenheit—and almost entirely isolated by hundreds of feet of impermeable sediment (the exceptions to total isolation may be a few scattered, rocky seamounts that pierce the sediment blanket). But a team of scientists led by James P. Cowen of the University of Hawaii in Honolulu decided to check it out for life anyway.

First they had to obtain water from the crustal reservoir without contaminating it—quite a feat in itself. In the mid-1990s the international research partnership known as the Ocean Drilling Program bored a hole in the Juan de Fuca Ridge, in the northeastern Pacific. The drilling, in 8,530 feet of water, went down through 810 feet of sediment and then an additional 157 feet of seamount crust. Pressures at the bottom of the ocean are enormous, but they're even greater within the crust's high points, and so crustal water gets pushed all the way up to the seafloor at the top of the drill-hole. Cowen and his team took advantage of a clever collection device, recently installed, that captures the fluid before bringing it to the surface. Samples can thus be examined for any micro-denizens of the deep that might reside there.

What did the team find? In the water were swarms of bacteria and archaea (ancient microorganisms that often thrive in tough places), as many as a few million per ounce—perhaps not as crowded as pond scum, but similar to the density near the seafloor. Some of the microorganisms are genetically similar to the heat-loving bacteria that live in the sulfurous hot springs of Yellowstone National Park. And some of the critters get their energy from nitrates, rendering the water around them rich with ammonia. However uninviting to most of Earth's inhabitants, the reservoir is further proof that even in what most life-forms would regard as noxious quarters, an empty niche is hard to find. ("Fluids from aging ocean crust that support microbial life," *Science* 299:120–23, January 3, 2003)

COLD PASSAGE Several Novembers ago, off the coast of Greenland, the captain of a fishing vessel was puzzled by one of the fish caught in the boat's gill nets. He decided to put it on ice and ask experts to identify it. Peter Rask Møller, a zoologist at the University of Copenhagen, and his colleagues have now pronounced the six-foot-long, 155-pound beast to be a Patagonian toothfish, *Dissostichus eleginoides*.

The surprising word here is "Patagonian." *D. eleginoides*, an overfished species marketed in the United States as "Chilean sea bass," had never before been sighted in the Atlantic Ocean north of Uruguay. To reach Greenland, the hardy traveler had to swim at

least 6,000 miles at depths of at least 1,600 feet; closer to the surface, temperatures in the tropics would have been lethal to such a cold-water specialist.

The only other explanation for the finding would be the previously unrecognized existence of a resident northern population. But that seems unlikely: two decades of intensive deep-sea fishing in the North Atlantic have turned up only that lone toothfish. Yet some marine creatures do exist in separate northern and southern populations. The wandering toothfish suggests deepwater migration might have led to those discontinuous distributions. ("Fish migration: Patagonian toothfish found off Greenland," *Nature* 421:599, February 6, 2003)



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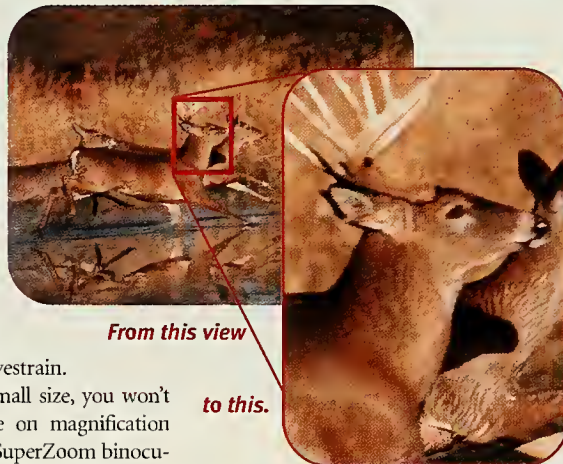
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IN THE SAME VEIN The network of blood vessels in a human being is not only extensive, it's also finely engineered. Some anatomists say that, placed end to end, the vessels would stretch 60,000 miles. As for the engineering, the British biologist Cecil D. Murray calculated the optimum size and number of each kind of conduit in 1926—assuming that nature would invest as little as possible in construction materials without jeopardizing the smooth flow of blood. Subsequent research showed that Murray's simplifying assumptions predicted the patterns of animal circulatory systems fairly well. In a precise, quantifiable way, the conduits increase in both number and total cross-sectional area as they get farther from the source of the fluid they carry.

Until recently, though, "Murray's law" had never been seriously tested in plants. One reason may be that many conduits in plants not only transport water but also

support the plant, undercutting the rationale for trying to apply the law. A team of biologists at the University of Utah in Salt Lake City, however, noted that some vascular conduits in plants provide little structural support. So they anticipated that the vessels in vines and in compound leaves such as those of the box elder—as well as in "ring-porous" trees such as ash, which make one ring of nonsupporting conduits every year to transport water from roots to leaves—might well conform with Murray's law.

One of the biologists, Katherine A. McCulloh, spent two years slicing thin cross sections of leaves, stems, and branches from local trees and vines; photographing the thin sections under the microscope; and measuring the diameters of nearly 100,000 of the plants' water-bearing con-



Cross section of a box elder leaf's petiole

duits with the help of image-analysis software. Her results bore out Murray's law: like us, plants have optimally efficient plumbing systems. Blood may be thicker than water, but the pipes that carry both of them follow the same rules of design. ("Water transport in plants obeys Murray's law," *Nature* **421**:939–42, February 27, 2003)

EXPERIMENT OF THE MONTH Use it or lose it: that's a rule that governs employee vacation days—and bones. In every bone there's a steady turnover of material, a continuous balancing act between bone formation and the resorption of bone tissue into the bloodstream. Those two processes are kept in healthy equilibrium by the near-constant compression and tension exerted on working bones. But if bones are not put to work, tissue formation slows down and resorption speeds up, and the bone structure weakens. Bedridden patients—and weightless astronauts in space—are prone to fractures simply because their bones aren't being used.



Black bear hibernating with her cub

But that raises a question: What about hibernating bears? Are their bones compromised by five to seven months' rest? To find out, Seth W. Donahue, a biomedical engineer at Michigan Technological University in Houghton, along with several colleagues, analyzed blood from seventeen wild black bears. (Blood samples are easier to get and less invasive than bone samples, and levels of certain protein fragments in the blood reflect the rates of bone formation as well as resorption.) First, however, Michael R. Vaughan of Virginia Tech in Blacksburg had to fit the bears with radio collars so that the investigators could locate the animals in summer and in winter, dart them with an anesthetic (even during hibernation bears can move with reasonable alacrity), and collect a few drops of blood.

The blood samples, as expected, showed substantial bone resorption, but surprisingly, bone formation had not slowed. Furthermore, the investigators detected a spurt of bone formation in early summer—greater than the bone growth measured in any other healthy adult mammal—that canceled out the net bone loss caused by a winter of inactivity. The result offers some long-term hope for people who suffer from osteoporosis or other bone diseases: bears could serve as a useful animal model in the search for effective treatments. ("Serum markers of bone metabolism show bone loss in hibernating bears," *Clinical Orthopaedics and Related Research* **408**:295–301, March 2003)

Stéphan Reeb is a professor of biology at the University of 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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NATURAL HISTORY

THE WONDERS OF THE UNIVERSE AT YOUR FINGERTIPS

The Rise and Fall of Planet X

Neptune and Pluto were supposed to “fix” the weird orbit of Uranus. Now, it seems, the orbit wasn’t “broke.”

By Neil deGrasse Tyson

H heard about Planet X lately? Probably not. It’s dead—no matter what anybody has told you. Astrophysicists no longer need to postulate the existence of an “undiscovered” planet to explain the motions of the other planets in our solar system.

The rise of Planet X begins with the German-born English astronomer Sir William Herschel, who more or less accidentally discovered the planet Uranus on March 13, 1781. That episode was an exciting moment in eighteenth-century astronomy. Nobody in recorded history had ever discovered a planet. Mercury, Venus, Mars, Jupiter, and Saturn can each be seen relatively easily with the naked eye, and all were known to the ancients. So strong was the bias against finding additional planets that Herschel, even in the face of contrary evidence, assumed he had discovered a comet. Other eighteenth-century star watchers were in denial as well. Charles Messier, the French astronomer and consummate comet hunter, noted, “I am constantly astonished at this comet, which has none of the distinctive characters of comets.”

Archival records of star positions show that several observers had seen Uranus before Herschel did, but each one had mistakenly classified the planet as a star. In an embarrassing example from January of 1769, the

French astronomer Pierre Charles Lemonnier did not discover Uranus six times! When Herschel finally noted that the mysterious object moved, astronomers were able to calculate an orbit with good precision because of the availability of nearly a century’s worth of “prediscovery” data on its position in the sky. Their calculations showed that the object’s

Uranus was behaving so badly that it seemed to ignore even Newton’s law of gravity.

orderly, near-circular path, far from the Sun, had nothing in common with the eccentric trajectories of all known comets. At that point, you would have had to be both blind and boneheaded to resist calling the new object a planet.

But all was not orderly in the solar system. Uranus was behaving badly. The new planet was not moving through space the way astronomers expected it to. Its trajectory around the Sun was not following the path Newton’s law of gravity would have it take. The historical observations fitted one orbit; the post-1780s telescopic observations fitted another.

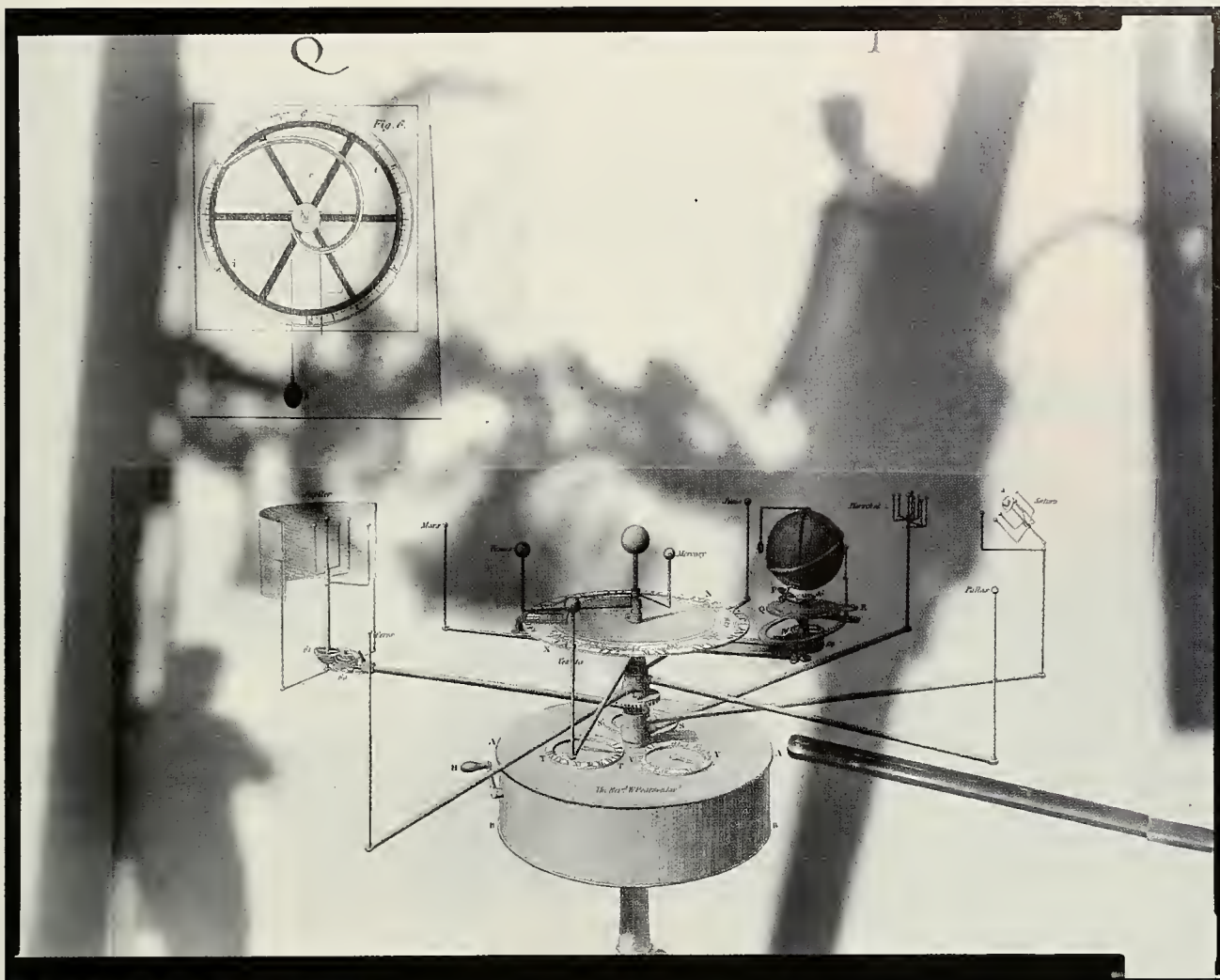
Some astronomers suggested that

Newton’s laws might be invalid at such large distances from the Sun. That wasn’t as crazy as it sounds—under new or extreme conditions the behavior of matter can and does deviate from the predictions of the known laws of physics. But only if Newton’s theory of gravity had been nascent and untested would there have been good reason to doubt it.

By the time Herschel discovered Uranus, however, Newton’s laws had had a hundred-year run of successful predictions. The most famous of them was Edmond Halley’s prediction of the 1758 return of the comet that would be named in his honor.

The simplest conclusion? Something else had to be out there, something yet undiscovered, whose gravity had not been accounted for in the predicted orbital path of Uranus.

In the life cycle of a physical theory, a scientist first makes a testable prediction about the world. Then a skeptical colleague runs a few actual experiments to see how well the prediction stands up to reality. The arithmetic differences between the theory’s predictions and the experimenter’s data are sensibly called “residual errors”—“residuals” for short—and they’re the measure of a theory’s success. Small residuals are good; big residuals are bad. If the theory describes nature accurately, and the experiment is well designed,



Olivia Parker, *Weighing the Planets*, 1984

the residuals are not only small, but they fluctuate between positive and negative values from one measurement to the next, yielding an average close to zero. If the average is anything other than zero, one can rightly say that crucial differences exist between the predictions and the measurements.

When that happens, it's not easy to assign blame. Maybe the theory needs to be modified, or maybe somebody blundered when the measurements were taken, or both. If your theory of gravity predicted that an object should fall upward when released, the theory would require significant modification, because the residuals between the predicted positions and

the actual positions along the object's trajectory would be gigantic, and would not average to zero.

In the late eighteenth century the French mathematician Pierre-Simon de Laplace invented perturbation theory [see "Going Ballistic," by Neil deGrasse Tyson, November 2002], giving astronomers an indispensable tool for analyzing the small gravitational effects of an otherwise undetected celestial object. Encouraged by the expansion of their arsenal, mathematicians and astronomers across Europe continued to investigate what might be perturbing Uranus. In 1845 a young, unknown English mathematician, John Couch Adams, ap-

proached Sir George Airy, Britain's astronomer royal, with a request that he search a specific patch of sky for an eighth planet. But neither looking for planets nor following the leads of spunky young mathematicians was part of the astronomer royal's job description, so Adams's request was dismissed. The next year, the French astronomer Urbain-Jean-Joseph Le Verrier independently derived a similar prediction. On September 23, 1846, he communicated his prediction to Johann Gottfried Galle, who was then assistant director of the Berlin Observatory. Searching the sky that very night, Galle found the new planet, soon to be named Neptune, within a single degree of the spot Le

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Verrier had predicted. It took him only an hour to locate it.

But once again, all was not orderly in the solar system. Uranus was still behaving badly. Its orbital residuals got smaller, but they didn't go away, even with the gravity of Neptune accounted for. And Neptune's orbit had some residuals of its own. Could yet another planet be waiting to be discovered?

In 1894 Percival Lowell, an independently wealthy American astronomer, built the eponymous Lowell Observatory in Flagstaff, Arizona. Lowell indulged a fanatical fascination with Mars, claiming that intelligent civilizations were in residence there, but he devoted most of the rest of his life to the search for the object he called Planet X ("X" for the algebraic unknown)—the mysterious body in the outer solar system that continued to perturb Uranus and Neptune.

One way to look for a planet is to make two photographs of the same patch of sky through a telescope, several days (or years) apart. But the next step is the rub: nobody wants to pore over images of the sky made up of countless millions of dots, hoping to spot the one that moved between one photo and the next. Fortunately, an ingenious mechanical-optical device known as a "blink comparator" would come to the rescue. This contraption, an early-twentieth-century innovation, exploits the remarkable ability of the eye to detect change or motion amid an otherwise unchanging field. First you place the two photographic images side by side in precise alignment. Next, you flash the two images back and forth in rapid succession. Against the background star field, any speck on the two photographs that brightens, dims, or shifts position from one photograph to the other becomes immediately apparent. In the search

for Planet X, the blink comparator minimized many sources of human error, including spurious measurements made by sleepy astronomers in the middle of the night.

At about four in the afternoon on February 18, 1930, a twenty-four-year-old amateur astronomer named Clyde W. Tombaugh discovered Planet X. He had been hired the year before by the Lowell Observatory to continue the arduous search. (Lowell himself had died in 1916.) The young fellow was looking at a pair of photographic plates he had

*You don't stop your survey just
because you've discovered something.*

taken on January 23 and 29 of the region around the star Delta Geminorum. Tombaugh became the third and last person ever to discover a planet in our very own solar system. On March 13 the observatory announced the news.

In Tombaugh's day many people associated the name given to the ninth planet with Pluto Water, a widely used laxative bottled on the grounds of the palatial French Lick Springs Hotel in Indiana, about fifty miles south of Bloomington. Other suggestions for names included Artemis, Atlas, Bacchus, Constance, Lowell, Minerva, Zeus, and Zymal. But "Pluto" eventually triumphed because Pluto is, after all, the god of the underworld, the realm of darkness—and what else, if not darkness, prevails four billion miles from the Sun? And because Jupiter and Neptune are Pluto's mythological brothers, the name also maintains a happy family. Finally (and perhaps fortuitously), the first two letters of "Pluto" are the initials of Percival Lowell, who instigated the search in the first place. [See "Pluto's Honor," by Neil deGrasse Tyson, February 1999.]

In any well-designed, well-conducted survey, you don't stop just because you've discovered something. By completing the survey, you might discover much more. So for the next thirteen years Tombaugh searched more than 30,000 square degrees of sky (out of a total of 41,253 square degrees). He found no more planets with a brightness equal to or greater than that of little Pluto. But his time wasn't wasted. The survey revealed hundreds of asteroids, six new star clusters, and a comet.

But was Pluto the Planet X of everybody's suspicions? Nope. Over the decades, as the measurements of Pluto's mass became more and more accurate, astronomers learned how little the place really is. Turned out it's far too small to account for the residuals of Uranus and Neptune. So Planet X still had to be lurking, undiscovered, in the outer limits of the solar system.

That, at least, was the prevailing belief until May 1993, when E. Myles Standish Jr. of the Jet Propulsion Laboratory in Pasadena, California, published a paper in the *Astronomical Journal* titled "Planet X: No Dynamical Evidence in the Optical Observations." Standish used the updated mass estimates of Jupiter, Saturn, Uranus, and Neptune that had become available from the Voyager flybys; in the case of Neptune, the mass difference amounted to nearly 0.5 percent—quite large by today's standards.

Assuming that the masses derived from the Voyager missions were accurate (a wise move), and discounting a single set of suspicious measurements made at the U.S. Naval Observatory between 1895 and 1905 (another wise move), Standish recalculated all the orbital parameters. The result? The large systematic trends in the residuals of Uranus and Neptune disappeared, and the remaining small residuals were consistent with the observational uncertainties of the modern data. In plain English: the apparent anomalies in the orbits of Uranus and Neptune

could be completely explained within the framework of the presently known solar system. In even plainer English: Planet X was dead. But was it buried?

Several years ago, shortly after Clyde Tombaugh died at the age of ninety, Pluto's planethood was thrown into question. Seven moons in the solar system are bigger. More than half its volume is ice, as is the case for comets. For a twenty-year stretch of Pluto's 248-year journey around the Sun, its elongated orbit takes it closer to the Sun than Neptune gets. And Pluto's moon, Charon, is massive enough to cause the center of gravity of the Pluto-Charon system to lie outside Pluto itself. Each of these distinctions has no counterpart among the other planets. Yet the Rose Center for Earth and Space in New York City got into big trouble with the national press and with third graders for being the first major public institution to demote Pluto in its

exhibits on the solar system. Not only was Pluto not Planet X; now poor Pluto wasn't even a planet.

In a further insult to Pluto's ego, Caltech astrophysicists recently discovered Quaoar, an icy world in the outer solar system that (like Charon) checks in at about half the diameter of Pluto. It's made of the same stuff, but Quaoar orbits in a near-perfect circle, something Pluto can only dream about.

If you are sentimental, and want to preserve Pluto's planetary rank, then in all fairness you must add Quaoar to the club—as well as any other yet-to-be-discovered orb that out-planets Pluto. And no, those objects won't be Planet X either. Like Pluto, they are all too small for their gravity to bother anybody but each other.

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



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Impostor in the Nest

A beetle disguised as an army ant eludes capture by ants as well as entomologists.

By Robert Dunn



*In the center of the image, a beetle (*Ectosius robustus*) moves among its host ants, *Neivamyrmex sumichrasti*, as the assemblage investigates a grasshopper femur. *E. robustus* is one of several beetle species that have been found as guests only among *N. sumichrasti* army ants.*

When most people think about the explorers and adventurers of the past, figures such as Captain James Cook or Sir Edmund Hillary come to mind: heroic individuals who explored the world's greatest oceans or climbed the world's highest mountains. My own heroes were another group of explorers, who set out with more modest conquests in mind. They were the

natural historians who headed for the hills to chase a new species of beetle, or snare a new bird, or climb a hollow tree to capture a new snake. As an entomologist working in the tropics, I see these collectors as my sometimes humbling, sometimes fumbling predecessors. When I kneel in the forest and turn over rocks, I feel some of the awe my predecessors must have felt.

Unfortunately, though, the days are

now few when I get into the field as a biologist, with no more tangled purpose than to find and observe rare species. Darwin had a ship that carried him to biologically unexplored terrain. My colleagues and I are preoccupied with committee meetings, student cheaters, and asbestos abatement.

So when Carl W. Rettenmeyer, a biologist and an emeritus professor at the University of Connecticut,

bumped into me in the hallway in the fall of 2002 and asked whether I would join him on an expedition to the cloud forests of Costa Rica, I started packing. Our mission: To look for a mysterious army ant and a rarely seen but look-alike beetle that lives in its midst.

The team that left for Costa Rica included Carl and his wife Marian; Charlene and Adam Fuller, photographers, collectors, general natural historians, and veterans of the Rettenmeyer army-ant expeditions; and David Lubertazzi and me, graduate student volunteers and all-around grunts. As our plane veered south from Hartford Airport, we left behind the frozen forests of New England for forests where insects, particularly ants, run the show year-round. For mammal watchers, the tropics can bring disappointment; large vertebrates are as scarce there as anywhere else. But the bugs, oh the bugs! Insects overflow in the tropics, both in number and kind. To an entomologist, the tropical forests are more than rich: they are overwhelming. Turn over a log, and one of the hundred or so small animals that scurry away is likely to be a new species of insect.

Many of the first explorers in the New World wrote home about army ants, as have more contemporary writers, natural historians, and the like. Army ants, particularly the species that raid above ground, are dramatic, abundant, and hard to miss. Some of the early or popular accounts of army ants are accurate, but most of them owe more to fantasizing than to observation. The army ants of myth eat everything in their path—children, tapirs, entire villages. They are monsters, to be sure, but predictable ones, scary and inexorable automatons conjured by our collective imaginations. In Carl Stephenson's short story "Leiningen versus the Ants," a Brazilian official says of army ants: "They're not creatures you can fight—they're an elemental—an 'act of God'! Ten

miles long, two miles wide—ants, nothing but ants!"

Real army ants are both more interesting and more complex than those of story or myth. Real army ants don't kill people; most of them don't even forage above ground. A typical army ant species lives in nests underground that are built out of the living bodies of its workers. It migrates en masse from place to place as it feeds on the soft brood of other social insects.

The army ant we were looking for, *Neivamyrmex sumichrasti*, was first documented by the French naturalist

but most are neutral: just there. Many such interlopers are so well adapted to life in the ant's special world that they can survive nowhere else. A single colony of army ants might host dozens of species of beetles, tens of species of mites, and a variety of silverfish and flies. That diversity and beauty has fueled Rettenmeyer's lifelong passion for army ant guests. One of his favorite guests, and the focal point of our mission, was a beetle that's been collected so far by only one scientific expedition (Rettenmeyer and Akre's 1963 trip to Costa Rica)—a little

Mythical army ants are scary monsters, to be sure.

