

NATURAL HISTORY

4/05

A dramatic night scene featuring a firefighter in silhouette, positioned in the lower center of the frame. The firefighter is facing a massive, intense fire that stretches across the bottom of the image. The fire is bright orange and yellow, contrasting sharply with the dark night. Above the firefighter, the sky is filled with thick, billowing white and grey smoke that rises into the upper half of the image. The overall atmosphere is one of a major fire incident.

FIRE DOWN UNDER

a monument to love, an ode in white.
a caravan of colours, bathed in light.
a river of passion, a timeless tide.
the colours of india, an incredible sight.

Incredible india



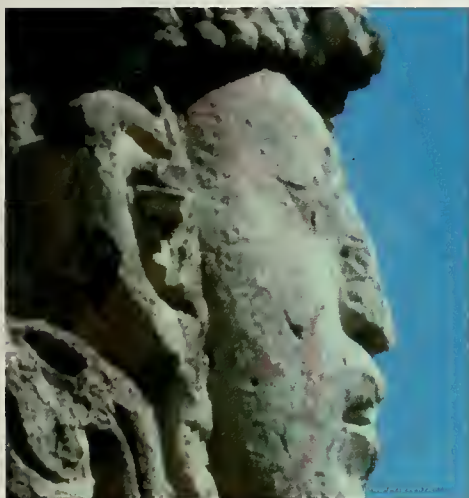
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APRIL 2005

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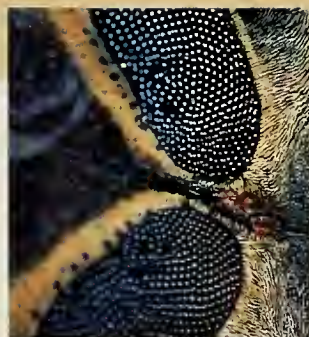
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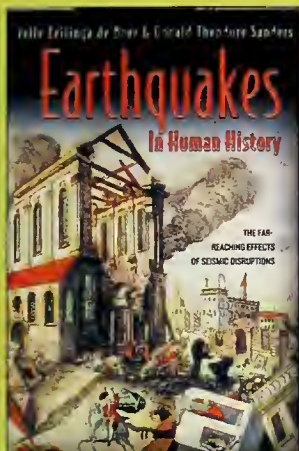
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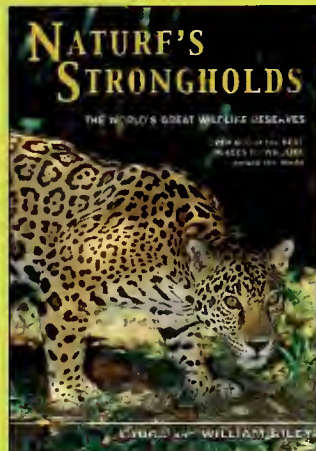
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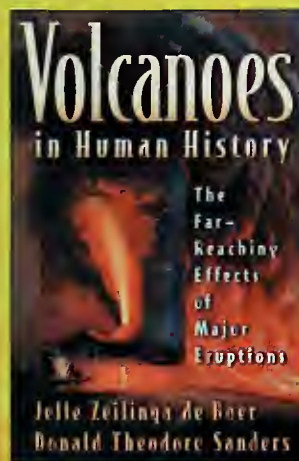
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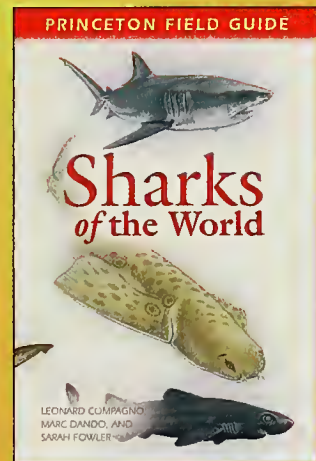
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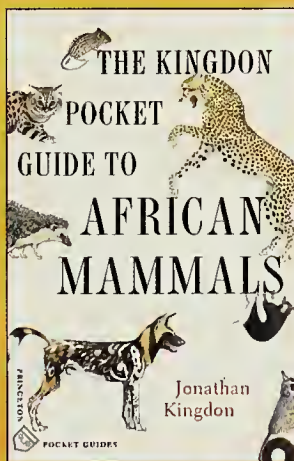
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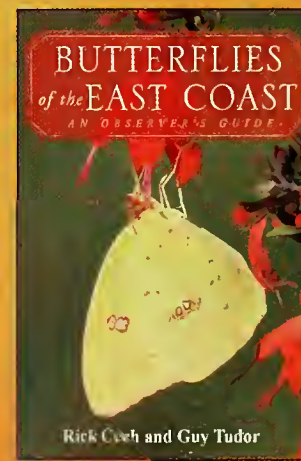
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THE NATURAL MOMENT

Hitchin' a Ride

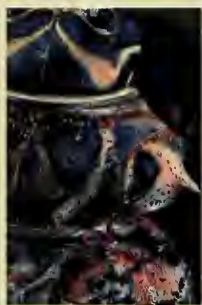
Photograph by Christian Ziegler





◀ See preceding two pages

Usually when a creature is whisked around by a big, strong, winged animal—as so often happens in fantasies for children—biologists call the hitchhiker a parasite. Certainly the harlequin beetle (*Acrocinus longimanus*), pictured here, gains nothing but grief from the dozens of red mites gorging on its back.



But what about the pseudoscorpion that is also visible on the harlequin (bottom center)? Pseudoscorpions (*Cordylocheres scorpionoides*) lack a stinger and burden a beetle only temporarily. All they need is a little help relocating to a “fresh” supply of rotting wood—their food source and main digs.

Male pseudoscorpions definitely cross the parasite line, though, when they use their chauffeurs as personal courting arenas. Staking claims on individual harlequins, they oust weaker males and welcome new females at every stop. Some males stay on board for as long as two weeks. For a safer ride, they spin silk “harnesses,” tethering themselves to the harlequins. Males need to be enterprising because female pseudoscorpions are remarkably promiscuous; in fact, if pregnant females have had fewer than three different mates, they are likely to abort their embryos.

Nature photographer Christian Ziegler spotted this beetle and its company of riders at the base of a decaying fig tree on Barro Colorado Island, Panama. Initially, he noted, a second pseudoscorpion was aboard, but it soon scurried off. Only one remained, king of the harlequin and ready for takeoff.

—Erin Espelie

Hard to Imagine

Sometimes I think the only realities people respond to are the ones staring them in the face. Watching a sunset from a tropical beach in midwinter, I find it almost impossible to remember how cold, wet, and miserable I felt just days earlier, trudging through mud and slush in the Northeast. Fired up to resume regular jogging by Adam Summers’s description of how the human body plan makes people “Born to Run” (page 34), I don’t even consider the aching, breathless, sweaty reality of running. When you think about it, though, sensory transience is probably a good thing. Where would the species be if people didn’t (mostly) forget about pain as soon as it went away (think: childbirth)—or didn’t, in general, downplay the risks of confronting the forces of nature?

Yet our talent for flattening all sensations that are *not* here and now has its drawbacks. The dearth of empathy is one of them. Hearing about the misfortunes of your family may make me stop and shudder, but I won’t really feel your pain. If you’re the target of genocide in Darfur, answering your cries for help across the cultural divide seems to take an effort of will beyond what most people can muster. And if all you can do is *warn* me about the dangers of environmental change, I’m likely to dismiss you with a wave of my hand: “We’ll take care of that if it happens.”

Jared Diamond, whose feature article, “Collapse,” appears on page 38, has heard those confident dismissals before. “The notion that environmental geography and biogeography influenced societal development,” he writes in his book *Guns, Germs, and Steel*, is a view “not held in esteem by historians; it is considered wrong or simplistic, or it is caricatured as environmental determinism and dismissed.”

But shrugging off the Indian Ocean tsunami isn’t much of an option for the residents of Banda Aceh. And Diamond’s reading of the long-term scientific record of human coping makes it clear that entire societies have become casualties of environmental change, often self-inflicted, whereas others have learned to live within their means—and survived. On May 1 the Natural History Museum of Los Angeles County will open a new exhibition—called “Collapse?”—which promises to extend Diamond’s reflections on human destiny beyond the limits of the printed page. Visitors will confront a sensory, visceral embodiment of the classic environmental problems and their solutions that is as direct as the museum can make it.

• • •

Another part of our essential nature was virtually unexplored when, three decades ago, Elizabeth Blackburn began her remarkable studies of the ends of chromosomal DNA. Recognizing her seminal work, the Franklin Institute in Philadelphia will present her with the Benjamin Franklin Medal in Life Sciences this month. Our correspondent Mary K. Miller spoke with Blackburn about her work and its broad implications for aging, cancer, and stress. Miller’s story, “Keeping the Ends in Sight,” begins on page 52.

—PETER BROWN

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Ziegler



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CHRISTIAN ZIEGLER ("The Natural Moment," page 4), a native of Germany, began photographing wildlife in countries as diverse as Thailand and Ivory Coast while he was still a graduate student. Ziegler provided the photographs for the book *A Magic Web: The Tropical Forest of Barro Colorado Island*, produced in conjunction with the Smithsonian Tropical Research Institute in Panama and featured in the February 2003 issue of *Natural History*. A collection of his photos can be seen at his Web site (www.naturphoto.de).

Following up on his Pulitzer Prize-winning book, *Guns, Germs, and Steel: The Fates of Human Societies* (W. W. Norton & Company, 1997), **JARED DIAMOND** ("Collapse," page 38) has now focused his attention on the failures—and successes—of societies that confront threatening environmental dilemmas. For the feature we have adapted from his newly published book, *Collapse: How Societies Choose to Fail or Succeed*, we have included three of the societies that will also be featured in a new exhibition opening on May 1 at the Natural History Museum of Los Angeles County: the ancient Mayan civilization; the island culture of Japan from the seventeenth until the nineteenth century; and modern Montana. Diamond began his scientific career in physiology and expanded into evolutionary biology and biogeography. He is a professor of geography at the University of California, Los Angeles. He last wrote for *Natural History* in July–August 2001.

DAN DROLLETTE ("Fire Down Under," page 44) says that when he first arrived "in the land down under" on a Fulbright fellowship in 1995, he felt as though he'd entered a world of mirror images: the driver's seat was on the right side of the car, the light-switch positions were reversed, the swans were black, and the ski season was in July. Drollette eventually returned to work as a science writer in Australia for four years, covering technology and the environment for American publications. He now makes his home in Northampton, Massachusetts, but he continues to report from both Australia and Southeast Asia. Some of his recent photographs can be seen at his Web site (www.dandrollette.com).

MARY K. MILLER ("Keeping the Ends in Sight," page 52) is a freelance science writer from San Jose, California. She is also a science and Web-cast producer at the Exploratorium in San Francisco, a job that has taken her to Antarctica, to the Galápagos, and inside Cold Spring Harbor Laboratory, on Long Island, New York. She has a degree in biology. Her most recent story for *Natural History*, on endangered Hawaiian forest birds, appeared in March 2004. You can follow some of her adventures on the Exploratorium Web site (www.exploratorium.edu/origins).

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NATURAL HISTORY

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LETTERS

Dogfight

In their review ["Can Dogs Think?" 2/05] of my recently published book, *If Dogs Could Talk: Exploring the Canine Mind*, Bruce Blumberg and Raymond Coppinger seem to hold an a priori conviction that any traits of dogs that are similar to traits in humans are only "tricks" played by dogs in order to mislead us. I cannot accept that viewpoint.

Humans and dogs are both classified among the higher vertebrates, which strongly suggests that there are similarities (as well as differences) in the operations of their brains. The gap between the workings of humans' and dogs' brains is precisely what we are

trying to understand. In a book written for the general public, one has to use language that is readily understood, with the proviso that adequate and detailed warnings be given about the pitfalls of such language. I believe that I amply satisfied this requirement in my book.

Among the examples of my alleged errors are the chapters in which I discuss personal observations and my "dog diary." I have never used personal observations or diary entries about dogs in the more than thirty scientific papers that my team and I have written in the past decade. I did use those observations, however, as starting points for designing rigorous experiments. In the experiments, my coworkers and I showed that the readiness of dogs to look at the human face has led to complex forms of animal-human communication that cannot be achieved with wolves, even after extended socialization. We have also shown that dogs can imitate a human demonstrator operating a machine. In the universe of Messrs. Blumberg and Coppinger, such experiments would not exist and could not be designed.

Vilmos Csányi
Eötvös Loránd University
Budapest, Hungary

Bruce Blumberg and Raymond Coppinger cite the recent work



"I knew it was a mistake to try to raise a family in the city."

with Rico, a border collie that has learned the names of 200 objects. But they fail to mention the most interesting point of the study. On several occasions, when Rico was asked to retrieve a toy whose name he had never been taught, the dog returned with the one toy he did not recognize. If that doesn't reflect thinking at some level, your reviewers are using the word "thinking" in a way that is foreign to the rest of us.

William Burger
The Field Museum
Chicago, Illinois

BRUCE BLUMBERG AND RAY COPPINGER REPLY: The two books we reviewed both addressed the question of whether dogs think like humans. Our view was that Stanley Coren came to the conclusion that they didn't, whereas Vilmos Csányi concluded that they did. We found three fundamental problems with Mr. Csányi's argument, as articulated in his book.

First, the use of human social signals by dogs says nothing about whether or not dogs think like humans

or are conscious of what they are doing. Nor is the use of human social signals by dogs necessarily an evolved characteristic.

Second, to say that dogs think like humans implies that thinking and its corollary, intelligence, can be measured on a linear, "more or less" scale across species. But cognitive scientists and philosophers increasingly agree that intelligence is a multidimensional phenomenon resulting from the interaction of tools in an animal's mental tool kit. Viewing intelligence in linear terms causes us to miss the elegant mental specializations that abound in nature. Such specializations often have little to do with what humans do well, but they do provide an animal with what are often simple solutions to the complex problems it faces in its ecological niche. As William Burger points out, exclusion learning is just one example of these elegant solutions in dogs.

Finally, writing a book for a general audience does not free an author from the obligation to use the same

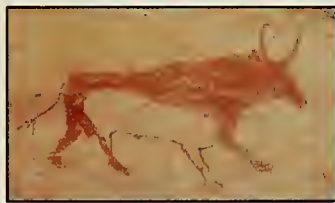
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care with language and exposition that one uses when writing for one's peers. Indeed, even more care is required, because the work itself serves as an object lesson on how experts approach the subject. In perhaps no other area of expository writing is this principle as true as it is in the case of books on the cognitive abilities of dogs.

Young at Heart

Adam Summers reports ("A Simple Heart" 2/05) on the elegant experiments of Jay R. Hove and Reinhard W. Köster, which suggest that the early heart of embryonic zebra fish creates shear forces that shape the heart itself. But those same shear forces are also

likely to be involved in creating the expanding blood vessel network. Endothelial cells lining blood vessels respond to shear force created by pulsating blood flow by secreting VEGF, a hormone that stimulates growth and division of neighboring endothelial cells. Thus, the pulses of the newly beating heart are likely doing double duty: they shape cardiac growth, and they stimulate the formation of blood vessels receiving blood from the heart.

*Warren Burggren
University of North Texas
Denton, Texas*

Urban Greenery

The ecological study of Pelham Bay Park, reported

in Stéphan Reeb's Samplings article "Green Gone" (12/04-1/05), highlights the challenges of maintaining biodiversity in urban settings.

The New York City Department of Parks and Recreation is committed to promoting a better overall ecosystem in New York City. Since its creation in 1984, our Natural Resources Group has documented and mapped the city's vegetation communities, and it has been able to assess the menace of invasive nonnative species. By removing these invasive species and replacing them with native flora we have restored more than 335 acres of New York City's natural areas. In just the

past three years, we have restored more than a hundred acres of woodland and wetland throughout New York City, including land along the Bronx River and in Van Cortlandt Park in the Bronx. In that time we have planted more than 54,000 native trees and shrubs and reintroduced 88,000 herbaceous plants citywide.

*Adrian Benepe
City of New York Parks
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SAMPLINGS



Queen's Laundry, a scalding pool in Yellowstone National Park

A Breath of Fresh . . . Hydrogen

A sulfurous odor permeates the air around the hot springs in Yellowstone National Park. Hordes of microorganisms live in the springs, at temperatures that can exceed 158 degrees Fahrenheit, too hot for photosynthesis. So how do the microorganisms get the energy they need? Until recently, the usual explanation was that they break down sulfur compounds.

Wrong, according to John R. Spear, a molecular biologist, and a team of biologists and astrophysicists at the University of Colorado at Boulder. They discovered that most members of Yellowstone's high-temperature microbial communities are bacteria that draw energy from H₂, molecular hydrogen.

At the scalding temperatures that occur

in the hot springs, dissolved oxygen is scarce. And in the absence of ample oxygen, hydrogen is easier to metabolize than are other sources of energy, such as sulfur. Other oxygen-poor watery habitats (lake sediments, rice paddies, sewage sludge) harbor many microorganisms that depend on hydrogen. Indeed, the human gut is home to several hydrogen metabolizers—the unwelcome *Salmonella* among them. Given the abundance of hydrogen in the universe and the wealth of hydrogen-loving microorganisms here on Earth, perhaps there are some living elsewhere, too. (*Proceedings of the National Academy of Sciences* 102:2555–60, 2005)

—Stéphan Reeb

Which Way Is Up?

Hikers' lore has it that (in the Northern Hemisphere) moss grows on the north, shady side of trees, and so can help you find your way through the woods. Not true: it often grows on the south side, or the leeward side, or even all around the trunk. One thing is certain, though: on Earth, even in total darkness, moss grows upward, opposite gravity's pull.

But how would the plant grow in the absence of gravity and light? Curious to find out, plant biologists Volker D. Kern of NASA and Fred D. Sack of Ohio State University in Columbus, along with several colleagues, arranged to have some colonies of moss launched aboard two space shuttle missions. The investigators expected the moss to grow in random directions. Surprisingly, its "tip cells"—the cells that, on Earth, elongate against gravity and grow toward

the light—grew outward, initially forming a starburst pattern and then a clockwise spiral as most of the moss filaments curved to the right.

Why would moss respond in such a nonrandom way to conditions never encountered on Earth? Perhaps spiral growth is an ancient default program in mosses, later overridden but never disabled. In any case, the orderliness of the plants' growth in space remains a mystery. (*Planta* DOI:10.1007/s00425-004-1467-3, 2005)

—S.R.



When sent to space, moss grows in spirals.

Picky Eaters

Vegetarians must balance their diet, because few plants can supply all the essential nutrients. The herbivores of the animal world do a balancing act as well, seeming to know instinctively what to eat, and in what proportions. Carnivores, however, should be unconcerned about balancing their diet, because most parts of an animal's body provide a fairly complete set of nutrients. Yet a new study shows that some invertebrate carnivores choose their prey carefully, day by day.

David Mayntz, a zoologist at the University of Oxford, and several colleagues studied three species of carnivore—the mobile ground beetle (which can select what's worth chasing), the "sit and wait" wolf spider (which can choose where to wait in ambush, but must content itself



Desert spider: tuned in to nutrition

with the traffic of the hour), and the web-building desert spider (which has no control over what arrives at its web of the week). All the animals received nutritionally unbalanced meals for one or two days. Some beetles got a powder rich in lipids; the rest got a powder rich in proteins. Some spiders got fat (lipid-rich) live fruit flies; the rest got lean (protein-rich) ones. Then the beetles were given a choice of both types of prey, the wolf spiders were given only one prey type but could choose how much to eat, and the desert spiders were given half an hour to deal with one prey type as they saw fit.

The beetles and the wolf spiders ate more of the type they'd been deprived of. The desert spiders did something even more interesting: they compensated for their last meal's imbalance by adjusting the amount of nitrogen (protein) and carbon (lipids) they extracted from the flies they ate for lunch. (*Science* 307:111–13, 2005)

—S.R.

Crow Bar

New Caledonian crows (*Corvus moneduloides*) are famous for poking twigs under bark or into crevices to dislodge grubs. Only one other species of bird, the woodpecker finch, uses an object for probing—a cactus spine. But are these cases of nature or of nurture? Does such resourcefulness



Clever crow

come naturally to the “average joe” crow (or woodpecker finch)? Or did some unsung Einstein among the birds invent a practice subsequently picked up by every other bird that cared to watch and learn?

Ben Kenward and his colleagues at the University of Oxford have a persuasive an-

swer. In separate aviaries littered with twigs and pocked with holes and crevices, the ornithologists hand-raised two New Caledonian crow chicks, each in isolation. The young birds spontaneously began to use the twigs to reach into the holes and crevices, and, at the tender ages of sixty-three and seventy-nine days, respectively, they got hold of their first tasty morsels. (Two other chicks, raised together and tutored in the art of twig probing by the investigators, first retrieved food from crevices on days sixty-eight and seventy-two.) On day ninety-nine, one of the isolated birds even shaped its own tool by tearing up a proffered leaf and probing for food with the remaining rib.

If two random New Caledonian crows can, by themselves, acquire expertise in twig usage—and if having companions and regular tutelage doesn't speed up the learning process—it seems safe to assume that most members of the species are naturals with an organic version of the bar that bears their name. The scientists conclude that the crow's brain is well wired for both tool use and toolmaking. (*Nature* 433:121, 2005)

—S.R.

Kindred Strokes for Different Folks

Greek or Latin, Hebrew or Mongolian, Tagalog or Tamil, most of the writing systems devised throughout human history are at heart surprisingly similar—and the similarities are probably not coincidental, say two neurobiologists, Mark A. Changizi and Shinsuke Shimojo of Caltech.

Writing is orderly mark making. In nonpictographic writing systems (such as the alphabet you're reading right now), lines, loops, and other strokes are combined to form individual characters—letters and numbers. Characters that are hard to write and (probably more important) hard to read are unlikely to catch on. In contrast, characters made of just a



few simple strokes stand a far better chance of surviving.

Changizi and Shimojo studied more than a hundred writing systems, and what emerged was a consistent economy of expression. Each character, on average, is made up of three strokes, no matter how many characters occur in the writing system. Such economy might be explained by earlier findings that people can store roughly three objects at a time in visual short-term memory. Even more astounding is the redundancy of the average character: even if half of its constituent strokes are removed, it remains potentially recognizable. (*Proceedings of the Royal Society of London B* 272: 267–75, 2005)

—T.J. Kelleher

Slick Sisters

Until recently, zoologists thought the membership list of the order Artiodactyla was limited to hoofed mammals with an even number of toes: camels, cows, deer, giraffes, goats, hippopotamuses, pigs, sheep. But mounting evidence suggests dolphins, porpoises, and whales—the water-dwelling mammals known as cetaceans—should be added to the list.

Until well into the 1980s, anatomical studies suggested that hippos may have evolved from pigs. DNA studies from the past decade, however, indicate that hippos are closer relatives of cetaceans than of pigs, which don't chew their cud, or of ruminants (cows, deer, goats, sheep, and so forth), which do. So Jean-Renaud Boisserie, a paleontologist at the University of California, Berkeley, and two French colleagues looked afresh at the fossil evidence—and also at a new trove of whale fossils unearthed in Pakistan—to see whether it supports the DNA link. The investigators compared eighty distinct skeletal and dental features of hippos with those of numerous other artiodactyls. The fossils, they conclude, confirm the DNA.



Very like a whale?

According to Boisserie and his colleagues, almost 60 million years ago a four-legged artiodactyl gave rise to two main offshoots: the early, quasi-aquatic cetaceans (later to become fully aquatic and lose their hind limbs) and a widespread, diverse group of piglike beasts that probably spent much of their time in water. Of the latter, only the hippopotamuses—which appeared some 15 million years ago—are still with us, and still fond of prolonged immersion in lakes and rivers. (*Proceedings of the National Academy of Sciences* 102:1537–41, 2005)

—S.R.

