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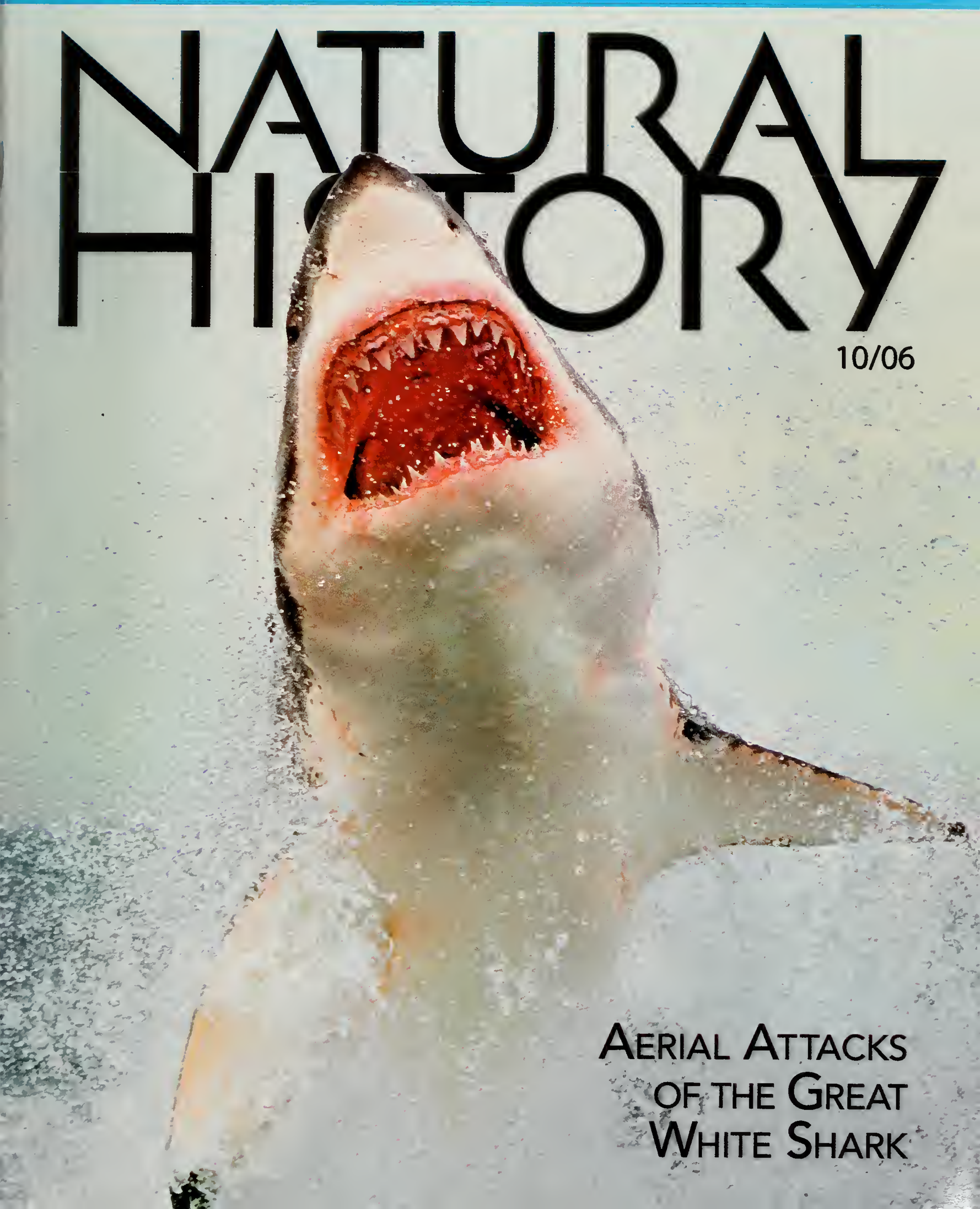
NATURAL HISTORY

10/06

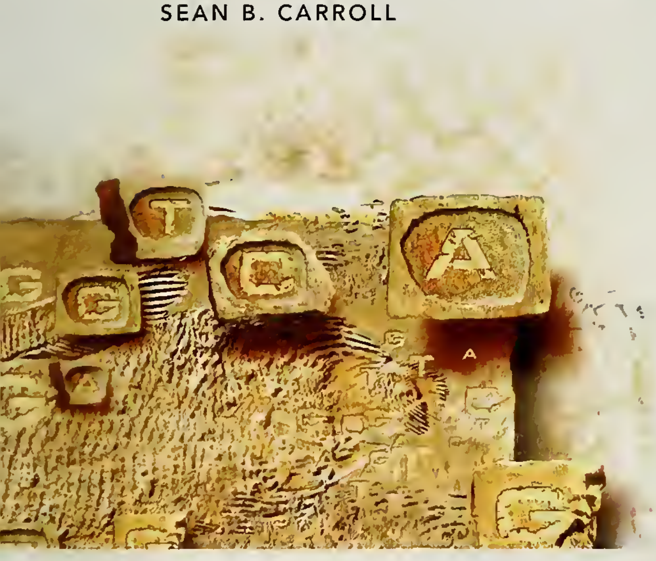


AERIAL ATTACKS OF THE GREAT WHITE SHARK

NATURAL HISTORY

OCTOBER 2006 VOLUME 115 NUMBER 8

FEATURES



ON THE COVER:
White shark launches itself skyward in pursuit of seal, False Bay, South Africa.
Photograph by Chris and Monique Fallows

NATURAL HISTORY

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DEPARTMENTS

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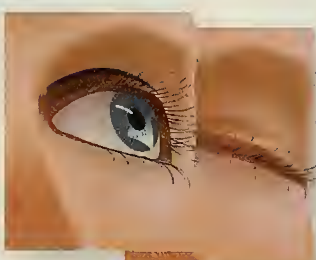

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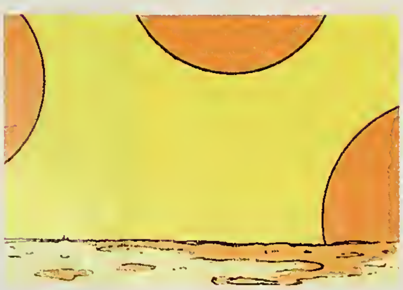

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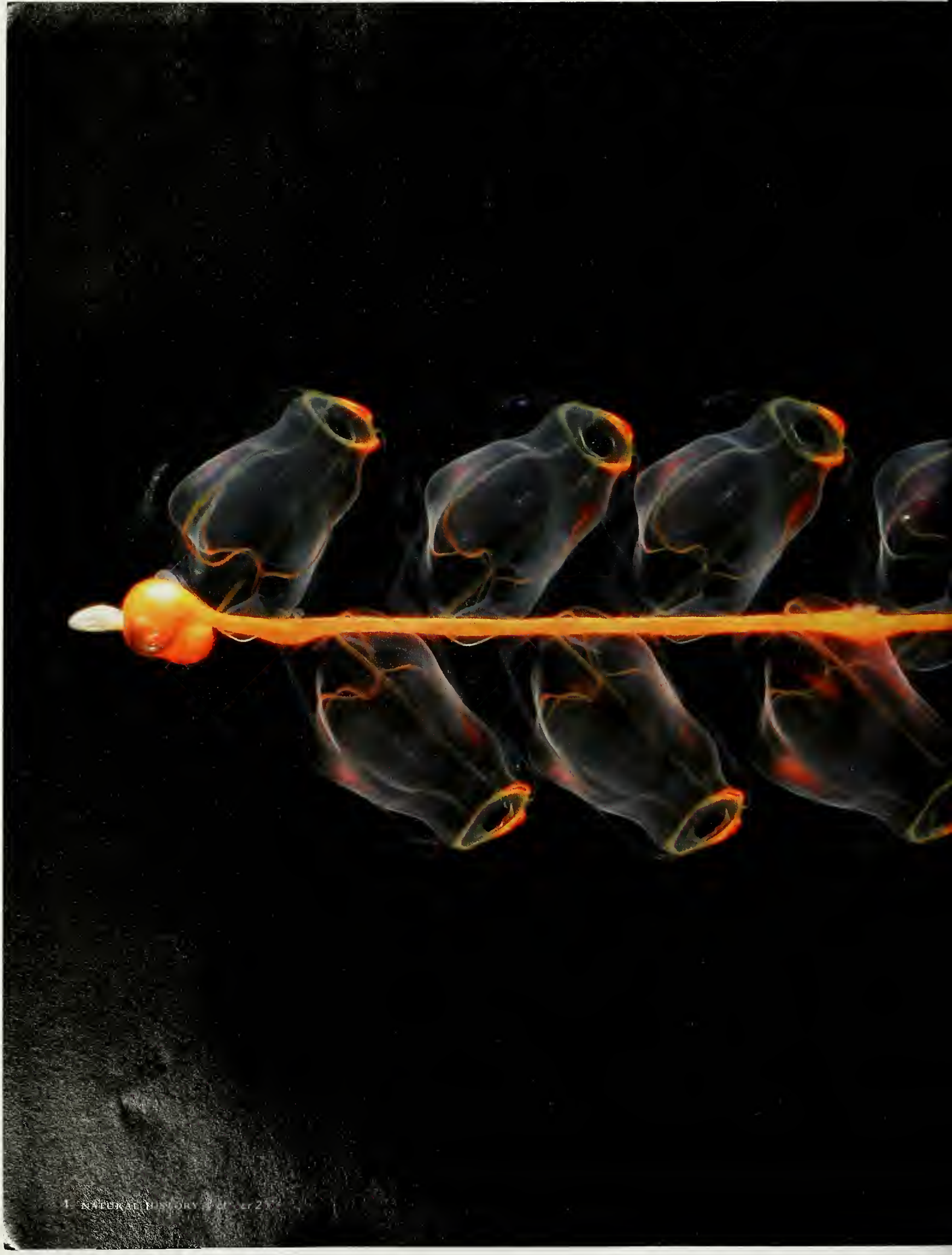


THE NATURAL MOMENT

Blast Off!

Photograph by Kevin A. Raskoff

THE NATURAL MOMENT

◄ *See preceding two pages*

Looking poised to rocket into space, the gelatinous siphonophore pictured here pumps its way through the deep ocean. And, all too much like an earthly spacecraft, if you bring this fragile machine to the surface too hastily, you'll risk breaking it apart. Techniques for capturing siphonophores—a group of animals that includes the Portuguese man-of-war—have vastly improved in the past few years. As a result, several new siphonophore species have been safely ferried to sea level, and several known ones have been discovered in unexpected places (as in the case of this surprise native of the Arctic Ocean).

Siphonophores seem put together in a more "machinelike" way than most other creatures: they are colonies, like corals, made up of repeating units, but they are far from uniform. Some units are bulbs attached to the central trunk of the organism, working in concert to propel the colony through the water; others dangle in a mass of stomach tissue, reproductive organs, and stinging tentacles.

The siphonophore pictured here belongs to the genus *Marrus* and measures anywhere from a foot long—scrunched-up as in the photograph—to a stretched-out length of six feet. In its long form, the colony trawls its tentacles like a drift net to snag prey. If disturbed, its cells flash a bright blue—self-generated bioluminescence.

Kevin A. Raskoff worked with a remotely operated robot and a team of fellow marine scientists to bring the siphonophore safely up from a depth of nearly a mile. Back in the laboratory Raskoff photographed the fiery life-form inside a walk-in refrigerator. —*Erin Espelie*

UP FRONT

Cover Shot

The sight of a white shark (aka great white) launching its one-ton body from the water—in the words of R. Aidan Martin and Anne Martin, "like a Polaris missile"—is surely one of the most heart-stopping spectacles in the animal kingdom. One look at the behavior, pictured on our cover as well as in the Martins' article ("Sociable Killers," page 42), was enough to convince them to return to False Bay, off the coast of South Africa, during shark season each year to learn what they could about these thrilling creatures.

So what can the Martins say about what curious minds everywhere want to know: do white sharks prey on people? The answer, notwithstanding the beach-horror flick *Jaws,* is probably not—at least, not often. To be sure, no one should doubt the fish's ferocity: enough unfortunate swimmers already have the scars to prove that white sharks make poor playmates in the water. But the Martins' observations have convinced them that many, perhaps most, shark bites in people are the result of the animal's curiosity (the shark's teeth and gums are remarkably sensitive and agile), not of its appetite for human flesh. Moreover, as the Martins' scientific observations make clear, the social lives of white sharks are quite rich, and their hunting strategies are surprisingly sophisticated.

• • •

Two of my favorite museums have exhibitions that expand on stories in this issue. Jaret C. Daniels and Stephanie J. Sanchez describe the near-demise of the Miami blue butterfly, and the efforts of many lepidopterists (successful, so far) to snatch the little beauty from the precipice of extinction (see "Blues' Revival," page 26). Visitors to the Florida Museum of Natural History in Gainesville can watch Miami blues being bred during the museum's Florida Butterfly Festival, October 14 and 15.

Arachnophiles will find two tales about their favorite animal in these pages. Either one would make a timely complement to a visit to the Spider Pavilion at the Natural History Museum of Los Angeles County, open from now through November 5. In "Nice Threads" (page 24) our resident biomechanist Adam Summers recounts how some incredibly dexterous investigators managed to unwrap five kinds of spider silk and test the strength of each. In "Winning Miss Muffet's Heart" (page 80), Rebecca Rupp wittily tells how her fear and loathing of her son's pet tarantula turned into . . . well, fond respect.

• • •

A break for Neil deGrasse Tyson from his "Universe" column this month makes room for a guest appearance by the M.I.T. physicist Robert L. Jaffe ("As Time Goes By," page 16). Jaffe urges a "Copernican" view of time, to replace the temporal parochialism of the familiar second, day, and year. The time line that accompanies his article, spread across pages 16 and 17, presents exhibit A in support of Jaffe's wider perspective, the vast range of durations relevant to the universe as a whole—from the infinitesimally Lilliputian "Planck time" (5.4×10^{-44} second) to the unimaginably Brobdingnagian lower experimental bound on the half-life of the proton (at least 10^{35} years). The case for awe in contemplating the universe has never been more forcefully made. —PETER BROWN

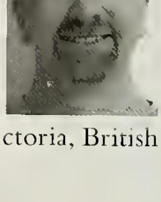
Having visited Samoa and other Pacific islands where Margaret Mead conducted her studies, Joseph and Lenore Scott find the masks in the Hall of Pacific Peoples some of the most intriguing artifacts at the American Museum of Natural History. (Photo by Craig Chesek/AMNH)

CONTRIBUTORS

Having spent his youth tagging along after his father, an oceanographer, on work trips off the California coast, marine biologist and photographer **KEVIN A. RASKOFF** ("The Natural Moment," page 4) feels most at home around and under the water. Much of his research, including the work that became the basis for his doctorate from the University of California, Los Angeles, has been done in conjunction with the Monterey Bay Aquarium Research Institute. Raskoff's specialty, soft-bodied animals such as jellyfish and their relatives, provides him with, as he puts it, "some of the most beautiful and exotic photographic models anywhere." That includes the spectacular siphonophore, looking like a rocket blasting through space, that is featured in this issue. Never far from the ocean, Raskoff teaches marine biology and environmental sciences at Monterey Peninsula College in Monterey, California.

R. AIDAN MARTIN and **ANNE MARTIN** ("Sociable Killers," page 42) are a husband-and-wife team of marine biologists based in Vancouver, Canada. Aidan, who specializes in the behavioral ecology of sharks and rays, is director of the ReefQuest Centre for Shark Research (www.elasmo-research.org); a research associate in the zoology department of the University of British Columbia, in Vancouver; and an adjunct professor at the Oceanographic Center of Nova Southeastern University, in Dania Beach, Florida. He is the author of *Field Guide to the Great White Shark* (ReefQuest Centre for Shark Research, 2003) and is at work on a book about shark behavior for Cambridge University Press. Anne, a salmon biologist with Fisheries and Oceans Canada, is also an underwater and topside photographer and videographer. She assists Aidan in his field research, lends a hand when he teaches field courses in shark biology and coral reef ecology, prepares graphics for his scientific and educational presentations, edits his writings, and permits him to dissect sharks in their kitchen.

SEAN B. CARROLL ("Broken Pieces of Yesterday's Life," page 50) is an investigator with the Howard Hughes Medical Institute in Chevy Chase, Maryland, and a professor of molecular biology and genetics at the University of Wisconsin–Madison. He is the author of a popular book on the development and evolution of animal forms, *Endless Forms Most Beautiful: The New Science of Evo Devo* (W.W. Norton, 2005). His most recent article for *Natural History*, "The Origins of Form," appeared in the November 2005 issue. His article in this issue was adapted from his latest book on evolution, *The Making of the Fittest: DNA and the Ultimate Forensic Record of Evolution,* which is being published this month by W.W. Norton.



The interactions of animals and plants hold a special fascination for **JONATHAN MORAN** ("Life and Death in a Pitcher," page 56). In addition to his long-term studies on the ecology of *Nepenthes* pitcher plants in Southeast Asia, his current research interests include the ecology of hummingbirds in North and Central America. An independent researcher and natural-history photographer, Moran earned his doctorate in ecology from the University of Aberdeen, in Scotland. He is based in Victoria, British Columbia, Canada.

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Natural History
P.O. Box 5000, Harlan, IA 51593-0257.

Natural History (ISSN 0028-0712) is published monthly, except for combined issues in July/August and December/January, by Natural History Magazine, Inc., in affiliation with the American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024. E-mail: nhmag@naturalhistorymag.com. Natural History Magazine, Inc., is solely responsible for editorial content and publishing practices. Subscriptions: $30.00 a year, for Canada and all other countries: $40.00 a year. Periodicals postage paid at New York, NY, and at additional mailing offices. Canada Publications Mail No. 40030827.

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LETTERS

Snakes from the Sea?

Laurie J. Vitt and Eric R. Pianka's article on the evolution of lizards ["The Scaly Ones," 7/06–8/06] is highly readable, but unfortunately, it largely ignores the squamate paleontological record. For example, the mosasaurs (from five to fifty-five feet long) ruled the seas for 30 million years and are known from more than thirty genera.

In the article this impressive group of extinct marine lizards is relegated to one sentence, in which it is mistakenly asserted that, according to one theory, "the first snakes were aquatic, having evolved from mosasaurs." The literature actually states that snakes belong to a group that includes extinct, long-necked, long-bodied, more or less aquatic lizards (adriosaurs, acteosaurs, eidolosaurs, pontosaurs, dolichosaurs). Among all squamates, the group's closest relative is a lineage of aquatic lizards including mosasaurs. The theory never proposed that snakes evolved from mosasaurs.

As for the consensus among herpetologists that all modern snakes are descended from a terrestrial snake ancestor—perhaps that will prove correct, perhaps not. The ultimate test will come from evidence provided by fossils.

Michael W. Caldwell
University of Alberta
Edmonton, Alberta
Canada

LAURIE J. VITT AND ERIC R. PIANKA REPLY: Our recent article focused on the evolutionary history of ecological traits among *modern* squamate reptiles, lizards in particular; we were not asked to review the fascinating history of the highly diverse marine squamates (nor would we be qualified to do so). We refer readers to "Terrible Lizards of the Sea," by Richard Ellis (9/03), for additional information on those creatures.

Michael W. Caldwell has correctly pointed out an error in our article: the marine (aquatic) hypothesis based on the fossil record does not claim that snakes descended from mosasaurs. It posits that they arose within a large group of autarchoglossan squamates, the Pythonomorpha, which includes mosasaurs and snakes, among other things.

On morphological grounds, snakes appear closely related to an extinct marine group known as the pachyophiids. A recent molecular analysis of snake origins would suggest that they—and thus the pachyophiids as well—arose in the Iguania, a primarily terrestrial and arboreal squamate group, and outside the evolutionary group to which mosasaurs belong. On that basis, if snakes originated in marine habitats, they did so independently of mosasaurs. The idea that snakes arose in aquatic (and probably marine) environments is supported by the similarity between the snake eye structure and that of aquatic vertebrates, but that evidence is debatable, and in any case sheds no light on where snakes arose within squamates. Most fossil data, as well as data on jaw structure, chemical sensing systems, and overall ecology, are consistent with our conclusion that snakes (and mosasaurs) originated within autarchoglossan lizards.

Perhaps all modern snakes descended from a terrestrial snake ancestor; perhaps not. Fossils will provide the ultimate test.

High Life Cornucopia

Kevin Krajick ["Living the High Life," 9/06] illustrates perfectly the unique diversity of species that await discovery. The highest reaches of the Andes seem devoid of life, yet such extreme environments harbor ecosystems that are inimitable. As exobiologists try to learn how and where life might exist elsewhere in the universe, much of our own planet, especially the parts that seem to us most like alien realms, remain unexplored.

Just as desert salt pans are home to remarkable ecosystems, as my colleagues and I have found [see "Desert Dreams," by Michael A. Mares, 9/03], the high Andes include more than 4,000 miles of isolated peaks, valleys, volcanoes, lava flows, lakes, salt flats, and verdant islands in the sky, islands that have impelled speciation. They merit special attention from biologists as global climate change alters those communities irrevocably.

Michael A. Mares
University of Oklahoma
Norman, Oklahoma

The Other Kinsey

Peter Del Tredici ["The Other Kinsey Report," 7/06–8/06] solves the mystery of why Alfred C. Kinsey's book *Edible Wild Plants of Eastern North America* was not published until long after he wrote it. Del Tredici also sorts out the contributions of Kinsey's elder colleague Merritt Lyndon Fernald to the book that bears both their names. Given all the attention Kinsey received for his work as a sex researcher, it is good to know that his other scientific contributions have not been forgotten.

Catherine Johnson-Roehr
The Kinsey Institute
Indiana University
Bloomington, Indiana

Peter Del Tredici writes that the two Kinsey books "have been credited with launching the sexual revolution of the 1960s." Credit should also be extended to Hugh Hefner, editor of *Playboy,* and to Frank B. Colton of G.D. Searle & Co., who developed Enovid, the first modern medical oral contraceptive.

Frank M. Sturtevant
Sarasota, Florida

Out on a Limb

Jennifer A. Clack's article "From Fins to Limbs" [7/06–8/06] reminds me of something I have long considered a basic truth of evolution, but have never seen in print. A transitional form is less fit (in the Malthusian-Darwinian sense) than the forms from which (and into which) it evolved. Thus the would-be terrestrial tetrapod is less well adapted for water living than the aquatic forms it is evolving from. It is also less well adapted for land living, compared with its more fully adapted descendants.

It is almost miraculous that some individuals survive the long and narrow path to the new form. Hence it should not be surprising that it is hard to find fossils of any transitional form—in other words, it explains the paucity of missing links.

Hans Berliner
Carnegie Mellon University
Pittsburgh, Pennsylvania

In reading Jennifer Clack's story, I was struck by the map of the Late Devonian world, in which the outlines of our present continents and countries clustered about the equator. My question is, what role did the oceans play during the "less than ten million years" when tetrapods arose? Ms. Clack writes of estuaries, river channels, and basins, as well as lakes. What lurked beyond the clump of continents in that warm and subtropical climate?

Forrest Bogan
Neavitt, Maryland

Jennifer Clack replies: The reason Hans Berliner may not have seen his generalization in print is that the fitness of transitional forms must be evaluated case by case. In fact, if one were to generalize from the transition of fishes to four-legged land animals, what seems to change first are the living conditions. When conditions change, some lineages can adapt and survive better than others. And once some initial barrier has been overcome, animals appear to exploit their new conditions quite rapidly, and their radiation into diverse niches leads to a great deal of speciation.

To answer Forrest Bogan, it seems there wasn't that much going on among vertebrates in the deep oceans. Ray-finned fishes, for instance, did not really master deep-sea conditions until late in the Mesozoic era. Most of the fossil vertebrates that have been found in the early to mid-Paleozoic era have come from sediments representing fairly near-shore environments.

Natural History *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

SAMPLINGS

Feast or Famine

Richard Onyango, Drosie and Family, *1994 (detail)*

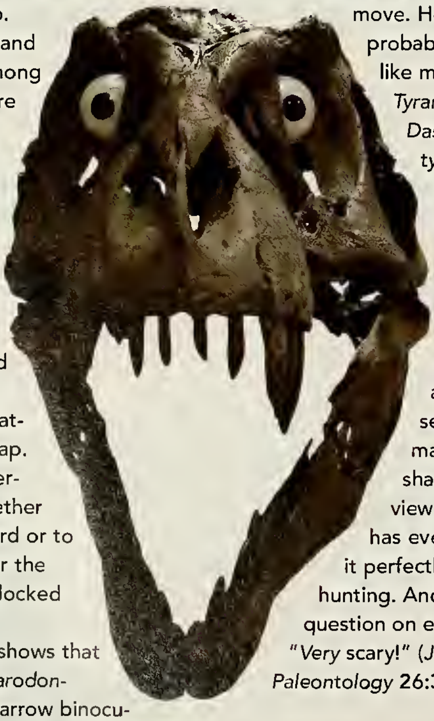
The prevalence of obesity and Type 2 diabetes in certain populations is often attributed to a "thrifty" genotype, selected for by frequent famines throughout those populations' prehistory. People who express the thrifty genotype are presumably predisposed to accumulate reserves of fat in times of plenty, for later use in times of famine. In today's constant plenty—so the theory goes—people with that once-useful genotype are prone to such metabolic problems as obesity and diabetes, which are common in groups such as Australian Aborigines, Native Americans, and Polynesians.

When the late American geneticist James V. Neel first articulated the theory in 1962, he also argued that the thrifty genotype should be more prevalent among hunter-gatherers than among farmers, because —he assumed—the hunter-gatherer lifestyle is the more prone to severe food shortages. But Daniel C. Benyshek, a medical anthropologist at the University of Nevada at Las Vegas, and James T. Watson, a physical anthropologist at Indiana University–Purdue University Indianapolis, contend that Neel's generalization was too broad.

With an extensive database on nutrition and food availability in preindustrial societies, which was compiled in the 1950s, Benyshek and Watson compared twenty-eight hunter-gatherer societies with sixty-six agriculturalist societies. They detected no link between lifestyle and amount of available food, or between lifestyle and frequency or duration of food shortages. Feast-or-famine cycles were probably common throughout human prehistory, and they may indeed favor thrifty genotypes, the anthropologists say. But the cycles seem to have been equally likely among foraging and farming economies. (*American Journal of Physical Anthropology* 131:120–6, 2006) —*Stéphan Reebs*

My, What Keen Eyes You Had!

Every schoolkid knows that *Tyrannosaurus rex* was really scary. Now a new study adds some frightening detail in answer to the question, How scary? Kent A. Stevens, a computer scientist at the University of Oregon in Eugene analyzed reconstructed heads of seven dinosaur species to discover how well they could see. In particular, he measured the extent of each species' binocular vision—how much the images from the left and right eyes overlap.



Depth perception and motion detection, among other optical feats, are greatly assisted by a large amount of binocular overlap, which enables the brain to judge the relative positions of objects in view. For each dinosaur reconstruction, Stevens mapped the region visible to each eye, then calculated the regions' overlap. The overlap was determined largely by whether the eyes faced forward or to the side, and whether the snout or its bumps blocked the view.

Stevens's analysis shows that *Allosaurus* and *Carcharodontosaurus* had only a narrow binocular overlap. To detect prey against a complex background, either the prey or the dinosaurs' own heads had to move. Hence both genera were probably ambush-predators, like modern crocodiles. *Tyrannosaurus*, along with *Daspletosaurus*, *Nanotyrannus*, *Troodon*, and *Velociraptor*, possessed a much wider overlap, conferring excellent depth perception and enabling both a stealthy approach and rapid pursuit. Thanks to that and its large, widely separated eyes, *T. rex* may even have had the sharpest, most detailed 3-D view of the world any animal has ever experienced, making it perfectly equipped for active hunting. And the answer to the question on every schoolkid's mind? "Very scary!" (*Journal of Vertebrate Paleontology* 26:321–30, 2006)

—*Nick W. Atkinson*

Before *Appellation Contrôlée*

The wild Eurasian grape, *Vitis vinifera sylvestris*, was first domesticated for winemaking in Transcaucasia, the region between the Black Sea and the Caspian, perhaps as long as 8,000 years ago. Early viticulturists selected for large, sweet grapes in a variety of colors, and they learned to propagate the plant vegetatively. The domestic cultivars found their way south, and by 5,000 years ago large-scale vineyards and wineries were well-established in Sumer and Egypt. From there the practice spread west, reaching the Iberian Peninsula by 2,800 years ago. Does that history, which is based on archaeological evidence, imply that all grapevine cultivars around the Mediterranean today are descendants of those wild Transcaucasian ancestors?

Buzzing Off

There's less buzz in the fields of Europe these days. A new study confirms what many observers have suspected: that the number of bee species in the United Kingdom and the Netherlands has declined markedly in recent decades. Strikingly, so have plant species that depend on them to reproduce. A team of biologists led by Jacobus C. Biesmeijer and William E. Kunin of the University of Leeds in England made the discoveries. For the two countries, the team studied records of change in plant populations, and compiled nearly a million observations of pollinating bees and hoverflies that were made since the late nineteenth century. In more than 60 percent of the sites surveyed, there were fewer species of bees after 1980 than there were before.

Biesmeijer and Kunin can't tell which decline came first, the plants' or their pollinators', nor whether one decline is causing the other. The biologists are also uncertain about the cause; the likely culprits are habitat loss, climate change, pesticide use, and pathogens. But whatever the reason, the loss of bee species is particularly worrisome to farmers who grow any number of crops that rely on the winged pollinators. Those of us outside Europe may also soon feel the sting: domestic honey bees in the United States are in trouble, increasing farmers' reliance on wild pollinators. And the investigators think wild pollinators around the world may be declining, too. (*Science* 313:351–4, 2006) —*S.R.*

Eucera nigrescens bee forages on clover. *The species is extinct in the U.K.*

Probably not, say Rosa Arroyo-García and José Miguel Martinez-Zapater, both plant geneticists at the National Center of Biotechnology in Madrid, Spain. With the help of an international team of collaborators, Arroyo-García and Martinez-Zapater discovered molecular evidence against a single ancestral grape population. Their team analyzed the DNA of more than 1,200 cultivars and wild plants from around the Mediterranean. They discovered that more than 70 percent of Portuguese and Spanish cultivars are related to local wild-grape populations—a hint that the wild grape may have been domesticated more than once. Now there's a ripe fact to impress your fellow wine connoisseurs with next time you sip a rich red from Andalusia. (*Molecular Ecology*, doi 10.1111/j.1365-94X.2006.03049.x, 2006) —*S.R.*

Go West, Young Primate

The earliest known primate fossils occur in 55-million-year-old geological deposits ranging across Asia, Europe, and North America. That almost simultaneous appearance has long posed a riddle to paleontologists: where did primates originate, and how did they subsequently disperse? Shortly before those early primate fossils were laid down, the Earth began a 100,000-year period of global warming. A new study now shows that the timing of the primates' rise may have been no coincidence: environmental changes caused by the warming probably enabled them to disperse fast enough to account for their rapid emergence on three continents.