Real army ants are both more interesting and more complex.

François Sumichrast, working at the time in Mexico. Sumichrast wrote of the ant that would later bear his name:

All the researches that I have made up to this time to discover the *formicarium* [nest] . . . have been fruitless, and I cannot obtain any information from the natives where these insects are common.

He observed and collected *N. sumichrasti* from Mexico, but the species ranges throughout the highlands of Mexico and Central America.

Sumichrast's sketchy text was one of the only published accounts of the ant, until Carl Rettenmeyer and his student Roger D. Akre found the ant again in Monteverde, Costa Rica, in 1963. Rettenmeyer studied the species long enough to become fascinated by the odd tagalong guests that live with it. In the years that followed, he often thought about returning to Costa Rica to study *N. sumichrasti* and its guests more completely. Last winter, almost forty years after that initial encounter, he finally got the chance.

Most ants cohabitate with guests, animals that live in or around the colony and depend on the ants for food, shelter, protection, transport, or some combination thereof. Some guests are welcome, others are not,

creature named *Ecitosius robustus*, which, roughly translated, means "the robust army ant beetle."

E. robustus is, by all accounts, a remarkable beetle, though any creature able to coexist with army ants would seem to qualify as remarkable. All ant guests have to avoid being eaten by their hosts. Most groups of beetles that live with army ants have evolved one of two body types that enable them to survive among the ants: a flattened, horseshoe-crab-like shape—the better to hunker down when the ants attack them—or the form of the ants themselves, to more easily avoid detection by the ants' probing antennae. Many guests even smell like their hosts—and because most army ants are virtually blind, odor camouflage can be protection enough.

The robust army ant beetle, however, has gone one step further. Many ant guests have evolved to superficially resemble their hosts, but *E. robustus* is unique in being nearly physically indistinguishable from its host ant. The beetle's waist is drawn in to look like the ant's waist. The beetle's antennae are stubby, like the ant's antennae. The beetle's body is dimpled, like the ant's body. Even under the microscope it is hard to tell the two species apart. Rettenmeyer was keen to find the beetles

again, to take their photographs, to watch their behavior—in short, to understand how and why they came to be such exquisite mimics.

But first we had to find the ants.

A few days after we arrived at the biological station of the Monteverde Cloud Forest Reserve, we found two colonies of a species of army ant and brought a few of the ants back to Rettenmeyer in a flask. He raised the ant flask to his nose, took a sniff, and said, “Well, smells like *burchelli*.” Each army ant has a particular smell; some are fruity, some are musky. *Eciton burchelli* smells of a combination of tangerine and body odor—unforgettable, once you’ve experienced it a few times. *E. burchelli* is famous for raiding homes with swarms meters wide, and literally cleaning house—of roaches, crickets, millipedes, and many other arthropods. Because of its predilection for most insect pests, it is welcomed by many people living in neotropical forests, as the forest version of the exterminator.

Whenever we encountered foraging columns of *E. burchelli* or of other army ants, we would try to trace the columns back to the colony’s nest, a transient structure that the ants form from their own bodies. Extending the military metaphor, entomologists call them bivouacs. Each worker ant grabs the legs of the next one, cling-



A segment of a nest of *Eciton burchelli* in a Panamanian rainforest. Unlike most army ants, *E. burchelli* often site their nests above ground. The light dots scattered among the blacker forms are the heads of the ants. Within the bivouac, their guests mill about, climbing from ant to ant. Note the two ants at left, linked by their legs.

cockroaches, earwigs, isopods, and other small arthropods ran to escape the advancing waves of ants. Even if they managed to avoid the ants, they were usually caught by something else. Small flies laid their eggs in the bodies of the escaping insects; antbirds grabbed most of the bugs the flies didn’t claim. The dry leaves crackled with movement. If someone led you blindfolded through the forest, you would still be able to smell the musk-sweet odor of an *E. burchelli*

enough or patient enough (or both), we would find colonies in their migratory phases. And what moves is an entire ecosystem, all of whose dark parts periodically disassemble themselves, only to reassemble again farther down the trail. The ants leave first, and then their motley crew of guests. Some of the beetles and most of the mites hitch a ride on or under the ants. If you look carefully, you might see a beetle hoist itself up, grab hold of an ant running past, and flip onto the ant’s back like a miniature cowboy. Other guests run on their own, using their antennae to follow the chemical trails laid down by the ants. Fifty or a hundred yards farther on, the worker ants form a new nest, and the colony files into place, rapidly at first and then more slowly as the last guests stumble in.

In 1963, when Rettenmeyer first saw *N. sumichrasti* in Costa Rica, he saw it “behind the cheese factory.” Amazingly, the cheese factory is still in the same place. Unfortunately, we didn’t know whether the elevation marked the top of the range for this species, the bottom of the range, or somewhere in between. We didn’t

*If you look carefully, you might see a beetle
flip onto an ant’s back like a miniature cowboy.*

ing tightly until an edifice of ants is formed. The queen stands in the middle of the cluster with her attendants. The workers hold their positions for hours or even days, guarding their queen and so protecting the future of their own genes.

After finding a colony’s bivouac, my companions and I would sit and inspect everything going in or out, filming the ants and searching their columns for guests. As we watched,

raid and to hear it unfold in the flutter of birds, the tap of the ants’ claws on the leaves, and the hum of thousands of tiny flies.

Army ant colonies have distinct phases of activity. For weeks at a time the colony simply forages outward from a single site. Then, when some internal alarm bell rings, the colony begins moving nightly from site to site. When we were lucky

even know if *N. sumichrasti* was still extant. After days of unsuccessful searching, we began to fear that the ant had gone extinct. Deforestation in the lowlands of Costa Rica has caused the country's cloud forests to become drier, essentially shifting the climatic zones uphill. Many species at middle elevations have moved higher up, where the forest is still wet. Many high-elevation species have become restricted to progressively smaller bands of suitable habitat at the tops of mountains, or, like the golden toad, have gone extinct. *N. sumichrasti*, as far as we knew, was a high-elevation species.

Then one afternoon Dave Lubertazzi came stumbling into the kitchen, sweating and smiling. He held a flask out to Rettenmeyer and said, "Who does this smell like?" Rettenmeyer sniffed and said simply, "*Sumichrasti*. Go back up that hill." Dave and I grabbed some dinner and then ran back up the trail into the forest, our pockets and backpacks clanging with empty flasks.

Usually you can sit beside the trails of army ants and watch for guests as the line goes by. But the beetles that live with *N. sumichrasti* look so much like *N. sumichrasti* that it is nearly impossible to recognize them in the field. We would have to collect all the "ants" we saw and hope that some of them were beetles. When Dave first saw the ants, he had marked their trail with red-and-white striped strings. Now Dave and I went to work beneath the strings, collecting as many individuals as we could. We slowly filled our empty flasks with ants. Glancing downhill at the research station, visible through the canopy of trees, we imagined Carl and Marian Rettenmeyer inside, smiling.

Unfortunately, every time we took a step we crushed ants or obliterated their chemical trail. After a few hours, the ants disappeared. We had no way of knowing where they had gone. We had not been able to track them well enough to find their nest. We were back where we started—without any

sign of an ant colony or a nest—except that we now had a few small flasks of *N. sumichrasti*. We returned to the same site the next day and for days after that, but we never found the ants again.

Meanwhile, at the research station, Carl and Marian were filming and photographing the ants we had collected. For hours they watched and took pictures as the ants ran around a circular aquarium. Carl saw one beetle, so he made more photographs, hoping to catch it on film. Afterward, he pulled the critters out of the aquarium, put them in alcohol, and examined them under a microscope. But the beetle we had collected was not *E. robustus* (not antlike enough). Instead it turned out to be an interesting mimic and a new species at that. We crossed our fingers that the beetle we sought would eventually show up in the vials or in Carl's photographs, and went on with our search.

With only a few days left in our trip, we had collected and filmed a great deal (including a scene in which



Two *N. sumichrasti* individuals traverse a stick covered in leafy liverwort. Foragers of this species typically travel single file while searching out such small prey as the brood of other ants.

a colony of army ants crawled over a resting boa constrictor), but we had found little more than a single foraging trail of *N. sumichrasti*. As Adam and Charlene went to search for new colonies, Dave and I went back up the hill to the spot where he had found the trail, hoping it would lead us to the queen and her bivouac. We crisscrossed the slope, walking up and down, swearing and mumbling at each other. We scanned the ground for anything that moved.

After a few hours I gave up, but Dave kept looking. I sat on a root to eat a jelly and jelly sandwich (a bit of a misunderstanding with the cook). On the ground in front of me, I noticed some small black ants that looked a great deal like *N. sumichrasti*. Looking closer, I saw that they were *N. sumichrasti*. I shouted to Dave. We had found them again! We dug and collected, and then radioed to Carl, whereupon the six of us spent the next hour figuring out what to do. After some excited debate, we decided that Dave and I would watch the colony until it stopped foraging for the night,

to make sure that it did not emigrate. In the morning, we would all go up together and examine the colony and its bivouac. It would probably be the first bivouac of *N. sumichrasti* ever seen.

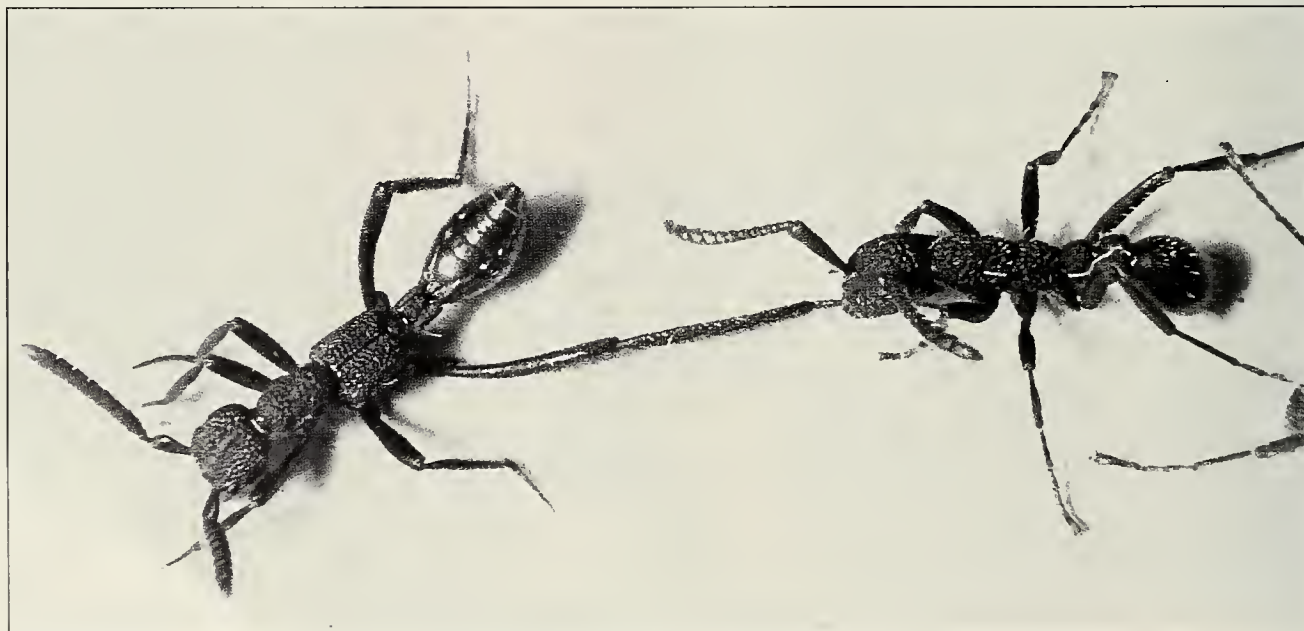
So that night, Dave and I went back up the hill with more jelly and jelly sandwiches and sat in near-darkness, observing the colony. The moon was wonderful. We made up constellations and imagined how many strange ant guests we would find inside the nest when we dug it up. We watched ants going in and out of a hole and imagined the million ants inside, grasping one another, guarding their single, bloated queen. After several hours, the colony stopped moving. The ants had called it a night. We walked back down the hill in the faint moonlight and went to sleep.

In the morning, our team trudged back up the hill with shovels, buckets, bags, and cameras. We found the spot where the colony had been, and stopped. There was nothing there. I poked the dirt. Nothing. I stuck a spade into the mud. Nothing. Adam

rolled a log over to look underneath. An earwig scampered, a hummingbird squeaked, but not an ant stirred. Either the colony had gone, or what we had seen had not been the colony. To make sure, we flipped a log over and dug some more. Frantically, we searched the hill.

But we didn't find the ants again. We never saw an *N. sumichrasti* queen, or an *E. robustus* beetle. No *E. robustus* beetles were found in our vials or photographs; other beetles showed up, but none as unique as *E. robustus*. The queen had led her small army away, and we would have to wait for another expedition to see her. As we left the forest for our flight back to Connecticut, *N. sumichrasti* foragers carried their prey down tunnels, back to nests full of creatures no one has ever seen.

Robert Dunn is a graduate student completing the final stages of his doctorate at the University of Connecticut, Storrs. His upcoming postdoctoral project, at the Curtin University of Technology in southwest Australia, will examine various aspects of the relation between ants and the seeds they disperse.



An *N. sumichrasti* ant (right) tugs at the leg of its guest beetle *E. robustus*. Note the similarity of the beetle's texture, antennae, legs, head, and general shape to those of the ant. The biology of both the guest and the host species remains poorly understood; no one has ever seen the queen of *N. sumichrasti* or the larvae or eggs of *E. robustus*. This photograph and the one on page 22 were taken by Carl Rettenmeyer and Roger Akre in Costa Rica in 1963.

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The Owl That Hunts by Light

After years of observing in the Yukon, the author has shown that the North American hawk owl is a more versatile predator than its better known European cousin.

By Christoph Rohner

My first encounter with a northern hawk owl came early in my career, on a cold day in mid-May. Fresh, wet snow weighed down the tree branches, reminding even optimistic souls that spring in the North can be tardy, almost shy. I had arrived that same day, after a week of travel to reach the remote Kluane–Saint Elias mountains, in Canada's Yukon Territory. It was a magnificent setting for a research project on the ecology of the boreal forest, the vast evergreen woods of the north.

As I was taking in the view of snow-laden trees, massive peaks, and Kluane Lake—the largest lake in the Yukon—I spotted the silhouette of a bird perched high in a bare tree. The northern hawk owl, a rare sight in the wild, pinned its yellow eyes on me and let out a sibilant screech that nearly made the hair stand up on the back of my neck. That episode is now long past, and I have since spent years studying owls of the northern forests. But I often think back to that moment as the beginning, when I first took notice of one of the least studied birds in North America, and gained a direction for my work.

Later on, as I read the literature on hawk owls, I found that most of the information in textbooks and field guides originated in Scandinavia, where the species has long been studied. But I wondered: did it make sense to assume that hawk owls in the New World have the same lifestyle as their cousins in the Old? Aside from some anecdotal reports, few nests in North



Unlike other owls, hawk owls depend more on vision than hearing when they hunt.

America had been described. The most extensive work had been done in the mid-1980s by Kenneth Kertell, now a senior scientist at SWCA Environmental Consultants in Tucson, Arizona. Kertell had studied hawk owl behavior at six nest sites in Alaska's Denali National Park.

My colleagues and I carried out field investigations for the Kluane Boreal Forest Ecosystem Project from 1987 through 1993. In the course of our work, we were able to expand the story of New World hawk owls. We now know that these owls diverge from their Eurasian counterparts not only in aspects of their breeding biology, but also in their behavior, which reflects certain basic differences in the ecology of their boreal homes.



Securing a vole in its talons, a hawk owl pauses before dismembering the prey. When readily available, voles account for most of the hawk owl's diet.

Northern hawk owls are unlike most owls, and, as the name "hawk" suggests, act in some ways like diurnal birds of prey. They hunt in broad daylight and rely on their long tails—shaped more like falcons' tails than owls'—to maneuver in rapid flight. Hawk owls lack the comblike structures along the outer edge of their primary feathers that give most owls silent flight. Their sense of hearing is only so-so for a bird of prey; the keen ability to perceive sound that enables other owls to pounce accurately on prey in the dark is absent in hawk owls.

They are, however, truly hawk-eyed. In a tag-and-release program in Alberta, Canada, field ornithologists "reel in" owls, using a fake mouse attached to a fishing line. Hawk owls are routinely attracted to the small lure from nearly a mile away.

The "northern" in the owls' name denotes their range. Hawk owls live and nest in the taiga, the subarctic band of forests that circle the northern reaches of the globe from Alaska to eastern Canada and from Scandinavia to Siberia. They are nomadic, readily shifting to new nesting areas

depending on the relative abundance of their small mammalian prey. And in winter, they sometimes irrupt, or move south of their more usual range in large numbers. The North American subspecies, *Surnia ulula ca-*

Bands of mosquitoes buzzed on the netting around my face. A yellow-rumped warbler grew so accustomed to me that he started to peck insects from my wool pants.

paroch, makes occasional winter appearances on farmland as far south as southern Canada and the northernmost regions of the contiguous United States.

Shortly after my arrival at Kluane I again spotted the bird that had caught my eye on that first day. I watched as it made its screeching call, and then I heard a second, responding hiss. When I raised my binoculars to a snag, or jagged top, of a broken, burned-out tree, I found myself

locked in a gaze with a female on her nest.

After that I began spending as many as twenty hours a day in continuous watch and was rewarded with intimate glimpses of the pair's family life. I was transfixed: One day a grizzly walked by about sixty feet away, but we ignored each other. Bands of mosquitoes buzzed on the netting around my face. A yellow-rumped warbler grew so accustomed to me that he started to peck insects from my wool pants. I became part of the forest.

The male owl hunted fairly close to the nest. Every few hours he returned to a low perch with a dead vole or mouse, called out, then decapitated the prey before presenting the remains to the female. He usually dismembered heavier prey at the site of the kill, then delivered morsels directly to the nest. Occasionally he tucked food remnants into tree holes and crannies for safekeeping. When I reached into one hiding place where the male had cached some meat, I grabbed the hind part of a juvenile hare.

Hawk owl eggs, like the two in this nest, hatch after about thirty days of

incubation. The parents cater to the owlets in the nest for another three or four weeks. When the owlets fledge, they exercise their new ability to fly by leaving the immediate nest area, but the parents continue to supply them with food for a few more weeks.

In Scandinavia and Russia, hawk owls (subspecies *Surnia ulula ulula*) are classic specialists: in the breeding season 95 percent or more of their diet is made up of small rodents such as mice, lemmings, and in particular, voles. In Denali National Park, Kertell

had discovered that voles made up only 70 percent of their diet; young snowshoe hares and squirrels made up the balance. He suspected that the population of hares influenced the Denali owls' diet. Having held in my hand the bloody evidence that the nesting birds in Kluane were also feeding on hares, I was eager to find out more about the link between hawk owls and hares.

Fortunately, my enthusiasm for hawk owls spread to my colleagues in the long-term ecosystem project. Some of them took censuses of the prey animals in the region, and their data on how the densities of voles, hares, lemmings, and squirrels varied from year to year proved to be the key to part of the hawk owl story. With the help of some volunteers, we found nine nests, the most ever included in a single hawk owl study. We systematically recorded all our observations of hawk owls, and collected and dissected their pellets (small bundles of the regurgitated hair and bones of prey).

The boom and bust cycle of the populations of small mammals is a phenomenon of the taiga and tundra regions of the north. For some still undetermined reason, the numbers of voles, lemmings, and hares soar in some years and plummet in others. Snowshoe hares peak about every ten years. When they were most numerous, so many hares would be hopping along and across the Alaska Highway that I would have to slow my car way down, to avoid a mass slaughter. In contrast, at the low end of a hare cycle, I could walk in the woods for hours and see hardly any hares.

But not all boreal-forest ecosystems are the same: in Scandinavia the populations of small rodents, including various species of voles and lemmings, peak together roughly every three to

four years. The biomass, or total organic weight, of those mammals is substantial. And as that biomass cycles

Hawk owls were considered vole specialists, but when I reached into the tree hole where a male had cached some meat, I grabbed the hindquarters of a hare.

between boom and bust, it accounts for more population change throughout the ecosystem than do the biomass cycles of any other vertebrate animals in the system.

In North America, however, the

their dietary mix had matched the densities of the available prey. But the diets of Yukon hawk owls are buffered by

the availability of other prey. When we began observing nesting hawk owls in Kluane, both vole and hare populations were rapidly increasing. Later, when the vole population crashed but the hare population continued to grow, the hawk owls remained in the nesting area. Voles did drop to about 30 percent of the hawk owl diet by biomass, and young hares and squirrels rose to about 50 percent. In a peak year for hares, the hares edged out the voles as a source of meat for both adult owls and their owlets. But the shift in the owls' diets from voles to hares didn't hurt breeding.

In Scandinavia, hawk owls usually breed only during bursts in the population of voles and lemmings. The average nest holds six or seven young, but at times even larger broods seem to be common. (The record is thirteen, but how many young in that megabrood survived is unknown.) Although investigators have not located as many nests in North America as they have in Scandinavia, hawk owls in the Yukon consistently rear smaller broods than do European hawk owls, between three and five nestlings.

No matter where hawk owls raise their young, breeding coincides with the availability of prey. Owlets fledge in late May or June, just when the boreal forest is teeming with inexperienced young prey animals. At Kluane the hares brought to the nests by parent hawk owls were, on average, only twenty-two-days old.

Hawk owls are also thought to scavenge the remains of adult snowshoe



White on white: a snowshoe hare in its winter coat. But in winter, even adult hares in camouflage are not immune to attack by hawk owls.

population cycles of prey animals are different. At the peak of their ten-year cycle, snowshoe hares, in terms of biomass, "outweigh" all other vertebrate species. Vole populations also peak and crash in North America, but do so more irregularly than those of hares.

In the Yukon, as in Eurasia, hawk owls seem to prefer voles to other prey. Our statistical analysis showed that they fed on voles significantly more often than they would have if

hares in winter. But we discovered, to our surprise, that these owls, weighing less than a pound, also attacked and killed live adult hares four times their body weight. The hares might have been weakened individuals; even so, the performance speaks to the ferocity and daring of North American hawk owls. The hawk owls of Alaska and Canada are about 6 percent larger than Scandinavian birds. Perhaps their size is an adaptation that increases their success in capturing larger prey.

It seems odd that the hawk owl should emerge as a vole specialist at all, given the owl's strong physical resemblance to birds that prey on other birds. Similarly shaped raptors, such as peregrine falcons and goshawks, are adept at the agile pursuit and rapid capture of birds in flight. But hawk owls, perhaps descended from bird hunters, are skilled aerial predators in their own right. In Scandinavia, during harsh winters when voles are scarce or inaccessible under thick snow, most of a hawk owl's diet can be made up of birds. During winters, our research team in Kluane saw hawk owls kill spruce grouse roughly as big as the owls themselves.

The ability to take advantage of a range of prey animals may give all hawk owls the flexibility they need to survive in harsh and variable northern climates. Compared with the Scandinavian birds, North American hawk owls turn out to be a bit larger, to have fewer young per clutch, and to be less specialized. As investigators gain a better understanding of the species across the entire northern forest, it's becoming clear that this small, fierce, and versatile owl may have been underestimated.

Recently, Wayne Lynch, a Canadian

wildlife photographer, and his field assistant Julia Burger witnessed an example of hawk owl predation that had never previously been reported. They were walking to a hawk owl nest near Chip Lake, Alberta, when they flushed an American wigeon. One of the hawk owl pair, perched in a snag above the nest, immediately attacked, hitting

the duck in flight and riding it to the ground. Opportunity, even for an unusual meal of waterfowl, had quickly brought out the aerial hunter. The hawk owl, its mate, and their young feasted on duck for days.

Christoph Rohner is a zoologist and writer who lives in Edmonton, Alberta, Canada.



An intent female tends her triplets, and in the process displays her distinctively long tail.