SAMPLINGS

Landscape of Plenitude

No one is certain why the watershed of the Amazon River is home to such a profusion of flora and fauna. What scientists do know is that many of its millions of species appeared sometime in the past 5 million years. Investigators have speculated that the region's geologic record might hold clues to the explosion of species, but few geologists have been able to examine the rocks. Now Dilce de Fátima Rossetti, a geologist at Brazil's National Institute for Space Research in São Paulo, and her colleagues have done just that in a 1,250-mile-long swath along both sides of the Amazon-Solimões River in northwestern Brazil.

About 20 million years ago, Rossetti's stretch of the Amazon lay at the bottom of



Amazonia, Earth's richest ecosystem—but why?

a huge lake. From time to time, the lake was flooded by a rising sea. Between 3 million and 1 million years ago, the climate became more arid. Now the lake turned into a system of turbulent, northeast-flowing rivers studded with islands. The rivers flooded periodically, creating fan-shaped deltas of large lakes and floodplains—much like the mouth of the modern Mississippi. The area became choked with sediment,

until rumbling tectonic faults dropped the land surface. Any streams that escaped flooding were shifted to a west-to-east flow. Those streams were the precursors of the modern Amazon River. Finally, as the climate became wetter, the area was again flooded.

According to Rossetti and her colleagues, the dynamism of the landscape probably put pressure

on plants and animals to adapt to changing conditions. Flooding may have pushed aquatic species into new habitats. The rivers-and-islands system may have trapped small groups of land creatures. Amazonia's organisms were forced to evolve rapidly, taking on the myriad forms seen today, when tens of thousands of species coexist per acre of land in some areas. (*Quaternary Research* 63: 78–89, 2005)

—Dave Forest

Returning Reeds?



A mudhif (above) is a typical floating house made of reeds by the marsh dwellers of southern Iraq. Once inhabited by abundant fish, birds, and people, most of the marshes' original 6,000 square miles were desiccated by 2000—the result of thirty-two dams built upstream since the 1960s and a massive drainage program in the 1990s. During the past two years, however, local residents have reflooded about 20 percent of the devastated areas by shutting down water pumps, opening sluice gates, and breaching embankments. Reflooding does not guarantee restoration, though. Ecologists think some of the marshland could be successfully restored, but stress that accumulated concentrations of salt and toxic wastes must first be flushed from the surface so that they do not redissolve and thus pollute the newly introduced water. (*Science* 307:1307–11, 2005)

Talented Newcomer

You might assume that the genes essential to the survival of an organism's genome would have evolved early in the history of the species. But it ain't necessarily so.

Here's how an alternate scenario might work. Imagine taking a job at a well-established corporation. At first your role is minor, but soon you come up with some highly beneficial innovations. Your work makes the corporation so successful that your co-workers must adjust to your innovations. Although you're a relative newcomer, you have become powerful—indispensable, in fact.

So it goes for certain genes, according to Benjamin Loppin, a geneticist at Claude Bernard University in Lyon, France, and an international team of molecular biologists. The gene *K81*, for instance, is vital in some fruit fly species. Without it, sperm cannot fertilize eggs. Yet it appeared "only" between 1 million and 2 million years ago, as a misplaced copy of another gene. The original gene still functions throughout the fly's body, but the now-modified copy functions only in the testes (though its exact job has not yet been determined).

How did the flies get by before the duplicate gene appeared? Other genes were probably doing the same job, just not as well, and they were made redundant by the newcomer's innovation. (*Current Biology* 15:87–93, 2005)

—S.R.

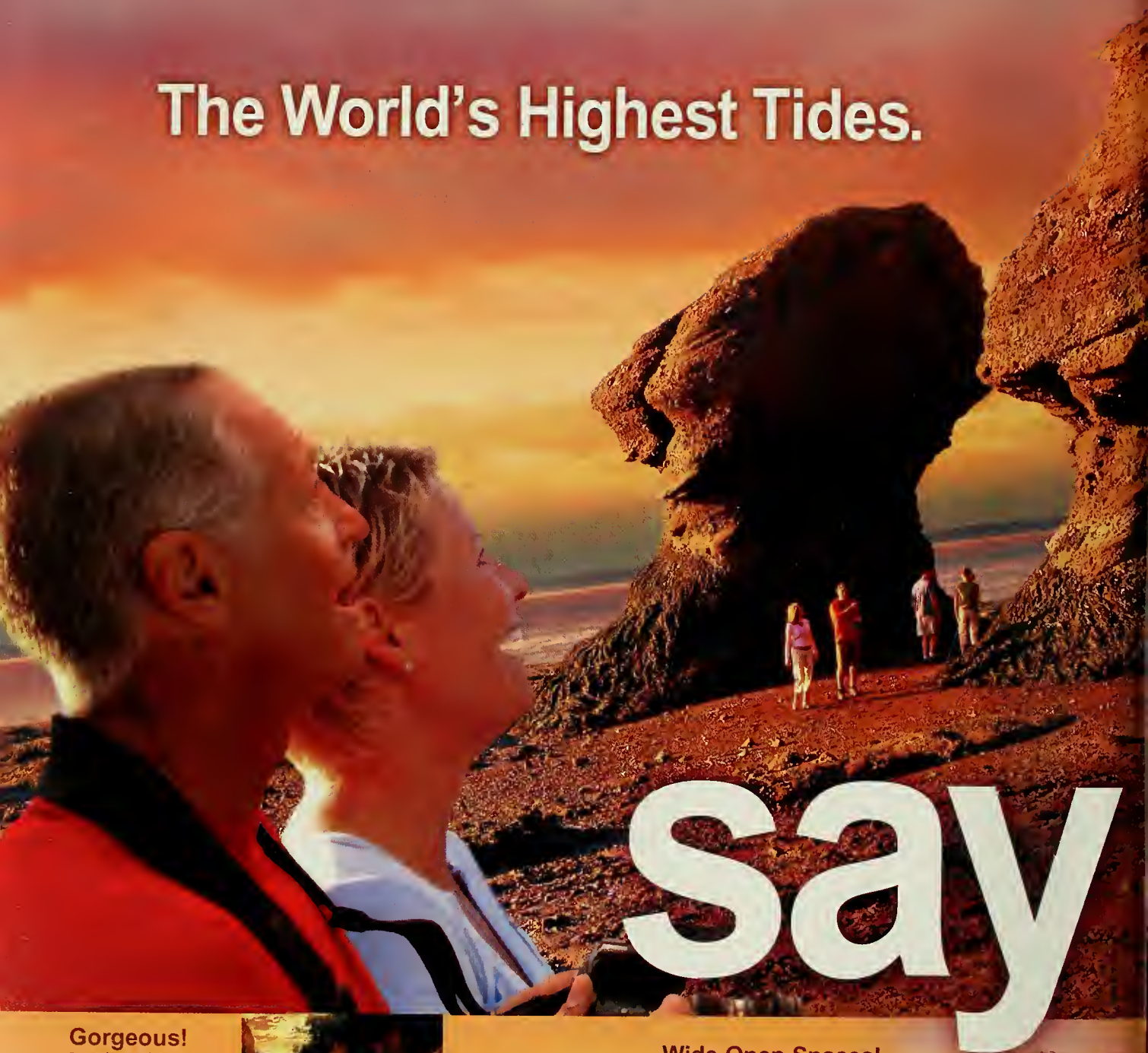
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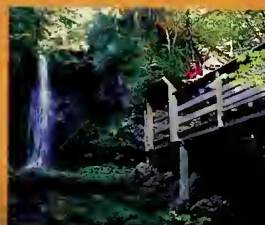
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There's diverse landscape here. Extending north-east from the Bay of Fundy are some of Canada's

most popular swimming beaches with some of the warmest salt water north of Virginia. Here you'll find the world's second longest sandbar, and one of the continent's last remaining white sand dunes at the Irving Eco-Centre, La Dune de Bouctouche. On the northern portion of the province lies the Baie des Chaleurs, recently named one of the most beautiful bays in the world.

Along the interior of the Province, rivers and waterways account for some of the best canoeing and kayaking to be had. Tour the St. John River Valley and witness the change in landscape from the calm of lush, green valleys to the whitewater rush of the Grand Falls Gorge up through the heart of the legendary Republic of Madawaska. The world-renowned Miramichi River beckons you to cast a line with some of Canada's best salmon fishing, and the beautiful Restigouche, St. Croix and



Kedgwick rivers will let you canoe for endless days along unspoiled wilderness.

Be awed by the untouched vastness of some of the oldest mountains on the planet. Hiking possibilities abound throughout the Province; for a spectacular view, climb some of the mountains, which are part of the Appalachian Range.

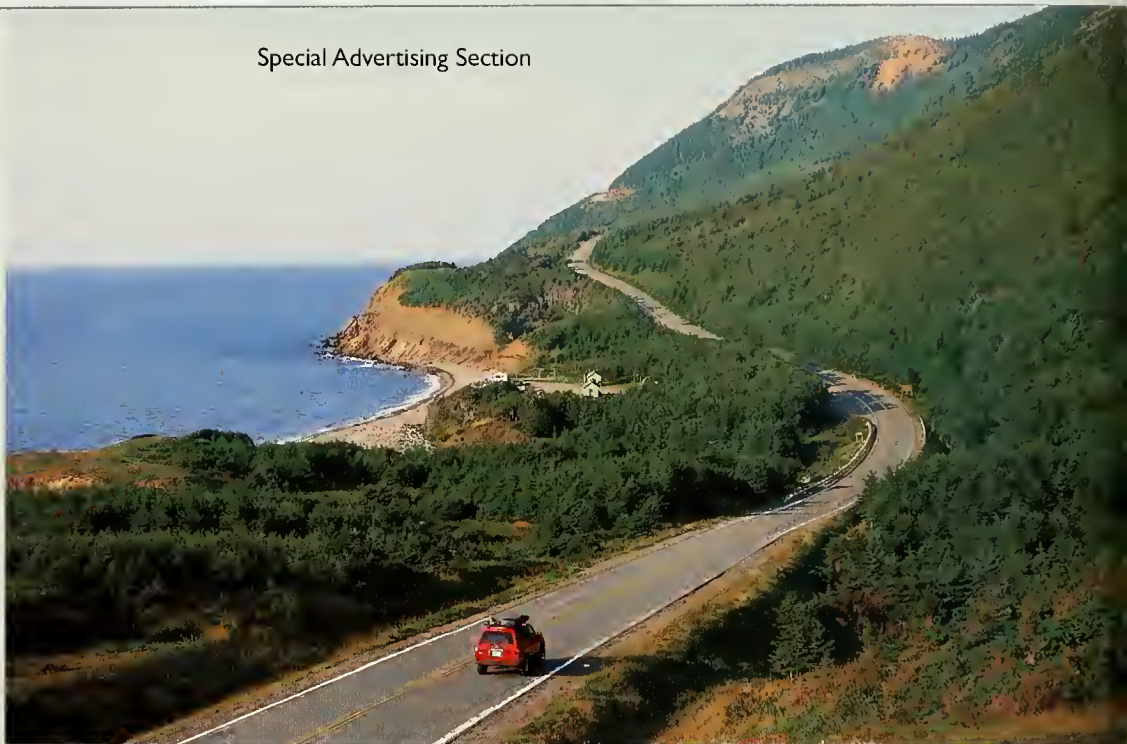
There's a world of natural wonder waiting for you next door with spectacular wildlife. More than 300 species of birds and up to 95 per cent of the world's sandpipers call New Brunswick their home. It's a birdwatching and whale-watching paradise. More than 15 species of whales visit New Brunswick each year, including the very rare Right whale; the best way to see them is aboard a boat, zodiac or kayak. Whether seeking forest-dwelling creatures while on a hike or spotting seals from a kayak, you're sure to find an outdoor wildlife adventure in

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Above left: Puffin, Bay of Fundy; top right: Restigouche River; above, lower left: Irving Eco-Centre, La Dune de Bouctouche, Saint-Édouard-de-Kent; above, lower right: Grand Falls Gorge, Grand Falls/Grand-Sault; above: High tide at The Hopewell Rocks, Hopewell Cape



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Bay of Fundy



Whales off the coast

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Don your boots for a two-hour hike to Cape Split, a narrow grassland lined by jagged cliffs overlooking the Bay of Fundy. Exertions are rewarded when the turbulent tide rushes over the ocean ridges below, pauses, then ebbs in the opposite direction. For scenic picnicking, fishing and swimming, visit Christie Brook and Falls near Bible Hill

in the East District, where a waterfall drops to a crystal-clear swimming hole surrounded by shallow caverns and looming cliffs.

Explore the rugged coastline of the Cabot Trail for inspiring and diverse land and seascapes—watch for pods of whales swimming and bald eagles soaring. Along the Trail, Cape Breton Highlands National Park is one of Canada's most exceptional wilderness and hiking regions, with a backdrop of moose grazing in the quiet shallows of lakes and streams. For water sports, sail the gentle, fog-free Bras d'Or Lakes, an ever-changing panorama of woodlands, coves and islands. Scuba dive beneath the surface to discover unique sinkholes rich in ecological diversity.

For sports and nature lovers Kejimikujik National Park, a natural Historic Site of Canada, has 91 kilometers of trail through untouched forests, rivers and lakes. Hiking, camping, canoeing, kayaking, snowshoeing and backcountry skiing are popular pastimes. For inspiration, photographers and tranquility seekers are drawn to the rugged solitude of Peggy's Cove, a postcard-lovely town set amid glacial deposits of rock and granite boulders. This is one of the most-photographed places in the world, and for good reason.



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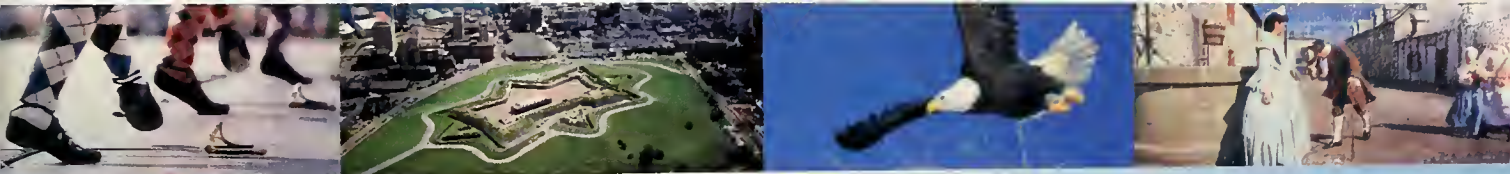
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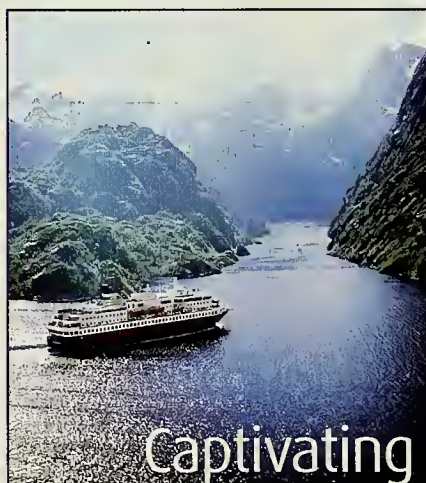
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EGYPT

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Roman Theater, Alexandria

AUTHOR LAWRENCE DURRELL FAMOUSLY dubbed the port city of Alexandria "the Capital of Memory." An apt description. One of the great cities of antiquity, Alexandria throughout its rich history has had a great impact on the cultural, political, and educational life in the ancient and contemporary worlds. From its beginnings as the Hellenic Empire's anchorage, to the days as the Ptolemaic capital and today's

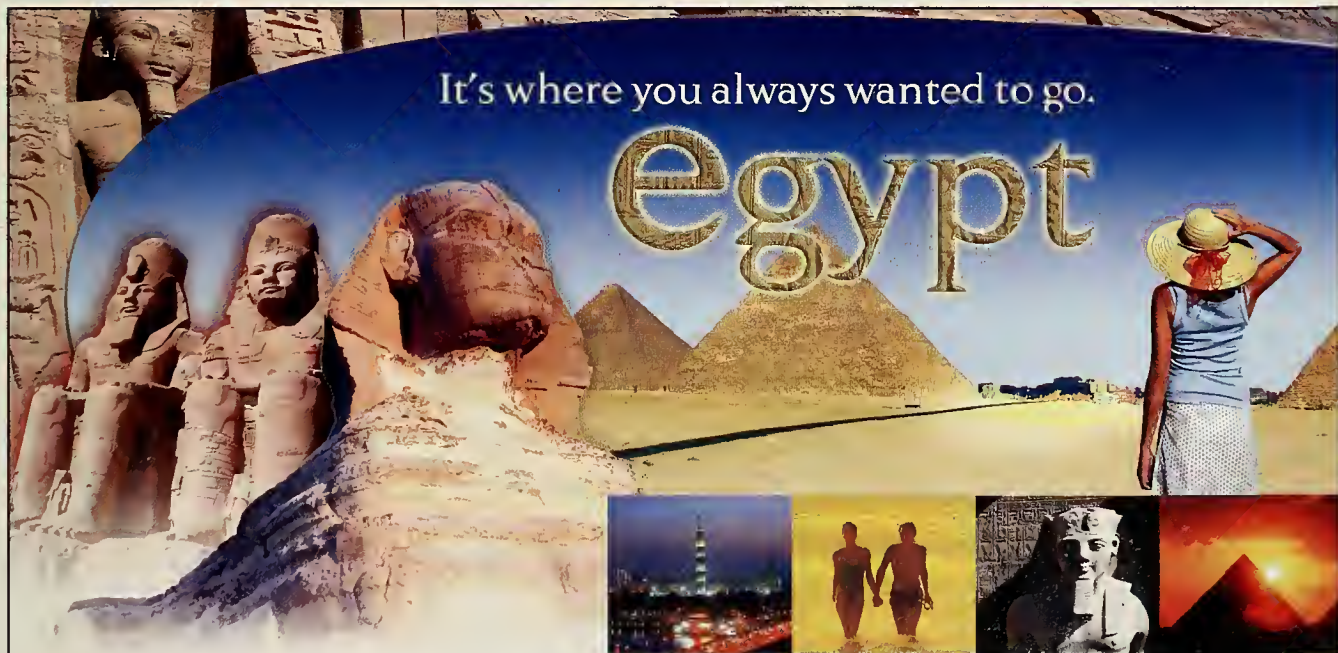
stature as Egypt's second-largest metropolis, Alexandria has been a center of global significance. Long a favorite destination for writers and artists, the city's cosmopolitan spirit and blend of cultures appeals to students of history... as well as vacationers attracted to its Mediterranean beaches, restaurants and breezy climate.

For those wanting a special glimpse into this city and Egypt itself, a visit to the Alexandria National Museum is a must. The newest jewel in this splendid city's cultural crown, it was opened in 2003, and is housed in a restored Italianate mansion dating from 1928. Surrounded by lush gardens with rare trees and plants, the museum holds more than 1800 archaeological treasures that narrate the Pharaonic, Greek, Roman, Coptic, Islamic and modern history of Egypt, as well as a high-tech restoration laboratory to preserve these and future finds for posterity.



TUTANKHAMUN AND THE GOLDEN AGE OF THE PHARAOH

For the first time in 25 years, priceless treasures from King Tutankhamun's tomb will leave Egypt and go on tour. Three times larger than the previous blockbuster Tut exhibition, more than 130 Egyptian artifacts found in King Tut's tomb will open at the Los Angeles County Museum of Art in June 2005, the Museum of Art in Fort Lauderdale in December 2005, London's Millenium Dome and then Philadelphia's Franklin Institute in February 2007. Proceeds will go to build a new museum in Cairo.



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The Long and Short of It

Aunes, cubits, leagues, palms, stadia—old-fashioned units of measurement make it hard to do science.

By Neil deGrasse Tyson

Give 'em an inch, they'll take a mile.

Kids love to count stuff. Bees, birds, dogs, monkeys, and rats count stuff, too. But if you want to describe objects and phenomena in the physical universe, you must move beyond mere enumeration. You could offer poetic evocations of an object's color, smell, sound, taste, or texture. Or you could quantify its attributes by using the methods and tools of science. But to do science, you must first establish a system of measurement. Fortunately, our technophilic predecessors have already been there and done that.

For thousands of years of human history, the world's farmers, merchants, tax collectors, engineers, and scientists have come up with hundreds of curious units: feet and fathoms, acres and hectares, bales and bushels, troy ounces and metric tons, weeks and fortnights. As knowledge of the universe advanced, more units of measure had to be invented—the kelvin, the pascal, the ampere, the joule, the watt per steradian, the tesla—so that attributes such as temperature, pressure, electric current, energy, radiant intensity, magnetic flux density,

and a host of others could be quantified.

Measurements and their attendant units turn pure numbers into physical quantities. Therein lies the foundation of engineering and experimental sci-

ence, distinguishing these enterprises from pure math, in which a number is just a number. If you knew nothing about units, but you had just gotten acquainted with the "number line," you might think eighty miles an hour is twice as big as a forty-cent bag of peanuts. But those two units have nothing in common, so the comparison is meaningless.

Two physical quantities are comparable only if they can be expressed in the same units: the number 25,000 is certainly bigger than the number 500, yet a giant tortoise chugging along nonstop at 25,000 feet a day moves hopelessly slower than a jet flying 500 miles an hour. Transporting the airplane into the tortoise's universe, 500 miles an hour becomes 63 million feet a day. Tortoise loses.

Once upon a time, life was lived and measured locally, and the actual quantity represented by a given unit—a bushel, a cubit, a foot, a gallon—often differed from

place to place. Basic liquid commodities such as wine, beer, and olive oil each had its own unit of measurement. Units of length might be based on the distance spanned by three dried grains



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of barley laid end to end (the Anglo-Saxon *ynch*, or inch); the distance traversed by a Roman legion in a thousand paces, each pace being a right step plus a left step (the Roman mile); or the distance walked by a horse in one hour (the Persian *parasang*). Lesser lengths such as the cubit, the ell, the finger, the foot, the hand, the palm, or the yard were often derived from the size of human body parts or the distance between one body part and another—though the person (often the

teeny or so gigantic that they had once been judged unmeasurable. The mass of a single *Escherichia coli* bacterium, for instance, is known to be 665 femtograms; one femtogram is 10^{-15} , or one-quadrillionth, of a gram. On the high end of the scale, the mass of the Virgo Supercluster of galaxies—which embraces our own, beloved Milky Way—checks in at about a quadrillion times the mass of the Sun.

Between 1960 and 1991 the mavens of measurement instituted a series of prefixes to span the metrological territory from the unimaginably small to the inconceivably large, ranging from “yocto” (10^{-24}) to “yotta” (10^{24}). And a few of the

prefixes toward the middle of this range have joined the pop lexicon: “kilo-” (10^3), “centi-” (10^{-2}), “milli-” (10^{-3}), even “nano-” (10^{-9}), which has come to mean anything very small.

Today there are standard units for measuring seven irreducible “base quantities”: length (the meter), mass (the kilogram), time (the second), electric current (the ampere), temperature (the kelvin), amount of a substance (the mole), and luminous intensity (the candela). Add the parade of approved prefixes, and you’ve got the fundamental worldwide system of measurement. From the base quantities come official “derived quantities,” such as area (square meters), volume (cubic meters), speed (meters per second), acceleration (meters per second per second), luminance (candelas per square meter), and scores of others. Then there’s the gray area: two dozen units that are neither officially base nor officially derived but that get officially listed as “accepted for use”—the minute of time, the minute of angle, the day, the hour, the liter, the hectare, the nautical mile, and the astronomical unit, to name a few.