Like today's global warming, the ancient warming was caused by massive releases of carbon-bearing greenhouse gases. Those releases altered the ratios of various carbon isotopes in the atmosphere, notably decreasing the fraction of carbon-13. Rock layers that trapped air during that period now help paleontologists calibrate the dating of geologic formations worldwide.

The relative dip in carbon-13 enabled Thierry Smith, a paleontologist at the Royal Belgian Institute of Natural Sciences in Brussels, and two colleagues to date early primate fossils more precisely than ever before. With their new dates, the investigators determined that a small, big-eyed tree-dweller of the genus *Teilhardina*, and possibly other early primates, originated in Asia, spread to Europe, and then continued on to North America. The entire journey took less than 25,000 years. Smith and his team theorize that the warm temperatures enabled the primates to cross the Atlantic at high latitudes, over a land bridge then linking the two continents via Greenland. Because *Teilhardina* was strictly arboreal, the investigators think evergreen forest must have covered a wide swath of the north. (*PNAS* 103:11223–7) —*Ciara Curtin*

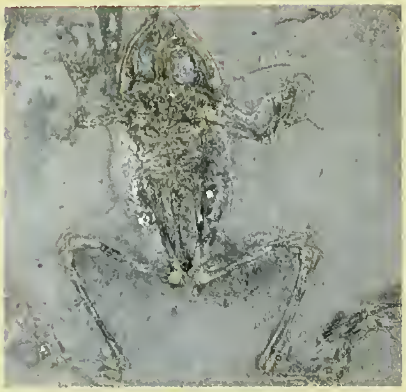
Teilhardina (artist's conception)

Jungle Smarts

Survival in the jungle takes more than dumb luck. A recent study of predators and their prey shows that relatively small-brained species are more likely to become a predator's meal than bigger-brained ones.

Susanne Shultz and Robin I. M. Dunbar, both evolutionary biologists at the University of Liverpool in England, studied the diets of chimpanzees and five cat species (golden cat, jaguar, leopard, ocelot, and puma) in five forests across Africa and South America. The investigators found that prey species such as antelopes, whose brains are small relative to their body size, were overrepresented in the predators' diets compared with their numbers in the local environment. By contrast, prey species with relatively large brains, such as monkeys, were underrepresented in the predators' diets.

Shultz and Dunbar can't say whether predators avoid hunting big-brained prey species, or big-brained species are simply better at outwitting their pursuers. Either way, the evolutionary outcome is the same: predation may be a factor in selecting for bigger brains. Ultimately, however, behavior plays a large role in making an animal easy or difficult for a predator to catch. Bigger brains confer greater learning ability and behavioral flexibility, so using one's head may well enable one to keep it. (*Biology Letters*, doi:10.1098/rsbl.2006.0519, 2006) —*N.W.A.*



Ancient frog: well preserved for its 10 million years

Lucky Break

A trace of life persists in prehistoric fossils. Amphibian bone marrow, discovered in 10-million-year-old fossils of frogs and salamanders from a sulfurous lake in Spain, is so exquisitely preserved that its red and yellow layers of tissue are still visible. The marrow may yield biologically important molecules, such as hemoglobin or even DNA. Maria E. McNamara and Patrick J. Orr, paleobiologists at University College Dublin in Ireland, and four colleagues made the discovery.

Most fossils form when minerals replace hard tissue, such as bone. Soft tissue decays too rapidly to mineralize, so traces of it are rare in the fossil record. Rarer still is soft tissue preserved organically, without decaying or mineralizing, the way the amphibian bone marrow was. In fact, there is only one other example of organically preserved soft tissue: still-stretchy blood vessels that were discovered last year inside a 70-million-year-old *Tyrannosaurus rex* femur.

After the dead amphibians settled on the muddy lake bottom, McNamara's team postulates, bacteria consumed their skin and muscle, but couldn't fit through minute pores in their bone to degrade the marrow. Instead, even smaller sulfur molecules seeped in and chemically fixed the marrow in much the same way formaldehyde would.

Sulfur-rich mud is fairly common in the fossil record, so why is organically preserved soft tissue so extremely rare? Most paleontologists probably never bother to look for it, McNamara says. Her own break came—quite literally—when she was studying fossils that had been cracked, revealing the marrow inside. Many more such finds may be in the offing. (*Geology* 34:641–4, 2006)

—*Edyta Zielinska*

A Rash of Consequences

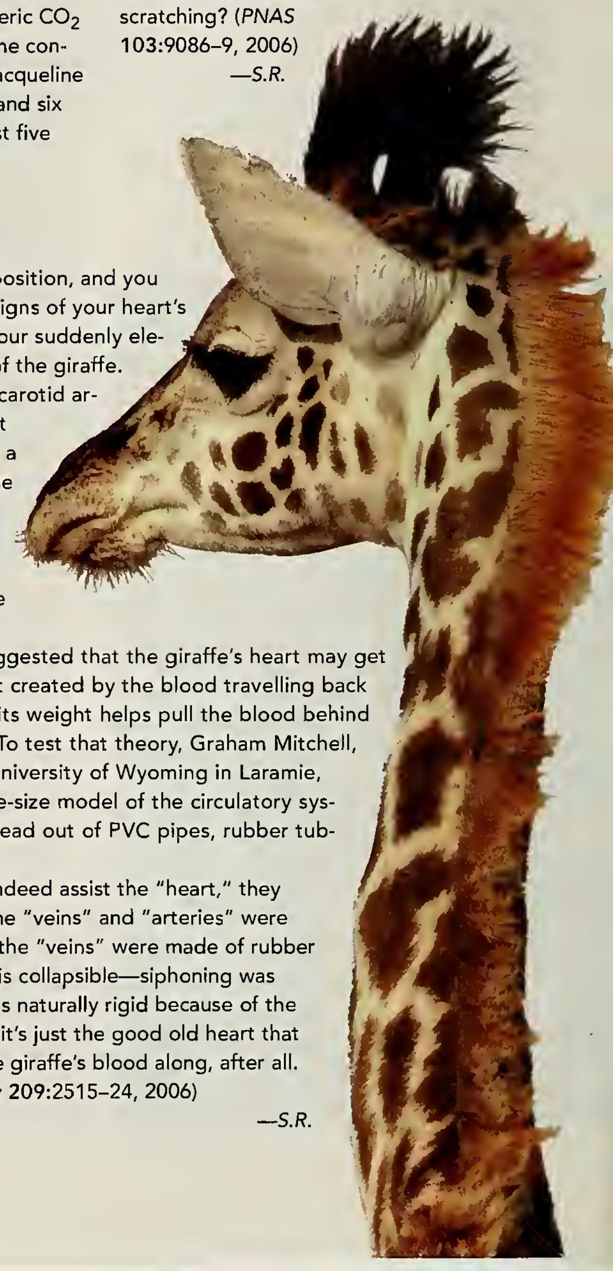
As if there weren't enough ominous consequences of global warming, here's a little bitty consequence that's just plain nasty: bigger, badder poison ivy. Already the irksome vine is responsible for more than 350,000 cases of dermatitis annually in the United States alone—and those are just the reported cases. A new study shows that as atmospheric carbon dioxide (CO_2, a major cause of global warming) becomes more abundant, poison ivy proliferates and makes a more toxic form of urushiol, the substance that triggers the rashes.

From 1996 until 2004 investigators pumped CO_2 into a pine plantation at Duke University in Durham, North Carolina. The idea was to simulate the 54 percent increase in atmospheric CO_2 expected by midcentury from the continued burning of fossil fuels. Jacqueline E. Mohan, a biologist at Duke, and six colleagues report that in the last five years of the study the poison ivy in the plantation grew nearly three times as fast as the plants normally do. And the toxicity of its urushiol shot up by some 33 percent.

Extra CO_2 boosts photosynthesis in all plants, but vines such as poison ivy invest relatively little of the extra energy they gain in growing more wood for support. Instead, vines can channel most of their extra energy into making even more photosynthetic greenery, a positive feedback loop that is bad news for trees: when vines are on the increase, as they are in many parts of the world, they often interfere with tree growth, and they even kill trees outright by shading or choking them.

Oh, and did I mention the part about more itching and scratching? (*PNAS* 103:9086–9, 2006)

—*S.R.*



Uphill Battle

Rise too quickly from a prone position, and you might see stars, the twinkling signs of your heart's struggle to send blood up to your suddenly elevated brain. So pity the heart of the giraffe. Its job is to push blood up the carotid artery to a brain towering six feet above. That column of blood is a heavy load. As a result, the base of the giraffe's carotid artery is the locus of some of the highest blood pressures in the world: twice the pressure in the carotid arteries of people.

Some physiologists have suggested that the giraffe's heart may get some help from a siphon effect created by the blood travelling back down the neck veins: perhaps its weight helps pull the blood behind it up the arteries to the head. To test that theory, Graham Mitchell, an animal physiologist at the University of Wyoming in Laramie, and three colleagues built a life-size model of the circulatory system of the giraffe's neck and head out of PVC pipes, rubber tubing, and a pump.

A siphon mechanism could indeed assist the "heart," they discovered, but only when all the "veins" and "arteries" were made of rigid PVC pipe. When the "veins" were made of rubber tubing—which, like a real vein, is collapsible—siphoning was impossible. (The carotid artery is naturally rigid because of the high blood pressure inside.) So it's just the good old heart that does all the work of moving the giraffe's blood along, after all. (*Journal of Experimental Biology* 209:2515–24, 2006)

—*S.R.*

As Time Goes By

Comparing the human experience of time with the fundamental tempos of nature yields a startling new outlook on our place in the universe.

By Robert L. Jaffe

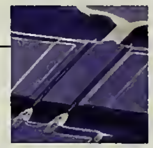
Duration of shortest laser pulse

10^{-18}

10^{-16}

Lamda life span: one trillion orbits of quark within lambda

10^{-14}



Switching time of fastest transistor

10^{-12}

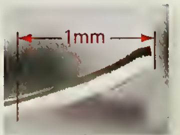
Time for rhodopsin, a visual pigment in the retina, to change its conformation when it absorbs light

10^{-10}

Life span of a lambda particle

Time for a typical home computer to execute a single instruction

10^{-8}



Crack in glass propagates about one millimeter

10^{-6}

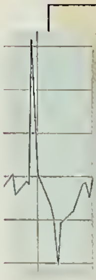
Electron beam in a standard TV paints one line

10^{-4}

10^{-2}

Blink of an eye

10^{0} = 1 second



Single human heartbeat

10^{2}

Time to sauté chicken breasts (20 minutes)

Average bonobo copulation (13 seconds)

10^{4}

A year (Earth completes one orbit around the Sun.)

10^{6}

Length of time before sexes can be distinguished anatomically in a human embryo

Age of Earth: 4.6 billion

10^{8}

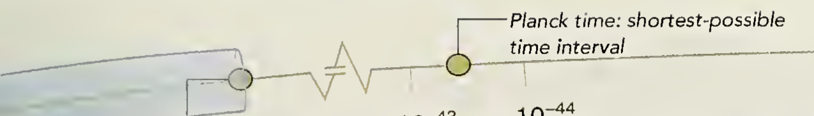
Human life span

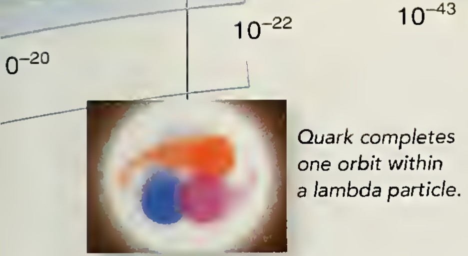
10^{10}

Duration of the Second World War

Age of the Great Pyramid of Giza

A few years ago a geologist friend at M.I.T. gave me a small chunk of gneiss from Canada's Northwest Territories. It rests now, backlit by the winter sun, on the windowsill behind my desk. A dull, fine-grained, gray-and-white rock, flecked with tiny crystals of black mica and hornblende, it looks like a stone she might have picked up almost anywhere in New England. Yet my stone is far from ordinary: its progenitor, the Acasta Formation, is the oldest known rock on Earth. The Acasta gneiss has persisted, largely undisturbed, at the core of North America since the rock crystallized more than 4 billion years ago, when the universe was only two-thirds its present age. The ripples in the gneiss on my windowsill have changed little in the billions of years since they formed. Meanwhile, great ranges of mountains have risen up and worn away; the lives of all our ancestors have flashed by.





Occasionally I take the rock in my hand, trying in vain to capture some feeling for that vast expanse of time.

My fragment of gneiss holds other secrets as well. In spite of its outward calm, a microworld lies deep within, buzzing with incessant motion. Its tempo is set by its smallest parts: not the molecules of quartz and feldspar vibrating like miniature tuning forks; not the electrons whirling in orbits about the nuclear cores of atoms; not even the protons and neutrons churning within the nuclei. Rather, my bit of the Acasta gneiss beats time to the rhythm of quarks.

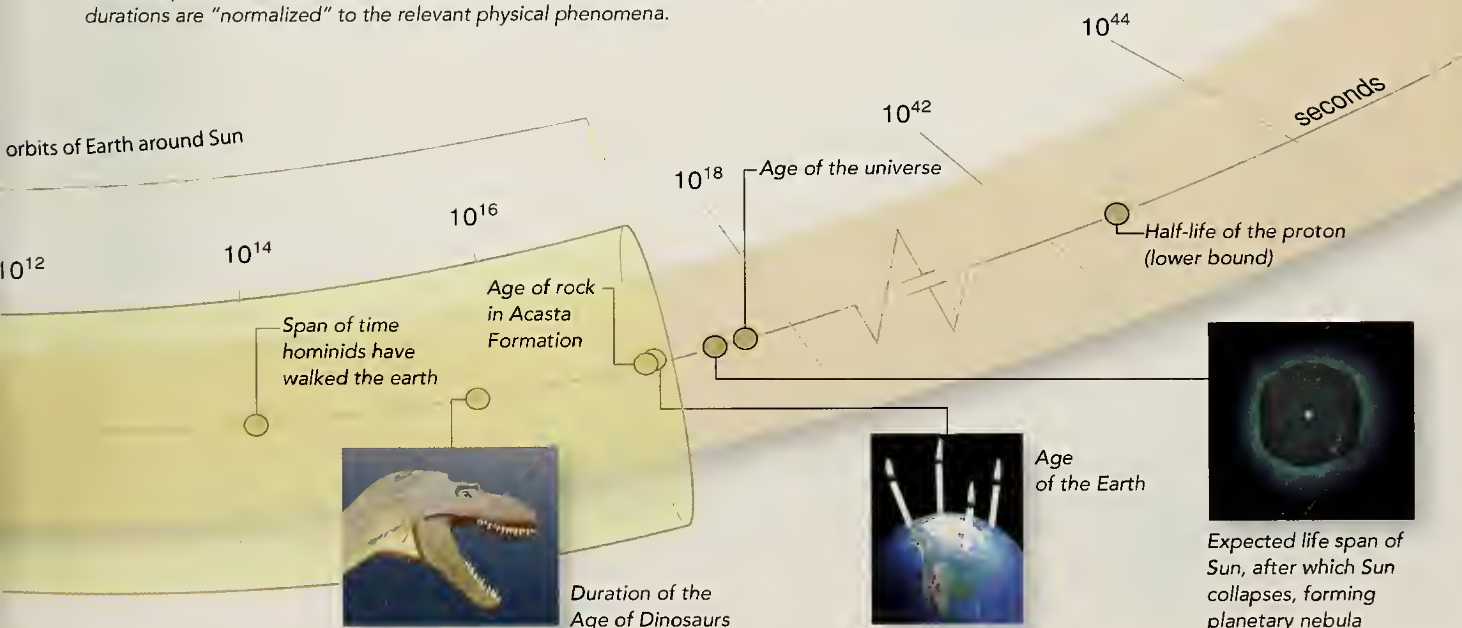
Whatever evanescent particles and subtle phenomena may await discovery, there is no doubt that we, and all we see around us, are made of quarks. Quarks account for 99.9 percent of the visible mass in the universe. Their orbits inside protons are exceedingly small, no more than a millionth of a millionth of a millimeter (10^{-15} meter) across, and their motions, which approach the speed of light, are exceedingly regular. Once around a proton takes a quark about 0.0000000000000 00000001 (10^{-22}) second, breathtakingly fast by any human measure. Just as the period of the Earth's orbit around the Sun defines the year, so the time it takes a quark to complete one cycle of its motion in a proton defines one tick of the clock of fundamental physics. Those ceaseless motions of quarks mark the heartbeat of the universe.

One plain stone, two extraordinarily disparate landscapes of time: the cosmological, the billions of years over which the drama of the universe plays out; and the fundamental, the hectic pace at which elementary particles dance to the tune played by the laws of physics. Those are the natural rhythms of the world. Between the two extremes, far briefer than the grand sweep of cosmology, but far longer than the helter-skelter pace of fundamental processes, lie our human measures of time—the second, the day, the year. They are the times of our lives, but they are not the natural rhythms of the world. Where did they come from? Where do we fit in?

The answers have emerged from a journey of discovery that has created a second Copernican revolution. Five centuries ago, the first Copernican revolution dislodged humankind from our privileged position at the center of the universe. Quietly and relatively recently, particularly in the past half century, the way physical scientists think about time has undergone a similar revolution.

Observed for the briefest moments, nature's forces turn out to have their own rhythms, built into them just as integrally as the clock speed of a microprocessor has been built into a computer at the factory. The smaller the part, the faster the tempo—but all of them are lightning quick compared to ordinary measures of human time. But if one suspends the attachment to human timescales, one can match the cinematographic frame speed of the mind's eye to nature's own rhythms, speeding up to capture the finest detail or slowing down to discern the broadest plan. The Copernican shift

Time intervals spanning eighty-six orders of magnitude are plotted on the spiral timeline on these two pages: from the Planck time, which lasts 5.4×10^{-44} second and is often considered the shortest-possible interval, to the half-life of the proton, which has been experimentally determined to be at least 3×10^{42} seconds. When time is measured in human-centered intervals, highly stable phenomena may be misclassified as fleeting. For example, in conventional units the lifetime of the lambda, a subatomic particle, is extremely brief, 10^{-10} second, yet the lambda is a highly stable system. The quarks that make it up orbit one another a trillion times before the particle disintegrates (translucent blue cylinder). For comparison, that is 200 times the number of orbits the Earth has completed around the Sun in the 4.6 billion years since the planet was formed (translucent yellow cylinder). In a more "Copernican" view of time, durations are "normalized" to the relevant physical phenomena.



in perspective can be startling: the microworld, which seems so fleeting by human measures, instead persists languorously. The cosmos, which seems to define the eternal, instead roils with ceaseless change.

My Copernican analogy is deliberate: what Copernicus did for the human sense of place, modern science has done for our sense of time. For millennia our ancestors believed the universe was made for us. The Sun, the Moon, and the stars appeared to revolve around us. We read our fortunes in their eclipses and conjunctions.

In the twentieth century we lost our bearings in time as utterly as our forebears in the Renaissance lost their special place in the universe.

Then, late in the Renaissance, the Polish astronomer Nicolaus Copernicus rudely plucked us out of the center, placing the Sun, not the Earth, at the hub of the solar system. The astronomers who followed Copernicus moved our small planet out toward the periphery of a huge galaxy, teeming with stars like our own. They found the universe to be full of galaxies, ours no more exceptional than the others.

Today we can no longer claim a special place in the universe. But there are compensations. First, it is better to know the truth than to be deceived. Moreover, the drama of modern astronomy, though less personal, is far grander than it was before Copernicus. Stars form, then die, often in great explosions, and leave behind corpses of unimaginable density. Galaxies whirl and collide. Although our skies are no longer inhabited by just the likes of Orion the hunter and the Great Bear, the heavens are full of wonder for all to see, the rewards of surrendering our place at the center of the universe.

In the twentieth century we lost our bearings in time as utterly as our forebears in the Renaissance lost their special place in the universe. From the beginnings of civilization people have measured time in human-size intervals: in seconds, the beat of our hearts; in days, the apparent circling of the Sun and stars about us; in years, the cycles of the seasons.

Before the twentieth century, scientists and philosophers did not realize that nature might associate a clock speed with a particular force. Instead, the duration of phenomena seemed to vary according to the circumstances. Take celestial mechanics. Planets far from the Sun take longer to orbit than the ones close in. But the period of the orbit depends only on its size—the larger the orbit, the longer the period. In Newton's law for calculating the force of gravity there is no constant that fixes the period of planetary orbits from the outset. Human measures of time may have seemed arbitrary, but they also were as good as any other.

Then, early in the twentieth century, revolutionary upheavals in physics led to the discovery that there are timescales intrinsic to the laws of physics themselves. Experimental physicists discovered that the mechanics of Newton is inadequate for describing the world of atoms. Newtonian mechanics was replaced by the strange and counterintuitive world of quantum mechanics, through which time entered physical law.

The German theoretical physicist Max Planck made the first key discovery in 1900. His study of radiant heat and light led him to conclude that, like ordinary water waves, those two forms of radiation vibrate, but that the radiation comes in packets, or "quanta." Moreover, the energy of the quanta is directly proportional to the vibrating frequency of the light wave. Expressing the relation mathematically is as simple as relating the mass of a quantity of water in kilograms to the volume of the same quantity in cubic feet. If V is the volume in cubic feet, and M the mass in kilograms, then roughly $M = 28 \times V$. Thus, the two quantities M and V vary in direct proportion, and they express related properties of the same substance. The more volume, the more mass. In this case the constant of proportionality, 28, is the density of water, the number of kilograms per cubic foot.

By the same token, if E is the energy of the radiation quanta in joules, and ν (the Greek letter *nu*) is the frequency of the quanta in vibrations per second, then Planck's equation states that the two are proportional: the more energy, the higher the frequency of vibration. In this case the constant of proportionality is roughly 6.6×10^{-34} joule-second and, as Planck discovered, it is universal. The same constant of proportionality applies for heat radiation, for light, and even for X rays. That constant, usually abbreviated h, is known as Planck's constant, and so the full statement of the proportion is $E = h \times \nu$. Standing with Einstein's better-known $E = mc^2$, Planck's equation is one of the twin pillars of modern physics.

Because Planck's constant is so minute, when expressed in everyday units, even a modest energy equates to oscillations on an astonishingly short timescale. One quantum of green light, for instance, has only about 4×10^{-19} joule of energy, but that translates into about one oscillation every 2×10^{-15} second. A little human perspective: the "blink of an eye" takes about 50 trillion times longer.

It wasn't until twenty-seven years after Planck's original discovery about light that the implications of his law for other forms of energy and matter—and thus for nature's fundamental timescales—became clear. The uncertainty principle articulated by the German physicist Werner Heisenberg provided the crucial link. The laws of quantum mechanics, Heisenberg realized, do not allow things to come perfectly to rest. It is impossible to know exactly where a particle is and, at the same time, where it is going. The more perfectly one tries to pinpoint the posi-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FOUR FUNDAMENTAL FORCES OF NATURE

FORCE	ACTS ON	MAJOR ROLE	RELATIVE STRENGTH	RANGE
Strong 	Quarks, gluons and hadrons	Holds nucleus together	1	Short (10^{-15} meter)
Electromagnetic 	Electrically charged particles	Drives all chemical and biological processes	10^{-2}	Long
Weak 	Quarks and leptons (which include electrons)	Causes some kinds of radioactivity	10^{-13}	Short (10^{-18} meter)
Gravity 	All particles	Holds Earth in orbit around Sun; keeps stars in orbit around galaxy	10^{-39}	Long

tion of a particle, the more momentum, and therefore the more energy, it may have during the short time it occupies that position.

The uncertainty principle requires that everything on the microscale is constantly in a kind of perpetual, restless movement, a quantum buzz known as zero-point motion. And Planck's equation determines the clock speed of zero-point motion: the smaller the system, the more precisely confined its position in space; the higher its energy; and, because $E=h\times\nu$, the faster the pulse of its zero-point motion.

Guided by quantum mechanics, twentieth-century physicists pushed deep into the microworld with ever more powerful instruments. Accelerators nearly the size of Manhattan have functioned as "microscopes" that could look for ever simpler, more fundamental processes, "listen" to ever faster tempos, and probe ever shorter timescales. When the physicists discovered new fundamental forces, such as the ones that hold electrons in atoms or quarks in protons, each force came with a natural clock speed, the pitch of the quantum buzz characteristic of the size of the system. All those clocks tick at frantic rates that make human intervals such as seconds, days, and years seem eternally long.

Freed from the constraint of viewing time in human terms, one can take a "Copernican journey" to find the tempos that rule the microworld. Imagine delving once more into my fragment of Acasta gneiss. This time, magnify the rock over and over again, just as you might repeatedly click the "+" button while you read a document on a computer. Your journey, lasting no more than a few minutes, will whisk you through hard-won discoveries that took a century to make. Just a few clicks—a few steps—will take you through the realms of the three fundamental forces that govern the microworld: electromagnetism, the strong force, and the weak force. Each has its own characteristic rhythm.

The first few clicks resolve the pattern of flecks and ripples in the gneiss into jewel-like crystals, but betray no hints of time. More clicks, and patterns of striations within the crystals, the first hints of molecular substructure, come into focus. Still nothing moves. Not until the patterns begin to resolve into individual atoms, at the scale of nanometers (10^{-9} meter), do the faint, regular, self-sustaining vibrations of zero-point motion become detectable. The atoms vibrate ceaselessly back and forth with periods of about 10^{-13} second. Throughout that range, from rock to single atom, electromagnetic forces hold sway. They are the forces responsible for chemical binding and for the elementary processes of biology.

A few more clicks and individual atoms fill the screen, with hazy clouds of electrons orbiting atomic nuclei deep within. Electromagnetism still rules: the negatively charged electrons are held in orbit by their electrical attraction to the positively charged nucleus. Electromagnetism and quantum mechanics dictate both the period and size of the electrons' orbits. An electron takes roughly 10^{-16} second to complete an orbit in a simple atom. Here at last is the beat of the electromagnetic force, the first of nature's fundamental clocks.

With more clicks, the realm of electromagnetism begins to give way to more powerful forces. Five more powers of ten in magnification are needed to reach past the haze of electrons and resolve the seething mass of protons and neutrons in the atom's nucleus. Only about 10^{-14} meter across, the nucleus accounts for nearly all the mass of the atom. Here another fundamental force, the strong force, emerges.

Although 100 times stronger than electromagnetism, the strong force is sequestered within atomic nuclei. It acts powerfully over distances less than 10^{-15} meter, typical of the distances between nuclear particles, but it rapidly becomes imperceptible as distances grow larger. At a range of 10^{-13} meter it is all but gone. The strong force holds protons and neutrons together in the nuclei of atoms. It fuels the nuclear fires that make stars shine, and also provides all the energy that makes life possible on Earth.

In its rawest form the strong force acts between quarks and confines them within protons and neutrons. Quarks (as far as physicists can determine) are indivisible bits of matter that carry "charges" somewhat like the electric

charge of the electron. Quark charges come in three varieties, known whimsically as "colors." Color charge is the source of the strong force, much the way electric charge is the source of the electromagnetic force. So the more accurate name for the strong force is the color, or "chromodynamic," force.

Only inside protons and neutrons, at a distance of 10^{-15} meter, does the true tempo of the chromodynamic force come into focus. Confined to such minuscule spaces, quarks struggle mightily, but futilely, to escape. The regular, periodic zero-point motion of the quarks that results sets the tempo of the strong force: a single vibration, as I noted earlier, lasts about 10^{-22} second. That interval, which seems inconceivably short to us, beats the natural rhythm of the strong force.

The next stop on this Copernican journey, and the last where any new phenomena appear, comes into view at about 10^{-18} meter, one one-thousandth the size of the proton. At that distance another force—the weak force—becomes as strong as the electromagnetic force. The weak force is a bit like the fungus of the physics world: it does not build up very complex structures, it is easy to overlook, and it is often an agent of decay. When a nucleus disintegrates, it is usually the weak force at work. Because its effective range is limited to distances of one one-thousandth the size of the proton, the weak force only rarely affects the motions of quarks—and it is never the agent that binds matter together. So the beat of the weak force, even though it is a thousand times more rapid than the tempo of chromodynamics, is rarely heard in the universe.

The electromagnetic, strong, and weak forces dictate the structure of the microworld. Each has its own natural rhythm. The beats are dizzying: roughly 10^{-16}, 10^{-22}, and 10^{-25} second, respectively. But "dizzying" compared to what? It is time to take another leap of imagination, time to put aside the prejudice of a human perspective that sees the microworld as evanescent and its tempo as too fast. It is time to ask: What does the world of quarks look like on its own terms?

Consider one of the particles discovered in the early 1950s, known by the Greek capital letter lambda (Λ) because its telltale signature is a pair of tracks forming an upside-down letter V. Like the more familiar proton, the lambda is made of three quarks. From time to time one of the orbiting quarks in a lambda gets too close to one of the others—and within range of the weak force. When it does, the straying quark decays and the lambda flies apart. Lambdas live, on average, about one ten-billionth of a second (10^{-10} second), a typical life span for a subatomic particle that decays because of the weak interaction.

But is that really so short a time? Not if you take the Copernican leap, escape the human temporal perspective, and examine the lambda from the perspective of the strong force that holds it together. Though imperceptible to us, 10^{-10} second is a long, long time relative to the tempo of chromodynamics. It takes a quark about 10^{-22} second to complete a single orbit within the lambda. Before the lambda decays, the quarks within it orbit one another about 10^{-10} second divided by 10^{-22} second per orbit, or one trillion (10^{12}) times, on average.

Nothing in our everyday experience lives so long in its own terms. Humanity's most enduring institutions—churches, nations, universities—have lived at most hundreds of human lifetimes. Our most ancient ruins have survived only thousands of yearly cycles of heat and frost. Even the solar system is far less stable. Since its formation, the Earth has circled the Sun about 5 billion times. That is roughly 1/200th the comparable number for the lambda. In "only" another 5 billion years or so, the Sun will expire and take humanity, or what is left of it, along. Taking a fundamental, rather than a human perspective on time, high-energy physicists usually ignore the fact that the lambda decays at all, and call it "stable," just like our solar system.

In "only" another 5 billion years or so, the Sun will expire and take humanity, or what is left of it, along.

After this journey deep into my fragment of the Acasta gneiss, the word "stable" has taken on new significance. In the 4 billion years since this rock has formed, the quarks in it have orbited 10^{39} times—now that's what I call stable! Hefting the stone in my hand, I find myself asking, What has enabled the universe to persist so long? If it were ruled by the tempos of the fundamental forces, one would expect the universe to have blinked into and out of existence in some tiny fraction of a second. What sets the immense scale of cosmological time? And what of gravity, which plays such a central role in cosmology?