Monitor Marathons

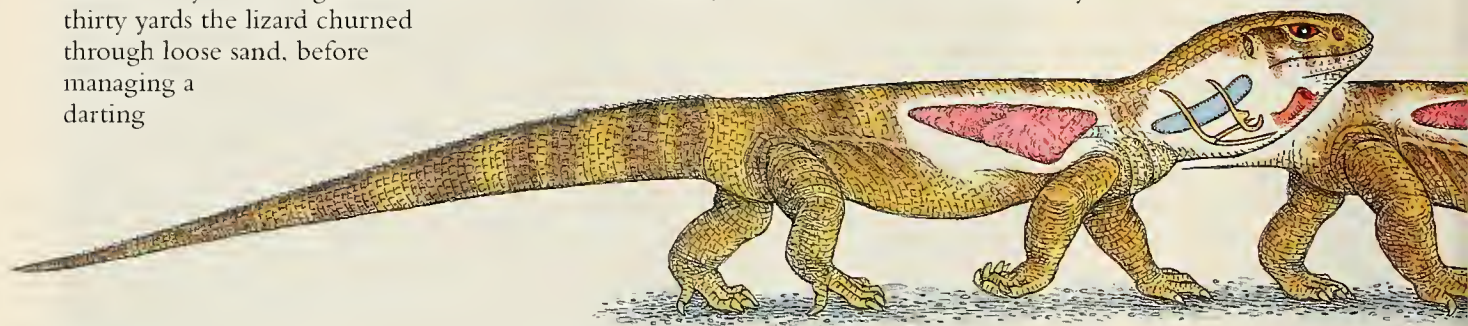
How one group of lizards turns a gasp into a gulp.

By Adam Summers ~ Illustration by Patricia J. Wynne

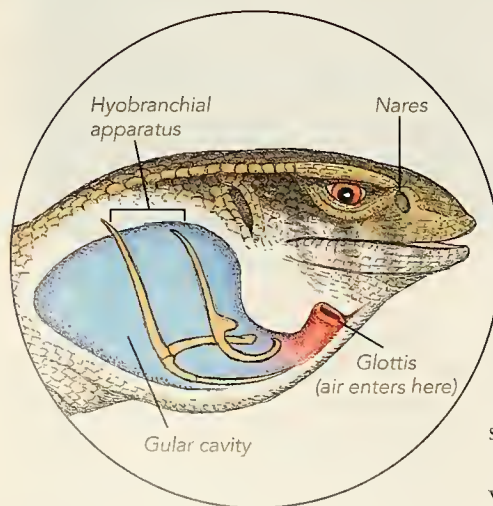
Making my way down a trail through rosemary scrub in Florida's central sandhills, I surprised a six-lined racerunner (*Cnemidophorus sexlineatus*, so named for the lines that run the length of its body) basking in a wheel rut. I gave chase and the lizard streaked off—easily keeping ahead of my stumbling run. For thirty yards the lizard churned through loose sand, before managing a darting

escape under a shady bush. The sprint was impressive, particularly for a lizard less than a foot long, but what was even more amazing was that the lizard had to make its dash without taking a breath. The racerunner's mechanical systems for breathing and running are linked in such a way that the lizard can do one or the other, but not both.

diaphragm, a dome-shaped muscle between the lungs and the liver, powers the second system. It works by pulling the lung cavity rearwards, toward the tail. The diaphragm is a mammalian innovation. Crocodiles and alligators have independently evolved a muscle that pulls the liver backwards, also effectively



(1) Gular cavity relaxed



Lungs in any animal are, of course, the site of oxygen and carbon dioxide exchange. But lungs themselves cannot draw air into an animal's body; they are really nothing more than stretchy bags that bring air into close proximity with blood. Lungs fill with air when the cavity housing them enlarges, enlarging the lungs as well; the resultant low gas pressure causes outside air to rush in.

Mammals have two systems for ventilating the lungs. The rib muscles power one system: they expand the chest by lifting and rotating the long flat bones to which they attach. The

inflating the lungs. But lizards and snakes lack any analogue to the diaphragm, and so they rely on their rib muscles alone to inflate their lungs.

David Carrier, a biomechanist at the University of Utah in Salt Lake City, observed that a lizard's rib muscles also play a vital role in locomotion: they stabilize the trunk, giving the forelimbs a steady platform from which to operate. But any locomotion also renders the rib muscles nearly useless for breathing; running makes them completely so. Studying the common green iguana (*Iguana iguana*), Carrier confirmed that the rib muscles are active dur-

ing locomotion, and that the lizard holds its breath while sprinting.

Now, any athlete can tell you that holding your breath while running will seriously cut down on your endurance. So Carrier posited that lizards (not unlike me) are restricted to short bursts of anaerobic exercise (less than thirty seconds), followed by prolonged panting to pay back the oxygen debt. (An oxygen debt accrues when muscles work without oxygen; the result is that lactic acid accumulates, and it must be oxidized after the work is done.)

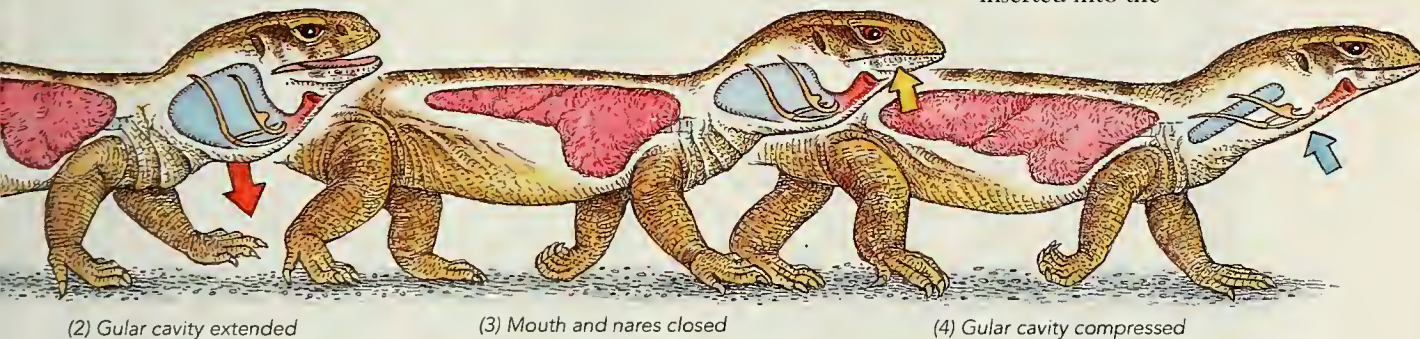
Carrier's hypothesis was controversial, particularly among respiratory physiologists. Other investigators had discovered that monitor lizards—a distant relative of Carrier's iguana—have high metabolic rates. That is, unlike most so-called cold-blooded animals, monitors burn a lot of energy rapidly. A good example is the

while moving. On the contrary, the animal should ventilate as often and as vigorously as a metabolically equivalent mammal. But if the lizard can't rely on its rib muscles to breathe while it walks, how does the monitor spend all day walking?

The resolution to this apparent paradox required the joint efforts of physiologists and biomechanists. Tomasz Owerkowicz of Harvard University and Beth Brainerd of the University of Massachusetts at Amherst trained savannah monitors to trot on a treadmill in front of an X-ray machine coupled to a video camera. The X-ray movies demonstrated that, as Carrier had predicted, when the animal ran relatively fast, respiration relying on the subatmospheric pressures generated by expansion of the rib cage was supplanted by a different

called gular pumping [see illustration below]. In fact, the use of head muscles rather than trunk muscles to power respiration predates the evolution of lungs. Fish, for example, pump water across their gills with their head muscles. But until the work of Owerkowicz and Brainerd, gular pumping had not been considered an important factor for lung ventilation in reptiles.

To show that gular pumping is the key to the monitor's endurance, Brainerd and Owerkowicz took a group of treadmill-trained lizards on a road trip to the University of California, Irvine. There, together with the physiologists James W. Hicks and Colleen Farmer, they custom-fitted the animals with small face masks, which enabled the biologists to measure the lizards' oxygen consumption while the animals ran a treadmill. First each lizard ran normally; then a plastic tube was inserted into the



Most lizards are like a clumsy person who can't walk and chew gum at the same time; the lizards' handicap, though, is that they can't breathe and run simultaneously. Their rib muscles, which expand the chest during each breath, must also brace the forelimbs during locomotion—especially running. The peripatetic monitor lizards have evolved an alternate route to get air into their lungs. As an animal moves (1), muscles attached to the hyobranchial apparatus (a collection of bones in the lizard's throat) depress the structure, expanding its gullet (2). Air flows into the cavity created; the lizard then closes its mouth and nares (3), and constricts its throat (4), pumping the air into its lungs.

savannah monitor (*Varanus exanthematicus*), an African monitor lizard weighing about ten pounds, which spends most of its day patrolling its territory for tasty insects. Its oxygen consumption is as high as that of such mammals as the armadillo, and so the monitor can't afford to hold its breath

method of breathing. Long, thin bones below the tongue and in the neck seemed to be causing the lizard's throat and the floor of its mouth to expand and contract: the animal was "gulping" air on the run.

This kind of lung ventilation, well known in frogs and salamanders, is

mouth to keep the animal's mouth open and prevent gular pumping. And sure enough, when the gular pumping was eliminated, the monitor lizards acted more like Carrier's green iguanas.

Gular pumping has turned out to be far more widespread in lizards than physiologists had previously thought. The monitors, though, with their high metabolic rate, rely on it more than their relatives do. For most other lizards, the drill remains: dash and pant, dash and pant . . . just like me.

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

Patterns in Nature

The new focus on self-organizing processes links such diverse natural phenomena as a zebra's stripes and a mound of termites.

By Scott Camazine

The natural world abounds in eye-catching patterns. Consider the synchronized movements of a school of fish gliding through deep ocean waters; or the coordinated turns and swoops of a flock of starlings whirling among tall trees before coming to rest on a telephone wire. How do all the individuals in the school or the flock avoid collisions with their neighbors? How do they orchestrate their graceful movements?

Other patterns in nature are just as dynamic, but develop so slowly that they appear as snapshots to the human eye: a brief, static moment in a biological process. Think of the striking regularity of alternating light and dark stripes on a zebra's coat, or the reticulations on the surface of the fruiting body of a morel mushroom. Zooming in for a close-up of a slime mold, you can observe the branching network patterns that emerge as the mold grows. On a still smaller scale, magnified several hundred times, similar patterns emerge on the surface of a pollen grain. Intricate reticulated patterns appear in the passageways of the fungus gardens of African termite colonies, and in the crisscrossing trails of foraging army ants.

The living world is filled with striped and mottled patterns of contrasting colors; with sculptural equivalents of those patterns realized as surface crests and troughs; with patterns of organization and behavior even among individual organisms. People have long been tempted to find some obscure "intelligence" behind all these biological patterns. In the early twentieth century the Belgian Symbolist playwright Maurice Maeterlinck, pondering the efficient organization of bee and termite colonies, asked:

What is it that governs here? What is it that issues orders, foresees the future, elaborates plans and preserves equilibrium, administers, and condemns to death?



The biblical songwriter in Proverbs marvels at the same phenomenon among the ants, though, more wisely than Maeterlinck, resists the temptation to invoke an intelligent ant:

Go to the ant thou sluggard; consider her ways, and be wise,
Which having no guide, overseer, or ruler,
Provideth her meat in the summer, and gathereth her
food in the harvest. (Prov. 6: 6–8)

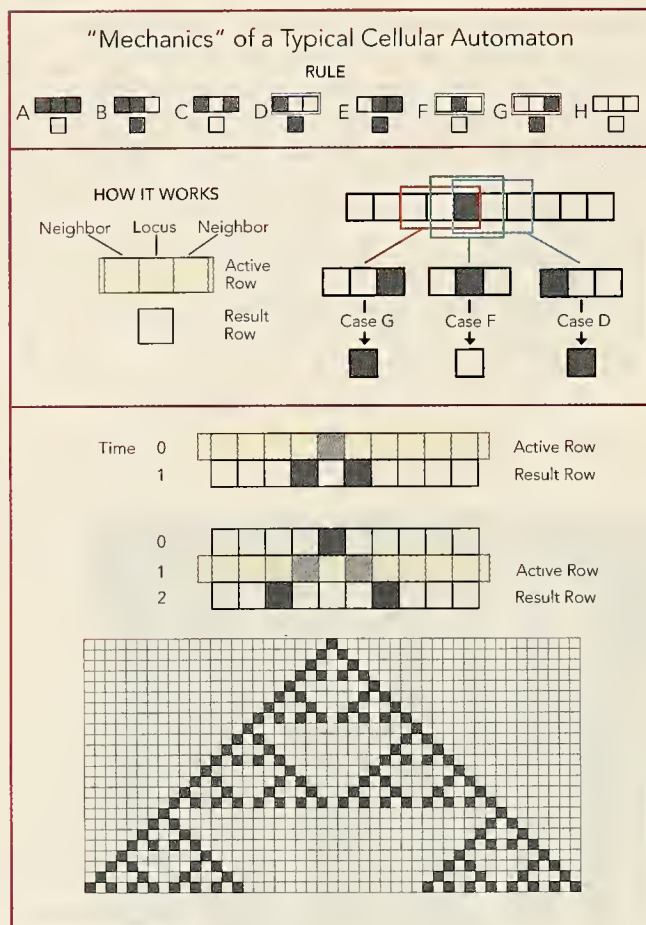
In this instance, science agrees with the Old Testament. Do ants or, for that matter, termite mounds, flocks of birds, or schools of fish have leaders that all the members of the group follow? The answer is, clearly, no. Imagine the kind of oversight that would be needed to build a termite mound. The mound

may be thousands or millions of times larger than an individual termite, and the construction of the edifice may take longer than dozens of individual lifetimes. It is simply inconceivable that an overseer guides all those processes. The same holds true of the flock and the school: although their movements are as elegant as the finest choreography, there is no choreographer to direct each bird or fish. The natural world, it turns out, is replete with patterns and processes that exhibit organization without an organizer, coordination without a coordinator.

For some people who come to appreciate this point, it then becomes tempting to attribute such complex patterns and processes to innate behaviors, instincts, or genetic information encoded



Striped markings on the coats of zebras exhibit the kinds of patterns that occur throughout nature, which can be described by simple mathematical tools.



Operation of a cellular automaton is easiest to demonstrate in its one-dimensional form. From a given initial state (row of white or black squares at time 0), a rule specifies how the color of each cell for each of an indefinite number of subsequent ticks of a clock depends only on the colors of a fixed group of neighboring cells; the rule simply itemizes the possibilities. If each step in the evolution is portrayed as a new row of cells, the result, which depends both on the rule and the initial state of the line of cells, is a two-dimensional grid that can simulate a wide range of patterns in nature. The intricate, nested pattern at the bottom of the diagram is the result of applying the rule over the course of twenty-three steps.



Zebra skin markings are simulated here by a two-dimensional cellular automaton, from an initial, random distribution of black and white cells (far left). Even with the first tick of the clock a pattern begins to appear (second from left). At the tenth tick of the clock, a stable pattern emerges (third from left), which is quite similar to an actual zebra coat (far right).

deep within the chromosomes of the organism. But such "simple explanations" are not likely and, in the best of cases, they merely sweep the question under the carpet. What then is the origin of all this stunning complexity?

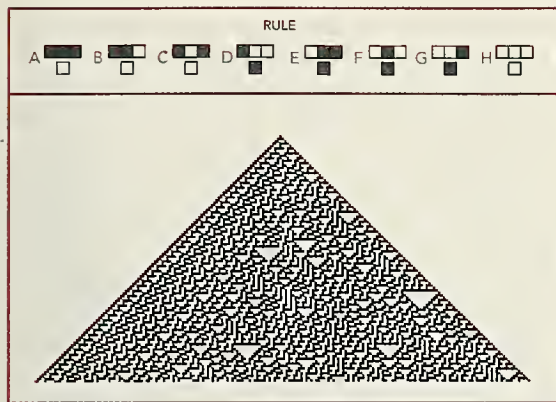
I have always been fascinated by the natural world, by the strange and complex creatures that inhabit it. As a child, I was drawn to small animals and insects and delighted in their diversity and behaviors. My curiosity took the form of carefully labeled collections of minerals, pressed flowers, feathers, and pinned insects, each specimen with a shape and pattern all its own. I often wondered how such patterns arose, but never found an explanation. Looking back, I think part of the difficulty was that people didn't have the tools needed to explore the question.

In the past several decades, however, a rich convergence of insight has come from a wide range of scientific disciplines, including biology, chemistry, computer science, mathematics, and physics. Out of that mix the field of complex systems emerged. I have followed the exciting developments in this field as a research biologist, physician and photographer.

In the years since my childhood, those who study complex systems have learned that many natural patterns share a similar mechanism of formation called self-organization. Self-organization refers to a wide range of processes in both living and nonliving systems. Those processes are characterized by simple "rules" that depend solely on local interactions among the subunits of the system. Yet despite their simplicity and the local range of their immediate effects, the rules and their actions on the subunits give rise to the spontaneous emergence of pattern, order, and structure on a global, system-wide scale.

To put the matter a slightly different way, in a self-organizing system order is not imposed from the outside, by external influences. No architect or foreman holds the blueprint or has a preconceived idea about what patterns will evolve. The patterns that arise are emergent properties, properties that cannot be predicted simply by examining the subunits in isolation. To understand them, the dynamic and often remarkably complex interactions among the subunits must be taken into account.

Think about the concentric pattern of honey, pollen, and brood that arises on the honey combs of a beehive. Thousands of bees contin-



Entirely different and unpredictable pattern arises as a result of applying a different rule (top of diagram) to the same initial state used in the upper illustration on the opposite page.

ually and simultaneously contribute to the emerging pattern: workers from the field bring in honey and pollen throughout the day; other workers consume the honey and pollen and feed it to the brood; the queen wanders over the combs looking for cells in which to place her eggs; the eggs hatch, become larvae, and finally vacate the cells when they pupate and develop into adults. My research has shown that the bees do not have special “designated” places to put the honey, pollen, and eggs. Instead, they conform to a simple set of what we call rules that guide their behaviors. Nevertheless, the dynamic interactions among all the bees result in the spontaneous emergence of a consistent, stable pattern.

Unfortunately the human mind is poor at predicting what happens when hundreds or thousands of “things” interact with one another, even if the interactions themselves are quite simple. Computers, however, are ideally suited to such a task. One tool for simulating self-organized pattern formation is readily implemented with computer software; the tool is called a cellular automaton, and the patterns that emerge, even from what seem to be the most trivial rules, make a highly convincing rationale for exploring the properties of automata.

One of the first cellular automata to be studied in any depth was the so-called game of life, devised by the mathematician John Horton Conway, now of Princeton University, and popularized by the writer Martin Gardner in his “Mathematical Games” column for *Scientific American* magazine in October 1970.

To understand how the game of life works, imagine a huge grid of squares, entirely covered by checkers, or cells, that are either black or white, “alive” or “dead.” Each cell is surrounded by eight neighboring cells whose squares share an edge or a

corner with the square occupied by the original cell. A clock ticks the time, and with each tick, the state of each cell on the entire grid evolves to its next state in accord with four simple rules:

1. A live cell surrounded by two or three live cells at time t will also be alive at the next clock tick, time $t + 1$ (it survives).
2. A live cell with no live neighbors or only one live neighbor at time t will be dead at time $t + 1$ (it dies of loneliness).
3. A live cell with four or more live neighbors at time t



Wide range of patterns in nature can be simulated by surprisingly simple rules. Here and on succeeding pages is a gallery of photographs suggesting the variety. Above, wind-blown ripples develop on the surface of the sand in the Gobi desert, in Mongolia.

- will be dead at time $t + 1$ (it dies of overcrowding).
4. A dead cell surrounded by three live cells at time t will be alive at time $t + 1$ (it will be born); otherwise, a dead cell remains dead.

When the rules are applied to some initial configuration of live and dead cells (at, say, time $t = 0$), the pattern that arises at time $t = 1$ can be quite unexpected. Moreover, if the same rules are applied to the new patterns of live and dead cells that result at times $t = 1$, $t = 2$, $t = 3$, and so forth, the patterns that evolve over time can be entirely unpredictable. In other words, for some initial patterns, the only way to determine how they evolve under the rules is to watch them.

To better understand how such a program works, consider an even simpler version of a cellular automaton. This one begins not with an entire

as successive horizontal rows, the “successor” pattern just under its predecessor. The pattern that results is a two-dimensional grid of cells that portrays the evolution of the top row throughout all the ticks of the clock.

Suppose the initial row of cells has a single black cell in the center. When the rule I just defined is applied to that row—the active row—and then to the subsequent rows, a complex pattern develops that is shown at the bottom of the illustration. Applying another rule to the same initial pattern would give rise to an entirely different set of successive rows [see upper illustration on preceding page].

It is difficult to convey the intricacy and dynamism of even the simplest cellular automaton with a verbal description or even with static diagrams. Curious readers can visit Web sites where they will be able to watch “home movies” of cellular automata as they evolve:



Yellow morel, black morel, and half-free morel



Scales on the wing of a painted lady butterfly, x400

checkerboard of cells (a “two-dimensional” cellular automaton), but instead with just a single row (a “one-dimensional” automaton). In other words, start with a horizontal row of square cells that extends indefinitely far to the left and right. As in the game of life, each cell is colored either black or white. The neighborhood of each cell in the row includes just the two adjoining cells, one to its left and one to its right. And again, as in the game of life, with each tick of a clock, the color, or state, of each cell in the row changes according to some simple rule.

For example, one rule might be the following: a cell becomes black on the next tick of the clock whenever one or the other, but not both, of its neighbors are black; otherwise it remains (or becomes) white [see upper illustration on page 36]. A one-dimensional cellular automaton has the advantage that successive patterns can be represented

www.radicaleye.com/lifepage

www.math.com/students/wonders/life/life.html

To see bird flocking simulations visit

www.red3d.com/cwr/boids/

Also visit StarLogo at these three sites:

education.mit.edu/starlogo/

www.kasprzyk.demon.co.uk/www/ALHome.html

lachlan.bluehaze.com.au/alife.html

As with all self-organizing patterns, the main feature of cellular automata is that they are based on a simple set of rules, and they use only local information to determine how a particular subunit evolves. But programs such as the game of life or the one-dimensional cellular automaton just described, while suggestive, lack direct biological relevance. If rules are to be useful for understanding the patterns in real life, such as the stripes of a zebra's coat, they must be different rules.

The zebra's coat alternates in contrasting areas of light and dark pigmentation. In technical jargon, the pigmentation reflects patterns of activation and inhibition—apt terms because of the dynamic process that generates the pattern. Cells in the skin called melanocytes produce melanin pigments, which are passed into the growing hairs of the zebra. Whether or not a melanocyte produces its pigment appears to be determined by the presence or absence of certain chemical activators in the skin during early embryonic development. Hence the pattern of the zebra's coat reflects the early interaction of those chemicals as they diffused through the embryonic skin.

With a new set of rules, a two-dimensional cellular automaton can readily simulate the pattern of the coat and so shed light on the mechanism of pattern formation in the zebra. Return to the square grid and randomly place a black cell or a

underlying physical reinforcements and inhibitions, and switch their states appropriately. As the regions of activator compete with one another through their local interactions, a regular pattern develops. What emerges is a self-organizing pattern that looks very much like the skin of the zebra [see the remaining three frames of the lower illustration on page 36].

Similar patterns occur in the brain. As the embryonic brain develops, competing influences from the right and left eye determine where connections are made in the back of the brain, the visual cortex. Clusters of neurons from one eye or the other dominate portions of the cortex in a distinct pattern. The pattern is thought to develop because the neurons from each eye compete with one another for space. Initially, the neuronal projections coming from the left or right eye are slightly different, a difference that presumably arises at random. The rules of the competition have the same general form as



Wrinkle pattern formed by a coat of varnish on a wooden surface



Plasmodial slime mold (*Physarum polycephalum*) growing on a leaf.

white cell on each square. The grid will look something like the leftmost frame of the lower illustration on page 36. Assume that each black cell represents a certain minimum level of pigment activator. Such a random array of activator or its absence is thought to be the starting point for the early development of coat patterns.

Now apply another simple rule, based on the following underlying physical effect: activator molecules that are near each other strengthen and mutually reinforce their effect. At the same time, they diminish the effect of activators that are farther away, inhibiting their ability to activate their own nearby neighbors.

In this example, as in the game of life, each cell can be either on or off, black or white. And again, with each tick of the clock, the cells interact with one another according to a rule that reflects the

the rules of activation and inhibition of zebra coat pigment. Projections of the neurons from one eye stimulate and encourage additional projections from the same eye. At the same time, those projections inhibit the development of projections to that area from the other eye. This local competition for real estate in the brain results in a pattern of stripes reminiscent of those of the zebra.