Ideally, the units you choose for expressing a quantity should make sense in the given situation. Consider, for in-

stance, mass—the material content of an object. You could legitimately state the mass of the Sun in nanograms, or the mass of a pollen grain in gigagrams, but you wouldn’t be communicating sensibly if you did. And if you told a highway patrol officer you were traveling no faster than 160,000 furlongs per fortnight, you’d probably soon regret being such a wise guy.

Occasionally someone might have a less-than-honest reason to use inappropriate units. Last December, having been called for jury duty, I appeared in court, eager to serve the criminal justice system. Naturally I was subjected to the voir dire process—that’s when the judge asks who you are, where you live, what your job entails. The last question he asked was whether I had a question for the court. I certainly did. The judge had already read aloud the charge against the defendant: possession of 1,700 milligrams of cocaine.

“Your Honor, I’m just curious,” I said. “Why does the charge read ‘1,700 milligrams of cocaine,’ when that’s the same thing as 1.7 grams? Which, by the way, is less than the weight of a dime. It sounds as if somebody is trying to make the amount sound bigger than it actually is.” Minutes later, the court sent me packing.

Astrophysicists specialize in large distances. One of our favorite units of measure for getting around the solar system is based on the average distance between the center of the Earth and the center of the Sun—or, more correctly, on the distance from the Sun at which a massless particle, traveling unmolested in a circular trajectory, would take 365.26 days to complete its orbit. Can you measure that in feet? Yes, but it’s unwieldy: 490,807,000,000. Can you measure it in miles? Yes, but it’s still unwieldy: 92,956,000, usually further rounded off to 93 million miles. We call that distance the astronomical unit, or AU—our very own yardstick, by which the Earth-Sun distance is simply equal to 1. Turns out that because the Sun daily loses mass (which is carried away



The judge read out the charge: possession of 1,700 milligrams of cocaine.

king) whose body parts were the standard might be far from the median size.

Units of weight might be based on such objects as a Babylonian (and later a Hebrew) silver coin called a shekel, a gold coin minted during the reign of the Roman emperor Augustus, or a grain of wheat taken from the middle of an ear. As recently as the early nineteenth century, several hundred different units of basic weights and measures were in use across rural England and Scotland.

All this quaintness and imprecision inhibit rational investigations of the physical universe. With their sights set on objectivity, precision, and repeatability, scientists (and barons of commerce) around the world were strongly motivated to standardize the fundamental units of measurement. The French took the first major step toward an international system of units in June 1799, near the end of their bloody revolution, by placing punctilious platinum prototypes of the meter and the kilogram—the fundamental units of length and mass—in the Archives of the Republic in Paris. Thus was born the metric system.

Today, two centuries later, the struggle for precision continues as metrologists devise ever more exacting techniques to measure quantities either so

in the solar wind), the value formally assigned to one AU is, in fact, a quantity that slowly changes with time. But that complication need not concern us here.

So, if Earth is, on average, 1 AU from the Sun, then Venus is 0.7 AU from the Sun, Mars is 1.5 AU, and distant Neptune is 30.1 AU. The solar system, from the Sun out to the Kuiper belt of comets (Pluto included), fits within about a hundred AU.

Using the AU makes it easier to map the big picture. Once you try to gauge the distance to the nearest stars, though, things get cumbersome again. The star Proxima Centauri, the Sun's nearest neighbor, is about 267,000 AU from the Sun. At that scale, we need to call in a new unit. What's sensible? Light travels 186,282 miles a second. A calendar year has 31,536,000 seconds. Multiply them, and we're back in business: one light-year is 5.87 trillion miles. Proxima Centauri lies a little more than four light-years away.

The Milky Way is about 100,000 light-years across.

Eventually you'll want to go to more distant places in the universe. How about the Andromeda Galaxy? That's about 2.4 million light-years away. The center of the Virgo Supercluster is some 60 million light-years away. Right about now, you might think, a new unit of measure could be useful. But cosmologists are so comfortable with millions and billions that none of them feel the urge to invent a unit much beyond the light-year or the parsec. One parsec (from "parallax" plus "second") is the distance at which a person floating way out in space would see the one AU separation between Earth and the Sun subtend an angle of one arc second, or $1/3600$ of a degree. That distance turns out to be 3.26 light-years, barely more than the light-year itself. A perennial favorite of science fiction writers, this pedagogically senseless unit remains in use for historical reasons.

We're done with distance—or it's done with us. But now combine distance with time, and we get one of the most common, down-to-earth derived quantities: speed. [See "Speed Limit," by Neil deGrasse Tyson, February 2005.] Daily life in our part of the world has much to do with buses and cars and planes and trains, and so it makes sense to measure speed in miles (or kilometers) per hour instead of meters per second. A New Yorker's walking pace down Fifth Avenue is three miles an hour. A car obeying the speed limit north of exit 15 on the New York Thruway won't exceed sixty-five miles an hour. A commercial airliner cruises at more than 500 miles an hour. But when it comes to bullets, measuring in miles per hour sounds a bit odd. It doesn't mean much to say how far a bullet travels in an hour, because bullets are designed to travel short range and affect their targets within fractions of a second. So, instead, the muzzle velocity for a bullet coming out of a gun

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is typically given in feet per second. A bullet shot from a .45 Colt might reach 1,000 feet per second; a bullet from the deadly M16A2 assault rifle, which is standard issue for the U.S. Army, can top 3,000 feet per second (almost three times the speed of sound).

Seems like a good time to leave Earth's surface.

How fast does Earth go around the Sun? About eighteen miles a second. Unless you live in the middle of nowhere, you're familiar with people, places, or things located eighteen miles away. If you could get there in one second, you'd be traveling as fast as Earth does. How about the speed of the Sun? Hauling its entire orbiting system of planets, asteroids, comets, and debris as it moves through space, the Sun circles the center of the Milky Way at about 140 miles a second.

Get too close to the supermassive black hole at the center, though, and its gravity will hurl you into space so fast you'll find yourself exiting the Milky Way. Astrophysicists just reported the first star ever seen doing so. Its speed is 400 miles a second, twice the speed necessary to leave the galaxy forever.

Ever since the first General Conference on Weights and Measures was held in Paris in September 1889, under the auspices of the French minister of foreign affairs, measurement experts from around the world have periodically convened to bring the standard international system of units and the decimal-based metric system of measurements in line with the latest scientific discoveries and technological advances. As of 2005, three backward countries have not yet officially adopted the metric system: Liberia, Myanmar, and the United States. Americans

like their miles and pounds—all well and good until it's time to communicate with the rest of the world.

An embarrassing and expensive example of what can happen when two groups of people use different units and don't tell each other is the story of the \$125 million *Mars Climate Orbiter*, a NASA space probe. Launched in December 1998, the probe was supposed to achieve an orbit around Mars in September 1999. But because of a mismatch of units, it spun off course after its jet thrusters fired. The engineering team that built the spacecraft and provided the navigation information had calculated the needed thrust in the British/American unit called the pound-force, whereas the team responsible for actually navigating the craft had assumed—because the mission specifications called for metric units—that the information was presented in the international metric unit called the newton. Both are units of force, but one pound-force is equal to 4.45 newtons. Traveling at perhaps 10,000 miles per hour, the doomed craft plunged into the atmosphere of

the Red Planet and was never heard from again.

To be fair, the U.S. has already become a little bit metric. Nearly all measurements regarding cameras and their performance are metric, from old-fashioned thirty-five millimeter film to the size of your camera's lens. One- and two-liter soda bottles are metric. Four-liter car engines are metric. As for the rest—inches, feet, miles, cups, quarts, pounds, tons, degrees Fahrenheit—I'm in no hurry to see it all go. It's part of our British-derived American culture, and peppers our language with words like “footage” (in cinema), “mileage” (in fuel efficiency), and “milestones” (in one's life).

When you visit another country, you're generally expected to adapt to its culture, language, and money during your stay. You need to know which side of the road the locals drive on. You need to learn when to eat all the food on your plate and when not to, when to take your shoes off, when to bow and when to shake hands, when to kiss one cheek or two. Having to learn feet and Fahrenheit is the least of a visitor's challenges upon arriving in America.

Some time ago, U.S. scientists adopted the international metric system. We're still working on the engineers. But if you're simply farming the back forty, and not talking to anyone but your neighbors, nobody will fault you if you still bake with a pinch of salt and say that an ounce of prevention is worth a pound of cure.

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



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Descent with Modification

A great-grandson of Charles Darwin's opens new vistas into the voyage of the Beagle.

Interview conducted by Richard Milner



Natives of Tierra del Fuego, with Darwin's ship, the Beagle, at anchor in the background. The painting is by Conrad Martens, who was the expedition artist on part of the ship's voyage.

Born in 1919, Richard Darwin Keynes is one of Charles Darwin's twenty-five great-grandchildren and one of Darwin's hundred or so living descendants. His mother was Margaret Elizabeth Darwin, daughter of Darwin's son George, and his father was Geoffrey Langdon Keynes, a prominent surgeon and the brother of the economist John Maynard Keynes. A retired professor, Richard Keynes distinguished himself as a neurophysiologist at the University of Cambridge long before he became involved, as a historian of science, in the "Darwin industry."

As a young man, working with the giant nerve fibers of squid, Keynes helped discover how nerve impulses are transmitted in all animals. Later he worked out how electric eels project electric fields outside their bodies. His investigations took him on several occasions to South America, where he met the late Carlos Chagas, a biologist who had access to a ready supply of eels and other electrical fish.

Coincidentally, Chagas's father was the physician who discovered the parasitic malady that some suspect Darwin contracted in South America, now known as Chagas' disease. The trips to South America sparked Keynes's scholarly interest in his illustrious ancestor. In this role he followed his mother's cousin Nora Darwin Barlow (1885–1989), daughter of Darwin's son Horace.



Richard Darwin Keynes, age 5, with his great-aunt Etty—Henrietta Darwin, Charles Darwin's third daughter

Keynes's house is situated near the Cambridge University Library, repository of the world's largest archive of Darwin letters and manuscripts. This interview, completed this past October, was conducted in his book-lined den, beneath a large portrait of Charles Darwin and pictures of other family members. Also hanging on the walls were some delicate sketches by Conrad Martens, who documented part of the Beagle's voyage, and a Victorian-era FitzRoy barometer (its inventor, Robert FitzRoy, was captain of the Beagle during Darwin's celebrated voyage).

NATURAL HISTORY: How are you descended from Charles Darwin?

RICHARD DARWIN KEYNES: I am his great-grandson. Darwin knew only one of his grandchildren, Bernard; he never lived to see the others. The rest of the grandchildren were born later, including my mother, Margaret Darwin Keynes, my aunt Gwen Darwin Raverat, and my mother's cousin and great friend, Nora Darwin Barlow. All spent idyllic summers visiting their widowed grandmother, Emma Darwin, at Down House, the old home-
stead in the Kent countryside. My great-grandmother had moved to Cambridge after Darwin's death, but always summered at Down House—which has been restored as the Darwin Museum. Gwen wrote a classic reminiscence, *Period Piece*, about her childhood there.

NH: Do you have any special childhood memories of any of your eldest Darwin relatives?

KEYNES: For some reason my great-aunt Etty [Henrietta Darwin] hated stinkhorn mushrooms, and destroyed them whenever she saw them. I remember going with her along country paths, watching her smash stinkhorns with a special stick that she reserved for the purpose. Most of what I know about her, however, I read in *Period Piece*.

I also remember my great-uncle Leonard Darwin, who gave me an inscribed copy of the reissued *Origin of Species* in 1935. Some years later, in 1942, I was working at a government naval radar research station, and Leonard lived nearby. He was a nice old man, and I once stayed with him, but we never talked about anything significant. Later I found out that he was a leading figure in the eugenics movement.

NH: When did you begin your own Darwin research?

KEYNES: In 1968 I visited Chile to discuss neurophysiological experiments with colleagues. One day I was in Buenos Aires on my way home, when a British official, who knew I was a descendant of Darwin's, asked if I had seen a private Darwin collection there. Honestly, at that time I had taken hard-



Conrad Martens

Conrad Martens and the Art of the *Beagle*

By Elizabeth Ellis

As the artist who accompanied Charles Darwin for a time aboard the *Beagle*, Conrad Martens recorded firsthand many of the places and sights encountered on the ship's voyage of discovery. Born in London in 1801, Martens studied landscape painting

in his early twenties under the watercolorist Copley Fielding. His historic experiences at sea began in 1833, when he took advantage of an opportunity to sail to India aboard the British navy ship *Hyacinth*, which was commanded by a friend. When the ship reached Rio de Janeiro, Martens learned that the *Beagle* expedition needed a draftsman and topographical artist to replace Augustus Earle, whose health had forced him to leave the venture.

Martens joined the *Beagle* in Montevideo, Uruguay, in July 1833. By then, the ship's captain, Robert FitzRoy, and Darwin had already been exploring the eastern coast of South America for a year and a half. Accompanied by the *Adventure*, a second, smaller vessel acquired by FitzRoy to help with the explorations, the *Beagle* sailed from Montevideo in early December, reaching Port Desire on the Patagonian coast around Christmas. In the months that followed, the expedition visited Tierra del Fuego and other South Atlantic regions, finally rounding Cape Horn through the Straits of Magellan in June 1834. When the ships arrived in Valparaiso, Chile, however, FitzRoy received word that the British Admiralty would not compensate him for the purchase of the *Adventure* or for payment to the artist. The ship had to be sold, and Martens, left behind, decided to travel to Sydney. He headed for Tahiti in early December and from there sailed to Australia, where he lived for the rest of his life.

But Martens's connection with Darwin was not at all severed. In 1836, when the *Beagle* arrived in Australia, Darwin visited Martens and bought two watercolors. And in 1862, after *Origin of Species* appeared, Martens wrote to his "old shipmate" to congratulate him on the book, although he said he had not read it and was reluctant "to think I have an origin in common with toads and tadpoles." He also sent Darwin a watercolor of the Brisbane River, in eastern Australia.

Martens, who died in 1878, enjoyed remarkable success in his adopted land, becoming "Australia's answer to J.M.W. Turner." His paintings and drawings are in the collections of the State Library of New South Wales and the Art Gallery of New South Wales, both in Sydney; in the Wollongong City Gallery, south of Sydney; in the National Library, in Canberra; and in the National Gallery of Victoria, in Melbourne; as well as in the British Museum and the National Maritime Museum, both in London, and the Darwin Archive at the library of the University of Cambridge.

Elizabeth Ellis, formerly curator of pictures and now Mitchell Librarian at the State Library of New South Wales, in Sydney, is the author of Conrad Martens: Life and Art (State Library of New South Wales Press, 1994).

ly any interest in my great-grandfather. But I was fortunately taken to see these materials from the *Beagle* voyage, which turned out to be portfolios of drawings made by Conrad Martens, one of two artists aboard the ship [see "Conrad Martens and the Art of the Beagle," on preceding page]. And these splendid drawings—I've got three of them hanging here in my study—are what switched me on to Darwin. I asked the owner if I could borrow them to take back to England.

winian studies, and I've been following in her footsteps ever since.

Then the owner of the Martens portfolio wrote and asked me if I would sell it for him. I couldn't understand why he wanted to part with it, because he was a wealthy collector. I certainly couldn't see it go up on the auction block, so I enlisted the help of Nora Barlow, who purchased the pictures and presented them to the Darwin Archive at the Cambridge University Library.

NH: Then you began to gather and

I next produced *Charles Darwin's Beagle Diary* [1988], a fresh edition of Nora Barlow's *Diary of the Voyage of H.M.S. Beagle*, which had been out of print for fifty years. When I was getting to the end of my electrophysiological work, I began to transcribe all of Darwin's zoological notes from the *Beagle* voyage, a massive undertaking that took me five years and was finally published by Cambridge in 2000 as *Charles Darwin's Zoology Notes and Specimen Lists from H.M.S. Beagle*. The whole of that book I typed out and designed myself, following the layout Darwin had used, and leaving room for his fifty drawings. [Cambridge University Press is now issuing a paperback edition.]

NH: What are some of the myths that have grown up around the story of Darwin's voyage?

KEYNES: Probably the most persistent one is that he saw all these different kinds of finches in the Galápagos, with different kinds of beaks, and realized at once that the islands were a living laboratory of evolution. He did make an observation about how similar Galápagos mockingbirds were to those of mainland South America, but he missed the lesson of the finches entirely.

As Frank Sulloway, now at the University of California, Berkeley, found out, he collected more than thirty specimens of finches from four different islands, but couldn't identify them all for what they were and didn't even carefully record which islands they came from. It was after Darwin's voyage, at the Museum of the Zoological Society of London, that an ornithologist named John Gould pointed out the specimens were all closely related finches. The reason Darwin never referred to them in the *Origin of Species* is probably that he realized he had failed to gather the sort of evidence essential to understanding how the finches had populated the archipelago.

NH: Your most recent book, *Fossils, Finches, and Fuegians: Darwin's Adventures and Discoveries on the Beagle, 1832–1836* (HarperCollins, 2002), is

(Continued on page 66)



Condors prey on a dead guanaco near the Santa Cruz River, Argentina. The watercolor was executed by Martens in 1878, based on a drawing he made in April 1834 during the voyage of the Beagle.

NH: What was Nora Barlow's influence on you?

KEYNES: The first thing I did when I returned home was to talk with her, and she realized at once the importance of the pictures. She had published, in 1933, a transcript of the *Beagle* diary, the journal that Darwin kept on board ship and sent piecemeal to his family from various ports. Nora's meticulous scholarship in publishing Darwin's informal writings was the inception of what is now called the Darwin industry. She became my mentor in Dar-

coordinate all the existing materials about the *Beagle* voyage?

KEYNES: Yes, because there were things to add to the available information, and the whole needed rearrangement. Darwin's own account, drawn from his diary and other notes, is very nicely written, but chronologically confusing in places. My first Darwin book was *The Beagle Record* [1979], which gathered a lot of bits and pieces into a coherent narrative and included some of the Martens paintings that had never been published before.



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Humans will never win a sprint against your average quadruped. But our species is well-adapted for the marathon.

By Adam Summers ~ Illustration by Tom Moore

Paleoanthropologists, the paleontologists of the human lineage, have a tough task. Hominid fossils are scarce, and they're usually incomplete. Worse, the missing bits are often the ones investigators would most like to find—making it difficult to assemble an evolutionary tree of fossil hominids.

But if that's a tough job, imagine what life is like for anyone seeking to describe how bones and muscles functioned in ancient hominids. The scarcity and incompleteness of hominid fossils has often prolonged biomechanical debates concerning hominids. "Lucy" (*Australopithecus afarensis*) is a case in point. She was discovered more than thirty years ago, but a disagreement about whether those of her species walked more like a person or more like a chimpanzee was only recently decided in favor of the former.

That debate was important because a long-standing hypothesis holds that long-distance walking migrations played an important role in the evolution of our genus *Homo*. Many of the features that distinguish the various species of *Homo*, which lived in the open savanna, from Lucy and her kin, which were forest primates, are traits useful for walking: longer legs, narrower waists, shorter toes. Now Dennis M. Bramble, a biomechanist and vertebrate biologist at the University of Utah in Salt Lake City, and Daniel E. Lieberman, a biomechanist and anthropologist at Harvard University,

have added a major new wrinkle to the story of human bipedalism. The two argue, in a review synthesizing several decades' worth of work by a large number of investigators, that running also played an important role in shaping our species.

If you've ever chased a cat that's trying to avoid a bath, you have every right to conclude that, for our size, we humans are pretty poor runners. But chasing a cat is sprinting. Where we excel is endurance running. Moreover, we run long distances at fast speeds: many joggers do a mile in seven-and-a-half minutes, and top male marathoners can string five-minute miles together for more than two hours. A quadruped of similar weight, about 150 pounds, prefers to run a mile at a trot, which takes nine-and-a-half minutes, and would have to break into a gallop to keep pace with a good recreational jogger. That same recreational jogger could keep up with the preferred trotting speed of a thousand-pound horse.

Good endurance runners are rare among animals. Although humans share the ability with some other groups, such as wolves and dogs, hyenas, wildebeest, and horses, we alone among primates can run long distances with ease.

But what evidence can support the idea that endurance running by itself gave early humans an evolutionary advantage, and that it wasn't just "piggybacking" on our ability to

walk? Many traits, after all, are useful for both activities; long legs, for instance, and the long stride they enable, are helpful to walking as well as to running. But running and walking are mechanically different gaits. A walking person, aided by gravity, acts as an inverted pendulum: the hip swings over the planted foot [see "The Biomechanist Went Over the Mountain," by Adam Summers, November 2004]. In contrast, a runner bounces along, aided by tendons and ligaments that act as springs, which alternately store and release energy.

Bramble and Lieberman point to a number of features, preserved in fossils, that imply *Homo* adapted to a bouncy gait—whereas *Australopithecus* stuck with walking [see illustration on opposite page]. Fossils lack tendons and ligaments, of course, but traces of their attachment points are sometimes present, and the characteristics of the missing tissue can be inferred by comparing how the attachments fitted with the rest of the animal's anatomy. For example, the Achilles tendon, attached to the heel bone, is one of the most important elements in a human's bouncy gait. In *Australopithecus*, however, the attachment point of the tendon is distinctly chimpanzee-like. Another spring occurs in the foot itself: tendons in the sole of a human's foot keep it arched. The arch flattens and springs back with each step. In contrast, Lucy had only a partial arch. *Homo habilis* had a full arch. Chimpanzees have no arch at all.

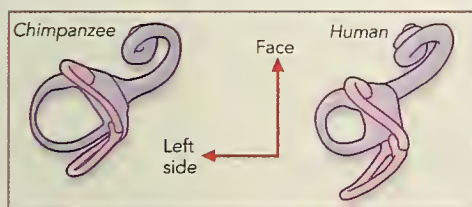
In addition to springs, endurance running requires more stabilization of the trunk than walking does. Members of the genus *Homo* have substantial gluteus maximus (butt) muscles. Those muscles have numerous large attachments from the hip to the base of the spine. In *Australopithecus* fossils, though, the muscle has a much more limited area of attachment. If you've seen a chimpanzee in trousers, you know how baggy they look. Chimpanzees are gluteally challenged as well. Large butt muscles are not only better looking in pants; they also make for efficient energy transfer during running by stabilizing each

hip. But the muscles are not used for walking on level ground.

In contrast with the trunk, the shoulder of the chimpanzee is well stabilized, tied to the spine and the head by several strong muscles. Lucy retained the stabilized shoulder, but in humans those muscle connections are less robust—and for good reasons. When we walk, our shoulders don't move much, but when we run, because of the relatively loose attachment, the shoulders rotate strongly one way while the hips rotate the other. The counterrotations help keep us in balance. And because only one part of the trapezius muscle at-

taches to the head, we can swing the upper body without inadvertently rotating the head—which enables us to see where we're going.

In spite of the loose attachment between head and shoulders, running joggles the head more than walking does. *Homo* therefore has several “antibobblehead” adaptations that other apes and *Australopithecus* lack. The first is a modification of the semicircular canals, the organs in each inner ear that tell the brain which way is up. Three such canals sit at right angles to one another in each inner ear. Two are enlarged in *Homo*, and the size makes it easier to sense, and presumably to counteract, a nodding head. An elastic ligament that runs from a ridge at the base of the skull to the base of the neck, damps the bobbing effect. Analogous ridge structures, to which damping ligaments can be attached, occur in dogs and horses, the other long distance runners, but not in Lucy.



Three semicircular canals (top view), the primary organs for maintaining balance, are situated in the inner ear of mammals. In humans, two of the three (pink) help stabilize the runner's head.