Gravity, that most familiar of forces, has not figured in our search for the tempos of the microworld, because gravity is too weak to affect atoms or nuclei. Human beings are only aware of it because it reaches out across great distances and builds up when huge quantities of matter are gathered together. Because it plays such an important role in the dynamics of stars and galaxies, could gravity hold the key to understanding the scale of cosmological time? The question suggests another journey, this one across cosmic distances and exceedingly long times. But that's a journey for another day.

ROBERT L. JAFFE is a professor of physics at M.I.T., where he has also served as chair of the M.I.T. faculty and director of the Center for Theoretical Physics. His research has focused on the properties of quarks, the way they bind together to form particles such as protons and neutrons, and the role of quarks in the structure of the universe. In recent years he has been working on the quantum structure of the vacuum. Photography, hiking, and writing occupy what is left of his time.

Buckeye Butterfly
Alan Chin-Lee

Monarch Chrysalis | Photo by Jeff Gage

Nice Threads

Orb weaver spiders can draw on a wide selection of silks that span a huge range of stretchiness and strength.

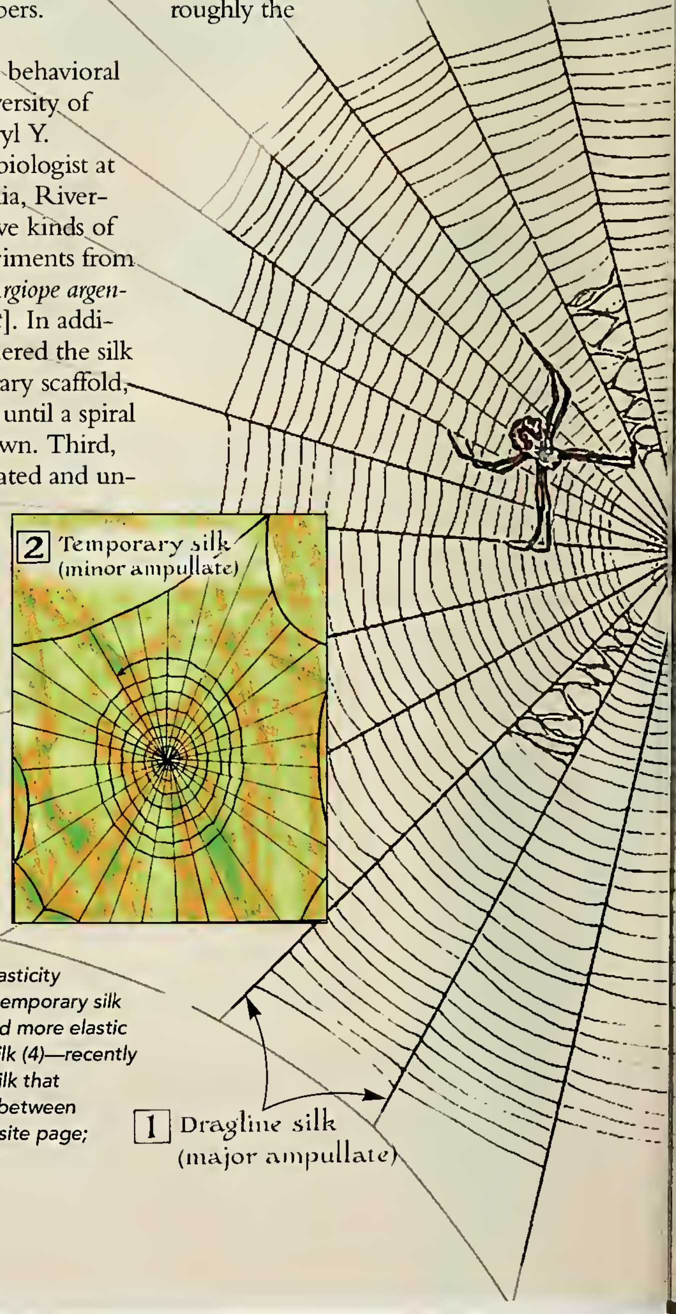
By Adam Summers ~ Illustrations by Laura Hartman Maestro

All species of spider—about 40,000 at last count—extrude silk from modified limbs, called spinnerets, on their abdomens. Many species, including the orb weavers, produce a whopping seven different kinds of silk. Two are gooey, but the other five silks are fibrous and together create an armamentarium that enables the orb weavers to perform weight-defying rope tricks. For twenty years workers have been trying to reproduce the showiest of the fibrous silks, the so-called dragline silk, which serves the spiders as rappel lines (for dropping in like Spiderman) or as radial trusses for a web.

In laboratory testing, dragline silk rivals such artificial polymers as nylon and Kevlar (the fiber of bulletproof vests), in stiffness and strength. Recently, though, two biomechanists showed that the four other fibrous silks are also worth imitating—perhaps even more so. Learning how to spin all five of those silken wares would be a boon not only to the building-minded, but also to the planet. After all, silk is synthesized in a spider's belly, an ecofriendly environment, solely out of biodegradable ingredients. It's even edible, at least to an arachnid: spiders eat their old webs to get extra protein. Looking at spider silks with such a panoply of properties could give valuable insight into a manufacturing process and a set of ingredients that might be adapted for the making of new, high-performance fibers.

Todd A. Blackledge, a behavioral ecologist at the University of Akron in Ohio, and Cheryl Y. Hayashi, an evolutionary biologist at the University of California, Riverside, managed to get all five kinds of fibrous silk for their experiments from the silver garden spider *(Argiope argentata)* [*see illustrations at right*]. In addition to dragline, they gathered the silk that functions as a temporary scaffold, holding the web together until a spiral of "capture" silk is laid down. Third, the biomechanists confiscated and unraveled spider-egg sacs to get a grooved fiber that protects the developing spiderlings from thumps and bumps. Fourth was the silk from the aciniform gland, used for wrapping and restraining prey. Finally, they collected the sticky and stretchy capture silk that forms the more permanent, spiral interior of the web: the stuff that does the morbid work of netting insect prey.

The investigators tested the five silks by stretching short sections of the individual fibers on a new kind of testing frame. Silk fibers are strong, but they're also so wispy that testing them takes a device of exceptional sensitivity and accuracy; until now, no one had been able to test temporary, egg-sac, or prey-wrapping silk from the same species of spider. (Both dragline and capture silk from a number of different kinds of spiders had been measured for stiffness, strength, and toughness.) The new testing frame can measure forces as small as a nanonewton—roughly the



Five kinds of silk spun by an orb weaver spider differ in breaking strength and elasticity (clockwise from near right): Dragline silk (1) forms the radial spokes of the web; temporary silk (2) forms a spiral scaffold for the web and is ultimately replaced with stronger and more elastic silks; egg-sac silk (3) protects the spider's developing offspring; prey-wrapping silk (4)—recently shown to be the toughest silk of all—binds prey; and capture silk (5), the sticky silk that captures prey, stretches far more than any other silk. The "stiffness," or relation between stretch and tensile force applied, is plotted on the graph at the far right of opposite page; the upper end of each curve represents the breaking strength of the material.

weight of the dried ink in the period at the end of this sentence.

To a materials scientist, stiffness is a measure of how much a sample stretches or deforms (as a percentage of its length) when a force is applied. Dragline silk, for instance, stretches just about as much as would a nylon thread of comparable diameter, if a spider fell on it. In casual conversation, strength sometimes means much the same thing. In its technical sense, though, "strength" is breaking strength: how much weight a strand can bear before it breaks. Here, too, spider silk is superlative; the breaking strength of dragline silk is about that of most steels.

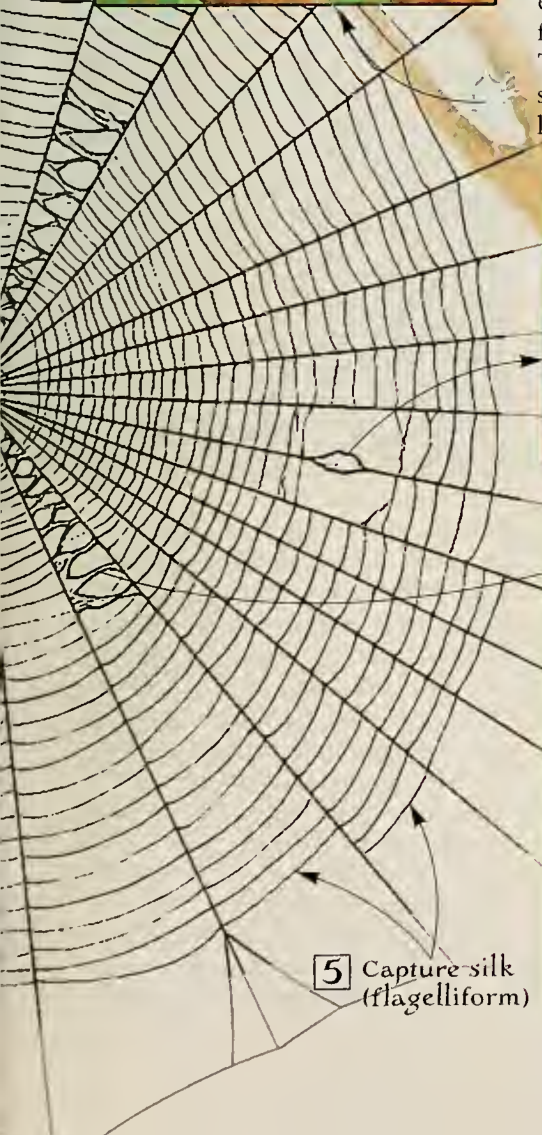
By the third measure, toughness, capture silk was thought to be the standout. Toughness is a kind of combination of stiffness and strength, a measure of how much energy can be absorbed (by stretching and bearing weight) before the material fails. In toughness, both capture silk and dragline silk trump Kevlar.

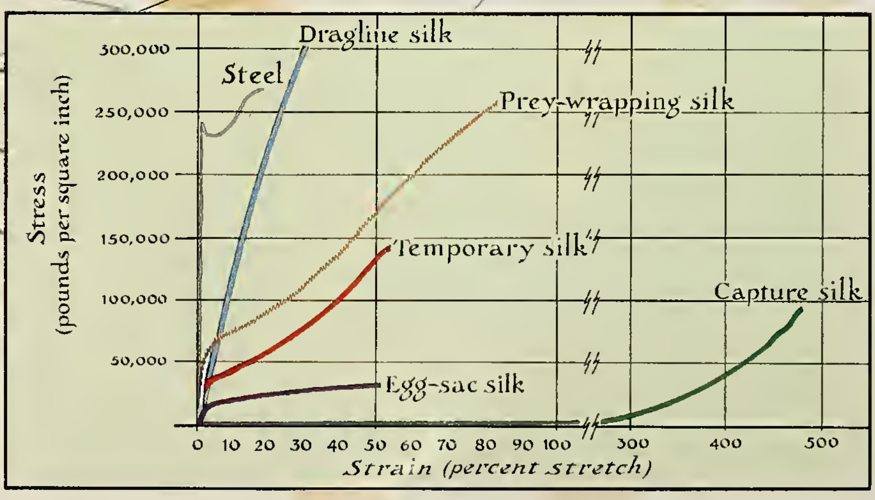
When they tested the spider's full toolkit for the first time, Blackledge and Hayashi confirmed the amazing properties of dragline and capture silk. But they also discovered that some of the highest-performance silks had been overlooked. The other three fibrous silks are all stiffer than dragline, at least for small loads, and egg-sac silk stretches to more than 50 percent of its resting length, nearly twice as much as dragline, before it breaks. The sticky silk of the capture spiral is still the flexibility champion, and dragline reigns as the strongest silk; but temporary silk and prey-wrapping silk, both stiffer than dragline, do nearly as well in strength [*see graphs below*].

The big surprise is that prey-wrapping silk is a real Kevlar killer. It can absorb twice the energy of any other silk before it breaks. Presumably the intimate, long-term contact with an insect struggling for its life demands a tougher material than do the single impacts that dragline must sustain. If prey-wrapping silk can be imitated, tougher, lighter-weight bulletproof fabrics should be in the offing.

With recent advances in understanding the biochemical content of silk and the genetics of the proteins that make it up, there is real promise that artificial spider silk can be made. Understanding the material properties of the various kinds of spider silk might help fine-tune and vary the basic manufacturing process for non-superman-made fibers. Personally, I'd like little nozzles that shoot the various kinds of silk from my wrists. I wouldn't just swing around; I'd fight crime. I promise.

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





Blues' Revival

Can a change in diet—and a little laboratory assistance—help a Florida butterfly escape extinction?

By Jaret C. Daniels and Stephanie J. Sanchez

Usually crowded with sun-loving tourists, the sandy beaches of the Florida Keys are vacant in the darkening afternoon sky. Palm fronds crackle as the wind picks up. Bahia Honda State Park, 524 acres of limestone and beach in the lower Florida Keys, is bracing for one of nature's most destructive forces: a hurricane. Hunkered down under vegetation, small Miami blue butterflies, each barely the size of a thumbnail, hang on for dear life. In the next twenty-four hours they will fight a critical battle for survival, one that if lost, could lead to their extinction.

Florida, of course, is no stranger to hurricanes. Storms have shaped the landscape of the peninsula for thousands of years, just as they have acted as a major force in the evolution of subtropical ecosystems throughout the Caribbean. But now, coupled with human land-use practices that fragment habitats and disrupt natural biological processes, even a single hurricane can have a devastating impact on wildlife. For rare organisms already at risk, such as the Miami blue, a massive storm can blow away an entire species forever.

Fifty years ago, the story was entirely different. The Miami blue *(Cyclargus thomasi bethunebakeri)*, endemic to Florida, was common, its future seemingly secure. Originally described from specimens collected near its namesake city, the butterfly once ranged along coastal parts of southern mainland Florida, on several barrier islands off the southwestern Gulf coast, and south from the Florida Keys to the Dry Tortugas [*see map on this page*]. It was at home in coastal hammocks where tropical hardwoods grew in dense, broad-leaved forests, along the sunlit margins of those forests, in pine rocklands, and amid beachside scrub. Now all those habitats have become endangered, either severely fragmented or lost entirely as a result of urbanization. Only a small fraction of the original coastal vegetation remains, primarily as remnant pockets or discontinuous small preserves.

Historic range of the endangered Miami blue is shaded in orange. By 1999 the butterfly population was reduced to about fifty individuals, all living in Bahia Honda State Park. A successful program of captive breeding has led to the reintroduction of the species in Everglades and Biscayne national parks.

Perhaps it was a hurricane that finally served as a wake-up call for those who love the Miami blue. The gradual loss of habitat was causing the Miami blue to vanish, virtually unnoticed, from the scene. The butterfly was all but eliminated from the Florida mainland and the western barrier islands by the late 1980s, when the last few reports of sightings trickled in from Sanibel Island and sites near the city of Homestead. In the Keys, where the insect was once abundant, it was also losing ground. By the early 1990s, the known populations of Miami blues were isolated and scarce.

Then on August 24, 1992, Hurricane Andrew slammed into south Florida with sustained winds of about 145 miles per hour. In the aftermath of the storm's devastation, even Key Largo, a historic stronghold for the butterfly, failed to register a single verified sighting of a Miami blue. Lepidopterists and amateur naturalists alike began to fear that the once-plentiful butterfly had died out. Seven years passed without a sighting. Finally, on November 29, 1999, a small colony was discovered in Bahia Honda State Park, a popular tourist destination along the Overseas Highway, about forty miles east of Key West.

In the years that followed, my colleagues and I at the University of Florida in Gainesville and others have taken part in a concerted effort to find, breed, and reintroduce Miami blues to the south Florida ecosystem. Although the effort has had its share of false starts and dark moments, a program to save the Miami blue is now on its way to being a qualified success. The details may encourage others in similar straits.

Paper cups (opposite page) at the Florida Museum of Natural History in Gainesville each house an egg-laying Miami-blue female. Sprigs of nicker bean provide substrate for the eggs, and cotton swabs injected with artificial nectar feed the hungry mothers. Mature caterpillar (above left) feeds in the wild while being tended by its ant companions. Female Miami blue (above right) shows off the underside of two of her wings in their upright, resting position. An array of spots are visible on her left hind wing, along with the penned marking (number 112) of the naturalist.

Following the dramatic rediscovery of the butterfly colony, preliminary estimates logged fewer than fifty individuals remaining and prompted a swift call for immediate conservation action from an atypical source—the general public. Concerned amateur naturalists from the North American Butterfly Association petitioned the Florida Fish and Wildlife Conservation Commission (FWC) to list the Miami blue as an endangered species on an emergency basis. The petitioners based their request on a laundry list of potential threats to its continued survival: the loss and fragmentation of habitat; mismanagement of the existing habitat, particularly through a failure to conduct regular controlled fires that maintain it; and the unethical collecting of specimens.

Fortunately for the butterfly, FWC temporarily granted the petitioners' request. Listing the insect as endangered meant there would be stiff fines for illegally collecting, harming, or even disturbing what had become one of the nation's rarest invertebrates. (The temporary protection became permanent just before the fourth anniversary of the discovery of the Bahia Honda colony, on November 19, 2003, when FWC unanimously approved the species-management plan for the Miami blue and its addition to Florida's list of endangered species.)

With that success, conservation efforts shifted to research and recovery. The first priority was to make an in-depth biological study of the Miami blue and the causes of its decline. Precisely because it was once so common, neither professional biologists nor amateur lepidopterists had ever extensively examined the butterfly, and as a result, many details of its biology and ecology remained poorly understood.

We began with surveys, hoping to uncover any other extant Miami-blue populations, while monitoring the known colony at Bahia Honda State Park. Yet though the surveys were extensive, no new sites were identified. Those disappointing results focused our attention back on the single locale on Bahia Honda Key—now more important than ever. There we made detailed observations and studied the population by gently netting, numbering, releasing, and later recapturing individual butterflies (a technique known as mark-recapture). In that way we confirmed the existence of more than a dozen distinct breeding colonies, a hopeful result. But we also estimated that at any one time the park typically supported fewer than a hundred individuals.

Preliminary estimates of adult longevity were even more worrisome. Female butterflies typically lived less than five days; males lasted barely two. Moreover, both sexes were remarkably sedentary: individuals seldom wandered more than thirty feet from their birthplace in the habitat. Both traits posed hurdles we would have to clear if we were going to manage and restore the population of these insects effectively.

Our most intriguing preliminary finding, though, may have been the butterfly's choice of food during its larval, or caterpillar, stage. Earlier populations had dined exclusively on balloon vine *(Cardiospermum corindum),* whose distinctive, inflated pods caterpillars chewed through to get at the "main course," the developing seeds inside. But balloon vine does not occur within the park, and it is scarce throughout the lower Keys. The remaining Miami-blue caterpillars fed instead on gray nicker bean *(Caesalpinia* *bonduc),* a thorny, rambling shrub native to the Florida coasts that sometimes encroaches on other vegetation much like a weedy invasive.

Shifting from one host plant to another is not uncommon among insects. But in the blues' case, the switch seemed extreme. Balloon vine, their food of choice, produces toxic cyanide-generating compounds that ward off most herbivores. The Miami blue had evolved highly specific metabolic pathways that enabled it to tolerate those nasty chemicals. The adaptation presumably provided the larvae with a competitive advantage: they could feed on plants that most other animals find unpalatable. So in switching plant families (from Sapindaceae to Caesalpiniaceae), the butterfly has apparently abandoned its original niche.

Moreover, the Miami blue completely altered its lifestyle. Now, instead of entering the protected confines of a balloon-vine pod, the developing larvae feed on the terminal growth of nicker bean. That leaves them exposed and seemingly vulnerable to a range of potentially fatal threats, including inclement weather, pesticides, and predators.

Male Miami blue (lower butterfly) has perhaps a couple of days of life in the wild to attract the attention of a female, such as the one in the upper half of the image, sucking nectar with her proboscis.

Happily, the larvae receive a helping hand. They are regularly tended by several species of ant. Like the larvae of many other species in the Lycaenidae family, Miami blues secrete small amounts of sugar- and carbohydrate-rich droplets, which the ants feverishly consume. In return for the plentiful food, the ants protect their herbivorous companions from roaming predators and parasitoids by patrolling the surrounding plant and aggressively attacking intruders. The larvae can also emit an alarm, a chemical signal that calls nearby ants to rally at the first sign of trouble.

Once the preliminary field research was behind us, we were ready to plan the recovery. As part of a coordinated effort, state and federal agencies agreed to launch a breeding program for the butterfly early in 2003. With a starter nucleus of just a hundred eggs collected in the wild, we established a captive colony in our laboratories. The population grew rapidly in the months that followed; under artificial Florida "sun," hundreds of hungry caterpillars busily devoured the cut nicker bean we placed in rows of paper cups that served as their makeshift homes.

Accommodating the short-lived adults was somewhat more difficult. We maintained them naturally, in large outdoor flight cages, and observed them carefully. As soon as a female mated, we brought her back into the controlled conditions of the laboratory and placed her alongside a fresh leaf of nicker bean in a mesh-covered paper cup. In the wild, individual females deposit a dozen or more eggs a day on such tender leaves. Our hope was to get our females to live longer than their counterparts do in the wild, thereby increasing egg production and directly improving our conservation efforts.

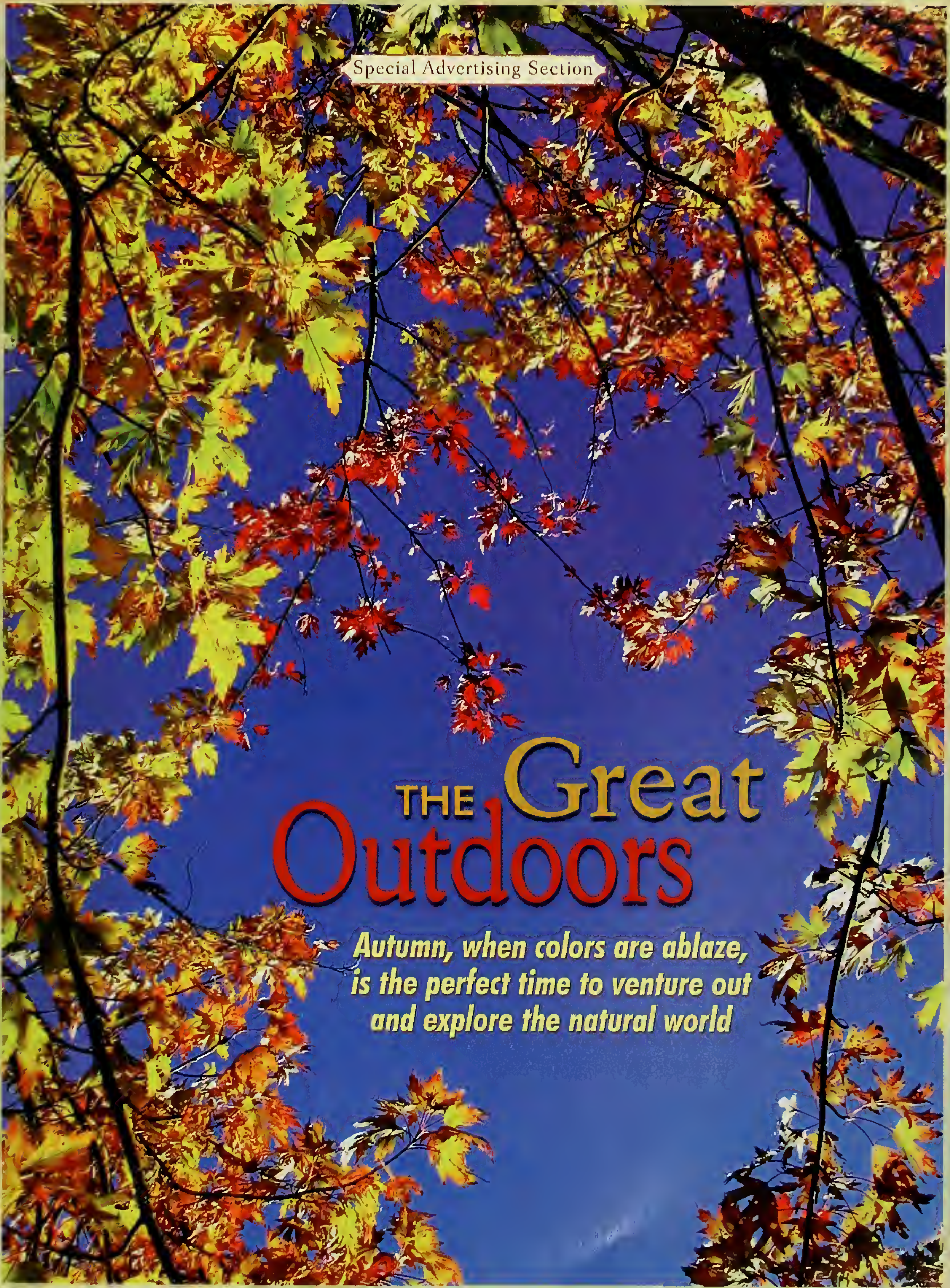
To keep our fragile beasts alive indoors without access to living flowers, we needed some kind of artificial nectar. We began by hand-feeding them several times a day. But the process proved both labor-intensive for us and stressful for them. After much trial and error, we devised a way for them to feed on their own schedule and without our touching them: In each paper cup we placed a cotton swab soaked in Fierce Melon–flavored Gatorade. By using this "artificial flower," we could periodically refresh the "nectar" with an insulin syringe, without disturbing the butterflies. And the Gatorade had the unexpected benefit of outperforming all the other forms of artificial nectar we tried, substantially enhancing the females' longevity. Some of them survived—and continued to lay eggs—for more than forty days!

As soon as our laboratory program was breeding plenty of butterflies, we scouted a variety of relatively inaccessible places in south Florida and ranked them as potential release sites for our captive-bred butterflies. Our first choices were in Everglades and Biscayne national parks, because they are remote and protected from direct human impact. To maximize our chances of establishing colonies, we planned to release both adult butterflies and fully grown caterpillars. The first reintroductions began in the spring of 2004 and continued throughout the year, ultimately ushering more than 2,500 Miami blues into the wild.

That might have been the happy ending to a simple story. But the chaotic weather of south Florida has posed a formidable challenge. In 2004 much of the state was in the midst of a prolonged drought, and the wilted landscape was less than ideal for the blues' survival. Still, at several of the release sites we monitored, we saw signs that the butterflies had subsequently reproduced.

The following year proved equally

(Continued on page 75)



THE Great Outdoors

Autumn, when colors are ablaze, is the perfect time to venture out and explore the natural world

ARIZONA

Steve Yoder

From red rocks and verdant forests to watercolor sunsets, Arizona is a state of vibrant variety

ARIZONA IS A LAND OF DRAMATIC RANGE, sweeping variety, and inspiring abundance, of deserts and forests, of towering saguaros and awe-inspiring canyons just short drives from bustling city life. Come autumn, the state is infused with stunning color. With a dazzling range of choices, lovers of the Great Outdoors can personalize their Arizona experience. Start your day on a Scottsdale golf course or bird-watch in Sierra Vista, then hit the slopes in Flagstaff before dinner. Explore the rugged morning desert by jeep and visit the ancient cliff dwellings or art galleries of Jerome in the afternoon. Boat on the Colorado River or hike breathtaking backwoods, then cap your day with a poolside massage or elegant dinner under the stars.

This fall, visit the Arboretum at Flagstaff to see the magnificent auburn hues of the sumac and bigtooth maple, and the golden tones of the willows. Stroll through the Mixed Conifer Habitat to see gold quaking aspen and reddish orange currant bush, and don't miss the Herb Garden, which boasts a beautiful display of Virginia creeper in brilliant reds. While in Flagstaff, stop by the Museum of Northern Arizona, whose mission is to inspire a sense of love and responsibility for the beauty and diversity of the Colorado Plateau through collecting,

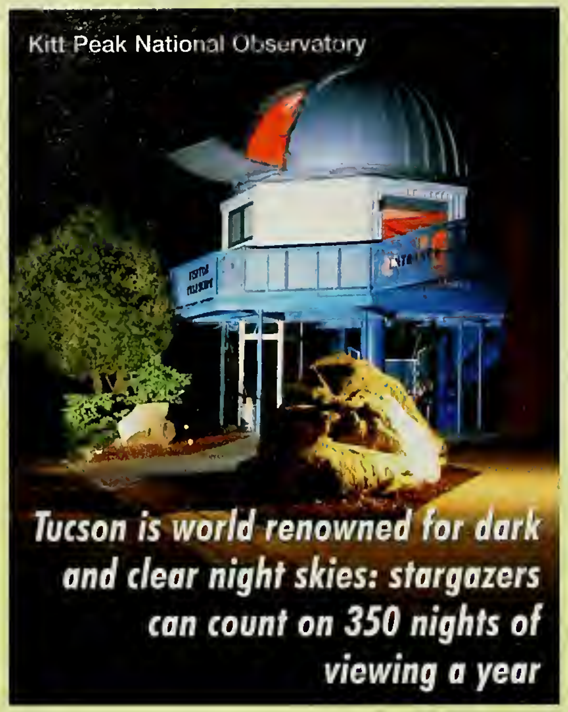
studying, interpreting, and preserving the region's natural and cultural heritage. Exhibits relate to the Museum's four main disciplines: anthropology, biology, geology, and fine art. The Museum has permanent exhibits in five galleries and changing exhibits in three additional galleries.

North of Sedona, a picturesque city surrounded by a unique geological area of red rock monoliths, you'll find Oak Creek Canyon, a breathtaking chasm along Highway 89A. Whether you hike or bike, you'll see a rainbow of colors this fall, from the rusts and golds of oak, sycamore, and aspen trees to the pinks of sugar maples. On your journey be sure to stop and inspect ancient Anasazi petroglyphs. With its elevation of 4,500 feet, at the upper margin of the Sonoran Desert, along with its distinct change of seasons and rich riparian areas, Sedona has a varied population of birds and so much more. Additional information is available at the District Ranger Station. With a vibrant variety of color, cultures, experiences. . .and choices, Arizona is worth a long visit any time of the year. For your free Arizona travel packet, call 1-877-636-2783 toll-free or visit arizonaguide.com.

Joel Grimes

Clockwise from left: The Arboretum at Flagstaff in the fall; Havasu Falls; Anasazi petroglyphs

TUCSON



Tucson is world renowned for dark and clear night skies: stargazers can count on 350 nights of viewing a year

WITH SOME OF THE CLEAREST SKIES IN THE U.S., and many of the world's most respected observatories, it's not surprising that southern Arizona is known as the Astronomy Capital of the World. Kitt Peak National Observatory, only a ninety-minute, scenic drive from Tucson, is perched high above the Sonoran Desert. It boasts the world's largest collection of optical telescopes and two radio telescopes. For an unforgettable experience, reserve a nighttime tour (tel. 520-318-8726), which introduces visitors to star charts, constellations, and state-of-the-art telescopes that open the mysteries of the universe.

Continuing south from Kitt Peak, visit the Fred Lawrence Whipple Observatory near Amado, Arizona, located at the base of Mount Hopkins, just 35 miles from Tucson. The Whipple features displays and exhibits on astronomy and astrophysics, including the history of optical telescopes from the time of Galileo to today. Guided, reserved-seat bus tours for the general public are conducted Mondays, Wednesdays, and Fridays from mid-March through November from 9:30 to about 3:00 p.m.; ride to the working research center and observatory at the mountain top, with spectacular views at 8,550 feet elevation along the way (tel. 520-670-5707).