Self-organizing patterns extend to the nonliving world as well. They appear in mineral deposits between layers of sedimentary rock, in the path of a lightning bolt as it crashes to the ground, in the undulating ripples of windblown sand on a desert dune. When the forces of wind, gravity, and friction act on sand dunes, the innumerable grains of sand ricochet and tumble. As one grain lands, it affects the position of other grains, blocking the wind or occupying a

site where another grain might have landed. Depending on the speed of the wind and the sizes and shapes of the grains of sand, this dynamic process creates a regular pattern of stripes or ripples.

Similar patterns arise accidentally on painted sur-

faces exposed to harsh weather. Paints and varnishes are designed, of course, to adhere permanently and evenly to a surface. Nevertheless, heat, moisture, and sunlight often combine to lift the paint off the underlying surface, causing the paint to crack or buckle. As a patch of paint begins to pull away from the surface, a dynamic tension—between the forces causing the paint to buckle and wrinkle and the adhesive force between the paint and the surface—develops at that spot. The more paint that pulls away, the weaker the adhesive force exerted by the paint nearby that is still sticking to the surface.

The result is a runaway situation but with a countervailing effect. At some point, the dynamic tensions begin to split the paint that has already pulled away. Once that happens, the tensions on the paint far from the split, still adhering to the surface, are reduced. The result is a pattern of buckling ridges.

The runaway process and its countervailing effect, so prominent in the example of the paint, are also key parts of the way patterns form in

even more melanin pigment. Sand dunes develop ridges when the wind deposits a chance accumulation of sand grains. One small, almost insignificant ridge becomes amplified because it acts as a barrier, promoting the accumulation of even more grains of sand on the windward side of the ridge.

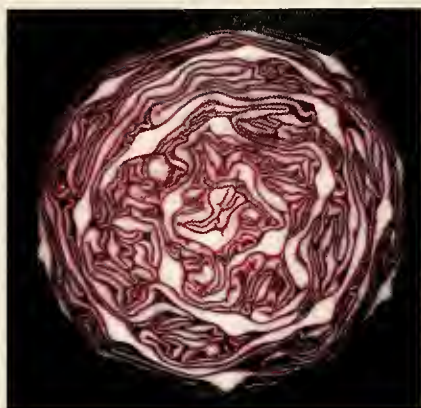
But if positive feedback operated alone and unchecked, there would be no pattern. The zebra would be entirely black; the sand dune would have no ridges. What comes into play is a second kind of process called negative feedback, in which more leads to less. Negative feedback puts the brakes on processes with positive feedback, shaping them so as to create a pattern. The presence of an activator in the zebra skin inhibits pigment production in nonadjacent skin patches and the zebra ends up as a mixture of black and white. (A similar mechanism may also explain the uniform coat of spots in a leopard, formed from islands of high activation.)

Self-organized patterns often arise in living systems because evolutionary processes can build the patterns so economically. The location and branching of each and every marking of a zebra need not be explicitly specified by the limited genetic information carried by DNA. Instead, all that needs to be genetically coded are the characteristics of the interacting molecules. Those characteristics determine just how the molecules act upon one another—what we interpreted as the “rules” that govern the positive and negative feedback processes of the underlying activators that are distributed across the embryonic zebra’s skin.

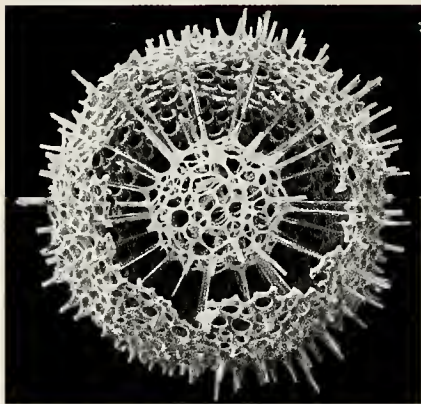
A second economy is an explanatory one: there is no need to invoke a different process to explain each of the many different striped and spotted patterns that occur on the surfaces of mammals, fish, and insects. All such patterns arise through similar developmental pathways. A particular pattern simply emerges from the ways in which certain substances activate or inhibit one another’s effects on the formation of pigment.

In nonbiological physical systems, self-organized patterns are epiphenomena that have no adaptive significance. There is no driving force that pushes cloud formations, mud cracks, irregularities in painted surfaces, or spiral waves in certain chemical reactions into developing the striking patterns they exhibit.

In biological systems, however, natural selection can act to favor certain patterns. The particular chemicals within the skin of the developing zebra diffuse and react in such a way as to consistently produce stripes. If the properties of the zebra skin, or the composition of the chemical activators, were



Cabbage



Radiolarian, x120



Polygonum pollen grain, x900

zebra fur and in sand. The runaway process is also called positive feedback: just as in a snowball rolling down a hill, more leads to even more. In the zebra, an elevated level of activator in the skin leads to more activation nearby, and so to the production of

even slightly different from what they are, a pattern would not develop. But in the course of evolution, the specific properties that result in precisely the kind of stripes that zebras possess were selected for and have persisted. One advantage of this pattern of disruptive coloration seems to be an effective adaptation to the presence of biting flies. The visual system of the tsetse fly is particularly sensitive to large blocks of contrasting color. A large black animal on a background of uniformly light-brown savannah is more easily recognized as a potential meal than is a pattern of fine black-and-white stripes.

Zebras' coats are just one example of the adaptive advantage of self-organized patterns. Such patterns also come into play on the folded, reticulated surface of the morel mushroom or on the lining of the stomach. In both those cases, the large surface area, a consequence of the folding, is an advantage: for producing spores in the first case, or for absorbing nutrients in the second.

Yet not all patterns that occur in nature arise through self-organization. A weaver bird uses its own body as a template as it builds the hemispherical egg chamber of its nest. A spider creates its sticky orb following a genetically determined recipe for laying out the various radii and spirals of the web. A caddisfly larva builds an intricate hideaway from grains of sand or other debris carefully fastened together with silk. In those cases, the building of structures does indeed involve a little architect that oversees and imposes order and pattern. There are no "subunits" that interact with one another to generate a pattern; instead, each of the animals acts like a stonemason, measuring, fitting, and moving pieces into place.

Finally, what about the graceful movements of birds and fish? Do they depend on leaders, or are they, too, system subunits that "follow rules" and that move gracefully despite the absence of any leaders to guide the group. Coordinated flocking appears to rely on three behavioral rules for maintaining separation, alignment, and cohesion of flock-mates: steer to avoid crowding or colliding with nearby birds; maintain the average

heading of nearby birds; and move toward the average position of nearby birds. Fishes' rules are similar, and they suffice to describe the phenomenon.

It is not easy for human beings to intuit how such a decentralized mode of operation can function so efficiently, because human groups rely so heavily on hierarchical organization. Executive



Windflower, *Anemone coronaria*

functioning, planning, and decision-making exist at many levels of the hierarchy. Imagine a world without supervisors, administrators, and managers, and many people would imagine sheer chaos. Nevertheless, self-organization in nature is efficient, economical, and ubiquitous. It is one of the least known, yet most powerful, devices for achieving pattern and order in the world. □

EDITOR'S NOTE: The looting and destruction that have befallen ancient artifacts from the museums and archaeological sites of Iraq are a calamity for civilization. The photographs on these four pages depict only a handful of the glories that had been unearthed in recent centuries; it is too soon to say with any certainty whether the items pictured here are safe or missing—or whether, if missing, they will somehow yet turn up.

In February 2001, *Natural History* published the article “Robbing the Archaeological Cradle,” by John Malcolm Russell, a professor of art history and archaeology at the Massachusetts College of Art in Boston and a leading authority on the antiquities of the Near East. Passages adapted from Russell’s article, which provide cultural and historical context for the artifacts, are presented here (*italic text*). David Keys, a freelance journalist based in Middlesex, England, who specializes in archaeology, has contributed a report about the looting and the early responses to it.

The “Mona Lisa of Nimrud,” possibly Ishtar. Ivory plaque of Phoenician workmanship, found in the Assyrian palace at Nimrud. Late 8th century B.C.



Lost Time

Damage control in Iraq

Called Mesopotamia by the Greeks, and variously Sumer, Akkad, Babylonia, and Assyria by its own ancient inhabitants, Iraq has an excellent claim to be the cradle of Western civilization. The emergence of complex communities was accompanied by developments such as writing, the wheel, irrigation agriculture, cities, monumental architecture, state-sponsored warfare, organized religion, written laws, kingship, a wealthy class, imperialism, centrally organized production of hand-crafted goods, and large-scale trade. The first eleven chapters of Genesis are set, by and large, in southern Iraq, in the land of Shinar (Babylonia). Eden, the Sumerian word meaning “steppe,” was the name of a district in Sumer, or southern Babylonia. Mesopotamian royal gardens, notably the Hanging Gardens of Babylon, may have inspired the story of the Garden of Eden.

—JOHN MALCOLM RUSSELL



Uruk (Warka) cult vase. This three-foot-high vase has five rows of limestone bas-reliefs depicting the abundant fields and flocks of the city-state of Uruk, water, corn growing from the water, sheep, men bearing offerings to the temple, and the king presenting them to the Goddess Inanna (Innin). From Uruk, 5th–2nd century B.C.



Winged sphinx. Ivory and gold, Sumerian, 8th–7th century B.C.

Aftershocks

by David Keys



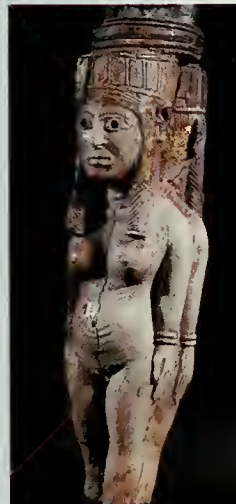
Funeral crown, a golden wreath of leaves and olives. From Uruk (Warka). Hellenistic, early 3rd century.



Lioness killing a man. Phoenician ivory inlaid with lapis lazuli. From Nimrud, 8th century B.C.



Gold necklace with lapis lazuli and carnelian pendants. Sumerian, 3000 B.C.



Two nude females. Figurative ivory handle, originally with gold foil. From Nimrud, 8th century B.C.

Around the world, the initial response to the looting of Iraq's internationally important museums and archaeological sites was, in the catchphrase of the moment, shock and awe. Early reports claimed near-total destruction of the collections in Iraq's National Museum in Baghdad, numbering some 170,000 ancient artifacts. Three weeks after the looting began, paralysis continued to dog the military reaction. Meanwhile, however, an international roster of organizations and scholars had begun to move toward coordinated action.

Subsequent estimates put the losses at roughly 15 percent of the collections, either smashed, damaged, or looted. Despite the disaster in the museum, virtually all 80,000 of the institution's cuneiform tablets appear to be safe, as do most of the precious Mesopotamian cylinder seals. The losses remain devastating, but they fall far short of complete ruination. What is

more, in response to appeals by Muslim religious leaders, some of the stolen objects are gradually being returned.

By the end of April, an alliance of leading Western museums and universities had announced a multimillion-dollar initiative to provide expertise and funding for the repair and conservation efforts. But the basic police work—sealing borders, hunting for thieves, tracking down illicit Iraqi antiquities that reach Western art markets—had been left to governments. Cultural institutions could do little more than beg political leaders to devote resources to an effective, aggressive recovery effort.

The looting of the National Museum itself began on April 10 and continued sporadically for several days. Successive waves of looters broke into dozens of rooms. Tens of thousands of documents, photographs, slides, and index cards were scattered over floors throughout much of the building.

Some of the papers had been gathered into piles by vandals who, it is thought, had intended to turn them into bonfires to burn the building down. But they must have been disturbed—possibly by other gangs of thieves. Some looters came equipped with glass and metal cutters and other tools—as well as trucks and vans for hauling away heavy pieces of looted treasure. The better-organized gangs ignored replicas and stole only genuine ancient treasures. And with considerable organization, they manhan-



Couple embracing. From Nippur, 2600 B.C.



Cylinder seals. Late Uruk, Jamdat Nasr period, 2900 B.C.

Prior to the First World War, when the area that is now Iraq was part of the Ottoman Empire, excavations by foreign archaeologists were carried out under permits issued in Istanbul. Mid-nineteenth-century excavators were allowed to export whatever they wished. That is how the British Museum and the Louvre acquired the bulk of their renowned Mesopotamian collections. Stung by the empire's loss of irreplaceable treasures, and anxious to establish Istanbul as a center for the study of ancient art, the Ottoman statesman Hamdi Bey founded the Archaeological Museum of Istanbul in 1881. Thereafter, foreign archaeologists were obliged to share their discoveries with the museum.



Bronze statuette of King Sulgi. Neo-Sumerian, 2094–47 B.C.

After the First World War, Iraq became a separate state, initially administered by Britain. With the energetic guidance of a British official, Gertrude Bell, who advocated that antiquities be retained by the country of origin, the Iraq Museum was founded in 1923 in Baghdad. A decade later, Iraq began to take charge of its own patrimony. A law enacted in 1936 decreed that all the country's antiquities more than 200

years old were the property of the state; amendments in the 1970s eliminated the Ottoman tradition of dividing finds with their excavators. The Iraq Museum, in the heart of downtown Baghdad, now began to accumulate the most important collection of Mesopotamian antiquities in the world. . . .

—JOHN MALCOLM RUSSELL



Musical instrument, gilded and inlaid, with bull's-head ornament. Found in the Temple of Puabi at Ur, 2450 B.C.



Cuneiform tablets. Left: Algebraic-geometrical table of triangles described by a perpendicular drawn from the right angle to the hypotenuse. Right: Algebraic-geometrical problem involving a rectangle whose diagonal and area are given and whose length and width are to be determined. From Tell Harmal, c. 1800 B.C.



Fluted gold beaker. From the royal cemetery at Ur. Sumerian, c. 2400 B.C.



Mythical creature with gazelle's head, lion's body, and snake's tail; enameled tile and ceramic brick. Detail from the Ishtar Gate, Babylon. Period of Nebuchadnezzar II, 7th–6th century B.C.

At the time of the 1991 Gulf War, archaeology was undergoing an extraordinary revival in Iraq. Dozens of foreign and Iraqi teams were working at an unprecedented rate. . . . When Iraq invaded Kuwait in the summer of 1990, virtually all archaeological activity ceased, and the war and subsequent imposition of UN sanctions have left Iraq's patrimony in peril. Not only is almost no money available for the preservation of antiquities, but some Iraqi citizens, squeezed between ruinous inflation and shortages of basic necessities, have turned to looting and selling artifacts from excavated and unexcavated sites and even from museums.

—JOHN MALCOLM RUSSELL



Bronze or copper head of King Sargon the Great of Akkad (c. 2334–2279 B.C.) or of his grandson, King Naram-Sin (2254–18 B.C.). Found at Nineveh. Akkadian, c. 2250 B.C.

dled all the museum's safes into one room—presumably where they had installed their metal-cutting equipment.

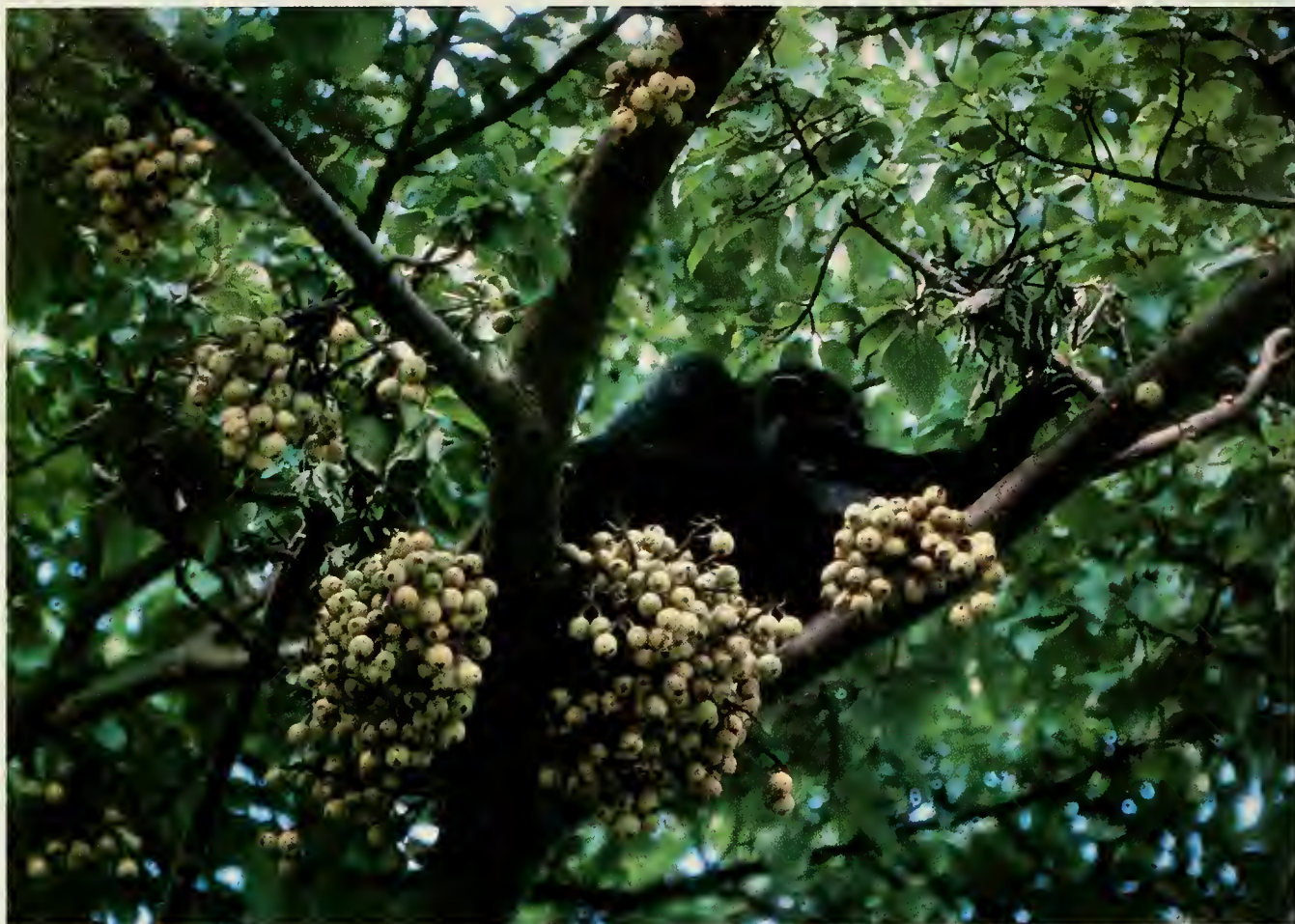
Looters also attacked the National Library, the library of the Ministry of Religious Affairs, and the library at Baghdad University. The museum in the northern city of Mosul—filled with treasures from Nineveh, Nimrud, and Hatra—was also badly looted.

More objects have probably been damaged than have been stolen. Many people outside Iraq have been at a loss to explain the sheer vandalism that Iraqis directed against their own cultural heritage. But as far as the poor of Baghdad are concerned, that heritage had become a surrogate for Saddam Hussein. Images of Hussein dressed as the seventh-century B.C. Babylonian ruler Nebuchadnezzar II stared down on Baghdad's population. Giant helmeted heads at a presidential palace in Baghdad depicted Hussein as the Muslim military leader Saladin. Top Republican Guard divisions were named after ancient Mesopotamian kings.

There is, of course, also plenty of anger in Iraq that the Baghdad National Museum was not protected by U.S. forces when they first occupied the city. Just a few days before the invasion, leading academics met with officials from the Pentagon and the State Department to discuss how best to protect Iraq's cultural artifacts, and the National Museum was number one on the list. The academics warned that serious looting would be inevitable unless the museum was properly guarded.

Yet the U.S. military offered virtually no protection to the museum during the first six days of the U.S. occupation. When the museum staff asked for help from a nearby tank crew, the soldiers told them that they had no orders to protect the building. Even when top museum officials appealed directly to senior military officers, no protection materialized.

The lack of a coordinated military response to what Donny George, the director of research at the Iraqi State Board of Antiquities and Heritage, has called "the crime of the century" was still the rule of the day three weeks after the initial occupation of Baghdad. U.S. troops stationed at border posts were still not searching vehicles for looted treasure, noted George, who personally crossed the Iraqi-Jordanian border. "Anyone can take anything and go out of the country," George added. "It's a tragedy." □



A chimpanzee consumes figs in the Budongo Forest Reserve in western Uganda.

Close Encounters

Mountain gorillas and chimpanzees share the wealth of Uganda's "impenetrable forest," perhaps offering a window onto the early history of hominids.

By Craig Stanford

It's a rare sunny morning in the Bwindi Impenetrable National Park of southwestern Uganda, and a party of chimpanzees is feeding noisily in an enormous fig tree. My colleague John Bosco Nkurunungi and I sit fifty yards away on the other side of the small valley, surveying the scene at eye level through binoculars. The apes, which belong to a group Nkurunungi and I have been observing

as part of our field studies, stand upright on thick branches as they stuff themselves with the little fruits. The group's alpha male—we call him Mboneire ("handsome" in Ruchiga, a local language)—eats next to a female we call Martha, and her daughter, May. Grizzled old Kushoto plucks fruit nimbly with his right hand (his left was damaged when it was caught in a poacher's wire snare).

Suddenly the branches in the forest understory begin to sway, and a large, black-haired figure pops partly into view from the green foliage.

"Who's that big guy?" I whisper, refocusing my binoculars. "That's not someone we've seen before." Judging from the size of the top of its head, the new arrival looks to be the biggest chimpanzee I've ever seen.

Peering through his binoculars, Nkurunungi straightens me out: "Craig," he says, "that's not a chimpanzee. It's a gorilla!"

Nkurunungi and I and our assistants in the Bwindi Impenetrable Great Ape Project are well aware that in this forest the ranges of the two ape species overlap. Yet this occasion, in the project's fifth year, is the first time we've ever witnessed an encounter between them. The newcomer, an adult female, emerges from the foliage and sits out in the open on a large branch only twenty feet below the chimpanzees. She's much larger than any of them, and displays the serene and confident demeanor that gorillas always seem to possess. As we watch, she climbs to within ten feet of the chimpanzees, casually plucking figs along the way. Then another gorilla shows up below her, this one a silverback, or mature male, that appears to weigh at least 400 pounds. He joins the female, and the two feed amicably side by side.

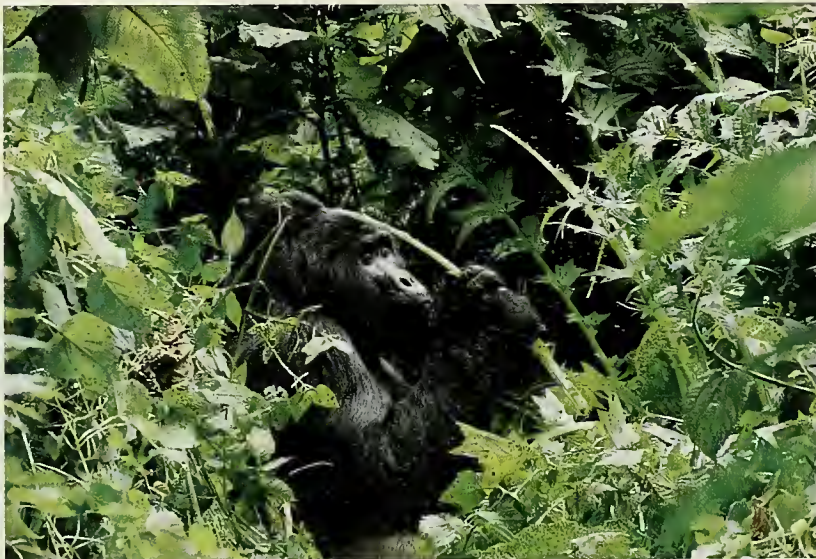
For the most part the two ape species pay no attention to each other, but after about twenty minutes the silverback notices us watching from across the way. As suddenly as they appeared, the two gorillas drop out of the tree and then disappear in the dense undergrowth.

As a biological anthropologist, I started the Bwindi Impenetrable Great Ape Project (or BIGAPE, as I like to call it) in 1996, and for seven years now, Nkurunungi, a doctoral student from Makerere University in Kampala, and I have worked together in Bwindi Impenetrable National Park (formerly, the Impenetrable Forest). Our goal is to understand the ecological relations between the chimpanzees (*Pan troglodytes schweinfurthii*) and the mountain gorillas (*Gorilla gorilla beringei*) that share this rugged habitat. Ecological theory predicts that in order for species to co-exist over the long haul of evolution by natural selection, they must avoid head-to-head competition. So two closely related species living in the same habitat typically diverge in some key aspects of their anatomy, behavior, or ecology. Diet is often the main point of divergence, and to find out if that

is the case among Bwindi's gorillas and chimpanzees, Nkurunungi and I have had to "walk the walk" of field observation.