Differences in human and chimpanzee anatomy highlight the human adaptations for long-distance running. There are fewer muscle connections between the head and the shoulders in the human than in the chimpanzee. The weaker connection enables the head to move independently of the shoulder, which rotates while running. In contrast, humans have more connections between the gluteus maximus muscle in the butt and the hip than chimpanzees do, which keeps the trunk and leg moving together. Both the Achilles tendon of the heel and the tendon of the arch of the foot are much smaller in chimpanzees than they are in humans; in a running person they act like springs, absorbing and releasing energy.

Bramble and Lieberman's wide-ranging analysis makes important corrections to the scientific picture of early humans. Our ancestors may have ranged across large distances in the heat of the African savanna in relatively short spurts of long-distance running, as well as by walking. They may have been trying to maximize the chance of encountering carrion before other scavengers did, or perhaps they were adapted to running down prey before spear throwers or bows were invented.

In any case, our current appetite for jogging is made possible by the early selective pressures that made humans one of the most accomplished endurance-running animals. For myself, though, I imagine another adaptation. The heat and the running must have been powerful motivators for our ancestors to sit in the shade and ponder how to affix a rock to a stick.

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Announcing THE FRANKLIN INSTITUTE *Awards*

Dating back to 1824, The Franklin Institute Awards Program seeks to provide public recognition and encouragement of excellence in science and technology. Since 1874, recipients have been selected by the Institute's Committee on Science and the Arts. Today, fields recognized include Chemistry, Computer and Cognitive Science, Earth and Environmental Science, Engineering, Life Science, and Physics. In 1998, the Awards Program was reorganized under the umbrella of The Benjamin Franklin Medals. The list of medal winners reads like a "Who's Who" in the history of 19th, 20th, and 21st century science. The honor roll includes: Alexander Graham Bell, Marie Curie, Rudolf Diesel, Thomas Edison, Niels Bohr, Max Planck, Albert Einstein, and Stephen Hawking—to name a few. To date, 101 Franklin Institute Laureates also have been honored with 103 Nobel Prizes.

The newest awards, the Bower Award for Business Leadership and the Bower Award and Prize for Achievement in Science, are made possible by a \$7.5 million bequest in 1988 from Henry Bower, a Philadelphia chemical manufacturer. The Bower Science Award carries a cash prize of \$250,000, one of the richest science prizes in America. The Awards Ceremony is April 21, 2005 in the Benjamin Franklin National Memorial at the Franklin Institute in Philadelphia, PA. More information on the Awards Program can be found at www.fi.edu/tfi_awards.

2005 FRANKLIN INSTITUTE LAUREATES

Bower Award and Prize for Science Achievement

HENRI B. KAGAN, PH.D.
Université Paris-Sud
Orsay, France

For his seminal discovery of fundamental chemical principles that explain the impact of catalyst shape on its effectiveness in controlling chemical reactions, thus greatly simplifying the manufacture of pharmaceutically important compounds.

Dr. Kagan studied at the Sorbonne in Paris before receiving his Ph.D. from the College of France in 1960. After a nearly 40-year career at the Université Paris-Sud in Orsay, France, he now serves as an emeritus pro-

fessor. His career has spanned the world, and he continues to be an active visiting lecturer, author, and enthusiastic mentor to young chemists.

Bower Award for Business Leadership **ALEJANDRO ZAFFARONI, PH.D.**

ALZA Corporation, Mountain View, CA
Alexza MDC, Mountain View, CA

For the creation, through a combination of scientific creativity and entrepreneurial insight and drive, has created new biochemical processes, drug delivery technologies—most significantly, the birth control pill, transdermal patches, and once-a-day pills—and biomedical indus-

tries. He has leveraged his business successes so that he is broadly respected as a philanthropist and technical leader.

Dr. Zaffaroni received his B.Sc. in 1941 from the University of Montevideo, Uruguay, and his Ph.D. in 1949 from the University of Rochester. He began his career at Syntex, a small pharmaceutical business in Mexico, which he helped transform into a major company headquartered in the U.S. He eventually became president of Syntex Laboratories and Syntex Research Institute. Since then, Dr. Zaffaroni has founded or co-founded nine companies—ALZA, DNAX, Affymax, Affymetrix, Symyx, Maxygen, SurroMed, Perlegen Sciences, and Alexza.

Benjamin Franklin Medal in Computer and Cognitive Science

ARAVIND K. JOSHI, PH.D.

University of Pennsylvania,
Philadelphia, Pennsylvania

For his fundamental contributions to our understanding of how language is represented in the mind, and for developing techniques that enable computers to process efficiently the wide range of human languages. These advances have led to new methods for computer translation.

After receiving his B.E. in electrical and mechanical engineering from Pune University and his D.I.Sc. in communication engineering from the Indian Institute of Science, both in his home country of India, Dr. Joshi began a fruitful academic career in the United States. He received his M.S. (1958) and his Ph.D. (1960), both in electrical engineering from the University of Pennsylvania, where he has been a professor for the last 40 years. Currently Henry Salvatori Professor of Computer and Cognitive Science, Dr. Joshi is also co-founder and co-director of the University's Institute for Research in Cognitive Science.

Benjamin Franklin Medal in Earth and Environmental Science

PETER R. VAIL, PH.D.

Rice University, Houston, Texas

For his pioneering and innovative ideas for using seismic reflections to identify sequences of subsurface rock layers, greatly enhancing exploration for oil-containing rock. He also recognized that similar changes in the rock record appear worldwide and can be attributed to global changes in sea level, thus contributing to greater understanding of the earth's geological history.

Peter Vail's innovative concepts of sequence stratigraphy have had far-reaching implications for both science and commerce, revolutionizing the field of stratigraphy and greatly enhancing methods for oil exploration. Dr. Vail received his B.A. from Dartmouth

College in 1952 and his Ph.D. from Northwestern in 1956. Following a 30-year career with Exxon Production Research Company and its predecessors, he began a second career, as W. Maurice Ewing Professor of Oceanography at Rice University, where he taught from 1986 to 2001. Dr. Vail now uses his vast wealth of experience as president of his own business, Peter R. Vail Oil and Gas & Consulting and Investing Company.

Benjamin Franklin Medal in Electrical Engineering

ANDREW J. VITERBI, PH.D.

The Viterbi Group, LLC
San Diego, California
University of Southern California
Los Angeles, California

For developing an efficient technique, known as the Viterbi Algorithm, that has advanced the design and implementation of modern space and wireless communication systems, including cellular telephony and digital image transmission from the distant reaches of our solar system. In addition, Dr. Viterbi played a leading role in the development of Code Division Multiple Access (CDMA) wireless technology, which allows multiple cellular phones to communicate effectively and simultaneously over a common frequency.

Dr. Viterbi received his B.S. and M.S. from MIT in 1957 and Ph.D. from the University of Southern California in 1962. He began his career at California Institute of Technology's Jet Propulsion Laboratory. In 1968, he co-founded LINKABIT Corporation and, in 1985, QUALCOMM, Inc., now a leader in digital wireless communications and products based on CDMA technologies. He served as a professor at UCLA and UC San Diego, where he is now a professor emeritus. Dr. Viterbi is currently president of the Viterbi Group, LLC, which advises and invests in startup companies in communication, network, and imaging technologies. He also recently accepted a position teaching at USC's newly named Andrew and Erna Viterbi School of Engineering.

Benjamin Franklin Medal in Life Science

ELIZABETH HELEN BLACKBURN, PH.D.

University of California, San Francisco
San Francisco, California

For her advancements in understanding how the cell preserves the ends of chromosomes—telomeres—while replicating its DNA. Her breakthroughs in understanding the protective role of telomeres have increased our understanding of aging and cancer.

Dr. Blackburn received her B.Sc. in 1970 and M.Sc. in 1972 from the University of Melbourne and her Ph.D. in 1975 from the University of Cambridge, England. She did postdoctoral work in molecular and cell biology at Yale University. After 13 years at the University of California, Berkeley, she moved to the University of California, San Francisco, where she has held a professorship for the past 15 years, currently in two departments—biochemistry and biophysics, and microbiology and immunology.

Benjamin Franklin Medal in Physics

YOICHIRO NAMBU, Sc.D.

The University of Chicago
Chicago, Illinois

For his path-breaking contributions leading to our modern understanding of sub-atomic particles—the Standard Model. His work has revolutionized our ideas about the nature of the most fundamental particles and the space through which they move.

His career in physics has led to the concepts of symmetry and quark "color". Dr. Nambu received his B.S. in 1942 and D.Sc. in 1952, from the University of Tokyo. After serving as a professor at Osaka University in Japan and as a member at the Institute for Advanced Study in Princeton, he began an extraordinary 50-year career at The University of Chicago, where he has been an emeritus professor since his retirement in 1991.

collapse

Ecological lessons in survival

By Jared Diamond

Societies normally endure minor rises and falls of fortune, even conquest by a neighbor, without undergoing a drastic change in total population or social complexity. But some societies have truly collapsed: their populations crashed and their complex social and economic organizations broke apart. Might such a fate befall our own society? Will tourists someday stare mystified at the rusting hulks of New York City's skyscrapers, much as we stare today at the overgrown ruins of Mayan cities?

Many collapses of the past appear to have been triggered, at least in part, by ecological problems: people inadvertently destroyed their environmental resources [see "Maya: A Classic Case," opposite page]. But societies are not doomed to collapse because of environmental damage. Some societies have coped with their problems, whereas others have not [see "Paths to Success," page 40]. But I know of no case in which a society's collapse can be attributed simply to environmental damage; there are always complicating factors. Among them are climate change, the role of neighbors (who can be friendly or hostile), and, most important, the ways people respond to their environmental problems.

In some respects we face greater risks than past societies did. Our technology (and its unintended destructive effects) is potent; our economy is global (so that now a collapse even in Somalia affects the United States and Europe); millions (and, soon, billions) of us depend on modern medicine for survival; and our population is much larger. No place is truly immune from environmental damage [see "Montana: Trouble in Paradise," page 42]. And for the first time in history, we face the risk of a global decline. Yet some of the same new conditions—technology, globalization, modern medicine—can help us find solutions to our problems.

Because we are the cause of most of our own environmental problems, we can choose to solve them. And we enjoy an unprecedented opportunity to learn quickly from developments everywhere in the world today, and from what has unfolded in times past.



Stela, or commemorative pillar, honoring Waxaklahun Ubah K'awiil, who ruled the Mayan city of Copán from A.D. 695 until 738. Centered in a fertile valley, the kingdom was one of many that rapidly declined during the ninth century. One cause was deforestation and erosion of the surrounding hills.

Maya: A Classic Case

No ancient civilization is more commonly associated with the word “collapse” than that of the Maya of Central America. In the ninth century A.D., the Mayan population fell from at least 5 million people to a tenth that size or less. At about the same time, in some of the most vibrant centers of Mayan settlement, there’s a sudden dearth of inscriptions featuring the names of kings or dates expressed in the “Long Count” calendar, signaling the disintegration of complex political and cultural institutions. Many cities were entirely abandoned and fell into ruin; then, overgrown with trees, they remained virtually unknown to the outside world for a thousand years.

Throughout the so-called Classic period of Mayan civilization, from about A.D. 250 to 900, Mayan society remained politically divided into small kingdoms. Typifying the Mayan collapse was a kingdom whose ruins now lie in western Honduras, at a site known as Copán. The best agricultural land in the kingdom, the fertile alluvial soil of a river valley, covered only ten square miles. Beginning in the fifth century A.D., the population of the valley rose rapidly, and by A.D. 650 people had begun to occupy and farm the surrounding hillsides. Archaeological evidence indicates that the hillsides were initially forested and less fertile than the river valley. But soon the forests were cut down, mostly for fuel, leaving the steep slopes open to soil erosion and probably also to the leaching of

nutrients. Cultivation of the hillsides apparently proved worthwhile for only about a century. Erosion also carried the poorer soils from the slopes down into the valley, compromising the better agricultural zones. Furthermore, because forests play a major role in water recycling, the massive deforestation may have also contributed to drought.

At its height, in the ninth century A.D., Copán’s population reached about 27,000; the last big buildings were erected around 800. The subsequent decline in population was not instantaneous—as late as A.D. 950 it was still about 15,000—but it was steadily dwindling. By about 1250

the valley was deserted.

Five strands, or major factors, contributing to the downfall of Copán can be tentatively identified. The first strand was simply that population growth was outstripping the available resources. The second strand, already mentioned, compounding that mismatch, was the array of negative effects that were brought on by deforestation and hillside erosion.

The third strand was



Temple I at Tikal, one of the largest Mayan centers. Contributing to the collapse of Tikal was a major drought that began about A.D. 760.



Maya: A Classic Case

increased warfare, as neighboring kingdoms fought over their diminishing resources. Bringing matters to a head was a fourth strand: climate change. The worst drought to strike the region in 7,000 years began about A.D. 760 and peaked about 800. By then there were no unoccupied favorable lands to which people could move to save themselves. The ensuing decline in the Mayan population must have come about partly from starvation and warfare, as well as from a fall in the birthrate and in the survival rate of children.

The fifth strand was a failure of the Mayan kings and nobles to address problems within their control. The attention of the leaders was evidently focused on enriching themselves, waging wars, erecting monuments, competing with each other, and extracting enough food and other resources from the peasants to support those activities. Like most leaders throughout human history, the Mayan kings and nobles did not heed long-term problems, if they noticed them at all.

Paths to Success

Failures offer many lessons, but so do successes. Many societies have survived in difficult environments for thousands of years. Their stories suggest two contrasting approaches to solving environmental problems: bottom-up and top-down. Three examples of societies that successfully addressed environmental issues by adopting one of those two approaches are highland New Guinea, Tikopia Island in the south Pacific, and premodern Japan [see map on opposite page].

In general, small societies—such as a society occupying a small island—can adopt a bottom-up approach. All the inhabitants are familiar with the en-

tire territory, all are keenly aware that they are affected by developments everywhere else, and all share a sense of common identity and common interests. Even the citizens of large, industrialized societies can often find bottom-up resource management effective within the neighborhoods where they live or work.

In a large, centrally organized society, such as one that embraces an entire archipelago, the general population may not be familiar with what is going on throughout the territory. A central ruler, however, may effectively exercise the necessary resource management. A king who wishes merely to see his descendants enjoy his domain in perpetuity has good reason to be aware of the need to limit environmental damage. He may order his subjects to manage resources in ways that favor himself and his heirs—but in the long run, those practices may be good for his subjects as well. Of course, such a top-down approach is also familiar to those of us who live in modern, developed countries (for “king,” read “government”).

One outstanding example of the bottom-up approach developed in New Guinea. Because New Guinea’s steep, mountainous interior is so rugged, Europeans who explored the island beginning in the sixteenth century were confined to its coast and lowland rivers. They assumed the interior was entirely forested and uninhabited.

It therefore came as a shock when the first overflights, in the 1930s, revealed a landscape transformed by millions of farmers previously unknown to the outside world. New Guinea now appears to have been one of the limited number of independent centers of plant domestication in the world.



Stool used for coconut shredding is carved on the South Pacific island of Tikopia. By adjusting their choices of land and sea resources and controlling population growth, people have survived on the 1.8-square-mile island for almost 3,000 years.

Voyage of Engagement

By Vanda Vitali

Even before Jared Diamond completed the manuscript for his latest book, *Collapse: How Societies Choose to Fail or Succeed*, I met with him and several of my colleagues at the Natural History Museum of Los Angeles County to explore the idea of creating an exhibition that would feature some of the key results from his research. But how were we to take some of the ideas from a 500-plus-page book and create an engaging experience for our visitors?

Museums typically tell stories through their collections. The focus of this exhibition, however, was to be on ideas, particularly the relation between society and its environment, which objects and specimens might be able to convey only indirectly. We decided to bring our collections to life amid rich and diverse settings—the temples of the ancient Maya, for instance, or a seventeenth-century Japanese interior—to which we would add provocative sound and video presentations and an original series of giant-size cartoons. An essential strategy for fulfilling our vision was to assemble a team of highly skilled and experienced professionals—museum curators, an architect-designer, a videographer, an interpretive specialist, and others—who could collectively invent a unique exhibition to serve our diverse audience.

As a scientific institution, a natural history museum has a responsibility to allow different voices to be heard and to enable visitors to appreciate the complexities of debate, particularly on issues such as the environmental challenges we face today. When deciding on the title for the exhibition—“Collapse?”—we used a question mark to indicate the fluidity of future possibilities and consequences.

Navigating through the exhibit, which opens May 1, visitors will voyage through time and around the globe. The journey starts with a multimedia exposition of contemporary environmental situations, followed by a look at issues affecting modern-day Montana. We introduce the principal factors Diamond associates with social collapse, then invite our visitors to proceed back in time to consider the decline of the ancient Mayan civilization and the survival of Japan during the Tokugawa period (1603–1867). Returning to the present, visitors see the challenges of climate, fire, and population growth that now confront the continent of Australia.

The final room is designed especially for our southern California audience. Water (both too little of it, and too much!), air quality, urban sprawl and transportation management, the destruction of endangered habitats, terrorism, dwindling energy supplies, and the shifting patterns of world trade will be among the issues we explore. This final stage, then, will serve both as a forum for the ongoing debate about our relation with the environment and, potentially, as a means to our long-term survival.

Vanda Vitali is vice president of public programs at the Natural History Museum of Los Angeles County.

Agriculture has been going on there for 7,000 years.

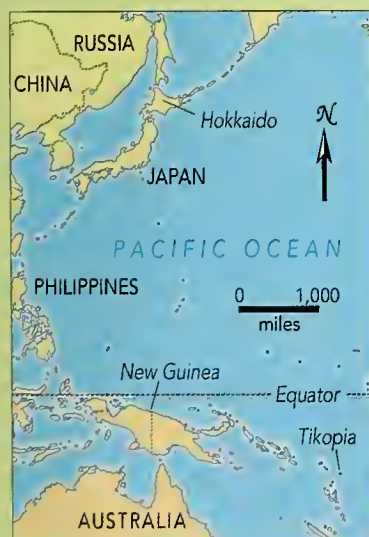
Over that time, through trial and error, New Guineans worked out a whole suite of techniques to maintain soil fertility, including crop rotation. They observed the consequences of deforestation and, in response, developed the practice of planting and cultivating trees for food and for timber. The population size was kept in check through warfare, contraception, abortion, and other practices.

Another example of bottom-up control comes from the Tikopia Islanders, who inhabit an isolated tropical island in the southwestern Pacific Ocean. Only 1.8 square miles in area, the island is home to about 1,200 people. Tikopians, too, have regulated their numbers through a variety of practices—explicitly to prevent the island from becoming overpopulated and to prevent a family from having more children than the family's land could support. In addition, they have been adjusting their use of resources from the time of the island's first settlement, nearly 3,000 years ago. Most dramatically, they made the momentous decision, about A.D. 1600, to kill off all the pigs on the island. Even though the pigs had become a luxury food for the chiefs, the animals raided and rooted up gardens and competed with humans for food.

A good example of successful top-down resource management is Japan during the Tokugawa period (1603–1867). In 1657 a fire ravaged the capital city, Edo. The demand for timber to rebuild the city served as a wake-up call to the rulers, because by then, most of Japan's original forests had been cut down. During the next two centuries, under the leadership of successive shoguns, Japan gradually achieved

a stable population and more sustainable rates of resource consumption. Part of the solution was to promote trade for food with the Ainu people on the northern island of Hokkaido (thus shifting some potential problems of resource depletion outside what was then Japan proper).

By 1700 the shoguns and their underlords had insti-



tuted an elaborate system of woodland management, and Japan gradually developed the idea of plantation forestry: trees came to be regarded as a slow-growing crop. Japan was favored in this by the country's high rainfall, high fallout of volcanic

ash and dust from Asia, and young soils—all factors that promote rapid regrowth of trees. In what was an era of peace and social stability, both the elite and the masses in Japan recognized their long-term stake in preserving their forests.

Montana: Trouble in Paradise

People have roamed Montana for at least 13,000 years. Before Europeans entered the New World, the region was the exclusive domain of Native American hunter-gatherers. The economy began to change with the arrival of the "mountain men"—fur trappers and traders from Canada and the United States, who extracted largely unprocessed natural resources from the land for export. During the next economic phase, beginning in the 1860s, agricultural products were added to the exports, and resource extraction shifted to mined minerals (especially copper and gold) and lumber.

In spite of the long history (and prehistory) of human occupation, most people—not without reason—associate Montana with pristine natural beauty. The federal government owns more than one-fourth of the land within the state boundaries, mostly as national forests. Moreover, the foundations of Montana's economy are ever less dependent

on resource extraction. Hunting and fishing have been transformed from subsistence activities to recreational ones; the fur trade is extinct; and mining, logging, and agriculture are declining in importance. The growth sectors of Montana's economy nowadays are tourism, recreation, retirement living, and health care.

That new emphasis on a service economy notwithstanding, Montana's environmental problems include almost all the ones that have undermined preindustrial societies in the past and that continue to threaten societies everywhere in the future.

One problem is toxic waste. Concern is mounting about runoff from fertilizer, manure, the contents of septic tanks, and herbicides. But by far the biggest toxic-waste issue is posed by the residues from metal mining and smelting. Waste rock and tailings containing arsenic, cadmium, copper, and zinc get into groundwater, rivers, and soil. When disturbed by mining and processing, Montana ores also yield sulfuric acid, because they are rich in iron sulfide. There are some 20,000 abandoned mines in the state, most of which have no surviving owners—or none wealthy enough to clean them up.

A second issue is deforestation. The housing boom that followed the Second World War, and the resultant surge in demand for lumber, caused timber sales from land in national forests to peak in about 1972. Logging was done by clear-cutting, a method that is efficient for loggers and also maximizes future timber yields. But clear-cutting eliminates shade, causing a rise in stream temperatures that is harmful to fish spawning and, ultimately, to their survival. The loss of shade also leads to a quick pulse of snowmelt in the spring, instead of a gradual release of meltwater that can be used for irrigation throughout the summer.

Headwaters of Daisy Creek, southern Montana, near the now-abandoned McLaren Mine. The creek lacks the aquatic life typical of most mountain streams, because mine tailings have polluted the creek with dissolved metals and acids.





Bitterroot River Valley, in southwestern Montana (shown here looking south from Hamilton), is the fastest-growing region of the state. The valley population is increasing at 4 percent a year, largely because of an influx of wealthy retirees from out of state. Even though rising land prices and taxes create housing problems for many local residents, the subdivision and development of farmland is virtually unrestricted because of traditional opposition to government regulation.

It was the most visible downside of clear-cutting, however, that sparked debate: clear-cut hillsides look ugly. A public outcry led to changes in logging policy affecting national forest. As for private forests, the main protection they may enjoy is that preserving the forested landscape for future real-estate development appears more profitable.

In recent years, forest fires have increased in intensity and extent in some kinds of forest. In part the increase is a result of climate change (a trend toward hot, dry summers), and in part it is traceable to human factors [see also *"Fire Down Under,"* by Dan Drollette, page 44]. One human factor is logging, which often turns a forest into what looks—and acts—like a huge pile of kindling. Another factor is the policy of fire suppression adopted by the U.S. Forest Service in the first decade of the twentieth century. By the 1980s, people began to realize that the policy itself was contributing to the buildup of fuel in the form of deadwood and undergrowth.

What about water, soil, and air? Both well water from underground aquifers and irrigation water from ditches fed by mountain streams, lakes, and rivers must serve an increasing number of users. At the same time, as a result of climate change—Montana is becoming warmer and drier—the amount of available water is decreasing. Soil

problems in Montana include nitrogen exhaustion, erosion, and salinization—the accumulation of salt in soil and groundwater. And for those who think of Montana as pristine wilderness, it comes as a shock that even here, some areas suffer seasonally from poor air quality. Worst of all is the city of Missoula, whose problems stem from a combination of vehicle emissions, wood-burning stoves in the winter, and forest fires and logging in the summer.