One of the country's newest observatory complexes, Mt. Graham International Observatory is home to several renowned telescopes,

including the world's most powerful (tel. 928-428-2739). Don't leave Southern Arizona without spending several nights observing the skies on your own. Enjoy open country stargazing at the Empire-Cienega Resource Conservation Area, near Sonoita; or watch the stars all night long at the Astronomer's Inn (520-586-7906), a bed-and-breakfast near Benson with an observatory and planetarium.

Southern Arizona also is a birders' paradise, with a wide variety of species—especially hummingbirds, which are plentiful—viewable throughout the year. It's located along the migratory path between Canada and Mexico, guaranteeing some world-class birding. More than 200 birds have been recorded at Madera Canyon, an outstanding cross-section of Southwestern bird habitats from desert grassland to mountain forest. Miles of grassland, riparian woodland, and cienegas ("marshes") attract a host of species to Las Cienegas National Conservation Area, the site of a historic cattle ranch near Sonoita. And 275 species—including the rare gray hawk—have been spotted in the groves of cottonwoods and willows at Patagonia-Sonoita Creek Preserve. Between bird-watching and stargazing, take time out to visit the wealth of Spanish colonial missions and churches and surround yourself with Old West history. Start planning now—call 1-888-2-Tucson or go to visitTucson.org.

QUÉBEC CITY

Photos: Luc-Antoine Courturier

Snow geese at Cap Tourmente

Follow the Geese: It's Migration Time Around Québec City

Old Québec

IN 2008, QUÉBEC WILL CELEBRATE ITS 400TH ANNIVERSARY. Much has happened since Samuel de Champlain founded this beautiful city, marking the beginning of the French presence in North America. Many of Québec's ancestral families originated from the area of Côte-de-Beaupré, which from the end of September to mid-October is bursting with spectacular shades of red and gold. Enjoy the autumnal glory along footpaths and scenic spots dotting the coastal landscape, a never-ending source of inspiration for artists from near and afar. The Beaupré coast is the cradle of French civilization in North America, but it's also part of the migration path for more than a million greater snow geese in the spring and fall, a spectacle unique to Québec City.

You may also observe these magnificent birds—along with 305 other species—at the Cap Tourmente National Wildlife Area, at the heart of the Atlantic Flyway and one of the best bird-watching spots in Québec. This protected natural area is located on the north shore of the St. Lawrence River, where great coastal marshes, plains, and mountains meet. The best way to see the birds is to walk along Cap Tourmente's 20 kilometer (twelve-mile) network of trails which connects to 200 (120 miles) more kilometers of hiking trails, leading you past waterfalls—one taller than Niagara Falls—and including a 180-foot-high suspension bridge. Don't miss October's Snow Geese Festival (Festival de l'oie des neiges), which features family and cultural activities, an arts and crafts fair, and shows and entertainment related to the migration. For more information, call 418-827-4591.

Whatever the time of year, take a gondola ride to the top of Mont-Sainte-Anne to experience the breathtaking landscape below. From the summit, a stunning panorama unfolds itself in all directions, from Québec City to Charlevoix. Be sure not to miss out on the many fun activities in this area, which is known for its skiing but also offers horseback riding, golf, museum tours, and opportunities to shop for local arts and crafts. Come rain or shine, Québec promises to be great fun with family and friends.

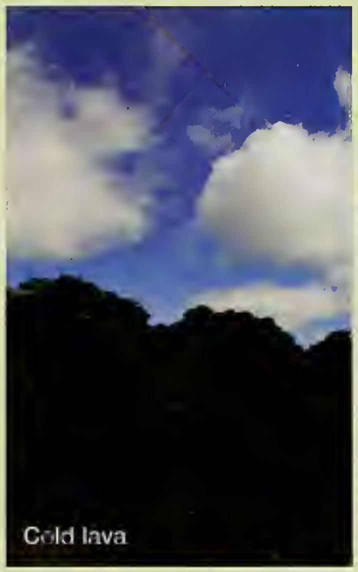
ICELAND

Spend part of your autumn in the land of fire and ice.

VOLCANOES, WATERFALLS, GEYSERS, GLACIERS, geothermal pools, and ancient lava fields: Iceland is a naturalist's paradise. Devotées of the great outdoors might ski in Akureyri, Iceland's second largest city, located 60 miles south of the Arctic Circle; take a snowmobile safari to a glacier; explore a lava field on a friendly, sure-footed Icelandic horse; or play a round of night-time golf underneath the midnight sun. Swimming is popular throughout the country, and most towns and villages have outdoor or indoor swimming pools filled with water from natural hot springs (temperatures average at 84 degrees).

For birdwatching, head to Latrabjarg in the West Fjords, the largest known bird cliff in the world, where you'll also find the largest razorbill colony in the world. Look for seabirds in the Westmann Islands, home to the world's largest puffin population; breeding ducks at Lake Myvatn in the north; and the great skua colony on the sands in South Iceland—the largest in the world.

Iceland's capital, Reykjavik, with its neighboring communities, has a population of around 180,000 and offers an interesting mix of cosmopolitan culture and local village roots. Best of all, you'll never be more than a 15-minute cab ride from the great outdoors.



Cold lava

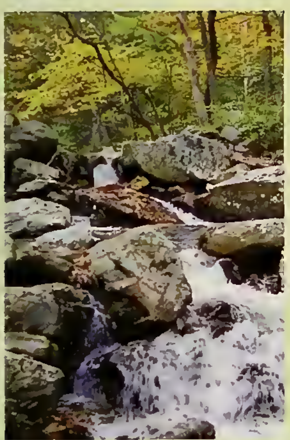
Skogafoss waterfall in southern Iceland

MARYLAND

Whether on its famed Eastern Shore or in the Capital Region, Maryland is the ideal state to experience autumn outdoors

DORCHESTER COUNTY

WITH 20 MILES OF LAND-TO-LAND BOUNDARY, Dorchester County is surrounded by the Choptank River, Chesapeake Bay and Nanticoke River. Acres of marshes, wetlands and coves makes this a natural place to explore the great outdoors. Dotted with fishing villages and waterfront restaurants, Dorchester County offers a glimpse into the waterman's way of life. This fall, pack your binoculars, bicycles or kayaks and head to Dorchester to experience some of the best bird-watching on the Eastern Shore, including the largest concentrations of breeding bald eagles on the East Coast, north of Florida. Blackwater National Wildlife Refuge, founded in 1933, attracts flocks of wintering waterfowl including thousands of ducks (twenty different kinds have been documented here), geese, and tundra swans as they head south on the Atlantic Flyway. Bike or drive along Wildlife Drive, which offers plenty of lookouts, or hike along trails, just off the drive, through pines and hardwoods. South and west of the refuge are Hoopers and Taylors Island where you can spot migrating songbirds and hawks that are especially prevalent in the fall. Adjoining Blackwater National Wildlife Refuge, you'll find 25,000 acres of tidal marsh and wetlands in Fishing Bay Wildlife Management Area. Excellent opportunities are available in this relatively untouched area for nature enthusiasts to drive or paddle in search of bald eagles, rails and assorted waterfowl.



FREDERICK COUNTY

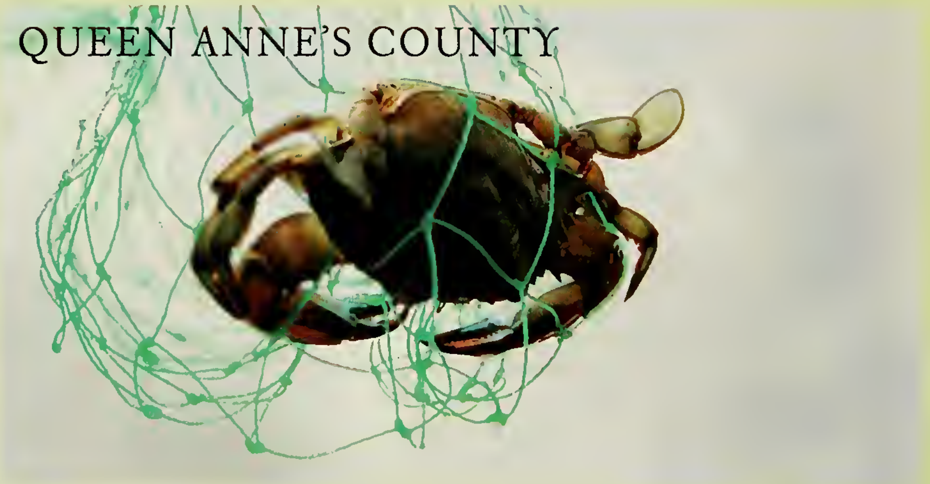
EVERY YEAR THOUSANDS OF PEOPLE travel to Frederick County to revel in the area's parks and recreational amenities. Highlighted by the Catoctin Mountains and the Potomac River, the county's 90 national, state, county, and municipal parks offer a wide variety of recreational activities such as swimming, boating, camping, skating, horseback riding, and nature programs in environments ranging from urban city parks to wilderness reserves. Wonderful outdoor experiences are to be enjoyed in every season.

Long popular with fly fishermen, Big Hunting Creek was first in the state of Maryland to be designated as a fly fishing only stream, then later became its first catch and return trout stream. Brook, brown, and rainbow trout spawn in the stream. A Maryland fishing license and trout stamp are required.

KENT COUNTY

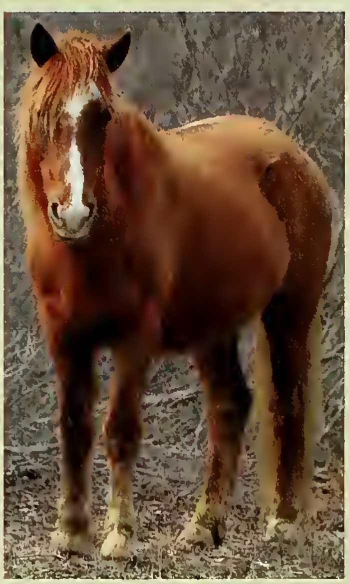
HISTORIC KENT COUNTY, ON MARYLAND'S Eastern Shore, is full of waterfront towns and stretches of low, rolling farmlands broken only by the tidewater tributaries of the Chesapeake Bay. Kent is a haven for fishing and boating enthusiasts, cyclists, birders, and—with its immense variety of plant and animal life—nature lovers. Explore the reeds and rushes of the tidal shore, home to ducks, geese, kingfishers, herons, and ospreys. These estuarine habitats also offer nearly ideal spawning and nursery conditions for many fish species, including alewife, shad, blue fish, perch, oysters, and the blue crab. Striped bass, known locally as rockfish, is perhaps the most prized fish found in these surrounding waters. Don't miss Eastern Neck National Wildlife Refuge, an unspoiled island with habitats characteristic of the Chesapeake region, from pine forests to meadows to tidal wetlands.

QUEEN ANNE'S COUNTY

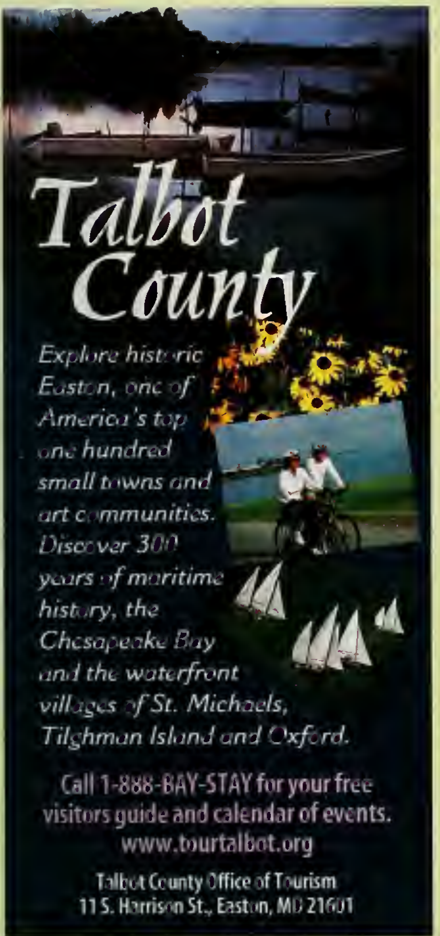


QUEEN ANNE'S COUNTY, FORMED IN 1706 WHEN MARYLAND was a royal colony, was named after the then-ruler of Great Britain and Ireland. Today the county is the gateway to the Eastern Shore of the Chesapeake Bay. Whether you want to try your hand at crabbing, fishing, boating, or water-skiing, it's hard not to find an opportunity to have fun on the water. The county's parks and trails beckon the weary traveler to stroll through woods ablaze with fall colors, fields, and marshland. Metapeake Park, a one-mile wood-chipped trail, nestled deep in a pine forest, provides an ideal location for spotting wildlife and plant species. The trail wanders through canopied woods and proceeds down to the Chesapeake Bay, where park patrons can observe breathtaking sunsets. Golfers will enjoy sweeping views of the Chester River at the Queenstown Harbor Golf Course. This 36-hole championship course boasts immaculately manicured bentgrass tees, greens, and fairways perfectly suited for a superb golfing experience.

WORCESTER COUNTY



FALL IS A PERFECT TIME FOR NATURE buffs to experience Worcester County, on Maryland's Eastern Shore. Maryland's only seaside county has the flat land and wide shoulders that cyclists treasure. The scenic Viewtrail 100, a bike trail that meanders through small roads in Worcester's unspoiled countryside, leads cyclists through farmlands and forests, along the Pocomoke River and cypress swamps, and is only a short distance from the Assateague National Seashore. You'll run across more than a few charming bed-and-breakfasts along the trail, and don't forget to stop for a meal of our famous crab cakes. With its variety of environments—including primeval forest and barrier island—it's not surprising that Worcester also has the best birding in Maryland. Almost 300 species have been sighted. In the fall, Assateague is home to such migratory species as peregrine falcons, merlins, and flocks of tree swallows; you'll see clusters of northern gannets as they pass just offshore.



NORTH OF DORCHESTER, YOU'LL find Talbot County, with over 600 miles of shoreline. Don't miss the Chesapeake Bay Maritime Museum in St. Michaels, with ten exhibit buildings, a 1879 Hooper Strait Lighthouse, and the largest collection of Chesapeake Bay traditional boats in the country. With the museum's Apprentice for a Day program (every Saturday and Sunday from 10:00 to 4:00), visitors can build a wooden skiff, or you can make your own arrangements to build your own boat with the museum's boatbuilders. Visit www.tourtalbot.org for a schedule of great fall events.

ORIENT LINES

"THE WORLD IS YOURS TO DISCOVER" is the philosophy of Orient Lines, the Destination Cruise Specialists. With its superb service and extraordinary cruises, Orient Lines guarantees a journey of luxury and learning in the four corners of the world. Its flagship, *Marco Polo*, travels to a series of European ports in October, ranging from Italy and the Riviera to an Adriatic and Aegean adventure.

In winter, Orient Lines explores the cultural diversity and natural splendor of South America and Antarctica on dazzling CruiseTours and Cruise Expeditions. You'll view the majestic Chilean fjords, Patagonia's wilderness, and visit the passionate cities of Buenos Aires, Montevideo, and Santiago. You may even venture to the magnificent Iguazú Falls. See the 2007 schedule at http://www.orientlines.com/calendar/calendar07.htm for all of Orient Lines' exciting sailings and shore excursions, including spectacular transatlantic crossings that revive the golden age of luxury cruising. Wherever you choose to go, you're likely to find the destination with Orient Lines.

GUATEMALA

San Pedro volcano across Lake Atitlan in Guatemala

Known for its Maya heritage and colonial cities, Guatemala is also a biologically rich country with quickly varying topography, making it the perfect place to take a Great Outdoors adventure.

CHOOSE FROM TEN ECOSYSTEMS, ranging from cloud forests tucked away in the mountains to lush jungles to mangroves on the coasts. In minutes you can travel from fog-covered forest to desert. There are 700 species of birds in the Land of the Quetzal.

Head about three hours west of Guatemala City to Lake Atitlan, whose waters reflect three of the country's 33 volcanoes. The lake is sprinkled with traditional Maya villages with markets where you can pick up Maya weavings and other indigenous items.

From here, determined birders can begin the climb to the top of Toliman volcano in search of the elusive horned guan. With a distinctive, coral-colored horn emerging from its forehead, the guan is in danger of extinction. It's partial to trees rather than the ground. Far easier to see at the foot of the volcanoes are two other natives, the pink-headed warbler and the azure-rumped tanager. The national bird, the quetzal, is found in mountainous forests.

Natural History Museum of Los Angeles County

naturalist

THE CALENDAR OF EVENTS FOR THE NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY

October 2006

Masters of Disguise

A still from *Gorilla at Large* (1954), starring the suited George Barrows and Anne Bancroft.

Photo from the Seaver Center for Western History Research, Natural History Museum of Los Angeles County. Courtesy Jane Jewell Barrows.


Find my Loot ...
or walk the plank!
A ghost ship has been spotted at the Natural History Museum with a ghastly one-legged apparition at the helm. Rumor has it, Peg-Leg Pete and his scurvy dogs are searching for their lost treasure.
Naturalist members ($275) and higher will be invited to join us on October 29, 2006 for a pirate-themed adventure at the third annual Haunted Museum. Fellows ($1,500) are invited to bring additional guests. Upgrade today and join us on this pirate adventure by calling 213-763-3512.
HAUNTED MUSEUM
Natural History Museum
of Los Angeles County

Polishing a Civic Jewel

Dear Friend,

This fall we prepare for the restoration and seismic strengthening of our 1913 Building. Originally a freestanding structure, the Los Angeles County Museum of History, Science, and Art was the first museum in the city to open its doors on November 6, 1913. The civic celebration that took place also saw the debut of Exposition Park's State Exposition Building and the groundbreaking for the Armory. To commemorate the completion of William Mulholland's Los Angeles Aqueduct the day before, a fountain of water shot into the air from the center of what is now the rose garden.

Because of the auspicious timing of the Museum's opening and the beauty of its Beaux Arts-inspired design, writers at the time noted that the Museum signified the birth of Los Angeles as a cultural center.

The building's patterned red brick exterior featured arched windows, terracotta ornamentation, and an arcaded formal entrance. Its focal point was, and remains, a rotunda surrounded by scagliola columns, fitted marble walls, and topped by a painted glass dome. Seven months after the Museum's opening, Julia Bracken Wendt's bronze sculpture "The Spirit of History, Science, and Art" was unveiled in the center of the rotunda. It was the first public statue funded by Los Angeles County.

Our Museum began with a strong history collection and a growing trove of fossils excavated at the La Brea Tar Pits. Its holdings quickly outgrew the original building's three wings, and substantial additions were completed between 1924 and 1930, including the Grand Foyer and four diorama halls.

The 1913 Building – or "Rotunda" as it is also known – is still remarkable and is included in the National Register of Historic Places. By preserving this civic jewel, we also preserve our connection to a formative time in Los Angeles' history, when the city's cultural landscape was beginning to take shape. The Museum was at the forefront of civic progress then, and today, with our mission to inspire wonder, discovery and responsibility in our natural and cultural worlds, we continue to play a pivotal role in its enrichment.

Sincerely,

Jane G. Pisano
President and Director

"Our mission is to inspire wonder, discovery and responsibility for our natural and cultural worlds."

photos by Leslie Harris

Our Masters of Disguise

The natural world is filled with things that look like other things, and sometimes, things that look like nothing at all. Humankind also has a penchant for illusion, though of course our goals are different. While animals use disguise for survival, we use it to teach, worship, entertain, and especially this time of year, to trick. Since October is a month rife with illusion, let's look at how a few of our specimens incorporate the art, and science, of disguise.

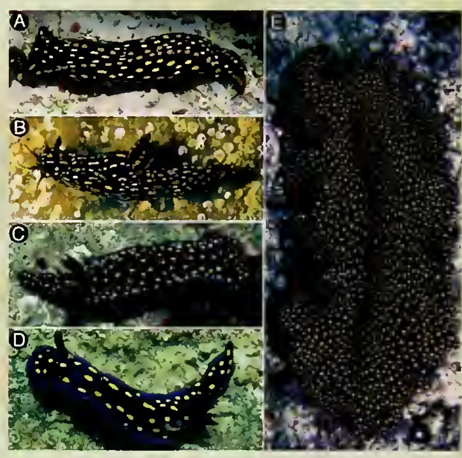
courtesy of the Anthropology Department, Natural History Museum of Los Angeles County

The Museum's Anthropology Department boasts costume elements from all over the world. Its mask collection includes the rare copper *tigre* (above) from the Mexican state of Guerrero, probably made in the early 20th century. Our History Department offers a glimpse inside another world of illusion – the entertainment industry. The Museum's early Hollywood collection is one of the world's most significant, with artifacts such as George Barrows' self-made gorilla suit (seen on the *Naturalist* cover), which appeared in several films and television shows. Other highlights include the belongings of actor and disguise impresario Lon Chaney. On the back page, Chaney is in his *Phantom of the Opera* (1925) costume, holding a makeup kit that now belongs to the Museum.

There are stick insects and katydids in our Insect Zoo that resemble the branches and leaves they live in. Our dioramas also show animals blending into their backgrounds. The North American Mammal Hall's artic fox, for example, is one of several species that alternates between a white winter coat and a brown summer coat to blend in with snow and dirt, respectively.

But perhaps the most diverse theater of disguise is the world's oceans. Carrier crabs devote hind legs to toting anemones or carved out sponges on their backs. Decorator crabs have Velcro-like hairs that allow them to attach shells and bits of seaweed to their exoskeletons, making them indistinguishable from the ocean floor. (The decorator above is shown with and without its algae and sea squirt costume.) Many don't use accessories at all: Stonefish look like rocks, for example, kelpfish like seaweed fronds, and shrimpfish like the spines of a sea urchin.

Below is a "mimicry complex," a group of normally unrelated organisms that share a color pattern for defensive purposes. The animal in figure A is a shell-bearing sea slug; B, C, and D are nudibranchs; E is a flat worm. At least B, C, and D have very toxic chemical defenses, and it's likely that A and E mimic the toxic species so predators confuse them and don't attack. And you thought two Wonder Womans at the same Halloween party was a curious phenomenon.



photos by Angel Valdés

Whatever a disguise's motivation – from survival to a little trick-or-treat candy – there has always been power in appearing as something "other."

—*Kristin Friedrich*

N NATURAL HISTORY MUSEUM

Through November 5, 2006

After the butterflies have gone, spiders take over our south lawn habitat. Curb your arachnophobia as you watch amazing Orb Weavers spin their webs, and then stick around to see what happens at feeding time! *Adults $3; Students and Seniors $2; Children (5-12) $1. Tickets are sold in half-hour time slots throughout the day. Members receive FREE admission and the first available tickets.*

photo by Gary Leonard

Support for family programs is provided by the Brotman Foundation of California Support for Critter Club is provided by the Gary Saltz Foundation and Transamerica. Support for family and children's programs is provided by Dinosoles (www.dinosoles.com/nhmla).

the Pleistocene GARDEN

photo by Robert Russell Reid

P PAGE MUSEUM

Open year round

Walk in the footsteps of the great saber-toothed cat and ancient ground sloth in this blooming Ice Age garden that was planted to resemble what Hancock Park might have looked like 10,000 to 40,000 years ago. Learn about how the land has changed, and admire the reintroduced native species of coastal sage scrub and chaparral plants that once thrived here.

critter club

Super Spiders

N NATURAL HISTORY MUSEUM

Saturday, October 14, 2006

10 am – 11 am

Visit our fabulous Spider Pavilion and learn all about awesome arachnids! We'll watch spiders eat their lunch, create a creeping craft, and hear spider stories! *All programs are FREE with paid Museum admission. Events are available on a first-come, first-served basis. No reservations are required. For more information about the Critter Club, please contact the Discovery Center at (213) 763-3230.*

Fossil Hunting in Silverado Canyon

Saturday, October 21, 2006

9:30 am - 12:00 pm

Search for marine fossils with Lindsey Groves, Collection Manager of Malacology, and LouElla Saul, former Collection Manager of Invertebrate Paleontology and current Museum Research Associate. This rich fossil site is a great place to get some dirt under your nails right along with Museum scientists. Bring a bag for your best finds. Participants provide their own transportation. *Grades 2 and up, accompanied by an adult. Members $29; General Admission $39.*

SCAVENGER'S SAFARI

FOR PATRON FAMILY MEMBERS!

Squids Will Be Squids

N NATURAL HISTORY MUSEUM

Saturday, October 21, 2006
11 am: Kids and Family tour
12 pm: Adults only tour

On this special safari, we'll go behind the scenes with Curator of Malacology Dr. Ángel Valdés. He will show us the highlights of the Museum's mollusk collections, including sea shells, naked mollusks, and even a giant squid – which is the biggest mollusk and the world's largest invertebrate! Following our tour, we'll take a guided scavenger hunt through the galleries on a mollusk-themed adventure. *Safaris are FREE with Patron Family membership ($165 per year). Reserve your space early by calling (213) 763-3426.*

photo by Dick Meier

Music in the Mansion

H WILLIAM S. HART MUSEUM

Saturday, October 21, 2006
7:30 pm – 9:30 pm

Cozy up with us inside William S. Hart's living room for a special performance by pianist Steven Schneider and cellist Jerome Kessler. Enjoy the music of Bach, Boccherini, Schumann, Shostakovich, and other famous classical composers. An artists reception will follow. *Members $20; Nonmembers $25; Children 12 and under $10. Reserve your space early by calling (661) 254-4584.*

photo by Dick Meier

Boo and Goo Family Overnight Adventure

P PAGE MUSEUM

Friday, October 27 at 7 pm through Saturday, October 28 at 9 am

Tour the Tar Pits at night, surrounded by mammoths and mastodons. Wear your costume and bring your sleeping bag, air mattress, and flashlight. Snack and breakfast provided. Ages 5 and up accompanied by an adult. *Reservations required, call (213) 763-ED4U. Members $40; Nonmembers $45.*

N NATURAL HISTORY MUSEUM

Sunday, October 29, 2006

The Museum has been marauded by pirates and we need your help making things shipshape again. Naturalist level members and higher ($275 annually) are invited to join us on this swashbuckling adventure, and Fellows are invited to bring additional guests. *To upgrade or join, call (213) 763-3426 or visit nhm.org/membership.*

Group Overnight Adventures

N NATURAL HISTORY MUSEUM

P PAGE MUSEUM

Through May, 2007

Ever wonder what goes on in the Museum at night? Come spend the night at either the Natural History Museum or the Page Museum at the La Brea Tar Pits and find out! Enjoy fun and educational activities with your group and wake up in the morning surrounded by fossils. *Minimum of 10 participants per group. Advanced reservations required. Child to adult ratio is 6:1. Please call (213) 763-3535 for more information or visit www.nhm.org.*

critter club

Cold Weather Quest

N NATURAL HISTORY MUSEUM

Saturday, November 11, 2006

Birds fly south for the winter, but what do turtles do? Help us find winter habitats for our animal friends. Critter Club is hands-on fun! *All programs are FREE with paid Museum admission. Events are available on a first-come, first-served basis. For more information about the Critter Club, please contact the Discovery Center at (213) 763-3230.*

Tourmaline Dreams

OFF SITE FIELD TRIP

Sunday, November 19, 2006

Explore a San Diego County tourmaline mine with Dr. Anthony Kampf, Curator of Mineralogy. Upgrade your membership to the Fellows level and receive an invitation to this exciting event. *Call (213) 763-3316 or visit www.nhm.org/fellows to learn more.*

SUN	MON	TUES	WED	THURS	FRI	SAT
OCT 1	2 Yom Kippur	3 Free Tuesday	4	5	6	7 USC Football Game (TBA)**
8	9 Columbus Day (Museum opens at 10 am)	10			13	14 N Critter Club USC Football Game (5 pm)**
		17			20	21 N Scavenger's Safari H Music in the Mansion
22	23	24			27 P Boo and Goo Family Overnight Adventure	28 P Boo and Goo Family Overnight Adventure
29 N Haunted Museum	30	31 Halloween	1	2	3	4
NOV 5 N Spider Pavilion closes	6	7 Free Tuesday	8	9	10	11 N Critter Club


photo by Dick Meier


photo from the Seaver Center for Western History Research

**Please note: Strict parking and traffic rules will apply.

every day at NHM

time	activity	location
Mornings	Fossil Cleaning Demonstration	Dinosaur Hall
11:00 am*	Live Animal Presentation	Discovery Center
12:00 noon*	Story Time with Crafts	Discovery Center
1:30 pm*	Tarantula Feeding	Discovery Center
2:00 pm	Story Time with Crafts	Discovery Center
2:00 pm	Gallery Adventure Tour	Dueling Dinosaurs
3:00 pm	Live Animal Presentations	Discovery Center
Afternoons	Learning Adventures	Dueling Dinosaurs

Page Museum

time	activity	location
1:00 pm	Hancock Park and Pit 91 Tour	Page Museum
2:15 pm	Gallery Adventure Tour	Page Museum

*These activities take place on Saturdays and Sundays only

N Natural History Museum of Los Angeles County
900 Exposition Blvd.
Los Angeles, CA 90007
www.nhm.org
213-763-DINO
213-763-3569 (TTY hearing impaired)

P Page Museum La Brea Tar Pits
5801 Wilshire Blvd.
Los Angeles, CA 90036
www.tarpits.org
323-934-PAGE

H William S. Hart Museum
24151 San Fernando Rd.
Newhall, CA 91321
www.hartmuseum.org
661-254-4584

TASMANIA

Dove Lake and Cradle Mountain

Tasmania's isolation and ancient landscape make it a bird watcher's hideaway, with 12 endemic species and nearly 200 other species of Australian birds throughout Tasmania and its 300 islands.

LOCATED IN THE SOUTHERN Ocean, Tasmania has a small landmass, but over 2,000 miles of coastline. Unlike mainland Australia, the landscape is mountainous, with rugged untouched valleys, snow-covered peaks, and broad sweeping buttongrass plains. On the western side of the island, swept clean by the winds of the Roaring Forties and washed by more than 100 inches of rain, you'll find coastal heaths, wetlands, and dense rainforests of ancient Gondwana relics including Antarctic Beech and endemic softwood pines. On the warmer, much drier eastern side, the white sandy beaches drift into coastal heath, sheltered lagoons, and dry eucalyptus forests. This diverse landscape offers a mosaic of habitats in which birds can live. Because of its isolation, Tasmania is one of the few places in the world—along with the Amazon, the Galapagos, and Mauritius—where the entire island is identified as an Endemic Bird Area. All but two of Tasmania's endemic species are relatively widespread and while spring (September to December) is always the best time to see birds, most Tasmanian endemics can be seen all year round.