Our interest, though, goes beyond the apes themselves. Anthropologists have long studied the behavior and ecology of the great apes—bonobo, chimpanzee, gorilla, and orangutan—to try to shed light on the lives of early hominids. Investigators have looked specifically at the relations between gorillas and chimpanzees for clues about how early hominid groups may have similarly shared a habitat. And, to be sure, at certain times and places in human prehistory, more than one species of hominid lived in the same habitat.

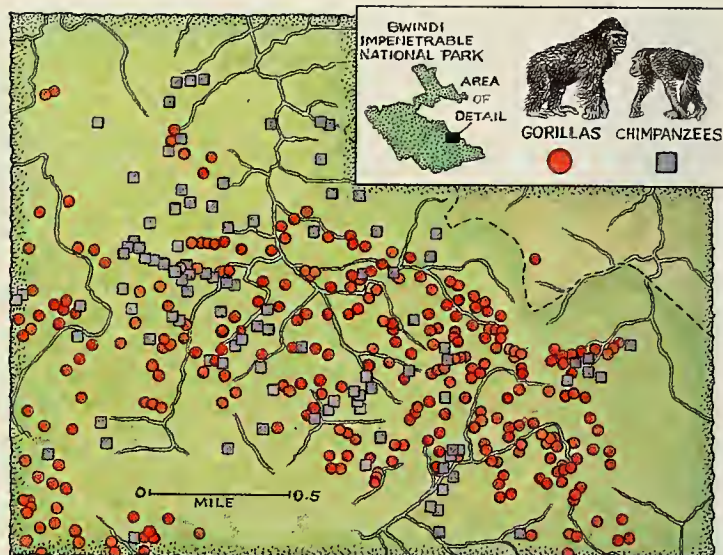
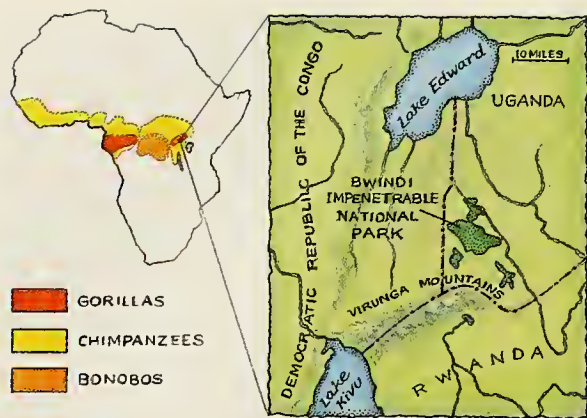
At Olduvai Gorge in northern Tanzania, for instance, *Australopithecus boisei* and *Homo habilis* (the latter an early member of our own genus) occupied the same territory about 1.8 million years ago. Still earlier, about 3.5 million years ago, both *Australopithecus afarensis*, of which the famed fossil Lucy was a member, and the recently discovered *Kenyanthro-*



In Uganda's Bwindi Impenetrable National Park, a female gorilla dines on wild celery.

pus platyops lived in fairly close proximity in East Africa. Anthropologists are keen to determine what kinds of associations such closely related species forged with each other. Did they share their habitat amicably, coming into peaceful contact on a regular basis? Or did they compete—perhaps even aggressively—for food, shelter, and other resources?

The most important clues to the ecological competitions of the distant past are teeth. Often well preserved in fossil records, teeth, their anatomy, and their wear patterns reflect the diet of



Where great apes share a home: Represented in broad strokes, above left, the ranges of the three African apes appear large, and they do overlap. Because of habitat loss, however, the animals are largely distributed in small, scattered populations. In Uganda's Bwindi Impenetrable National Park, both gorillas and chimpanzees roam through the same montane forest. A detail of Bwindi Park, above right, records sites where the two species made their sleeping nests over the course of two years.

their former owner. For example, Olduvai's *H. habilis* possessed unimpressive molars in a modestly proportioned skull. We believe this hominid consumed fruit, leaves, and some meat. In contrast, *A. boisei* had massive molars and a skull with a large bony crest on top, along the midline—the attachment place for formidable jaw muscles. Those features indicate that *A. boisei* was adapted to a diet of either tough and fibrous or hard-shelled foods. Fossil investigators think those dietary differences made it possible for the two human relatives to survive alongside each other for hundreds of thousands of years. Had they instead competed for the same resources, one of them would probably have become quickly extinct.

Beginning with the pioneering studies of wild chimpanzees by the primatologist Jane Goodall and of mountain gorillas by the primatologist Dian Fossey, investigators have watched apes in their natural habitats for more than four decades. As the data accumulated, it began to seem as if the two species occupied quite different ecological niches. In fact, aside from living in tropical forests across equatorial Africa, the two apes were long thought to have little in common. Chimpanzees were portrayed as high-energy arboreal nomads, traveling miles each day to gather a high-carbohydrate diet of ripe fruit supplemented with leaves, insects, and mammalian prey. They ate and made their sleeping nests in tall trees.

Gorillas, in contrast, appeared to be ground-based foragers of wild celery and other fibrous, nutrient-poor foods. Fossey portrayed them as

lumbering, sedentary, terrestrial beasts. The idea grew that, although their large brains were impressive, gorillas were the cows—the slow-moving herbivores—of the ape world.

In recent years, however, the general view that there is a wide ecological dichotomy between chimpanzees and gorillas has, to some extent, broken down. As other populations of gorillas have been studied across Africa, it has become clear that Fossey's gorillas, which inhabit the cold, mountainous forest cloaking Rwanda's Virunga volcanoes, lead quite different lives from those of gorilla populations elsewhere. Recent studies show that most gorillas, like chimpanzees, actually prefer fruit, and travel considerable distances to find it. To get other cherished foods, such as fungi and epiphytes, they climb tall trees, just as chimpanzees do. And sometimes they, too, nest in trees, even near the tree nests of chimpanzees. With all those parallels, how chimpanzees and gorillas can be ecologically separated while living in the same habitat is not immediately clear.

Bwindi Impenetrable National Park encompasses some 130 square miles of wet, rugged hills cut into steep ravines by cold rushing streams. The park is one of the last large tracts of montane wet forest in eastern or central Africa. It boasts an extraordinary biodiversity—at least ten primate species live there, as well as nearly 400 species of birds, including some that occur nowhere else in the region.

The population of Bwindi gorillas is about 300. That may seem so small that the population is at

risk of vanishing, but apparently it is stable. The situation is more alarming in other parts of Africa, where gorillas are under much greater pressure from forest cutting, poaching, and, most recently, an outbreak of Ebola virus. In the past five or ten years alone, the total number of gorillas in Africa, believed to have been between 80,000 and

The Bwindi gorilla group we are following is quite a cohesive one, made up of thirteen individuals, including two silverbacks. These animals do not follow the lifestyle of their chimpanzee neighbors, and their behavior also differs in key ways from that of the gorillas in the Virunga mountains. In a break from the herbivore stereotype, from January

Using handheld Global Positioning System units, we plot every observation of the two ape species, their sleeping nests, and fruit trees.

100,000, may have been cut in half. We know less about the Bwindi chimpanzee population, estimated at no more than 200, but across Africa the species faces the same perils.

Research in Bwindi, however, is not without its drawbacks. The area has suffered several periods of political instability in the past. In early 1999 Rwandan rebels killed a warden and kidnapped fourteen people from a tourist camp, and shortly thereafter they murdered eight of their captives. Since that tragedy, however, the Ugandan government has worked to ensure that the area is secure. Both ecotourism and research are thriving once again.

My colleagues and I are compiling a digital map, aided by Global Positioning System technology, which shows how the chimpanzees and gorillas use the Bwindi landscape. Carrying handheld GPS units, our research assistants plot the coordinates of every observation of the two ape species, noting if an observation is made at a sleeping nest or at a feeding tree. They also map sites where the animals have nested and the position and fruiting season of every major food tree—including the great fig trees that tend to fruit unpredictably. As the mapping has proceeded over a period of years, we have been able to build a digital portrait of how the two apes differ in their use of habitat from month to month [see illustration on opposite page]. We can see whether the movements and feeding of one species influences those of the other, and record overlaps in their diets.

until July, when fruit is most plentiful, our gorillas search for it far and wide. Most of the fruits they eat are the same ones eaten by the chimpanzees, but the gorillas in both Bwindi and in the neighboring forests of eastern Congo exploit a greater variety of fruits than do the chimpanzees in the same habitats.

From August until December, when the fruit supply in the forest is low, the gorillas turn to browsing leafy forest undergrowth, a salad that is low in calories as well as in most other nutrients, but is abundantly available. The consumption of this fallback staple is what seems to distinguish gorillas from chimpanzees everywhere. In the same



Chimpanzees in the Uganda Wildlife Education Centre in Entebbe use twigs to fish for termites. This kind of behavior was first observed in the wild in Gombe National Park, Tanganyika (now Tanzania), by the primatologist Jane Goodall. Bwindi's chimpanzees do not fish for termites, but they do use sticks to probe bee nests for honey.

months that gorillas rely on leafy matter, chimpanzees simply expand their search for the increasingly scarce trees with ripe fruit, traveling greater distances each day across Bwindi's hills and valleys.

Another *Gorillas in the Mist* stereotype pictures all gorillas plowing slowly through cold misty meadows of ferns, never bothering to seek the fruits readily available in the upper reaches of the trees. In fact, though, the Bwindi gorillas we observe climb with

fruit trees (in fact fewer trees of any kind) grow there. Virunga gorillas often have no choice but to stay on the ground and eat herbs. The difference in habitat may also explain why there are no chimpanzees living in the Virungas.

A third feature of gorilla behavior we expected to confirm turned out to be just as misleading a stereotype as leaf-eating and ground-foraging. We suspected at the outset of our study that the chim-

When different early hominid species lived side by side, did they share resources amicably, or did they compete—perhaps aggressively?

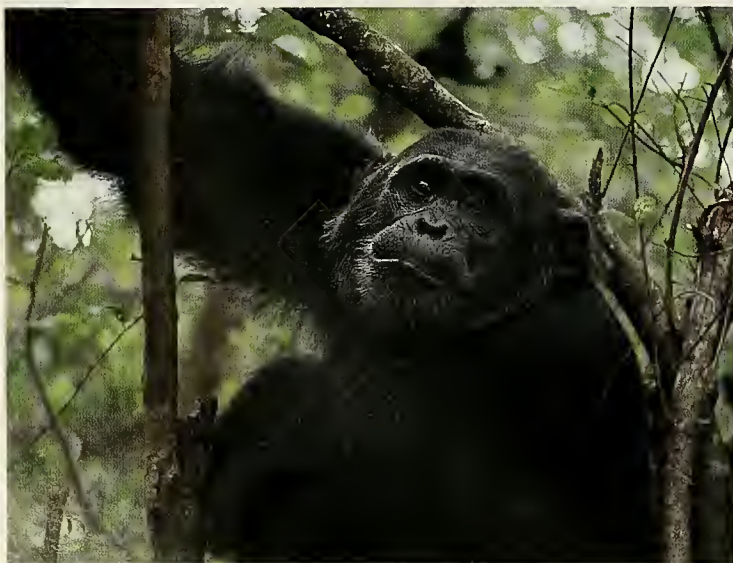
agility. To see a 400-pound silverback swaying from the uppermost tree branches as he picks figs or orchids and other epiphytic plants for his lunch is a truly impressive sight. Although some investigators have suggested that Bwindi mountain gorillas might possess some genetic adaptation to tree foraging, I prefer a far simpler, common-sense explanation.

The mountainous terrain in Bwindi park extends from 4,000 to 8,000 feet in elevation, whereas Rwanda's Virunga volcanoes, which lie just twenty-five miles to the south, rise as high as 14,700 feet. The lower altitude of Bwindi's mountains makes for a warmer habitat, one that is much more hospitable to fruit trees. In contrast, the habitat of the Virunga gorillas is so cold that few

panzees would always nest in trees and the gorillas would nest on the ground. Hence nighttime would find them ecologically separated. But at Bwindi, about one-fifth of all gorilla nests are built in small understory trees, which groan under the weight of such massive occupants. And unlike most other chimpanzees that have been studied, the ones in Bwindi occasionally build nests on the ground.

Our studies of Bwindi apes suggest that the striking behavioral and ecological differences between gorillas and chimpanzees stressed by earlier investigators were, in part, artifacts of the environments where those early studies were done. But our close observations still confirm important behavioral differences that others have noted between the two species of ape. Unlike the cohesive gorillas, for instance, the Bwindi chimpanzees live in the same fluid groups that characterize chimpanzees everywhere. The group we study, which ranges over at least eight square miles, is made up of at least twenty-five chimpanzees. It includes five adult males, plus females and their offspring. At any given moment, however, it is likely to break up into temporary subgroups, or parties.

I noted earlier that chimpanzees and gorillas diverge in their reliance on "fallback" foods, eaten in times of scarcity: the gorillas turn to fibrous plants, whereas the chimpanzees scour more territory for fruits. Another obvious dietary difference is the chimpanzees' love of meat. Virtually everywhere they have been studied—and Bwindi is no exception—chimpanzees avidly hunt and eat monkeys and forest antelope. Although the density of these mammals in our study area is fairly low, we have found that nearly 10 percent of chimpanzee fecal samples contain the bones or hair of prey. In contrast, gorillas do not eat meat at all, and have been only rarely observed in the wild consuming in-



Frodo, a male chimpanzee in Gombe National Park. Pioneering work here established that members of the species fashion and use tools, hunt and eat mammalian prey, and engage in other behavior that could not be deduced from the observation of captive animals. As primatologists have fanned out to study additional populations, the variations within the species have begun to emerge.

sects. Studies of gorillas in captivity show that their ability to metabolize the fats and cholesterol in meat is quite limited.

In our study area—the high elevation part of the park—the two ape species share roughly the same home range. But within that area the two apes use the forest differently. Chimpanzees are long-distance commuters, covering large parts of their range every week. The gorillas, meanwhile, range over only small portions of the area even in a given month, and it may take them a year or more to fully exploit the available resources. That difference may reduce the ecological overlap between the two species.

Measuring ecological overlap is one thing. But another goal of our study is to investigate whether there is competition between the two apes. That is much more difficult, because it requires showing that one species, through its behavior, is actually reducing the food intake of the other.

The most straightforward way to demonstrate such competition is to document encounters between chimpanzees and gorillas. We have now recorded four such encounters, in which members of both groups occupied the same tree. Three of them were quite amicable: the gorillas arrived at a tree in which chimpanzees were feeding, entered the tree themselves, fed near their cousins, and then departed.

But one encounter was not nearly so cordial. In April 2002 a party of nine chimpanzees was feeding in a tall *Chrysophyllum gorungosanum* tree (a species of star apple). The tree was laden with the fuzzy brown fruits with their milky-white pulp that both chimpanzees and gorillas relish. As the chimpanzees fed, our research assistants heard gorillas grunting and moving about in the undergrowth below the tree, apparently feeding on fallen fruits. Then a female gorilla, followed by one of the silverbacks, began to climb up the trunk. That prompted two of the male chimpanzees to stop feeding and descend to the first large fork of the trunk, where they obstructed the ascent of the two gorillas with a noisy, hair-bristling, branch-slapping display.

The standoff continued on and off for nearly an hour. All the while, the gorillas remained on the ground or lower branches, calmly watching their boisterous challengers. Finally, the arrival of other research assistants who had been tracking the gorillas startled the chimpanzees, which fled to an adjacent treetop. The gorillas immediately climbed into the *Chrysophyllum* tree and began to partake of the fruit.

This interaction may have been confrontational because *Chrysophyllum* fruit is more highly prized



A silverback—a mature male gorilla—climbs a tree in Bwindi. The gorillas in this forest regularly seek out tree fruit and sometimes make their sleeping nests in trees.

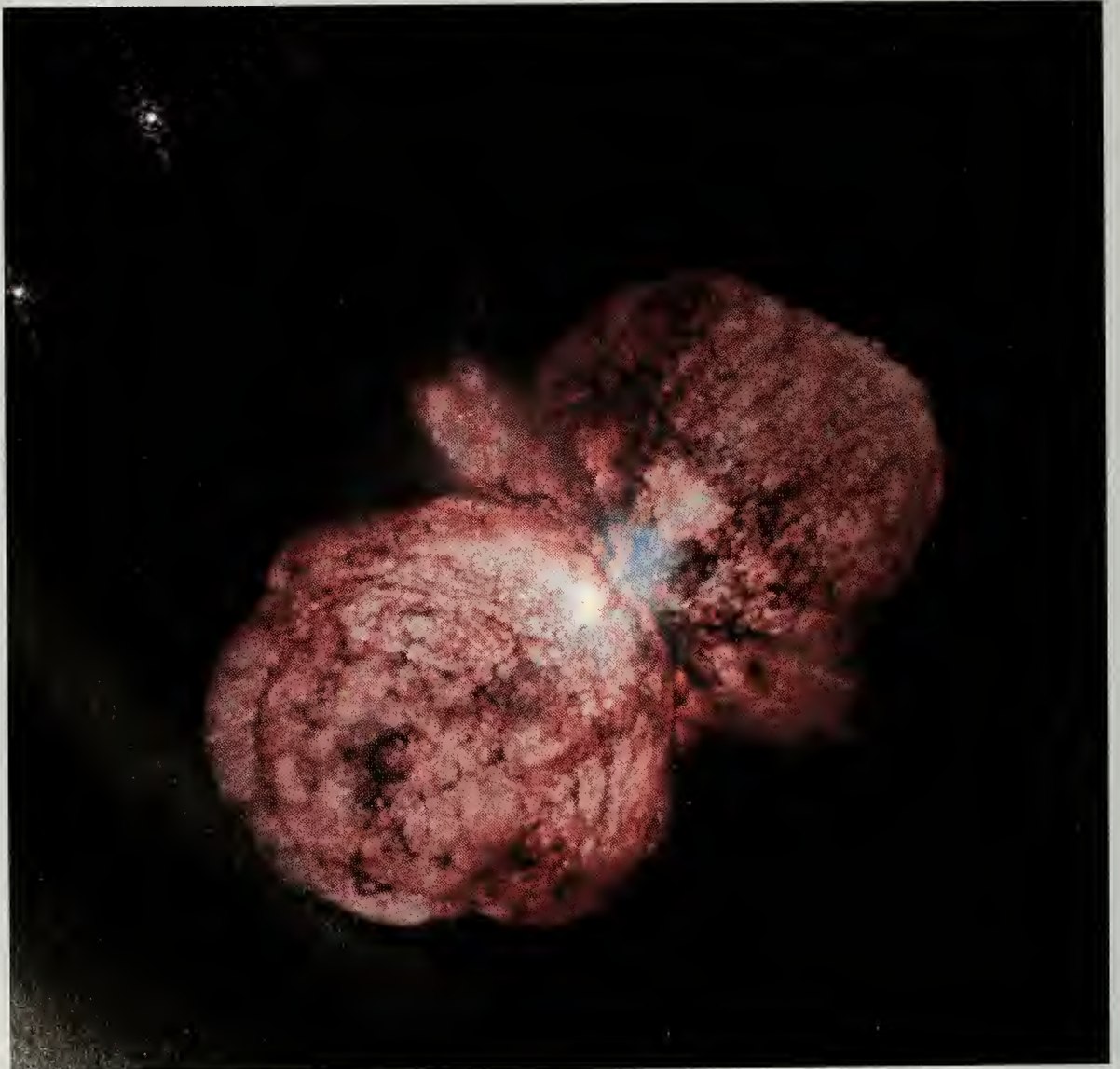
than the figs the apes were eating in the other encounters we witnessed. Although it is risky to generalize from this one observation, the outcome of the contest suggests that in Bwindi, chimpanzees are dominant to gorillas when it comes to competition over food.

It is tempting to imagine, too, that, millions of years ago, *H. habilis*, a direct human ancestor, played chimpanzee to *A. boisei*'s gorilla. Perhaps *H. habilis* was the more freely ranging hominid, less inclined to give in to foraging for salad when the going got tough. Perhaps *H. habilis* was the meat eater, smaller but more aggressive. We will never be certain. But we are certain that in African forests today, two of our closest kin are threatened with imminent extinction. They seek only to co-exist—with each other, and with us. □

Peering at the Edge of Time

In search of the black hole at the center of our galaxy

By Fulvio Melia

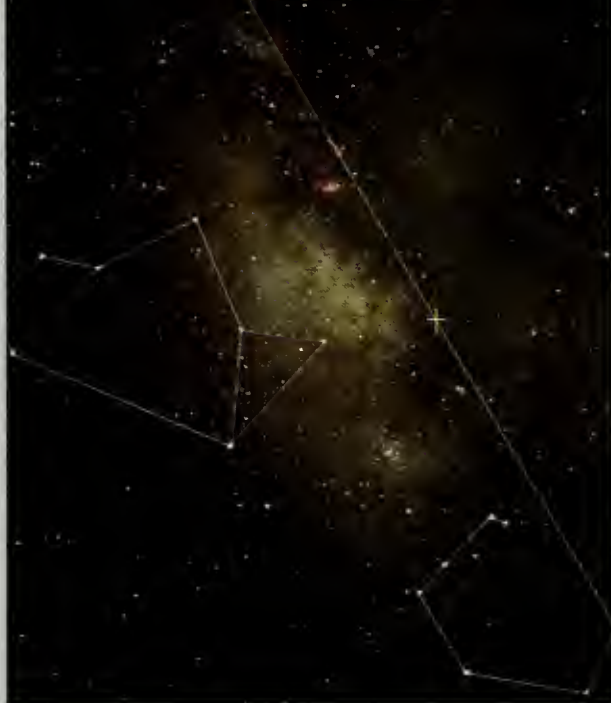


The star Eta Carinae, a hundred times more massive than the Sun, survived the spectacular outburst shown in the photograph, without becoming a supernova—for a time. Expected to explode soon, it may leave a black hole in its ashes.

Take a trip someday to the town of Port Douglas on the northeast coast of Australia. There, lying on the warm, sandy beach, you will see the evening splendor of the Milky Way arching from horizon to horizon across the cosmic vault. No doubt, as you peer into the starry void, the magnificence of this glorious and overpowering structure we humans proudly call our galaxy will overwhelm you.

But perhaps even more alluring is another realm, concealed deep inside this vista and shielded from the Earth by a one-way membrane—an event horizon—that eternally separates the world within from the cosmos without. This isolated world at the core of our galaxy is a black hole. First proposed by the physicist J. Robert Oppenheimer in the 1930s, and named by the physicist John Archibald Wheeler in 1967, a black hole is a collapsed aggregate of matter with a gravitational field so strong that the magnitude of the velocity for an object to escape its pull is greater even than the speed of light. And that means no one—not just a stargazer on an Australian beach, not even an astronomer probing the cosmos with the finest instruments known to science—can see it, at least not directly.

But no such technicality has kept astronomers from looking for it. As a species, human beings seek truth and find beauty in the heart of things; the primacy of the central realm beckons. Jules Verne felt it; in his novel *A Journey to the Center of the Earth*, Professor Hardwigg and his fellow explorers encounter an assortment of strange, breathtaking wonders as they approach Earth's core. In early Chinese culture, art and invention were to be found only in the "central kingdom." The supreme oracle of the ancient Greek world sat at Delphi, the *omphalos*, or navel, of the world. The pragmatic Romans echoed the sentiment, holding up their imperial capital city as the center of anti-barbarism. By extension, the heart of something as majestic as the Milky Way must be special indeed, and who would



The galactic center lies in the constellation Sagittarius (lower right) and is marked here by the cross. The diagonal represents the plane of the galaxy, and the constellation Scorpius is partly outlined to its left. The bright center and diagonal can be seen plainly in the radio image on the left of the next page.

not be drawn to it, teased by what it reveals, tormented with the desire to see more?

The direct observation of a black hole is a chance to see the principles of Einstein's general theory of relativity writ large, and the quest for that sight is what drives astrophysicists like me to look toward the dark behemoth within the Milky Way. But only in recent years have observational methods attained such technological virtuosity that astronomers can focus their attention on the galactic nucleus itself.

The center of the Milky Way lies in the direction of the constellation Sagittarius, the archer, close to the border with the neighboring constellation Scorpius [see photograph above].