Finally, Montana, like most other regions, must confront the twin problems affecting species diversity: the introduction of harmful nonnative species and the loss of valuable native ones. For example, northern pike, illegally introduced into some western Montana lakes and rivers, have virtually eliminated the populations of bull trout and cutthroat trout on which the northerns prey.

All the environmental problems in this familiar litany could be addressed through a combination of bottom-up, grassroots organization and top-down, government regulation. Ironically, Montanans are beginning to realize that two of their most cherished attitudes are in direct opposition: a fierce belief in individual rights, often expressed in strong resistance to any government regulation, and pride in their quality of life. They are coming to see that by permitting unrestricted land use, which encourages the influx of new residents, their own opposition to government regulation could become responsible for the further degradation of their beautiful natural surroundings. □

*These excerpts were adapted from Jared Diamond's book *Collapse: How Societies Choose to Fail or Succeed*, published by Viking Penguin.*

Fire Down Under



Bushfire season pays Australia a hellish visit each year. Drought and climate change could be making the infernos worse.

by Dan Drollette

By midday on January 18, 2003, a hot, summer Saturday in Canberra, Australia's capital city, smoke from the largest wildfires in the history of the surrounding Australian Capital Territory had eclipsed the Sun. Firefighters were battling flames along a twenty-two-mile front.

Few people were overly concerned. Summer is fire season in bush country, and Canberra, on the southeastern fringe of Australia's outback, is often called the bush capi-

tal. Wildfires there are as much a part of a down under summer as barbecues on the beach at Christmas. Although low-intensity fires fed by grass and scrub had been steadily advancing on the city's sprawling outer suburbs, they seemed to pose little danger to life, limb, or property.

But a two-year drought had primed the Australian Capital Territory for something bigger. At about 1:30 in the afternoon, wind-fanned flames leapt to the tops of the native eucalypts and imported pines, igniting them.



Firefighters (left) battle the fire that struck the Australian Capital Territory (ACT) in January 2003. The intensity of the fire was exacerbated by a drought induced by El Niño, which itself was exacerbated by pollution and global warming. Some two-thirds of the Capital Territory burned. Two figures (above) flee heavy smoke from the 2003 fire.

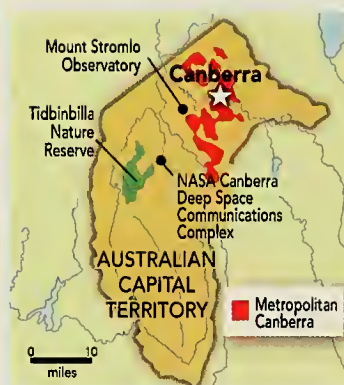
What came next is best described by the professional terminology of fire meteorologists: a “blowup.” Modest ground fires became high-intensity blazes with temperatures exceeding 1,800 degrees Fahrenheit—hot enough to melt copper. Eyewitnesses described plasmalike balls of fire detaching from the fire front and blowing forward to ignite everything in their paths. Flames towered a hundred feet above the trees, and the wildfire grew so hot that it generated 150-mile-an-hour winds. Cars and trailers were blown around. Three-foot-wide trees were uprooted and hurled atop houses, and full-grown pines were snapped in half.

Fire crews had no time to evacuate. The firefighters huddled beneath their vehicles while fire-induced winds blew in windshields and tore off doors. Fire commander John Ryan of the New South Wales Rural Fires Service later told the *Advertiser* in

Adelaide, “There were birds falling out of the sky as we were overrun by the firestorm.” Some firefighters reported that wild animals that had caught fire also hid beneath the trucks. Describing the scene later, Peter Roth, Ryan’s deputy, told reporters, “It was more like a fire hurricane than a firestorm.” The deputy added, “I said to the chief, ‘If we don’t see you again, it’s been nice knowing you.’”

Roth and Ryan survived, but others were not so lucky. The fires ultimately killed four, destroyed more than 500 homes, and reduced nearly two-thirds of the Australian Capital Territory to ash. The losses included the Australian National University’s giant optical telescopes at the Mount Stromlo Observatory, just west of Canberra [see maps on next page]. They were completely destroyed, their metal domes and telescope mountings melted.

The fires could be as capricious as tornadoes. Farther outside town, flames stopped just yards from the radio dishes of NASA’s Canberra Deep Space Communications Complex, vital for maintaining contact with dozens of spacecraft, including the Mars rovers Spirit and Opportunity. Losing the



Australia is a nation beset by wildfires and drought. Massive fires struck the Eyre Peninsula of South Australia this past January. Drought has had a major impact on the drainage of the Murray and Darling rivers. The Australian Capital Territory suffered the largest fire in its history in 2003. Both the Mount Stromlo Observatory and the Tidbinbilla Nature Reserve were destroyed by the flames, but the nearby NASA Canberra Deep Space Communications Complex was saved by the hard work and bravery of its firecrew.

complex would have been a serious setback for NASA, potentially causing a communications blackout for eight hours a day. Yet even as they spared the NASA site, the fires burned more than 99 percent of the 13,600-acre Tidbinbilla Nature Reserve, just three miles away—where I had spotted my first emu and my first eastern gray kangaroo. The reserve was also home to dozens of koalas, only one of which, horribly burned, survived.

The fires of 2003—and the ones that struck the Eyre Peninsula of South Australia this past January, killing nine people and incinerating some 200,000 acres—were not totally unexpected. After all, much of Australia is hot and dry, and the continent has been that way for a long time.

But Australia might be getting even hotter and drier and, by all historical comparisons, the intensity of the recent fires is epic. A deep drought has continued for the past decade. Reservoirs serving the city of Canberra and nearby areas have been storing as little as 35 percent of capacity. Canberra has recovered steadily since the fire of 2003, but every Australian knows the risk of fire each summer remains high. A number of climate experts have begun to ask whether the current drought and the recent fire seasons, which have been considered exceptional, are actually the new commonplace.

To answer that question, a number of familiar global phenomena must be taken into account. The weather system known as El Niño, for instance, has had major effects on Australia's climate for millennia. The effects of global warming, atmospheric pollution, and water shortages—for which humanity may bear a substantial responsibility—must also be

factored in. And even if climatologists can sort out the causes of Australia's suffering, is there anything humanity can do to reverse their effects? The answers are not necessarily encouraging.

The conditions in Australia today seem unlike anything on record. Early written accounts, archaeological data, tree rings, cores of ocean sediments, and other indicators are all beginning to paint a picture of the history and prehistory of Australia's climate. According to David A. Jones, a climatologist at the Bureau of Meteorology in Melbourne, Australia's climate is rapidly warming, and the warming trend is compounding the drought. Another climatologist, Timothy P. Barnett of the Scripps Institution of Oceanography in San Diego, agrees. He points out that the center of Australia—what Aussies call the “dead heart”—appears to be getting hotter and drier more quickly than the edges of the continent. Such preferential heating, he says, is evidence of a prolonged, permanent climate shift.

Droughts are becoming distressingly common across many of the world's less-watered regions. Although droughts can develop anywhere, areas dry to begin with seem most likely to be hit. At a recent meeting of the American Meteorological Society, Aiguo Dai of the National Center for Atmospheric Research in Boulder, Colorado, announced that the percentage of the Earth's land area undergoing “serious drought” has doubled in the past thirty years. Climate experts at the U.S. National Oceanic and Atmospheric Administration envision such prolonged, severe, geographically wide-ranging events in the fu-

ture that they have coined the term “megadrought” to describe them.

From his studies of historical climate patterns recorded in tree rings, Thomas W. Swetnam of the University of Arizona in Tucson (a former firefighter with the U.S. Forest Service) sees a clear link between the worst droughts and the worst fire years. And there are good reasons to think that El Niño, a big factor in Australia’s droughts, is becoming more powerful.

For three or four years out of five, on average, ocean temperatures stray very little from their mean. But in that fifth year—the interval itself is a rough one—the sea surface and atmosphere in the tropical regions of the western Pacific Ocean warm dramatically. The warm water and air masses move eastward across the equatorial region, until they reach the west coast of the Americas. Because it arrives around Christmas, the warm currents and air masses are known as El Niño, literally “the (Christ) child.” El Niños usually last between one and two years, and cause wet conditions off Peru and in the U.S. Southwest. In Australia, however, an El Niño causes drought, as high-pressure cells, or air masses, develop over the northern part of the Australian continent and create persistent warm and dry conditions there.

After an interval of three to seven years, an opposite phenomenon, dubbed La Niña, “the girl,” takes hold, which lasts a similar length of time to El Niño. In La Niña years Australia becomes wetter.

The cycling between the two extremes encourages the evolution of fire-dominated ecosystems. In wet years, grasses, trees, and other vegetation grow abundantly, producing large amounts of fuel to burn during dry periods. The ashes from the fires serve as fertilizer for a new round of explosive growth during the next wet phase.

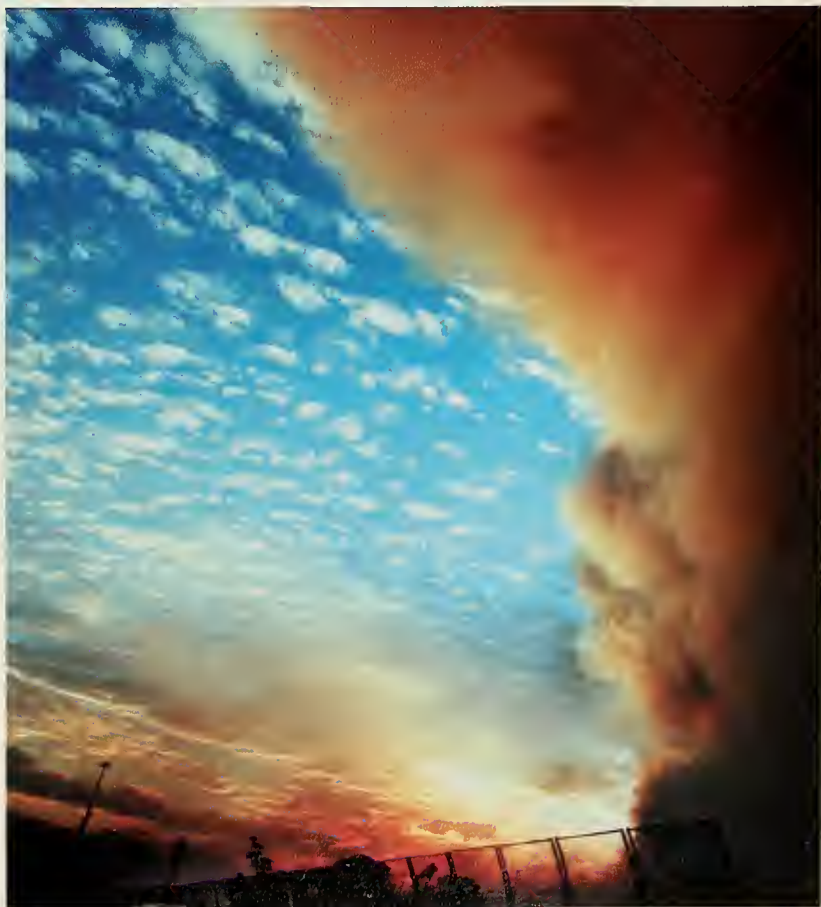
The exact mechanism driving an El Niño year is complex and still being worked out, and the cycles are not entirely predictable. But in the late 1980s Neville Nicholls, a climatologist at Australia’s Bureau of Meteorology, pointed out that the pressure difference between highs over Darwin, the capital of the Northern Territory, and lows over the island of Tahiti has been a good historical indicator of whether an El Niño was either under way or about to begin. That difference, Nicholls suggested—now known as the Southern Oscillation Index (SOI)—could serve to forecast future Australian droughts; the more negative the index, the better the chances for a drought. The index has become so widely accepted that it is misused for short-term forecasting: the latest SOI is now a part of every weather report on the Australian evening news.

Climatologists are still seeking the answers to two million-dollar questions. First, what drives the frequency of the switches from hot, dry El Niño years to moist La Niña ones over the centuries? And second, what causes the varying intensities of the events? Longer cycles, in which one or the other extreme predominates, apparently exist; explaining those would go a long way to predicting whether, say, one wet year after a five-year drought signals only temporary relief or marks the beginning of multiyear wet period.

There is, of course, a third question. Why are the extremes becoming more extreme? Why are the wet phases getting wetter, and the warmer phases getting drier and more beset by fire? Global warming seems a prime suspect. “Among scientists, there’s no real question about whether global warming exists or not,” says Barnett. “The only questions are more a matter of how much and how fast, and what its specific impacts are in a given area.”

“The debate about global warming is over,” he adds, “at least among rational people.”

According to the Intergovernmental Panel on Climate Change, the past decade included five of the hottest years since accurate meteorological records



Pillar of smoke from the ACT fire creates an otherworldly sky.

began to be kept in the nineteenth century. That fact is just one piece of the evidence that global warming is caused, at least in part, by human activities.

The story by now is a familiar one, but it is no less urgent for that. When certain gases—carbon dioxide, water vapor, methane, chlorofluorocarbons, and others—are released into the atmosphere, they naturally act like the glass panes of a greenhouse. Visible light can pass through them, but radiant heat from the Earth's surface cannot so readily flow back through the gases and into space.

The heat-retaining actions of greenhouse gases

in the atmosphere, global rainfall is reduced, including the rainfall over Australia. So as El Niño brings dry times, aerosols make the climate even drier.

Intriguingly, Liepert discovered that the effects of aerosols, like those of global warming, are uneven: they do not weaken India's monsoon system, for instance. In fact, she predicts, the combined effect of greenhouse-gas warming and more aerosols in the atmosphere would make the Indian monsoon wetter, even as it makes Australia drier.

In spite of such progress in understanding the system, much work remains to be done. "We've only known about El Niño in the past twenty years," says Swetnam, "and only better understood it in the last ten." And, he adds, there are other weather cycles that climatologists are only beginning to recognize.


David Jones also emphasizes

the uncertainties. No one knows, he says, whether 90 percent or 10 percent of the changes in rainfall are the result of human-induced climate change. Yet "it is now fairly clear," he continues, "that the current large and complex patterns of climate change are the result of aerosol changes, ozone change, and greenhouse-gas changes, with a component of natural variability thrown in for good measure."

Whether or not humanity in general is exacerbating global warming and thus intensifying the droughts that plague Australia, the Australians themselves are certainly contributing to the water shortage on their continent. The country's most economically important river system, the Murray-Darling, which drains much of Queensland and New South Wales, is drier now than it has been at any earlier time in recorded history, its feeble flow the result of drought and voluminous withdrawals for farms, cities, and reservoirs.

Some Australians further narrow the culprit to "big irrigation": three water-intensive crops—cotton, rice, and sugar—together account for about a third of the country's agricultural water consumption. The Murray-Darling basin's rice farms collectively use almost as much water as all of Australia's 20 million citizens. Some argue that Australian farmers should grow less thirsty produce. At any rate, tying up more and more water in water-intensive agriculture makes the rest of the place drier and more prone to burn.

But are global warming, increased drought, and recent human activity really the most important factors in making Australia increasingly prone to fire? Some ecologists have argued, on the contrary, that Australia is fire-prone chiefly because Australia's Aborigines made it so. In popular books such as *The Fu-*



Greenhouse gases and aerosols make India wetter but Australia drier and more prone to fire.

already in the atmosphere have been enhanced by a 30 percent increase in atmospheric carbon dioxide since the Industrial Revolution began. Carbon dioxide levels are now higher than they have been at any other time in the past 420,000 years. The resultant warming is thought to be a factor in the further desiccation of areas that are already dry.

Australia's normal climate variability makes it hard to pinpoint the effects of global warming—not that they are easy to sort out even in far less complicated systems. Global warming, despite its name, is not just a uniform rise in global temperature. The retained heat can lead to quite paradoxical outcomes. Some global-warming models, for instance, predict a massive cooling in northern Europe, as changes in the salinity of Atlantic seawater, resulting from the melting of polar ice, shut down the Gulf Stream.

An additional, complicating factor in the case of Australia is the effect of aerosols—fine droplets of water, or particles of dust, soot, pollen, and the like, which can remain suspended in the atmosphere for weeks at a time or longer. Beate G. Liepert, a climatologist at Columbia University's Lamont-Doherty Earth Observatory in Palisades, New York, studied the effects of atmospheric aerosols in combination with global warming. With a computer model developed by Johann Feichter and Erich Roeckner at the Max Planck Institute for Meteorology in Hamburg, Germany, and Ulrike Lohmann of the Swiss Federal Institute of Technology in Zurich, Liepert found that atmospheric aerosols make Australia drier. Aerosols, like greenhouse gases, contribute to global warming. The warmer the atmosphere, the more water it can hold. And in general, if water is locked up

ture Eaters, by Timothy F. Flannery, the director of the South Australian Museum in Adelaide, and *The Burning Bush*, by Stephen J. Pyne, an environmental historian at Arizona State University in Tempe, the idea is advanced that Aboriginal practices in place for tens of thousands of years were what really transformed the land into a fire-dependent ecosystem.

According to the hypothesis, the Aborigines practiced relentless, wide-scale burning in Australia for millennia—to drive game, clear land, forge pathways, and encourage new growth. The frequent burning would have eliminated shade-loving plants and favored fire-loving, sun-worshipping eucalypts. The latter have developed specialized, enlarged woody

late through the years. Thus, to reduce the risk of large fires, smaller ones should frequently be set.

In favor of the hypothesis, some Aborigines are known to have practiced “fire-stick farming” in some regions—purposeful, periodic clearing of large areas to manipulate the land for their own purposes. But opponents of the hypothesis counter that ascribing the evolution of a fire-prone ecology solely to the hand of fire-wielding humans is too simplistic.

Reexamining the early written records of the first European explorers in Australia, Rod J. Fensham of the Queensland Herbarium in Toowong found that though Aboriginal burning was prevalent along Queensland’s coast, it was infrequent inland. Most



Wallaby carcass lies on the scorched earth left by the Australian Capital Territory fire.

growths called lignotubers, which can store nutrients and water in the earth, out of the reach of fire. If a tree is destroyed by fire, the lignotubers can send up new shoots almost immediately. In addition, the layered bark of the eucalypt forms a protective shield, which burns off in successive layers like the heat shield of a spaceship on re-entry. So, the argument goes, over many eons a self-reinforcing, dynamic process emerged: people burned the land, eucalypts thrived, people burned some more.

The hypothesis has two major practical implications for today’s Australia: modern agriculture, by eliminating fire from its toolbox, has inadvertently increased the risk of massive fires by allowing fuel to accumu-

late through the years. Thus, to reduce the risk of large fires, smaller ones should frequently be set. Aborigines were losing their land, becoming exposed to new diseases, and running into conflicts with Europeans. The fires the explorers saw may not have been set to manage the land, but rather to protect Aborigines from European intruders, or perhaps to signal the newcomers’ presence to others.

Recently Scott D. Mooney, a paleoecologist at the University of New South Wales in Sydney, studied charcoal in lake sediments at Jibbon Lagoon in Royal National Park, just south of Sydney. He showed that concentrations of charcoal were lower before the arrival of Europeans in Australia, in 1788,

than they were afterward. Furthermore, Mooney found, the number of fires increased dramatically after 1930. He asserts his evidence proves that Aboriginal people did not conduct regular burns in the land now encompassed by the park. In addition, he notes, his studies in the nearby Blue Mountains show that fires there in the past 14,000 years were linked primarily with climate change; the Aboriginal contribution to them was marginal.

The problem with many popular accounts, Mooney contends, is that they simplistically assume that all Aborigines lived the same kinds of lives. "The last Aboriginal people to live traditional lifestyles," he notes, "lived in desert communities in Western Australia and the Northern Territory, and they *did* use fire, but to apply this to all landscapes and to all Aboriginal groups in Australia is ridiculous."

In a final twist, Neville Nicholls turns the argument that Aboriginal practices created a fire-prone Australia on its head. In a 2002 paper, Nicholls suggested that Australia's highly variable, drastic climate swings may have made permanent agriculture less attractive to Australia's hunter-gatherers. Rather than changing the landscape with fire to suit their needs, the Aborigines, Nicholls argues, were forced to remain hunter-gatherers by their climate's drastic swings and the fires it caused.

If so, then even today climate change is far more important in regulating the frequency and intensity of wildfires than people are. Setting regular, low-intensity ground-fires can burn off excess fuel and diminish the frequency of explosive fires (an attitude Mooney disparages as "we need to burn more regularly like the Aborigines did"). Such fire-management practices certainly may help save individual homes, sheep stations, and businesses. But fire management alone cannot address Australia's long-term wildfire problems, for the simple reason that such burns can do nothing to ameliorate the climate.

Australia is in crisis. Australians used to live by the slogan "Populate or perish." Only a few decades have passed since the Australian government paid people to immigrate. Yet it now seems likely that Australians will have to rethink their ideas about limitless resources—and limitless population growth—if they want their country to survive.



Banksia cone depends on the heat of a fire to open up, as shown in the photograph, and release its seeds. Although bushfires have increasingly been unmitigated disasters for Australians, they, like the Banksia cone, will need to adapt if they hope to continue to call Australia home.

If current investigators are right—that the hot, dry, fire-prone climate of Australia molded the lifestyles of the Aborigines—modern Australians, too, may have to adopt a lifestyle more in keeping with a hot, dry ecosystem. That means growing less water-intensive crops and developing technologies that consume less water and produce less greenhouse gas.

People may have to rely on rooftop water-collecting tanks that were once common in the outback. In place of air conditioners, they may have to use shaded porches; in place of fossil fuels, photovoltaic devices; in place of lush English gardens, plants suited to a dry environment.

Americans—particularly those living in the more arid regions of the U.S.—may glimpse part of their own future in Australia, a future in which water restrictions, drought, and more intense, longer-lasting, and deadlier fire seasons become a way of life. The U.S. would be prudent to start planning now for worst-case scenarios in the West and Southwest, which were settled in unusually wet periods. Recently populations in those areas have undergone massive spurts of growth. According to U.S. Census Bureau figures, Nevada's population grew by 66 percent between 1990 and 2000, and Arizona's by 40 percent. Meanwhile, the water supply remained finite. "Drought is the number-one cause of economic loss in the United States," notes Mark Svoboda, a climatologist at the National Drought Mitigation Center in Lincoln, Nebraska—yet the U.S. has no overarching, codified, national policy to combat its effects.

