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Pines: White Pine Group

Eastern White Pine

Pinus strobus

WEYMOUTH PINE, PUMPKIN PINE

Evergreen. Tall, often over 100' (max. 220'); or a low-creeping shrub at timberline. The only native white pine in its range. Easily identified by large size, irregular crown, long horizontal branches, slender needles in bundles of 5, and slender, stalked cones that lack prickles. One of the most important lumber trees in the East.

Common and widespread in rich, well-drained soils. Many cultivars, including dwarf and weeping forms, and very commonly cultivated (zones 3–7); often planted in public parks.

Cultivated Eastern White Pines can be distinguished from Western Whites by smaller cones that are never purple, and by more slender and flexible needles that appear greener. When viewed at very close range, needles of Eastern White show at least one side without white lines; needles of Western White have white lines on all sides.) Other exotic white pines should also be considered when identifying cultivated trees (see page 46).

Western White

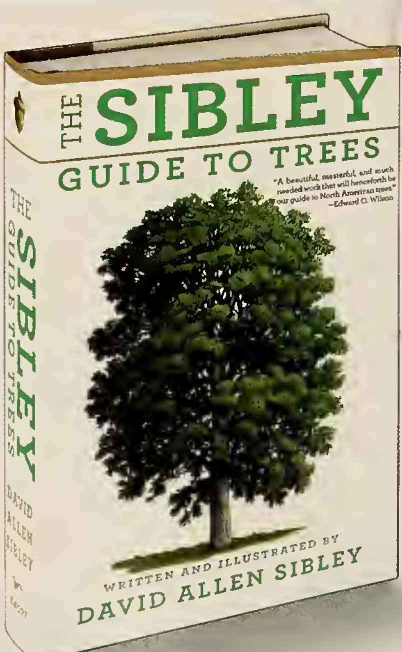
Pinus monticola

MOUNTAIN WHITE PINE, SIL

Evergreen. Tall, often to 1(Closely related and very si White Pine, but no natural Distinguished from other p by tall, narrow form, dense needles, and slender, hangi mercially important species, most wooden matchsticks.

Locally common in forests from sea le to 10,000'. Rarely cultivated.

Photo © Erinn Hartman



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NATURAL HISTORY

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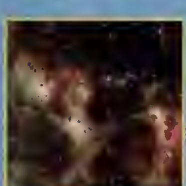
SEPTEMBER 2009 VOLUME 118 NUMBER 7

FEATURES

DEPARTMENTS



ON THE COVER: *Fossil ammonite* Placenticeras sp.
Image by John Cancalosi

➤ *See preceding two pages*

THE NATURAL EXPLANATION BY ERIN ESPELIE

Jewel scarab, above; left: longhorn beetle

At noon the day entomologist Piotr Naskrecki hiked into Arizona's Madera Canyon, the mercury was pushing 120 degrees Fahrenheit in Tucson, about forty miles away. "It was too hot for the grasshoppers and katydids, but not for the beetles," Naskrecki says. Along his path a cactus longhorn beetle munched on a prickly pear, while a jewel scarab gripped a yucca plant [*see photographs above*]. The base of the canyon offered cooler temperatures as well as a species that Naskrecki had been expecting to see: the western red-bellied tiger beetle (*Cicindela sedecimpunctata*).

Half a dozen of those tiger beetles raced and flitted around the cracked bed of a drying stream, feasting on flies and small butterflies drawn to drink. Tiger beetles—of which there are about 2,300 species—boast speeds of as much as 1.2 miles an hour on foot. For creatures measuring about one-third of an inch long, that equates to roughly ten times the speed of the fastest human sprinter. And they can also go airborne at an instant's notice. So Naskrecki's only hope of photographing the dynamos came from a pair slowed to a vulnerable standstill by mating.

For a male, the risk of being picked off by a predator pales in comparison with assured paternity. A female has little choice—particularly once a male pinions her with his mandibles and inserts his hooked genitalia. "For more than thirty minutes," Naskrecki recalls, "I watched as other males tried to approach the couple, but every time that would happen the mating male steered the female away"—never once letting go.

Stand up too quickly in the outdoor sauna of an Arizona summer and you might see spots in a momentary fragmentation of vision. A different, but equally blinding effect can hit tiger beetles on the move. Generally their vision is superb, but when in rapid pursuit of prey, they don't receive enough photons reflected off the intended victim to form a good image. By periodically pausing mid-chase, however, they can regain their target, and so rarely miss a meal.

In addition to being superlative speedsters, tiger beetles can squeak by without much oxygen. A recent study shows that adults of some species can survive between ten and forty-six hours submerged in low-oxygen water, and their larvae even longer. So when Madera Canyon floods next, no need to worry about these fleet beetles, though our mating couple might need to come up for air.

Piotr Naskrecki received his PhD in entomology in 2000 at the University of Connecticut, where he studied the evolution of acoustic behavior in insects as well as speciation in mites. Now an associate at the Museum of Comparative Zoology at Harvard University, Naskrecki has identified more than 150 species of insects and arachnids new to science, and is considered a world expert on katydid systematics. Visit www.insectphotography.com to see more of his images.

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

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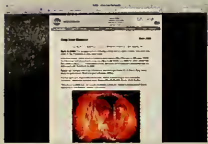
OUR QUIET STAR



ON A VISIT TO THE newly renovated and expanded Griffith Observatory in Los Angeles I heard Jay M. Pasachoff, an astronomer from Williams College in Massachusetts, tell about his plans to travel to China to observe the total solar eclipse of July 22. Having witnessed twenty-eight total eclipses before that one, he had already seen more than anyone else. But what really got my attention was his remark that lately the Sun has been unusually devoid of sunspots. Those relatively cool blemishes on the Sun's surface normally wax and wane in an eleven-year cycle, but this is the deepest "solar minimum" since 1913, according to NASA (science.nasa.gov/headlines/y2009/01apr_deepsolarminimum.htm). For my guide to Web sites exploring the mysteries of sunspots, please visit the magazine online (www.naturalhistorymag.com).

ROBERT ANDERSON is a freelance science writer who lives in Los Angeles.

WORD EXCHANGE

Kudos

Marina Cord's article "Face-Offs of the Female Kind" [9/08] was chosen for the forthcoming book *The Best American Science Writing 2009,* edited by Natalie Angier and published by Ecco/HarperCollins. And the Solar Physics Division of the American Astronomical Society selected "Skylog" columnist Joe Rao's feature story "Shades of Glory" [10/08] for a journalism award.

Vittorio Maestro
Editor in Chief

More than a Blink

In "The Day We Found the Universe" [6/09], Marcia Bartusiak says that astronomers can calculate the distance to Cepheids—special stars that regularly dim and brighten—"by measuring the time between blinks." But doesn't that also require measuring their apparent luminosity?

Daniel Lipp
Fort Collins, Colorado

THE EDITORS REPLY: Indeed, our wording glossed over what, in itself, is a complex story. Marcia Bartusiak addresses the subject in this month's issue [*see page 16*].

©NHPA/PHOTOSHOT

Brazilian porcupine

Hanging on a Tail

An illustration accompanying "Splendid Isolation," by John J. Flynn [6/09], shows a South American porcupine and a platyrrhine primate, both curling their prehensile tails over a branch. In the monkey, the tail's friction pad is underneath, and the tail is correctly depicted extending from the animal and over the branch, then curling down. In porcupines, however, the friction pad is on the top, and the tail should pass under and then curl up around the branch. Don't make a monkey out of a porcupine!

Uldis Roze
Queens College, CUNY
Queens, New York

THE EDITORS REPLY: "Who knew?" Porcupine expert Uldis Roze, author of "Smart Weapons" [3/06], did.

Erratum

The credit for the illustrations accompanying the time line of South American mammals [6/09, page 29] should have read Pedro Fernandes.

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A Mother's Burden

For female freshwater mussels, reproduction is a stressful affair. Now zoologists have discovered an extra burden on pregnant Texas hornshell mussels, *Popenaias popeii:* an unexpected assailant that eats them away from within.

A mussel mom's stresses start when her fertilized eggs enter tubes within her gills and develop into *glochidia*, or larvae. The glochidia reduce water flow, limiting her oxygen and food supplies. Eventually, they enter a parasitic phase, and must relocate to a fish host. So the female often casts her glochidia, embedded in a web of mucus, into the water, hoping that a fish will swim through and pick some up.

DAN WILLIAMS, NMDGF

Dragonfly nymph, top, likely caused gill damage (arrows) to this Texas hornshell mussel. (Both appear life-size.)

Throughout her pregnancy, the mussel is vulnerable to parasitic mites or crustaceans and predatory vertebrates. But during a mussel census in New Mexico, Todd D. Levine, his graduate adviser at the time, David J. Berg of Miami University in Hamilton, Ohio, and a colleague spotted an aggressor unlike any of the others. A nymph of the dragonfly *Gomphus militaris* was devouring the gills and glochidia of a gravid Texas hornshell. The team went on to find many similarly damaged gravid (but few non-gravid) mussels.

It's unknown how much the insect, in its dual role as parasite (of female mussels) and predator (of glochidia), affects the Texas hornshells' survival. But considering that only two populations of the mussels are known, the researchers are hurrying to find out. (*American Midland Naturalist*)

—*Graciela Flores*

Shrew Loo

In the mountains of Borneo, the pitcher plant *Nepenthes lowii* sports traps shaped like broad toilet bowls with lids agape. Now, in a tidy twist, new research shows that the pitchers' form fits their function. Tree shrews defecate in them, and the plant assimilates the feces' nitrogen.

Living on impoverished soils, pitcher plants normally obtain their nitrogen from insects that slip and drown in their water-filled traps. Indeed, that's how juvenile *N. lowii* plants make a living, keeping their pitchers low to the ground to capture ants. But ants are too rare in the Bornean mountains to sustain big adult plants. So the adults dangle reinforced, nonslippery pitchers from their leafy vines instead. The lids exude a sweet secretion highly attractive to tree shrews, which have few other nectar sources. While licking the stuff astride the pitchers, the tree shrews often leave a calling card.

Teaming up with four colleagues, Charles M. Clarke of Monash University in Malaysia and Jonathan A. Moran of Royal Roads University in Victoria, Canada, video-recorded the tree shrews in flagrante delicto. Using isotopic analysis, the scientists confirmed that between 57 and 100 percent of the plant's nitrogen originated as tree-shrew poo.

©CH'IEN C. LEE

Tree shrew pauses mid-meal to use the facilities.

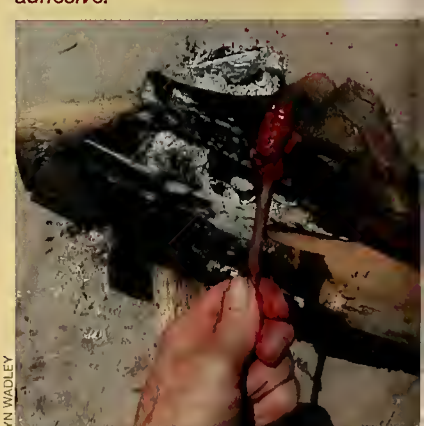
The tree shrew–plant pair makes a great example of mutualism, two partners exchanging necessities. (In fact, the plant only grows where tree shrews live.) As every gardener knows, plants thrive on manure, but this may be the only one that trades for it. (*Biology Letters*) —*Stéphan Reebs*

Stone Age Multitasking

Modern parents, teenagers, and executives are all masters of multitasking, but people who lived 70,000 years ago may have shared that talent. Stone blades found in Sibudu Cave, near South Africa's Indian Ocean coast, bear traces of compound adhesives that once joined them to wooden hafts to make spears or arrows. Our distant ancestors discovered that mixtures of plant gum and red ocher or fat, heated carefully over a fire, made the superglue of their day, say Lyn Wadley and two colleagues at the University of the Witwatersrand in Johannesburg. So how is that evidence of multitasking?

By systematically replicating the ancient glues, using only Stone Age techniques and ingredients, the researchers discovered that ocher improves the bonding capacity of such natural adhesives as acacia gum. They also learned that those ingredients are highly variable in chemical composition and thus in key characteristics, such as viscosity, that affect the strength of the bond. To make an effective glue, says Wadley, ancient artisans would have had to adjust their recipes in real time to compensate for unpredictable ingredients, staying mindful of their goal while shifting their focus back and forth among the various steps in the process.

Researcher heats experimental adhesive.



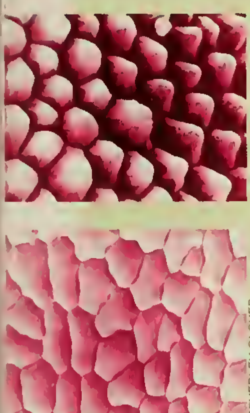
LYN WADLEY

Just when such modern cognitive abilities arose has been hard to pin down, but Wadley argues that glue making is the earliest evidence that sticks. (*PNAS*) —*Harvey Leifert*

Landing Pad for Pollinators

The petals of most flowers are covered with cells in the unusual shape of cones, the pointy ends jutting up. But why? Researchers in England have shown that those cells let insects get a grip on unsteady flowers while gathering nectar and pollen.

Heather M. Whitney, at the time a researcher in Beverley J. Glover's lab at the University of Cambridge, and two colleagues took advantage of a mutant line of snapdragons that have flowers paved with flat, rather than conical, cells. The team first found that bees could learn to distinguish mutant flowers from normal ones by texture alone. Then they enticed the bees with a sugary reward to visit epoxy casts of smooth and rough flower surfaces. When the casts' surfaces were horizontal, the bees visited the two equally, but when they were nearly vertical, the bees much preferred the rough one. High-speed video showed bees flailing for a grip, wings beating, as they slipped down the smooth surface, but alighting easily on the rough one.



BEVERLEY GLOVER

Conical cells of normal snapdragon petals, top, and flat cells of mutants, bottom, shown magnified in false color.