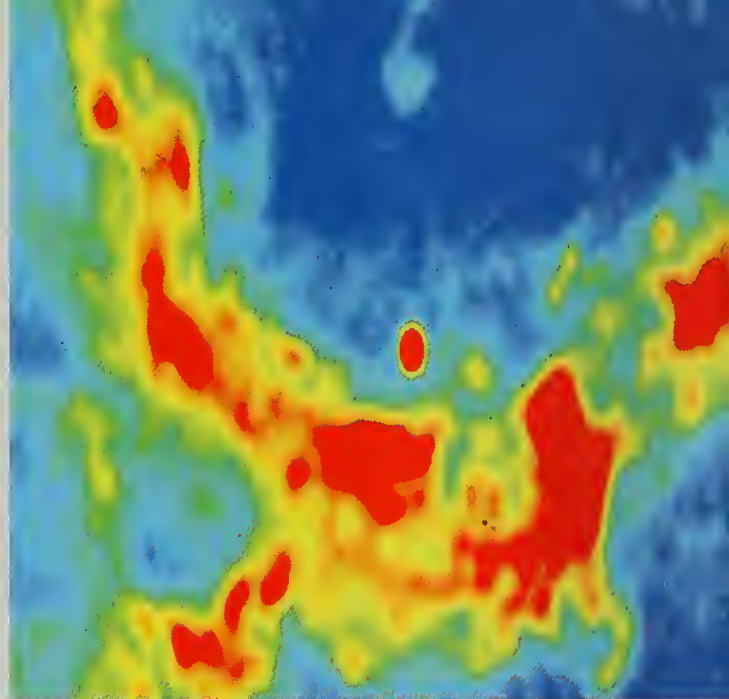
Today astronomers tend to name celestial objects and features after the constellation in which they are found; the galactic center is said to lie in the Sagittarius A complex, a large, radio-wave-emitting structure near the constellation. The most unusual object in this region, discovered in 1974, stands out on a radio map of the sky as a bright dot, and, unlike everything else stargazers have seen in the galaxy, it orbits nothing. Rather, it defines the exact center of the Milky Way. Astronomers call it Sagittarius A* (pronounced "ay-star"), the asterisk meant to convey its uniqueness and importance.

The significance of Sagittarius has been unknown for most of the history of astronomy. The reason, in large part, is the intervening dust. That ubiquitous and relentless vagrant of the household is often quite an annoyance to astronomers, and not just because they like tidy laboratories.

The effect of dust on what astronomers see depends rather directly on the color of the light they are trying to sense. Imagine a gondola on the waters just off the Piazza San Marco in Venice. The water, moving in waves, is like the light of space, and the gondola is a grain of dust. Water waves that undulate very slowly, so that crests pass by the boat at long intervals, have little influence;



The bright spot at the center of this radio image, made by the Very Large Array radio telescope, hints at our galaxy's central black hole, called Sagittarius A*. The circular glows are supernova remnants; the bright spot glows with the radiation emitted by highly ionized hydrogen interacting with Sagittarius A*.



Sagittarius A* is inside the bright oval at the center of this image, a many-fold enlargement of the bright region at the center of the image at left. Above the oval, near the top, is a red giant star (light blue spot with a comet-like tail pointing toward the top of the page); gas from the red giant is being blown away by the black hole.

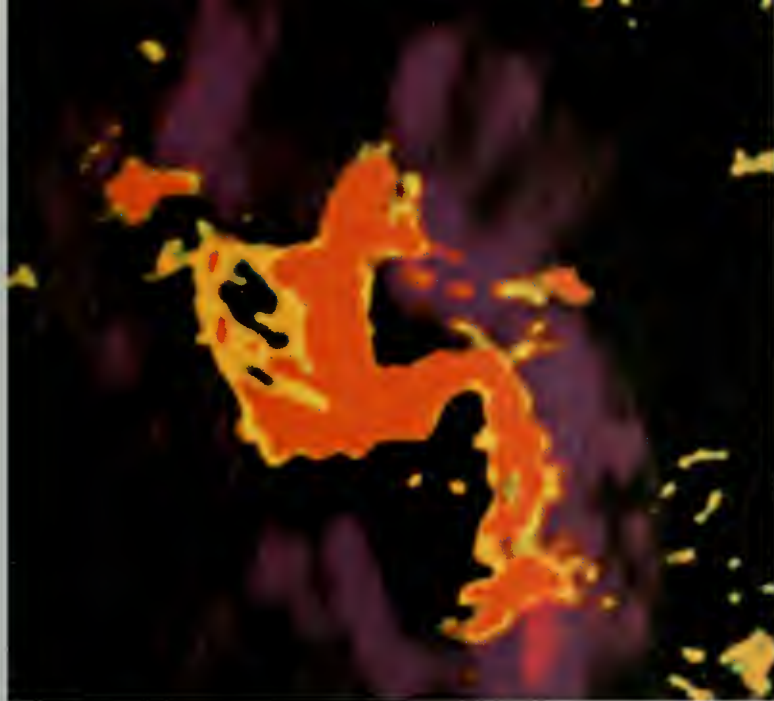
the boat rides peacefully as the waves pass by. Waves whose crests pass at intervals much smaller than the size of the boat—basically ripples—also have little effect; they “bounce” off the gondola with minimal interference. But waves whose crests are separated by a distance comparable to the size of the boat disturb it significantly as they pass, and the gondola disrupts those waves as well.

Coincidentally, the light that our eyes are best suited to see also happens to have the wavelength—that is, the crest separation—for which space dust is the greatest nuisance. Dust dims our view toward the galactic center by a factor of at least 100 million. And so it happens that the heart of the Milky Way, which would otherwise be the brightest patch of nighttime sky, is so heavily obscured by dust that even the most powerful optical telescopes are useless for observing it.

But astronomers can part this dusty veil by collecting light whose wavelength is different from what our eyes can sense. Instruments that detect radio waves, for example, have opened up bright new vistas in the heavens. Radio waves have a crest separation of a centimeter or more, far greater than the size of space dust. Like the slowly undulating water waves flowing past the gondola in Venice, they bypass the dust with no discernible effect. So by looking at the galactic center with a radio telescope, astronomers see a fountain of brilliance instead of what is, optically, a gloomy scene [see images above and on opposite page].

Imagine now plunging deeper into the middle of the bright region imaged by the radio telescope, to a point just one-twentieth of a light-year from the center of our galaxy. In that neighborhood such a region comprises as many as a million stars. Furthermore, an examination of the dark, or non-stellar, matter near the galactic center reveals that it harbors even more material that is yet unseen. Here is a territory where physical conditions become exotic, if not extreme. And embedded within a hot cauldron of swirling gases, lurking in the very middle of this inferno, is Sagittarius A*—the deceptively unpretentious face of a colossus with a mass equivalent to 2.6 million Suns.

Nature must surely be a chiaroscurist, a grande dame of light and dark, of shadow and contrast. On the cosmic canvas, astronomers can discern one of the greatest paradoxes in science—that black holes tend to be the brightest objects in the universe. And so it happens that images of the galactic center show not a dark spot, but rather a radiant brilliance. In part, the absence of blackness is a consequence of our remoteness from the central region. At this distance, it is hard to identify features as small as the black hole itself, which should be about as wide as five solar diameters. On an image such as the one at the right on this page, the radius of the black hole would be small indeed, at most one ten-thousandth the size of the



The orange structure in this image is the galaxy's center, glowing brightly with radio waves, superposed on an image of the cosmic dust. The black hole lies just above and to the right of the near-right angle formed by the orange spiral, at the exact center of this image.

central oval visible there. In fact, what blazes away in the center of the Milky Way cannot be the black hole itself—though the nature of the black hole does have something to do with the bright spot's presence there.

What is known is that the outpouring of radiation arises because Sagittarius A* does not exist in isolation from the rest of the universe—even though its interior is forever entombed within an unbreakable seal. Any matter or radiation that haplessly wanders nearby feels its very presence with overwhelming force. Some recently discovered stars swing past it, as close as several light-days, in orbits with periods as short as two decades. Those stars signal the gravitational influence of the black hole with such accuracy that astronomers now know not only its mass, but also its location relative to other objects at the galactic center.

But the stars don't contribute to the central beacon of radio light shining from the black hole itself. Instead, that beacon is a result of Sagittarius A* shining by proxy, inducing the environment to radiate on its behalf, revealing its presence indirectly. Most of the radiation that detectors sense from Sagittarius A* is likely emitted by the glowing, hot plasma—essentially a cloud of charged particles—that moves at near the speed of light as it falls into oblivion past the event horizon. Before

disappearing from our universe, the hot plasma glows like the aurora borealis in the Earth's magnetic field, producing radio waves visible to our equipment.

So far, then, our view of the black hole has been, at best, indirect. Yet, as remote as this region of space is, the black hole's shadow will, after all, soon be visible against the backdrop of luminous plasma.

In a series of influential papers published in the early 1970s, a pair of physicists, James M. Bardeen of Yale University and Christopher T. Cunningham of the University of Washington in Seattle, posed what seemed to be a mostly esoteric question: "What would a black hole look like if we had the technology to actually be able to see it?" To address their

own question, they had to take an indirect approach; they simulated how a black hole would affect the appearance of a bright object that lay beyond the hole, from the viewpoint of an observer.

Back then, of course, the Hubble Space Telescope was only a twinkle in the eye of Congress. X-ray astronomy—also impervious to interference by cosmic dust—was barely getting off the ground. Single-stage rockets had propelled only crude X-ray detectors into the Earth's upper atmosphere. Radio astronomers would not be detecting a mysterious bright radio source at the galactic center for another year or two. All in all, the prospects for seeing an actual black-hole image like the one Bardeen and Cunningham had simulated seemed rather thin.

To see the black hole is to know that its character is forged in the crucible of general relativity.

In spite of those practical difficulties, the two physicists reasoned that their efforts to simulate the visual effects of a black hole were scientifically useful. Knowledge of what a black hole would look like—if only one could peer through the dense glowing plasma surrounding it—could help astronomers predict how the light emitted in its vicinity might vary in response to changing conditions in the surrounding medium. Armed with

such predictions, astronomers could then look for the variations. Once found, those variations would imply the presence of a black hole. Little did Bardeen or Cunningham know that astronomers would indeed find a means whereby they could hope to see through the hot plasma, virtually all the way to the event horizon of the black hole itself. Observers would after all be put in a position to test the predictions of general relativity for uncommonly strong gravity.

Two decades after Bardeen and Cunningham published their results, astronomers realized that Sagittarius A* is just the kind of object to which those intriguing theoretical ideas might be applied. In 1994 a former U.S. marine and nightclub performer from Arkansas by the name of Jack Hollywood—a nom de plume derived from his earlier persona—decided after several attempts at establishing alternative careers that his true calling was physics. He enrolled in the graduate program at the University of Arizona in Tucson and almost immediately chose general relativity as his field. Hollywood moved effortlessly into a study of the effects of strong gravity associated with all aspects of Sagittarius A*, including its appearance.

A growing sentiment at the time was that stars near the black hole were too far from it—about 50,000 times its predicted radius—for their mo-

Bromley of the University of Utah in Salt Lake City, Heino Falcke of the Max Planck Institute for Radio Astronomy in Bonn, Germany, and Siming Liu of the University of Arizona, has demonstrated the viability of carrying out an experiment to produce an image of the black hole at the center of our galaxy.

Many astronomers now expect that within this decade an image of Sagittarius A* resembling the computer simulation shown on the opposite page will be attainable with a worldwide array of radio telescopes now under development. Such an image would bring a certain measure of closure to the often fitful, century-long effort to find a way of testing general relativity's description of regions of very strong gravity. Specifically, the image could confirm a bizarre prediction of the theory: that a sufficiently condensed aggregate of matter gives rise to an event horizon. In the image the event horizon would be manifested as a dark, roughly circular "shadow" against the background of glowing gas. The shadow would appear because light emitted by gas directly behind the hole doesn't reach Earth; instead, along the way, it must pass into a region where gravity is so strong that it gets permanently trapped. The process is somewhat analogous to a solar eclipse; the rays propagating from the Sun toward the Earth are blocked by the Moon, and so we see the Moon's shadow, as well as the Sun's visible light all around it.

But there is an important difference between the Moon's capricious attenuation of the Sun's rays and the black hole's absorption of the light radi-

ated by the section of the plasma that lies behind it. Rays that reach the event horizon aren't exactly blocked by it; instead they pass through it, never again to emerge.

Even more pronounced are the differences for light rays passing close to the intervening object. Rays passing near the limb of the Moon are, in effect, moving along straight lines. That is certainly not the case for the light rays passing near Sagittarius A*. The gravitational pull of the black hole is so strong that it severely bends the light. The closer a ray approaches the event horizon, the greater the curvature of its path. So even beams that do not pass through the event horizon are still diverted away from Earth. In consequence, the shadow of the black hole is bigger than its event horizon. Calculations predict the shadow must be two and half times the width of the event horizon itself.

Nature must surely be a chiaroscurist, a grande dame of light and dark, of shadow and contrast.

tions to show the general relativistic effects of the strong gravity near the hole. To this day, in fact, for many astrophysicists, a true appreciation of a black hole's general-relativistic character will come only when astronomers can "view" it directly.

The soon-to-be-minted Dr. Hollywood and his colleagues published several papers outlining how general relativity ought to influence every aspect of what astronomers would see of Sagittarius A*—its radiance, the variations in its luminosity over time, its environment—if only instrumentation existed to resolve it.

But no one could have foreseen how quickly telescopes would improve, particularly the ones that can detect radiation at millimeter wavelengths. In recent years, the work of an international collaboration that includes Eric Agol at the California Institute of Technology in Pasadena, Benjamin



A simulation of the cloud of hot plasma surrounding Sagittarius A shows how general relativity predicts the light from the cloud would be bent by the black hole; the dark central region, or shadow, would appear because light coming from regions near or opposite the hole would be either bent away from our vantage on Earth or swallowed by the hole.*

In the early development of general relativity, the observed bending of light was a real surprise, a major first triumph that later cascaded into several additional, successful tests of the theory. General relativity is almost surreal in the way it mysteriously compels us to accept truths about nature that are hard to appreciate solely on the basis of everyday experience. No other scientific theory so dazzles us with its profundity. Perhaps the reason for its capacity to amaze is that general relativity does something both enchanting and disquieting to space and time, the two main threads of our being. It folds them, twists and pulls them, and then weaves them into a single multifaceted unit.

Our curiosity is piqued, of course, by the chance to see what severe distortions of space-time can do. The discovery of another universe entombed within a black hole, with an alternate metric of reality, would force us to think deeply about our own. The nature of black holes has collected all those musings into one easily identifiable unknown—that's why they excite us, and haunt us even more. And Sagittarius A*, because of its size and its proximity, is our principal gateway into this uncharted territory.

The theory of general relativity mandates a unique shape and size for the region where the bending and capture of light are severe. Soon, those properties will be measurable. No physicist has ever had a comparable opportunity to place the existence of black holes and their strong gravity on such a firm footing. This coming decade may finally give us a view of one of the most important and intriguing scientific discoveries of our time.

Yet the theory is at risk as well. A nondetection of the shadow with sufficiently careful techniques would pose a major problem for physicists' understanding of strong gravity. The mass is undoubtedly there, confined within a region barely the size of the Earth's orbit. But if the mass is not collapsed within itself, general relativity will have broken down at the point where gravity is stronger than it has been in any of the earlier tests. Would such a failure add credence to alternate descriptions of reality, such as string theory, in which gravity is just one element in a purported theory of everything? No one yet knows what steps ought to be taken, should physics be faced with such an unexpected, though not unprecedented, outcome. □

Ages of Aquarius

In an Idaho canyon, temperate rainforest plants found refuge from ancient climate change.

By Robert H. Mohlenbrock

In 1968, when Robert Steele and Frederic D. Johnson, both forest ecologists at the University of Idaho in Moscow, explored a remote region along Idaho's North Fork Clearwater River, they found warm, south-facing slopes, cool north-facing slopes, perennial springs, and moist river terraces. They also found stands of forest populated with western red cedar and Douglas fir, as well as with several species previously unknown in Idaho, notably red alder. As they surveyed the vegetation, they were reminded of the temperate rainforests along the northern Pacific Coast, some 300 miles away. Stranger still, some of the plants were associated with Eastern deciduous forests.

Unfortunately, from a botanical point of view, soon thereafter a dam was built about fifty miles downstream, and two-thirds of the area was

flooded by the upper reaches of the Dworshak Reservoir. The good news is that six square miles of the surviving rainforest fall within Idaho's Clearwater National Forest and were designated the Aquarius Research Natural Area in 1991. The name Aquarius came from an old campground farther upstream, but how that site got its name no one knows.

The fossil record indicates that before 30 million years ago, temperate rainforests grew in what is now northern Idaho. At that time, to the west lay only shallow seas and tidal flats, making for heavy fogs, ample rainfall, and mild temperatures from the Pacific Ocean that nurtured the habitat. The tree species included dawn redwood, ginkgo, bald cypress, and relatives of present-day sassafras, tulip tree, and magnolia. Tall ferns probably grew in abundance, and

mosses cloaked rocky terrain and fallen logs.

Beginning 30 million years ago, however, as a result of plate tectonic events, tumultuous volcanic eruptions uplifted the Cascade Range, blocking much of the Pacific moisture. Temperatures in what is now northern Idaho became more extreme. Some trees, such as red alder, were isolated from members of their species farther west. Others, such as bald cypress and numerous broad-leaved trees, disappeared from the region, though they survived in eastern North America. Still other species, such as the dawn redwood and ginkgo, vanished from North America, though they remain to this day in China.

Nevertheless, some temperate rainforest plants persisted in Idaho, finding refuge in canyon bottoms during the ice ages. One such refugium was the canyon of the North Fork Clearwater River. When the last glaciation ended, however, about 12,000 years ago, temperatures rose and the climate became drier. Conditions became generally unfavorable for rainforest plants.

But at least along one river—as discovered by Steele and Johnson—some rainforest plants *did* survive. In large part they owe their lives to the 5,000- to 7,000-foot-high mountains that surround the steep-walled canyon where the plants grow. The mountains capture plenty of moisture—as precipitation and fog—during the growing season. In addition, the fairly low elevation of the river (about 1,650 feet) keeps the temperature from swinging to extremes.



Red alders line Isabella Creek.



Western red cedar and bracken fern

HABITATS

Temperate rainforest Western red cedar is usually the dominant tree, but Douglas fir is common on the relatively dry slopes facing south. Grand fir occurs alongside both species. Western red cedar and Douglas fir are prominent on the Pacific coast and in the western Cascades, but are less common in the intervening territory. Other plants that fit with the same disjunct pattern are clustered lady's-slipper, white shooting-star, broadleaf starflower, evergreen violet, Henderson's sedge, and crinkle-awn fescue.

Species of the eastern deciduous forest are northern maidenhair, maidenhair spleenwort, and oak fern. Plants that occur only in or near northern Idaho refugia are Clearwater

corydalis, Constance's bitter cress (a lavender-flowered member of the mustard family), and Idaho barren strawberry (whose closest relative is in the eastern United States).

Aquarius Research Natural Area is particularly rich in ferns, including Western polypody, spreading woodfern, oak fern, male fern, bracken fern, and sword fern. Huge lady ferns fill the understory on gentle slopes and on terraces above the river. On moist slopes above the terraces, northern maidenhair replaces the lady fern, and oceanspray populates the shrub layer. One unusual native species is phantom orchid, which is pure white. Devoid of chlorophyll, it derives all its nutrients from fungal associates in the soil. One-flowered Indian pipe, which also grows here, pursues the same strategy.



For visitor information, contact:
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Orofino, ID 83544
(208) 476-4541
www.fs.fed.us/r1/clearwater/

Streamside Within the Research Natural Area flow several streams that empty into the North Fork Clearwater River. The adjacent habitat usually includes red alder, black elderberry, Scouler's willow, black cottonwood, red-osier dogwood, and yellow monkey flower.

Robert H. Mohlenbrock is professor emeritus of plant biology at Southern Illinois University in Carbondale.



Red-osier dogwood in bloom

Voyage of the Barnacle

Darwin paid his dues as a scientist by exploring a miniature universe of marine animals.

By Richard Milner

As a city boy, I once supposed that fossils were as rare as large meteorites and could be encountered only in museums. Eventually I learned that they are almost everywhere: Mesozoic ammonite shells from ancient oceans populate the polished marble of skyscraper lobbies; microscopic plankton skeletons inhabit every piece of chalk; herds of fossil rhinoceroses lie beneath Nebraskan farms.

In 1811 James Parkinson, the English physician and amateur geologist chiefly remembered for identifying the disease that bears his name, marveled that his European contemporaries lived literally surrounded by fossils. In volume one of his work *Organic Remains of a Former World*, he noted that extinct marine organisms “have become the chief constituent parts of the limestone, which forms the humble cottage of the peasant; and of the marble which adorns the splendid palace of the prince.” But what Parkinson found even more astonishing was that no one seemed to share his intense curiosity about how and when those organisms had found their way into the building materials of hovels and mansions alike.

Billions of primitive marine animals still share the planet with us today. One of the more ubiquitous of them is the barnacle—the small invertebrate that clings to whales as well as to dock pilings and shoreline rocks. In her entrancing book *Darwin and the Barnacle*, Rebecca Stott, a professor of English at the University of Cambridge, quotes Charles Dickens’s *Little Dorrit* on this creature’s omnipresence: “Wherever there was a square yard of

ground in British occupation under the sun or moon, with a public post upon it, sticking to that post was a Barnacle.” Perhaps most human activity directed at barnacles has been devoted to that despised sailor’s task—scraping them off ships’ hulls.

Stott begins her tale by recalling childhood visits to the seashore, where she first encountered cone-shaped bar-

***Darwin and the Barnacle:
The Story of One Tiny Creature
and History’s Most Spectacular
Scientific Breakthrough***

by Rebecca Stott
W.W. Norton & Company, 2003;
\$24.95

nacle shells. Each one held a “bizarre inhabitant, a cream-coloured shrimp-like creature, upside down, glued to the rock by its head, fishing for plankton through the hole in its cone with its feathery feet.” Stott also came across the stalked barnacles that cluster on driftwood, which some consider a seafood delicacy. She began to wonder: Just what kind of critters are barnacles? Are they mollusks? Crustaceans? How many kinds are there? Where did they come from? How far back can one trace their ancestry? By the time she summoned the courage to order barnacles in a seafood restaurant, she associated them with Charles Darwin, whom she realized was obsessed with the odd creatures.

In 1831, when twenty-two-year-old Darwin set sail as a fledgling naturalist on HMS *Beagle*, no one

knew much about barnacles—and few cared. But young Darwin was, as his uncle described him, “a man of enlarged curiosity.” In 1835 he collected a conch shell on a Chilean beach and noticed that there were hundreds of tiny holes in it, which interested him more than the species of the shell itself. He suspected that some small creature had made the holes, although he could see none. Later, under a microscope, he spotted the culprit: a minuscule, soft-bodied inhabitant cemented into the hole by its head and waving its jointed legs in the air. Anatomically it resembled an acorn barnacle. But that creature was defined by its cone-shaped shell.

Darwin had discovered something as yet unknown to science: a rare burrowing barnacle with no shell-house of its own. The questions raised by this creature’s anomalies would occupy him for years. As Stott reveals:

Darwin will carry this Chilean barnacle on a journey around the world, from the South American beach back to London, preserved in a jar of wine spirits. When he has finished finding homes for all the 1,529 species he has collected . . . on the *Beagle*, he will return to the puzzle that the creature’s strange anatomy presents; and then he will write this Chilean barnacle’s evolutionary biography—a puzzle that will take him eight years to think through.

Eight years, from 1846 until 1854, devoted entirely to barnacles? By 1842 Darwin had already sketched out his theory of evolution by natural selection. But he pushed it all aside, squirreling it away to work on the barnacle riddle. What was so com-

pling about these invertebrates that Darwin chose to postpone the completion of his major work—*Origin of Species*—for their sake?

Hundreds of books have touched on diverse aspects of Darwin's discoveries: his encounters with finches on the Galapagos Islands; his elucidation of sexual selection, orchid pollination, and the formation of coral reefs; his treatise on the evolution of emotional expression. Barnacle anatomy and classification, however, is an arcane technical field that most Darwin scholars have treated only superficially. Now, at last, Rebecca Stott, albeit a nonspecialist in barnacles, has had the courage and tenacity to make Darwin's barnacles—and their importance—accessible to the rest of us.

Before Darwin's work, these seemingly insignificant invertebrates were as little known to Victorian science as were the tribes from Tierra del Fuego that Darwin encountered on his *Beagle* voyage. Stott describes the naturalist's quiet excitement as he explores the world of the barnacle on his tabletop, his eye glued to a microscope day after day, his large hands manipulating little pins for tearing apart pickled creatures in order to "daily see some more beautiful structures."