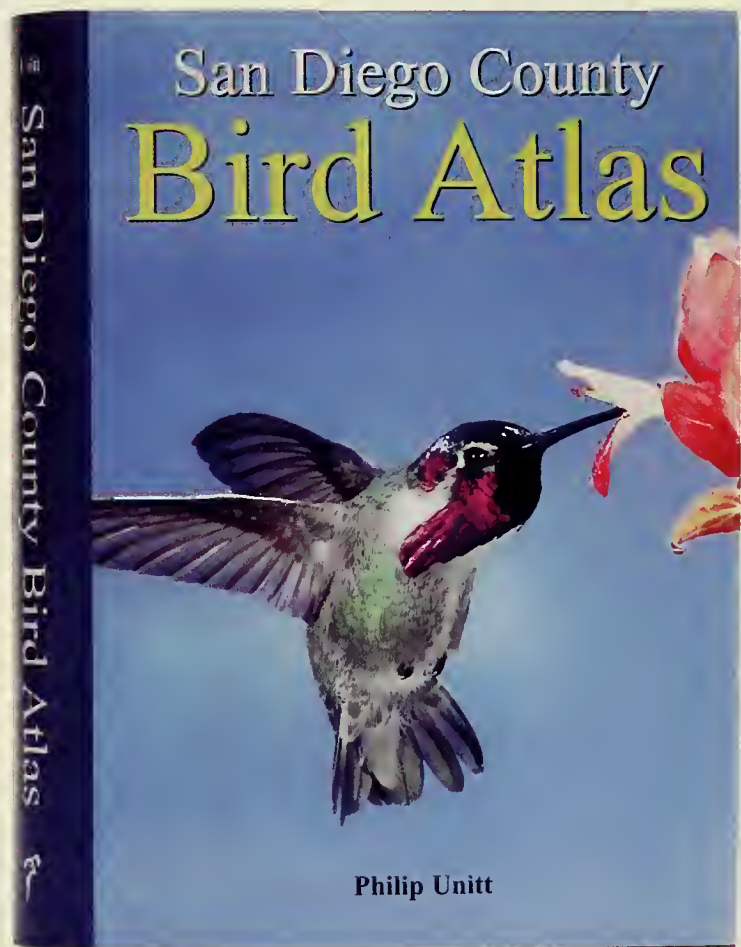
Americans may not always be aware of it, but the U.S. sometimes follows Australia's lead. For example, Australia pioneered the widespread public use of penicillin and the anonymous, or "Australian," ballot. The late evolutionary biologist Ernst Mayr once suggested that change happens fastest among small populations in geographically isolated areas. If that applies here, Americans would do well to observe how the 20 million people living on the world's largest island cope with changes to their environment.

"We're in the hottest decades in history," Thomas Svetnam declares. "It's gonna get warmer, and we're gonna see more fires." □

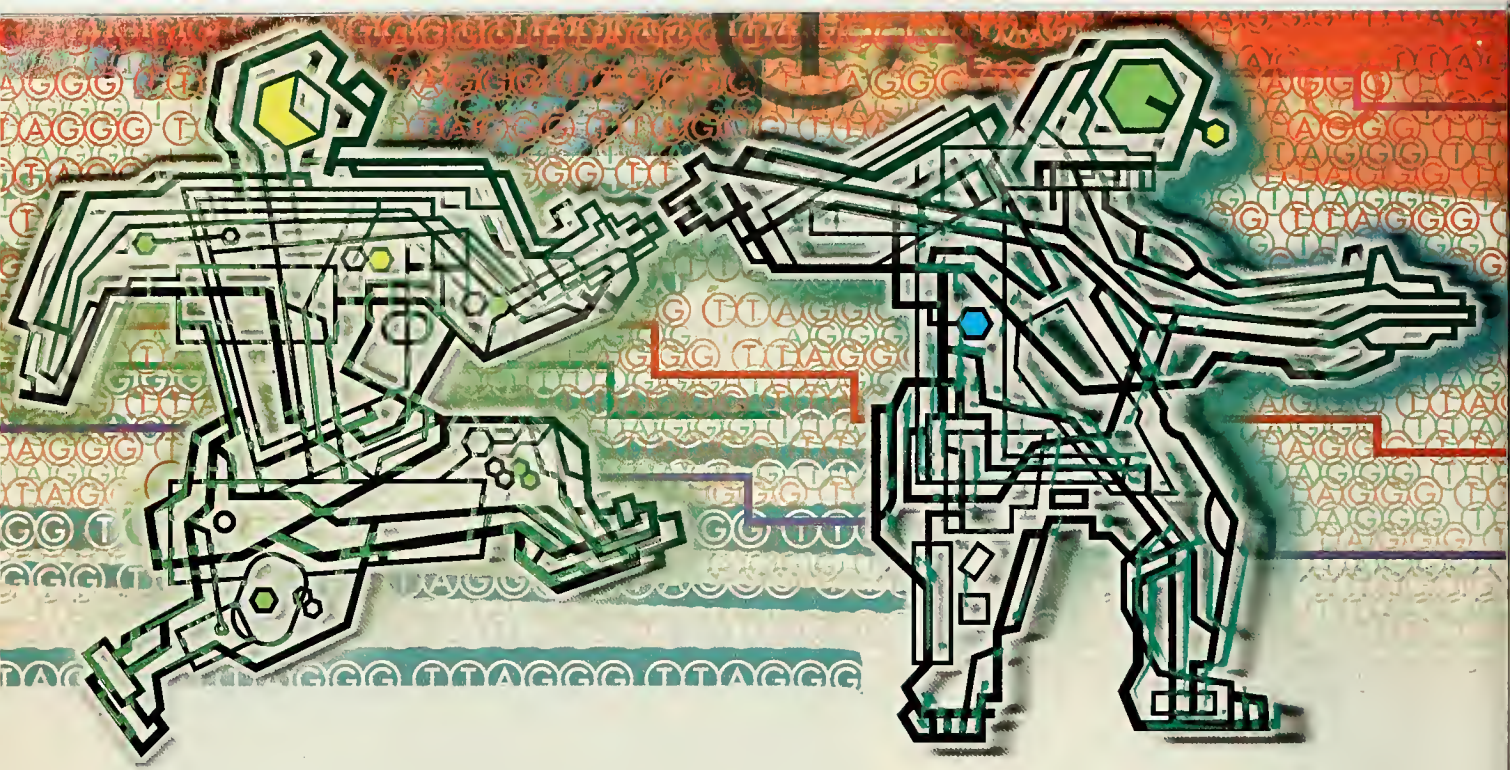
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Keeping the Ends in Sight

Elizabeth Blackburn's focus on the once-obscure DNA at the ends of chromosomes has led to promising lines of research on aging, cancer, and stress.

By Mary K. Miller

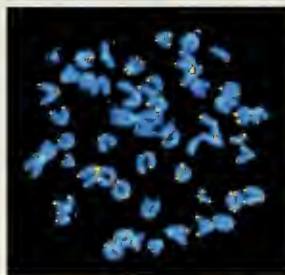
Elizabeth H. Blackburn, a pioneer in the study of telomeres—the ends of chromosomes, which play a role in aging and cancer—has always taken the unexpected path. Growing up in a family of physicians in Tasmania, Australia, she chose to enter medical research rather than medicine. Instead of studying the animals she had loved as a girl, she became fascinated with the chemical machinery of cells. At the University of Melbourne, where she lived in a women's residential college, she majored in biochemistry. For graduate school, she ventured abroad, in 1972, to the University of Cambridge. While there, Blackburn immersed herself in genetics under the mentorship of the Nobel laureate biochemist Frederick Sanger.

After three years at Cambridge, Ph.D. in hand, Blackburn was bound for a postdoctoral appointment at the University of California, San Francisco,

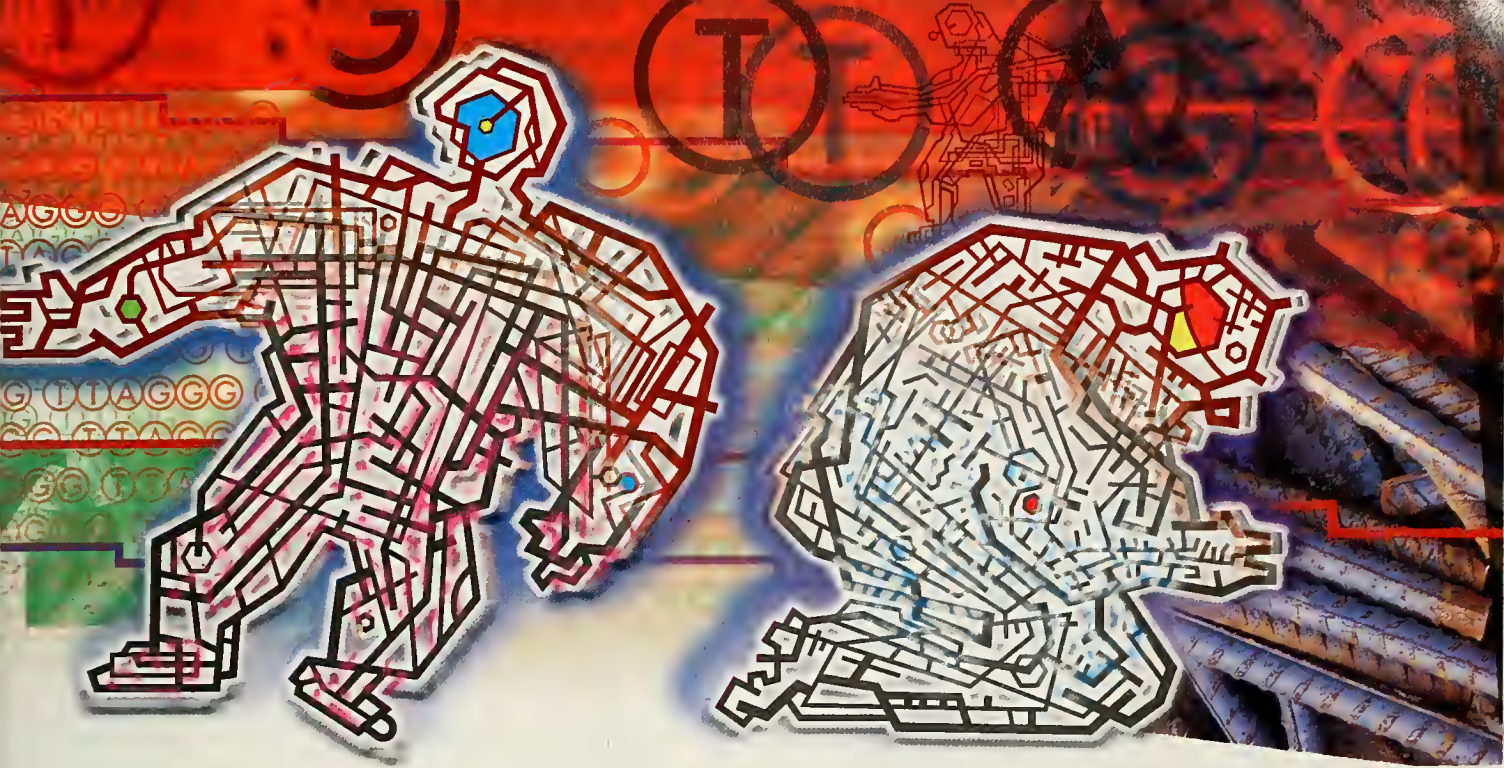
to sequence viral DNA. But her fiancé, John W. Sedat, was headed for Yale. She switched projects and opted for Yale. Thus began a lifelong passion for telomeres.

The early-twentieth-century American geneticist Hermann J. Muller coined the term “telomere” from the Greek words *telos* (end) and *meros* (part). Muller and the American geneticist Barbara McClintock independently theorized that telomeres must serve a protective function for chromosomes, somehow keeping them separated from one another (the “naked” ends of two long, string-like chromosomes would otherwise fuse end to end). “McClintock did an amazing thing in the 1930s,” Blackburn notes with admiration. No one knew

about DNA at the time, but McClintock “could see and study chromosomes under the light microscope. She correctly surmised that the chromosome ends somehow stabilized the structure [of the chromo-



Telomeres (yellow) at the tips of paired chromosomes, highlighted by contrast staining



somes] during replication.” Forty years after McClintock, when Blackburn decided to apply the DNA sequencing skills she had picked up at Cambridge, she was the only scientist studying telomeres. “I thought, ‘Wow, I wonder what they’re like?’ Nobody knew. There was no hypothesis.”

Blackburn’s encounter with telomeres, and their associated biochemistry, began a life’s work that has placed her among the world’s leading cell biologists today. Telomeres have turned out to be a far more fascinating, and more important, line of biomedical research than even Blackburn originally suspected they would be. In her three decades of research and more than 120 peer-reviewed papers on the once-neglected subject, Blackburn has played a key part in major discoveries in the field of telomeres. Having joined the faculty at the University of California, San Francisco, after a fifteen-year delay in her original plans to go there, she is a mentor herself, to a number of young scientists. Together, Blackburn and her students, both former and current, have helped explain how telomeres act in protecting chromosomes from damage, in regulating cell division and cell death, and in such processes as aging and its associated diseases.

For her innovative and groundbreaking work, Blackburn has been recognized by peers, and richly honored. She is a member of the National Academy of Sciences and an elected fellow of the Royal Society of London, as well as the American Association for the Advancement of Science. She served on the President’s Council on Bioethics during President George W. Bush’s first administration but was

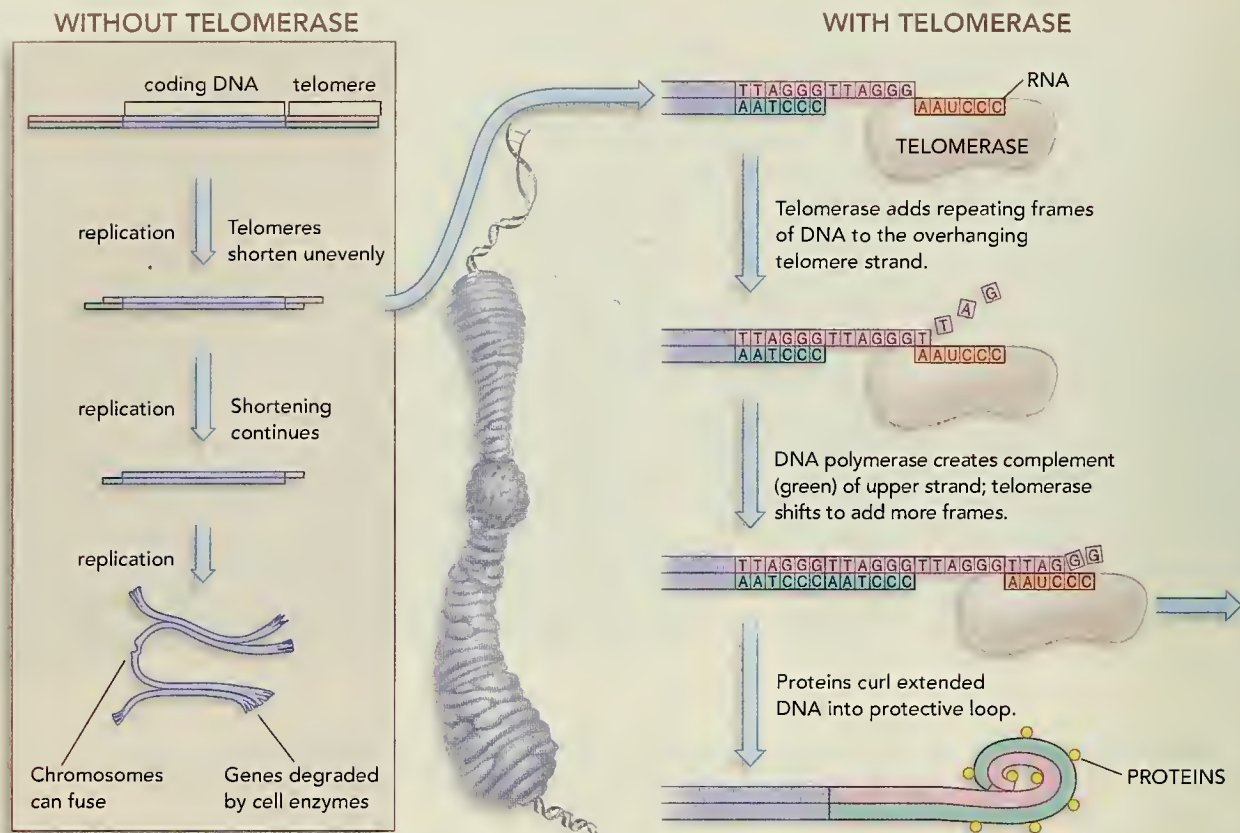
dismissed in 2003 for her vocal objections to reports on aging and on stem cell research, among others. The reports, she felt, were neither balanced nor accurate reflections of the scientific fields from which they purported to draw. This April she will receive the Benjamin Franklin Medal in Life Sciences, presented annually by the venerable Franklin Institute in Philadelphia; the award has become one of the nation’s most prestigious honors conferred on a scientist. Many Franklin Medal winners in science are also past or future recipients of the Nobel Prize.

For the first decade of her career, however, Blackburn toiled in relative obscurity. At her postdoctoral fellowship at Yale she joined the laboratory of cell biologist Joseph G. Gall. Gall had seen the value of working with a model organism, *Tetrahymena*, a pond-dwelling, single-celled ciliated protozoan. Like all eukaryotic organisms (organisms whose cells have a nucleus), including people, *Tetrahymena* has linear chromosomes inside the cell nucleus. What sets ciliated protozoans apart, though, is the sheer number of their chromosomes: *Tetrahymena* has as many as 40,000 in a single cell. (Each somatic cell of a human being carries just forty-six chromosomes.) The abundance of chromosome ends makes *Tetrahymena* an ideal organism for the study of telomeres, and so Blackburn set about determining their genetic sequence.

What she discovered was very curious: Telomeric DNA is made up of short, simple, repeating sequences of nucleic acids. (Much longer, more complex runs of nucleic acids make up the DNA sequences that constitute genes.) Soon she and other



Elizabeth Blackburn



Telomeres shorten with every round of replication. Without telomerase the shortening can eventually cut into DNA that codes for genes, and entire chromosomes can fuse end to end. When telomerase is present in the cell it works to extend telomeres; other proteins then curl the telomeres into a protective loop.

investigators found similar patterns of repeating DNA segments in the telomere sequences of other species—though the number of repeats varied from organism to organism. For instance, *Tetrahymena* has strings of *TTGGGG* repeated about 50 times, and humans have strings of *TTAGGG* repeated about 2,000 times. (T, A, and G stand for the nucleic acids thymine, adenine, and guanine, respectively.)

That evidence and some other results led Blackburn to suspect that the simple sequences were performing a more complex function, and that something else in the cell was controlling the telomeres. Her colleagues remained politely interested but unimpressed, even as she was working out how the sequences were maintained over time. "After we described this work, I would go to meetings and be the last speaker in the last session of the day," Blackburn says.

From McClintock's era on, biologists had simply accepted the idea that telomeres somehow cap the end of a chromosome, just as plastic caps the ends of a shoelace and protects it from becoming unraveled. The cell is normally vigilant about detecting and repairing breaks in its chromosomes. In so doing, though, the cell could mistake an unprotected chro-

sosome end for a break and attempt to fuse it to another chromosome end. The telomeres prevent that from happening. Blackburn was determined to find out how, but it would be many more years before she would have enough clues to sketch the process, and much about it remains unknown.

"We now think that there's something that hides the chromosome ends in plain sight," Blackburn says. "The cell sees the ends, but instead of hiding—and we still don't understand how they do this—the cell turns the recognition of the ends into a response appropriate to the telomeres. It's a very dynamic process, not like a passive shoelace end, and that was not expected at all."

Another cellular enigma was how telomeres manage to maintain their length and, hence, their functionality. By the early 1970s, biochemists realized that the normal process of DNA replication could not copy a chromosome all the way to its end. Consequently, with every chromosome replication and cell division, the telomeres should theoretically get shorter [see illustration above]. Eventually, without anything to arrest the process, the telomeres

would get so short that any further chromosome replication would cut into the genes themselves, and the cell would die. Because bacterial cell lines can live and divide for thousands of generations, chromosome shortening became a paradox known as the “end-replication problem.”

There was much speculation about how the cells might solve the problem, but no empirical explanation. “In biology you can wave your hands and make up all these paper schemes,” Blackburn says. “But the key thing was to show in the test tube that

collaboration between RNA and a protein,” Blackburn explains. No one understands exactly how the two work together, but what is known is that the RNA codes for short segments of DNA that are added piece by piece to the ends of telomeres [see illustration on opposite page]. Thus telomerase restores bits of telomere lost during cell division.

The finding came as a surprise, Blackburn recalls, because “people had thought that only bad things, like the HIV virus, did this conversion of RNA to DNA. But here is a molecule that does this, not for

Telomeres in people over 100 are longer than one would expect. Could robust telomeres and extra telomerase be protecting long-lived people?

there really was a tangible mechanism.” So in the mid-1980s Blackburn, who was running a laboratory at the University of California, Berkeley, and an especially determined graduate student named Carol W. Greider went back to *Tetrahymena* to figure out how cells preserve their telomeres. “We normally think of genetic material as sacred,” Blackburn says. “But [*Tetrahymena*] chop up their somatic [non-germ line] chromosomes and add new repeat DNA [sequences] to the ends.”

Blackburn had hypothesized that an undescribed enzyme within *Tetrahymena* cells was building new telomeric sequences. Another enzyme that assembles strands of DNA, called DNA polymerase, was already known. But DNA polymerase builds a new strand of DNA by using a single strand of the double helix that forms a chromosome as a copy template. The new strand is a complementary copy of the original. (Nucleic acids that make up DNA always pair with their complement: adenine with thymine, and cytosine with guanine.)

Unlike DNA polymerase, Blackburn and Greider’s mystery enzyme, which they called telomerase, would have to build telomere sequences from scratch, with no template. To find the enzyme, Greider mixed synthetic telomeres, created in the laboratory, with extracts of *Tetrahymena* cells. The synthetic telomeres, Greider and Blackburn had reasoned, would be extended only if the *Tetrahymena* extracts contained the hypothesized telomerase enzyme. To their delight, the synthetic telomeric DNA grew longer, proving the existence of telomerase.

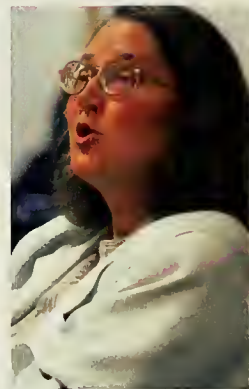
Their newly discovered enzyme turned out to be a remarkable molecular complex. Like most enzymes, telomerase contains protein. But the telomerase complex also includes a single molecule of RNA, a chemical cousin to DNA. “Telomerase is a

evil, but for a critical function necessary for continued life.” She now suspects that telomerase is an ancient molecule, a relic from a prebiotic world dominated by RNA reactions, rather than by proteins and DNA.

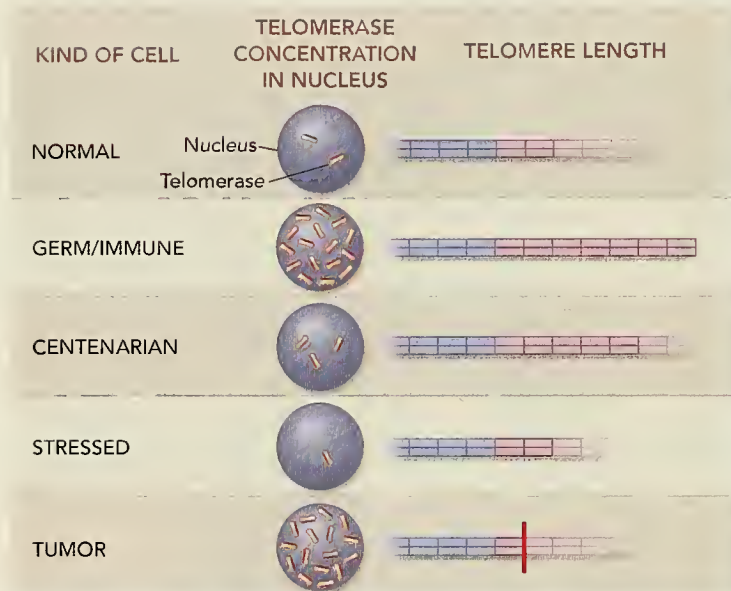
With their molecule in hand, Blackburn and others could start to tease out how telomerase works in the cell. From work in the 1960s it was known that human cells grown outside the body, unlike the cells of single-celled organisms, have a limited life span. After some twenty to fifty divisions (a number thought to be highly dependent on cell type), human cells stop dividing and enter a static phase known as senescence. Could telomeres be functioning as a clock that tells cells when they have reached the end of their line?

