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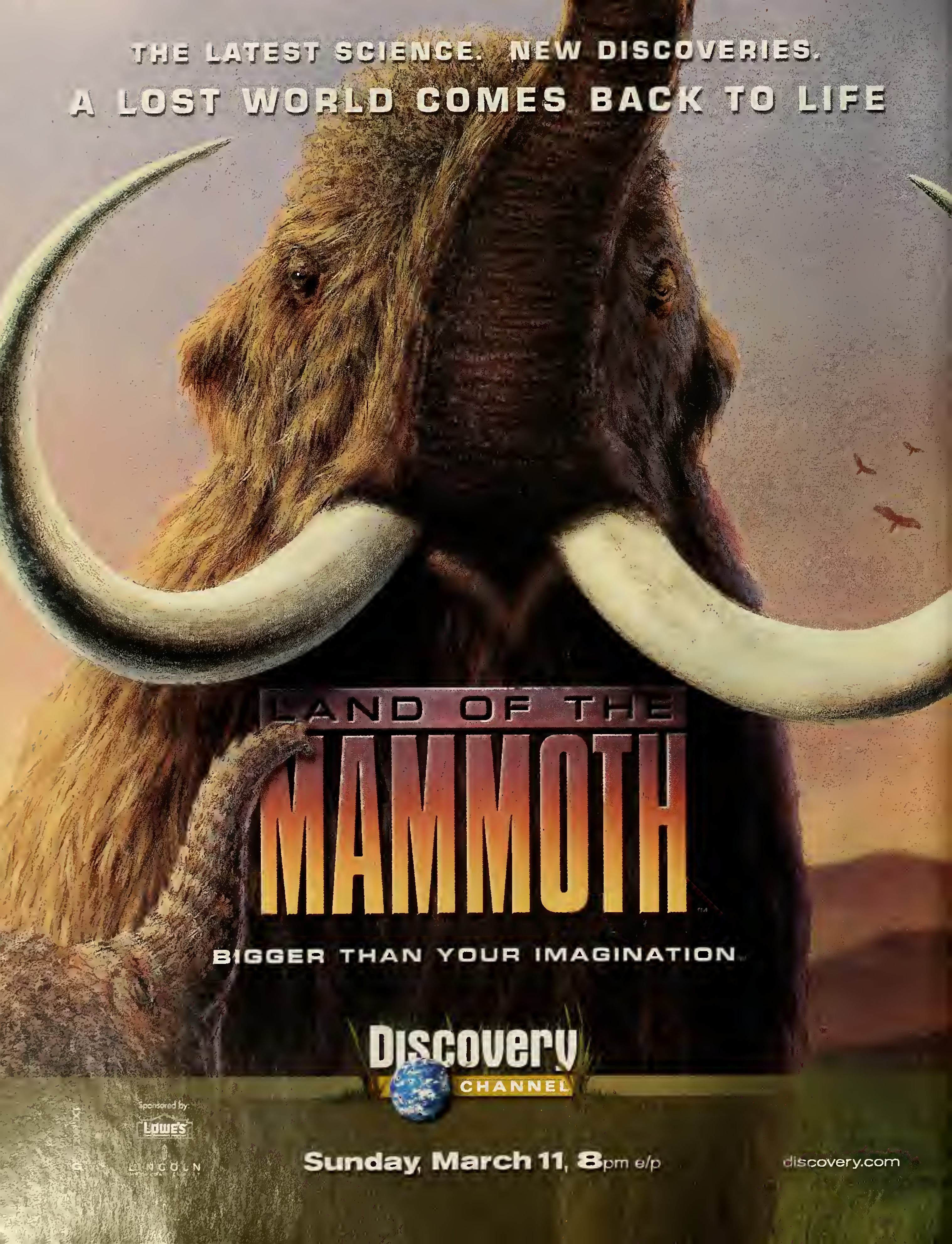
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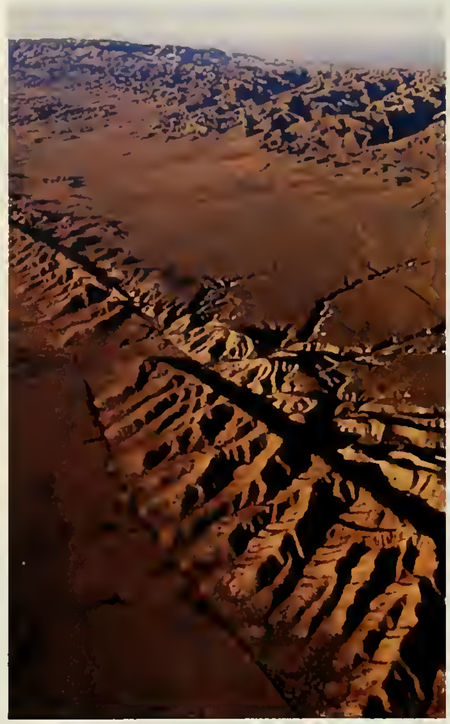
MARCH 2001 VOLUME 110 NUMBER 2

FEATURES

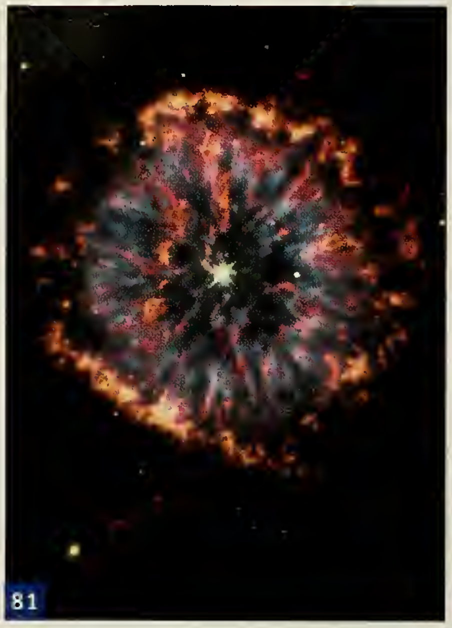


COVER The seven-spotted ladybird beetle is found in Japan, a country with an insect-friendly culture.

STORY BEGINS ON PAGE 70

PHOTOGRAPH BY HIROSHI OGAWA; NATURE PRODUCTION

DEPARTMENTS



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UP FRONT

In Defense of Larvae

Larva. To a lot of people, the word signifies something half-formed, ugly, and likely to devour food stores, winter clothing, or green leaves. As a rule, we glorify the butterfly and dismiss the caterpillar. Exceptions may be made for tadpoles, which at least, like us, are vertebrates. Perhaps humans are inclined to this form of prejudice because we are direct developers, going from babyhood to reproductive maturity without changing much more than our bodily proportions. Yes, as embryos we have gills, and along the way to adulthood we pick up a few secondary sex characteristics, but we do not truly metamorphose. And when fictional humans undergo transformations in books and films, it's almost always bad news (think Gregor Samsa in Kafka's "Metamorphosis" or Vincent Price in *The Fly*).


A scale worm larva

PETER PARKS; IMAGE QUEST 3D

Fortunately for *Natural History*'s readers, some people appreciate metamorphosis and have made the study of larvae an important part of their life's work. One is evolutionary biologist Gregory A. Wray, who in this issue's special section, "A World Apart" (page 52), provides a corrective to direct-developers' chauvinism by pointing out that the larval lifestyle is the most common developmental pathway in the animal kingdom. Sea stars, nudibranchs, sea lilies, corals, clams, and barnacles are among the multitude of marine invertebrate organisms that spend days or months in larval form, swimming or drifting near the surface of the world's oceans. For Wray and the other seven scientists who write about larvae this month, these intermediate forms offer beauty, mystery, and a wealth of insight into developmental biology.—*Ellen Goldensohn*

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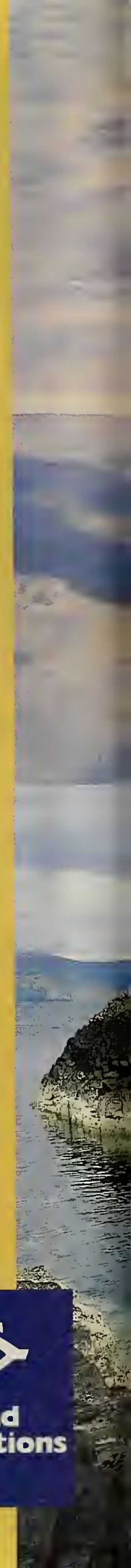

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LETTERS

Word Count

In his article on the evolution of language, *"Homo Grammaticus"* (12/00–1/01), Martin A. Nowak states that "English has about 100,000 words." But an article in the December 2000 issue of *Smithsonian* notes that English has "a total vocabulary of maybe two million words." There is a wide disparity between the two figures. Could you shed some light on which is the more accurate total?