NATURAL HISTORY
OCTOBER 2006

Sociable Killers

New studies of the white shark (aka great white) show that its social life and hunting strategies are surprisingly complex.

By R. Aidan Martin and Anne Martin

It's twenty past seven on a winter morning. Our research vessel drifts off Seal Island, South Africa. A lone Cape fur seal pup porpoises through the gently rolling swells toward the island. Suddenly, a ton of white shark launches from the water like a Polaris missile, the little seal clamped between its teeth. Framed against purple clouds washed with the orange light of breaking dawn, the shark clears the surface by an astonishing six feet. It hangs, silhouetted in the chill air for what seems an impossibly long time before it falls back into the sea, splashing thunderous spray beneath a gathering mob of seabirds. We and our crew of five student volunteers watch breathlessly as the drama unfolds. Now mortally wounded and lying on its side at the surface, the seal raises its head and weakly wags its left foreflipper.

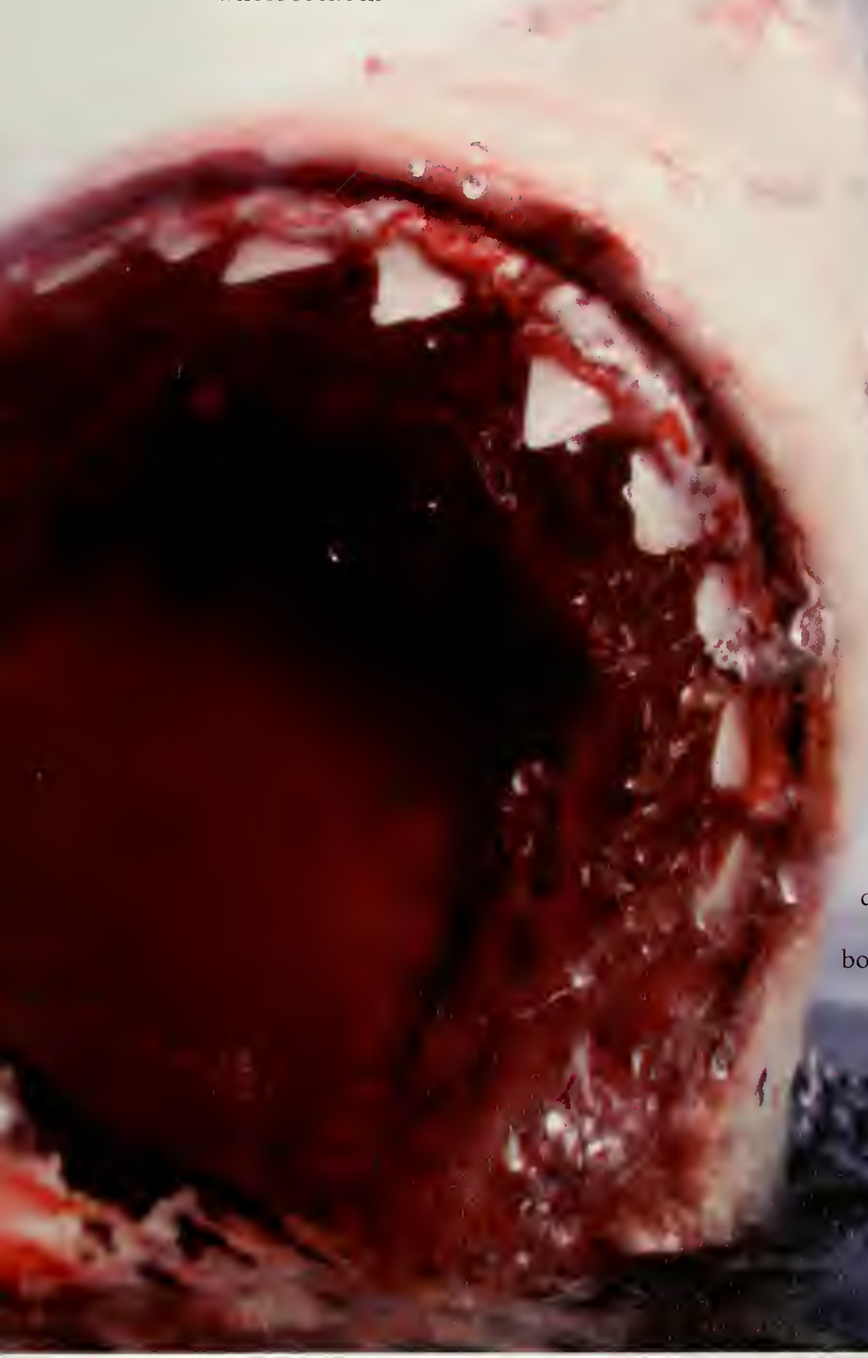
The shark, an eleven-and-a-half-foot male we call Sneaky, circles back unhurriedly and seizes the hapless pup again. He carries it underwater, shaking his head violently from side to side, an action that maximizes the cutting efficiency of his saw-edged teeth. An ominous blush stains the water and the oily, coppery smell of the wounded seal prickles our nostrils. The seal carcass floats to the surface while gulls and other seabirds compete vigorously for its entrails, squawking avian obscenities at one another. Sneaky returns to his meal, and another white shark rises from below—a thirteen-foot male we call Couz.

For white sharks (also known as great whites), socializing trumps dining. Sneaky turns his attention to Couz. Is he friend or foe? Of higher or lower rank? For half a minute, Sneaky and Couz swim side by side, warily sizing each other up as white sharks do when they meet. All of a sudden, Sneaky hunches his back and lowers his pectoral fins in response to the threat posed by the larger shark [*see illustration of "hunch display" on page 44*], whereupon he and Couz veer apart. As we record their interactions, a female sweeps in and usurps the remains of Sneaky's abandoned meal. Then calm returns to the sea. Just six minutes have passed since the seal pup was innocently making its way to shore.

Watching such ferocious predatory assaults and intense socializing is a shark biologist's dream. In fact, despite the white shark's reputation as the animal kingdom's

White shark, or great white, emerges from the depths off the port town of Gansbaai, southeast of Cape Town, South Africa. The white shark's eclectic diet includes crabs, snails, squid, fish, and other sharks. But its preferred repast is seal and sea lion, particularly the young, whose thick blubber makes for a calorie-rich meal. Each year white sharks return to seal hotspots, such as Seal Island in nearby False Bay, to prey on seal pups just learning to fish at sea.

überpredator, surprisingly little is known about the basics of its foraging behavior: its hunting tactics, its feeding cycle, its preferences in prey. Its migration routes and favorite hunting grounds, aside from the waters around Seal Island and several other places, remain largely unknown. And even less is known about its social behavior. Most people—at least since the movie *Jaws*—assume the creatures are solitary, stupid, antisocial brutes. But after observing the white sharks at Seal Island for eight seasons, and documenting more than 2,500 predatory attacks, we have arrived at quite a different opinion. Our research demonstrates that white sharks are intelligent, curious, oddly skittish creatures, whose social interactions and foraging behavior are more complex and sophisticated than anyone had imagined.



Nowhere is that social and foraging behavior on more vivid display than at Seal Island, a rocky, five-acre islet in False Bay, twenty-two miles south of Cape Town. The island is home to some 64,000 Cape fur seals, plus thousands of cormorants, gulls, penguins, and other seabirds. Mother fur seals give birth here in the spring, around the end of December. By early May the pups are joining their older siblings on fishing trips into False Bay and beyond. That's when the white sharks start showing up—from parts unknown—to hunt the young-of-the-year pups.

Chris Fallows and Rob Lawrence, South African naturalists based in Simon's Town on False Bay, discovered the site's attractions in 1995, when they observed the sharks' vigorous seasonal predatory activity and their remarkable aerial hunting style. (Both behaviors can be observed elsewhere, but far less frequently than at Seal Island.) At Fallows and Lawrence's invitation, we visited Seal Island in 2000 to see for ourselves. Since then we have returned each southern winter to continue studying the remarkable behavior of the white shark.

In the popular imagination, *Carcharodon carcharias* is the quintessential predator. The largest of all predatory sharks, it reaches a length of more than twenty feet and a weight of 4,500 pounds. The white shark possesses acute color vision, the largest scent-detecting organs of any shark, and sensitive electroreceptors that give it access to environmental cues beyond human experience.

As for habitat, the white shark prefers cool and temperate seas worldwide. Its brain, swimming muscles, and gut maintain a temperature as much as twenty-five Fahrenheit degrees warmer than the water. That enables white sharks to exploit cold, prey-rich waters, but it also exacts a price: they must eat a great deal to fuel their high metabolism.

The white shark's diet includes bony fish, crabs, rays, sea birds, other sharks, snails, squid, and turtles, but marine mammals may be its favorite meal. Many of them are big, powerful animals in their own right, but predators with the means to catch them hit caloric pay dirt when they sink their teeth into the mammals' thick layer of blubber. Pound for pound, fat has more than twice as many calories as protein. By one estimate, a fifteen-foot white shark that consumes sixty-five pounds of whale blubber can go a month and a half without feeding again. In fact, a white shark can store as much as 10 percent of its body mass in a lobe of its stomach, enabling it to gorge when the opportunity arises (such as when it encounters a whale carcass) and live off its hoard for extended periods. Usually, though, white sharks eat more moderately.

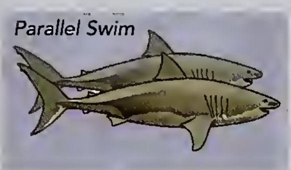
How does a white shark decide what to eat? A model known as optimal foraging theory offers a mathematical explanation of how predators weigh the calorie content of food against the energetic cost of searching for it and handling it. According to the theory, predators employ one of two basic strategies: they seek to maximize either energy or numbers. Energy maximizers selectively eat only high-calorie prey. Their search costs are high, but so is the energy payoff per meal. Numbers maximizers, by contrast, eat whatever kind of prey is most abundant, regardless of its energy content, thereby keeping per-meal search costs low.

Based on optimal foraging theory, A. Peter Klimley, a marine biologist at the University of California, Davis, has proposed an intriguing theory about the feeding behavior of the white shark. According to Klimley's theory, white sharks are energy maximizers, so they reject low-fat foods. That neatly explains why they often feed on seals and sea lions but rarely on penguins and sea otters, which are notably less fatty. As we mentioned earlier, however, white sharks eat many other kinds of prey. Although those prey may be low-cal, compared with sea mammals, they may also be easier to find and catch, and thus sometimes energetically more attractive. It seems likely that white sharks follow both strategies, depending on which is the more profitable in a given circumstance.

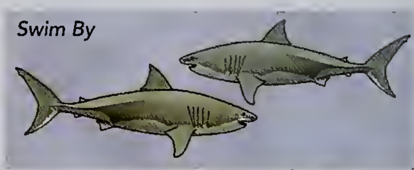
Of all marine mammals, newly weaned seals and sea lions may offer the best energy bargain for white

High Society

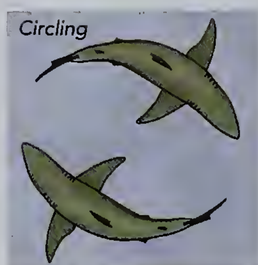
White sharks engage in at least twenty distinct social behaviors; eight are shown below. The significance of the behaviors remains largely unknown, but many help the sharks establish social rank and avoid physical conflict.



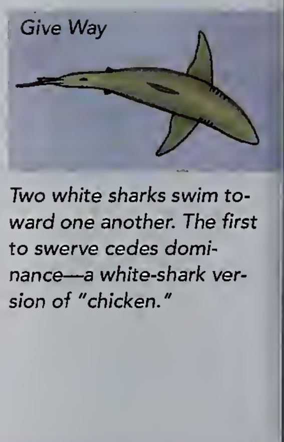
Two white sharks swim slowly, side by side, several feet apart, perhaps to compare size and establish rank, or to determine ownership of a disputed kill. The submissive shark flinches and swims away.



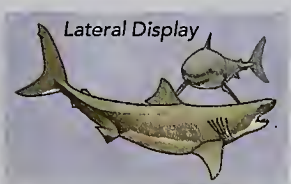
Two white sharks glide slowly past each other in opposite directions, several feet apart. They may be comparing sizes to determine which is dominant, or simply identifying each other.



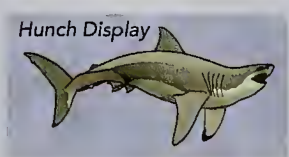
Two or three white sharks follow one another in a circle, perhaps to identify one another or to determine rank.



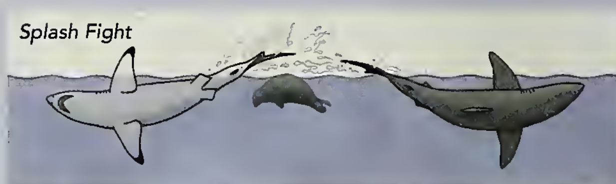
Two white sharks swim toward one another. The first to swerve cedes dominance—a white-shark version of "chicken."



White shark in foreground stretches out perpendicular to another shark for a few seconds, perhaps to show off its size and establish dominance.



White shark arches its back and lowers its pectoral fins for several seconds in response to a threat, often from a dominant shark, before fleeing or attacking.



Two sharks splash each other with their tails, a rare behavior, apparently to contest the ownership of a kill. The shark that makes the most or biggest splashes wins, and the other accepts a submissive rank. A single shark may also splash another to establish dominance or contest a kill.

sharks. They have a thick layer of blubber, limited diving and fighting skills, and a naïveté about the dangers lurking below. Furthermore, they weigh in at about sixty pounds, a good meal by anyone's standards. Their seasonal presence at certain offshore islands—Seal Island, the Farallon Islands off San Francisco, and the Neptune Islands off South Australia—draws white sharks from far and wide. Each winter, white sharks drop by Seal Island for between a few hours and a few weeks, to feast on young-of-the-year Cape fur seals. White sharks that visit either Seal Island or the Farallon Islands come back year after year, making those islands the marine equivalent of truck stops.

Cape fur seals surf the waves at Seal Island. Seals maintain nearly constant vigilance for white sharks and watch each other carefully for signs of alarm.

Far from being the indiscriminate killers the movies have portrayed, white sharks are quite selective in targeting their prey. But on what basis does a shark select one individual from a group of superficially similar animals? No one knows for sure. Many investigators think predators that rely on single-species prey groups, such as schools of fish or pods of dolphins, have developed a keen sense for subtle individual differences that indicate vulnerability. An individual that lags behind, turns a little slower, or ventures just a bit farther from the group may catch the predator's eye. Such cues may be at work when a white shark picks a young, vulnerable Cape fur seal out of the larger seal population at Seal Island.

The location and timing of predatory attacks are also far from indiscriminate. At high tide on the Farallon Islands, for instance, there is heavy competition for space where northern elephant seals can haul themselves onto the rocks, and the competition forces many low-ranking juvenile seals into the water. Klimley—along with Peter Pyle and Scot D. Anderson, both wildlife biologists then at the Point Reyes Bird Observatory in California—has shown that at the Farallons, most white-shark attacks take place during high tide, near where the mammals enter and exit the water.

Similarly, at Seal Island, Cape fur seals leave for their foraging expeditions from a small rocky outcrop nicknamed the Launch Pad. Coordinated groups of between five and fifteen seals usually leave together, but they scatter while at sea and return alone or in small groups of two or three. White sharks attack almost any seal at Seal Island—juvenile or adult, male or female—but they particularly target lone, incoming, young-of-the-year seals close to the Launch Pad. The incoming seal pups have fewer compatriots with which to share predator-spotting duties than they do in the larger outgoing groups. Furthermore, they're full and tired from foraging at sea, making them less likely to detect a stalking white shark.

The white shark relies on stealth and ambush when hunting seals. It stalks its prey from the obscurity of the depths, then attacks in a rush from below. Most attacks at Seal Island take place within two hours of sunrise, when the light is low. Then, the silhouette of a seal against the water's surface is much easier to see from below than is the dark back of the shark against the watery gloom from above. The shark thus maximizes its visual advantage over its prey. The numbers confirm it: at dawn, white sharks at Seal Island enjoy a 55 percent predatory success rate. As the sun rises higher in the sky, light penetrates farther down into the water, and by late morning their success rate falls to about 40 percent. After that the sharks cease hunting actively, though some of them return to the hunt near sunset.

But Cape fur seals are hardly helpless victims. They are big, powerful predators in their own right, and take defensive advantage of their large canine teeth and strong claws. They also exhibit a remarkable range of antipredator tactics. Swimming quickly in small groups to or from the Launch Pad minimizes their time in that high-risk zone, and they remain in the relative safety of the open sea for extended periods. When they detect a white shark, seals often do a headstand, vigilantly scanning underwater with

Repetitive Aerial Gaping

White shark holds its head above the surface, repeatedly gaping its jaws, often after failing to capture a decoy. The behavior may be a socially non-provocative way to vent frustration.

their rear flippers in the air. They also watch one another closely for signs of alarm. Alone, in pairs, or in threes, Cape fur seals occasionally even follow a white shark, swirling around it as if to let the would-be predator know its cover has been blown.

To avoid a shark attack, seals may leap in a zigzag pattern or even ride the pressure wave along a shark's flank, safely away from its lethal jaws. If an attacking shark does not kill or incapacitate a seal in the initial strike, superior agility now favors the seal. The longer an attack continues, the less likely it will end in the shark's favor. Cape fur seals never give up without a fight. Even when grasped between a white shark's teeth, a Cape fur seal bites and claws its attacker. One has to admire their pluck against such a formidable predator.

After the morning flush of predatory activity at Seal Island, white sharks turn to socializing. We have discovered, by observing both from the surface and with underwater cameras, that the social behavior of these sharks is astonishingly complex. During the past five years, we have cataloged twenty distinct social behaviors in white sharks at Seal Island, half of which are new to science. We are just beginning to understand their significance, but many are related to establishing social rank [*see illustrations on preceding two pages*].

Even when grasped between a white shark's teeth, a Cape fur seal bites and claws it attacker.

Rank appears to be based mainly on size, though squatter's rights and sex also play a role. Large sharks dominate over smaller ones, established residents over newer arrivals, and females over males. Why such a focus on rank? The main reason is to avoid combat. As many as twenty-eight white sharks gather at Seal Island each day during the winter seal-hunting season, and competition among them for hunting sites and prey is intense. But since white sharks are such powerful, heavily armed predators, physical combat is a risky prospect. Indeed, unrestrained combat is extremely rare. Instead, the white sharks at Seal Island reduce competition by spacing themselves while hunting, and they resolve or avert conflicts through ritual and display.

At Seal Island, white sharks arrive and depart year after year in stable "clans" of two to six individuals. Whether clan members are related is unknown, but they get along peacefully enough. In fact, the social structure of a clan is probably most aptly compared to that of a wolf pack: each member has a clearly established rank, and each clan has an alpha leader. When members of different clans meet, they establish social rank nonviolently through any of a fascinating variety of interactions.

For example, as was the case with Sneaky and Couz, two white sharks often swim side by side, possibly to compare their relative sizes; they may also parade past each other in opposite directions or follow each other in a circle. One shark may direct splashes at another by thrashing its tail, or it may leap out of the water in the other's presence and crash to the surface. Once rank is established, the subordinate shark acts submissively toward the dominant shark—giving way if they meet, or avoiding a meeting altogether. And rank has its perks, which can include rights to a lower-ranking shark's kill.

Another form of nonviolent, tension-diffusing behavior often takes place after a shark repeatedly fails to catch bait (typically a tuna head) or a rubber seal decoy: the shark holds its head above the surface while rhythmically opening and closing its jaws. In 1996 Wesley R. Strong, a shark investigator then affiliated with the Cousteau Society in Hampton, Virginia, suggested the behavior might be a socially nonprovocative way to vent frustration—the equivalent of a person punching a wall.

White sharks have a number of markings that may serve a social purpose. The pectoral fins, for instance, feature black tips on the undersurface and white patches on the trailing edge. Both markings are all but concealed when the sharks swim normally, but are flashed during certain social interactions. And a white patch that covers the base of the lower lobe of the shark's two-pronged tail may be important when one shark follows another. But if those markings help white sharks signal to one another, they may also make the sharks more visible to their prey. And if so, the trade-off between camouflage and social signaling demonstrates the importance of social interactions among white sharks.

Complex social behaviors and predatory strategies imply intelligence. White sharks can certainly learn. The average shark at Seal Island catches its seal on 47 percent of its attempts. Older white sharks, however, hunt farther from the Launch Pad and enjoy much higher success rates than youngsters

Female white shark, about eleven feet long, attacks a seal decoy off Simon's Town, near Seal Island. Spectacular aerial attacks on seals are more common in False Bay than anywhere else. White sharks rush their quarry from directly below; the power of the attack often hurtles both predator and prey out of the water.

do. Certain white sharks at Seal Island that employ predatory tactics all their own catch their seals nearly 80 percent of the time. For example, most white sharks give up if a seal escapes, but a large female we call Rasta (for her extremely mellow disposition toward people and boats) is a relentless pursuer, and she can precisely anticipate a seal's movements. She almost always claims her mark, and seems to have honed her hunting skills to a sharp edge through trial-and-error learning.

We are also learning that white sharks are highly curious creatures that systematically escalate their explorations from the visual to the tactile. Typically, they nip and nibble to investigate with their teeth and gums, which are remarkably dexterous and much more sensitive than their skin. Intriguingly, highly scarred individuals are always fearless when they make "tactile explorations" of our vessel, lines, and cages. By contrast, unscarred sharks are uniformly timid in their investigations. Some white sharks are so skittish that they flinch and veer away when they notice the smallest change in their environment. When such sharks resume their investigations, they do so from a greater distance. In fact, over the years we have observed remarkable consistency in the personalities of individual sharks. In addition to hunting style and degree of timidity, sharks are also consistent in such traits as their angle and direction of approach to an object of interest.

Young seal that survived a white-shark attack makes its way on Seal Island.

Any discussion of white sharks must acknowledge their occasional, though much-publicized, "attacks" on people. The vast majority of them, however, bear no resemblance to shark attacks on prey. The attacks on people are slow and deliberate, and the resulting wounds are relatively minor compared with the wounds inflicted on prey. About 85 percent of the victims survive. Deaths do occur from blood loss, but there are very few verified cases in which a white shark actually consumed a person. Clearly, we are not on their menu.

Klimley suggests that, compared with blubbery marine mammals, people are simply too muscular to constitute a worthwhile meal. Our view is different: we believe that white sharks probably bite people not to eat them but to satisfy their curiosity. Fortunately, the shark's investigation of a person is usually interrupted by the victim's brave companions.

For all the fear white sharks inspire, it is ironic that people probably pose the single greatest threat to white sharks. People kill them for sport and trophies, and hunt them to reduce their populations near swimming and surfing beaches. In addition, there's a flourishing and lucrative black market in white-shark jaws, teeth, and fins, even though such trade is illegal under international law. White sharks take between nine and sixteen years to reach maturity, and females give birth to just two to ten pups every two or three years. Such a life in the slow lane makes the white shark extremely vulnerable to even moderate levels of fishing.

In recent studies, electronic tags attached to individual white sharks and monitored by satellites have shown that the animals can swim thousands of miles a year. One individual swam from Mossel Bay, South Africa, to Exmouth, Western Australia, and back—a round trip of 12,420 miles—in just nine months. Such long-distance swimming may take white sharks through the territorial waters of several nations, making the sharks hard to protect (not to mention hard to study). Yet a better understanding of their habitat needs, their movement patterns, their role in the marine ecosystem, and their social lives is critical to the species' survival.

As September approaches, the white sharks' hunting season at Seal Island draws to a close. Soon most of them will depart, remaining abroad until their return next May. The Cape fur seal pups that have survived this long have become experienced in the deadly dance between predator and prey. They are bigger, stronger, wiser—and thus much harder to catch. The handful of white sharks that remain in False Bay year-round probably shift to feeding on fishes such as yellowtail tuna, bull rays, and smaller sharks. In effect, they seasonally switch feeding strategies from energy maximization to numbers maximization.

Next May we, too, will return. But fieldwork always has its surprises, and we cannot predict what the white sharks of Seal Island will have in store for us. □

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Broken Pieces of Yesterday's Life

Traces of lifestyles abandoned millions of years ago are still decipherable in "fossil genes" retained in modern DNA.

By Sean B. Carroll

A magnificent early Christmas present arrived one morning in December 1938, when Marjorie Courtenay-Latimer received a message: the *Nerine,* a local trawler, might have some fish for her collection. Courtenay-Latimer, the first full-time curator of the East London Natural History Museum, on the eastern coast of South Africa, was busy trying to put together a dinosaur skeleton she had excavated. Still, she seldom got such calls, so she put her work aside and went down to the dock. Boarding the trawler, she surveyed a stinking pile of sharks, sponges, and other familiar creatures lying out in the heat of the sun. She was about to return to the museum when it caught her eye: "the most beautiful fish I had ever seen. . . . It was five feet long and a pale mauve-blue with iridescent markings."

The fish was also unlike any other she had ever seen. It had four limblike fins and a strange puppy-dog tail. She managed to persuade a taxi driver to put the 127-pound hulk into his car and haul it back to the museum. Its director promptly dismissed her prize as nothing more than a rock cod.

Courtenay-Latimer thought differently. She recruited a second opinion from J.L.B. Smith, a chemistry lecturer and amateur ichthyologist at Rhodes University, a hundred miles away. When Smith studied Courtenay-Latimer's description and sketch of the fish, he was unsettled by a possibility that his brain kept telling him was impossible—that this fish was a coelacanth, a member of a group of fishes with paired fins thought to be closely related to the first four-legged vertebrates. Paleontologists thought the fish had been extinct for more than 65 million years.

But it *was* a coelacanth. Ultimately, the new species was named *Latimeria chalumnae,* in honor of Courtenay-Latimer. And in the decades since the discovery, many more coelacanths have been

Coelacanths have lived in the oceans for hundreds of millions of years and provide a window into the lives of other creatures that became extinct long ago. They and many other life-forms also carry gene fragments that offer similar windows into the past—represented here by the base pairs A, C, G, and T that make up the genetic code. Those gene fragments—dubbed "fossil genes"—no longer code for proteins, but they can be "excavated" from living genomes and studied for clues to the evolutionary past.

dredged up from their deep-sea habitats, including a second species discovered near Indonesia in 1998.

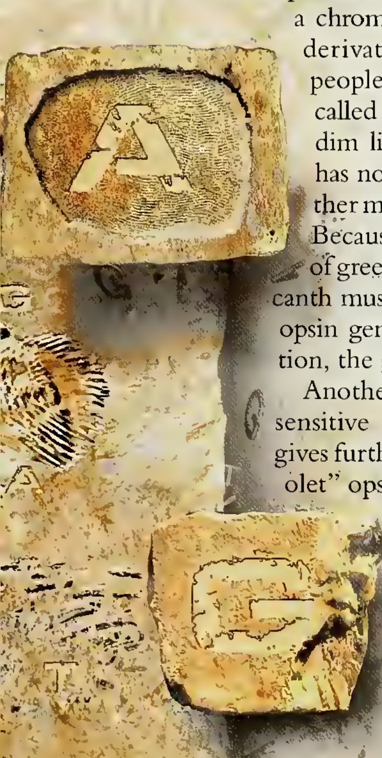
The coelacanth holds a special place in natural history. The animal is the only living link to an ancient tribe of fishes that swam the oceans 360 million years ago. For that, it has been dubbed a "living fossil." Such illuminating finds are so rare that only the most fortunate scientists get to experience the kind of excitement Courtenay-Latimer and Smith must have felt. Yet today, geneticists have begun to recognize that they, too, are living a golden moment, as they come face to face with an altogether different kind of living fossil.

In living creatures, including the coelacanth, there are sequences of DNA that once, but no longer, served as blueprints for making functional proteins: "fossil genes." Fossil genes were initially dismissed as "junk" DNA, but geneticists are now recognizing them as extraordinary records of genetic history—and thus, ways of life—that date back millions of years. The fossilized sequences are embedded in a genome made up of thousands of ordinary, coding genes that contribute to the organism's survival. Because random mutations can quickly cripple or even disable a coding gene, natural selection tends to weed out mutations in them, and so coding genes, as a rule, are rigorously conserved. Fossil genes are different. They show the effects of wear and tear as they break apart and erode away over time, much the same way ordinary fossils do in sedimentary rock.

The reason fossil genes are not conserved is that, because of some past change in lifestyle of the organism that carried them, the genes no longer matter to survival. No longer are they subject to the discipline of natural selection. Instead, the genes can "relax"; random mutations no longer affect the organism—positively or negatively. The very existence of fossil genes proclaims one of the cardinal rules of genetic evolution: use it or lose it. Yet precisely because such fragments of DNA are no longer used, they can provide links to former, now vanished ways of life. When geneticists realized that certain noncoding DNA sequences had at one time been functional genes, they knew that they had discovered a valuable new window on the past. Excavating yesterday's decaying

DNA from living, working genomes gives biologists insights into the lives of ancestral species, natural selection, and evolution.

The coelacanth carries its own extinct genes, which offer good examples of why and how genes become fossilized. Undersea explorers seeking to observe the coelacanth in its native habitat discovered that it retreats by day into underwater caves, 300 feet deep or more, off the Comoros Islands in the Indian Ocean near Mozambique, and in waters around South Africa; by night it cruises slowly over the ocean floor to feed. Yet even during the day, only dim, blue light penetrates to those depths, and so biologists and geneticists have taken a special interest in the coelacanth's visual system.



All species that can detect visible light produce pigments in their retinas. The pigments are made up of proteins called opsins and a small molecule called a chromophore, which in people is a chemical derivative of vitamin A. In particular, both people and coelacanths possess a visual pigment called rhodopsin, which enable them to see in dim light. Curiously, though, the coelacanth has no genes for opsins sensitive to light at either medium (green) or long (red) wavelengths. Because most vertebrates have at least one kind of green or red opsin, the ancestors of the coelacanth must also have had at least one "green-red" opsin gene. Sometime during coelacanth evolution, the green-red opsin gene was lost.

Another gene, which codes for an opsin that is sensitive to light at short wavelengths (violet), gives further insight into gene loss. In people, "violet" opsin detects the corresponding color, and it enables various other species to see in the ultraviolet range. In the coelacanth, however, only fragments of the code for the violet opsin gene are recognizable in its genome. Deletions and changes throughout the sequence of bases that make up the gene severely disrupted it.

For example, where the mouse and other species have the three bases CGA in the DNA code for violet opsin, the coelacanth has TGA. The change from a C to a T may seem small, but in this case it is a whopper. In the language of DNA, the letters TGA are a "stop" code; when the cell machinery for making the opsin protein comes to the letters TGA, it simply stops, ignoring the rest of the sequence of bases in the gene for making the violet opsin. The stop code, as well as many other disruptions, have made what was clearly, at one time, a functional violet opsin gene into a nonfunctional sequence: in the coelacanth the once-functional gene became a fossil gene. And because it is not functional, it will continue to accumulate additional mutations and deletions that will erode it further, until eventually they erase it from the coelacanth's DNA forever, just as its green-red opsin gene was erased.