Greider left Blackburn’s laboratory in Berkeley in 1988, for a postdoctoral fellowship at Cold Spring Harbor Laboratory, in Long Island, New York. There she discovered that the telomeres in laboratory-grown human skin cells get shorter with every cell division. The idea took hold that shortened telomeres could be a signal to the cell that its genetic material is getting old and is at risk of losing its integrity—in short, the shortened telomeres become the canaries in the coal mine that tell a cell it is dangerous to continue dividing.

Greider’s finding led to speculation that the telomerase gene is turned off in normal cells; that telomerase remains active only in other actively dividing cells, such as immune cells and germ cells. “We know now that there’s a smidgen of telomerase in just about all cells, and that it is protecting telomeres,” says Blackburn. “But there’s not enough telomerase to keep up with the shortening. With time, she adds, “the telomeres will gradually run down.”



Intriguingly, human telomeres vary in length from individual to individual. Telomeres in centenarians, for instance, are longer than one would expect. Could longer telomeres be protecting long-lived people? After all, centenarians live longer in part because they don't die from the diseases that kill most of their age cohorts. Perhaps robust telomeres and extra telomerase are helping protect them against heart disease and other diseases.



Normal cells have shrinking telomeres because telomerase levels are low, but immune and germ cells can keep producing telomerase and therefore maintain their long telomeres. People hardy enough to live a hundred years tend to have longer telomeres in general, whereas stress seems to prematurely shorten telomeres. The telomeres of tumor cells shorten to a critical point and then overproduce telomerase so that they can continue to divide.

An important link between telomerase, disease, and aging was identified in 2001, with the discovery of a genetic mutation responsible for a rare disease called dyskeratosis congenita. People with the condition are born with only one functioning gene for telomerase, and as a result, their telomeres shorten rapidly. They show some signs of premature aging, such as gray hair in their teenage years, but the most dire effect is that they usually die in early adulthood or middle age from bone marrow failure and a resulting inability to fight infections. "It's a striking reminder that we need a lot of self-renewal and telomerase in immune cells," says Blackburn. Immune cells have to multiply rapidly when they meet an antigen. Without sufficient telomerase, those cells cannot survive enough cell divisions to overcome the invader.

Once it became clear that telomere shortening might have a role in cell aging and, conversely, that

long telomeres might somehow contribute to human longevity, Blackburn's colleagues began to take notice. The once-quiet field exploded, and the cumulative citations for "telomerase" in medical and biological journals skyrocketed. As others began working on telomeres and telomerase, new insights into disease and aging have come to light. With them has come the potential for developing new treatments against some of humanity's most intractable killers.

One recent discovery is that shortened telomeres do not necessarily spell imminent cell death, or even loss of vitality; the more important factor is whether enough telomerase is available in the cell nucleus to rescue and protect the remaining telomere ends. Remarkably, available telomerase turns out to be at least one key to the ability of cancer cells to circumvent the genetic safeguards of normal cell senescence.

In a malignant tumor, cancer cells divide and multiply indefinitely, becoming immortal, runaway tissue that consumes all the resources that would otherwise go to healthy tissue. In the early 1990s Greider and others found that the telomerase concentration in cancer cells is 100 times higher than it is in normal cells. The elevated telomerase occurs both in cancer-cell lines grown in the laboratory and in ovarian tumors growing in the body.

Somehow, then, on the road to becoming malignant, cancer cells switch on the telomerase gene before the telomeres become too short for cell division. Surprisingly, the telomeres in cancer cells are often much shorter than the telomeres in the cells of surrounding tissue—evidence that the cancer cells had already begun to replicate (and their telomeres had begun to shorten) at breakneck speed, before the telomerase came back on the scene to perform its vital function.

If telomerase could somehow be inactivated, malignancies would presumably stop before they could spread to other parts of the body, establish new malignancies, and do their extensive damage. (Blackburn suspects, nonetheless, that cancer cells may be able to subvert telomere shrinkage in other ways as well.) Hence, blocking the production of telomerase has become an attractive target for cancer therapies, particularly if they can home in on specific tissue and avoid cells, such as immune cells, that depend on telomerase to keep the body healthy. For the investigators in Blackburn's lab, as well as for geneticists at other universities and within the biotech industry, telomerase blockers have become an important, emerging line of research.

Cancer is by no means the only cell-damager associated with telomere length. In 2004 Blackburn joined forces with Elissa S. Epel, a psy-

chiatrist and clinical colleague at the University of California, San Francisco, to test the role of psychological stress in aging at the cellular level. "We started with the observation [of Epel's] that people look really old and drawn when they have chronic worries and stress in their lives," Blackburn explained. "But we had no hypothesis about whether we'd see an effect on telomeres in the cell. Nobody knew, so I said we should just look."

Blackburn, Epel, and Richard M. Cawthon, a geneticist at the University of Utah in Salt Lake City, conducted a study of thirty-nine women, ages twenty to fifty, who had been caring for a child suffering from a serious chronic illness, such as autism or cerebral palsy. Those women, presumably highly stressed, were compared to a control group of nineteen mothers of healthy children. Stress was quantified in part

that's what we're trying to do in the lab: figure out what things influence telomerase."

Blackburn credits much of her success to supportive research environments and the resulting opportunity to pursue curiosity-driven science. "Thank goodness I don't work in industry," she says. "You can do really good research in industry, but you have to stay on some kind of goal-directed line. [At universities] you're still goal directed, but you can be more creative."

She remains keenly aware of the importance of scientific mentors—in her case, Sanger at Cambridge and Gall at Yale. "Sanger was supportive in a quiet way," she says. "He loved being in the lab and liked talking about science. It was important to feel that I could always converse with him." Gall was equally

Highly stressed women with chronically sick children have shorter telomeres and lower levels of telomerase in their cells.

by the number of years each woman in the test group had been caring for an ill child. That number was combined with other objective measures of stress, including so-called oxidative stress (damage to DNA caused by "free radicals"), one of the major risk factors for cardiovascular disease.

The investigators discovered a clear correlation between the number of years a woman had been caring for her sick child and shortening of telomeres. The stressed women also had lower levels of telomerase in their white blood cells and higher levels of oxidative stress. Moreover, the investigators found that the perceived stress in their test group, as measured by a subjective battery of ten questions called Cohen's Perceived Stress Scale, was also correlated with shorter telomeres and lower telomerase levels in the blood cells. The finding held whether the mother had an ill child or not. "We didn't expect to see such a clear relationship right across the full range," Blackburn says. "Elissa crafted a beautiful study where she had a well-controlled group of individuals, and the relationship between stress and telomere length really held." In other words, a woman's perception of the level of her own stress is correlated with her body's cellular response. As far as Blackburn and Epel can determine, this result was the first time a mind-body link that reaches into the cell was established.

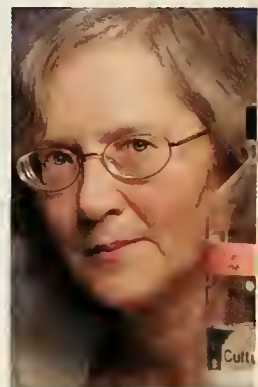
"Of course, now we want to understand exactly how stress is affecting the cell," says Blackburn. "Stress is changing hormones in your blood and bathing the cells in something that's different. So

supportive. "Joe Gall was famous for having a good proportion of women postdocs who had done well," Blackburn says. "He would announce to the lab when one of his former students or postdocs got tenure. Joe realized it was important to be sending a positive message."

In her turn, Blackburn is quite serious about her own role as a mentor, particularly for women in science. "Carol Greider said the fact that I had a child was encouraging to her," Blackburn recalls. "It's important to show that you don't have to give your entire life over to science, that you can be successful by being smart and efficient and not always working long hours and weekends."

When Blackburn thinks about the future direction of her lab's work on telomerase, she has a two-pronged approach. "I would like to go deep into the chromosome and really understand what is happening structurally and functionally around the telomeres. This is a dynamic, robust system, like a buzzing bazaar with all sorts of molecules coming and going. I would love to understand the dynamics."

But it's also important to her that such deep knowledge be applied to healing the body. What can knowledge add to the understanding of how things can go wrong? How can it help treat cancer, chronic stress, and heart disease? "We want to exploit knowledge of telomerase and telomeres to develop therapies at a cellular level," she says. Ambitious goals, to be sure. But considering how far Elizabeth Blackburn has already pushed the study of telomeres, such goals could well be within her grasp. □



The Philosopher Fish: Sturgeon, Caviar, and the Geography of Desire
by Richard Adams Carey
Counterpoint, 2005; \$26.00



Sturgeon by the boatful: lake fishing in Russia's north-central Kirov region, ca 1947

The sturgeon, whose eggs are prized above those of all other fish, may be "the single most valuable wildlife resource in the world," according to the author, Richard Adams Carey. Caviar lovers understand. With fine beluga from the Caspian Sea retailing at about \$100 an ounce, the cost of a decent gourmet snack nowadays exceeds the budget of all but the unimaginably rich.

It was not ever thus. Caviar, always an acquired taste, did not really become an object of conspicuous consumption until the boom years of the 1920s. In fact, before the twentieth century the various species of sturgeon were so abundant that it was considered at best a ho-hum fish, the canned tuna of its day. In the heyday of the Hapsburgs, Viennese noblemen, for want of other diversion, amused themselves by firing cannonballs into the annual armadas of migrating beluga sturgeon that swam up the Danube to spawn. As recently as the

1870s, a half-ton white sturgeon was selling for twenty-five cents at wholesale fish markets in Oregon, and in New York City bars, free caviar was offered to stimulate drinking, the way free peanuts or pretzels are provided today.

For a decade or so the United States capitalized on its piscine overabundance, becoming, next to Russia, the major supplier of the world's caviar. In the late 1800s, the city of Caviar, New Jersey, at the northern end of Delaware Bay, sent fifteen railroad cars a day to New York City, loaded with smoked sturgeon (known as "Albany beef") and kegs of slippery roe.

But soon, like so many seemingly limitless resources, the sturgeon was fished into oblivion. By the First World War, the American caviar industry was only a memory. The city of Caviar had literally dis-incorporated, leaving nothing more than a cluster of dilapidated houses and overgrown sheds.

Carey, who spins graceful prose whether he is writing about fish, fishermen, or the food they provide, takes the reader on an informative (and sometimes mouth-watering) tour of the planet's remaining sturgeon reserves. They are to be found, surprisingly, in all the world's temperate zones. Some sturgeon survive in the rivers of the Northeast, where they have recolonized the Hudson. Vestigial populations live in Wisconsin's Lake Winnebago, where sportsmen spear a precious few of the big fish through holes in the ice each winter. Southern cousins of the Wisconsin fish swim along the Suwannee River in northern Florida.

In California, commercial sturgeon hatcheries are going strong, and careful husbandry could raise the cachet of American caviar, in the same way that careful vineyard cultivation raised the reputation of American wines. Even the Caspian sturgeon, whose unborn generations once graced the tables of

the tsars, seems to be hanging on, if only barely, amid the political, economic, and religious struggles of the post-Soviet world.

Plants and Empire: Colonial Bioprospecting in the Atlantic World
by Londa Schiebinger
Harvard University Press, 2004;
\$39.95

It is a measure of the richness of tropical biodiversity that even today, 500 years after Columbus's first voyage, much of the botanical resources of the Caribbean and its shorelines remain undocumented. Londa Schiebinger's scholarly study covers botanical exploration during what the author calls "the long eighteenth century": from the 1670s until about 1802. This was a period of dawning European recognition that the real treasures of the New World lay not in fabled cities of gold but in the vines, bushes, and flowers that crowded village gardens and grew in the jungles beyond.

There were fortunes to be made, clearly, in cultivating such indigenous species as chocolate, cotton, and vanilla for export, and in establishing imported rootstocks such as sugarcane and tea. But many of the most sought-after plants were the sources for what we today would call "herbal remedies."

The cinchona tree was, in effect, the key to all the other riches of the New World, because without it Europeans could not survive the debilitating fevers that seemed to strike everyone who ventured into the Americas. European powers regarded their sources of quinine and other drugs as virtual military secrets, and, since secrecy breeds countersecrecy, a subculture of "biospies" grew up in the colonies—shadowy souls who collected information on the herbal discoveries of competing nations.

Biopiracy, though it makes for exciting reading, is only a small part of Schiebinger's narrative. Most of the bioprospectors she profiles were legitimate



Natives of the Antilles under a pawpaw tree, from a 17th-century woodcut

naturalists, driven by the collector's impulse to catalog and describe the exhilarating profusion they encountered. Schiebinger pays special heed to the work of Maria Sibylla Merian, who spent twenty-one months collecting in Surinam in 1699. Merian published a monumental volume of scientific drawings of the tropical insects of that country in 1705, but her accompanying text also recorded the medicinal uses of indigenous plants. For her information on medicines she relied heavily, it seems, on local informants, often noting that "they told me this themselves."

Among the useful plants her informants told her about was the red "peacock flower" (*Poinciana pulcherrima*), common throughout the Caribbean and South America. Slave women, according to Merian, used the flower to induce abortion. Then, as now, the practice was laden with emotion, but in those days it also resonated with issues of race and class, as well as religion and gender. To refuse to bear children, who were viewed only as a form of free labor to the slaveholder, was a particularly bitter form of social protest against the system that held the women in bondage.

P. pulcherrima, as can be imagined, found its way into European culture along a route rather different from that of other botanical remedies. The virtues

of most new herbal drugs were widely transferred into the European pharmacopoeia. Not so the peacock flower. Numerous specimens crossed the ocean to the botanical gardens of Europe, and several authors, in addition to Merian, mentioned the medicinal use of the flower. Yet knowledge of the peacock flower and its use as an abortifacient remained confined, by and large, to the slave camps and backwoods villages of the New World colonies. Schiebinger's thoughtful study, then, sheds light not only on how new knowledge comes to be, but also on how some new knowledge comes to be ignored.

*Frozen Earth: The Once
and Future Story of Ice Ages*
by Doug Macdougall
University of California Press, 2004;
\$24.95

It may seem counterintuitive, but it's no secret to geologists that we are living in an ice age. The simple fact is that throughout most of the 4.5 billion years of history on our planet, the climate has seldom been as frigid as it has been of late. By "of late," I don't mean the past century or so, which has been characterized by warming trends, but the past several million years, when planetary temperatures took a nosedive. The result has been a succession of massive ice sheets that bulldozed their way into what were once temperate, or even tropical, lands.

Of course, even ice ages have occasional respites—warm periods during which the ice retreats. We are living in one now, a kind of global Indian summer. It is so temperate these days that it is hard to imagine the ice-locked world of 18,000 years ago, when glaciers sometimes two miles thick covered North America as far south as central Pennsylvania.

Signs of the most recent glaciation are all around us, though. Huge glacial erratics, boulders unlike most of the other rocks in their surroundings, stand in mute testimony to their cross-country transport by advancing ice. Mean-

dering ridges of gravel, so-called glacial moraines, trace glacial retreat, where streams of rushing meltwater slowed down enough to deposit their burden of sand and pebbles. But it was not until the 1800s that close observers of the countryside were able to apply a kind of forensic geology to the scars left behind by flowing ice, and thereby reconstruct the chronology of glaciations past. Doug Macdougall, an earth scientist at the Scripps Institution of Oceanography in La Jolla, California, tells an enlightening tale of how that knowledge came to be, and what the science of geology has discovered about the causes and consequences of the ice ages in recent years.

A central figure in Macdougall's story is the Swiss-born naturalist and geologist Louis Agassiz. Having hiked over Alpine glaciers as a youth, Agassiz had a keen eye for the effects of ice. He convinced the scientific community that much of the lowland landscape had been carved by the same kind of glacial action he had seen at high altitudes. Later in life he emigrated to the United States and accepted a professorship at Harvard, where he founded the Museum of Comparative Zoology. There he became something of a national celebrity. The poets Henry Wadsworth Longfellow and Oliver Wendell Holmes Sr. celebrated Agassiz's ideas in verse. At his funeral in 1873 the U.S. vice president and the governor of Massachusetts were among the mourners.

Agassiz contented himself with showing that there had been ice ages, leaving the question of *why* to less charismatic but no less brilliant investigators. James Croll, a self-taught geologist who lived in the second half of the nineteenth century, showed how the ebb and flow of ice over long periods of time is governed by changes in the shape of Earth's orbit and in the inclination of the planet's axis caused by the tug of the other bodies in the solar system. Croll's work was refined by a Serbian mathematician and engineer, Milutin Milankovitch, in the 1920s, who

matched the predicted orbital variations with a growing body of data showing how Earth's climate had changed.

Since then the available historical data has expanded at an accelerated pace, both in volume and in detail. In 1998 an ice core was extracted from the Antarctic ice sheet to a depth of nearly 12,000 feet, providing a virtually unbroken record of global climate changes (as recorded in the annual ice layers), spanning more than 400,000 years. Yet current theory cannot account for the complex patterns in the data. For example, climate has sometimes flipped within a single decade—too rapidly to



Iceberg calves from the confluence of the Dugdale and Murray glaciers in Antarctica.

have been caused by slow changes in Earth's orbit. And during the period now known as the "little ice age," which peaked from the seventeenth until the nineteenth centuries, an unexplained absence of sunspots was accompanied by unusually hard winters all over Europe.

Just as surely as sunshine follows rain, the present warming period will give way to a return of the ice, despite the inadvertent influence of our fossil-fuel economy. But no one yet, not even a scientist as knowledgeable as Macdougall, can say whether the new ice curtain will fall in a century or 10,000 years in the future.

LAURENCE A. MARSCHALL, author of The Supernova Story, is W.K. T. Sahn Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy. He is the 2005 winner of the Education prize of the American Astronomical Society.

nature.net

Living with Fire

By Robert Anderson

Those of us living in the hills around Los Angeles don't need to follow the news from Australia [see "Fire Down Under," by Dan Drollette, page 44] to understand what it's like to live with wildfire. Often enough, cool ash from the incinerated chaparral rains down on us, a tangible reminder that every forested hillside that doesn't burn this year is just fuel for the fires in the next.

A search of the Internet turned up a number of sites that deal with the dilemma: how to reconcile increasing development of the landscape with the natural forces of fire. My first stop was a Web page published by the National Humanities Center in Research Triangle Park, North Carolina (www.nhc.rtp.nc.us). Click on "Teacher Serve" in the menu at the left, select "Nature Transformed: The Environment in American History," and under "The Use of the Land," click on "History with Fire in Its Eye." The essay on this page, by Stephen J. Pyne of Arizona State University in Tempe, provides a good overview of the problem.

To the right of the title to Pyne's essay, you can click on "Links to Online Resources" for more detail about the human interaction with fire. Following one of the links took me to the home page of the National Interagency Fire Center (NIFC) (www.nifc.gov/). Here, you can check out the predictions for fire hazards in your area by downloading a map from the NIFC: select "Current Fire Information" from the menu on the home page, scroll down to "Weather, Outlooks and Assessments," and click on "National Monthly Outlook Map."

Thanks to the Terra and Aqua satellites orbiting Earth, and the publishing capabilities of the Internet, wildfires can be tracked as readily as hur-

ricanes. At the site of the U.S. Forest Service's "MODIS Active Fire Mapping Program" (activefiremaps.fs.fed.us), you can view a map that displays daily wildfire sightings in the continental U.S. (on the menu bar under the title, click "Fire Detections"). You can also discover where fires are burning in your region on a given day: on the menu bar, click "Regional Maps"; when a colored map appears, click on your geographical area, then select the kind of image you want to view from the choices at the right.

Good, up-to-date information on wildfires in Australia, including archived videos, can be found at the Web site of the Australian TV news program National Nine News (news.ninemsn.com.au/firewatch).

For a more thorough global perspective on wildfires, go to the Web site of NASA's Earth Observatory (earthobservatory.nasa.gov/Library/GlobalFire). This site makes it clear that extensive and long-burning fires can actually affect climate by pumping greenhouse gases and aerosols such as smoke particles into the atmosphere. After huge fires in Indonesia ignited the peat-covered forest floors there in 1997, atmospheric scientists recorded the largest annual jump in atmospheric carbon dioxide since CO₂ concentrations were first measured in 1957 (see the science bulletin on this subject, published by the American Museum of Natural History, at sciencebulletins.amnh.org/biobulletin/biobulletin/story581.html).

The vast boreal forest that girds the northern latitudes has emerged recently as a new area for investigators studying climate change [see "Northern Exposure," by J. David Henry, February 2005]. Information at the Woods Hole Research Center (www.whrc.org/borealamerica/role_of_fire.htm) explains why more frequent and intense fires in the north could have powerful effects on climate worldwide.

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

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Ripples in the Cosmic Pond

Astronomers have detected a long-sought relic from the early universe.

By Charles Liu

The next time you're walking beside a quiet body of water, toss in a handful of pebbles. Each pebble will create ripples that spread outward. Soon the ripples will collide, overlap, and form wavy, cross-hatched patterns that will expand outward to the water's edge.

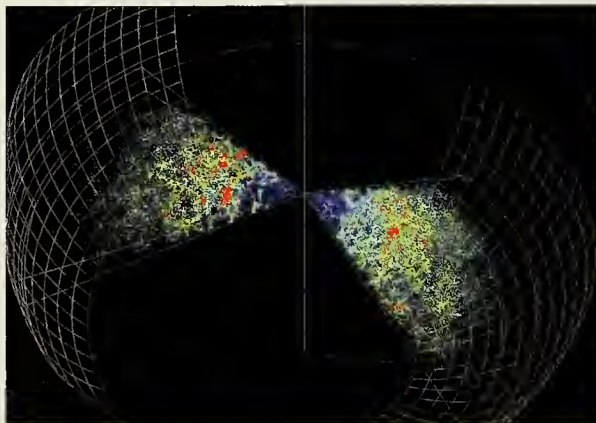
Those gravity-induced ripples, imprinted into the early, expanding universe, should still be visible in the overall distribution of galaxies in space—albeit very faintly, and on vast cosmic scales. Until recently, however, the existence of the ripples could not be confirmed. Now, two groups of astrono-

universe closely enough to see, say, our solar system, you'll never recognize the grand texture of the universe, or even our galaxy.

So what's the scale for seeing ripples left over from the early universe? Theorists calculate that such ripples should now trace regions some 500 million light-years across (they have expanded a great deal since they were formed in the early universe). Such regions would be outlined by visible matter—galaxies; so to map out the ripples, just map out galaxies. The only trouble is, detecting faint differences in galaxy densities across such a large volume would require pinpointing the positions of many millions of galaxies—a daunting task.

Amazingly, several huge galaxy surveys have recently made such studies feasible. None of the surveys is perfect—survey-makers still cannot measure the precise position of every galaxy

False color map of the 2dF Galaxy Redshift Survey (right) plots galaxy densities for more than 221,000 galaxies in the direction of our galaxy's north and south poles. Colored dots reflect galaxy densities; red marks the highest, blue the lowest. Analysis by two teams has found remnants of acoustic waves that permeated space after the big bang and have resulted in elevated galaxy densities about 500 million light-years apart. A schematic model of these waves (far right) shows what the pattern might look like if it were discernible to the eye.



Ripples permeate the cosmos as well. According to the big bang theory, matter and energy in the universe were originally spread almost uniformly throughout space. But within moments after the big bang, as the universe rapidly expanded, tiny fluctuations—peaks and valleys of varying density—developed in the expanding matter and energy. The densest regions, where gravity was strongest, acted like pebbles in a pond—except that the “pond” they disturbed was the universe itself, and the “water” they rippled was the stuff of the cosmos.

mers—one led by Shaun Cole of the University of Durham in England, the other led by Daniel Eisenstein of the University of Arizona in Tucson—have announced that the ripples have at last been found.