Don Bessette
Wassaic, New York

If I counted every word in the *Oxford English Dictionary,* would I come up with a number reasonably close to the 100,000 quoted by Martin A. Nowak? And would an ordinary seventeen-year-old really know half of these?

H. (Morrie) Kuhlman
via e-mail

THE EDITORS REPLY: Psychologists, linguists, and dictionary publishers use different methods to derive their estimates of the number of words in a language. Nowak's figure is conservative. The roots and stems of words, derivatives and compounds, suffixes and prefixes, proper names, acronyms, and the words for numbers can all come into play when totaling words in a language and when estimating the number of words in an individual's vocabulary. For references, as well as a readable discussion of how some of these variable figures are reached, Nowak recommends Steven Pinker's book *The Language Instinct* (HarperCollins, 1994). Pinker maintains that "people can recognize vastly more words than they have occasion to use in some fixed period of time or space," and he believes that an average high-school graduate would probably be credited with around 60,000 words. Nowak also encourages interested readers to look at W. E. Nagy et al., "The Acquisition of Morphology: Learning the Contribution of Suffixes to the Meanings of Derivatives" (*Journal of Reading Behavior* 25, 1993) and W. E. Nagy and R. C. Anderson, "How Many Words Are There in Printed School English?" (*Reading Research Quarterly* 19, 1984).

Expedition of Two

The note on the 1943–44 Paricutín Expedition to Mexico ("An Expedition Notebook, 1900–2000," 12/00–1/01 supplement) brought back memories, for I went to see that volcano with my sister in August 1944. We went by bus from Uruapan to get as close as possible. When the bus could go no farther, we mounted horses and made our way down a steep incline. Everywhere there was desolation—trees black

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and bare-limbed and the ground covered with gritty black ash. Such utter desolation, yet, scattered here and there, white mountain poppies managed to push up through the ash.

The lava flow ended abruptly in a jumbled high wall. A short distance away rose the bell tower of a church, all that remained visible of the village of San Juan Parangaricutiro. My sister and I climbed up the ragged lava with great care. From deep crevices we could feel the heat where lava had not as yet cooled from the last flow. By this time it was getting dark, and a misty rain was falling. We made our way over the lava and walked into the shelter of the open bell tower. We stood there in the dark, listening to the roar of the volcano beyond, a sound like continuous thunder, and watched fiery boulders shoot into the air. Some fell back into the crater; others hit the lip and went bouncing down the sides of the volcano in a shower of sparks while behind us the rain spit and sizzled in pockets of still-hot lava. Awesome memories. Thank you.

Doris Hopper
Jacksonville, Illinois

Nerd Humor

I read Neil de Grasse Tyson's article on the laws of physics ("Universe," 11/00) and found his point about the universality of laws based on numerous observations and experiments to be well made. I loved the reference to his old T-shirt bearing the words "Obey Gravity." I have one that states "Why Fight Entropy?" Of course, it is falling apart.

Jim Massa
via e-mail

First Fight

In "Who's on First?" ("Reviews," 7/00–8/00), Anna Curtenius Roosevelt reviews my book *The Settlement of the Americas: A New Prehistory* and E. James Dixon's book *Bones, Boats, and Bison: Archeology and the First Colonization of Western North America.* Readers who are unacquainted with the archaeology of the first Americans may be impressed by Roosevelt's assertions. But in response, I urge them to look at two publications that appeared in a scientific journal and that refute her claims. They are (1) D. J. Meltzer et al., "On the Pleistocene Antiquity of Monte Verde, Southern Chile" (*American Antiquity* 62:4, 1997) and (2) R. E. Taylor and C. V. Haynes, "Radiocarbon Analysis of Modern Organics at Monte Verde, Chile: No Evidence for a Local Reservoir Effect" (*American Antiquity* 64:3, 1999).

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CONTRIBUTORS

The impending birth of his first child inspired **Carl Zimmer** to write about the genealogy of the whole human family ("'After You, Eve,'" page 32). This article marks the inauguration of *Natural History*'s new bimonthly column "The Evolutionary Front," in which Zimmer explores the latest research and thinking about evolution. For almost two years, Zimmer has been responsible for the magazine's "Biomechanics" column, which will be taken over by other writers following the April 2001 issue. A former senior editor at *Discover* and a contributor to *National Geographic, Science, Audubon,* and *Nature,* Zimmer is the author of *At the Water's Edge: Macroevolution and the Transformation of Life* (Free Press, 1998) and *Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures* (Free Press, 2000). His next book, to be published this fall by HarperCollins, is the companion to an upcoming PBS television documentary on evolution.

To learn more about *Homo erectus pekinensis,* **Noel T. Boaz** and **Russell L. Ciochon** ("The Scavenging of 'Peking Man,'" page 46) visited the site in China where the remains of this early human relative were discovered and also carefully reviewed the fossils, fossil casts, and related materials stored in museum collections. Collaborating with Chinese paleontologists Xu Qinqi (center) and Liu Jinyi (not pictured), Boaz (right) and Ciochon (left) uncovered new evidence concerning the fate of these Ice Age people and their relationship with the animals that shared their territory. Boaz and Ciochon first met while attending graduate school at the University of California, Berkeley, and "cut their teeth" on bone research by serving on the Omo Research Expedition to southern Ethiopia. Boaz subsequently led expeditions to the Libyan Sahara and to the western Great Rift Valley of Uganda and the Democratic Republic of Congo, while Ciochon has organized expeditions to Myanmar, Vietnam, China, and Indonesia. Boaz is a professor of anatomy at the Ross University School of Medicine in Dominica, West Indies, and Ciochon is a professor of anthropology at the University of Iowa.

Raised in cities and towns east of the Mississippi River, seismologist **Susan Elizabeth Hough** ("The Aftershocks That Weren't," page 64) became interested in earthquakes during her undergraduate years at the University of California, Berkeley, when she discovered that she could put her mathematical talents to use to help solve socially relevant problems. She received her doctorate from Scripps Institution of Oceanography, spent four years as a postdoc at Columbia University, and has worked for the U.S. Geological Survey in Pasadena, California, for the past nine years. Hough (pictured here with her youngest son, Paul) particularly enjoyed her research on the 1811–12 New Madrid quakes, in part because it gave her an opportunity to work with her father, a professor of political science at Duke University. "He helped me to understand the importance of seeing the information from a historical rather than purely scientific perspective," she says. Hough is currently finishing *Earth Shaking Science,* aimed at the general reader and scheduled for publication next year by Princeton University Press.

A native of Ath, near Brussels, **Erik L. Laurent** ("Mushi," page 70) has dual credentials as a zoologist and a cultural anthropologist. He studied the Japanese language in Paris and then pursued fieldwork in Japan. While working in the mountain village of Nagano, he got to know the local silkworm breeders; later, while living in a seaside temple in Kayama, he worked with rice farmers. Wherever Laurent went in Japan, he was impressed with the prominence of insects in the national culture. "You can't escape insects in Japan," Laurent says. "They eat crops, and some, such as locusts, are eaten by people. They figure in poetry and novels as symbols of life, death, and change." Having spent a decade of fieldwork on *mushi*, Laurent now plans to study human sexuality in Japanese culture.