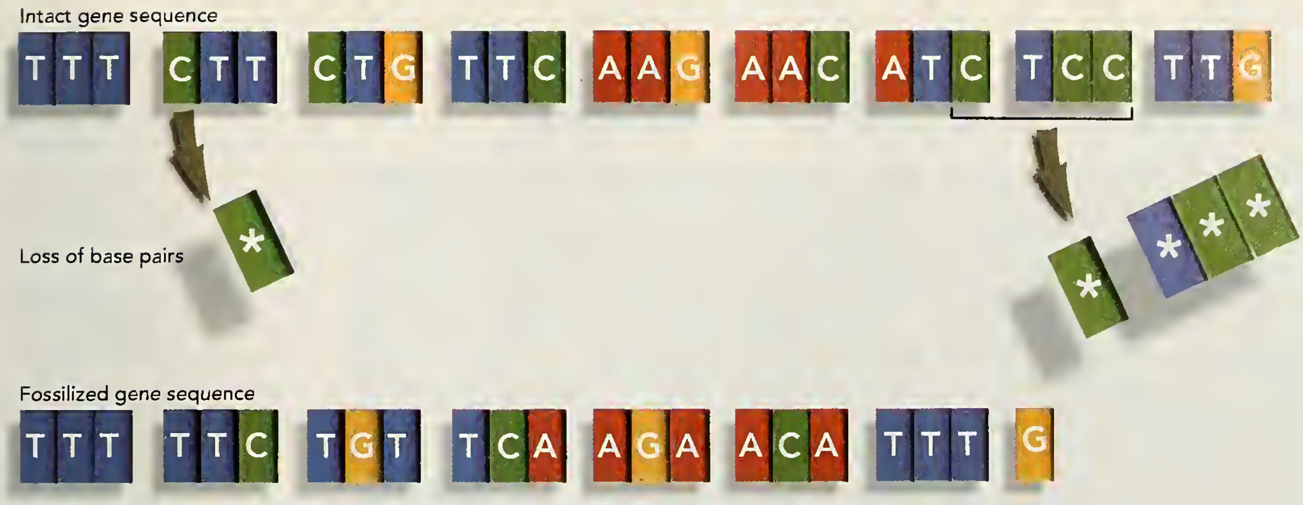
The loss of a gene raises several general questions: How and why is a gene so useful to some species lost in others? Why is a good gene ever allowed to decay? Are fossil genes a rare kind of mistake that occurs only in weird animals such as coelacanths?

The answer to the last question is, Certainly not. The violet opsin gene in dolphins and whales has also become nonfunctional, though it is still identifiable from its fragments, and so it, too, has become a fossil. Is there anything common to animals as dissimilar as coelacanths, dolphins, and whales that could explain why their violet opsins are fossilized?

The best explanation comes from considering their ecology. Dolphins and whales belong to the only order of mammals that is fully aquatic and lacks the potential for any form of color vision. The coelacanth also lives deep in the oceans—where, as I noted earlier, only dim blue light can reach. With all of the other wavelengths filtered out, the three groups of animals apparently have no use for color vision—their survival no longer depends on it. Ecologically, the violet opsin was lost because it became dispensable to their evolutionary ancestors.

The capacity for color vision has evolved in many ways among many animals. Humans, great apes, and Old World monkeys have three opsins, which provide full color vision across the spectrum, from violet through blue, green, and yellow, and on to red. Other land mammals—cats, dogs, squirrels, and the like—have only two opsins and limited color vision. But full color vision is by no means a unique advance of Old World primates; birds, many fishes, and reptiles have four or more opsins—and, consequently, fabulous color vision. In fact, compared with most other vertebrates, nonprimate mammals have fewer opsin genes and relatively poor color vision.

One leading theory about the deficiencies of color vision in nonprimate mammals is that because the earliest mammals were nocturnal, full color vision was largely dispensable. Happily, one kind of evidence for testing that theory, and the general idea that gene fossilization is linked to shifts in lifestyle, is still around today. A nocturnal lifestyle has evolved repeatedly and independently in mammals, and so one can examine how more recent



Fossilization of the opsin gene for violet-sensitive vision is depicted in the diagram. Millions of years ago the cow and the dolphin shared a common ancestor that carried an intact gene, or sequence of DNA base pairs, which enabled it to see the color violet (part of the gene is shown in the top row). As an ancestor of dolphins began to evolve an aquatic lifestyle, sensitivity to violet light no longer mattered for its survival; the opsin gene for violet vision accumulated mutations, including the deletion of five base pairs (middle row). Because base pairs are "read" in groups of three, the lost pairs disrupted the gene's code, and the ancestor became blind to violet. Nevertheless, modern dolphins still carry the disrupted DNA sequence—a fossil opsin gene—for violet vision in their genome (bottom row).

species evolved, with markedly different lifestyles.

The owl monkey, for instance, is the only nocturnal species among the higher primates. And sure enough, its violet opsin gene has accumulated mutations that render it nonfunctional. Moreover, all the relatives of the owl monkey that are active by daylight have an intact violet opsin gene. Those two observations are pretty good evidence that the shift to the nocturnal lifestyle led to relaxed selection on the violet opsin gene. Possessing the gene no longer matters to the survival of the owl monkey.

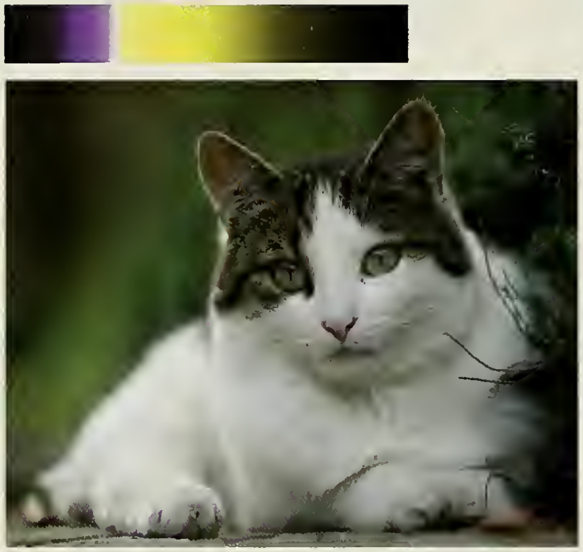
What about animals that go underground? The blind mole rat has the most degenerated eyes of any mammal. Yet the fossil record suggests that rodents evolved from an aboveground ancestor that could see. The mole rat's eyes are small, buried under the skin, and covered by a layer of fur. Still, the animal's retinas can detect light intensity, and so the blind mole rat can tell the time of day. Thus the eyes help the animal maintain its circadian clock and regulate its daily biorhythms.

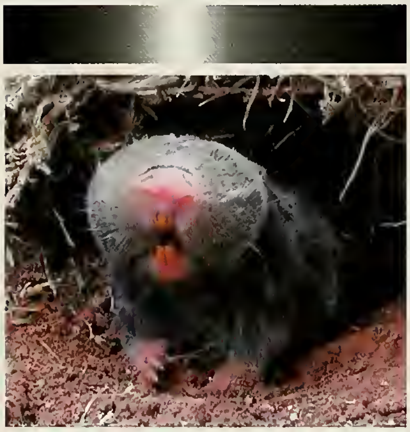
Biologists who examined the blind mole rat found it carries two intact opsin genes: the first encodes a green-red opsin that is tuned, or shifted, toward the red, to detect the light received through the subcutaneous eye; the second encodes a dim-light rhodopsin. Hence despite the mole rat's atrophied vision, selection continues to control mutations in the two opsin genes, apparently to maintain the animal's biological clock. Its violet opsin gene, however, carries numerous mutations that disrupt the code for making the violet opsin protein; in other words, the gene is a fossil.

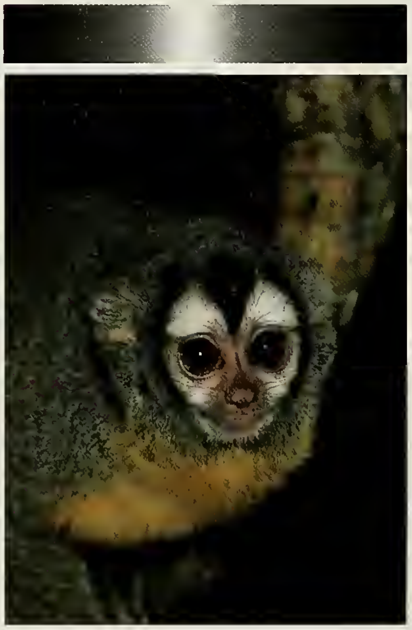
Thus in all the species I have mentioned—in the coelacanth, the whale, the dolphin, the owl monkey, and the blind mole rat—the fossilization of the violet opsin gene is correlated with habitat. The mutations that disable the gene in the various species are not the same, and the species themselves belong to quite different branches of the evolutionary tree. Furthermore, close relatives of the species do have functional violet opsins. Those facts demonstrate that independent, unrelated mutations have repeatedly fossilized the violet opsin gene at various times in evolutionary history—overwhelming support for the fundamental prediction that relaxed selection on a gene leads to its decay. Furthermore, in all those species, other kinds of opsins are intact and functioning, which demonstrates that the decay of genes is highly selective.

And what about people? What might we have lost along the evolutionary way? Well, consider the sense of smell, which is vital to animal behavior and survival. One walk in the park with a dog is usually enough to persuade anyone that the dog's "view" of the world is shaped by its acute sense of smell. A dog's nose can find food, identify mates and offspring, and detect danger.

But for a long time it was a mystery how animals detect and discriminate odors. Then in 1991, working at Columbia University, the molecular biologists Linda B. Buck and Richard Axel discovered a family of genes that encoded odorant receptors. In fact, they found, the so-called olfactory receptor genes are the largest family of genes in mammal genomes. Mice







Color perception varies greatly among animals and often correlates with environment. People and other Old World primates have trichromatic vision; the color bar above the photograph at top left shows roughly what they see for input colors from violet at the left of the bar to red at the right. Almost all other land mammals such as the domestic cat see in two colors. The color bar above the cat is a speculative reconstruction of the colors it sees for the same violet-to-red range of input colors. Both the blind mole rat (above left), which lives underground, and the owl monkey (above right), which is nocturnal, are monochromats. The eyes of the blind mole rat are covered with skin and fur, but the animal can distinguish external light intensity. The gray tones in the bars above their photographs show how efficiently their monochromatic sensors respond to input colors across the range visible to humans.

have about 1,400 of them in a genome of 20,000 genes. Buck and Axel also discovered the basis for the specificity of olfaction: Each sensory neuron in the olfactory system generally produces just one of the many olfactory receptor proteins. How a given airborne chemical is perceived as a scent depends on the combination of receptors that detect it.

The human olfactory genes have been studied in great detail, and compared to those of the mouse they are nothing to brag about. About half of them are fossilized. The contrast between people and other mammals is most striking for a class of receptors encoded by the so-called *V1r* genes. People have only four functional *V1r* genes, whereas the mouse has more than 180 in good working order. Yet the human genome includes nearly 200 fossilized *V1r* genes. No question: our repertoire of olfactory receptor genes has gone to pot.

The extraordinary proportion of fossilized olfactory receptor genes suggests we no longer rely on our sense of smell to the degree our ancestors once did. Two questions spring to mind. Why have we abandoned the use of such a large fraction of our odor receptors? And when did the loss take place?

Clues to the answers emerge from studying the fraction of fossilized odor receptors in other primates and mammals. Yoav Gilad, now at the University of Chicago, and his fellow geneticists at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, surveyed the olfactory genes of apes, lemurs, New World monkeys, and Old World monkeys, and compared them with the olfactory genes of the mouse. In mice, lemurs, and New World monkeys—almost all of which lack full color vision—the investigators noted that 18 percent of olfactory receptor genes are fossilized. But in Old World monkeys, which have full color vision, the proportion of fossilized olfactory receptor genes rises to 29 percent. In nonhuman apes such as the chimpanzee, the gorilla, and the orangutan, which also have full color vision, the proportion reaches 33 percent. Finally, in people, some 50 percent of the genes were fossilized.

In short, the fraction of fossil olfactory receptor genes is significantly higher in all species with full color vision. It seems that the evolution of trichromatic vision in primates—which enables them to find food, identify mates, and detect danger with visual cues—reduced their reliance on smell. Relaxed selection on the olfactory receptor genes in trichromatic species has allowed the genes' codes to decay. Conversely, in animals that rely heavily on their sense of smell, the fraction of intact olfactory genes is much higher.

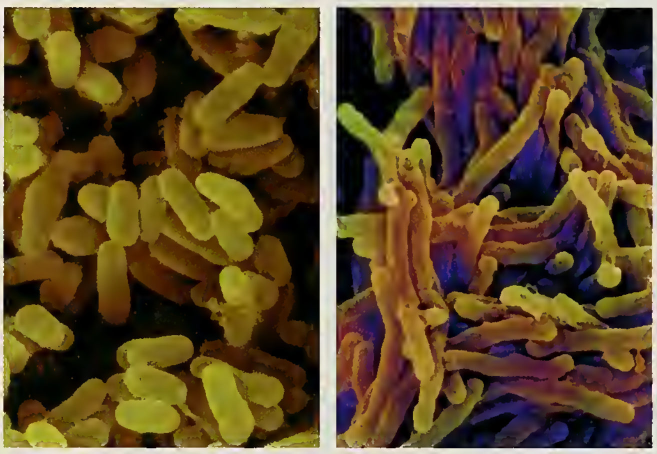
An organism that has lost great swaths of functional DNA is the bacterium *Mycobacterium leprae,* the pathogen that causes leprosy. Gene sequencing has shown that the *M. leprae* genome carries about 1,600 functional genes and about 1,100 fossil genes—a far greater proportion of fossil genes than that of any other known species. *M. leprae* is closely related to *M. tuberculosis,* the species responsible for pulmonary tuberculosis. But *M. tuberculosis* has about 4,000 intact, functional genes and only about six fossil genes. Comparing the genomes of the two species shows that *M. leprae* has fossilized or lost some 2,000 genes in the course of its evolution. What explains the vast disparity between the two bacteria?

Once again, the answer comes down to lifestyle: *M. leprae*'s is very different from that of its cousin. The leprosy bacterium can live only within cells of its host; in fact, despite decades of effort, it has never been grown on its own in the laboratory. It is also the slowest-growing bacterium of all known bacterial species: it takes about two weeks to divide. (Compare that with the *E. coli* in the human gut, which can divide every twenty minutes.) *M. leprae*'s specialized mode of living has enabled it to rely on its host for many functions it would otherwise have to carry out on its own. Since the host-cell genes do so much of the work, natural selection has relaxed its control on maintaining many *M. leprae* genes. As a result, those genes have decayed on a massive scale. The example demonstrates that a large fraction of all the genes in an organism's genome can become dispensable when its lifestyle shifts.

The fossilization of individual genes, sets of genes that build metabolic pathways, or even larger groups of genes has important consequences for the evolution of an organism's descendants. Because decaying genes accumulate multiple defects, their inactivation cannot readily be reversed. So the loss of gene functions is generally a one-way street—once gone, the functions will not return.

"Use it or lose it" is an absolute rule imposed by the fact that surveillance by natural selection acts only in the present, without planning for the future. The downside is that if circumstances change, even very slowly, the lost genes will not be available to adapt to the new circumstances. The one-way loss of genes may be an important factor in the success or extinction of species. Keep in mind that biologists think that more than 99 percent of all species that ever existed are now extinct.

The process of gene fossilization and loss is a powerful argument against the idea of "design" or intent in the origin of species. The leprosy bacterium, for instance, is a stripped-down version of its former self, carrying around more than a thousand useless, broken genes that are vestiges of its ancestry. Such a history of trial and error is hardly evidence of design. Similarly, people carry around the genetic vestiges of an olfactory system that was once much more acute than the one we have today.



Leprosy-causing bacteria (shown above left in false color) lug around a lot of fossil genes—about 40 percent of all the genes they carry. By contrast, only about 1 percent of the genes are fossilized in the closely related bacterium responsible for tuberculosis (above right, also in false color). Many of the genes of the leprosy bacterium are thought to have fossilized because the organism relies more on its host than its ancestors did. Both micrographs are magnified 6,000X.

The patterns of gain and loss are exactly what one would expect if natural selection acts only in the present, not the way an engineer or a designer would. Natural selection cannot preserve what is not being used, and it cannot plan for the future. Furthermore, the recurrence of gene fossilization in entirely different groups of animals is striking evidence that, when selection is relaxed on a particular trait, the same events will repeat themselves in DNA. The new disciplines of genetic archaeology and paleontology will keep hauling up unexpected things from the depths of the past, providing answers about which directions life has taken, and why. □

This article was adapted from Sean Carroll's forthcoming book, The Making of the Fittest: DNA and the Ultimate Forensic Record of Evolution, *which is being published this month by W.W. Norton & Company, Inc.*

Life and Death in a Pitcher

Prey's-eye view from inside an N. rafflesiana pitcher in Borneo

Carnivorous plants that seem to employ a simple dunk-and-drown tactic for capturing prey turn out to have more up their leaves.

By Jonathan Moran

Insect-trapping pitcher of Nepenthes bicalcarata, *about six inches from base to top, awaits a meal in Borneo. Ants of the species* Camponotus schmitzi *(not shown) nest only inside the enlarged tendrils that support* N. bicalcarata *pitchers and feed at nectar glands in the two fanglike thorns overhanging each pitcher's opening.*

In the summer of 1854 a young Welsh naturalist on a collecting expedition to southeast Asia stopped for a rest on the rocky slopes of Mount Ophir, in what is now peninsular Malaysia. The Welshman and his guides had been assured that water would be available nearby. Yet none was to be had: "We looked about for it in vain," he wrote,

> as we were exceedingly thirsty. At last we turned to the pitcher-plants, but the water contained in the pitchers (about half a pint in each) was full of insects and otherwise uninviting. On tasting it, however, we found it very palatable, though rather warm, and we all quenched our thirst from these natural jugs.

The parched Welshman was Alfred Russel Wallace, who four years later would formulate his own theory of evolution by natural selection, almost simultaneous with, yet independent of, Charles Darwin's theory. Of course, the pitchers that slaked his thirst that day on Mount Ophir were not there for the benefit of passing hikers. They were the insect traps of a remarkable carnivore, an Old World pitcher plant of the genus *Nepenthes.*

Capturing and killing animals is a role-reversal that might seem unusual for members of the plant kingdom. Carnivorous plants often grow in impoverished terrain, though, and digesting prey augments the nutrients the roots obtain from the soil. By one means or another, roughly 600 plant species capture animals for food. Some, such as sundews [*see "The Natural Moment," September 2006*] and butterworts, entrap their prey in sticky "flypaper" on their leaves. Others, such as the Venus flytrap [*see "Snap!" by Adam Summers, June 2005*] and the waterwheel plant, have traps that spring shut. The bladderworts, which are predominantly aquatic, suck their victims from the water with bladder-shaped vacuum traps; the traps are "primed" by pumping water out, and "fired" when prey inadvertently brush trigger hairs.

Pitcher plants take a more minimalist approach: they capture their prey in deep pitfall traps, from which there is usually no escape.

Many North Americans are familiar with New World pitcher plants, all members of the family Sarraceniaceae. Their traps are elongate, tubular leaves that rise directly from the soil. The Nepenthaceae of the Old World are unrelated. More than eighty species are known, all members of the genus *Nepenthes,* and a couple of new species are discovered every decade or so. They grow throughout the Asian tropics, from Madagascar in the west to northern Australia and New Caledonia in the east [*see range map at top of next page*]. But the center of their diversity is the island of Borneo, home to thirty-one species of *Nepenthes,* of which more than twenty occur there alone.

Nepenthes are climbers that need adjacent plants for support. Their pitchers are jug-shaped, with an opening typically shaded by an overhanging lid. Each pitcher forms at the end of a tendril that grows from the tip of a leaf. The traps of the various species of *Nepenthes* exhibit a striking diversity. They vary from an inch to a foot in height and range in liquid capacity from a teaspoon to more than a pint. In color, they vary from pale green to bright red to almost black.

The reasons for all that diversity are now coming to light. Aficionados of the genus once assumed that all *Nepenthes* were passive generalists that rely only on the most basic enticement—nectar—to capture any hapless insect that stumbles into a pitcher. But in recent years investigators have learned that the plants in the genus display a wide range of feeding strategies, some of which are exquisitely fine-tuned for trapping specific prey. Furthermore, it has now become clear that not all their prey are animals. For example, my own research, in which I measure the ratios of nitrogen isotopes in the tissues of various *Nepenthes* species, has confirmed that their diets extend beyond the animal kingdom to include plant material. And when they do deal with animals, *Nepenthes* species have a broader repertoire than most carnivorous plants: not only do they consume animals, but they also engage in a range of nonfatal relationships with them, symbiotic and otherwise.

Nepenthes pitcher plants all develop according to the same basic pattern. First, a seedling generates a number of pitchers that rest on the ground. Those terrestrial traps are generally urn-shaped, with two conspicuous, parallel, leafy "wings" running the full length of the pitcher, from the tendril to the pitcher mouth. As the plant continues growing, its uppermost leaves bear a second kind of pitcher, the aerial form. Aerial pitchers tend to be more elongated than terrestrial ones, and they do not have wings.

Vine of the pitcher plant N. gracilis *grows on a Cicada tree* (Ploiarium alternifolium) *in Brunei. The pitchers are about four inches long.*

The plant's prey—usually small invertebrates—are attracted by the color of the pitchers and, at least in one species, by their fragrance. Once the unsuspecting animals arrive, they feed at nectar glands on the outside of the pitcher. The largest such glands, however, are concentrated around the peristome, or mouth of the pitcher, and lure the visitors into ever more dangerous territory. Depending on the *Nepenthes* species, the peristome may or may not provide firm footing. The unwitting visitor that loses its grip may become prey if it falls into the pitcher, landing in a pool of liquid secreted by the plant. Or the visitor may venture over the peristome and onto the inner wall of the pitcher. That, too, is usually a fatal mistake. In most *Nepenthes* species, the upper portion of the inner wall is covered with

Range of Nepenthes *pitcher plants is depicted in orange.*

microscopic waxy scales, which cause the prey to slide into the liquid below.

Once in the liquid, the prey quickly becomes waterlogged, making flight or even crawling impossible. The only chance of escape is to bite through the pitcher wall, but few species have mouthparts with enough power to do so before they drown. The liquid—about as acidic as Pepsi and full of enzymes that break down proteins—slowly digests the prey. Nitrogen-rich compounds that digestion releases from the prey carcass are absorbed by glands in the pitcher wall.

In the natural world form follows function. So it comes as no surprise that the structural diversity of *Nepenthes* pitchers is matched by a diversity of strategies for capturing nutrients. They range from the relatively simple to the outright bizarre.

Operating at the simple end of the spectrum are species such as *N. gracilis*, which is common in open, sunny, lowland scrub from Thailand across the Indonesian archipelago to the island of Sulawesi. *N. gracilis* traps are narrow, pale green, and only two to four inches long. They work by offering their prey the most basic enticement: sugary nectar. Ants are the most common prey; their affinity for nectar makes them easy targets. Beetles, flies, and small wasps are also frequent victims.

An observer watching ants forage at *N. gracilis* pitchers in coastal Borneo could hardly fail to notice another *Nepenthes* species growing there, *N. rafflesiana*. Its pitchers are at least twice the size of those of *N. gracilis* (in fact, a rare form from Brunei produces pitchers a foot in length), and they are boldly patterned in colors from yellow to scarlet [*see photographs on this page*]. *N. rafflesiana* is a much more sophisticated carnivore than its smaller relative; it is also my personal favorite, because I spent several years studying its biology.

The peristome of *N. rafflesiana* is much broader than that of *N. gracilis,* and its coloration makes a strong contrast to adjacent parts of the pitcher. It reflects green and blue, and absorbs ultraviolet wavelengths, to which a large number of insects are visually sensitive. In addition, the aerial pitchers of *N. rafflesiana* give off a sweet fragrance attractive to many insects. Both kinds of lures, the visual and the olfactory, are compelling examples of convergent evolution: like flowers, pitchers lure insects via color, fragrance, and

"Aerial" pitchers that grow from Nepenthes' *upper leaves usually differ from "terrestrial" pitchers that grow at ground level. An aerial pitcher of a rare, giant variety of* N. rafflesiana, *far left, features a color pattern and fragrance that attract pollinating insects. A terrestrial pitcher from the same plant, left, has leafy "wings" running up its exterior, as all terrestrial pitchers do. It lacks the aerial pitchers' distinctive pattern and fragrance, and, accordingly, captures ants but few pollinators.*

nectar, but the two structures evolved quite independently [*see "Origins of Floral Diversity," by Amy Litt, June 2006*].

As one might expect, the aerial pitchers of *N. rafflesiana* trap many pollinating insects, including bees, beetles, and moths. Both the aerial and the terrestrial pitchers trap ants. The two forms of pitcher, with their differing collections of attractants, enable *N. rafflesiana* to catch a broader spectrum of prey than its neighbor, *N. gracilis.*

Terrestrial pitcher of N. rajah *is the largest of all* Nepenthes *pitchers. The species grows only on two mountains in Borneo.*

A third species occasionally grows alongside *N. gracilis* and *N. rafflesiana* in the lowlands of Borneo. *N. albomarginata* may be the most specialized insect predator in the family Nepenthaceae. In the late 1980s, Charles M. Clarke, an ecologist now at James Cook University in Queensland, Australia, and I noted that *N. albomarginata* preys predominantly on termites of the genus *Hospitalitermes.*

A decade later, Dennis J. and Marlis A. Merbach, a husband-and-wife team of botanists at the University of Frankfurt in Germany, explained how the plant attracts the termites and traps them. Both the aerial and terrestrial pitchers of *N. albomarginata* have a cream-colored band of hairy-looking tissue on their outside surface, immediately under the peristome [*see lower photograph on this page*]. Nectar glands on the peristome make little or no nectar. They have no need to—the attractant is the distinctive band of tissue. The termites normally feed on lichens, which *N. albomarginata* mimics with its hirsute band. Attracted to the pitchers, perhaps by chemical cues, the foraging termites feed on this band. Large numbers of them inevitably tumble into the pitchers, where they are digested.

Termites of the genus Hospitalitermes *swarm on a pitcher of* N. albomarginata. *The cream-colored band just below and outside the pitcher's rim attracts the termites by mimicking the lichen they eat; inevitably, many termites tumble into the pitcher and feed the plant, instead.*

Marlis Merbach, Clarke, and I, along with two other colleagues, later confirmed the association between *N. albomarginata* and *Hospitalitermes* termites via a process known as stable-nitrogen-isotope analysis. Nitrogen exists as two stable, or nonradioactive, isotopes, known as nitrogen-14 and nitrogen-15. Both isotopes are fixed from the atmosphere by soil microorganisms, then absorbed through the roots of plants, which incorporate the nitrogen in their tissues. Plant-eating animals subsequently accumulate the nitrogen in their bodies. Each time the nitrogen is consumed by another organism further up the food chain, the ratio of nitrogen-15 to nitrogen-14 that collects in the tissues increases. Because *Hospitalitermes* termites are vegetarians, the nitrogen in their tissues is a good deal less rich in nitrogen-15 than the nitrogen in the tissues of ants, whose diet includes animal matter. By comparing the nitrogen-isotope ratios in the leaves of *N. albomarginata* with the ratios in the leaves of the ant-eating pitcher plant *N. rafflesiana,* we confirmed that *N. albomarginata* does indeed get much of its nitrogen from termites.

Most lowland *Nepenthes* species grow in open, sunny habitats, but a small number tend to live beneath the forest canopy. The most common forest species is *N. ampullaria,* which ranges from Thailand to New Guinea [*see photograph below*]. Even the casual observer would not fail to notice that the species is unusual. It almost never grows aerial pitchers, and the terrestrial pitchers often form conspicuous mats several feet wide on the forest floor. Their structure is odd, too. The nectar glands are small and unproductive, and the slippery, waxy layer on the inner wall of each pitcher—a crucial part of the trap, one would think—is absent. The pitcher lid is vestigial and bends away from the pitcher mouth. In overall effect, the mat of pitchers looks like a crowd of gaping mouths waiting for food from above. What's going on here?

N. ampullaria *pitchers, spread in a mat about a foot wide over the forest floor, gape open to catch leaves and other debris that fall from the canopy. The species appears to be unique among* Nepenthes *in deriving some of its nitrogen from plant material.*

N. ampullaria grows primarily in tropical heath forests, so called because their soils are sandy, acidic, and poor in nutrients. In such an ecosystem, the limited nutrients are seldom left idle, and plants scavenge nitrogen as soon as it becomes available. Many heath-forest trees grow thick root mats just beneath the soil surface to capture the nutrients from the slow but steady rain of organic material from above—excised leaves, flowers, and the like. Clarke and I, along with Barbara J. Hawkins, a biologist at the University of Victoria in British Columbia, suspected that *N. ampullaria* deploys its mats of pitchers to intercept that rain of material even before it reaches the forest floor.

To confirm our suspicions, we compared the ratio of nitrogen-15 to nitrogen-14 in leaves of plants growing in forests with that of plants from open areas. Sure enough, the forest plants, which enjoyed plenty of manna from above, had lower nitrogen-15 levels than did the plants from open areas, as well as a higher overall nitrogen concentration in their tissues. Thus, *N. ampullaria* not only traps, but also consumes vegetable matter. (The *Nepenthes* growing in open areas get all their nitrogen from whatever insects they managed to trap.) It is worth highlighting how forest-dwelling *N. ampullaria* has evolved to fill its nutritional needs. A structure that developed to obtain nutrients from animal prey has now evolved further to get the nutrients from vegetable matter.

Another *Nepenthes* with strange dietary habits is *N. lowii,* a highland species that inhabits several mountains in Borneo. It bears distinctive pitchers, eight to ten inches high, each with a flaring, funnel-shaped mouth, a narrow waist, and a large lid that secretes copious quantities of a crystalline, sugary substance. Clarke noticed that the pitchers rarely trap insects. Inside them, however, he often discovered a large amount of another bountiful source of nitrogen: feces.

What animal uses pitcher plants as toilets? The most likely suspects are tree shrews, small squirrel-like animals that feed on invertebrates and sweet fruits. Several observers have seen tree shrews scurrying on and around the pitchers of *N. lowii,* perhaps drawn there by the plant's sugary offering. Such observations are purely circumstantial evidence, but Clarke and I hope to solidify them with stable-nitrogen-isotope analyses. What is clear is that the various species of *Nepenthes* have diverse appetites: most prefer meat, one is primarily vegetarian, and at least one other seems to prefer its nitrogen predigested.

One might think that the inside of a *Nepenthes* pitcher, which evolved primarily to trap and kill animal prey, would be a hostile environment in which to live. In fact, nothing could be further from the truth: many animal species rely on *Nepenthes* pitchers for at least part of their lifecycles, and despite the punishing acidity and enzymes, some of them live there and nowhere else.