She also weaves some of Darwin's personal traumas into the narrative: the heartbreaking loss of his beloved ten-year-old daughter Annie to tuberculosis; his own battles with a mysterious malady while under the care of a quack. Both episodes took place during his so-called "barnacle years." So protracted was his barnacle study that his children assumed it was the normal occupation of every father: When one of Darwin's young sons visits a neighbor's home, he asks his friend there, "Where does your father work on his barnacles?"

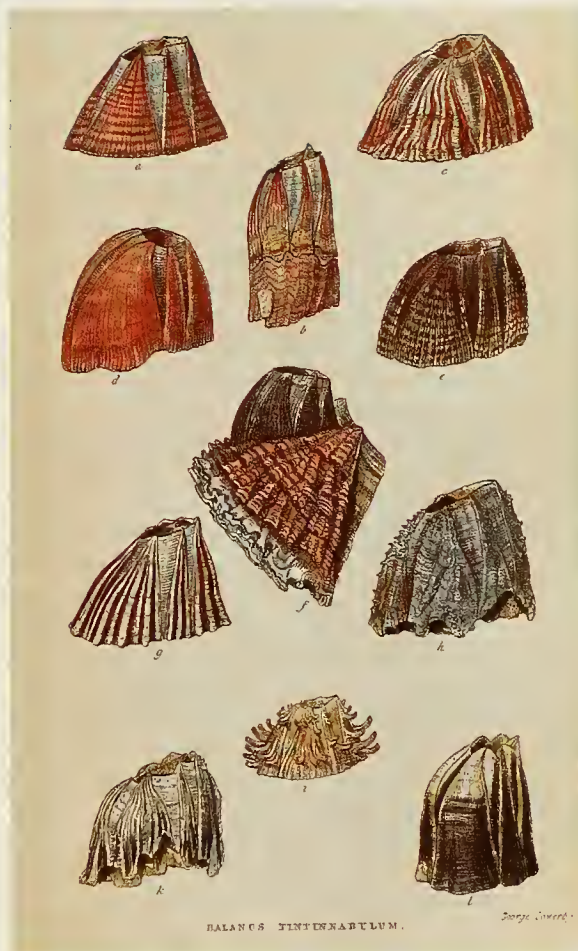
Erasmus Darwin—Charles's grandfather and, by some accounts, the first European naturalist to publish a theory of evolution—had believed that all living things were descended from microscopic sea creatures. (Erasmus had even designed a Darwin family crest with the motto *ex omnia conchis*, "all from shells.") His grandson Charles was awarded the Royal Medal

millions of years, from common ancestors. Grandfather Erasmus—who died before Charles was born—would have been pleased.

In the 1830s and 1840s marine invertebrates were enjoying a scientific vogue, and papers about them dominated the zoology section at meetings of the British Association for the Advancement of Science. Among the leading lights of invertebrate research were Thomas Huxley, the naturalist who had devoted himself to crayfish, squid, and jellyfish, and the zoologist and botanist Edward Forbes, who had worked on starfish and medusae. Puzzling over the origin of life, they noted the similarities of form between those marine invertebrates and the early stages of vertebrate embryos. In studies with a microscope, Forbes had shown that hydroid jellyfish known as naked-eyed medusae reproduce not only by spewing eggs, but also by asexual budding, which he found marvelous to behold:

What strange and wondrous changes! Fancy an elephant with a number of little elephants sprouting from his shoulders and thighs, bunches of tusked monsters hanging epaulette-fashion from his flanks in every stage of advancement! . . . It is true that [naked-eyed medusae] are minute, but wonders are not the less wonderful for being packed into small compass.

Barnacles were at one time grouped with mollusks, but by the 1830s zoologists had shown that the adults, which spend their lives fastened to one spot, develop from free-swimming young, making them more similar to crustaceans. Zoology textbooks of the time also recited a second misconception: that all barnacles are hermaphrodites. Darwin was finding otherwise. Still carefully dissecting them piece by piece, he was discovering that al-



An illustration of barnacle shells from Darwin's 1854 work *A Monograph of the Sub-Class Cirripedia*, with figures of all the Species

of the Royal Society in 1854 for his work on barnacles—in effect, carrying on a family tradition. Charles not only described thousands of living exemplars, but also compared them with fossil specimens. The result was an evolutionary classification—published well before *Origin of Species*—that showed how hundreds of variously adapted species branched out, over

though barnacles do indeed lead bizarre sexual lives, hermaphroditism wasn't always part of the mix. The males of one species (*Cryptoplialus minutus*), Stott tells us, had "quite the largest genitalia [Darwin] had ever seen in the barnacle world." In one of Darwin's descriptions of a *Cryptoplialus* penis, he characterizes it as

wonderfully developed . . . when fully extended, it must equal between eight and nine times the entire length of the animal! . . . [The barnacle] has an orifice at its upper end, and within it there lies coiled up, like a great worm, the probosciform penis . . . there is no mouth, no stomach, no thorax, no abdomen, and no appendages or limbs of any kind.

This burrowing barnacle group from Chile (which Darwin had at first affectionately named Mr. Arthrobalanus but later christened *Cryptoplialus*) seemed at first to be comprised entirely of males, whereas the genus *Ibla*,

one of the stalked rather than coned barnacles, seemed to be made up solely of females. Darwin soon discovered, however, that not only were some *Ibla* specimens hermaphroditic, but that in a related species with distinct sexes, what he had taken to be parasites on the females were actually minute males—little more than tubes containing sperm—clinging to the female bodies. Although the male larvae were free-swimming, he wrote:

at the instant they cease being locomotive[,] larvae become parasitic within the sack of the female, & thus fixed & half embedded in the flesh of their wives they pass their whole lives & can never move again.

Those findings led Darwin to believe he could demonstrate a series of evolutionary sequences from hermaphrodite to separate-sex species. The wide range of sexuality he had seen among sea creatures was so improbable and fantastic that he wondered whether anyone would believe him. "You will think me a Baron Münchhausen amongst Naturalists," he once warned a botanist friend, alluding to the eighteenth-century figure known for his impossible adventures. Other scientists investigating this miniature marine universe were similarly astonished; the spectacular spectrum of sexuality they discovered was shocking to Victorians. For the scientists' wives and lady friends, Stott imagines, "hushed parlour conversations about undersea reproduction, the slime and tentacles of marine courtship, were doubtless piquant, grotesque, and erotic."

Darwin had been aware since 1837, when he began the notebooks for his *Origin*, that the creationist doctrine of fixed species would crumble if only he could find extreme mutability within one species. "Once grant that species . . . [of] one genus may pass into each other," he wrote, "& whole fabric [of fixity of species] totters & falls." As it happened, the first genus



John Swain, *Valuable Addition to the Aquarium*, *Punch*, London 1860

he had chosen to study, *Cryptoplialus* (the group that included his burrowing barnacle), would turn out to be the very epitome of mutability, revealing the astounding variability of organisms in nature.

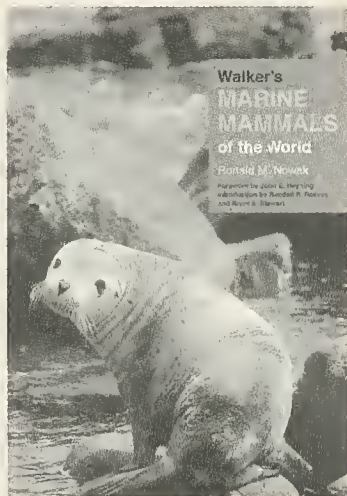
Darwin's friend, the botanist Joseph Hooker, had warned him that "no one has the right to examine the question of species who has not minutely described many." The barnacles won Darwin that right. Through his intense labor with them, he developed an extensive network of correspondents in the scientific community who would later greet his *Origin* with respectful attention. Classifying the barnacles gave Darwin new skills as a dissector, a microscopist, an observer, a classifier, and a theoretician. Moreover, he had satisfied himself that nature produced no sharp lines of demarcation between varieties and species.

"My life goes on like Clockwork," he wrote his old captain, Robert FitzRoy, during the barnacle years, "and I am fixed on the spot where I shall end it." Stott sums up his forty years at Down House, his country estate in Kent, with an apt metaphor:

The larval Darwin has metamorphosed. He has found his rock. Anchored to it, he will stay here like the adult barnacle, for the rest of his days, reproducing himself, fishing with his feet as the tide comes and goes. And his life . . . as regular as the tides."

Richard Milner is an associate in anthropology at the American Museum of Natural History and a contributing editor of this magazine.

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Stiff: The Curious Lives of Human Cadavers

by Mary Roach

W.W. Norton & Company, 2003;

\$23.95

Warning: Do not read *Stiff* lying down. First of all, it's a trifle unsettling to eyeball its dust jacket while supine; the toe-tagged soles on the cover make you feel as if *you* are the body lying in a morgue. Second, if you share your bed with a dozing partner, you may endanger your relationship by laughing yourself silly. In her own edgy way, Mary Roach is an extremely funny science writer.

Roach doesn't flinch when confronted with the no-longer-living, because she finds the macabre so frequently absurd. When she visits a face-lift workshop at a university medical school, for instance, she discovers that a disembodied human head is included in each participant's price of admission. Walking between the tables, she confronts rows of these dissection specimens from donated cadavers, each neatly arrayed in a roasting pan. It's a bit less unsettling, she thinks, to imagine the lab as a rubber-mask factory, and the surgeons as sculptors—which, in a way, they are.

The absurdity of "cadaverology," you realize, lies in the mixture of the mundane and the bizarre one encounters in the world of corpses. Working with dead bodies, we all dimly acknowledge, has many practical uses—yet, like sausage-making, it's best not to know too much about how it's done. Roach gets a guided tour of the "body farm" at the University of Tennessee, where cadavers are set out to rot, and forensic scientists study them in varying states of putrefaction to learn how to determine the time of death. Near the end of the visit she learns that, after three weeks, a body's internal organs resemble chicken soup. "So," says her guide in all seriousness, "lunch?"

At a military medical research lab, other grisly scenes unfold: cadavers are dangled, marionette-like, over armed land mines to test the effectiveness of protective shoes. If the corpses were blocks of gelatin rather than formerly living muscle and blood, no one would give it a second thought. Roach, in fact, also witnesses ersatz thighs (made of gelatin) being shot full of holes to determine the stopping power of bullets, and learns that a "tweaked version of Knox dessert gelatin" is a good substitute for human flesh, though not vice versa.

A dense Latin title, something like

alive inside other animals by hooking them up to the circulatory system. (The idea, as I understand it, is that people with terminal illnesses might have their heads swapped with those of brain-dead patients—effectively providing a whole-body transplant to needy multimillionaires.) She travels to Sweden to visit a company that markets a high-tech body composter as an alternative to crematoriums. (I imagined dinner at a friend's organic farm: "My late husband's in the tomatoes and the spinach. I hope you find him tasty.")

And in one of the most hilarious



Bartolome l'Anglais, *Dissection of a Cadaver*, fifteenth century

De cadaveribus male olentibus, ("on foul-smelling dead bodies"), for instance, might have suited Roach's book better. She crams it with stories from so many sources that it resembles a medieval traveler's tale, indiscriminately conflating fact and rumor. To her credit, though, Roach has tracked many a weird tale to its source. She interviews the neurosurgeon Robert White, for instance, who experimented with keeping the isolated brains of dogs and monkeys

scenes in the book, the intrepid investigator flies to the Chinese island of Hainan to verify a 1991 Reuters article. Two brothers, according to the wire service, had been caught stealing the buttocks and thighs of cadavers awaiting cremation and turning them into "Sichuan-style dumplings," a popular mainstay of the local White Temple Restaurant. Roach later discovers that the whole story is a hoax—neither the brothers nor the restaurant exists—but not before she

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confronts the six-foot-tall director of a local crematorium, where one of the brothers allegedly worked, and is treated to a ten-minute harangue.

That some of Roach's stories are the stuff of urban legend comes as no surprise. That many of them are true, however, is what makes the guilty pleasure of reading her "book of the dead" so worthwhile.

The Great Wave: Gilded Age Misfits, Japanese Eccentrics, and the Opening of Old Japan
by Christopher Benfey
Random House, 2003; \$25.95

Many of my college friends spent the early 1960s dreaming of smoke-filled San Francisco cafes where poets such as Lawrence Ferlinghetti, Allen Ginsberg, and Gary

the liberating philosophy of the East.

But in fact, that discovery had been made a century earlier. In the years following the "opening" of Japan by Commodore Matthew Perry in the 1850s, a group of intellectuals centered in New England had turned to Japan as a source of spiritual renewal. They viewed the austere aestheticism of Japanese culture as an antidote to the decorative excess of the Victorian era, and as a palliative for the spiritual agony of the Civil War. Ironically, at that same moment Japan was opening its doors to the West and, driven by an impulse toward modernization, moving away from the ceremonial formalism of feudal society. The Old Japan of the samurai and the Zen master was disappearing just as the West was coming to know it.

Christopher Benfey, a professor of English at Mount Holyoke College, has written a series of perceptive bio-

Japan, where he became one of the principal agents of modernization; he served as a go-between when Perry visited Yokohama, translated a seminal work on navigation from English into Japanese, and introduced such Western innovations as photography and telegraphy to the islands.

Melville, who crossed the Pacific in the other direction at almost the same time, never knew Manjiro, though they had acquaintances in Honolulu in common. Unlike Manjiro, who interpreted the material ingenuity of the West as a way to a better life, Melville was searching for moral renewal, and he associated that quest with the mysterious culture of Japan. The climactic scenes in *Moby Dick*, set near the Japanese coast, epitomized the yearning of the famous author and his contemporaries for what he described as "unknown Archipelagoes, and impenetrable Japans."



Yoshitoshi Tsukioku, *Commodore Perry arrives in Japan 7/8/1853*, c.1880

Snyder would intone the deep wisdom of the Orient. Snyder, perhaps because he had disappeared from the scene for a while, was the most alluring. After a prolonged Zen pilgrimage to Japan, he had returned with epigrammatic mantras extolling nature and the quest for unity with the cosmos. It was exhilarating to feel that our Western culture, its soul having been wasted by industrialization, was at last discovering

graphical essays that illustrate what happens when two such literate and disparate cultures begin to intermix. His opening essay cleverly contrasts the careers of the Japanese intellectual John Manjiro and the American author Herman Melville. Manjiro was adopted in the 1840s by a New England sea captain, who rescued him from a Pacific island after a shipwreck. He eventually returned to

The cultural dichotomy is reflected in the lives of the remarkable figures who appear in Benfey's book: Henry Adams, chronicler of fin-de-siècle angst, was a pilgrim to the East; Percival Lowell, known today as the astronomer who thought Mars was inhabited, made his reputation by writing several books on life in out-of-the-way corners of Japan; Edward Sylvester Morse, who made the first archaeological digs in Japan, amassed immense collections that formed the core of museums on both sides of the Pacific; Isabella Gardner, Boston patron of the arts, had a love affair with the East that included Japanese intellectual Kakuzo Okakura, whose writings introduced Western socialites to the romance of the tea ceremony.

The dawn of the twentieth century, the point at which Benfey concludes his book, was of course only the beginning of cultural interchange between East and West. In the clean lines of Frank Lloyd Wright's houses, in the Japanese design of energy-efficient automobiles, and in the idealized orientalism of New Age culture, one can see elements of the same process

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of cross-fertilization that began in the late 1800s. Benfey calls it "the great wave," an expression of the power and precariousness portrayed in Katsushika Hokusai's famous woodblock print. The ripples of that great wave are still coming ashore today.

*The Seashell
on the Mountaintop:
A Story of Science, Sainthood,
and the Humble Genius
Who Discovered a New History
of the Earth*
by Alan Cutler
Dutton, 2003; \$23.95

Nicolaus Steno died in 1686, at the age of forty-eight, with scarcely a penny to his name. Ten years earlier, before abruptly renouncing the pleasures of the world to become a priest and a religious ascetic, he had been the darling of Florence's intellectual elite and was known far and wide as a gifted anatomist and a brilliantly perceptive naturalist. His worldly goods at the time of his death amounted to little more than a decrepit clerical wardrobe and a shelf of well-worn books, yet he left behind a legacy of the highest order: the key to reading the deep history of the Earth, written in sedimentary rocks.

Renaissance thinkers of Steno's generation had come to the reasoned conclusion that the story of the Earth had been correctly set down in Scripture, the only generally accepted source of information about the distant past. No less a thinker than Newton had devoted reams of paper to the biblical chronology, and, like most everyone, Newton took it for granted that the events recorded in the Bible, including Noah's flood, were literally true. By counting "begets" and "begats" after the joining of Adam with Eve, and

then adding a week for the Creation, one could work back to the date of *fiat lux*. The details varied from Renaissance writer to Renaissance writer, but the conventional wisdom was that the Earth had been around for about five or six thousand years.

Steno, however, was never a conventional thinker. He noted that the remains of shells could be found on mountaintops far from the sea; even forty days and forty nights of rain could not have raised sea levels that high. He marveled at how closely fossil shells resembled the shells of living species, rejecting the suggestion that fossils were naturally occurring formations that grew spontaneously in the rocks themselves. During his travels across Europe, Steno developed the idea that an intelligible order lay beneath the apparent jumble of the landscape's diverse geological features. Renaissance painters had tended to idealize landscapes, regarding them as immutable backdrops to human history. Steno realized that, on the contrary, rocks themselves had a story to tell.

Shortly before he entered ecclesiastical life, Steno published a slender



Fossilized mollusks

volume "concerning a solid body enclosed by process of nature within a solid," setting forth a methodology for reading geological history in rock layers. Fossils, he claimed, were the remains of once-living organisms, turned to stone inside layers of silt or



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sand deposited by water. Subsequent events may have tilted or folded these layers, or eroded them over time, but they originally had been laid down horizontally, with the oldest layers at the bottom.

Such ideas, of course, are the fundamental principles of the sciences now called sedimentology and stratigraphy. By accepting Steno's principles, one had also to accept, by implication, a world millions or even billions of years old, for the mills of deposition—which can be observed in every river bottom and on every seashore—grind exceedingly slow. By mapping sediment layers and by noting similar strata, bearing similar fossils, one could put together a time line of geological history, chronicling the changing populations of plants and animals and the corresponding alterations in topography. Steno's insight, in short, implied a profound revolution in science, so it is notable that, though many books deal with the astronomical revolution of Copernicus, Kepler, and Galileo, Alan Cutler's short book is the first popular English-language treatment of Steno's life.

Steno died piously, fighting, through his example, what he considered a venal Catholic church bureaucracy. The great polymath Gottfried Wilhelm Leibniz, one of Steno's ardent admirers, lamented that "from being a great physicist he became a mediocre theologian." But Steno's scientific life, though tragically short, inspired many other pioneering students of the Earth's history: not only Leibniz but James Hutton, Charles Lyell, and, eventually, Darwin. Cutler's smart and readable biography puts Steno right at the forefront of the geological revolution. Clearly, he had joined the pantheon of science long before the church beatified him in 1988, officially setting him on the road to sainthood.

Laurence A. Marshall, author of The Supernova Story, is the W.K.T. Sahn professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces software for education in astronomy.

nature.net

SARS

By Robert Anderson

On February 11 authorities in China's Guangdong Province issued their first report of what they called an "atypical pneumonia." A global network of scientists began urgently exchanging news and findings via the Internet. Just two months later, they had positively identified



Memento Mori, Roman, fifth century

the virus that causes severe acute respiratory syndrome (SARS). And, more remarkably, in those same few weeks two separate teams had sequenced its genome—all of its approximately 30,000 nucleotides. What made it all possible was the Internet. To learn how investigators responded so rapidly, visit the World Health Organization's Web page (www.who.int/en) and click on the "SARS" box. Under "For More Information," click on "WHO Collaborative Networks," and follow the Web trail there.

The SARS bug is a member of a group known as the coronaviruses, one or more of which are responsible for some common colds. At a site provided by the Centers for Disease Control and Prevention (www.cdc.gov/ncidod/sars/) you can

consult the page choices on the left for both general and practical information about SARS—everything from "What Everyone Should Know" to travel advisories and fact sheets on quarantines.

To find out what the enemy looks like, go to www.rkm.com.au/VIRUS/CORONAVIRUS/index.html. In the artist's image of a single virion, you can see the "crown" of clublike projections for which the group of viruses was named. Click on any one of the drawings on the main page and scroll down: the illustrations are accompanied by information about viral replication and disease transmission, and there are also links to other sites. At the link "Coronaviruses and SARS," for example, Alan Cann, a virologist at the University of Leicester in England, has synthesized what is known about the disease to date. Cann's site is a good place to look for up-to-date, though fairly technical, information on infectious diseases in general. (You can access the site directly at www-micro.msb.le.ac.uk/3035/coronaviruses.html.)

Other viruses, many quite beautiful to look at, are depicted and described at the "Big Picture Book of Viruses" (virology.net/Big_Virology/BVHomePage.html), and at the University of Wisconsin-Madison's Institute for Molecular Virology (virology.wisc.edu/IMV/).

Finally, in a short article posted by the University of California at Los Angeles (www.college.ucla.edu/webproject/micro12/m12webnotes/viralevolution.htm), you can learn about viral evolution and its role in the epidemics of the past century. Some, like the influenza virus, are occasionally transmitted to people via contact with birds or other animals harboring new strains. That, incidentally, may well be the transmission path of the SARS virus.

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

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Ironing Out the Solar System

A long-extinct radioactive species sheds light on Earth's origins.

By Charles Liu

Our Sun formed a little more than four and a half billion years ago. Like every other star in the universe, it was born swaddled in a cloud of gas made almost entirely of hydrogen and helium. But the scattered debris of exploded stars—a fine cosmic dust made of heavier elements including carbon, oxygen, aluminum, calcium, and iron—was also sprinkled throughout the cloud. Those dust particles, far smaller than the ones that gather on a windowsill, served as collection points in the solar nebula: other matter, including ice and frozen carbon dioxide, aggregated around them. And so the aggregates grew larger, becoming pebble-size, then rock-size, then boulder-size masses.

Within a few million years, trillions upon trillions of icy, stony, or metallic bodies swarmed around our infant Sun. During the next quarter-billion years, many of those objects continued to coalesce, forming the major planets, moons, asteroids, and Kuiper Belt objects [see my column "Tightening Our Kuiper Belt," February 2003]. Smaller objects are still out there orbiting the Sun, scarcely changed since their formation so long ago.

Occasionally, one of those leftover chunks of protoplanetary matter strikes Earth's surface. When it does, it becomes a meteorite. Souvenir collectors prize meteorites for their novelty, but we astronomers value them for their history. Such bodies record the story of the early solar system, the



Moving the Ahnighito ("Tent") meteorite into the American Museum of Natural History, August 14, 1907. This meteorite and others provide important data on the early history of the solar system.

same way plant and animal fossils record the story of life on Earth. Sometimes it's possible to use them to examine the origin of the solar system itself. A new study conducted by Shogo Tachibana and Gary Huss at Arizona State University in Tempe does just that; by looking for radioactive iron—or, rather, its ghosts—in two of the oldest known meteorites, they've taken an important step toward identifying the event that triggered the birth of the Sun.

Iron on Earth isn't radioactive—at least not anymore. More than 90 percent of the iron atoms in everyday life, whether in buildings, brussels sprouts, or blood, contain twenty-six protons and thirty neutrons. Such atoms are known as iron-56. The remaining atoms contain either twenty-eight, thirty-one, or thirty-two neutrons. The varieties, or isotopes, of an element are diagnosed by the number

of neutrons in their nuclei, but are named by adding the numbers of neutrons and protons together: thus, iron-56, iron-58, and so on.

Those four iron isotopes are all radioactively stable. Other isotopes of iron can exist, but they aren't stable. With time, atoms that make up the unstable isotopes spontaneously eject subatomic particles from their nuclei. That process (known as nuclear decay) changes the number of protons or neutrons in the nuclei, giving rise to other isotopes, or even to other elements. Eventually any given supply of an unstable isotope disappears.

The rate of such radioactive decay can serve as a clock for pinpointing important dates in the history of the Earth and the solar system. Measuring the ratio of a particular radioactive isotope to its stable decay products in some object makes it possible, at least in principle, to deduce how much time has passed since the object was last enriched with that particular radioactive species.

Because each radioactive isotope decays at its own constant rate, the decay rate can be expressed as a half-life, which is defined as the amount of time it takes for half of a sample of the isotope to decay. Measurements of short-lived isotopes such as carbon-14, whose half-life is about 5,700 years, can date archaeological finds from early human cultures; measurements of longer-lived isotopes such as uranium-238, with a half-life of

nearly 4.5 billion years, can date the formation of rocks, planets, and stars.