James Warwick ("The Natural Moment," page 88) started taking photography seriously in 1995, just after graduating from the University of Oxford with a degree in materials science. He was inspired by a trip to Kenya and has since made excursions to the Kalahari Desert, Namibia, and India. Most recently he visited the Wolong Nature Reserve in China to photograph pandas. Warwick strives for evocative ways to capture his subject. In his image of a starling flock over Brighton's West Pier, taken with a Nikon F90X and a 28–80mm lens, he used a slow shutter speed that helped to give "an Impressionist feel to the composition." Warwick (www.jameswarwick.co.uk/) won two awards in the 1998 BG Wildlife Photographer of the Year competition, and his work has appeared in journals worldwide. He resides on the coast of the English Channel, not far from the West Pier.

An associate professor of biology at Duke University, **Gregory A. Wray** ("A World Apart," page 52) wrote on sea stars and other echinoderms in the December 1998–January 1999 issue of *Natural History*. That article ("Body Builders of the Sea"), coauthored with Rudolf A. Raff, prompted our editors to put together the present set of articles on marine invertebrates. Wray, right, continues to study the evolution of developmental mechanisms in echinoderms (as well as in ants). The peculiar anatomy of marine larvae was what first sparked his interest in asking how natural selection shapes the way an animal develops, a question that led in turn to his current research on the evolution of gene networks in embryos and larvae. Wife and husband **Elizabeth J. Balser** and **William B. Jaeckle** ("And Then There Were Two," page 54) are assistant professors in the department of biology at Illinois Wesleyan University in Bloomington, Illinois. They welcome the chance afforded by ocean plankton to explore the diversity of larval form and function and hope soon to identify, down to the species level, the cloning larvae they are studying. Balser provided the videos of marine invertebrate larvae viewable on *Natural History*'s Web site (www.naturalhistory.com) this month. **Steven Morgan** and **Skyli McAfee** ("Getting to the Point," page 57), another husband-and-wife team, are researchers at Bodega Marine Laboratory in California. Morgan is also an associate professor in the department of environmental science and policy at the University of California, Davis; McAfee is currently studying white sharks off the California coast. Most of Morgan's research has centered on the complex dynamics of populations at the land-sea margin—a focus he feels is essential if we are to "fully understand, and conserve, marine life in the face of a burgeoning human population." **Larry R. McEdward** ("The Long and the Short of It," page 58) is an associate professor in the department of zoology at the University of Florida. He conducts research on echinoderm larvae in the Florida Keys and the San Juan Islands of Washington State. His recent research has involved about equal parts diving, lab studies, computer modeling, and mountain biking. A senior scientist at Harbor Branch Oceanographic Institution in Fort Pierce, Florida, and head of the institution's department of larval ecology, **Craig M. Young** ("Out of the Frying Pan, Into the Freezer," page 61) has participated in more than sixty deep-sea research cruises and has visited the seafloor more than a hundred times. He is senior editor of *The Atlas of Marine Invertebrate Larvae*, forthcoming in July from Academic Press. **Richard Strathmann** ("A Method for the Masses," page 62) is a professor of zoology and associate director of the Friday Harbor Laboratories on San Juan Island. He explains his interest in marine embryos and larvae very simply and in a way that is surely true for all his colleagues: "Because they are beautiful and I want to understand their form." Inspired by early-twentieth-century English embryologist and poet Walter Garstang, Strathmann encourages his students to write poems of their own about larvae.

IN SUM

DADDY'S NO BOOB According to some evolutionary biologists, males will act to favor the reproduction of their own genes at the expense of their rivals' genes. Male blue-footed boobies provide extensive parental care, including defending the nest, incubating the eggs, and helping to feed the chicks.

How can males prevent their prodigious labors in the seabird colony from profiting other males that may try to cuckold them while they are off gathering food? According to Marcela Osorio-Beristain and Hugh Drummond, of the Universidad Nacional Autónoma de México, when an egg's paternity is in doubt, some male boobies push it out of the nest.

To test the male birds' reactions to eggs that may have been fertilized in their absence, the researchers (working on Isla Isabel, off Mexico's Pacific coast) removed a number of males from their nesting territory for ten to

Male booby destroying egg

MARK JONES

twelve hours and then returned them to their mates. One group of males was removed a few days before their females' fertile period (about a week before females lay their eggs); a control group had been temporarily isolated several weeks earlier. The scientists found that females did not suddenly become promiscuous while their mates were away. Some copulated with other males, but the rate of these pairings was low. Yet of the males sequestered just before the females' fertile period, 43 percent expelled the first-laid egg from the nest, although none of the control males did so.

The researchers concluded that a large proportion of male boobies will eliminate any possibility of lavishing their efforts on a "deadbeat dad's" offspring by destroying eggs of questionable paternity—even though some of them could be their own. ("Male Boobies Expel Eggs When Paternity Is in Doubt," *Behaviorol Ecology* 12:1, 2000)

SMART SLIME Scientists at the Bio-Mimetic Control Research Center in Nagoya, Japan, placed blobs of the single-celled amoeba-like organism *Physarum polycephalum* inside a miniature maze in which four different routes led to food (ground oat flakes) placed at the start and end points. In a series of trials, the slime organism consistently chose the shortest path to reach the prize.

Maze-solving slime

TOSHIYUKI NAKAGAKI

Classified as fungi, slime molds seem to share characteristics with both plants and animals. Like other fungi, they reproduce with spores, yet like amoebas, they can change shape and extend pseudopodia—tubelike legs with which they reach out to move and to absorb food. When pieces of a *P. polycephalum* were placed in the maze, they spread and coalesced to form a single organism spanning the shortest route from start to end. Then the mold extended its pseudopodia to connect the two food sources, reaching for a double helping.

The research team, led by Toshiyuki Nakagaki, concluded that the organism changes shape to maximize foraging efficiency, eventually forming one thick tube covering the shortest distance between food sources—a "cellular computation" demonstrating a "primitive intelligence." ("Maze-Solving by an Amoeboid Organism," *Nature* 407, 2000)

BALLISTIC TONGUE Chameleons are well known for being able to change color but also for their spectacular ability to capture prey by shooting out their long, sticky tongues. While many other kinds of lizards can extend their tongues to seize small prey, only chameleons have evolved a powerful suction device: a pouch on the lingual tip. This pouch enables them to grab birds and lizards as heavy as 15 percent of the chameleons' body weight—a feat comparable to a 150-pound man lifting a 22-pound weight with his tongue. Using high-speed video, X rays, and electromyography, a team led by Anthony Herrel, of the University of Antwerp, and Jay Meyers, of Northern Arizona University, has elucidated the mechanism in various chameleon species.

Herpetologists already knew that chameleons had a pair of pouch-retractor muscles in their tongues, but it was thought that the pouch splayed open on contact with prey, creating suction. Herrel, Meyers, and colleagues have shown that these muscles actually open the pouch just before contact and that two modified muscles then pull the tongue pad inward. (When the researchers cut the special nerves that extend into the pouch-retractor muscles, the chameleons were unable to hold onto their targeted meal.) These intricate, coordinated movements, including the full retraction of the tongue with its captive, are completed in less than half a second. The suction adaptation, the team believes, arose when the lizards took to the trees, where targeted prey would fall if not instantly well secured. ("The Mechanics of Prey Prehension in Chameleons," *Journal of Experimental Biology* 203, 2000)