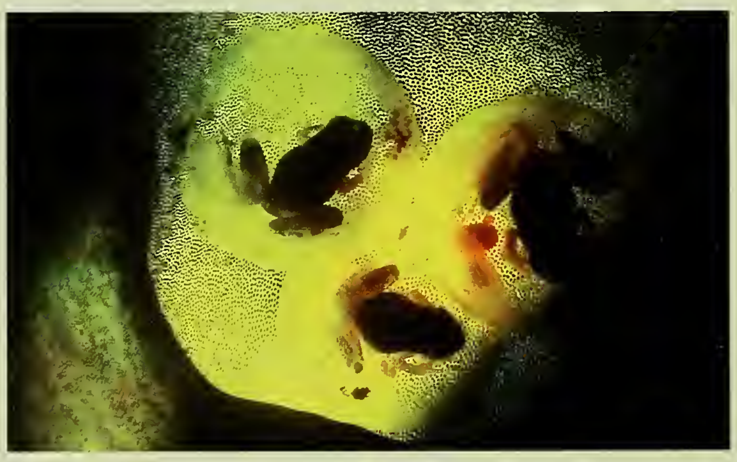
Crab spider (Misumenops nepenthicola) *lives only in* Nepenthes *pitchers and makes its living by intercepting the plants' prey.*

Thirty-three species of invertebrates, including mites and the larvae of hoverflies, midges, and mosquitoes, have been discovered inside the pitchers of *N. bicalcarata,* a Borneo endemic. Even more remarkably, *N. bicalcarata* appears to have a symbiotic relationship with an ant, *Camponotus schmitzi.* The tendrils connecting the base of its pitchers to the leaf are swollen and hollow [*see lower photograph on page 56*]. The ants live inside them. Furthermore, the plant provides the ants with sustenance. Beneath the lid of each pitcher are two inch-long, fanglike thorns that project over the mouth. Botanists once speculated that those thorns might prevent animals such as primates from stealing prey from the pitchers. The thorns are now known to house giant nectar glands, at which *C. schmitzi* worker ants feed.

What does *N. bicalcarata* get in return for the room and board it provides to the ants? One might expect that the ants protect the plant, perhaps by aggressively repelling plant-eating animals. That's just what happens in the well-known association between certain species of acacia trees and ants of the genus *Pseudomyrmex.* But *C. schmitzi* ants are not at all aggressive. And a moment's thought suggests that a symbiotic partner that discouraged visits to the pitcher, at least by other insects, would be bad for business.

Clarke has studied *N. bicalcarata* and its ant partners in their native habitat, and his observations of the ants' remarkable behavior gives the most probable account of their contributions. Unlike most other ants, *C. schmitzi* can swim. The ants regularly enter the pitcher fluid for as long as thirty seconds, and haul large prey, such as cockroaches, out of the fluid and up the pitcher wall. When they reach a sheltered spot under the overhanging peristome, they dismember the carcass and consume it, dropping small pieces back into the fluid as they eat. Clarke hypothesizes that the removal of overly large prey matter prevents bacterial overload, putrefaction of the pitcher contents, and consequent loss of pitcher function—a common enough occurrence. But *C. schmitzi* does more than merely scavenge. Clarke has observed the ants actively hunting live mosquito larvae in the pitcher fluid, then hauling out and consuming their catch.

Swimming ants are not the only danger the pitcher-dwelling mosquito larvae must face. The crab spider *Misumenops nepenthicola,* which lives only in *Nepenthes* pitchers, is a kleptoparasite: It intercepts and devours prey that the pitcher attracts [*see photograph at top of this page*]. Dangling from silken safety lines, the spider takes up station on the inner wall of the pitcher, waits for prey to enter, and

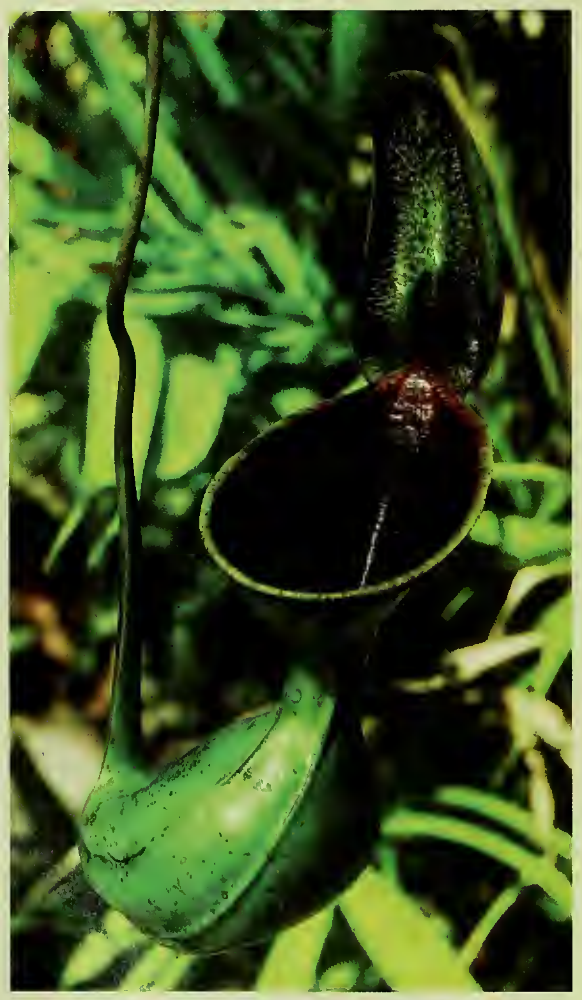


Froglets of the genus Philautus *prepare to hatch from their eggs in the fluid of an* N. bicalcarata *pitcher. Whether they can escape from the pitcher once they hatch is not known.*

then seizes it as it feeds at the nectar glands. If disturbed, the spider drops into the pitcher's fluid and remains there until the threat has passed. It may also enter the fluid for another reason. On several occasions I have watched *M. nepenthicola* seize and eat mosquito larvae in *N. rafflesiana* pitchers.

Occasionally, larger animals make their own use of *Nepenthes* pitchers. Once, while examining a large

N. rafflesiana pitcher, I was startled to discover a hairy brown mass suspended above the fluid. It turned out to be two small bats roosting there for the day. I have also encountered tree frogs of the genus *Philautus*, or rather their eggs, containing tadpoles or froglets, floating in pitcher fluid [*see lower photograph on preceding page*]. One of the most intriguing associations is between *N. ampullaria* and terrestrial crabs of the genus *Geosesarma*. Several observers, myself included, have seen the crabs foraging in and around the plants' pitchers. Whether the crabs are feeding on detritus or wetting their gills remains to be learned.



Bristles beneath the lid of an N. lowii *pitcher secrete a sugary substance that attracts tree shrews. Some of the shrews' feces drop into the pitchers, perhaps feeding the plant with an unusual nitrogen source.*

Of course, there is always a danger that a visiting animal may fall prey to a pitcher. Lizards, perhaps in search of a drink, are sometimes drowned and digested. How do biologists know that? The lizards leave behind two pairs of miniature translucent gloves—the skin of their hands and feet, which for unknown reasons is indigestible. There are even records of rats drowning in the foot-deep pitchers of *N. rajah* on Borneo's Mount Kinabalu.

In some seasonally dry areas, *Nepenthes* pitchers are the only perennial source of water for large mammals. I missed witnessing Wallace's encounter, but I have seen wild pigs tear apart *N. rafflesiana* pitchers to quench their thirst. Various species of primate sip from pitchers—in a manner decidedly more civilized than the pigs'. In fact, the Malay term for the genus, *periok kera*, translates to "monkey cup."

But what of *Nepenthes*' associations with the "highest" mammals? Given their unusual appearance, it is perhaps not surprising that *Nepenthes* have spawned their share of folklore. In Brunei, for instance, where I worked for several years, local people maintain that the fluid from a young pitcher, applied to the human head, has hair-restorative properties. Once—strictly in a spirit of scientific inquiry, you understand—I tested the idea. It didn't work. More practical uses include employing the pitchers as little rice-cookers. The exact method varies by locale. Typically a pitcher is washed out and stuffed with rice, then steamed or left in hot ashes. When done, the rice is eaten, and the pitcher discarded.

It is probably fortunate that *Nepenthes* species rarely grow in the lowland rainforests now being cleared for timber throughout their range. Nevertheless, the conversion of deforested spaces to agricultural or commercial use may have serious implications for the long-term prospects of some lowland species. In contrast, highland *Nepenthes* typically grow in locales that are protected from exploitation or are so hard to access that timber extraction is still considered impractical.

A more immediate threat, particularly to certain highland species, stems from illegal harvest by unscrupulous collectors. Since the 1970s, when *Nepenthes* became widely available by mail order, the genus has had a resurgence as a collector's item in the West and in Japan. (It was also highly prized during the Victorian era.) The demand has fueled a trade in rare and beautiful species, such as *N. rajah*, which are often smuggled from their home countries, in violation of international law.

Happily, though, many species of *Nepenthes* continue to thrive in the wild. Should you decide to follow in Wallace's footsteps and ascend Mount Ophir (or Gunung Ledang, as it is now known), you will still find *Nepenthes* there. Just don't forget your water bottle. □

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By Laurence A. Marschall

Rhododendrons in bloom, Exbury Gardens, Hampshire, England

Tales of the Rose Tree: Ravishing Rhododendrons and Their Travels Around the World
by Jane Brown
David R. Godine; $35.00

To Jane Brown, who writes with florid enthusiasm, the world looks best through rhododendron-colored glasses. Brown's rhododendrocentrism is understandable. Members of the genus *Rhododendron* inhabit territories as diverse as Borneo, Japan, Switzerland, and the Himalayas. Notable for their dense, thick greenery and bountiful flowers, they are hardy, showy plants that readily adapt to cultivation and hybridization. Even nongardeners know them—members of the genus include the gaudy azaleas and the waxy, large-leafed bushes that shade front porches and jostle for space in the corners of backyards.

In the wild, the plants are impressive, growing in vast, dark thickets that are splotched with brilliant color if you catch the plants in bloom. One of my favorite parts of the Appalachian Trail takes me along a stream so crowded with rhododendrons that, on a sunny day in late May, the passage is a dark tunnel decorated with bright bouquets of white. In his book *Riddle of the Tsangpo Gorges,* Frank Kingdon Ward, a noted botanical collector, recalled his travels to China in the early 1900s, where he saw a valley

> roofed by grey skies, with the white snowfields above, . . . and everywhere the rocks swamped under a tidal wave of tense colours which gleam and glow in leagues of breaking light. "Pimpernel" whose fiery curtains hang from every rock; "Carmelita" forming pools of incandescent lava. "Yellow Peril" heaving up against the floor of the cliff in choppy sulphur seas breaking from a long low surf of pink *lacteum,* whose bronzed leaves glimmer faintly like sea-tarnished metal.

Brown's stories give rhododendrons a central place, not only in the development of gardening, but in mainstream cultural history. Long before globalization became everybody's business, rhododendrons were establishing beachheads of diversity in the gardens of Europe. In 1736 a botanizing Pennsylvania farmer named John Bartram sent to England some of the first American rhododendrons, gathered along the Schuylkill River not far from my stretch of Appalachian Trail. The plants did well in many English gardens—and their descendants still survive in Windsor and other places.

Another forty-three species from the Himalayan foothills took root in English soil in the mid-1800s, collected by Joseph Hooker during a year of travels in India and Sikkim. Still other rhododendrons came from remote regions of Tibet, thanks to the derring-do of George Forrest, a late Victorian who hunted flora with the panache of Indiana Jones. While dodging an urban uprising in China he bagged the seeds of *R. sinogrande* for the tame potting sheds of J.C. Williams of Cornwall.

With such exotic foreigners as cultivars, gardeners worked to create new variations through hybridization. Part of the challenge, of course, was to produce plants that felt at home in soil far from their homeland. But the real aficionados also strove for new tints, purer hues, and blossoms that appeared on various dates, so that, whatever the month, a garden would display a full spectrum of blooms, tailored to the aesthetic designs of the landscaper.

Before the advent of commercial garden centers, such obsessions were only for the private rhododendron gardens of the wealthy. Pundits labelled them "stockbroker" flowers, even into the mid-1900s. Lionel de Rothschild, a founder of the British Rhododendron Association, was a typical rhododendrophile, as was Queen Mother Elizabeth, her husband, King George VI, and her brother-in-law the Duke of Windsor.

But you don't have to be royalty to enjoy those lovely blooms today. And a quick dash through Jane Brown's chatty book will make you feel like royalty, anyway.

Darwinism and Its Discontents
by Michael Ruse
Cambridge University Press; $30.00

Readers of this magazine scarcely need to be persuaded of the power of Charles Darwin's theory of evolution. But few, I dare say, have thought deeply about why Darwinism has been so successful. One of those few is Michael Ruse, a professor of philosophy at Florida State University, who has written eloquently for decades about the foundations of the life sciences. His latest book ties that work together, giving an overview of the issues Darwin raised and the criticisms leveled against him in the past century and a half.

In making his spirited defense of evolutionary biology, Ruse does not devote much space to creationism or its place in the public school curriculum. Perhaps his reason is that, though the creationist critique of Darwin is by far the most visible one in the media, it is also the least substantial. The main concession Ruse makes about engaging the creationists is to discuss, and debunk, the work of Duane T. Gish, a "young earth" creationist and author of *Evolution: The Fossils Say No!*, who seems to seriously believe that a preponderance of the evidence demands a universe less than 10,000 years old.

Mostly, though, Ruse turns his wit to examining just what Darwinism claims—basically, that speciation arises from the slow, natural selection of inherited traits—and how it supports those claims. What do the fossils say about evolution? What insights does molecular biology contribute? How do strands of evidence weave together into such a convergence of conclusions among the disciplines (biology, geology, chemistry, and astronomy, to name just a few) about the history of life on our planet?

Faustin Betbeder, Prof. Darwin *(caricature from* The London Sketch Book*), 1874*

Ruse's most compelling writing addresses the claims of mainstream intellectuals, some of whom, in the name of Darwinism, have expected more of it than it can deliver. Evolution, for instance, is often equated with progress, though nothing about the process of natural selection guarantees that things must get better with time.

Among the greatest of the progressive Darwinians was the Victorian enthusiast Herbert Spencer, whose voluminous and widely read writings identified evolution as a driving force in both nature and society. Spencer's idea that the struggle for existence in the natural world is mirrored in economics, politics, and morality spawned the strain of thought known as "social Darwinism." Robber barons cited it to justify their success: the obscene concentrations of wealth they acquired were just the fruits of doing what comes naturally. *Mein Kampf* perverted those ideas still further into the "fanatasy" of a master race. Ruse points out how mistaken Spencer was about evolution—and indeed, virtually no one reads Spencer nowadays. But social Darwinism still serves as a straw man for modern antievolutionists who argue against what they regard as the inherent moral corrosiveness of Darwinian theory.

Darwinism, Ruse argues, is both less and more than either its vehement critics or its ardent proponents suppose. It is not a form of atheism, as the arch-Darwinist (and arch-atheist) Richard Dawkins (in rare agreement with creationists) claims. Nor is it a manifestation of God's plan for the universe, as the theologian Pierre Teilhard de Chardin had it. Rather, it is a strong scientific theory that provides important insights into the natural world. But to those who would ask it to tell us about God, society, or the meaning of life, Ruse has a warning: "Beware of anything that answers everything. It usually ends by answering nothing. And that is certainly not true of Darwinism."

The Singing Neanderthals: The Origins of Music, Language, Mind, and Body
by Steven Mithen
Harvard University Press; $25.95

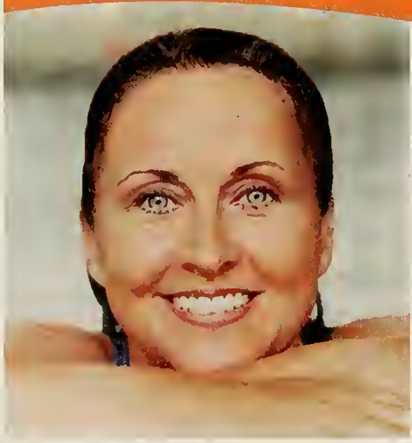
Among the most dicey academic inquiries are the ones that deal with the origin of human consciousness. It is hard enough to know what goes on in the heads of our contemporaries, who speak and write in a language we share, without speculating about ancestors who spoke in languages long lost and who never wrote anything down. To explore the prehistoric mind-set, the best one can do is reconstruct plausible scenarios from bones, pottery, and other surviving artifacts. Evidence of primitive consciousness, then, by its very nature, is fragmentary, circumstantial, and open to a wide range of interpretation.

Faced with difficulties of such daunting scope, Steven Mithen, professor of archaeology at the University of Reading in England, remains undaunted. In his 1996 book, *The Prehistory of the Mind,* he argued that both the origins of thought and the origins of human language are natural outcomes of evolution. But according to the first chapter of Mithen's latest work, *The Singing Neanderthals,* that story was incomplete.

What it neglected was the central role of music in the psychosocial makeup of our species. Is it possible to imagine Zog the caveman with a tin ear, not feeling the rhythm in the chipping of a stone axe? Did Zog never feel the urge to move his feet when he wasn't stalking a tasty mammoth? Did he never hum a tune, pound a drum, or join in a communal dance? "Without music," Mithen writes, "the prehistoric past is just too quiet to be believed."

And so we're off, on a journey across the disciplines, gleaning from each an instructive perspective on the origins of human music-making. Neurological studies, for instance, suggest the brain is somehow wired for music, more or less independently of its circuitry for speech. Lesions and strokes can lead to *amusia,* the inability to comprehend or produce music. The medical literature has documented cases of stroke patients who could speak and write, but could no longer sing or play an instrument.

Developmental psychologists have established that even babies respond to music. The rhythm and modulation of a mother's voice holds her baby's attention before the child can distinguish the meanings of individual words. That's why parents sing lullabies, and perhaps why adults naturally adopt a high-pitched singsong delivery when



"The Singing Zogs" were the third contestants to be sent home.

they speak to children. The musicality of speech may even help in learning language: the melody, it seems, precedes the message.

Thus, Mithen speculates, humanity might have developed much as the individual does: music first, then language. From an evolutionary standpoint, music would not only help ensure the well-being of the individual, but also the cohesiveness of the group. Calling on primate studies, Mithen likens group music-making to grooming, an activity that evokes feelings of contentment and belonging. When Zog's family beat out the rhythm of a dance, their music-making may have helped them work together, thus enhancing their success in the hunt and giving them an evolutionary advantage over other families with less musical ability. Perhaps they also musically mimicked the motions and behaviors of the animals they hunted. Music could have served as an early form of communication, characterized by an acronym coined by Mithen: "Hmmmmm." In other words, he explains, the earliest language was *H*olistic (not expressed so much in words as by overall feeling); *m*anipulative (aimed at affecting the behavior of others); *m*ulti-*m*odal (expressed as rhythm, melody, and so forth); *m*usical; and *m*imetic (imitative).

"May have" and "might have" are the most common qualifiers in Mithen's book, and by the time he has woven together all the strands of this argument, the reader may be intoning *Hmmmmm* in counterpoint with the author. Taken as a look at the natural history of music, Mithen's book is thoughtful and certainly entertaining. But does it make an airtight case—as the subtitle suggests—for "the origins of music, language, mind, and body"? Or is it just a clever academic song and dance?

LAURENCE A. MARSCHALL, author of The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

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Ripping Earth

By Robert Anderson

Early on the morning of April 18, 1906, a section of the San Andreas Fault that was "locked," or stuck in place by friction, suddenly gave way. The break began under the Pacific Ocean, two miles west of San Francisco, and raced outward in opposite directions: northwest 202 miles to Cape Mendocino; southeast 93 miles to San Juan Bautista. The resulting earthquake was the most destructive in U.S. history, and it left the thriving city of San Francisco a smoldering ruin. In the past year, as if to mark the hundredth anniversary of the disaster, the Earth has continued to wreak havoc: most notably, as of this writing, with a devastating quake in western Iran and several major quakes in Indonesia following the disastrous temblor of October 8, 2005, in Pakistan, which killed at least 80,000 people.

To recall the San Francisco earthquake and to remind the public of future threats, the U.S. Geological Survey has assembled an impressive collection of material on the Internet (earthquake.usgs.gov/regional/nca/1906). Start with the "Virtual Tour" of that tumultuous 1906 event, which uses Google Earth software (available at earth.google.com) to explain its causes and effects. The section devoted to the tour, as well as other linked sections on the site, has video and animations worth viewing; to download them quickly you'll need high-speed Internet access. The San Diego Supercomputer Center's "TeacherTECH" program (education.sdsc.edu/teachertech/videos.html) also has simulations of that infamous quake as it rippled outward from the fault.

A century after the calamity, seismologists still cannot pinpoint when a fault will finally release its pent-up stress. Computing power, however, has provided what are literally new views of the problem, leading to refined assessments of hazards. Seismologists begin by measuring where the Earth's crust is being pulled apart and where it is being squeezed. Go to the World Stress Map Project (world-stress-map.org) and, after you've entered the site, click on the "WSM poster" to get a feel for the stress data—depicted as swarms of vector arrows indicating where the rocks are likely to let go. You can also look at the maps generated by the Global Seismic Hazard Assessment Program (www.seismo.ethz.ch/GSHAP) to see where the danger lies.

In the past couple of decades, geologists have begun to model how earthquakes change the stresses in the upper part of the crust, to determine whether the new stress pattern makes temblors more or less likely on adjacent faults. The site posted by the USGS Earthquake and Volcano Deformation and Stress Triggering Group (quake.wr.usgs.gov/research/deformation/modeling/index.html) shows how their modeling works. Click on "Stress Triggering and Earthquake Probabilities" to get a brief explanation, then check out the animations page showing how quakes propagate over time along fault lines in several active regions.

Los Angelenos like me should be concerned by the complex network of faults beneath us. The University of Southern California (velocity.usc.edu/UseIT/movies.html) has some remarkable movies showing the faults, which look like brightly colored ribbons dissecting the crust. The Puente Hills Fault, which extends directly under downtown L.A., looks particularly ominous. San Diego State's Education Center on Computational Science and Engineering (www.edcenter.sdsu.edu/ssc/3d/ssc3dproject.html) has video clips that illustrate why Rayleigh waves (which move the ground up and down) are so destructive and why seismic waves of all kinds propagate at higher amplitudes in soft sediments. The extensive list of geology sites at serc.carleton.edu/NAGTWorkshops/structure04/internetresources.html includes many that offer animations of fault motions.

At the Southern California Earthquake Data Center's site (www.data.scec.org/index.html), click on the last box, "Historic Earthquakes in Southern California," to find a map of past events. Click on the large red dot at the upper left, and you'll learn about the 1857 Fort Tejon event, when the San Andreas Fault slipped along a 220-mile stretch. Far to the south, the Los Angeles River was reportedly "flung out of its bed." Cracks in the ground appeared near San Bernadino and in the San Gabriel Valley.

Return to the San Diego Supercomputer Center's site, which I mentioned earlier, and select "Animation of a 7.7 Quake on the San Andreas Fault" to see the prolonged ground shaking that is likely in the L.A. basin if the San Andreas ruptures near Palm Springs. The simulation took four days to compute. I hope the people at FEMA—under orders from Congress to develop a detailed plan to reduce earthquake hazards—get a chance to see it.

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

OUT THERE

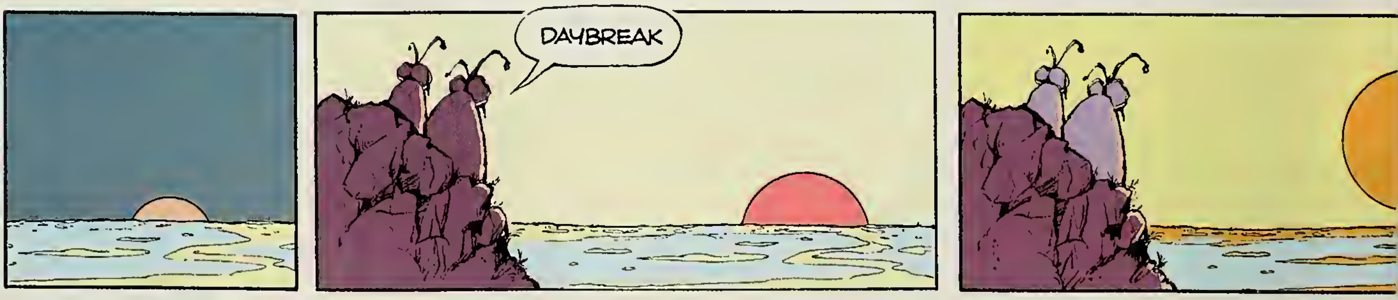
My Three Suns

How many planets survive in multiple-star systems?

By Charles Liu

Titles of scientific research articles are usually drier and more enigmatic than Martian dust. But a recent paper in the *Astrophysical Journal*—"Two Suns in the Sky"—bucks the trend with the blunt force of a summer movie title. Has a new star joined our own, unleashing cosmic destruction on our solar system?

Happily, the paper is not about us. In "Two Suns," Deepak Raghavan and his collaborators at Georgia State University in Atlanta examine a long-standing question: How many exoplanetary systems—those outside our solar system with at least one confirmed planet—have more than one star?



Jim Unger, Herman, *July 13, 2003*

The question is of interest not merely to scientists; it's long caught the fancy of nonscientists, too. Remember the scene in *Star Wars* in which Luke Skywalker looks across the vast desert landscape of his home planet, Tatooine, as he watches two suns setting in the dusky sky? Or maybe you've read a short story titled "Nightfall," in which the science-fiction writer Isaac Asimov envisions a humanlike civilization on a planet tucked into a six-star system. Every 2049 years the planet's solitary moon, unseen in the perennial daylight, eclipses the sixth sun after the other five have set. The planet's inhabitants, having never known night, go mad, burning their civilization to the ground in a desperate effort to bring back the light.

When you write stories about planetary systems with multiple stars, you don't have to worry about the physics. Out there in the real universe, though, the laws of planetary and stellar dynamics place strict constraints on what can and cannot happen. One planet and two stars, all interacting solely through their mutual gravitational forces, present a vivid example of the so-called three-body problem, one of the most famous puzzles in the history of science.

Generally, in a three-body problem, no equation can tell you exactly where the three orbiting objects were (or will be) at every moment in the past (or future). In most cases, the orbits of the objects are unstable, and become increasingly chaotic with the passage of time. Eventually, either two of the objects collide, or one of the three flies out of the system, after which the two remaining objects usually settle into a stable orbit.

With that in mind, picture a planet in a system with two or more stars—a pair of giants buffeting a puny, hapless slave with their far more powerful gravitational fields. What hope is there that the planet can avoid annihilation? Either one star swallows it or the gravity of the two stars slingshots it out of the system altogether. At first blush, the chances of finding a planet in a multiple-star system seem slim to none.

As the eighteenth-century mathematician Joseph-Louis Lagrange and others have pointed out, though, some three-body configurations do give rise to stable orbits [*see "The Five Points of Lagrange," by Neil deGrasse Tyson, April 2002*]. Moreover, if one of the three bodies is far from the other two, the gravity of the distant body becomes too weak to have much effect, so the two closer bodies orbit as a fairly stable, essentially binary, system. And because such systems are mathematically possible, you can count on us astronomers to look for them—even if the chances of finding one are slight.

Building on the work of several other astronomers in the past decade, Raghavan and his collaborators conducted a detailed search for stellar companions among almost all known exoplanetary systems reported as of July 2005. Their list included 131 systems, with a total of 155 exoplanets. The astronomers' goal was to determine whether each star that appears to be near the host star of an exoplanet is, in fact, a companion of the host. After all, even if two stars appear close to each other in the sky, they may merely lie along roughly the same line of sight, but remain too far apart to be gravitationally bound.

Here's the heart of the issue. A typical astronomical image is filled with stars. Even if all of them lie within our own Milky Way, their distance from Earth can range from a few light-years to many thousands of light-years. Stars can also vary widely in brightness: a faint dwarf star can emit less than a millionth the energy of our Sun, whereas a typical blue or red supergiant can emit more than a million times the Sun's energy.

Imagine a baseball stadium on a dark night packed with fans, on the field as well as in the stands. They are all carrying some kind of light—flickering candles, halogen searchlights, and everything in between—as they move around the stadium. Now, move many miles away from the stadium and take a photograph of it. From the two-dimensional "star field" in your photo, how can you tell, for any given pair of nearby lights, whether the two people carrying them are holding hands?

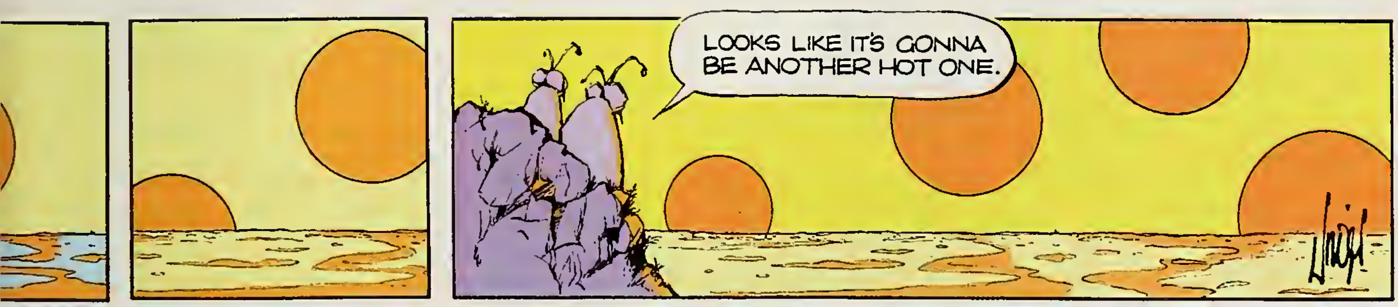
The key lies in measuring the apparent motions of stars across the sky. All the stars are always moving, some of them at speeds of millions of miles an hour. But they're so many *trillions* of miles from Earth that, from our vantage point, they look to the unaided eye as if they're standing stock-still. In fact, to an astronomer, a star is moving at a breakneck pace if it takes less than a millennium to travel one degree of arc—about the width of your fingernail when you hold your hand at arm's length.

So let's modify the stadium analogy a little. Imagine that the people holding lights are walking around at slightly differing speeds while you take a series of photographs. If two of the people are holding hands as they walk, their lights will not only look close together but will also move together at the same speed and in the same direction.

Following the same logic, Raghavan's team took advantage of carefully prepared photographic sky surveys, made decades apart, of the exoplanets' host stars and their apparent stellar neighbors. The team looked for neighbors that followed the same path as a given host star, and they paid special attention to systems previously identified as double stars. Then, to verify that both stars in a pair were approximately the same distance from Earth, they measured the distance from our planet to each star in each stellar pair: independent evidence that the stars could be close together. Of the 131 exoplanetary systems they studied, Raghavan and his colleagues found that between thirty and thirty-six of them—about one in four—are double- or triple-star systems.