Iron-60, a radioactive isotope with a half-life of just under 1.5 million years, can be readily produced only by high-mass stars just before they self-destruct in supernova explosions. That unique origin is a useful property when it comes to reconstructing cosmic events. If there was any iron-60 in the original solar nebula, it was probably all there right off the bat, inherited from the molecular cloud that gave birth to the Sun. That gives a solid starting point from which to calibrate any aging processes that the clocklike decay of iron-60 can measure.

Tachibana and Huss examined the isotopic composition of about a dozen small samples from two ancient meteorites. The two objects, called Bishunpur and Krymka after the places where they were discovered (in India and Ukraine, respectively), are chondrites—a class of objects that

formed within a few million years of the Sun's birth. Any iron-60 that was incorporated into the two chondrites is long gone; it all decayed into radioactive cobalt-60, which in turn decayed into a stable atom, nickel-60.

Examining microscopic mineral grains embedded in the meteorites, Tachibana and Huss measured a significant excess of nickel-60, indicating that iron-60 was once present. Using other elements and isotopes as reference clocks, they then backtracked through the decay history of iron-60 and found that the solar nebula was originally made up of about 300 atoms of iron-60 for every billion (10^9) atoms of stable iron-56. That might seem like a minuscule figure, but it's ten times the typical ratio present in the interstellar gas of our Milky Way galaxy today. And that additional iron-60 in the early solar system speaks volumes about our cosmic origins.

Astronomers know that the Sun was created in an interstellar gas cloud. We also know that something happened to induce part of that cloud to reach a critically dense state, which caused it to collapse inward and eventually to form the solar nebula. What was that triggering event?

A model proposed long ago suggests that the blast wave of a supernova was the culprit. The concentration of iron-60 in the two ancient meteorites lends new support to this idea. The expanding shell of stellar material, infused with iron-60 from the supernova explosion, may have seeded the presolar nebula with this radioactive-iron clock. At the same time, it would have provided just the kick needed to begin the formation of the Sun, the solar system, and, ultimately, the Earth.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.

THE SKY IN JUNE

By Joe Rao



Mercury reaches its greatest western elongation on the 3rd—24 degrees from the Sun on the dome of the sky—but skywatchers will still have to struggle to glimpse the reticent planet. In the first three weeks of the month, Mercury scarcely surmounts the east-northeastern horizon at mid-twilight. With good binoculars you might detect it as sunrise draws near; nearby Venus can

serve as a guide. Early in the month Mercury shines just 4 degrees to the right of Venus and draws to within half a degree by the 21st, to Venus's lower right. A few days thereafter, Mercury disappears into the dawn glow.

Venus rises an hour before sunrise for yet one more month. You'll find it very low, just above the east-northeastern horizon, about twenty to thirty minutes later.

Mars rises at about 1 A.M. local daylight time at the start of June and before midnight by month's end. Look for it above the east-southeastern horizon. Mars outshines every other starlike object except its consort, Venus. As the distance between Mars and Earth decreases from 71 million miles to 53 million miles during June, the planet's apparent brightness doubles, from magnitude -0.7 to -1.4 .

Even though **Jupiter** is on the far side of the Sun and about as small as it ever appears, it is still the brightest evening "star," and in a telescope it still shows the largest disk of any planet. It sets progressively earlier all month long: at about 12:30 A.M. at the start of June, and about 10:45 P.M. by the end. On the 4th, Jupiter shines to the right of the waxing crescent Moon.


Saturn may be visible during the first week of June. On the 1st it sets less than ninety minutes after the Sun. As darkness falls, the planet hovers below and to the left of the slender sliver of a crescent Moon, close to the west-northwestern horizon. A week or so later, Saturn disappears into the evening twilight glow; it reaches conjunction with the Sun on the 24th.

The **Moon** waxes to first quarter on the 7th at 4:28 P.M., and waxes full on the 14th at 7:16 A.M. It wanes to last quarter on the 21st at 10:45 A.M., and cycles back to new on the 29th at 2:39 P.M.

The **solstice** takes place on the 21st at 3:10 P.M. Summer begins in the Northern Hemisphere, and winter in the Southern.

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

AT THE MUSEUM

AMERICAN MUSEUM OF NATURAL HISTORY 

The Lure of Chocolate

Chocolate has enchanted humanity for centuries with its tempting taste. The Maya had a glyph for it and at one time there were nearly 2,000 chocolate cafés in London alone. Now here is a chance to look at the science behind the seduction. Starting June 14, the American Museum of Natural History will feature *Chocolate*, an exhibition devoted to the ecology, anthropology, history, and economics of this treat. The exhibition will be on view in Gallery 3 through September 7, 2003.

Chocolate begins by luring visitors into a tropical rain forest where they can examine a replica of a *Theobroma cacao* tree, which produces the seeds that are used to make the sublime substance. This section explores the complex ecosystem that supports the tree, the insects that pollinate it, and the birds that nest in its limbs.

The exhibition goes on to consider the role of chocolate in the lives of ancient indigenous civilizations. On view will be carved vessels, cacao seeds in dishes, and chemical residues in pots that helped scientists trace the roots of chocolate to the ancient Maya, the first to turn the bitter



Sweet chocolate candy is a rather recent invention. It made its debut in 1847.

CHOCOLATE
June 14–September 7
Gallery 3

seeds of the cacao into a spicy beverage used in ceremonies and trade. An interactive Aztec marketplace will demonstrate the power of chocolate—its use as a luxury libation for the elite, an offering to the gods, payment to rulers, and money in the market. Visitors will also find out what treasures Cortés discovered in Montezuma's storerooms.

The sections that follow document chocolate's extensive reach, beginning with the Spanish conquest of the Americas and the ensuing European quest for cacao. Exhibits will illustrate that while wealthy consumers frequented the most elite chocolate houses in Europe during the 17th, 18th, and 19th centuries, thousands of slaves toiled on sugar and cacao plantations to keep up with demand. Visitors will also learn about the important role chocolate manufacturing played in the industrial revolution

and the fascinating relationships among growing, selling, and consuming cacao in the modern global market.

Chocolate concludes with the cacao bean's role in the world today. Visitors will learn how it is harvested and prepared; what farmers are doing to earn an income while preserving the rain forest; the role of chocolate in different world cultures; and the myths and realities of chocolate's effect on health.

Chocolate and its national tour were developed by The Field Museum, Chicago. This project was supported, in part, by the National Science Foundation.

Art(ifacts) and Science of Chocolate

Ten celebrated chocolatiers and pastry chefs have been invited to sculpt signature pieces in chocolate inspired by the Museum's collections. Several of the pieces will be on exhibit at the Museum in early June and the remaining pieces will be unveiled on July 17 when, at 7:00 p.m., some of the participants will gather to discuss the creation of their pieces. Robert Wolke,

professor of chemistry and a syndicated columnist for *The Washington Post*, will discuss the chemical and physical processes that enable chocolate to be molded into art. Don't miss this fun and fascinating event! For more information, call 212-769-5200.

Chocolate for this project has been donated by Felchlin, Valrhona, the Guittard Chocolate Company, and Dairyland.

CONFERENCE

The Science of Chocolate:

Recent Discoveries

Tuesday, 6/17, 1:00–5:00 p.m.
Botanists, archaeologists, and chemists come together to discuss the cutting edge of research into chocolate. Scientists will consider the ritual uses of chocolate among the Maya, the recent discovery of the oldest-known chocolate, the medicinal qualities of the substance, and more.

LECTURE

Can Chocolate Save the Rain Forest?

Tuesday, 6/17, 7:00–9:00 p.m.
Chris Bright and Radhika Sarin of the World Watch Institute discuss the future of "forest-friendly" chocolate agriculture in Brazil and the Ivory Coast with Meg Domroese of the Museum's Center for Biodiversity and Conservation.

FAMILY PROGRAM

The ABCs of Chocolate

Saturday, 6/28, 2:00–3:30 p.m.
(Ages 7 and up, each child with one adult)
Discover the delectable world of fine chocolate in this hands-on experience. Learn how cacao is grown and processed, and roll your own chocolate truffle. *Not recommended for children with food allergies.*

ADULT WORKSHOP

Chocolate Appreciation

Sunday, 6/29, 11:00 a.m.–12:30 p.m., or 2:00–3:30 p.m.
In this intensive class designed for beginners as well as those with more experienced palates, renowned pastry chef Steve Klc will teach you how to recognize the characteristics of fine chocolate and how to shop for it.



© 2002 CORBIS

Chocolate Tastings

CHOCOLATE SHOP,
THIRD FLOOR

Most weekends during the run of the exhibition *Chocolate*, you can sample fine chocolate in the retail shop outside the exhibition. Chocolatiers will be on hand to discuss the characteristics of their distinctive products and the luxurious treats will be available for purchase. Visit www.amnh.org or call 212-769-5100 for the complete schedule of tastings, book signings, and other events.



CHRIS BRIGHT

A cacao tree on an organic farm in Bahia, Brazil.

MUSEUM EVENTS

EXHIBITIONS

Vietnam:

Journeys of Body, Mind & Spirit

Through January 4, 2004

Gallery 77, first floor

This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.



C. CHESKAMINH

A life-sized votive horse made of paper and bamboo.

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the **Freeman Foundation**. Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.

Discovering Vietnam's Biodiversity

Through January 4, 2004

Akeley Gallery, second floor

This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

Einstein

Through July 27, 2003

Gallery 4, fourth floor

This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial and groundbreaking that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.

ADULT WORKSHOPS

Genomics Laboratory Workshops

Tuesday, 6/10, 7:00–9:00 p.m.,

or Tuesday, 6/17, 7:00–9:00 p.m.

An introduction to genomics, followed by isolating and sequencing your own DNA.



CRYPTOGAMIC BOTANY COMPANY, 2003

Ulva lactuca, pressed seaweed specimen

The Artistry of Algae

Saturday, 6/28, 10:00 a.m.–5:00 p.m.,
and Sunday, 6/29, 1:00–5:00 p.m.

This two-day workshop combines science and art. With Alex Frost, Director of the Cryptogamic Botany Company.

SUNSET CRUISES

Sunset Cruise up the Hudson River

Tuesday, 6/10, 6:00–9:00 p.m.

Survey the geological features of the river and the Palisades, and learn about the environmental concerns facing this important waterway today.

The Nooks and Crannies of Eastern New York Harbor

Tuesday, 6/17, 6:00–9:00 p.m.

Follow the East River into Newtown Creek and then head to the Brooklyn Navy Yard, the South Street Seaport, and Buttermilk Channel.

FAMILY PROGRAM

The Underwater World of Sampson the Frogfish

Saturday, 6/14, 2:00 p.m.

Close-up 3-D photography brings to life the beautiful world of coral reef habitats.

CHILDREN'S WORKSHOPS

Drawing and Painting African Mammals

Sunday, 6/8, 10:30 a.m.–1:30 p.m.
(Ages 9 and 10)

Yikes! Your Body Up Close

Sunday, 6/8, 10:30 a.m.–1:30 p.m.
(Ages 7 and 8)

Experience the sights
and sounds of a bustling

Vietnamese Marketplace

and sample traditional
foods at Café Pho.

Through January 4, 2004

77TH STREET LOBBY, FIRST FLOOR

Fly Me to the Moon

Saturday, 6/14, 12:00–1:30 p.m., or
2:30–4:00 p.m.
(Ages 4–6, each child with one adult)

Dinosaur Expedition

Sunday, 6/15, 10:30 a.m.–1:30 p.m.
(Ages 9 and 10)

Crime Lab Investigation

Sunday, 6/22, 10:30 a.m.–1:30 p.m.
(Ages 8 and 9)

The Sun and Its Energy: A Summer Solstice Celebration

Sunday, 6/22
12:00–1:30 p.m. (Ages 7–9)
2:30–4:00 p.m. (Ages 10–12)

Astronomy across Cultures

Tuesday–Thursday, 6/24–26,
2:00–3:30 p.m.
(Ages 10–12)

HAYDEN PLANETARIUM PROGRAMS

Virtual Universe:

The Solar Neighborhood

Tuesday, 6/3, 6:30–7:30 p.m.

Celestial Highlights:

Carnivores in the Sky

Tuesday, 6/24, 6:30–7:30 p.m.

SPACE SHOWS

The Search for Life:

Are We Alone?

Narrated by Harrison Ford

Passport to the Universe

Narrated by Tom Hanks

Look Up!

Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6
and under)

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www.amnh.org. A service charge
may apply.

All programs are subject to change.

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For further information call 212-769-5606 or visit www.amnh.org.



Starry Nights: Live Jazz

Friday, 6/6, 5:30 and 7:00 p.m.

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Damsels Cause Distress

By Gwen Mergian

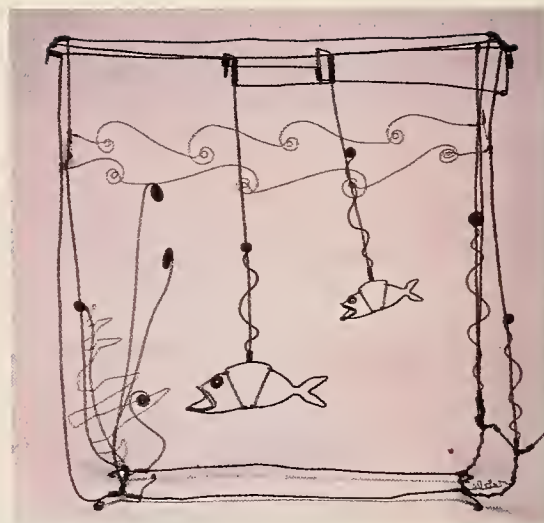
After waffling for years, my husband took the plunge and purchased a large saltwater aquarium for his office. That he did so while I was out of town at a conference may have shown a certain lack of confidence that I would react favorably, but he needn't have worried: I was hooked right from the start.

The tropical fish tank came fully equipped: pumps, filters, hoses, light fixtures, coral arrangements, and a small cadre of lively black-and-white-striped damselfish, also called demoiselles. These gals, however, were no ladies-in-waiting. Like many coral-reef species, damselfish are aggressive and highly competitive. As we soon discovered, even small fish can display some mighty big attitude.

Take our alpha female, a fish that quickly earned the name Tuffy. This one-inch wonder ruled every inch of the tank, demanding—and getting—the most food, the best hiding place, the last word in everything. What's more, the dominant demoiselle seemed to flaunt her power, chasing her underlings and pinning them into corners of the aquarium. Sometimes Tuffy kept them trapped for hours before allowing them to escape. As I watched these daily shenanigans, I was compelled to note the similarities between the world of fish and the world of business. I had run into quite a few Tuffys in my time.

Soon after the aquarium arrived, my husband decided to add two small snails to the system, hoping to control the growth of algae. When he popped them into the water, the pair went to work, slowly scouring the gravel at the bottom of the tank with their little antennae. "Ah, another fish-tank phenomenon to marvel at," I thought.

But Tuffy thought otherwise. Within minutes of the snails' arrival the hostilities commenced. Tuffy began the assault by dive-bombing the newcomers, swimming first to the top of the tank to gather momentum, then crashing straight into them at full force. The snails scattered under the fury of the at-



Alexander Calder, *Fish Bowl*, 1929

tack. After a while, Tuffy adopted a second approach: she would pick up a snail with her mouth, swim to a patch of jagged rocks, hover over them, and drop the snail down on them. The merciless assault went on for hours and resumed the following day.

I hardly slept that night.

The next morning, I tiptoed up to the tank, only to discover a strange and curious sight. The two snails were anchored to the glass at the front of the aquarium and had formed a barrier that effectively blocked the only entrance to Tuffy's favorite retreat—a barnacle-like structure, centrally located, that she used as her personal palace. Tuffy dive-bombed the pair, trying to break their hold, but it was useless: the snails, one clinging to the top of the other, had wedged themselves perfectly between the barnacle and the glass. She tried to squeeze past them—first going forward, then sideways, finally backward. But the snails' adjoined, triangular shells held fast; there was simply no way for Tuffy to get past.

And the snails were in no great hurry to leave. They steadfastly maintained their position for three days. Only on the fourth day of the standoff did they finally move on, returning to the usual business of being snails. I breathed a sigh of relief: Is there anything that a few good friends, working together, cannot accomplish?

Life in the tank is calmer these days. Tuffy is still taunting her companions into daily acts of submission, but she mostly ignores the two snails. And the snails are quite content to roam around in their deliberate, gentle way. My husband is happy too, because he's got the algae growth under control at last. And Tuffy is back in her favorite place, peering out with satisfaction over her dominion.

Gwen Mergian and her saltwater friends live in upstate New York.

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2003

ATLANTIC OCEAN

- ◆ The Making of America Aboard *Clipper Adventurer* — September 7–21, 2003
- ◆ Swiss Alps to Budapest Aboard *Amadeus Classic* September 8–22, 2003

OCTOBER

- ◆ Village Life Along the Dalmatian Coast Aboard *Monet* — October 7–15, 2003
- ◆ AMNH in Patagonia — October 15–28, 2003
- ◆ Burma's Great Irrawaddy River Aboard *Pandaw 2* — October 16–November 1, 2003
- ◆ Polar Bear Watch on Canada's Hudson Bay October 17–22 & October 24–29, 2003
- ◆ Circumnavigating Sicily Aboard *Harmony* & October 25–November 3, 2003

2004

- ◆ The Food & Wine of Northern California Aboard *Yorktown Clipper*
- ◆ Safari Sketching Workshop in South Africa & Namibia

MAY

- ◆ Istanbul to Vienna Aboard *Amadeus Classic*
- ◆ Ireland & Scotland Aboard *Polar Star*
- ◆ Springtime in Japan Aboard *Clipper Odyssey*
- ◆ The Legacy of Buddhism in Tibet & Mongolia
- ◆ Southern Africa's Great Rail Journey
- ◆ Early Man: Lisbon to Bordeaux Aboard *Clipper Adventurer*
- ◆ D-Day Remembered: A Special Invitation from Smithsonian Institution

JUNE

- ◆ North Pole Aboard *Yamal*
- ◆ Montana by Rail
- ◆ Family China
- ◆ Ancient Rituals by Private Jet
- ◆ Archaeology of the Ancient Olympics: The Greek Isles Aboard *Harmony G*
- ◆ Alaska Aboard *Empress of the North*
- ◆ Iceland & Greenland Aboard *Peregrine Mariner*
- ◆ Artists of Russia's Golden Ring Aboard *Borodin*
- ◆ Australian Outback by Private DC-3

AUGUST

- ◆ The Legacy of Lewis & Clark August 20–30, 2003
- ◆ The Great Lakes Aboard *Le Levant* August 22–30, 2003
- ◆ Lemur Conservation: Tattersall's Madagascar August 24–September 8, 2003

SEPTEMBER

- ◆ North Pacific Odyssey: Aleutian Islands, Kamchatka Peninsula & Kuril Islands Aboard *Bremen* — September 2–19, 2003
- ◆ Conservation in Action: South Africa, Namibia & Botswana — September 2–20, 2003
- ◆ Daily Life in Morocco — September 6–20, 2003

JANUARY

- ◆ The Galápagos Islands Aboard *Isabella II*
- ◆ Egypt Aboard *Sunboat II*
- ◆ Exploring Antarctica, the Falkland Islands & South Georgia Aboard *Peregrine Voyager*
- ◆ The Sea of Cortes: Baja Whale Watching Aboard *Spirit of Endeavour*

FEBRUARY

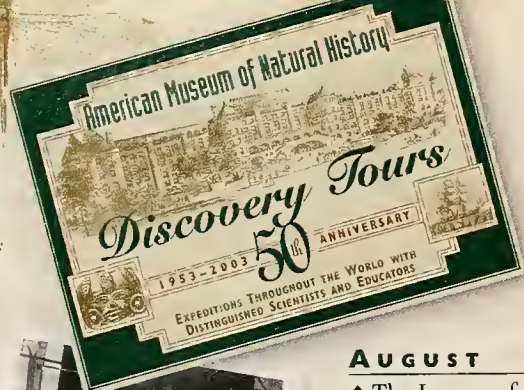
- ◆ New Zealand Aboard *Clipper Odyssey*
- ◆ Marine Ecology of Andros Island, Bahamas
- ◆ Astronomy & Volcanology Seminar in Hawaii
- ◆ Lands of the Maya Aboard *Nantucket Clipper*
- ◆ Thailand Cultural Festival
- ◆ The Kingdom of the Monarchs

MARCH

- ◆ The Amazon Aboard *La Amatista*
- ◆ Mysteries of Southeast Asia
- ◆ Family Costa Rica

APRIL

- ◆ The Great Markets of the World by Private Jet
- ◆ The Golden Age of Natural History: An AMNH & Oxford University Seminar



Assembly of Apatosaurus, unveiled at AMNH, 1905

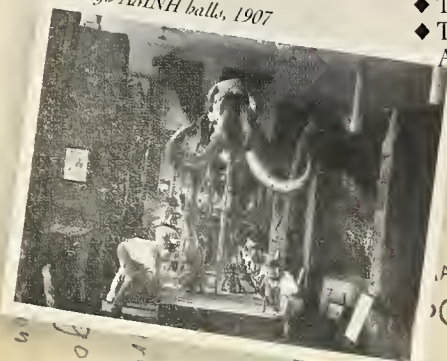


Abnigbito meteorite arriving at AMNH, 1907



Using Akeley's taxidermy technique, 1954

Wheeling a mastodon through AMNH halls, 1907



NATURAL HISTORY



South Pacific

INDIAN OCEAN
Programs Australia & New Zealand

◆ In the Wake of Moors & Mariners: Spain, Morocco & the Canary Islands Aboard *Sea Cloud*
October 27–November 9, 2005

◆ Festivals of India: Featuring the Pushkar Camel Fair & *Palace on Wheels*
October 28–November 13, 2005

◆ Bhutan: The Dragon Kingdom
October 30–November 14, 2005

NOVEMBER

◆ Cuba: A World in Transition
November 6–17, 2005

◆ AMNH & The Center for Cuban Studies Presents The Living Arts of Cuba
November 10–19, 2005

Preview

◆ Kamchatka: The Natural History & Indigenous Peoples of Russia's Far East

JULY

- ◆ Family Galápagos Aboard *Santa Cruz*
- ◆ Family Canadian Rockies
- ◆ Slavic Pompei: Archeology of Ukraine
- ◆ The Wilds of Borneo: A Family Adventure
- ◆ Family Peru

AUGUST

- ◆ The Baltic Sea Aboard *Song of Flower*
- ◆ The Trans-Siberian Railway from Vladivostok to Ulaanbaatar
- ◆ Kilimanjaro: Trek to the Summit
- ◆ Trans-Canada by Rail

SEPTEMBER

- ◆ China & the Yangtze River
- ◆ Elephant Conservation & the Great Serengeti Migration in Kenya
- ◆ Trekking in Bhutan
- ◆ The Chinese Path to Enlightenment: Philosophers, Monks, & Hermits

Delivering school collections, 1908



◆ Exploring the South Pacific Aboard *Clipper Odyssey* — November 13–28, 2005

DECEMBER

◆ Australia's Great Barrier Reef Aboard *Coral Princess II* — December 9–19, 2005

◆ Christmas in Quebec
December 10–15, 2005

◆ Family Thailand
December 19–30, 2005

◆ Tanzania: A Family Safari in the Serengeti
December 19–31, 2005

◆ Rainforests, Reefs & Ruins: A Belize Family Adventure
December 27, 2003–January 4, 2004

- ◆ Scotland Through the Ages
- ◆ The Great Lakes Aboard *Le Levant*
- ◆ Swiss Alps to Budapest Aboard *Amadeus Classic*
- ◆ Treasures from the Hills of Atapuerca
- ◆ Burma's Great Irrawaddy River Aboard *Pandaw 2*

OCTOBER

- ◆ Festivals of India: Featuring the Pushkar Camel Fair & *Palace on Wheels*
- ◆ Over the Andes: Chile & Argentina
- ◆ Across Melanesia Aboard *Spirit of Oceanus*
- ◆ Margaret Mead's Papua New Guinea: Featuring *Melanesian Discoverer*
- ◆ Polar Bear Watch on Canada's Hudson Bay
- ◆ Greece to Sicily Aboard *Sea Cloud*
- ◆ The Ethnic Traditions & Biodiversity of Vietnam

NOVEMBER

- ◆ Casablanca to the Cape: West Africa by Private Plane
- ◆ The Archeology of Egypt & Jordan

DECEMBER

- ◆ Tanzania: A Family Safari in the Serengeti



Osborn Expedition; Egypt, 1907

Fossilized dinosaur tracks; Texas, 1959



Jochelson Expedition; Siberia, 1901



Tangiers, Morocco, 1929



View of AMNH from Central Park



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