—*Richard Milner*

X ray of a chameleon extending its tongue

JAY MEYERS AND ANTHONY HERREL

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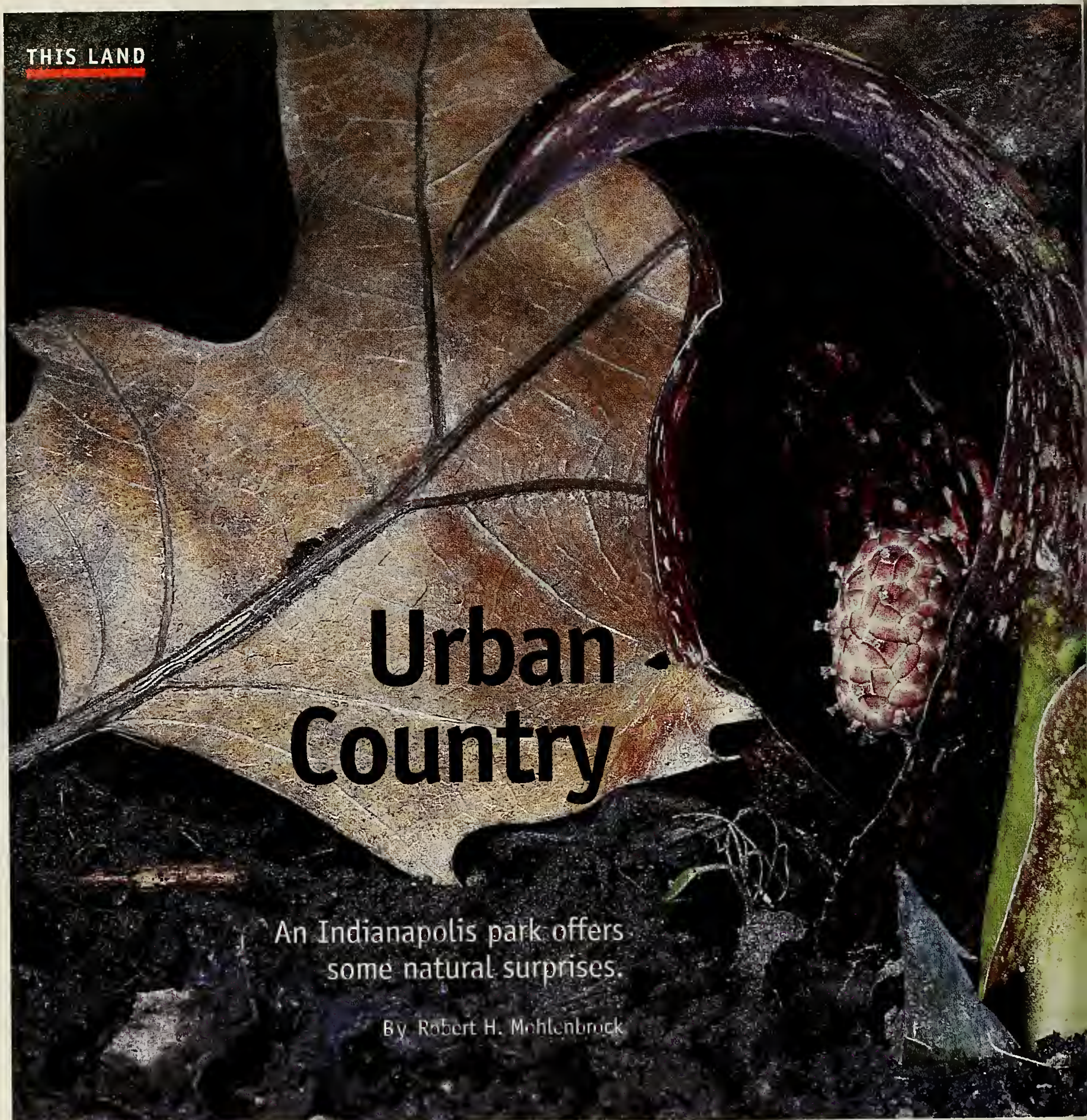

Urban Country

An Indianapolis park offers some natural surprises.

By Robert H. Mohlenbrock

In 1916 John Holliday, who founded the *Indianapolis News* and the Indiana National Bank, donated his country estate to Indianapolis for family recreation and nature study. Today, managed by the Indianapolis Department of Parks and Recreation (IndyParks), it provides an enclave within the city limits where local residents and visitors to the state capital can sample an array of natural habitats. Covering eighty-three acres, Holliday Park borders Indiana's White River, which originates near the state's eastern edge and snakes southwest, taking a circuitous route through Indianapolis and finally emptying into the Wabash River. The heavily wooded park is crisscrossed by trails, some with boardwalks that help the hiker negotiate the wetter zones.

When the White River is at normal stage, it is bordered by a

Skunk cabbage

JAMES P. ROWAN

narrow, muddy beach. Wetland plants grow in shallow water nearby, while the inland floodplain is covered with tree species that can tolerate periodic flooding. Farther off, low hills are home to a drier, upland forest containing a wide variety of trees, shrubs, and wildflowers.

Because of the unique structure of its seed capsules, lopseed *(Phryma leptostachya)*, a wildflower of the upland woods, has a family classification all its own. Most botanists believe it is distantly related to verbenas. It has pink blooms and, for a plant that is often less than a foot tall, relatively large leaves. The seed capsules, shaped somewhat like parrots, lie flat against the stem and point straight down.

Several natural springs on the hill slopes yield clear, cool water that trickles in rivulets toward the river. A mesic (moist) forest, where wildflowers bloom abundantly in spring, covers a small area near the foot of the hills. And at the convergence of the rivulets is an extensive wetland known as a fen, a boglike habitat more frequently found in northern Indiana, northern Illinois, Michigan, and Canada.

Whereas bogs are acidic, the water in a fen is basic, owing to the presence of bedrock composed of limestone or dolomite. Some wetland plants do well in either habitat, but others are more restricted. Plants at Holliday Park that are usually confined to fens are swamp blue aster, speckled joe-pye weed, and a rather rare species of pink turtlehead.

Stepping out of Holliday Park and heading south just one mile, visitors will encounter a historic residential zone that lines Meridian Street. With its huge homes, this narrow, tree-lined corridor between 38th Street and 57th Street is an elegant reminder of Victorian-era Indianapolis.

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

For visitor information, contact:
Holliday Park Nature Center
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www.indygov.org/indyparks

HABITATS

Shoreline plants include soft-stem bulrush, hardstem bulrush, river bulrush, and an aquatic, purple-petaled wildflower known as water willow. Although its somewhat narrow leaves are similar to those of willow trees, water willow is actually a member of a small group of colorful flowering plants related to wild petunias (which, incidentally, are unrelated to cultivated petunias).

Floodplain forest is thick with green ash, American elm, sycamore, cottonwood, and silver maple, with box elder near the water's edge. In early spring, white-flowering bulbous cress and waxy yellow swamp buttercup provide bright splashes on the forest floor. By mid-May, coarse herbs begin to fill the understory, and in summer their junglelike growth can make hiking difficult. A further deterrent is the prevalence of wood nettle and stinging nettle, which have acid-tipped hairs on their stems and leaves. Another nettle, known as golden glow, is a robust plant whose late-summer flower heads resemble those of its cousin, black-eyed Susan, except that those of golden glow have a yellow rather than a brown center.

JOE LEMONNIER


THOMAS A. POTTER; HOLLIDAY PARK NATURE CENTER

The White River viewed from Holliday Park

Mesic forest is dominated by Ohio buckeye, green ash, tulip poplar, and sugar maple. Here and there is a blue ash, unusual among ashes because of its square twigs. The dense shade of the trees creates a rich habitat for moisture-loving shrubs and wildflowers. Spicebush, with its pleasantly scented leaves, and bladdernut, with its inflated fruits, are the chief shrubs. One bladdernut growing here is certainly among the largest of its kind in the world, having a trunk diameter of six inches. The wildflowers, many of which bloom in May, include waterleaf, wild ginger, red trillium, Jack-in-the-pulpit, smooth and woolly blue violet, Solomon's seal, false Solomon's seal, and enchanter's nightshade. Missouri ironweed, zigzag goldenrod, arrow-leaved blue aster, and late boneset provide a second wave of blossoms in autumn.

Upland woods contain red mulberry, slippery elm, white ash, and wild black cherry. Black oak, red oak, chinquapin oak, bitternut hickory, and pignut hickory are common near hill summits, where the driest conditions prevail. Spring-blooming wildflowers are the broad-leaved spiderwort, downy yellow violet, and hairy phlox. Few plants flower in the upland woods during the summer, although lopseed is fairly common.