The scientists point out that even some flowers pollinated by hovering animals—moths, hummingbirds, and the like—have conical surface cells. Indeed, in addition to providing traction, the cells contribute to the richness of a petal's color: the mutant snapdragons were first noticed because of the washed-out pink of their flowers, a result of their unusually flat petals' reflecting more light than normal. (*Current Biology*) —*S.R.*

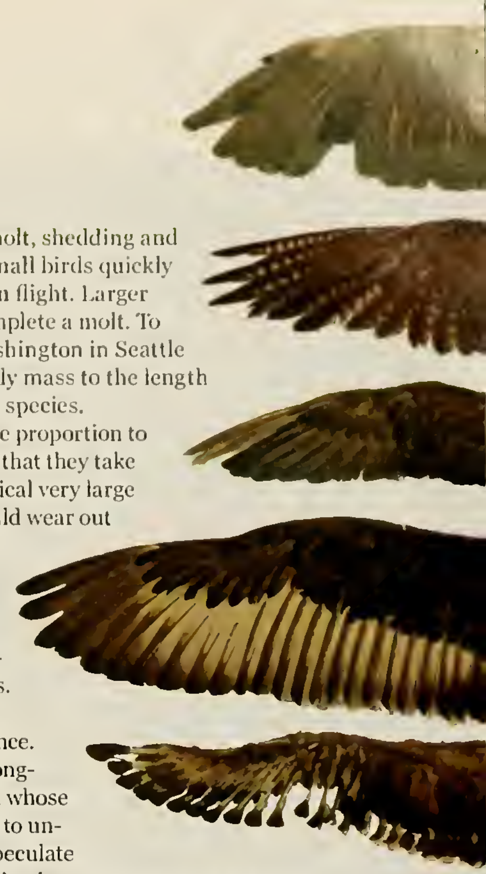
Avian Moltitasking

To avoid getting grounded, birds must periodically molt, shedding and regrowing worn-out feathers. Once or twice a year small birds quickly replace all their wing quills—the long feathers used in flight. Larger birds, however, can take as long as three years to complete a molt. To find out why, Sievert Rohwer of the University of Washington in Seattle and three colleagues analyzed the relationship of body mass to the length and the growth rate of wing quills in forty-three bird species.

Large birds' wing quills are longer, in much the same proportion to body size as those of smaller birds. Yet the team found that they take disproportionately long to grow. Therefore, a hypothetical very large bird would take so long to molt that its wing quills would wear out before they could fully grow in. Thus molting may put an unforeseen limit on bird size, the researchers say.

Apparently to compensate for their slow-growing wing quills, some big birds—especially those that must fly to find food or escape predators—shed and replace a few at a time, in a pattern that avoids large gaps. Those that can do without flying for a stretch, such as swans and geese, tend to molt their wing quills all at once.

The authors think that *Argentavis magnificens*, a long-extinct raptor that weighed a massive 150 pounds, and whose longest wing quills measured five feet, might have had to undergo an extreme version of the latter strategy. They speculate that every few years, it spent about two months sheltering in Argentine cliffs, consuming its fat reserves while molting. (*PLoS Biology*) —*G.F.*



Wings of several bird species show different molting patterns.

SIEVERT ROHWER

Mass Movements

Imagine flipping a Frisbee in Quebec, Canada, and seeing it land in Zimbabwe. That's a distance of 8,000 miles now, but 2.6 billion years ago, with good wrist action, it would have been no feat at all (if only there had been Frisbees and, of course, people). Present-day Quebec and Zimbabwe were adjacent way back then, say geologists who are using new techniques to map Earth's early continents.

Some 300 million years ago, the supercontinent Pangea included much of the landmass of today's continents, all crammed together. Prior to that, continental masses joined and separated several times, but scientists haven't been able to reconstruct those earlier arrangements with much precision.

Richard E. Ernst of the University of Ottawa, Michael A. Hamilton of the University of Toronto, and several colleagues intend to remedy that. They've developed new ways to collect and to precisely date rare microscopic minerals found in ancient basalt veins. If the minerals and dates from several veins on one ancient landmass match those on another, there's a good chance the landmasses were contiguous when the basalt formed.

Within five years and for just $1 million, the team hopes to provide a series of snapshots showing the continents' positions over the past 2.6 billion years. (*American Geophysical Union Joint Assembly. May 2009*) —*H.L.*

Ancient basalt vein, Greenland

MICHAEL A. HAMILTON

JOE SHARKEY

Wrong as Rain

Raindrops just broke their own speed record: they can drop faster than anyone thought possible.

Larger drops are speedier than smaller ones because they are heavier and so can more easily overcome air resistance. But there's a limit to how fast a drop can go, a "terminal velocity" achieved when the downward force of gravity equals the upward drag of the air. Thus, whenever smaller drops are detected apparently beating larger ones in the race to the ground, atmospheric scientists interpret the observations as errors by recording instruments.

But Guillermo Montero-Martínez and Fernando García-García of the National Autonomous University of Mexico in Mexico City and colleagues audaciously propose that the scientists, and not the instruments, have been wrong. After measuring the speed and size of 65,000 raindrops, they concluded that half of all drops break their supposed speed limit.

The explanation: when a large drop falling at full speed breaks up—either because it becomes unstable or collides with another drop—the resulting droplets continue at the same speed, too fast for their diminutive size. After a few milliseconds, air resistance slows each drop to its own expected terminal velocity.

The transgression, however short-lived, is noteworthy. By interpreting small, fast drops as larger ones, meteorologists relying on specialized rain gauges or Doppler radar over the years might have been overestimating the amount of rainfall by as much as 20 percent. (*Geophysical Research Letters*) —*G.F.*

Trilobite Togetherness

Seeking safety in numbers is an age-old maneuver—at least 465 million years old, it turns out. Ordovician-period fossils discovered in Portugal show groups of trilobites hiding out or molting together—rare clues to the ancient marine arthropods' social and survival behaviors.

The fossils come from a roofing-slate quarry near the town of Oporto. Small trilobites often appear together in single files that zigzag or wave their way across the rock. It's as if predator-wary trilobites sought shelter in long, narrow tunnels, say Juan C. Gutiérrez-Marco of the Institute of Economic Geology in Madrid and his colleagues, who analyzed the fossils.

Other clusters are made up of hundreds of *exuviae*, the exoskeletons discarded by molting trilobites. The exuviae point every which way, a clue that a trilobite assembly, and not a water current, deposited them. Mass molting—followed by mass mating—is something trilobites' relatives the horseshoe crabs still do today. The new find joins other fossil groupings that indicate trilobites probably followed the same molt-mate pattern—mass actions being a good way for any one tender-shelled animal to protect itself and its spawn from being eaten.

Trilobites were fossilized while congregating in line.

MANUEL VALERIO/AROUCA GEOPARK

Gutiérrez-Marco's team also reports the presence of giant specimens in the Portuguese trove, including an incomplete one that they estimate was three feet long in life. If so, it would be the largest trilobite ever found. Bigness may have been an adaptation to cold water: back then, Portugal lay near the South Pole. (*Geology*) —*S.R.*

THE WARMING EARTH

Rising Stars

Climate change will deal clams, mussels, and other marine bivalves a double whammy. Biologists already expect them to have trouble making their shells because elevated carbon dioxide (CO_2) levels will acidify seawater. Now it seems they'll also have to contend with brawnier predatory starfish.

Bivalves are the preferred prey of the purple ocher sea star (*Pisaster ochraceus*), a familiar denizen of the intertidal zone along the Canadian and American west coast. Curious to see if the predator would suffer as much from global warming as its prey, Rebecca A. Gooding, her graduate advisor Christopher D.G. Harley of the University of British Columbia in Vancouver, and a colleague took purple ochers to the lab and measured their growth under elevated temperature and CO_2 levels that are likely to occur by the end of the century. Surprisingly, the animals actually grew faster than they did under normal conditions.

In sea stars, calcium forms small nodules embedded in soft tissue—not a full shell, as bivalves secrete. Gooding found that the nodules did shrink in water that was acidified (still basic, but lowered in pH). However, the surrounding soft tissues actually grew more, though the physiology of the response remains unclear. Evidently not all animals will suffer equally as the planet warms. There will be losers and there will be winners—just don't bet on the bivalves. (*PNAS*) —*S.R.*

Purple ocher sea stars prey on mussels

DAVE COWLES

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Finding a Cosmic Yardstick

By Marcia Bartusiak

Henrietta Swan Leavitt's painstaking observations inspired a new way to determine the distances to far-off celestial objects.

Henrietta Swan Leavitt, at work for the Harvard College Observatory, Cambridge, Massachusetts

AIP EMILIO SEGRE VISUAL ARCHIVES

First-time travelers to the Southern Hemisphere might mistake the deep-space nebular clouds visible there for high cirrus formations, somehow made luminous in the dark of night. Yet the Large and Small Magellanic Clouds are each a chaotic collection of stars, richly diffused with glowing gas. Such novel and fascinating sights were a compelling reason for early European and American astronomers to set up observatories in the Southern Hemisphere.

In the early 1890s, the Harvard College Observatory established a southern station in the highlands of Peru. For more than a decade, Harvard had been cataloging every star in the northern sky and accurately gauging its color and brightness. With a sizable endowment for a program in spectroscopy, observatory director Edward C. Pickering resolved to further classify the brightest stars by their chemical spectra. The Peruvian observatory allowed Harvard to extend all those endeavors to the southern sky. Pickering was helping astronomy move beyond just tracking the motions of stars across the sky to figuring out their basic properties.

With a huge number of glass photographic plates of the northern and southern skies stacking up, Pickering shrewdly recognized the value of smart young women yearning to contribute in an era that generally denied them full access to scientific institutions. These woman "computers," as they were called, some with college degrees in science, could be hired for less than half the pay of a man. Stationed at the observatory's headquarters in Cambridge, Massachusetts, they peered at plates all day through magnifying glasses, swiftly and accurately numbering each star, determining its exact position, and assigning it either a spectral class or a photographic magnitude.

One of Pickering's most brilliant hires was Henrietta Swan Leavitt, who began work as a volunteer soon after graduating, in 1892, from what later became Radcliffe College. She proved herself an expert in stellar photometry, gauging the magnitude of a star by assessing the size of the spot it imprinted upon a photographic plate. As she worked, she was also instructed to keep an eye out for variable stars, those that regularly increase and decrease in brightness.

Leavitt left Harvard in 1896, first traveling through Europe for two years and then moving to Wisconsin to be with her father. In 1902, she returned to Harvard as a paid employee. Two years later, variable stars came back into her life in full force. Looking through a magnifying eyepiece at two plates of the Small Magellanic Cloud, taken at different times, she noticed that several stars had changed in brightness, as if they were undergoing a slow-motion twinkle. Over the following year, she looked at additional images of the cloud and found dozens more variable stars. Soon she included old plates, going back to 1893, in her tally, and then the Large Magellanic Cloud. By 1907 she had found a record-setting total of 1,777 new variable stars within the prominent, mistlike clouds.

Leavitt dutifully reported her findings in the 1908 *Annals of the Astronomical Observatory of Harvard College,* paying particular attention to a special group of sixteen variable stars in the Small Magellanic Cloud. They were later identified as Cepheid variables, stars thousands of times more luminous than our Sun. One sentence in Leavitt's report would become her most venerated statement. "It is worthy of notice," she wrote, "that . . . the brighter variables have the longer periods." Because all her Cepheids

were situated in the Small Magellanic Cloud, Leavitt could assume they were all roughly the same distance from Earth. Their periods, therefore, were directly associated not only with their apparent brightness as seen from Earth, but with the actual emission of light. Leavitt's discovery would lead to a new cosmic yardstick, one that would allow astronomers to determine the distances to far-off celestial objects, which had never been measurable before.

Leavitt was on track to discover the celestial equivalents of lighthouses on Earth. A sailor at sea who knows the intensity of light emitted by a lighthouse can estimate how far away it is by how bright the beacon appears. Similarly, if an astronomer could know the absolute brightness of a Cepheid—how luminous it would appear up close—he could estimate how far away it must be to appear as the faint point of light seen from Earth. But, just as some lighthouses shine with brighter lights than others, so do Cepheids. Only their relative intensities can be measured from afar. The promise of Leavitt's discovery was this: if the absolute brightness of just one Cepheid could be known, the absolute brightness of the others could be figured out based on the differences in their periods. In this way, each Cepheid could become an invaluable "standard candle" (as astronomers call it) for gauging distances deep into space.

In 1908, however, Leavitt was wary that her initial sample of sixteen Cepheids was too small to secure a firm and predictable "period–luminosity" law. She needed more, but chronic illnesses, one of which had earlier left her deaf, and the death of her father delayed her a few years. Moreover, Cepheids, though very bright, are also very rare. Not until 1912 was Leavitt able to add nine more Small Magellanic Cepheids to her list. With twenty-

Composite image of the Large Magellanic Cloud. Leavitt studied variable stars—ones that regularly brighten and dim—within that galaxy and its neighbor, the Small Magellanic Cloud.

NASA/JPL-CALTECH/M. MEIXNER (STSCI) & THE SAGE LEGACY TEAM

five in hand, all at roughly the same distance from Earth, she could at last establish a distinct mathematical relationship between the rate of a Cepheid's blinking and its perceived brightness. In a logarithmic-scale graph of her data, the visible brightness of her Cepheids rises in a sure, straight diagonal line as the stars' periods get longer and longer.

Cepheids stood ready to be the perfect standard candles, but first Leavitt needed to know the true brightness of at least one. From that one, her graph could be calibrated such that an astronomer could pick out a far-off Cepheid anywhere in the sky, measure its period, and infer its actual luminosity. Knowing that, the star's distance could be calculated from its much fainter apparent brightness.

First, however, Leavitt required the reverse: knowing the distance to one bona fide Cepheid was the only way to calculate its true brightness! But Leavitt's going to a telescope to pursue an answer was out of the question, not only because women were denied access to the best telescopes at the time, but because of her frail condition. She had been advised by her doctor to avoid the chilly night air habitually braved by observers. If she had the know-how, she could have carried out a calculation from her desk, using stellar data from previously published work, but Pickering held the strong conviction that his observatory's prime function was to collect and classify data, rather than apply it to solve problems. At his behest, Leavitt instead dedicated herself for several years to a project on stellar magnitudes. Ultimately, her work served as the basis for an internationally accepted system that is still in use, though now revised.

In the meantime, recognizing the value in Leavitt's truncated research, the Danish astronomer Ejnar Hertzsprung picked up where she left off. In 1913, he devised a statistical model using known Cepheids in the Milky Way to calibrate Leavitt's period–luminosity graph. From that, he calculated the first intergalactic distance, to the Small Magellanic Cloud, thereby fulfilling the momentous promise of her work.