If that sounds like a high fraction of multistar systems, well, it is and it isn't. For centuries astronomers have known that most stars in our galaxy are part of such systems. Our Sun, a solitary star so far as anyone knows, is the exception, not the rule. Yet given the stringent limitations on orbital stability in multibody systems, you might think that long-lived planets near multiple stars should be a rarity. So Raghavan's study presents a puzzle: how could so many planets have survived for so many millions, even billions, of years in multiple-star systems?

Here's a clue. All the binary stars confirmed by Raghavan and his team occur in the same general three-body configuration: the exoplanet closely orbits one of the stars, while the second star orbits both the planet and the primary star at a much greater distance. For example, the exoplanetary system 55 Cancri, visible near the constellation Cancer, the crab, includes at least four planets, all orbiting within about half a billion miles of a primary star. The second star in the system orbits at 200 times that distance—100 billion miles away! The configuration is certainly a multiple-body one, but if the planets are home to any inhabitants, they would hardly notice the gravity of the secondary star. It's just too far away.



That brings to mind another of science fiction's fanciful ideas. It's long been imagined that our own Sun might be part of a binary-star system, with a small, faint companion so far away that astronomers haven't yet recognized it for what it is. In its distant orbit, that secretive secondary star would occasionally wander close enough to disrupt the orbits of distant comets and other small solar system objects, flinging them toward the Sun as well as toward Earth. Could such a star, over the eons, have gravitationally slung deadly stones toward our planet—cosmic missiles that caused ecological destruction, triggered mass extinctions, and altered the course of life? If the binary configurations of exoplanetary systems are an indication, the chance that such "fiction" could be fact might be a tiny bit less farfetched than we all once thought.

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

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EXPLORER GUIDE

(Continued from page 28)

unkind. Although productive rains returned, an unprecedented hurricane season unfortunately accompanied them. All the earlier reintroduction sites were ravaged. Even more alarming was the damage to Bahia Honda State Park. In just a few months, the small island absorbed glancing blows from four major tropical cyclones. The salt spray and storm surges from the storms severely damaged some 90 percent of the habitat occupied by Miami blues, transforming robust green plants into brown, leafless twigs. The shortage of nectar and host resources raised concerns that the butterfly population would not soon—or ever—fully recover.

Yet despite the seemingly continuous misfortunes, the Miami blue persisted. In the months following the storms, it made a steady comeback in the park, and today its local revival is just one reason for optimism. The captive-breeding program continues to thrive: now some thirty generations old, it has produced more than 20,000 individuals. Field reintroductions and numerous additional research projects continue, boosting the butterfly's chances for a full recovery. With the ongoing support from countless organizations and a little help from Mother Nature, there is good reason for hope that the Miami blue will again soon flourish in south Florida.

JARET C. DANIELS and STEPHANIE J. SANCHEZ, a husband-and-wife team, met while working on the recovery of the federally endangered Schaus swallowtail butterfly. They have collaborated on research ever since. Daniels is an assistant professor of entomology and assistant director for research at the McGuire Center for Lepidoptera and Biodiversity at the Florida Museum of Natural History at the University of Florida in Gainesville. He heads the Miami-blue conservation efforts. Sanchez is an endangered-species researcher at the McGuire Center. Visitors to the Florida Museum of Natural History can observe the Miami-blue breeding program firsthand during the inaugural Florida Butterfly Festival, October 14 and 15, 2006.

THE SKY IN OCTOBER

By Joe Rao

Mercury begins the month shining, with an orange hue, at magnitude −0.1, in the constellation Boötes, the herdsman. Look for the planet low in the west-southwest about thirty minutes after sunset during the first half of October. To see it, though, you'll probably need optical aid and a ton of luck. Although it attains its greatest elongation, twenty-five degrees from the Sun, on October 17th, it remains south of the celestial equator, in the constellation Libra, the scales, and so lies low in the sky for observers in the Northern Hemisphere. By the end of the month, Mercury is so low and faint that few viewers north of the equator can see it at all.

Venus is out of sight in October; it reaches superior conjunction, on the far side of the Sun, on the 27th. The planet returns as a bright evening "star" by early to mid-December.

Mars, like Mercury and Venus, is hidden deep in the Sun's glow throughout the month. The Red Planet is in conjunction with the Sun on the 23rd.

Jupiter sets about an hour and three-quarters after the Sun at the start of October, but fifty minutes after sunset by month's end. Unfortunately, the solar system's largest planet is too low at dusk for good telescopic viewing, but binoculars help a lot. My guess is that, realistically, the evening of the 24th is the last time most observers can see it this month. If you do locate Jupiter that evening, try to spot the exceedingly thin crescent Moon about ten degrees to the planet's left, albeit somewhat lower in the sky. You might also spot dim Mercury, about four degrees below and to the left of Jupiter. Binoculars can also track Jupiter as it pulls away from the star Zubenelgenubi, in the constellation Libra, early in the month.

Shining at magnitude +0.5, Saturn reigns over the October skies, the only bright planet well placed for viewing. At midmonth it rises soon after 2 A.M. and is a good distance above the eastern horizon at dawn. Saturn creeps 2.5 degrees eastward in the constellation Leo, the lion, and closes the month six degrees west of the bluish, first-magnitude star Regulus, also in Leo. Of all the stars within thirty degrees of Saturn, only similarly hued Procyon, in the constellation Canis Minor, the little dog, shines brighter than the Ringed Planet. The edge of the rings continues tilting slowly toward our line of sight; a telescope shows the rings' southern side tilted 13.7 degrees toward us at the start of the month and 12.7 degrees by month's end. On the morning of the 16th Saturn lies below and slightly to the right of a fat crescent Moon.

The Moon is full on the 6th at 11:13 P.M. Because this full Moon is the one closest to the autumnal equinox, it is also known as the Harvest Moon. Late on the night of the 9th and into the early morning hours of the 10th, in its waning gibbous phase, the Moon occults, or passes in front of, the Pleiades star cluster. Because the Moon is so bright at the beginning of the occultation—87 percent of its disk is illuminated—viewing the stars may be difficult. It may be particularly hard to see them disappear, because the bright edge of the Moon passes in front of them first. It should be easier to catch them as they pop out from behind the dark edge. The Moon further wanes to last quarter on the 13th at 8:26 P.M., and to new Moon on the 22nd at 1:14 A.M. Our satellite waxes to first quarter on the 29th at 4:25 P.M. eastern standard time.

Daylight saving time ends on the 29th, the last Sunday of the month. People in most of Canada and the U.S. should set their clocks back one hour. On this date the "clock hour" from 1 until 2 A.M. officially repeats.

Unless otherwise noted, all times are eastern daylight time.

Around the Country

ARIZONA

Mesa

MESA SOUTHWEST MUSEUM *Through October 29:* **"From Above: Images of a Storied Land."** Imagine you are an eagle soaring above the desert Southwest in this exhibition of sixty large-scale photographs that include aerial views of the Aztec Ruins National Monument, Casas Grandes, Chaco Canyon, and many other locations. Photographer Adriel Heisey captured these images from an ultralight airplane, revealing the imprints that ancient and modern cultures have left on the land.
53 North Macdonald Street
480-644-2230
www.mesasouthwestmuseum.org

Phoenix

ARIZONA SCIENCE CENTER *Ongoing:* **"Wired for Thought: The Developing Brain."** What does current research tell us about how the brain grows and changes over time? This new exhibition explains what science has discovered about the brain in early childhood, teen years, and adulthood. Visitors can perform activities based on scientific experiments that study how the brain changes and adapts in response to biological and environmental conditions, including substance use and abuse.
600 East Washington Street
602-716-2000
www.azscience.org

CALIFORNIA

Los Angeles

NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY *Through November 5:* **"Spider Pavilion."** See spiders spinning webs, interacting with their environment, and feeding on their prey in the only public spider-viewing center of its kind in the U.S. Gallery interpreters lead visitors on tours through the museum's greenhouse, explaining habitats and behaviors of the exhibition's inhabitants, which include banded garden and golden silk species.
Exposition Park
900 Exposition Boulevard
213-763-DINO
www.nhm.org

Original poster for the 1956 film *Godzilla,* now on display in "Dinosaurs: Reel & Robotic" at the San Diego Natural History Museum

Redlands

SAN BERNARDINO COUNTY MUSEUM *Through November 5:* **"Pottery from the Pueblos."** More than 200 early to mid-20th-century pieces from the museum's anthropology collection explore the range of history and craftsmanship in the pueblo cultures of the southwestern U.S. Unique designs and colors from fifteen pueblos reflect the heritage of the Anasazi, Hohokam, and other ancestral cultures.
2024 Orange Tree Lane
909-307-2669
www.sbcountymuseum.org

San Diego

SAN DIEGO NATURAL HISTORY MUSEUM *Through January 1, 2007:* **"Dinosaurs: Reel & Robotic."** Rare movie memorabilia, video presentations, and animatronic dinosaurs tell the story of how Hollywood has portrayed dinosaurs during the past ninety years, often in response to advances in scientific knowledge. The show includes *Gertie,* the 1914 cartoon that first featured the animal; promotional posters for the original *King Kong,* in which the ape battled dinosaurs; and lifelike modern dinosaur models created in consultation with paleontologists.
Balboa Park
1788 El Prado
619-232-3821
www.sdnhm.org

San Francisco

CALIFORNIA ACADEMY OF SCIENCES *Through February 4, 2007:* **"Dinosaurs: Ancient Fossils, New Discoveries."** Presenting an up-to-date look at what scientists currently think about dinosaur physiology and behavior, this new exhibition builds on cutting-edge research, includes an impressive, detailed walk-through diorama of a Mesozoic-era environment, and explores the newest research related to why dinosaurs became extinct.
875 Howard Street
415-321-8000
www.calacademy.org

COLORADO

Denver

DENVER MUSEUM OF NATURE AND SCIENCE *Ongoing:* **"Ancient Denvers."** When we think of the Rockies, we envision massive mountains and jagged peaks, but this land was once dramatically different. In 1999 a museum team drilled a well nearly half a mile deep to extract a core sample of rocks and sediments representing the region's geologic history. Local artists, working with museum scientists, then re-created several "ancient Denver" landscape paintings complete with such startling features as crocodiles, deserts, dinosaurs, giant millipedes, palm trees, rainforests, seas, and other features that seem so foreign to today's Denver.
2001 Colorado Boulevard
800-925-2250
www.dmns.org

FLORIDA

Gainesville

FLORIDA MUSEUM OF NATURAL HISTORY *Through*

MEMBERSHIP HAS ITS REWARDS

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See www.astc.org/passport for more information.

January 7, 2007: "**Hatching the Past: The Great Dinosaur Egg Hunt.**" See the bowling ball–size egg of a *Titanosaur*, touch authentic dinosaur bones, dig for dinosaur eggs, and meet "Baby Louie," the nearly complete skeleton of a dinosaur embryo from a newly discovered species. Dinosaur eggs and nests from China and Argentina—as well as models of embryos and hatchlings and paintings of dinosaur family life—help explain new scientific discoveries about how dinosaurs reproduced and raised their young.
University of Florida
Cultural Plaza
SW 34th Street and Hull Road
352-846-2000
www.flmnh.ufl.edu

Bust of Lucius Verus, co-emperor of the Roman Empire with Marcus Aurelius, A.D. 161–169, now on display in the "Imperial Rome" exhibition at Atlanta's Fernbank Museum of Natural History

Tampa

MUSEUM OF SCIENCE AND INDUSTRY (MOSI) *Ongoing:* "**Kids in Charge!**" This recently opened facility features more than 20,000 square feet of colorful, interactive exhibits designed to encourage children's creativity and science skills. Try out differently shaped wings in a wind tunnel, lie down on a "bed of nails," figure out how to crack a safe with a mathematical code, discover facts about an animal's history from a single tooth, play checkers on a twenty-foot-square board, and much more. A separate area for toddlers features activities that focus on gross and fine motor skills, balance, coordination, and movement.
4801 East Fowler Avenue
813-987-6100
www.mosi.org

GEORGIA

Atlanta

FERNBANK MUSEUM OF NATURAL HISTORY *Through January 3, 2007:* "**Imperial Rome.**" More than 450 artifacts portray how emperors and commoners lived in the Roman Empire more than 1,700 years ago. The show features architectural models, ceramics, coins, glass, jewelry, sarcophagi, bronze and marble statues, urns, and other objects that give visitors a glimpse of an ancient time. The show's "Education Alley" section includes hands-on activities for children.
767 Clifton Road NE
404-929-6300
www.fernbank.edu/museum

ILLINOIS

Aurora

SCITECH HANDS ON MUSEUM *Ongoing:* "**Virtual Reality.**" An innovative gallery lets you explore things that might otherwise be too small, too far away, or too dangerous to see. Put on some special goggles, sit in front of the large computer-graphics screen, and watch a beating heart, fly around Jupiter and its moons, look inside an ant, or buzz around the Wright brothers' first airplane.
18 West Benton Street
630-859-3434
scitech.mus.il.us

Chicago

THE FIELD MUSEUM *Through January 1, 2007:* "**Tutankhamun and the Golden Age of the Pharaohs.**" Twice the size of the 1977 Tut exhibition, this show features more than 130 artifacts from the boy king's tomb and other royal burial sites. Gold objects, jewels, and gilded-wood items in the show tell the story of Egypt at the height of its imperial power, during the 18th dynasty, including the pervasive role of religion and its emphasis on the afterlife. The exhibition also describes the 1922 discovery of Tut's undisturbed tomb, and includes CT scans of his mummified body, revealing new information about his life and death.
1400 South Lake Shore Drive
312-922-9410
www.fieldmuseum.org

INDIANA

Fort Wayne

SCIENCE CENTRAL *Ongoing:* "**Swap Shop.**" A wide range of natural-history objects is available for hands-on inspection—and trading! Bring in your own items, whether from the backyard or somewhere more exotic, and get pointers about how you can acquire such new natural treasures as spectacular pinecones, unusual mineral samples, ancient fossils, and much more.

Coffinette that held some of King Tut's mummified internal organs, now on view in the "Tutankhamun and the Golden Age of the Pharaohs" exhibition at The Field Museum in Chicago

1950 North Clinton Street
260-424-2400
www.sciencecentral.org

KENTUCKY

Louisville

LOUISVILLE SCIENCE CENTER *Through January 1, 2007:* "**Candy Unwrapped.**" Explore the science of sweets—their biology, chemistry, physiology, psychology, and cultural history—in this interactive exhibition. Watch the facial reactions when your friends bite into super-sour pieces of candy. Find out which culture considers silkworm pupae to be delicacies. Discover the difference between taste and flavor by eating a jelly bean with your nose plugged.
727 West Main Street
800-591-2203
www.louisvillescience.org

FROM LEFT: SAN DIEGO NATURAL HISTORY MUSEUM; FERNBANK MUSEUM OF NATURAL HISTORY/CONTEMPORANEA PROGETTI; THE FIELD MUSEUM/ANDREAS F. VOEGELIN, ANTIKENMUSEUM

Simulated base camp on the surface of Mars, part of the "SPACE" exhibition, opening October 7 at the North Carolina Museum of Natural Sciences in Raleigh

MISSOURI
Saint Louis
SAINT LOUIS SCIENCE CENTER *Ongoing:* "SportsWorks." Test your mind and your body in one of the largest sports and science exhibitions in the world, and discover what athletes know about biology, health, and training. Step into a regulation batting cage and toss a pitch to a virtual major leaguer, try your hand (and feet) at climbing a rock wall, experience gravitational force on a bicycle-powered vertical loop high above the ground, and much more.
5050 Oakland Avenue
800-456-SLSC
www.slsc.org

NEW MEXICO
Albuquerque
NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE *Ongoing:* **"Jurassic Super Giants."** A new gallery focuses on the Jurassic, featuring a dramatic display with two huge dinosaurs fighting each other: a *Seismosaurus*, one of the longest land animals that ever lived (100 feet), and a *Saurophaganax*, the largest meat-eating dinosaur of the time.
1801 Mountain Road NW
505-841-2800
www.nmnaturalhistory.org

NEW YORK
Buffalo
BUFFALO MUSEUM OF SCIENCE *Ongoing:* **"Whem Ankh: The Cycle of Life in Ancient Egypt."** Learn about daily life as it was lived on the banks of the lower Nile River 2,200 years ago. Meet the mummies of Nes-hor and Nes-min, who were priests of the Egyptian fertility god Min. Find out how different life was then and, yet, in important ways, how similar it is to our own lives today.
1020 Humboldt Parkway
716-896-5200
www.buffalomuseum ofscience.org

New York
AMERICAN MUSEUM OF NATURAL HISTORY *Through January 7, 2007:* **"Lizards & Snakes: Alive!"** More than sixty living squamates (reptiles with scales) are on display in re-created habitats, complete with rock ledges, tree limbs, live plants, and ponds—ranging from a four-inch tropical lizard to a fifteen-foot Burmese python. There are several interactive stations where visitors can listen to recorded squamate sounds, explore the inner workings of a rattlesnake, and more. The exhibition also features a wide range of squamate fossils and casts, as well as information on current research and breakthroughs in scientific applications, such as advances in diabetes research made possible by studying Gila monster venom.
Central Park West
at 79th Street
212-769-5100
www.amnh.org

Tupper Lake
THE WILD CENTER, NATURAL HISTORY MUSEUM OF THE ADIRONDACKS *Ongoing:* **"Living River Trail."** At this spectacular new museum in the heart of New York's Adirondack Park region, the exhibition traces the course of a river from its source in the mountains down to the marshlands. Along the way, visitors can discover bog, forest, and stream ecosystems, including live animals such as river otters and rare brook trout species.
45 Museum Drive
518-359-7800
www.wildcenter.org

NORTH CAROLINA
Durham
MUSEUM OF LIFE AND SCIENCE *Through January 8, 2007:* **"Holiday Springs and Sprockets."** Visitors can watch a vertical drill press create candy canes, exercise bicycles propel reindeer, automatons wash dirty cookie-baking utensils, and much more in this new holiday-themed exhibition that combines equal parts art, engineering, and whimsy.
433 West Murray Avenue
919-220-5429
www.ncmls.org

Raleigh
NORTH CAROLINA MUSEUM OF NATURAL SCIENCES *Opening October 7:* **"SPACE: A Journey to Our Future."** Touch actual rocks from the surfaces of Mars and the Moon, "ride" a re-creation of the first manned spacecraft to land on the Moon, or walk through a model of the International Space Station in this exhibition about past, present, and future space exploration.
11 West Jones Street
877-4NATSCI
www.naturalsciences.org

PENNSYLVANIA
Philadelphia
THE ACADEMY OF NATURAL SCIENCES *October 7–8:* **"Shell Show."** Dive into the largest annual shell show in the Northeast, featuring thousand of seashells from all over the world, behind-the-scenes tours of the museum's renowned malacological collection, and—for the kids—free shells and an opportunity to meet another ocean denizen: SpongeBob SquarePants from the animated Nickelodeon television series.
1900 Benjamin Franklin Parkway
215-299-1000
www.acnatsci.org

Pittsburgh

Carnegie Museum of Natural History *Through January 7, 2007:* **"Amazon Voyage: Vicious Fishes and Other Riches."** This exhibition explores the biodiversity and native people of the Amazon River region. Touch the teeth of the world's largest piranha, test the zap of an electric eel, or discover Brazilian folklore's *Encante* world beneath the river.
4400 Forbes Avenue
412-622-3131
www.carnegiemuseums.org/cmnh

TEXAS
Fort Worth

Fort Worth Museum of Science and History *Ongoing:* **"Lone Star Dinosaurs."** This new permanent exhibition puts visitors in paleontologists' shoes by providing opportunities for them to experience fieldwork and subsequent laboratory and imaging processes. Visitors can map a dig site, extract fossils from rock, and create a digital picture that summarizes their findings. The show also features five new dinosaur species found in Texas, including two that are not yet named, and describes what scientists are learning from their fossils.
1501 Montgomery Street
817-255-9300
www.fwmuseum.org

Houston

Houston Museum of Natural Science *Opening October 13:* **"Benjamin Franklin: In Search of a Better World."** More than 250 artifacts from the scientist-statesman's life—including his original printing equipment and personal copy of the U.S. Constitution—help celebrate the 300th anniversary of his birth. Visitors can climb aboard a 25-foot ship model to recreate his method of charting the Gulf Stream and investigate several of the other scientific questions that intrigued him at a time when science as we know it today was known as "natural philosophy."
One Hermann Circle Drive
713-639-4629
www.hmns.org

VIRGINIA
Martinsville

Virginia Museum of Natural History *Opening October 28:* **"Chinasaurs: The Great Dinosaurs of China."** Huge skeleton casts from China—many making their first trip to the U.S.—highlight similarities between dinosaurs from Asia and those from North America, but they also illustrate several unique characteristics. From *Monolophosaurus*, with its unusual curved headcrest, to *Lufengosaurus*, with its widely spaced teeth, the exhibition presents a fascinating overview of dinosaur life in China during the Triassic, Jurassic, and Cretaceous periods.
1001 Douglas Avenue
276-666-8600
www.vmnh.net

Bengalensis cone-snail shell, one of thousands on display and for sale October 7–8 during the annual "Shell Show" at Philadelphia's Academy of Natural Sciences

Top portion of lightning rod designed by Benjamin Franklin, part of the exhibition examining his wide-ranging achievements, opening October 13 at the Houston Museum of Natural Science

WASHINGTON
Seattle

Burke Museum *Through December 31:* **"A Celebration of Souls: Day of the Dead in Southern Mexico."** This colorful photographic exhibition documents some of the traditions with which people honor the dead in the rural areas of Mexico's Oaxaca state. Large-format images capture people preparing centuries-old recipes, scattering trails of marigolds for guiding spirits home, offering chocolate at community gatherings, and much more. The exhibition will be anchored by a Day of the Dead *ofrenda* (ceremonial altar) created by Seattle artist Isaac Hernandez Ruiz.
University of Washington
17th Avenue NE and
NE 45th Street
206-543-5590
www.washington.edu/burkemuseum

Pacific Science Center *Through January 7, 2007:* **"Discovering the Dead Sea Scrolls."** Featuring ten original scrolls and three facsimiles, along with other artifacts from the ancient settlement of Qumran near the Dead Sea, this exhibition explores one of the greatest archaeological discoveries of the 20th century, the oldest known Biblical manuscripts. Written mostly on parchment in Hebrew, Aramaic, and Greek, the scrolls also include sectarian and apocryphal texts. The show will include four artifacts that have never been displayed in public before—fragments of Genesis, Exodus, Ezekiel, and the War Rule—as well as a variety of hands-on exhibits that explain the science behind the excavation, conservation, and interpretation of the scrolls.
200 Second Avenue North
206-443-2001
www.pacsci.org

WISCONSIN
Milwaukee

Milwaukee Public Museum *Ongoing:* **"Nunnemacher Arms Collection."** Trace the development of firearms around the world in this collection of 3,500 historic firearms from the 17th century to World War II. U.S. objects include a Ferguson rifle from the Revolutionary War (one of the first rapid-firing rifles), Confederate firearms from the Civil War, and a series of Colt semiautomatic pistols from the early 1900s.
800 West Wells Street
414-278-2702
www.mpm.edu

FROM LEFT: CLEAR CHANNEL EXHIBITIONS; THE ACADEMY OF NATURAL SCIENCES; THE FRANKLIN INSTITUTE/PETER HARHOLDT

ENDPAPER

Winning Miss Muffet's Heart

By Rebecca Rupp

Normal people don't like spiders. All those scrabbly and asynchronous little legs set off red alerts in the primitive parts of our brains, anxiety attacks egged on by awful ancestral memories from the early age of mammals. Little Miss Muffet, fleeing with a shriek from her arachnid-infested tuffet, was uttering a primal scream.

My eldest son, who is not a normal person, owns a Mexican redknee tarantula. He keeps it in a plastic enclosure of wholly inadequate security, where it amuses itself by lurking, burrowing in vermiculite, and eating live crickets. Spider aficionados refer to the redknee as "handsome" and "amiable," but to the average arachnophobe, it's a crawling nightmare: a spider the size of a hockey puck with an aggressive glint in its eight near-sighted little eyes. If annoyed, it scrapes barbed hairs off its abdomen and flings them at you; if really annoyed, it bites.

To be fair, those behaviors are defensive and relatively mild compared to, say, the spit of a cobra or the charge of a raging bull. The barbed, urticating hairs, embedded in the provoker's skin, may cause an allergic reaction; the bite injects a venom of such puny potency that it poses little risk to anything larger than a rat. No person, to my knowledge, has ever dropped dead from a tarantula bite, though it seems to me not unlikely that some might succumb from pure fright.

Then there's the cricket thing. I like crickets. I have happy childhood memories of them: bedtime stories about crickets who sang opera or communicated via Morse code or—Jiminy Cricket in *Pinocchio*—who wore a little tailcoat and had such a formidable command of ethics.

Around here, a cricket dropped into the tarantula's cage lasts about as long as a steak dropped into a pack of timber wolves. The spider senses the cricket's whereabouts with specialized leg hairs that detect motion. (Crickets bring it on themselves with their idiotic hopping; a still cricket is a safe cricket.)

Once the position of dinner is identified, the ordinarily sluggish redknee pounces with lightning speed, chomping down with fangs said to be strong enough to bite through a human fingernail. The tarantula's feeble venom is enough to paralyze the hapless cricket, which it proceeds to pump full of digestive juices. The spider then feeds by slurping up the dissolved nutrients.

It's hard not to side with the cricket here, especially if, on late-night TV, you've seen the 1955 horror flick *Tarantula!,* in which a spider the size of a small skyscraper attacks horses, sheep, scientists, townspeople, and policemen, before being downed by a young Clint Eastwood with a fighter jet full of napalm.

In real life, tarantulas are surprisingly fragile. Drop one and it breaks like an egg—a sad fact that, in the early days of my acquaintance with my son's pet, led to some diabolical fantasies on my part. An adroit flip off the table with a spatula would do the trick, I thought, followed by a dramatic apology and a commemorative little cairn in the garden. No one would ever know.

Since then, though, I've slowly come around. Tarantulas, observed up close and daily, grow on you. "They're quite attractive really," I found myself saying recently, with astonishing sincerity to a cringing visitor; and the redknee, which not only has red knees, but also reddish ankles and a jaunty red ring around the thorax, is positively glamorous. The aforementioned habit of lurking, viewed dispassionately, looks not so much sinister as contemplative. Tarantulas, by and large, are shy creatures, retiring homebodies, desirous—like Virginia Woolf—of rooms of their own.

In truth, there's a restful dignity about them, a trait common to all things powerful and large, like the aging Queen Victoria—though unlike the queen, tarantulas are undemanding. They're peaceful, low-maintenance creatures that shun extraneous entertainment and small talk. Beside tarantulas, crickets begin to seem fidgety and annoying.

A tarantula, viewed without the blinders of prejudice, is a spider with substance: a spider, in fact, with which anyone anywhere should be proud to share a tuffet.

REBECCA RUPP is a cell biologist who has written fifteen books and many articles for national magazines. Her most recent book is Four Elements *(Profile Books, 2005), a natural history of water, air, fire, and earth. She lives in Vermont with her husband, three sons, two cats, six fish, and a spider.*

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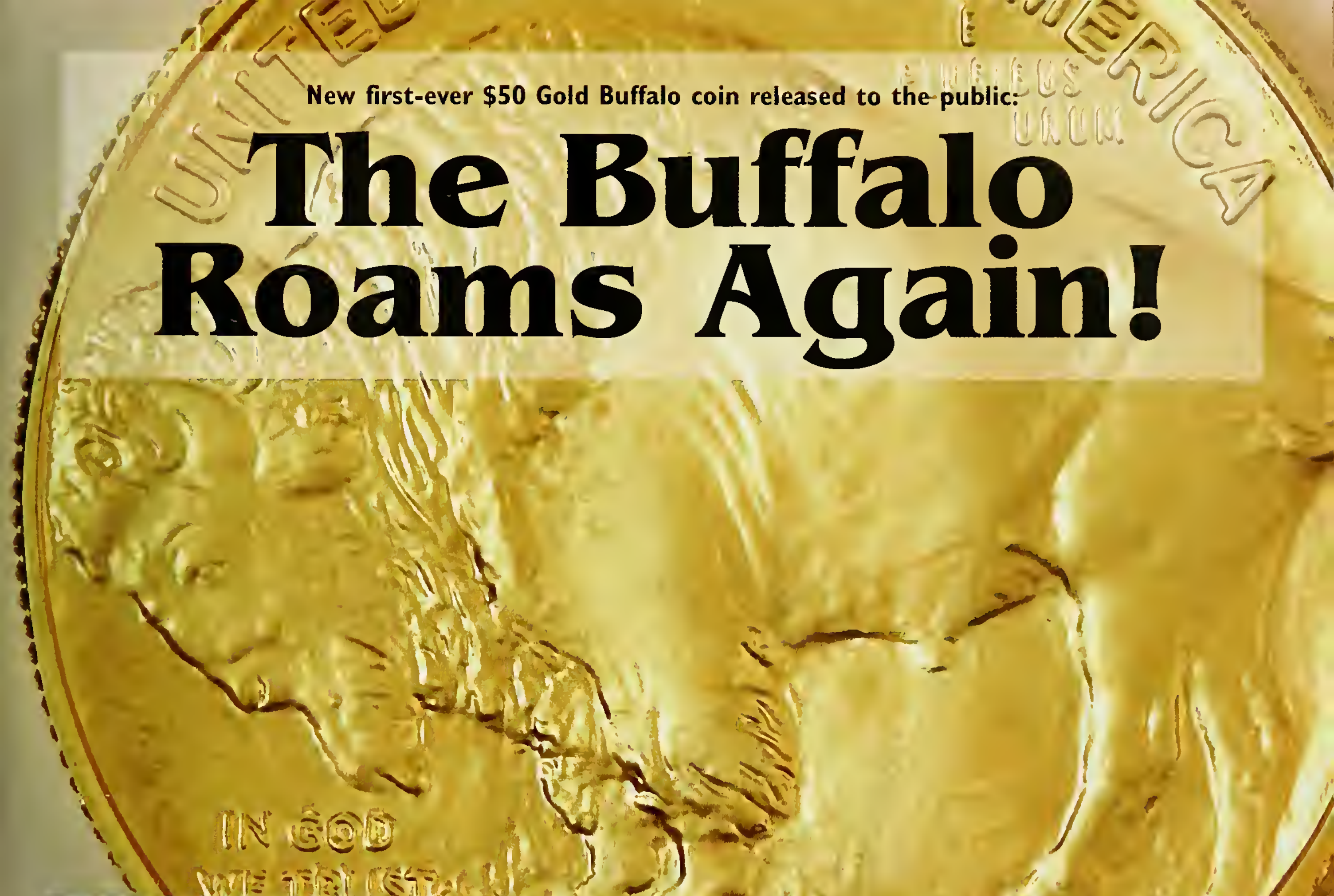

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