Fen plants include watercress and wild forget-me-not, which grow in clear, flowing water. Watercress, whose leaves are a delicacy in salads, has flowers with four white petals; wild forget-me-not has five-petaled blue flowers with a yellow center. Broad-leaved arrowhead and lizard's-tail are found where the water is deepest, while skunk cabbage, with its huge leaves, lines the perimeter of the fen. A typical wildflower is obedient plant (so named because its flowers can be turned in any direction and, once released, will remain there for some time). Others are swamp blue aster, a pink turtlehead *(Chelone obliqua)*, speckled joe-pye weed, great lobelia, Pennsylvania buttercup, and several kinds of sedges. Black ash is the only tree species—one that is rare in central Indiana but more common in the northern counties.


RICHARD SHIELL; DEMBINSKY PHOTO ASSOCIATES

Ohio buckeye


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Solomon's seal

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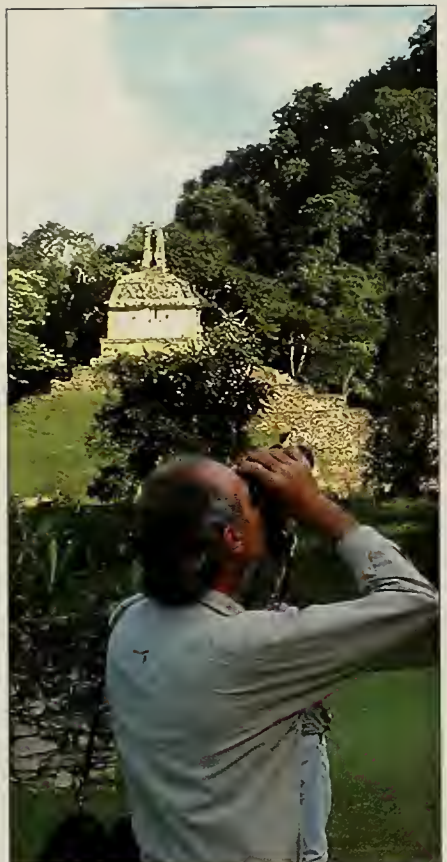

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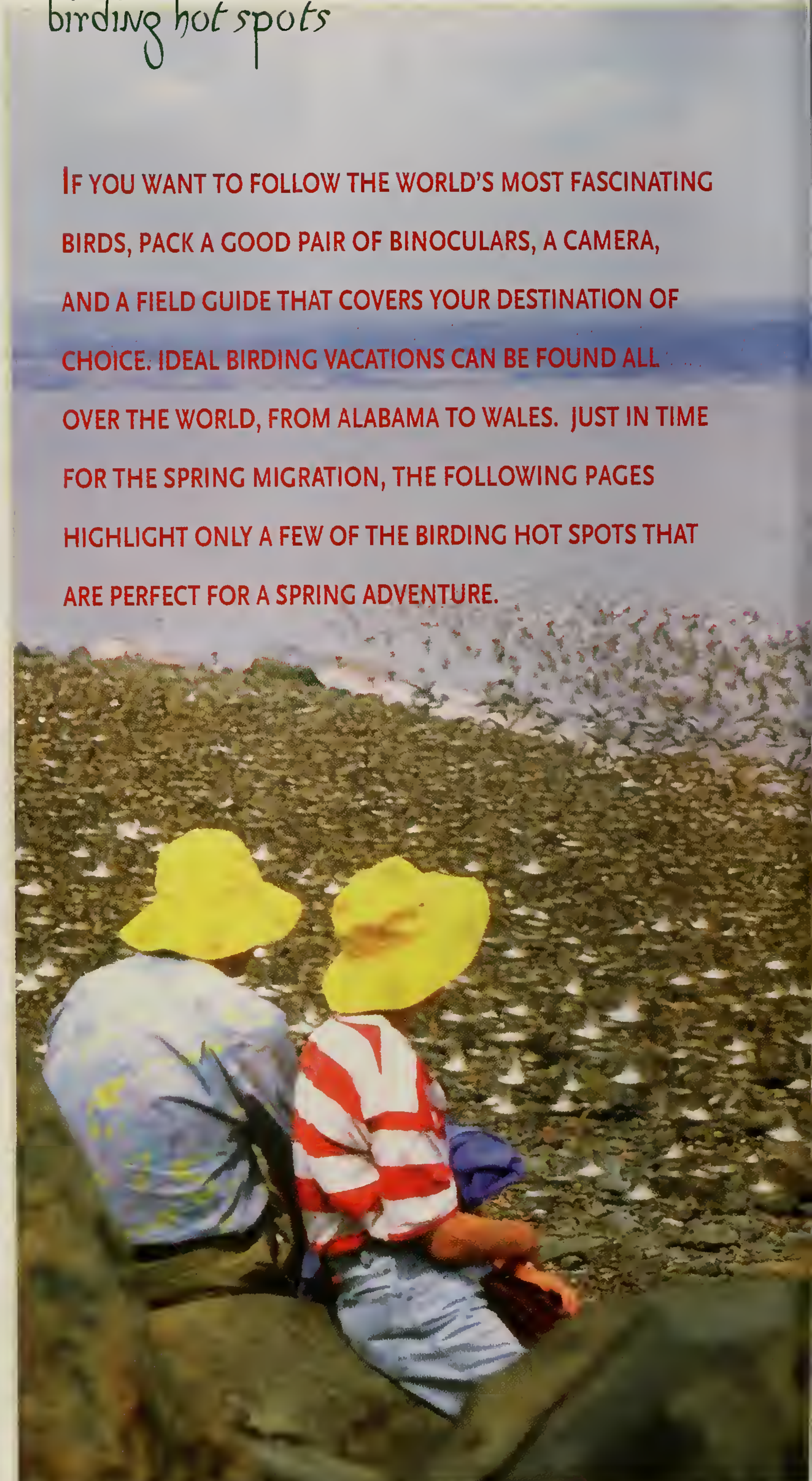