Yet Leavitt's desire to pursue further research on the variables never left her. Soon after Pickering's death in 1919, she at last divulged her interest to the observatory's soon-to-be director, Harlow Shapley. But just as she was on the verge of completing her prolonged stellar-magnitude project—when she might have at last returned to her work on variables—Henrietta Leavitt passed away, at the age of fifty-three. She had endured a grueling struggle with stomach cancer. By the time of her death, on December 12, 1921, she had discovered some 2,400 variable stars, about half the number then known to exist.

Unaware of Leavitt's passing, four years after her death a member of the Royal Swedish Academy of Sciences contacted the Harvard Observatory to inquire about her discovery, intending to use the information to nominate her for a Nobel Prize in Physics. By the rules of the award, however, the names of deceased individuals could not be submitted.

Marcia Bartusiak is a science writer with a master's degree in physics who has been covering astronomy and physics for three decades. She is the author of five books on astronomy, including Archives of the Universe *(Pantheon Books, 2004) and* Einstein's Unfinished Symphony *(Joseph Henry Press, 2000).*

In recognition of 2009 being the International Year of Astronomy, this article is the second of several on the events and scientists that have advanced our understanding of the cosmos during the last hundred years. This article was adapted from *The Day We Found the Universe*, by Marcia Bartusiak, © 2009. Reprinted with permission from Pantheon Books.

From Gravedigger to Assassin

How the habits of one species of burying beetle have changed

By Stephen T. Trumbo

*Female burying beetle (*Nicrophorus pustulatus*) attends to five offspring inside a parasitized snake egg.*

Your everyday burying beetle is an upstanding ecological citizen, a consummate recycler. It will clear the fields and woods of small dead rodents and songbirds, turning their nutrients into new life. Usually the clearing process involves digging beneath a small carcass so that it sinks below the soil surface—hence the common name of "burying" beetles for all members of the genus *Nicrophorus*. Interring the tiny corpse—baby food for larvae soon to come—helps to get the prize out of sight and out of smell of scavengers, carrion flies, and competing burying beetles.

Sounds benign, right? I thought so for the first eighteen years I studied the habits of these creatures. Then I realized that there was at least one species that had more sinister aims: to inhabit, consume, and eventually kill a vertebrate host.

In 2000, herpetologists Gabriel Blouin-Demers and Patrick J. Weatherhead of Carleton University in Ottawa were monitoring nests of black rat snakes (*Elaphe obsoleta*). They discovered larvae of burying beetles inside hollow snake eggs, whose contents appeared to have been devoured. Burying beetle adults were nearby, raising suspicions. Had the beetles and larvae chanced upon broken snake eggs and, being meat eaters, scavenged the contents? Or had the parent beetles sought out viable snake eggs, deposited their spawn nearby, and then opened the eggs so their young could crawl inside and gorge? Blouin-Demers and Weatherhead suspected the latter. A number of black rat snake and fox snake nests turned up the same species of burying beetle, *Nicrophorus pustulatus*, hinting that the relationship was not merely casual.

What Blouin-Demers and Weatherhead were suggesting was very un-burying-beetle-like behavior. Had a species of the beetles begun to seek out living flesh? When I came across the report of those observations, I was intrigued by a possible case study in evolutionary transition—and one with obvious implications for the conservation of reptiles.

Burying beetles work in mated pairs from late spring to early fall. Typically, a male and female will move a small carcass underground and then diligently remove any hair or feathers, round the resource into a ball, and preserve it with antibiotic secretions from their hindgut. The female lays between twenty and forty eggs in the surrounding soil. After only a few days the eggs hatch, and the emerging larvae crawl to their parents' nest, where they are cared for and nourished with regurgitated food. That pattern has been observed in the field for every one of the burying beetle species studied except *N. pustulatus*. Thousands of *N. pustulatus* individuals have been trapped at black lights or feeding on blowfly-ridden carcasses (the main fare for adults) throughout their range, over the eastern half of North America from Nova Scotia to Florida. Yet no one had caught the enigmatic species preparing a small carcass for their offspring in the field. Snake eggs now seemed the place to look.

I wanted to test the idea that *N. pustulatus* had made an evolutionary shift from breeding on carrion to breeding on snake eggs. For starters, herpetologist Neil B. Ford at the University of Texas at Tyler supplied my animal-behavior laboratory with eggs from brown house snakes. A graduate student, Garrison Smith (who was working in my lab at the University of Connecticut while getting his degree from the University of Arizona), began by presenting burying beetles with from one to five snake eggs. He offered the eggs to male–female pairs

PHOTOS: STEPHEN T. TRUMBO

of *N. pustulatus*, as well as to pairs from two related species, *N. orbicollis* and *N. defodiens*. Those other burying beetles ignored any and all intact snake eggs, oblivious to potential resources inside.

However, pairs of *N. pustulatus* clearly became excited in the presence of snake eggs. The beetles intently crawled over the eggs, and would even open a small hole in the shell to sample the contents. Within twelve hours the female would lay her own eggs nearby, forgoing the elaborate burying and preparation behaviors that were adaptations for working with a carcass. When the larvae hatched, they instinctively crawled inside a snake egg (opened for them ahead of time by the adults) and began to feed. The adults attentively stayed near, producing a soft chirping sound that may be a signal to the young.

Smith also found that parents adjust the size of their brood to match the number of snake eggs by killing some of their offspring. Other burying beetles will make the same kind of adjustment when resources are limited, ensuring that surviving offspring will have enough to eat.

The adaptation to feed on snake eggs makes *N. pustulatus* a type of parasite known as a "parasitoid." Parasitoids are relatively large with respect to their host: they are only parasitic as larvae, live only within a single host, and eventually kill the host. So marked a change, from breeding on small vertebrate carcasses to parasitizing viable snake eggs, seems almost too great an evolutionary leap. But *N. pustulatus* is clearly descended from more conventional burying beetles. Its body form and DNA point to its ancestry within burying beetle stock, as shown by entomologist Derek S. Sikes, now at the University of Alaska Museum of the North.

The behavior of *N. pustulatus* also provides evidence of its ancestry. If you present it with a mouse carcass in the laboratory, it will demonstrate burying, rounding, and hair-removing habits—though the hair is not always completely removed, and the carcass is not formed into as tight a ball as it is by other burying beetle species, in which natural selection continues to mold those skills. In fact, *N. pustulatus* has retained many similarities to its fellow buriers. In addition to regulating the size of its brood and regurgitating food to its young, it defends them against insect predators, and the male adopts a handstand posture when emitting a sex pheromone to attract the female—all characteristic of the genus.

One novel adaptation of *N. pustulatus* may be that when it flies in search of a resource on which to breed, it no longer responds to the odor of decaying flesh. Instead, it uses a different set of cues, still unknown, to locate snake nests. Understanding those cues is essential to knowing what egg-laying animals are susceptible to parasitism by *N. pustulatus*.

Adult burying beetle, N. orbicollis, *regurgitates to larvae atop a mouse carcass.*

Dead mice—before and after being prepared by N. orbicollis. *That work is typical of burying beetles, though* N. pustulatus *will not round a carcass as neatly.*

The black rat snake that we know is being victimized is listed as a threatened species in several U.S. states and Canadian provinces. In six of the first seven snake nests Blouin-Demers and Weatherhead checked, they found evidence of marauding—with up to 100 percent of eggs affected. And, as black rat snakes can nest communally, a large number of eggs can be vulnerable at one location. Up to the challenge, *N. pustulatus* produces as many as 200 young at a time, five times the fecundity of a typical burying beetle.

Other egg-laying reptiles on the federal list of endangered and threatened species may be at risk. In the laboratory *N. pustulatus* will parasitize eggs of turtles, but this has not been looked for yet in the field. Because its parasitic habits were but recently discovered, and reptile nests are not easily inspected, there could be many more species affected. (Randolf F. Lauff of St. Francis Xavier University in Nova Scotia has even found evidence that these beetles are making their way into tree canopies, perhaps in search of abandoned bird eggs.) Although loss of habitat is the primary threat pushing several North American reptiles toward the brink of extinction, an oddball burying beetle could well roll them over the edge.

STEPHEN T. TRUMBO, *an animal behaviorist at the University of Connecticut in Waterbury, received a PhD from the University of North Carolina at Chapel Hill. He has studied burying beetles in North Carolina, at the University of Michigan Biological Station in Pellston, as well as near his current home in Connecticut.*

Bodies in Syn

The contagiousness of laughter, yawns, and moods offers insight into the origins of empathy.

BY FRANS DE WAAL

Two young chimpanzees, orphans residing in the Republic of Congo's Tchimpounga Sanctuary, maintain a close bond through hugging and grooming. Physical expression, including unconscious imitation, is a fundamental glue that holds groups and societies together.

MICHAEL NICHOLS/NATIONAL GEOGRAPHIC STOCK

One morning, the principal's voice sounded over the intercom of my high school with the shocking announcement that a popular teacher of French had just died in front of his class. Everyone fell silent. While the headmaster went on to explain that the teacher had suffered a heart attack, I couldn't keep myself from a laughing fit. To this day, I feel embarrassed.

What is it about laughter that makes it unstoppable even if triggered by inappropriate circumstances? Extreme bouts of laughter are awkward: they involve loss of control, shedding of tears, gasping for air, leaning on others, and even wetting of pants while rolling on the floor! What weird trick has been played on our linguistic species, that we express ourselves with stupid "ha ha ha!" sounds? Why don't we leave it at a cool "That was funny!"?

Philosophers who regard a sense of humor as one of humanity's finest achievements may find it puzzling that it is expressed with the sort of crude abandon associated with mere animals. But laughter is an inborn, universal human trait, one that we share with our closest relatives, the apes [*see "The Laughing Species," December 2000-January 2001*].

A Dutch primatologist, Jan van Hooff of Utrecht University, set out to learn under what circumstances great apes utter their hoarse, panting laughs, and concluded that ape laughter has to do with a playful attitude. It's often a reaction to surprise or incongruity—as when a tiny infant chimp chases the group's top male, who runs away "scared," laughing all the while. This connection with surprise is still visible in children's games such as peek-a-boo, or jokes marked by unexpected turns, which we save until the very end and appropriately call "punch lines."

What intrigues me most about laughter, however, is how it *spreads*. It's almost impossible not to laugh when everybody else is. There have been laughing epidemics that lasted months, in which no one could stop for long. There are laughing churches and laugh therapies based on the healing power of laughter. All because we love to laugh and can't resist joining those laughing around us.

The infectiousness of laughter even works across species. Below my office window at the Yerkes Primate Center in Atlanta, Georgia, I often hear my chimps laugh during rough-and-tumble games, and cannot suppress a chuckle myself. It's such a happy sound. Tickling and wrestling are the typical laugh triggers for apes, and probably the original ones for humans. The fact that tickling oneself is notoriously ineffective attests to its social significance. And when young apes put on their "play face" (as the laugh expression is known), their friends join in with the same expression as rapidly and easily as humans do with laughter.

Shared laughter is just one example of our primate sensitivity to others. We aren't Robinson Crusoes, sitting on separate islands; we're all interconnected, both bodily and emotionally. This may be an odd thing to say in the West, with its tradition of individualism and liberty, but members of the species *Homo sapiens* are easily swayed in one emotional direction or another by their fellows.

That is where empathy and sympathy start—with the synchronization of bodies—not in the higher regions of imagination, or in the ability to consciously reconstruct how we would feel if we were in someone else's "shoes." And yet empathy is often presented as a voluntary process, requiring role taking, higher cognition, and even language. Accordingly, most scholarly literature on empathy is com-

Two young bonobos exhibit the ape equivalent of the human laugh, a "play face," which is accompanied by laugh-like panting sounds. Just as in humans, if one ape laughs others usually do as well, especially during wrestling and tickling games.

FRANS DE WAAL

ERIC BACCEGA

Siamang gibbon mates sing a wild and raucous song composed of high-pitched barks and piercing shrieks. The longer a pair has been together, the more synchronized and harmonious their song, qualities that advertise the couple's solidarity to any gibbons encroaching on their territory.

pletely human centered, never mentioning other animals. As if a capacity so visceral and pervasive could be anything other than biological! To counter such widespread views, I decided to investigate how chimpanzees relate to and learn from one another.

Empathic synchronization of bodies assumes many forms: moving when others move, laughing when others laugh, crying when others cry, yawning when others yawn. Most of us have reached the advanced stage at which we yawn even at the mere mention of yawning—as you may be doing right now!—but that is only after lots of face-to-face experience.

Virtually all vertebrates, including fish, show the peculiar "paroxystic respiratory cycle characterized by a standard cascade of movements over a five- to ten-second period" that defines the yawn. Chimpanzees yawn when they see others of their species yawn—as do some monkeys, as well as dogs. Yawn contagion, like laughter, also works across species. I once attended a lecture on involuntary pandiculation (the medical term for stretching and yawning) with slides of horses, lions, and monkeys—and soon the entire audience was pandiculating. Since it so easily triggers a chain reaction, the yawn reflex opens a window onto mood transmission, an essential part of empathy. Notably, children with autism spectrum disorders are immune to the yawns of others, thus highlighting the social disconnect that defines their condition.

Synchrony may be expressed in the copying of small body movements, such as a yawn, but it also occurs on a larger scale, such as group travel. It is not hard to see its survival value. You're in a flock of birds and one bird suddenly takes off. You have no time to figure out what's going on: you take off at the same instant. Otherwise, you may be lunch. Or your group becomes sleepy and settles down, so you too become sleepy and rest.

Mood contagion serves to coordinate activities, which is crucial for any traveling species (which most primates are). If my companions are feeding, I had better do the same, because once they move off, my chance to forage will be gone. The individual that doesn't stay in tune with what all the others are doing will lose out, like the traveler who doesn't go to the restroom when the bus has stopped.

The power of synchrony can be exploited for good purposes. On one occasion in the Netherlands, a herd of some 120 horses got trapped on a patch of dry pasture in the middle of a flooded area. With twenty horses already drowned, people were attempting to save the others. One of the more radical proposals was for the army to erect a pontoon bridge, but the local riding club came up with a far simpler solution. Four brave women on horseback mixed in with the stranded herd, then splashed through a shallow area and, like pied pipers, drew the rest with them in single file. The horses had to swim a few stretches, but all made it safely to *terra firma*.