To find a pattern in nature, you have to know its scale. Think about the bricks in a wall. From a distance, it's easy to see the regular pattern of the brick wall. If you zoom in too close to the wall, though, all you'll see are the random pits of an individual brick. Similarly, if you look at the

in the sky. Instead, they must resort to some form of sampling—much the same way pollsters here on Earth carefully sample people's opinions—that will limit the potential for systematic errors. Then, when the astronomers analyze the galaxy data to search for matter ripples, they must try to work with the strengths of the survey data, if plausible results are to be extrapolated for the universe as a whole.

With those caveats in mind, Cole's group worked with the 2dF Galaxy Redshift Survey, a data set of 221,414 galaxies out to a distance of 2 billion

light-years from Earth. From the positions of the galaxies the group computed the so-called power spectrum of the survey—a measure of the overall texture of the galaxies' distribution in space.

Eisenstein's group used a very different data set, from the Sloan Digital Sky Survey, and a subtly different strategy. Rather than basing their analysis on every galaxy in a given volume of space, they chose a sparser sample from a much larger volume that would optimally trace out large-scale ripples of matter. Then they made a statistical tally of how far apart these galaxies are from one another.

In spite of the two groups' dissimilar techniques, their results were remarkably similar. Cole's analysis showed peaks and valleys consistent with the existence of a broad pattern of ripples 500 million light-years across. Eisenstein's analysis showed that galaxies are statistically much more likely to be

500 million light-years apart than, say, 400 million or 600 million light-years apart.

By studying the ripples in a pond, an astute observer can deduce the size of the pebbles that made them, and perhaps even the depth of the water. Just so, working backward from the scale of the cosmic ripples, the two teams were able to calculate some basic characteristics of the universe. Matter makes up between 20 and 30 percent of the contents of the universe; all the rest is "dark energy," whose true nature is entirely unknown. Moreover, only about a fifth of the matter in the universe is made up of ordinary matter—the protons, neutrons, and electrons we all learned about in science class. The composition of the remaining four-fifths is "dark matter"—whose nature is also a complete mystery.

Those calculations of the relative abundances of dark energy and dark matter in the universe are consistent with other recent findings, including the results from the Wilkinson Microwave Anisotropy Probe [see "Sharper Focus," by Charles Liu, May 2003]. That's great news, because it sets the foundation of modern cosmology on even firmer footing. These first scientific results are only the first step, however. The origin of the enormous matter ripples actually predates the formation of the cosmic microwave background, the oldest directly observable relic of the early universe. Now, nearly 14 billion years after they first began to spread, the ripples could open up a new view on the infant cosmos.

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

THE SKY IN APRIL

By Joe Rao

Mercury reaches its greatest western elongation, twenty-seven degrees from the Sun, on April 26. As viewed from mid-northern latitudes, however, the apparition, a morning one, is lousy. The zero-magnitude planet, which rises less than an hour before the Sun, does not escape the twilight glow.

Venus, which reached superior conjunction with the Sun on March 31, remains essentially hidden deep in the glow of sunset all month.

During April, **Mars** rises about two-and-a-half to three hours before the Sun. Throughout the month, the planet speeds eastward against the starry background and brightens gradually from magnitude 0.9 to 0.6.

Jupiter, shining with outstanding brilliance at magnitude -2.5, is by far the most prominent "star" in the April nighttime sky. Still within the bound-

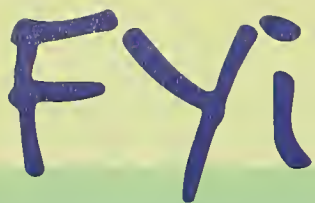
aries of the zodiacal constellation Virgo, the virgin, Jupiter arrives at opposition on the 3rd, so it shines brightly all night: in the east during the evening, high in the south around midnight, and in the west before dawn. An almost full moon appears to follow Jupiter across the sky during the night of April 22-23.

Although **Saturn** has passed overhead before dusk, the planet, because it appears well north of the celestial equator, remains visible for several hours after sunset. At magnitude 0.1, in the constellation Gemini, the twins, Saturn is nearly three times as bright as nearby Pollux, one of the constellation's "twin" stars. Any telescope capable of showing Saturn's rings can also show its ninth-magnitude moon Titan, which is always within four ring-lengths of the planet. Titan circles Saturn in a sixteen-day orbit. Look for it to the east of the planet

around the 1st and 17th, to the west around the 8th and 24th.

The **Moon** wanes to last quarter on the 1st at 7:50 P.M. eastern standard time and to new on the 8th at 4:32 P.M. Our satellite waxes to first quarter on the 16th at 10:37 A.M. and to full on the 24th at 6:07 A.M.

The new Moon eclipses the Sun on the 8th. *Never look directly at the Sun or an eclipse without using proper protection for your eyes*, such as #14 welder's glasses or aluminized Mylar plastic. You can also project the view through a small hole onto a sheet of paper. *To ignore those precautions is to court serious retinal injury.* The eclipse is an example of the rarest type of solar eclipse, a "hybrid" in which some areas see a total eclipse while others see an annular, or ring-shaped, eclipse. The annular eclipse appears over regions of the
(Continued on page 66)



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THE SKY IN APRIL

(Continued from page 63)

Earth that the Moon's umbral shadow does not reach. For this eclipse, totality is visible over the open waters of the South Pacific. The path of the annular eclipse passes across Costa Rica, Panama, the Gulf of Urabá, northern Colombia, and central Venezuela before coming to an end there at local sunset.

In the United States, viewers to the south of a curve running roughly from Imperial Beach, California, through Quincy, Illinois, to Perth Amboy, New Jersey, can see a partial eclipse of the Sun during late afternoon to early evening hours. The extent to which the Moon eclipses the Sun's disc increases the farther south one is of that curve.

Daylight saving time returns for much of Canada and the U.S. on Sunday, the 3rd. Remember to "spring ahead," that is, set clocks ahead one hour.

Unless otherwise noted, all times are eastern daylight times.



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CONTACT

(Continued from page 32)

your fourth book about the voyage of the *Beagle*. How does it differ from its predecessors?

KEYNES: This time I've taken Darwin's narratives and woven them together with more letters and journals of Captain FitzRoy and other crew members, so that many of the gaps of the earlier accounts are filled in. Also, in revisiting some of the places Darwin saw, I was able to add some fresh perspectives. For instance, on the very beach at Bahía Blanca where he found the fossil bones of a giant sloth, I ran into two Argentinean paleontologists who had just found petrified footprints of the same animal. In addition, I've included some letters from Captain FitzRoy that shed some light on his relationship with Darwin, which some have thought to be not only formal but also strained, because, for instance, Darwin differed with the captain's biblical literalism and support of slavery.

NH: Could you point to some examples of these letters?

KEYNES: Here's a bit of an August 1833 letter FitzRoy wrote when Darwin, who suffered greatly from seasickness, was ashore exploring in Argentina. It was addressed to "My dear Philos"—Darwin was known to his shipmates as "Philosopher":

I do assure you that whenever the ship pitches (which is *very* often as you *well* know), I am extremely vexed to think how much *sea practice* you are losing; and how unhappy you must feel upon the firm ground.

He also adds this postscript: "I do not rejoice at your extraordinary and outrageous peregrinations because I am envious—jealous,—and extremely full of all uncharitableness."

Here's part of another letter, written in October 1833:

My good Philos why have you told me nothing of your hairbreadth escapes & moving accidents? How many times did you flee from the Indians? How many precipices did you fall over? How many bogs did you fall into? How often were you carried away by floods? and how many times were you kilt?

The captain also enthuses about Conrad Martens, the artist who was just then joining the expedition. More of Martens's previously unpublished drawings appear in my book, showing us vividly what Darwin saw during the voyage. FitzRoy describes him as "a stone pounding artist—who exclaims in his sleep 'think of me standing upon a pinnacle of the Andes, or sketching a Fuegian Glacier!!'" FitzRoy goes on to say, "He is very industrious—and gentlemanlike in his *habits*,—(not a *small* recommendation)." Clearly, one can see now that despite differences in



Richard Darwin Keynes

their temperaments and ranks aboard ship, the two young men—both in their twenties—enjoyed a very warm friendship, full of playful humor.

NH: After working on all these books based on Darwin's manuscripts, do you feel a special intimacy with him?

KEYNES: When you transcribe several hundred thousand words written in your great-grandfather's hand about places—many of which you visited 160 years later, and where not much has changed—sometimes you can feel you're almost talking to him. He must have been the nicest person that ever lived. He had a true genius for friendship; he really was quite outstanding in that respect. He never said anything nasty about anyone—quite unlike his great-grandson!

RICHARD MILNER is a contributing editor of this magazine. His new book, *Darwin's Universe*, will be published this year by the University of California Press.

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At the Museum

AMERICAN MUSEUM OF NATURAL HISTORY 

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Paleontology at the American Museum of Natural History

Home to the world's largest collection of vertebrate fossils, the American Museum of Natural History has a long and distinguished history of paleontological research around the globe. Museum scientists in the Division of Paleontology study the history of life on Earth through the discovery, analysis, and comparison of fossil remains. The Museum's history includes some of the greatest names in paleontology and some of science's most important and groundbreaking field expeditions, including Roy Chapman Andrews's seminal Central Asiatic Expeditions (1921–1930), and Barnum Brown's India-Burma Expedition (1922–1923).

The first curator of the Department of Invertebrates was hired in 1877. Under Henry Fairfield Osborn, founder of the Department of Vertebrate Paleontology in 1892 (and later Museum President), the Department's collection became the largest repository of fossils in the world. The research of Osborn's successors, George Gaylord Simpson, Edwin H. Colbert, and Bobb Schaeffer, established the Museum's central role in the study of paleozoogeography, the "Evolutionary Synthesis" theory, and functional morphology.

Currently, Mark A. Norell, an expert on "feathered" dinosaurs as well as coelurosaurs, is Curator and Chairman of the Division of Paleontology. Among other projects, Dr. Norell is working with Joel Cracraft, Curator in the Division of Vertebrate Zoology, on a project illustrating the family relationships among all archosaurs, a group that includes modern birds and their dinosaurian relatives.

Along with Michael J. Novacek, Senior Vice President, Provost, and Curator, Dr. Norell has co-led 15 joint expeditions since 1990 to the Gobi Desert of Mongolia with the Mongolian Academy of Sciences. These expeditions have yielded spectacular discoveries: the Gobi has preserved a broad spectrum of creatures, from towering dinosaurs to tiny mammals, all in exquisite detail.

In the past decade, Dr. Norell has also been making annual visits to China to confer with paleontology colleagues at Beijing University, the Chinese Academy of Geological

Sciences, and the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing. These visits enhance the productive exchange of research that has developed between these Chinese institutions and the Museum and allow the study of the newest fossils collected from rich fossil beds in China.

Dr. Novacek has also conducted extensive research on the evolutionary relationships of extinct and living mammals, drawing upon evidence from the fossil record and molecular biology. In 1993, he was one of the discoverers of Ukhaa Tolgod, the richest Cretaceous fossil site known in the world.



Roy Chapman Andrews (top). The skull of *Dilong paradoxus*, a newly identified feathered tyrannosaur (bottom left). Paleontology storage (bottom right).

Other Division curators include Niles Eldredge, an evolutionary theorist whose curatorial colleagues in the Division include Eugene S. Gaffney, an expert on the evolution of turtles; John J. Flynn, who studies the evolution of mammals; Neil H. Landman, an expert on ammonoids (now extinct) and nautiloids (persisting today as the genus *Nautilus*); John G. Maisey, who studies extremely rare shark fossils; and Jin Meng, who studies the evolutionary relationships among early mammals.

COLLECTIONS

The American Museum of Natural History's paleontology collection contains an estimated five million fossil specimens collected over 125 years. Archival materials also contribute to the value of the collection, which is visited by more than 100 scientists each year. With support from NASA, Division staffers have been developing a digital database of the Museum's paleontology collection to enhance access and study.

The Museum's vertebrate paleontology collection is the largest and most diverse of its kind, including more than one million specimens and filling 13 rooms. Due to space and fragility concerns, few of these holdings can be displayed in ex-

hibits. To ensure the preservation of these irreplaceable prehistoric specimens, in November 1999, the Division moved its dinosaur collection and its invertebrate type collection into the C. V. Starr Natural Science Building, a new eight-story facility with state-of-the-art climate-controlled storage.

With the acquisition of James Hall's massive collection of Paleozoic fossils in 1873, the Museum's invertebrate paleontology collection was launched. It now exceeds four million specimens. These collections include a large number of North American ammonite (prehistoric marine animals) fossils that are extremely informative about the history of life, the age of rocks in which they are found, and the location of prehistoric seas.

The Division houses two preparation laboratories—one for vertebrates and one for invertebrates—each equipped for mechanical, micro, acid, and mechanized preparation techniques.

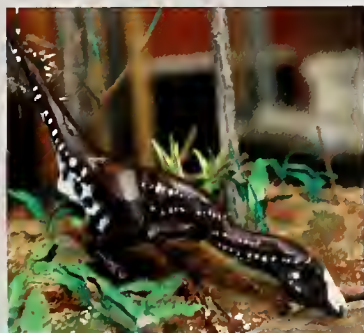
The combination of the Museum's superlative fossil collection, outstanding facilities, highly skilled support staff, and world-class curatorial cadre all reflect the Division of Paleontology's illustrious past while also promising a bounty of new discoveries and fascinating insights for years to come about the history of Earth's living creatures.

DINOSAURS:

Ancient Fossils, New Discoveries

OPENS MAY 14, 2005
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Stroll back in time through a 700-square-foot re-creation of a Mesozoic forest and come face to face with the creatures that lived there 130 million years ago. This groundbreaking exhibition reveals, through fossil specimens, casts, and models, how current thinking about dinosaur biology has changed dramatically over the past two decades. *Dinosaurs* presents the most up-to-date look at how



A model prepared for *Dinosaurs*

scientists are reinterpreting many of the most persistent and puzzling mysteries of the dinosaurs—what they looked like, how they behaved, how they moved, and ultimately, why they became extinct.

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

This exhibition is organized by the American Museum of Natural History, New York, in collaboration with the Houston Museum of Natural Science; California Academy of Sciences, San Francisco; The Field Museum, Chicago; and North Carolina Museum of Natural Sciences, Raleigh.

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

PEOPLE AT THE AMNH

Jin Meng, Associate Curator, Division of Paleontology

The bones of tiny prehistoric rodents and rabbits are the usual fare for Jin Meng, who studies the evolution of early mammals. But in the past year, he had the good fortune to study the nearly complete fossil of a relatively large Mesozoic mammal. The fossil came with a rare bonus—the bones of a psittacosaur were preserved in the mammal's stomach area, representing its last meal.


The fossil find represented a number of "firsts" in paleontology—the first known Mesozoic mammal the size of an opossum, the first direct evidence that early mammals ate meat, and the first evidence that mammals could take on dinosaurs. "This new evidence of larger size and predatory, carnivorous behavior in early mammals is giving us a drastically new picture of many of the animals that lived in the age of dinosaurs," Dr. Meng said.

Dr. Meng often examines the ears, skulls, and tooth enamel of fossils, but in this case, the quickest way to the paleontological answer was through the fossil's stomach.



Jin Meng (left) and graduate student Hu Yaoming (right) unveiling the recently described fossil of a 130-million-year-old mammal, *Repenomamus robustus*, with a small psittacosaur preserved in its stomach area, the first direct evidence that some primitive mammals fed on small vertebrates, including young dinosaurs.

Museum Events

AMERICAN MUSEUM OF NATURAL HISTORY 

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EXHIBITIONS

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

This groundbreaking exhibition celebrates the beauty, power, and symbolism of the magnificent tradition of Native American arts, examining techniques, materials, and styles that have evolved over the past century as Native American jewelers have transformed their traditional craft into vital forms of cultural and artistic expression.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter

Through May 30, 2005
A return engagement of this popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed habitat that approximates their natural environment.

Exploring Bolivia's Biodiversity
Through August 8, 2005

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

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

Sunscapes

Opens April 2, 2005
Special optical systems and detectors capture fiery images of the Sun's atmosphere. This exhibition



In the Butterfly Conservatory

displays the most dramatic of these images.

Vital Variety: A Visual Celebration of Invertebrate Biodiversity
Ongoing

Invertebrates, which play a critical role in the survival of humankind, are the subject of these extraordinarily beautiful close-up photographs.

LECTURES

Liquid Land: A Journey through the Florida Everglades
Tuesday, 4/5, 7:00 p.m.

Ted Levin assesses a planned restoration project for the at-risk Florida Everglades.

Adventures in the Global Kitchen: Exquisite Mushrooms
Tuesday, 4/12, 7:00 p.m.

Mushroom lover Gary Lincoff and chef Amy Farges transform the way you view the not-always-lowly fungus.

Carnivorous Nights: On the Trail of the Tasmanian Tiger
Thursday, 4/14, 7:00 p.m.
Naturalists Margaret Mittel-

bach and Michael Crewdson and artist Alexis Rockman go in search of the now-extinct Tasmanian tiger.

Descent: The Heroic Discovery of the Abyss
Thursday, 4/21, 7:00–8:30 p.m.
Author Brad Matsen recounts the 1930s ocean explorations of Otis Barton and William Beebe.

From Autonomous Villages to the State
Friday, 4/22, 7:00 p.m.
Robert L. Carneiro, Curator, Division of Anthropology, reconstructs humankind's gradual movement from small self-governing groups to larger political units.

Cosponsored by the Institute of General Semantics.

Katy Payne: The Elephant Listening Project
Thursday, 4/28, 7:00 p.m.
Katy Payne observes forest elephants in the Central African Republic.

FAMILY AND CHILDREN'S PROGRAMS

Dr. Nebula's Laboratory: Wind and Water

Sunday, 4/17, 2:00–3:00 p.m.
Science theater for the whole family: Dr. Nebula's curious lab assistant, Scooter, dodges tornadoes and other forces of nature.

Space Explorers: The Moon and Its Phases

Tuesday, 4/12, 4:30–5:45 p.m.
(Ages 8 and up)

On the second Tuesday of each month, kids (and their parents) can learn under the stars of the Hayden Planetarium.

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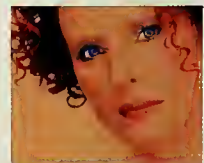
Start a Rock Collection

Saturday, 4/23, 11:00 a.m.–12:30 p.m. (Ages 5–7, each child with one adult)
Hunt for rocks in Central Park and learn how to identify them.

STARRY NIGHTS Live Jazz

ROSE CENTER
FOR EARTH AND SPACE
Friday, April 1
6:00 and 7:30 p.m.

Lynn Arriale Trio



The 7:30 performance will be broadcast live on WBCO Jazz 88.3 FM.

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsor Constellation NewEnergy.



T. COFFMAN/AMNH

HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

Virtual Universe

Redder Than Red:

The Infrared Sky

Tuesday, 4/5, 6:30–7:30 p.m.

This Just In...

April's Hot Topics

Tuesday, 4/19, 6:30–7:30 p.m.

Celestial Highlights

Carnivore's Corner

Tuesday, 4/26, 6:30–7:30 p.m.

LECTURES

A Different Universe

Monday, 4/11, 7:30 p.m.

With Nobel laureate Robert

Laughlin, Stanford University.

COURSES

*Stars, Constellations,
and Legends*

Four Wednesdays, 4/6–4/27
6:30–8:00 p.m.

Introduction to Astronomy:

Galaxies and Cosmology

Six Mondays, 4/4–5/9
6:30–8:30 p.m.

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m.,
or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

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NEW!

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Monday–Friday, 4/25–4/29
9:00 a.m.–4:00 p.m.

Oceans to Ocean Life

(For 2nd and 3rd graders)

Destination Space:

Astrophysics

(For 4th and 5th graders)

Robotics

(For 6th and 7th graders)

CENTER FOR BIODIVERSITY AND CONSERVATION'S TENTH ANNUAL SPRING SYMPOSIUM

*New Currents in Conserving
Freshwater Systems*

Thursday and Friday, 4/7 and
4/8, 8:30 a.m.–6:00 p.m.

Visit <http://cbc.amnh.org>
for details.

Scientific Revolution

Five Wednesdays, 4/6–5/4
6:30–8:30 p.m.

PLANETARIUM SHOWS

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8:30, and 9:30 p.m.

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Learning the Language of “Bear”

By David Petersen

Like no other tree I know, the quaking aspen (*Populus tremuloides*) is a storyteller—a sylvan logbook of recent local life. Recorded in its bark are tales of encounters with deer and elk, porcupine and black bear. Tonight the markings on a split of aspen I’m easing into the wood stove have caught my attention. They are claw scars, telling with simple eloquence of a bruin’s brief embrace as it descended, slipped, slid, tightened its grip, and arrested its own fall. I have seen the makings of such marks several lucky times. The most recent was on a perfect evening, late last year. . . .

I’m approaching the lip of a ledge above a small secluded spring, when I hear loud splashing below. Dropping to hands and knees, I creep toward the lip, but before I get there the splashing stops. In its place are thudding, rock-rolling sounds of something big on the move, coming toward me. Adrenaline whines through my veins. I crouch and wait. Soon enough, a patch of beige appears behind a bush. I think, “That’s a mighty short elk.”

A moment more and the low-rider elk morphs into a bear. I note a milk-chocolate torso, dark lower legs and face, a broad flaxen saddle across the shoulders and back, long wavy hair: this bear is fall-fat and gorgeous, a monstrous old boar of a black bear, I think. But now two tiny cubs come bouncing up the hill to the big “boar’s” flanks. Incredible, but there is no room for doubt: this mountain of a bear is a girl.

No sweat. Truly wild black bears, including sows with cubs, are rarely a threat to human adults, so timid is the species. Besides, even as close as she is, I’m downwind, dressed to blend in, motionless, and kneeling. No sweat.

But I don’t have time to finish these optimistic thoughts before the bear alters course ninety degrees to starboard and—coincidentally, still oblivious to my hunkering, trembling presence—starts straight for me. The two cubs, their fur wet and matted from their recent romp in the pool, follow their mother close at heel. With no time to indulge the luxury of inaction, I do a quick draw for the pepper-spray canister riding ready in a holster on the right side of my day pack.

My sudden flash of movement wins the big bear’s instant attention, and she stops cold just ten feet away. Rather than instinctively charging, as a grizzly sow would, my adversary stands and glares at me through eyes far too small for her washtub of a head. At the same instant, and with neither grunt nor glance from mom, the cubs rocket up separate aspen trees to bawl and thrash about in histrionic terror, like giant freaked-out squirrels.

I study the sow’s eyes and face. We are so close now that I think I can smell the chlorophyll on her breath. Glancing at hackle hairs, posture, head position, I search for clues in her body language to mood and intent. But I find her, like all females, essentially inscrutable.

Enough. Squatting here trading stares with a really big bear is foolish. “Bigger” is more threatening to predators, hence safer. Without further ado, I stand up smoothly and in the same motion take a first step: not directly away from her, which might trigger her chase instincts, and not directly toward her, which could prompt a defensive attack. Instead, I move obliquely away, my bear spray aimed point-blank at her nose.

My confident movements have the desired effect. The sow blows a tremendous whoof, swaps ends to show her fat, furred fanny, and bulldozes back down the hill she just came up, roaring and huffing ferociously, albeit in faceless retreat.

Unceremoniously abandoned, the cubs de-tree at terminal velocity—each autographing its aspen with a series of elongated, slip-sliding claw marks as it drops. They hit the ground running, and bleat like terrified lambs as they chase after their moaning mom.

As the stove now warms my cabin, I can still hear the fading sounds of the three fleeing bears, and I give thanks for such moments of wild abandon. Thus does the burning aspen log, with its intriguing scars, speak to me in the feral language of the forest.

This essay was adapted from David Petersen’s forthcoming book On the Wild Edge: In Search of a Natural Life, which is being published by Henry Holt and Company in April.



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