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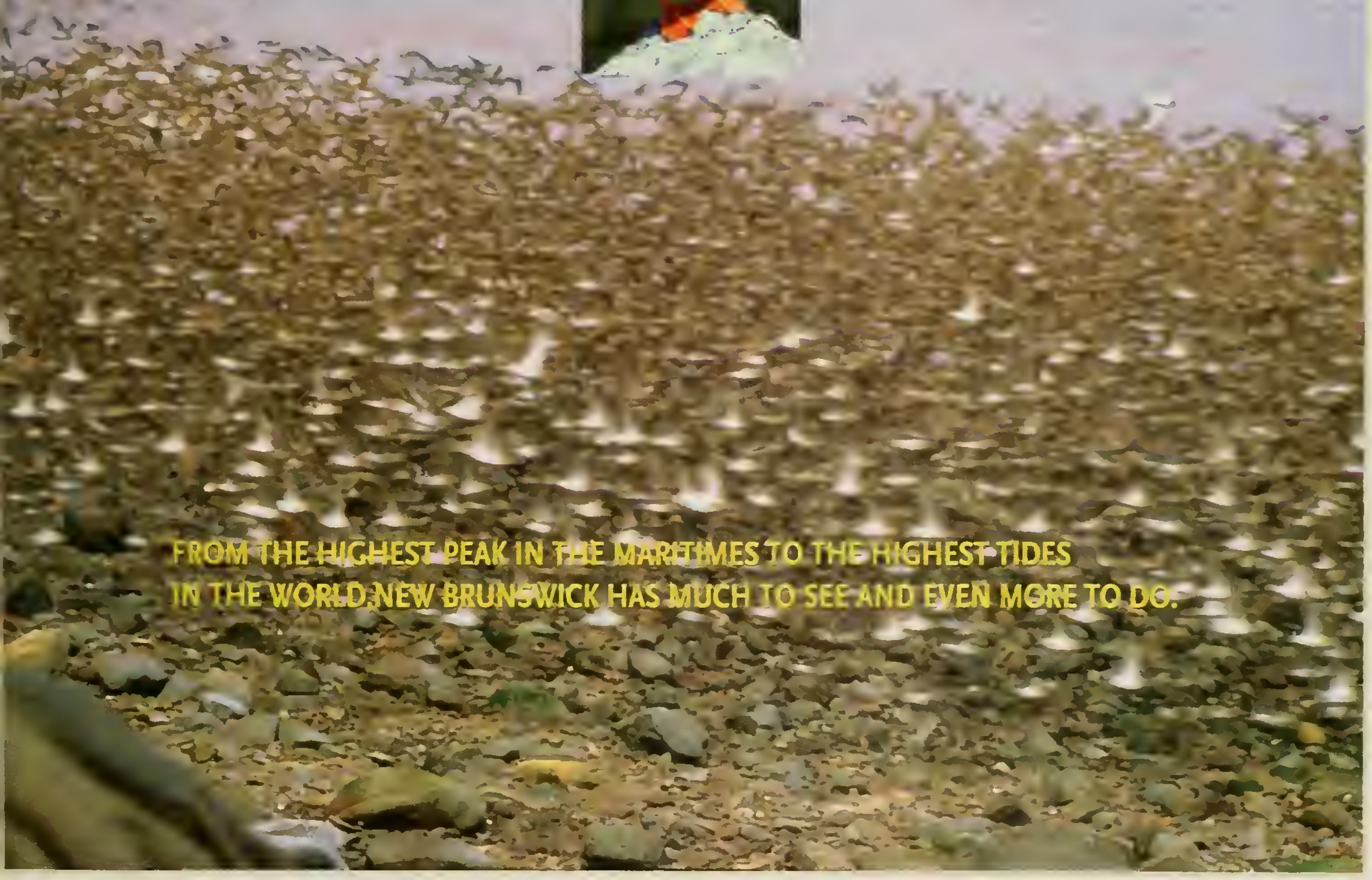

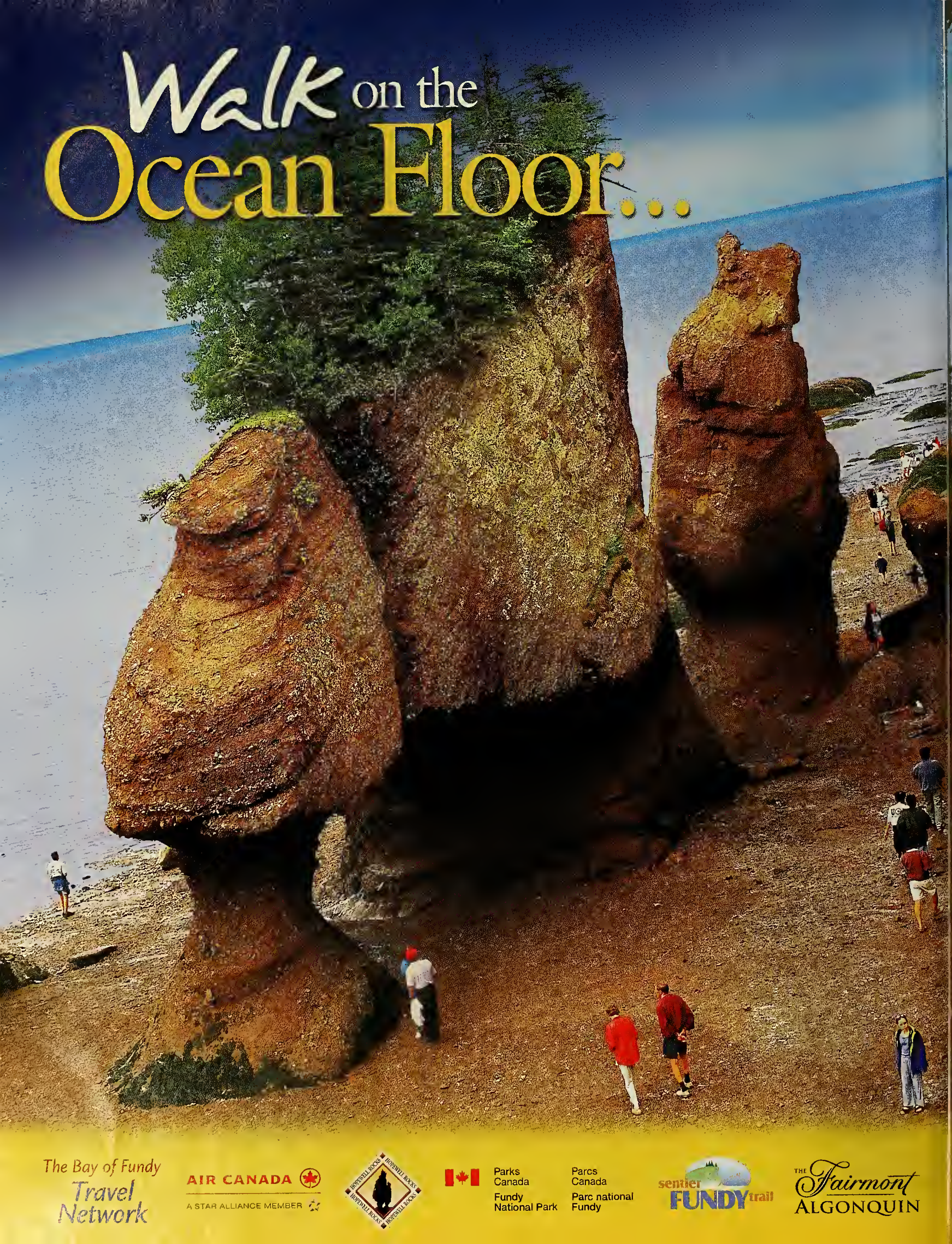
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Another location that is quickly becoming a popular ecotourism destination is the Copper Canyon, part of the Pacific slope of the Sierra Madre. Home of the Tarahumara Indians, the Copper Canyon is one of the largest and most complex canyon systems in the world. Its many distinctive habitats offer some of the most wonderful resident, migrating, and wintering bird species in the area.

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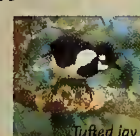

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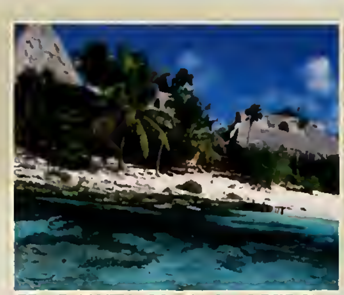
I was born thousands of years ago, and soon I taught the world to count the days by the sun, the months by the moon, and the years by the stars. **Today I am affectionately called México, and I am full of intrigue and wonder.**



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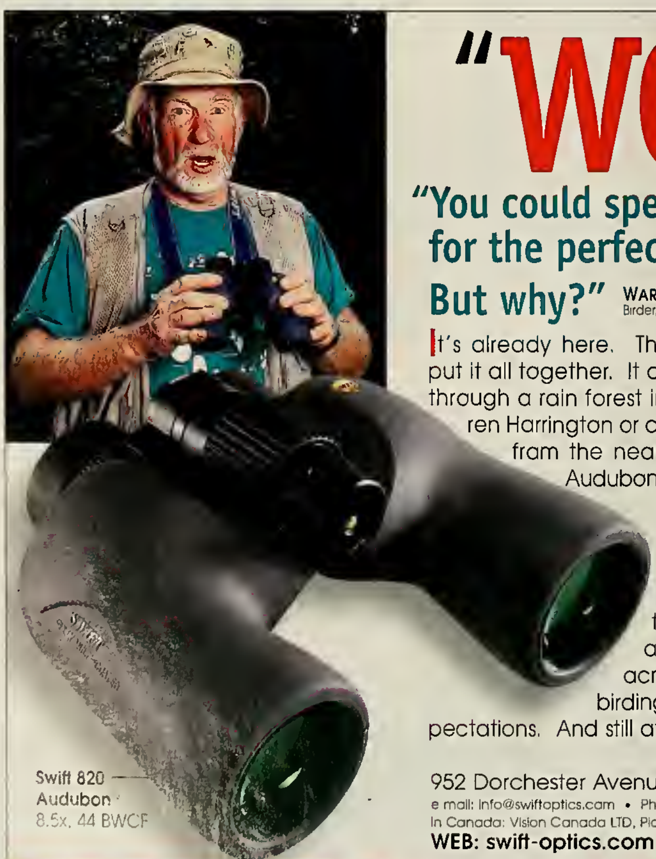