Movement coordination both reflects and strengthens bonds. Two horses hitched to a cart, for example, may at first jostle each other and pull at cross-purposes, each following its own rhythm. But after years of working together, the two end up acting like one, fearlessly pulling the cart at breakneck speed through water obstacles during cross-country marathons. They become so attached to each other that they object to even the briefest separation.

Synchrony, in turn, builds upon the ability to map one's own body onto that of another, and make the other's movements one's own, which is exactly why someone else's laugh or yawn makes us laugh or yawn. Body mapping starts early in life. A human newborn will stick out its tongue in response to an adult doing so, and the same neonatal imitation applies to monkeys and apes. How does the baby know that its own tongue, which it can't even see, is equivalent to the pink, muscular organ that it sees slipping out from between an adult's lips? In fact, the word "know" is misleading, because it all happens unconsciously. Scientists may bring up neural resonance or mirror neurons [*see "Mental Mirrors," May 2008*], but that hardly makes it less miraculous.

The automatic nature of empathy is revealed through imitation—an anthropoid forte, as reflected in the verb "to ape." Give a zoo ape a broom, and he'll move it across the floor the way the caretaker does every day. Give her a rag and she'll soak it and wring it out before applying it to a window. Hand him a key, and you're in trouble!

Previous studies of ape mimicry tested whether apes imitated human experimenters in white coats. The results cast doubt on apes' proclivity for imitation. But my chimps at the Yerkes research center obviously haven't read the scientific literature: imitating is an integral part of their daily life, and they do so spontaneously, often without any reward in mind. I set up an ambitious research project together with a British colleague, Andrew Whiten of the University of St. Andrews, to find out just how well chimps learn food-obtaining tasks from one another. From an evolutionary viewpoint, it doesn't really matter what they learn from us humans—all that matters is how they deal with their own kind.

To have one chimp act as a model for another, however, is easier said than done. I can instruct a coworker to demonstrate a particular action ten times in a row, but try telling that to an ape! So first we constructed a puzzle box that can be opened, for example, by using a stick to lift a lever, causing a treat to roll out. We then teach the technique to one member of the group, usually a high-ranking female, and let her demonstrate it for others. Allowed to watch and imitate their groupmate's new skill, chimps entirely live up to their reputation as apes. They're literally in one another's faces, leaning on one another, sometimes holding the model's hand while she's performing, or smelling her mouth when she's chewing the goodies she has won. Such close personal contact—which would be far too dangerous for a human experimenter—makes

The contagiousness of yawns and laughter synchronizes activities and solidifies bonds.

In adulthood, women report stronger empathic reactions than men, which is one reason why a "tending instinct" has been attributed to women.

all the difference. Our chimps often replicate the observed actions even before they've gained any rewards themselves. That brings me back to the role of the body.

How does one chimp imitate another? Is it because he identifies with the model chimp, and absorbs her body movements? Or could it be that he focuses on the puzzle box? Maybe all he needs to know is how the thing works. He may notice that a door slides to the side, or that something needs to be lifted up. The first kind of imitation involves reenactment of observed manipulations; the second merely requires technical know-how.

Thanks to ingenious studies by Whiten and others, in which chimps were presented with a so-called ghost box, we know which of those two explanations is correct. A ghost box derives its name from the fact that it magically opens and closes by itself. If technical know-how were all that mattered, such a box should suffice as a teaching tool. But in fact, letting chimps watch a ghost box until they're bored to death—with its various parts moving and producing rewards hundreds of times—did not teach them anything.

In order to learn from observation, apes need to see actual fellow apes perform an action. Imitation requires identification with a body of flesh and blood. We're beginning to realize how much cognition in humans and other animals runs via the body. Indeed, bodies figure in everything we perceive or think. The same hill is assessed as steeper, just from looking at it, by a tired person than by a well-rested one. An outdoor target is judged farther away by a person burdened with a heavy backpack than by one without it.

The field of "embodied" cognition is still very much in its infancy, but it has profound implications for how we look at human relations. We involuntarily enter the bodies

Three stills from a computer animation of an apelike head yawning: chimpanzees that view the animation often yawn too. Such contagious yawning is based on motor mimicry and empathy. In contrast, chimpanzees do not yawn in response to still images or to animations that depict simple mouth movements (such as opening and closing).

of those around us so that their movements and emotions echo within us as if they're our own. This is what allows us, or other primates, to re-create what we have seen others do. Body mapping is mostly hidden and unconscious, but sometimes it "slips out," as when parents make chewing mouth movements while spoon-feeding their baby.

The same can be seen in other animals. Katharine (Katy) Payne, a biologist at Cornell University, once saw an elephant mother do a subtle trunk-and-foot dance as the elephant's son chased a fleeing wildebeest. "I have danced like that myself," writes Payne, "while watching my children's performances—and one of my children, I can't resist telling you, is a circus acrobat."

Not only do we mimic those with whom we identify, but mimicry in turn strengthens the bond. Human mothers and children play games of clapping their own and each other's hands in the same rhythm. These are games of synchronization. And what do lovers do when they first meet? They stroll long distances side by side, eat together, laugh together, dance together. In romantic situations, a woman will feel better about a date who leans back when she does, crosses his legs when she crosses hers, picks up his glass when she lifts hers, and so on.

This familiar effect may explain why music is just as universal in human societies as language. When many people listen together to the same music, mood convergence and bonding are the result. Examples of similar bonding in other animals are easy to come by, from howling howler monkeys to roaring lions. Take large black gibbons called siamangs, which sing high up in the trees in the Malay and Sumatran forests where they live. For many animals, it's the male's job to keep intruders out, but with siamangs—which live in small family groups—both sexes work together toward this end. The female produces high-pitched barks, whereas the male often utters piercing screams that at short range will put every hair on your body on end. Their wild and raucous songs grow in perfect unison into what has been called "probably the most complicated opus sung by a land vertebrate other than man."

As shown in a composite image, audience members feel suspense watching a high-wire artist because they share her experience. High-wire artists often perform apparent slips on purpose because they know the audience is with them every step of the way.

It takes time for a pair of siamangs to learn to sing in harmony, and harmony may be critical to holding onto a partner or territory. Other siamangs can hear how close a pair is, and will move in if they discern discord. Thomas Geissmann, a primatologist at the University of Zürich in Switzerland, observed that deserting an established partner would not be a very attractive option, because the duets of new couples are noticeably poor. He found that couples that sang together a lot also spent more time together and synchronized their activities better. One can tell a good siamang marriage by its song.

According to Ulf Dimberg, a psychologist at Sweden's Uppsala University, we don't decide to be empathic—we simply are. Having pasted small electrodes onto his subjects' faces so as to register the tiniest muscle movements, he presented them with pictures of angry and happy faces on a computer screen. Humans frowned in reaction to angry faces and pulled up the corners of their mouths in reaction to happy ones, even if the pictures flashed on the screen too briefly for conscious perception. That is a rather primitive kind of empathy known as emotional contagion—a first step on the road toward full-blown empathy.

Empathy engages brain areas, such as the limbic system, that are more than 100 million years old. The capacity arose long ago with motor mimicry and

TOP: ANIMATION PRODUCED BY J. DEVYN CARTER USING LIGHTWAVE 3D FROM NEWTEK, INC.
BOTTOM: WEEGEE(ARTHUR FELLIG)/INTERNATIONAL CENTRE OF PHOTOGRAPHY/GETTY IMAGES

emotional contagion, after which evolution added layer after layer, until our ancestors not only felt what others felt, but understood what others might want or need. That ultimately led to sympathy: while empathy is a way we gather information about someone else, sympathy reflects our concern about the other and a desire to improve the other's situation. Sympathy is anything but automatic. Nevertheless, it is common not only in humans but also in other animals, such as apes, dogs, elephants, and birds.

Apes will groom and hug those in distress. There is also evidence of that behavior in dogs. Belgian biologists watched more than a thousand spontaneous fights among dogs released every day onto a meadow at a pet-food company. After aggressive outbursts, nearby dogs would approach one of the combatants—usually the loser—to lick or nuzzle, play with, or simply sit with him or her. Doing so seemed to settle the group, which quickly resumed its usual activities.

As for its origins, empathy probably started with the birth of parental care. During 200 million years of mammalian evolution, females sensitive to their offspring outreproduced those that were cold and distant. When a pup, cub, calf, or human baby is cold, hungry, or in danger, its mother needs to react instantaneously. Females that failed to respond did not propagate their genes.

Descended as we are from a long line of mothers who nursed, fed, cleaned, carried, comforted, and defended their young, we should not be surprised by gender differences in human empathy. Two-year-old girls who witness others in distress treat them with more concern than do boys of the same age. And in adulthood, women report stronger empathic reactions than men, which is one reason why a "tending instinct" has been attributed to women.

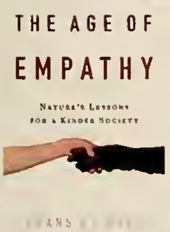
Believing we are seeing a person with whom we have just cooperated receive a painful electric shock (though it's actually staged) activates pain-related areas in our own brains. That applies to both men and women. But some experiments show that if a man feels he has been duped by someone, he shows the opposite of empathy: when he sees the other's pain, his brain's pleasure centers light up. Those men are getting a kick out of the other person's misery! Women, in contrast, remain empathic. The underlying theme (male lack of empathy for potential rivals) may well be a mammalian universal.

None of this denies male empathy. Indeed, gender differences usually follow a pattern of overlapping bell curves: men and women differ on average, but quite a few men are more empathic than the average woman, and quite a few women are less empathic than the average man. In addition, with age, the empathy levels of men and women seem to converge. Some investigators even doubt that in adulthood there's much difference left.

Disciplines that view humans as rational decision makers, individually weighing the pros and cons of their own actions, underestimate the way we are influenced by the bodies that surround us, unconsciously responding to voice, mood, posture, and so on. But those influences are what provides the "glue" that holds entire societies together.

Human empathy is so ingrained that it will almost always find expression. As a consequence, at times it must be suppressed. Doctors and nurses in emergency rooms, for example, just cannot afford to be constantly in an empathic mode. They have to put a lid on it. Soldiers must be trained to dehumanize the enemy. Empathy can also be enhanced, as we do when we urge a child who is hogging all the toys to be more considerate of her playmates.

Like other primates, humans can be described either as highly cooperative animals that need to work hard to keep selfish and aggressive urges under control, or as highly competitive animals that nevertheless have the ability to get along and engage in give-and-take. I rank humans among the most aggressive of primates, but I also believe that we're masters at connecting, and that social ties constrain competition. Many economists and politicians model human society on the perpetual struggle they believe exists in nature. But in fact many animals survive through cooperation, so there is a long evolutionary history to compromise, peaceful coexistence, and caring for others. Empathy is part of the survival package, and human society depends on it as much as many other animal societies do.



This article was adapted from *The Age of Empathy: Nature's Lessons for a Kinder Society*, ©2009 by Frans de Waal. Published by Harmony Books, a division of Random House, Inc. On sale in bookstores September 22.

Frans de Waal is a Dutch-born biologist who lives and works in Atlanta, Georgia. One of the world's best-known primatologists, de Waal is C. H. Candler Professor of Psychology and Director of the Living Links Center at the Yerkes National Primate Research Center at Emory University. He has been elected to the National Academy of Sciences and the Royal Dutch Academy of Sciences. In 2007, *Time* selected him as one of the world's 100 most influential people.

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THE SEARCH FOR EVIDENCE OF MASS EXTINCTION

A QUARTER OF A BILLION YEARS AGO THE "GREAT DYING" CHANGED EARTH'S ECOLOGICAL RULES. DO CURRENT GLOBAL EVENTS SIGNAL A SIMILAR REVOLUTION?

BY SCOTT LIDGARD, PETER J. WAGNER, AND MATTHEW A. KOSNIK

Above: Marine sedimentary rocks, exposed in Tibet as a result of mountain building, record the end of the Permian period and beginning of the Triassic, about 251 million years ago. The mass extinction at that juncture also marks the transition from the Paleozoic era to the Mesozoic. Opposite page: Silurian- or Devonian-period fossils of crinoids, about 410 million to 420 million years old, were collected in Morocco. Crinoids were among the many sedentary, filter-feeding animals of the Paleozoic era.

CHARLES DARWIN FAMOUSLY CONCLUDED *On the Origin of Species by Means of Natural Selection* with upbeat reassurance: "There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that . . . from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved." But the subtitle of his work—*The Preservation of Favoured Races in the Struggle for Life*—is a reminder that nearly all of those "endless forms" are extinct. Moreover, we now know that both evolution and extinction are not always the gradual, incremental processes that Darwin envisioned. The escalating impact of the human population on Earth is even billed as a "sixth mass extinction." With extinction the rule rather than the exception, however, disentangling the mechanisms and outcomes of a "mass" extinction turns out to be anything but easy.

Darwin and the geologist Charles Lyell took the fossil record to be incomplete and were skeptical that it could reveal much about patterns of extinction and diversity. But in 1860, only a year after *Origin*'s publication, the geologist John Phillips begged to differ in a groundbreaking lecture at Cambridge, published as *Life on the Earth, Its Origin and Succession*. "Surely this imperfection of the geological record is overrated," he wrote. "With the exceptions of the two great breaks at the close of the Palaeozoic and Mesozoic periods, the series of strata is nearly if not quite complete, the series of life almost equally so." Looking back in time, Phillips saw that the fossil faunas of Britain during the Paleozoic, Mesozoic, and Cenozoic were distinct from one another (we now call those great successive stretches of time *eras*, using the term *period* for shorter subdivisions). He also showed that drastic reductions in the variety of fossil life at the ends of those eras were followed by radiations of new forms.

Such mass extinctions and subsequent radiations appeared to differ from the gradual turnover of life forms typical of most of the fossil record. Naturally, scientists were tempted to hypothesize causes. In 2006, Richard K. Bambach, a professor emeritus of paleontology at Virginia Tech, reviewed the historical highlights of that quest. In 1952, for example, geologist Norman D. Newell proposed that mass extinctions might best be accounted for by a drastic drop in sea level that would have devastated ocean life in all the broad shallow zones. Soon thereafter, the paleontologist Otto H. Schindewolf suggested that catastrophic bursts of cosmic radiation from supernovae could have caused some faunal changeovers. And in 1980, evidence of an asteroid impact at the end of the Cretaceous period captured the popular imagination, not only because the evidence was concrete but also because the event affected two charismatic groups of animals, with the so-called Age of Dinosaurs giving way to the Age of Mammals.

Before addressing *why* a mass extinction occurred, however, scientists need to determine what counts as an abnormally large extinction event. The problem is akin to identifying a great athlete. We would not label an athlete "great" after a few good games: any good athlete can have winning streak or a successful career. But only a great athlete will set new records and have a major impact on the history of a sport. By the same token, the label "mass extinction" should be invoked only for an event that kills off an unusually high number of species over a relatively short geologic interval, over a broad geographic range, and among many ecologic and taxonomic groups.

For much of Earth's history, marine fossils preserve the only evidence of life's evolution, and they provide the most complete record even after plants and animals took to the land. In 1982, the University of Chicago paleontologist J. John (Jack) Sepkoski drew up a compendium of fossil marine families and, with David M. Raup, then of Chicago's Field Museum of Natural History, demonstrated that beginning in the Paleozoic, 542 million years ago, five candidates for mass extinction stood out particularly starkly from background extinction levels. Subsequently, Sepkoski compiled a database of global marine diversity that records the times of origination and extinction for some 36,000

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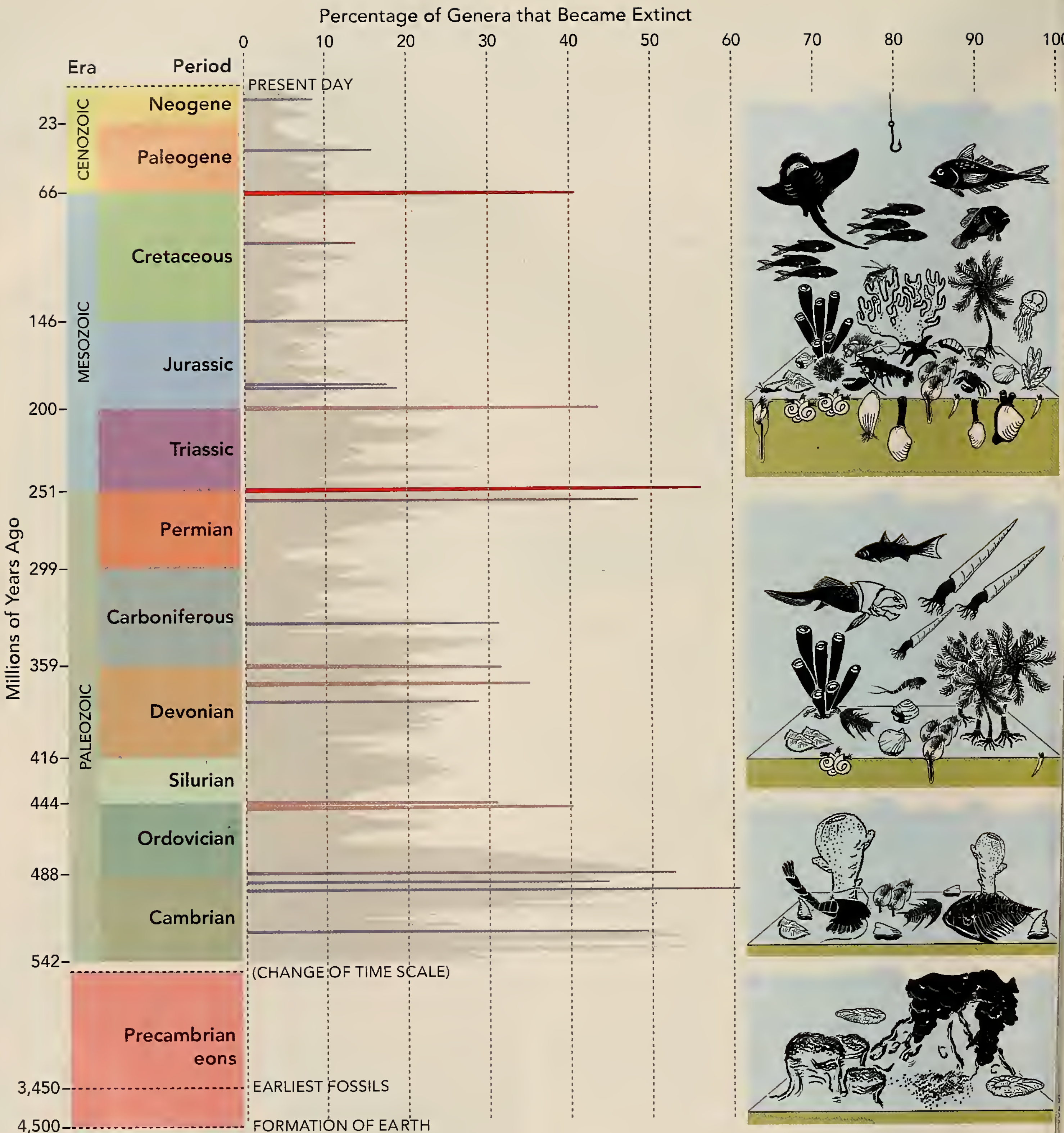


Geological time line of Earth, from Precambrian eons (bottom) to the present (top): Beginning with the Cambrian period, fluctuations in the percentage of marine genera becoming extinct are represented by the shaded graph, based on 165 evolutionary intervals tabulated by the paleontologist J. John (Jack) Sepkoski. The extinction peaks at the end of the Permian and end of the Cretaceous (red bars) are universally considered mass extinctions. Some paleontologists think one other peak and two pairs of peaks (brown bars) may reflect three more mass extinctions. Other peaks (blue bars) most likely reflect distortions in collected data, not catastrophic events. The vignettes of life (right) portray the increasing ecological complexity of marine communities over time.

genera (a computerized version was published posthumously in 2002). On that basis, eighteen statistically respectable candidates for mass extinction have been identified [*see chart on opposite page*]. Other analyses have suggested, however, that many of those eighteen are merely artifacts of missing fossil records. But in everybody's book, two events stand out: one ended the Cretaceous period and Mesozoic era, 65 million years ago, and the greatest mass extinction of all ended the Permian period and Paleozoic era, about 251 million years ago.

Such catastrophic intervals do much more than just sweep some of the players off the global playing field. They change the game. Back in 1860, Phillips perceived a trend of increasing complexity, writing that "the *variety of life*, estimated by the marine tribes existing in a given period, is greater in the more recent periods." He realized more was involved than the *abundance of life*, or the number of individuals. Phillips's insight has since been reinforced, in part from refinements in correlating geological strata from different parts of the world and in assembling more comprehensive lists of the players and their evolutionary appearances and disappearances.

But the biggest surprises in the past few years have come from comparisons of fossil assemblages in a cooperative venture known as the Paleobiology Database, an electronic repository of information about thousands of fossil communities. Our own analyses in that regard led us to an unexpected conclusion: the end-Permian event not only eliminated large numbers of species; it also set the stage for reorganizing marine ecosystems.

OFTEN CALLED THE GREAT DYING, the end-Permian mass extinction killed off at least 50 to 60 percent of all marine genera, embracing perhaps 90 percent of marine species, in a geologically short span of time. Immense shallow-water reefs died off completely. Among bottom-dwelling organisms, sedentary animals may have suffered the most, such as filter-feeding corals, brachiopods, and single-celled fusulinids. Filter-feeding crinoids that in earlier periods blanketed many shallow continental shelves did not diversify again for tens of millions of years. The trilobites, mobile detritus-feeding arthropods dominant through the Paleozoic, already in decline, now finally met their end.

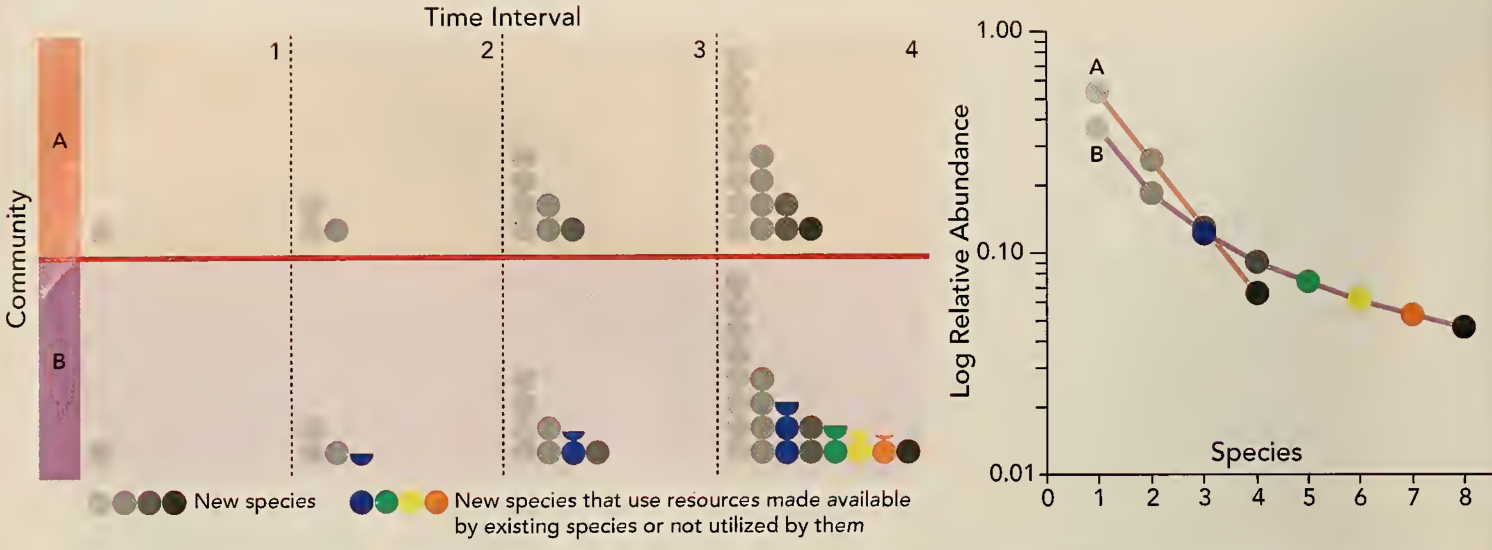
Earth itself apparently unleashed this disaster—an asteroid impact like the one that wiped out the dinosaurs seems much less likely. David J. Bottjer of the University of Southern California, along with several of his collaborators, and Douglas H. Erwin of the Smithsonian Institution independently reviewed and critiqued the many proposed causes. Both empirical evidence and climate modeling indicate that buildup of carbon dioxide and other greenhouse gases, global warming, and reduced circulation or even stagnation of the world oceans were all on the march during the Late Permian. Those already stressful conditions were punctuated by a continental-scale volcanic eruption of lava in what is now Siberia, the largest known instance in Earth history of what is called flood basalt deposition. The present-day landscape that testifies to that event, known as the Siberian Traps, extends some 750,000 square miles, but the lava may have originally covered three and a half times that area, in places to a depth of a mile or more.

As it flowed up to the surface the magma vaporized minerals and organic matter, adding to the outpouring of volcanic gases—carbon dioxide, sulfur dioxide, hydrogen sulfide, methane, and halocarbons. Like pure halogens, halocarbons may have degraded the protective ozone layer, though some researchers believe that was more than offset by an ozone buildup. Climate fluctuations probably increased following eruptions, and photosynthesis on land and in oceans was likely disrupted; both those consequences are known on regional scales following major eruptions in historical time. Carbon dioxide and (to a much lesser extent) methane would have diminished the proportion of oxygen in the atmosphere and accelerated global warming. Elevated carbon dioxide levels probably also acidified most ocean waters, impairing the ability of many organisms to secrete carbonate skeletons.

Hydrogen sulfide may have reached toxic levels, in part because lower ocean layers containing the gas in dissolved

LEFT: M. LABARBERA; RIGHT: CHARLES MESSING COURTESY T. BAUMILLER

Brachiopods of the species Terebratulina unguicula, *left, and the crinoid* Neocrinus decorus, *right, are living descendants of two groups of sedentary, filter-feeding marine animals that dominated in Paleozoic seas. Brachiopods, once very diverse and abundant on typical ocean bottoms, have been largely replaced by such mollusks as clams and snails. Crinoids, which were once attached to vast areas of the seafloor, are echinoderms related to free-living sea stars and urchins. Modern crinoids are either restricted to deep, dark waters or are able to swim or crawl, making them mobile enough to hide from predators during the day.*



In two theoretical models of ecological communities (left), each shade or color of dot represents one species; the number of dots for each species indicates the relative abundance of that species in the total population of its community. In community A, grayscale dots represent new species as they make their appearance at regular time intervals and compete for the same resources. The model assumes that species present longer are more abundant relative to newcomers because of their "head start" in exploiting those resources. When graphed mathematically as a log scale (right), this results in a simple, straight-line relation between the number of different species and their relative abundance. In community B, colored dots represent additional species that are able to eke out a living by exploiting new resources unused or produced by the preexisting species (including the older species themselves, which might become prey). The graph of that community now shows a variety of newcomers, though relatively rare, "bending the curve" in their favor. The authors' research showed that simple ecological models, such as A, often suffice to characterize fossil communities before the end-Permian extinction. Thereafter, complex models are needed far more often.

form rose onto the continental shelves, possibly even breaching the surface. The resultant dilution of oxygen and poisoning of shallow waters would have wiped out nearly all but the anaerobic organisms living there. Sulfide-reducing bacteria, for instance, likely thrived, and that could explain the large-scale bacterial blooms and mats that overran some shallow parts of the ocean. Such marine changes may have been exacerbated by runoff and decomposition of terrestrial detritus.

In sum, the massive volcanism unleashed a rapid cascade of kill mechanisms, concentrating the end-Permian extinctions in tens of thousands of years. Direct evidence of precisely which mechanisms caused the extinctions may be elusive. But as Bambach observed in his review of all the reputed mass extinctions, "Fossils were once alive, and death is a biological, not geological, phenomenon." He emphasized the power of evaluating the physiologies and life habits of both victims and survivors to determine the physical nature of the catastrophes.