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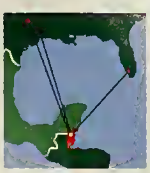

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For more information on birding in Wales, contact the British Tourist Authority at **1-800-462-2748** or **www.visitbritain.com**. ✧

BELIZE THE BIRDER'S PARADISE

WITH ECOSYSTEMS as diverse as swamplands and tropical forests, this small country boasts not only 540 species of birds but also some of the most exotic and rare. Much of the wildlife found in Belize is thriving, thanks to the protected areas that make up more than 40 percent of the country.

One very special area that birders won't want to miss is the Crooked Tree Wildlife Sanctuary, a wetland preserve in the north-central part of the country that is home to more than 250 species. A wonderful example of successful ecotourism, the sanctuary was founded by the village of Crooked Tree's 750 residents, many of whom now earn a living by helping visitors learn more about their region. Chau Hiix Lodge is one of the properties in Crooked Tree that caters exclusively to birders, offering package rates that include all meals and guide services.

If you're interested in forest birds, a unique conservation organization called Programme for Belize devotes 260,000 acres of rain forest to research, education, and includes a wildlife sanctuary as well.

Plan to stay at Chan Chich, an upscale lodge that is set on the plaza of an ancient Maya site. There, blue crowned mot mots, Scott's orioles, Montezuma oropendulas, and many kinds of colorful parrots will serenade you as you enjoy this birder's paradise. A 10-mile network of nature trails provides plenty of opportunity to explore this unique area.

TO OBSERVE SOME COASTAL SPECIES, visit the popular island of Ambergris Caye, an ideal base for observing the birds that live along Belize's 185-mile- long barrier reef. You can stay at the Caribbean Villas, a seaside hotel that boasts a five-level "people perch" that allows you to peer into the island forest.

For more information about Belize, contact the Belize Tourism Board at **800-624-0686**, or go to **www.travelbelize.org**. ✧

This special editorial/advertising supplement was created by the Natural History Special Sections Department and did not involve the magazine's editorial staff. **WRITER:** *Stephanie Fekety* **DESIGN:** *Mindy Phelps Stanton*

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IN THE FIELD


JIM BRANDENBURG; MINDEN PICTURES

Beaver lodge, Minnesota

Warm Welcome

A beaver's lodge is its castle, particularly when ice covers the pond.

By Peter J. Marchand

Northern winters can be long for a beaver—longer than for most nonhibernating mammals. Though equipped to gnaw through the hardest wood, beavers show little inclination to chisel through ice and thus are seldom seen from the time their ponds freeze over until spring melt, often long after snow has left the land. Yet beavers rarely die during the winter from cold stress or a shortage of food. The key to their success in the North seems to lie, in large measure, with their lodge—the most massive communal nest constructed by any animal.

Not until I actually crawled inside a lodge did I understand the full implications of this structure for a beaver's life under ice. My opportunity came early one winter in northern Vermont as a result of an unusual circumstance. Just before freeze-up, a local highway maintenance crew had rifted a colony's dam to prevent the flooding of a road. When the pond's water level dropped below the entrances to their lodge, the beavers, rather than attempting to repair the dam, vacated the premises. A month later, my students and I ventured onto the frozen pond to investigate the lodge and found the exposed entrances. We couldn't resist the temptation. Shedding some of our bulky clothing, two of us wiggled and squirmed (with an occasional push from behind by others) into opposite tunnels until we met in the middle.

That firsthand inspection gave me an insight into the winter lives of beavers that none of my previous studies had ever provided. Outwardly, a beaver lodge appears to be nothing more than a mud-plastered pile of woody debris—an unkempt heap of odd-sized sticks that occasionally reaches twenty feet in diameter and rises four or more feet out of the water. In this case, the interior turned out to be a marvel of neatness and cleanliness. The earthen floor of the lodge was worn smooth by the countless comings and goings of wet feet on silky clay. The walls and ceilings were trimmed evenly; not a single nub protruded to discomfort a huddling animal (which explained why the beavers in lodges I'd previously attempted to study had been so quick to chew off the ends of some temperature probes I'd inserted). A small chamber branched to the side of one entrance tunnel, apparently having served as a feeding platform just above the water level. It held a single scrap of food: a frozen aquatic quillwort, still whole and green. The main nest chamber, roomy enough to permit us to raise our heads and pass a camera back and forth between opposite tunnels, was devoid of any detritus—not a trace of food, fecal material, or odor.

The lodge had been empty for some time, but my initial sensation upon entering it was one of subtle warmth. Heat, conducted upward from the unfrozen water beneath the floor, maintained the temperature near the freezing point—considerably warmer than the snowy world outside. It was easy to imagine the relative comfort of an occupied chamber. A family of beavers crowded into a small space, huddling and grooming, can generate significant heat (it is not unusual for a pair of adults and two litters of kits to winter together). On a zero-degree day, I once recorded a lodge temperature of 60° F, well within a beaver's thermoneutral zone (the temperature range within which an animal can remain comfortable without raising its metabolic rate) and warm enough to melt a hole in the snow at the top of the lodge.

But there's another, colder side to this picture. Beavers face an energy dilemma every time they slip into the icy water for an excursion to their food cache. (In the fall, beavers stockpile tree branches underwater.) The compression of their fur in the water and the resultant displacement of air from the otherwise superbly insulated pelt, coupled with water's high capacity to conduct heat, greatly accelerate heat loss from the beaver's body and can render the animal hypothermic within about thirty minutes. The need to procure food can become a repeated trauma for the kits, which may enter the water daily in feeding forays lasting from less than five minutes to more than forty. (Adults may make fewer trips, subsidizing their energy needs with fat stores in the tail.) A foraging beaver benefits by being able to return to a warm lodge, where its body temperature can be quickly restored to the requisite 98° F.

But herein lies a potential problem. Four hundred cubic feet of earthen lodge, if allowed to cool, can quickly turn into a massive heat sink instead of a life-saving refuge. One way to prevent this might be for family members to stagger their foraging trips, ensuring that the lodge is occupied at all times—and this is where an unusual aspect of beaver behavior comes into play.

To maximize effectiveness in functions such as feeding and mating, virtually all animals maintain biological rhythms that are precisely cued to day length and seasonal cycles. Scientists aren't sure why or how, but beavers' biological clocks (and thus their activity patterns) drift out of phase with the day/night cycle in winter. Although long isolation in the lodge without external light cues would promote such drift (and I can attest to the darkness of a lodge interior), even infrequent excursions underwater should recalibrate internal clocks, since light easily penetrates ice and snow cover on a pond. Yet all across southern Canada and the northern United States, beavers display winter activity patterns based on a twenty-six- to twenty-nine-hour cycle, resulting in a considerable shift, over time, in their daily schedules. Having a free-running internal clock probably carries little risk under the ice, where predators are not a threat, but what is the advantage? One possibility is that in winter, staggered foraging times may maintain an equable indoor temperature, guaranteeing a warm welcome whenever a beaver returns to its lodge.

Peter J. Marchand is currently a visiting scientist at the Carnegie Museum of Natural History's Powdermill Biological Station near Rector, Pennsylvania.

JIM BRANDENBURG; MINDEN PICTURES

Beavers with an aspen branch, a favorite food

THE EVOLUTIONARY FRONT

"After You, Eve"

Research on the Y chromosome only hints at the complexity of the human genealogical tree.