The fossil evidence for several million years after the Great Dying shows that only simple communities of small marine animals survived, along with widespread bacterial mounds, evidence that dire conditions persisted. But gradually during the Mesozoic, newly diversifying groups of burrowing bivalves exploited food resources and refuges deep beneath the sediment surface—much more so than during the Paleozoic, which was characterized by filter-feeding, sedentary animals that lived on the sea bottom. Although trilobites and other mobile, detritus-feeding animals were common in the Paleozoic, and mobile predators such as nautiloid mollusks existed, beginning in the Mesozoic highly mobile, shell-crushing or shell-boring predators underwent dramatic radiations. Their descendants included many arthropods such as lobsters and crabs, neogastropods, marine reptiles, and ray-finned fishes. At the same time many prey animals evolved greater skeletal defenses. The product of that evolutionary arms race is widely known as the "Mesozoic Marine Revolution."

OUR OWN RESEARCH did not set out to highlight the end-Permian or any other mass extinction, but to test a more general hypothesis: that the complexity of marine communities increases through geologic time. How to measure ecological complexity is a controversial question even for modern ecologists, because complexity has many meanings. Three indices are often used: taxonomic *richness*, a tabulation of the different kinds of organisms that live in a given place; *abundance*, the number of individuals; and *evenness*, the relative commonness or rarity of the different kinds of organisms. On average, for example, the number of genera in late Cenozoic communities of skeletonized, bottom-dwelling animals is 2.5 to 3.7 times greater than in mid-Paleozoic communities. There is also a trend toward greater evenness, implying a change from dominance by one or a few groups of organisms to more equal abundance. Comparisons of living communities show that those with greater evenness often have a hierarchy of different niche types.

An even more powerful way of examining these communities is rooted in ecological theory, which holds that the ways organisms partition resources will strongly affect the "relative abundance distributions" (RADs) of species in a community. Model RADs summarize elements of all three indices of ecological complexity mentioned above in one quantitative measurement representing all the fundamental diversity information in a community. In communities alive now, different RADs are typically associated with different types of ecological structuring. In the simplest models, for example, all individuals from all species compete for the same set of resources. The relative abundance of species is determined by the order and frequency with which species appear, and how those that have been around longer use up available resources. The exact pattern depends on whether new species arrive regularly (either like clockwork, say one each year, or probabilistically, on average one each year), and also on whether there is a finite limit to resources.

Alternatively, consider a community where species do not all compete for the same resources. Consider further that some resources become available only after particular species have colonized a community. The predator–prey relationship offers an obvious example, because predators can consume prey only after prey species appear. There are many other ways in which members of one species take advantage of resources that are created (or made accessible) by members of another species. In such cases, the available niches expand as diversity increases. A new species can add to the resources available, or leave some resources completely untouched, thus boosting the opportunities for future species. [*See diagram on opposite page.*]

While we couldn't directly observe vanished ecological communities in action, we could determine the most likely statistical fit of various model RADs to fossil assemblages. We did this for each of 1,176 fossil communities drawn from the Paleobiology Database. Our samples spanned the past 542 million years—from the Cambrian period, when animal life underwent its first major diversification, to the present. Among our strategies was to focus on marine genera or families with better chances of discovery when looking at fossils on a global scale, as opposed to tabulating all known species. As expected, despite intervals of decline that could represent mass extinctions, as well as intervals without much net change, marine genera increased overall from the Cambrian period onward. With more kinds of organisms comes the prospect of more complex interactions among them.

What we discovered, looking at the data as ecologists, is that prior to the end-Permian mass extinction, our simpler RAD models fit fossil communities slightly more frequently than complex models. For the post-Paleozoic, however, complex RADs predominate. Not only did that mass extinction decimate the global variety of life, it permanently altered the typical complexity of marine communities. This was not just a trend, it was some kind of abrupt shift. No other extinction event had that profound effect.

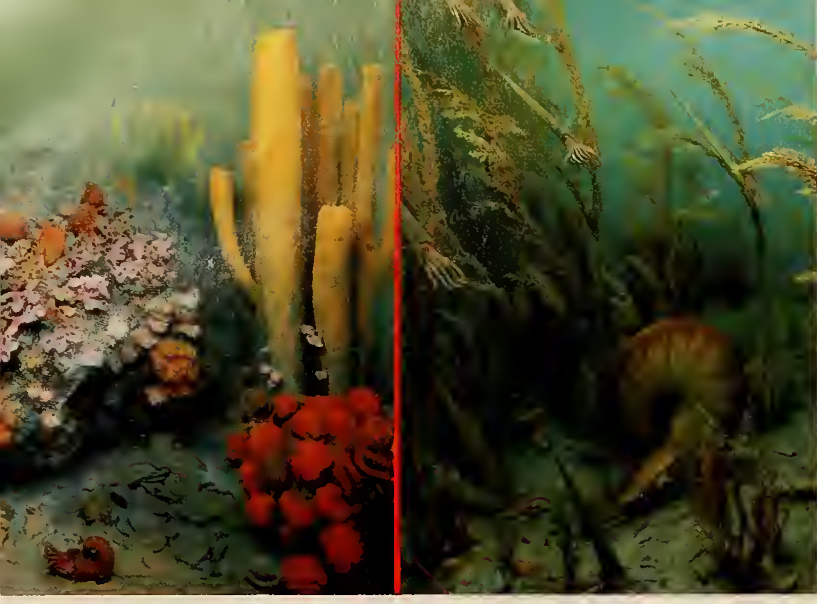
At first we couldn't believe our results, or more precisely, one of us said, "It has to be an artifact." But it wasn't. We had already taken into account different sample sizes among the communities. We tested to see if our results were tied to different sediment types, global richness levels, worker bias in compilation of the original data, or alternate timing of events. None of those variables could explain away our finding.

GOING FROM THEORY to biological reality, one notable characteristic of typical Paleozoic communities is the dominance of animals that lived sedentary lives on top of or attached to the ocean bottom, filtering organic particles suspended in the seawater. Although such organisms are still abundant in modern marine ecosystems, they are now joined by a great diversity of mobile predators and detritivores. Whereas a large proportion of the Paleozoic organisms were competing for much the same resource, namely particulate matter floating in the water column, in

Weathered basaltic rock in the mountainous region known as the Siberian Traps is the remains of a gigantic outpouring of lava about 251 million years ago. The volcanism coincided with the end-Permian mass extinction and may have been the precipitating cause, on top of underlying trends in climate change.

JON RANSON, NASA

JOE SHARKEY



RON TESTA ©THE FIELD MUSEUM

Marine life in the Late Permian period, far left, depicted in a former diorama at the Field Museum in Chicago, is dominated by sedentary, filter-feeding animals, such as the tubular yellow sponges and light-colored brachiopods (on mound at left). Near Left: A diorama of life late in the Triassic, the period that followed the Permian, shows many free-swimming organisms. Among them are a large coiled ammonite (center) and long nautiloids (both animals with tentacles like modern squids), as well as clams and snails.

the post-Paleozoic there is an increased richness and abundance of organisms competing for other resources.

Other lines of evidence seem to be consistent with this change in ecological complexity. The end-Permian extinction more adversely affected groups of animals with relatively low metabolic rates. Perhaps those that had higher metabolic rates could also exert better control over the diffusion of gases dissolved in seawater, enabling them to gain essential oxygen while excluding harmful toxins. Separately, taxa that formed skeletons from material other than calcium carbonate proved less vulnerable compared with those that were heavily calcified, most likely because they were less affected by acidification of seawater. This pruning of the evolutionary tree through the selectivity of mass extinction possibly opened the door to subsequent diversification of taxa whose ancestors had been present in the Paleozoic, but neither as diverse nor abundant as other groups that had a stronger foothold. Still, the reasons why this one mass extinction seems to have been such a game changer remain to be unraveled, as do the synergistic events that caused it.

THAT A “SIXTH MASS EXTINCTION” is currently underway is not hyperbole. In an assessment of the ecological health of the modern oceans, Jeremy Jackson at Scripps Institution of Oceanography describes a combination of greenhouse-gas buildup, ocean warming, increased acidification, massive nutrient runoff, pollution, and habitat destruction that has eerie similarities to our emerging picture of the end-Permian environment. The ocean contains large “dead zones” depleted in oxygen. Enormous coral reefs are dying. Reduced rates of calcification have been measured in a number of organisms. Assaulted as well by bacterial and toxic algal blooms and disease, diverse, complex marine communities and food chains are degrading into simpler ones. Overfishing by humans has disrupted marine communities, destroying their structural balance by removing the larger regulators of those systems.

The causes of the Great Dying and the current extinction event are not the same—humans were not a factor then, eruptions of flood basalts are not a factor now. Climatic conditions are different as well. We live in a cool interglacial period of geological history, not a hot, arid one. Atmospheric carbon dioxide levels during the end-Permian crisis may have been three to six times higher than the preindustrial levels of 200 years ago. What is staggering is the pace of modern environmental degradation, which is occurring in hundreds of years rather than over tens of thousands or more.

Many species will fail to adjust to this pace. It is too soon to say which ones. But a glance far back in time does tell us that the survivors, no matter how decimated, will eventually evolve new complex communities, as unfamiliar as we might find them.

Scott Lidgard, who earned a PhD in paleobiology from Johns Hopkins University, is an associate curator of fossil invertebrates at the Field Museum in Chicago. His research interests include the ecology and evolution of colonial bryozoans.

Peter J. Wagner earned his PhD in paleobiology from the University of Chicago and is now a curator of Paleozoic mollusks at the Smithsonian Institution's National Museum of Natural History (NMNH) in Washington, D.C.

Matthew A. Kosnik holds a PhD in paleobiology from the University of Chicago. His postdoctoral research has taken him to the NMNH and to James Cook University in Townsville, Australia. His research focuses on ecological and evolutionary processes in shallow marine environments.

All three have been involved with development of the Paleobiology Database, organized by an international community of scholars.

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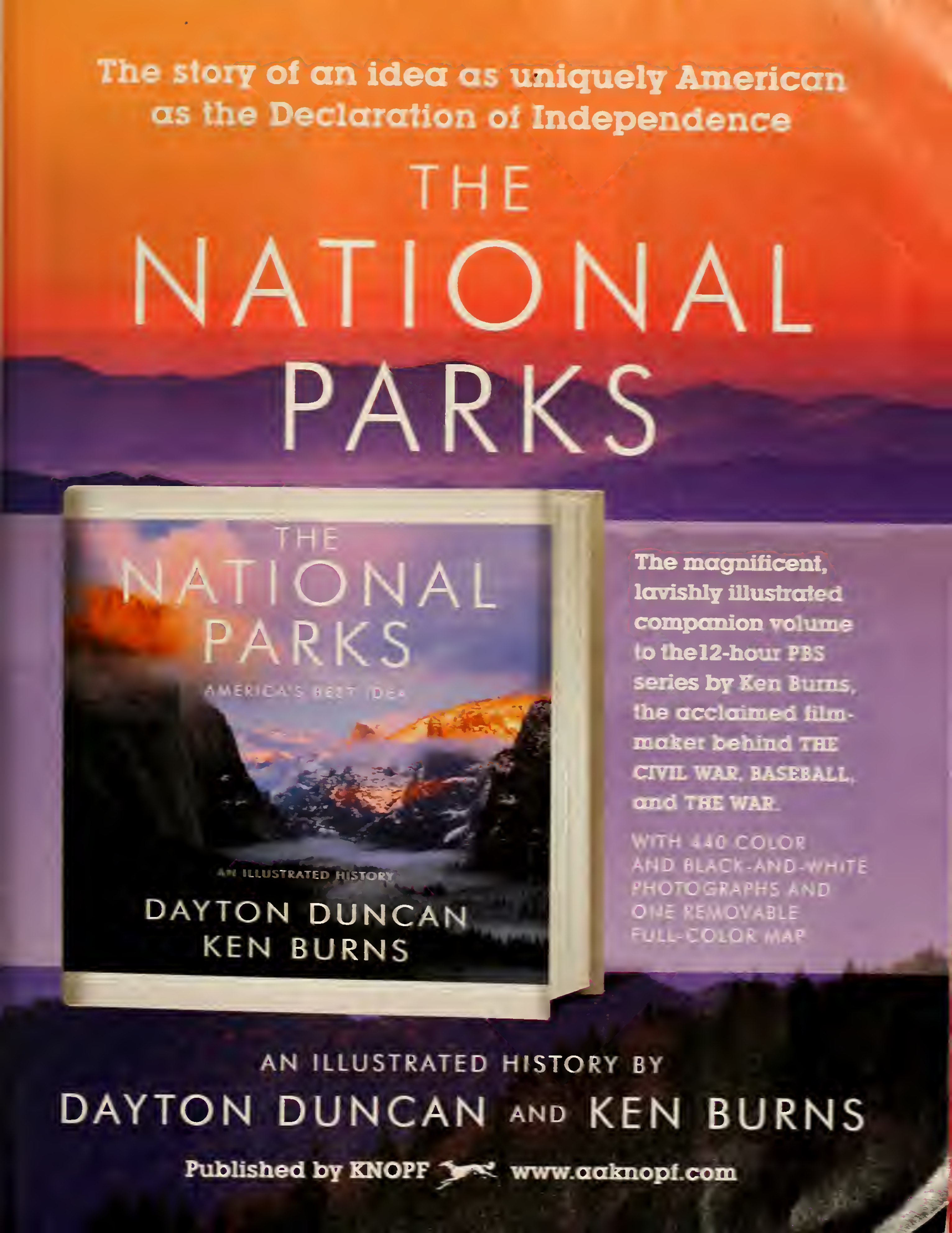
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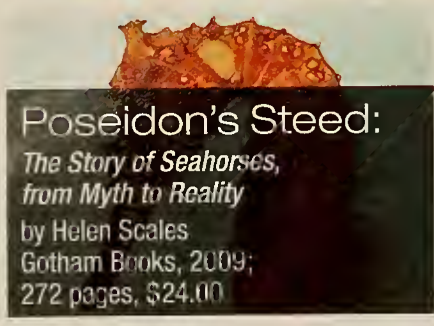


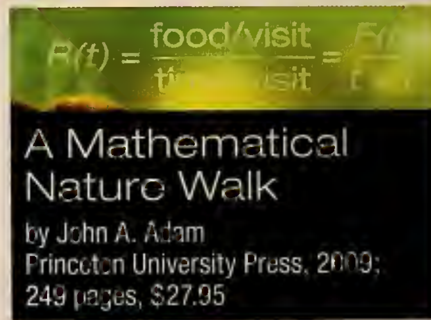
So bizarre is the seahorse, its disembodied head, neck, and tail decorated with extravagant filigree, that someone who had never seen a living specimen might dismiss it as fantasy—no more real than a mermaid or a unicorn. Not so. Marine biologist Helen Scales reassures us that seahorses not only exist, but are found in almost every marine environment around the globe. For all their apparent weirdness, they sport the standard anatomy of a fish: gills, internal air bladder, and spine. Straighten out their curlicue tails, which the fish use to grip vegetation, and they resemble their cousins, the long and slender pipefish.

Don't expect to spot seahorses at your local beach, however. Even Scales, who has spent a lot of time exploring under the waves, had to do quite a bit of hunting before she saw her first live seahorse. Timid and solitary creatures, seahorses cling to sea grass strands, mangrove roots, or knobs of coral, waiting to snatch small shrimp as they swim by. Because they can't swim far or fast themselves, seahorses evade predators—and curious ichthyologists—by changing the color of their skin to match their background, a disappearing act that is ideally suited to what Scales calls "life in the slow lane."

So what else is special about seahorses? For one thing, they can literally make their bodies talk, emitting sharp chirps and snaps by rubbing together two protuberances on their heads. For another, their males get pregnant. When two seahorses make love, it's the female who deposits eggs through a slender tube into a pouch on the belly of the male. From then on, dad's in charge, gestating the fertilized eggs for three weeks until the little sea colts are ready to emerge. Males even go through labor, which can last as long as three days. No sooner is his ordeal over, and the diminutive herd dispersed, than mom returns to possibly impregnate him again. Seahorses are monogamous, staying together for at least one breeding season, and often for a lifetime, up to ten years.

Unfortunately for seahorses, their fantastic appearance has given rise to a rich tradition of myths about their magical powers, in particular their ability to work wonder cures. The Greek physician Dioscorides, writing in the Roman Empire of the first century A.D., recommended a mixture of charred seahorse and goose fat as a remedy for baldness. Traditional Chinese medicine, which still flourishes today, incorporates seahorse in tablets to control cholesterol, increase virility, and treat a host of ailments from ulcers to bone fractures. As a result, there's a lively trade in seahorses, which, despite their elusiveness, are regularly caught as byproducts of commercial trawling.

And so the delicate seahorse is in trouble. Six of the thirty-seven known seahorse species are listed as "vulnerable" by the World Conservation Union, largely, Scales believes, as a result of the medicinal trade. Regulation of commercial fishing may help some. So may the promotion of alternatives to seahorse among practitioners of Chinese medicine: those in the know agree that English walnut seed and possibly human placenta have similar benefits. Equally important, though, is a book like this, elegant and engaging, that informs us about the marvels of these little creatures and exhorts us to help the seahorse keep on hanging on.

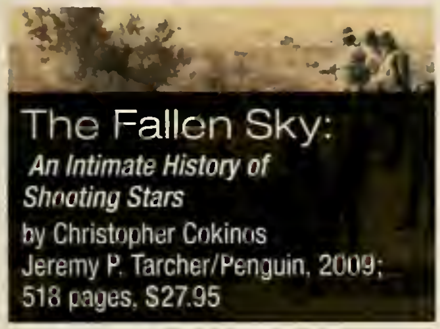


If you are a walker, as I am, your daypack probably contains sunscreen, a poncho, a floppy hat, and a pair of binoculars. After reading this snappy guide to the mathematics of the outdoors by John Adam, a professor of mathematics at Old Dominion University in Virginia, you might consider tossing in a programmable calculator.

Adam presents insights into patterns in nature that most of us never notice at all. Were you aware that the inside of a rainbow is brighter than the outside? That you can determine the distance of a mid-ocean storm by measuring the rate at which waves break on the shore? That you can look back over the stern of a ship and prove the Earth is round from the width of the wake where it disappears over the horizon? A sharp eye and an ingenious mind are at work on every page.

Adam presents these gems of nature lore as a sort of catechism. He poses nearly a hundred questions, most only a line or two, and follows each with detailed exegesis, usually invoking a bit of estimation, a bit of guesswork, and a bit of calculation. Why can you see farther in a heavy rainstorm than in a fog? It's because, for a given amount of moisture, the smaller drops in a fog have a larger surface area, and therefore block out more light. A rough calculation using the diameter of raindrops and mist-drops serves to demonstrate that, while you can see for more than a third of a mile in a typical rainstorm, you can barely see twenty feet in a typical fog. Like this example, many of the ones in the book employ nothing more than simple geometry and a few rules of thumb.

Adam's field guide is just the latest in a select literature I term "recreational science," which takes as its subject matter the little things in nature: shadows, halos around the Sun, the shapes of eggs, and the like. These are books that don't aim to solve the mysteries of the universe or tell you how to make a fuel-efficient engine, but simply want you to appreciate the workings of the everyday world. Read this book with pencil and paper in hand. Then go forth, enjoy the view, and impress your friends!



Long before men walked on the Moon, humans had touched the soil of alien worlds. More than 100 tons of extraterrestrial material shower the Earth every day. Most of it is in the form of tiny specks of rock and metal, the smallest of which drift to the ground unnoticed, while slightly larger pieces provide a brief fireworks show as they burn up in the atmosphere. But once in a while, a chunk the size of a walnut or bigger makes it to the ground intact; and even more infrequently, someone recognizes it as something curious and picks it up.

Nature writer Christopher Cokinos's unusual book appears at first to be a layman's guide to the science of meteorites, which provide important information on how the Earth and other planets formed. At its heart, though, *The Fallen Sky* is about the people who collect these bits of planetary history. They are a subculture of cosmic beachcombers, dreamers infected with a strain of interplanetary fever. In the 1880s, Eliza Kimberly, a Kansas farm wife, had the bug so bad that the growing pile of black rocks in her yard earned her the derisive local epithet of "the rock woman." But when academics started coming by to inspect the pile, and, better yet, started paying to lug the rocks away to their labs, Eliza had the last laugh. Her farmstead, renamed the Kansas Meteorite Farm, provided the Kimberly family with a new cash crop—a gift, as it were, from on high.

Daniel Barringer was an ambitious mining entrepreneur whose obsession with meteorites cost him a fortune. In 1902, he heard about a mile-wide hole in the desert near Flagstaff, Arizona, where numerous small iron meteorites had been found. The conventional wisdom was that this was the crater of an ancient volcanic steam explosion, but Barringer thought it was a scar left by an incoming meteorite, and that as much as $700 million worth of pure iron might still be buried in the crater floor. Over the next three decades, he drilled shaft after shaft, amassing only a mountain of debt for himself and his investors, and earning the general disdain of the geological community. But he was on the right track. The crater, we know today, was indeed caused by a 150-foot-wide meteoroid that collided with the Earth about 50,000 years ago, although—alas for Barringer—the object was vaporized by the explosive force of the impact.

The cast of characters here is a writer's dream: Harvey Nininger, who gave up a sedate academic position and a settled family life to accu-

Continued on page 42

FILM REVIEW

Enjoy and Conserve

By Daniel Lenihan

Early tourists at Yellowstone National Park

The National Parks:
America's Best Idea
Directed by Ken Burns

Florentine Films and
WETA Washington, D.C.
The six-episode series begins airing on PBS stations September 27.

Perhaps it's no surprise that Ken Burns would be the one to do it—create a documentary series that really does explain why America's national parks were, as the writer and historian Wallace Stegner said (quoting an admiring Brit), "the best idea we ever had." Splendid scenery is found in many nations; the difference is that it was in America that the natural landscape was first determined to be a national birthright and set aside for the many rather than the privileged.

The key point reinforced with each episode of the documentary is that conflict lies at the core of that "best idea." America, the land of the free, was also the land of Manifest Destiny, with an endless frontier available for the taking by simply heading west and displacing any aboriginal species, including humans, that got in the way. But somehow, the same American ethos that permitted the near destruction of the bison fostered the setting aside of millions of acres as *national* properties owned by all Americans, rather than as resources to be exploited by those living closest to them.

With the establishment of the National Park Service, the series considers how the nation reconciled the need for strict conservation (the mission of the parks) with the concept of "multiple use," in which resources are managed, extracted, and consumed to accrue the greatest good for the greatest number (the mission of the Forest Service). A common sociopolitical view—one that the film seems to ascribe to the Forest Service—is that natural resources were all put here by God for man's "wise use." On what basis, then, is there an argument for absolutely sacrosanct landscapes?

That conflict is artfully illustrated by showing how the San Francisco quake and firestorm became a justification for flooding part of Yosemite to construct a reservoir, supposedly to save the city from any such future catastrophe. Also brought out is the curious schizophrenia that underlies the mission of the National Park Service: to "provide for the enjoyment of," yet to "conserve" for "future generations." What a beautifully impossible mandate for park superintendents and rangers, who must work in a present political reality to meet the needs of a constituency yet to be born.

I only found two omissions from the twelve-hour series truly disappointing. One is the strict focus on areas of the national park system that have achieved "National Park" status, ignoring the greater number of National Monuments, National Seashores, National Historic Sites, and so on. Also, no attention was paid to submerged portions of parks (there are at least sixty units with significant underwater properties).

But on the whole, the series is excellent. Its subtext is that the story of the National Parks is the story of America. That gives the film the potential for either true greatness or true overreaching. It does not overreach.

A longer version of this review is available on our newly redesigned Web site, www.naturalhistorymag.com. *Daniel Lenihan, a frequent contributor to* Natural History, *is one of the world's leading underwater archaeologists. Founder of the National Park Service's Submerged Cultural Resources Unit, now named the Submerged Resources Center, he is the author of* Submerged: Adventures of America's Most Elite Underwater Archeology Team *(Newmarket Press, 2002).*

Shawn larger than actual size of 27 mm in diameter

Above: Contra Costa wallflower and other vegetation at Antioch Dunes; right: Antioch Dunes evening primrose

Dune Buggies

What is the sound of one katydid stridulating?

By Robert R. Dunn

David Rentz remembers the day in his childhood when his grandmother got down on her hands and knees and picked up a grasshopper for him to see. She was curious about the living world and wanted him to be, too. He was. And so it was hardly surprising when, as a teenager in the late 1950s, he became a volunteer curator of the crickets, grasshoppers, katydids, and their kin at the California Academy of Sciences in San Francisco. He loved their variety of scrapers, titillators, wing patterns, and most of all, songs. And then one day while looking through a drawer of katydids classified as *Neduba carinata,* Rentz came across an individual that looked out of place. According to the small tag impaled by the specimen pin, a kind of insect headstone, it had been collected in 1937 in an area known as the Antioch Dunes, just forty miles outside of San Francisco.

To hear what its song sounded like, Rentz needed to find a living specimen of the katydid. Jacques Helfer, a schoolteacher, wildlife illustrator, and beetle collector, guided him on a field trip to the Antioch Dunes in 1960. The dunes were formed from bits of mountains worked to pieces by glaciers and then blown into great piles of sand that rose at the confluence of the Sacramento and San Joaquin rivers. A sandy corridor had once connected the dunes with the Mojave Desert to the south. As climate changed, the corridor retreated, isolating the species living in the dunes from their Mojave kin. Rentz and Helfer plunged into that desert oasis.

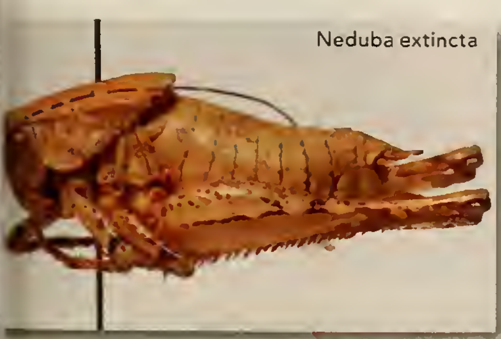
The setting was far from pristine habitat, however. During the mid-1800s, gold had been discovered near the dunes, and the town of Antioch was founded. Coal and copper too were soon mined; horses, sheep, and dairy cows grazed the local grasses. Entrepreneurs established a vineyard and a shipyard. The dunes were circumscribed by a railroad line, bracketed between electrical towers, and invaded by introduced plants. Their very sands were raided for asphalt and brick-making enterprises. Nevertheless, in the 1930s the Antioch Dunes became a popular place to look for new species, and many were identified. They included two plant subspecies, and two species and two subspecies of insects, known from nowhere else on Earth. Other insects were first collected in and named from the dunes before being found elsewhere.

In the years that followed, the dunes' vegetation was burned; sand mining intensified; and paper mills, a sewage treatment facility, and a gypsum plant were built close by. Arriving in the evening (prime katydid-listening time), Rentz and Helfer were thus greeted with fewer than a hundred untended acres along the south bank of the San Joaquin River. What they found was surreal: in the twilight, the white dust from the gypsum plant, coating the vegetation, made the landscape look like winter in New England.

The scene was inauspicious, but Rentz and Helfer walked and listened, hoping to hear a song that just might belong to a living *Neduba* katydid that resembled the unusual collected specimen. Initially, they just heard the white noise of town and the chirps of common species. And then they heard a distinct song, something wonderful and new. But it wasn't Rentz's *Neduba*. They followed the call and found another unfamiliar katydid—one that had been first collected in the 1930s but never formally identified. Years later, Rentz would name the species, *Idiostatus middlekauffi* as part of his 1973 PhD dissertation at the University of California, Berkeley.

The *I. middlekauffi* find was encouraging, but as Rentz and Helfer walked on into the night, they still heard no *Neduba*. Rentz returned to the dunes on several subsequent occasions, but still no luck. He waited for someone, anyone, to find it. Finally the boy scientist, now Dr. Rentz, decided the katydid deserved its own species name. He called it, pointedly, *Neduba extincta*.

In 1977, when he published his scientific description of *N. extincta*, Rentz wrote that the dunes had been so negatively affected by humans that their death knell had sounded. Indeed, today, two of the insects known only from the Antioch Dunes appear to be extinct—one of them, of course, *N. extincta*. A third hasn't been seen in more than twenty years, nor have other rare species, among them Rentz's *I. middlekauffi* katydid. But to protect Lange's metalmark butterfly—a subspecies unique to the dunes—and the two unique plant subspecies, the Antioch Dunes National Wildlife Refuge was established in 1980.


Neduba extincta

The name of the refuge almost dwarfs the area it embraces, two parcels that total only fifty-five acres. Still, the dunes are enjoying a fragile revival. Restoration efforts include trucking in local sand, contouring new dunes, weeding out invasive vegetation, and planting naked-stemmed buckwheat, the butterfly larva's only host. The two subspecies of plants found nowhere else on Earth, the Antioch Dunes evening primrose and the Contra Costa wallflower, still bloom in the spring. And during July and August, hundreds of Lange's metalmarks, some of them captive bred and released, open and shut their wings and then rise into the air.

Public access to the dunes is restricted, but refuge staff and local educators schedule guided tours and special events. And two or three times a month, much-needed volunteers plant seeds and clear away nonnative plants that threaten to choke out the fragile endemics. No one, according to the manager, has methodically searched for the lost insects of Antioch in twelve years. But if you go to the dunes to join the volunteers, keep your eyes and ears open. You may be lucky enough to see a Lange's metalmark. You may be luckier still and see one of the species gone missing.

As for *Neduba extincta*, its lone specimen, a male, still sits in a drawer, as if poised to leap out. And Rentz and his wife have long since leapt to Australia, where they live happily in the rainforest with cassowaries, brush turkeys—and a host of katydids that call out, though they are not yet named.

A frequent contributor to Natural History, ROBERT R. DUNN *is an ecologist in the Department of Biology at North Carolina State University in Raleigh.*

VISITOR INFORMATION
Antioch Dunes National Wildlife Refuge
501 Fulton Shipyard Road
Antioch, CA 94509
707-769-4200
www.fws.gov/sfbayrefuges/antioch/

HABITATS

Stabilized interior dunes support the endangered Antioch Dunes evening primrose and Contra Costa wallflower. Other native wildflowers include bluehead gilia, California croton, California poppy, deerweed, elegant clarkia, gumweed, Kellogg's tarweed, and telegraph weed. Shrubs or shrublike vegetation include coyote brush, Douglas's ragwort, Jimson weed, naked-stemmed buckwheat, San Joaquin snakeweed, silver bush lupine, and western ragweed. Nonnative wildflowers include rattail fescue, ripgut brome, slender oat, winter vetch, and yellow star thistle.

Coastal live oak woodland is named for its scrubby variety of oak tree (possibly a hybrid). Other native shrubs or trees are arroyo willow, elderberry, narrow-leaved willow, and toyon. A nonnative is the tree of heaven, regarded as a weedy species in many urban areas.

Coastal and valley freshwater marsh borders the river. Rare native wildflowers are Mason's lilaeopsis and Suisun Marsh aster. Among the more common wetland natives are California tule, cattail, common threesquare, Delta tule pea, floating marsh pennywort, low club rush, Sitka sedge, tufted hairgrass, and water ragwort. Nonnatives include giant reed, Himalayan blackberry, and pampas grass.

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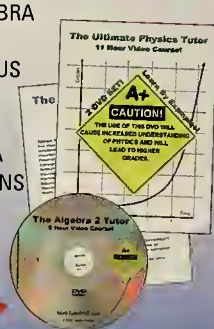

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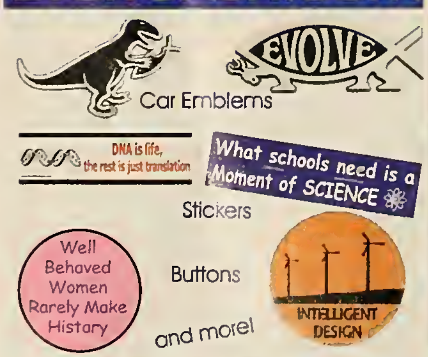

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Several feet below the Turritella Bed is a "Pecten Bed" consisting of a medium-grained, loosely compacted, orange-brown sandstone containing abundant individual shells of two species of scallop shells, *Argopecten abietis abietis* and *Oppenheimopecten vogdesi.* Both species reached a fairly large size, up to three or four inches in diameter. The Pecten Bed, occurring more deeply than the Turritella Bed, almost always occurs in the part of the city where the Broadway Faunal Horizon shell beds are present. These shell beds were described by Department of Paleontology curator Dr. Tom Deméré (1981) after the beds were uncovered during excavation for Horton Plaza. He referred to the shell beds collectively as the "Broadway Faunal Horizon."

These "Ice Age" deposits are from the Pleistocene Epoch with an estimated age of about 500,000 years old. *Turritella gonostoma, Laevicardium elatum,* and *Oppenheimopecten vogdesi* (as well as several other species occurring in these beds) are species that occur today along the west coast of Mexico, but are absent in southern California, indicating the ocean water of this time period was considerably warmer than it is today. Furthermore, all species found from these beds are species that are today typical of protected bays. Therefore, the shell beds of the Broadway Faunal Horizon provide evidence that in the late Pleistocene, while the mammoths lived on land, downtown San Diego consisted of a large, tropical bay.

Read Part II of this article in next month's Field Notes.

Foundation Profile: Helen K. and James S. Copley Foundation

For over a decade, the Helen K. and James S. Copley Foundation has generously supported the Museum. The Copley Foundation provided a major gift to the Museum's $40-million capital campaign, a project that more than doubled the building's size. The Foundation also demonstrated its commitment to cultural excellence by sponsoring two recent exhibitions, *Dead Sea Scrolls* and *Water: A California Story.* We thank the Helen K. and James S. Copley Foundation for helping to bring world-class exhibitions to San Diego.

Mia's Visit to the Museum

On April 23, the Paleontology Department hosted 9-year-old Mia Shand (far left) and her family on a visit arranged by the Make-a-Wish Foundation. Mia, who was diagnosed with a brain tumor in January, had a wish to participate in a real fossil dig. When she heard about the dig at the Thomas Jefferson School of Law construction site, she hoped to be a part of it. The San Diego Natural History Museum invited Mia to come see the fossils recovered from the site and meet the paleontologists who worked on the site and were now processing the fossils.

Maggie Carrino, Paleontology Lab Manager, gave the family a behind-the-scenes tour of the Paleo Department where Mia met the entire staff of "real" paleontologists. She was thrilled with the fossil experts who showed her the Museum's research collection of fossils, how they were cleaned, identified, organized, and stored. She even got to watch the cleaning of the bones from the Thomas Jefferson site.

Mia also spent time with Paleontologist Brad Riney, hearing about his dinosaur finds, beginning with his first at the age of 12.

Member Services

The Membership Department can be reached Monday through Friday, 9 AM–5 PM at 619.255.0275, or by e-mail at membership@sdnhm.org for assistance with any of the following:

- Benefits information
- Change of address
- Replacement cards
- Renewing or upgrading your membership
- Other questions regarding your membership

(Re)Introducing Eowyn Bates, Ann Laddon, and Donna Raub

The SDNHM Institutional Advancement Department is charged with spearheading ambitious fundraising goals for the current fiscal year and beyond. During this economic climate it is particularly important to stand on a solid foundation of fundraising practices and principles while welcoming new opportunities and ideas. The department has recently undergone an extensive evaluation and restructuring process and we are pleased to introduce the new senior staff.

Many of you may remember Ann Laddon (center)—she was an integral part of the Museum's Development Department from 1997–2002 during the building campaign. Ann considers the years she spent with the Museum as the most productive and professionally satisfying in her career. During her years at the Museum she developed an appreciation and dedication to the natural history of southern and Baja California, its unique and fragile beauty, and its rich environment. In July, Ann accepted the position of Vice President of Institutional Advancement and is excited to be back at the Museum.

Donna Raub (right) brings more than 20 years of experience in fundraising and development to the Museum as the new Director of Major Gifts and Planned Giving. She has worked as Director of Development and Major Gifts Officer for organizations such as Planned Parenthood, Mills College, Stanford University, UC Berkeley, and Santa Clara University. Donna has a MS in communications and journalism from San Diego State University and recently moved to Solana Beach from the Bay Area.

Eowyn Bates (left) is a familiar face at the Museum. Having served as the Director of Annual Fund and Membership Programs since 2005, Eowyn has recently been promoted to Director of Development and Membership. Before coming to the Museum, Eowyn worked at organizations including the Salk Institute, and Project Concern International. Eowyn grew up in northern Wisconsin and developed a bond with the outdoors on numerous adventures with her father, a naturalist and writer. She is delighted to have the opportunity to work for an organization where she is truly passionate about the mission.

With over 50 years of combined experience in a range of positions and organizations Ann, Donna, and Eowyn bring a wide breadth of insights and ideas. All three welcome your questions or concerns and can be reached at:

Ann Laddon, *aladdon@sdnhm.org, 619.255.0212*
Donna Raub, *draub@sdnhm.org, 619.255.0314*
Eowyn Bates, *ebates@sdnhm.org, 619.255.0172*

September Family Programs at the Museum

Wacky Science Sundays with Ms. Frizzle™ and The Magic School Bus©

Recommended for children ages 4–8.

Wahoo! Join us for live performances EVERY Sunday at the Museum. Get ready to explore the wild and wacky worlds of mysterious creatures, fascinating habitats, and phenomenal hands-on science! FREE with Museum admission.

Call the Frizzle hotline 619.232.3821 ext. 110 or visit www.sdnhm.org/frizzle for the latest information.

Sundays, 12:15 PM and 2:15 PM

Grandparent's Day on the Bay

Open to ages 6 and up.

Bring your grandparents for an introductory paddling lesson and a scenic paddle under the beautiful Bay Bridge to the Coronado Ferry Landing. Along the way, gaze across the blue waters of San Diego Bay to the stunning downtown skyline. Price includes equipment and paddling instruction. No previous kayaking or swimming experience is required.

Member $55 per adult; Nonmember $65 per adult; $20 per child age 6–12 paddling in a double kayak with a parent.

Sunday, September 13, 9 AM–1:30 PM

Fish Bellies: Art and Anatomy

Open to ages 8 and up.

Learn about fish from the inside out. Examine fish anatomy and physiology and how it compares to our own bodies. Show off your artistic side by making a fish print and learn which external features make a fish a fish. Become a scientist by dissecting a fish to discover which adaptations allow fish to survive.

Member $24 per adult/child pair; Nonmembers $32 per adult/child pair; $10 additional child (maximum 2 children per adult).

Saturday, September 19; 10 AM–noon

For more information or to register for programs, visit www.sdnhm.org or call 619.255.0203 (M–F).

New Exhibition at the Ordover Gallery at the San Diego Natural History Museum

Baja California

September 19, 2009–January 3, 2010.

This exhibition will feature spectacular imagery by *National Geographic* photographer, author, and expedition leader Ralph Lee Hopkins. In addition to photographs by Hopkins, outstanding images by American and Mexican photographers will also be shown.

ENDPAPER

Female shaman reads a client's fortune.

SEOKYONG LEE

A Shaman for New Times

By Laurel Kendall

Driving a bright red car with a Buddhist rosary and a talisman entwined around the rear-view mirror, Ms. Shin, as I'll call her here, collects me and a fellow anthropologist from the Inchon train station in 1992. Ms. Shin is a plump young woman with bright eyes, a sharp wit, and a capacity for emphatic conversation. She is also a gifted diviner, committed to preserving the knowledge of the old North Korean refugee shamans in her area. Like most modern-day Korean diviners and shamans, she is as much a therapist as a fortune-teller, and speaks of establishing good relationships with her clients so that they will leave her house in a happy frame of mind after a divination session. (Unlike most shamans, however, she does not perform *kut*—elaborate rituals in which gods and ancestors appear, speak, mime, and act in the person of costumed shamans.)

When we ask Ms. Shin about the kinds of problems clients bring to her, she surprises us: "In the past, sixty percent of the women were worried about adulterous husbands. Nowadays, if I ask a woman, 'Do you have a lover?' ninety percent admit to it." Ms. Shin sprinkles her speech with such statistics like a social commentator in a women's magazine, and offers her own analyses. She regrets the lack of a meaningful "women's culture" (*yŏsŏng munhwa*) to occupy the time and energy of modern South Korean housewives.

When my colleague observes that the subjects of our anthropological interviews would probably never admit to adultery, Ms. Shin soon has us in giggles as she compares herself to a doctor: "You go to the doctor because you want to know what's wrong, so you strip off your brassiere, you strip off your panties, you bare everything. It's the same with me. They come to me because there's something they want to know. They set their money down, and then it all comes out."

Subsequently, in the late 1990s, Ms. Shin embarked on a campaign to marshal the Seoul and Inchon shamans into an organized religion. She saw that as the only means of gaining respect for an occupation that for most of the twentieth century had been low in status, regarded as superstition. When the project collapsed a few years later, undermined by acrimony and rivalries within the shaman community, the deeply disappointed Ms. Shin dropped out of sight, and I lost touch with her.

A group of Korean shamans attends an international conference at Ewha Women's University in Seoul in 2005 to hear what scholars have to say about their rituals. A strapping young *paksu*, or male shaman, in a modern version of traditional garb, seems to be their leader. He greets me by my Korean name: "Kyŏngdallae-ssi! Don't you know me? You've interviewed me at my house." I smile but do not recognize him.

"I'm Ms. Shin!"

Happy to see her again but also flustered, I stammer an apology: "You've cut your hair. You look different."

"And lost weight," she adds. She has, and her new appearance suits her. Where I remembered a heavy, laconic, and casually groomed young woman, the new Ms. Shin, dressed in immaculate white, walks with a swagger. She seems more at home in her body than in the past, with gestures to match the energy of her voice and intellect—or perhaps she is simply happier.

Researchers who know her well tell me that she dresses like a man to be an effective manager for a team of shamans. That team is dedicated to performing a series of *kut* for the former Korean "comfort women," who had been conscripted as military prostitutes for the Japanese Imperial Army. Adopting the role usually filled by a male at the head of a shamans' advocacy organization, the new Ms. Shin deals effectively with provincial officials who are unused to conducting business with a woman. Perhaps she has finally found a way to unify shamans around a common cause.

I think of another visionary who cut her hair and dressed like a boy to do battle: Joan of Arc.

Laurel Kendall is Curator of Asian Ethnographic Collections in the Anthropology Division at the American Museum of Natural History and has been encountering Korean shamans for the last thirty years. This story is adapted from her forthcoming book, Shamans, Nostalgias, and the IMF: South Korean Popular Religion in Motion *(University of Hawaii Press, 2009).*

Ceremonial altar set up by a shaman in Seoul, South Korea


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