By Carl Zimmer

My wife, Grace, and I are expecting our first child in July, so I've had a lot on my mind recently. Most of it has been pretty mundane stuff: What's the fastest route from our apartment to the hospital? How exactly do you swaddle a baby? But sometimes loftier thoughts invade. I think about our child as the union of two heritages. My wife's flows back to Ireland, to County Kerry in the south and County Derry in the north. My own heritage is more far-flung, encompassing Wales, England, Germany, and Hungary, as well as countries in eastern Europe that no longer exist, having been bisected and trisected by countless wars.

Both our family trees extend back only a few generations, at which point written records and the memories of relatives fail. But we, like all other humans, also carry a genetic genealogy. Encrypted in our DNA is a history of our species. Scientists are learning how to decode that history, and they find that if you go back far enough in time, my wife's heritage and my own eventually fuse, along with that of the rest of humanity.

There's an apparent paradox in our molecular genealogy, however: different genes tell different stories. Research on one set of genes indicates that all humans on earth descend from an African woman who lived 170,000 years ago. Scientists studying a different group of genes recently concluded that all humans descend from an African man who lived 59,000 years ago. Even allowing for a healthy margin of error in these estimates, it would seem that Eve lived more than 100,000 years before Adam.

You might think that the scientists involved need to find the mistake that produced two such different conclusions. But as contradictory as the results may appear, they are perfectly compatible. Genealogy is much stranger than most of us realize.

The quest for humanity's genetic

JAMES MARSH

genealogy began in the early 1980s, when researchers were just starting to decipher the genetic code. DNA is shaped like a twisted ladder, and each of its rungs is made of a pair of building blocks called bases. When scientists began to read the sequence of these base pairs, some of the first genes they chose to decode were a peculiar sort. Nearly all of our 30,000 genes are located within the cell nucleus. But 37 genes reside outside the nucleus, in sausage-shaped structures known as mitochondria, which act as the powerhouses of the cell.

These outlying genes are also unusual because of the way they are inherited. The genes in a human cell nucleus are arranged on twenty-three pairs of chromosomes. At the time an egg or a sperm cell is being formed though cell division, the chromosomes in each pair swap parts of their genetic material (with one important exception, which I'll get to later). Each egg or sperm then receives only one from each pair of rearranged chromosomes. When a sperm fertilizes an egg, it contributes its chromosomes, and a new set of twenty-three pairs is established. Thanks to the swapping episode, it's a unique combination of genes.

Mitochondria are different. Mitochondria themselves do not engage in sexual reproduction. Moreover, a father cannot contribute mitochondrial genes to a child, because mitochondria in sperm can't enter the egg cell. My child inherited only my wife's mitochondrial genes, my wife inherited her mitochondrial genes only from her mother, and so on, back through thousands of generations of women.

In the mid-1980s Allan Wilson, a geneticist at the University of California, Berkeley, recognized that the genes in mitochondria were loaded with historical information that other genes lack. Our chromosomes go through a complex shuffle in every generation, but mitochondrial genes create a clean, unmuddled pedigree. The only way a difference between the mitochondrial genes of a mother and her child can arise is if they mutate. In some cases, a mutation will cause a genetic disorder with symptoms such as weakness, respiratory problems, or deafness. Natural selection steadily removes the most harmful of these mutations from the human gene pool. On the other hand, mutations can alter mitochondrial genes without causing harm (and, in very rare cases, may even bestow some benefit). If a woman acquires a harmless mutation in her mitochondrial DNA, she will pass it on to her children, and her daughters will pass it on to their own children. It will mark her descendants as distinct from other people—distinct even from the descendants of her own sister.

Mitochondrial Eve's genes came to dominate our species much the way one surname can take over an entire village.

Wilson and his students studied some of these markers by gathering samples of mitochondrial DNA from people around the world and comparing specific stretches from each individual. They found that different groups of people shared certain markers, suggesting that these groups had descended from a common ancestor. For example, Europeans all shared markers that no one else did, while Asians had unique markers of their own. Wilson's team also found that Asians and Europeans shared certain other markers that Africans lacked. By grouping people on the basis of their markers, Wilson's team was able to construct an evolutionary tree for humanity. The branches that sprouted closest to the base of the tree were all African lineages, suggesting that mitochondrial DNA in all humans living today descended from an African woman.

Wilson's team named not only the place, but also the time, of human origins. "All these mitochondrial DNAs stem from one woman who is postulated to have lived about 200,000 years ago, probably in Africa," they announced in *Nature* in 1987. To come up with their age estimate, the researchers compared the variations in mitochondrial DNA and then calculated how long it must have taken for so many mutations to build up in different lineages. Their estimate of 200,000 years was shockingly recent. It was already clear from the fossil record that human relatives lived in Europe and Asia at that time; now Wilson's work suggested that when ancestors of living humans migrated out of Africa, these other humans—with their own, different mitochondria—went extinct.

As it turned out, Wilson's statistics weren't as sound as he had believed, but later studies on mitochondria have come to essentially the same conclusions. Wilson worked only with fragments adding up to about 9 percent of the mitochondrial genome; in the December 7, 2000, issue of *Nature*, Swedish and German scientists reported on the results from examining all the mitochondrial genes—the entire sequence of about 16,000 base pairs. Comparing the sequences of fifty-three individuals, these researchers, too, found that their genes had come from an African woman. But instead of living 200,000 years ago, they estimated, she lived 170,000 years ago.

Newspaper reports on Wilson's 1987 paper dubbed this African woman "mitochondrial Eve." But despite the biblical overtones, she was not the sole female progenitor of all living humans. She was simply the most recent female ancestor to whom we can all trace this particular genealogical connection. Mitochondrial Eve existed alongside thousands of other women in Africa, all of whom had mitochondrial genes of their own. Many of those other women had children who inherited their genes, and some of their descendants had children with mitochondrial Eve's descendants. But over the course of thousands of years, the other mitochondrial lineages gradually disappeared. A lineage would have vanished if the women carrying it died without having children or gave birth only to sons. As these different mitochondrial genes were dropping out, Eve's were becoming more widespread.

The way her genes came to dominate our species is similar to the way in which a patrilineal surname can take over an entire community. In a village where many different family names were in use thousands of years ago, everyone alive now could conceivably share just one. The fact that everyone in the village is named Chen, however, doesn't mean that one man named Chen was their sole male progenitor. Similarly, we descend from thousands of other women who were alive at the same time as mitochondrial Eve. We just don't carry their mitochondrial genes.

Just as mitochondrial genes contain a record of female lineages, men have a set of genes that can tell a story about the other half of our species. Of the twenty-three pairs of chromosomes carried by men in the nucleus of their cells, twenty-two consist of partners identical in length, shape, and sequence of genes. The remaining pair is different. From his father, a boy inherits a chromosome called Y, and from his mother, a chromosome called X. During the formation of sperm, as the other chromosomes shuffle their genes, only a small section of the Y chromosome exchanges bits of material with its partner. Most of it remains aloof, providing a clean, unmuddled pedigree passed down from father to son—a male counterpart to mitochondrial DNA.

The story embedded in the Y chromosome has been much harder to extract than that of mitochondrial DNA. The mitochondrial genome is small, only 16,000 base pairs long, making it easy to sequence, and every human cell contains an average of 1,700 mitochondria, offering plenty of targets for genetic probes. By contrast, each of a man's cells contains a single Y chromosome, and it is big, measuring 60 million base pairs long. Searching for markers on the Y chromosome is like looking for a few typos in a thirty-volume encyclopedia. By 1994, scientists had managed to find a grand total of only two markers on the Y.

The Y chromosome has finally been tamed by investigators at the laboratory of Stanford University geneticist L. Luca Cavalli-Sforza. In 1995 Stanford researchers Peter Underhill and Peter Oefner found a way to speed-read through the Y-chromosome encyclopedia. Soon they and their colleagues were discovering a new mutation every month or so (they're now up to 167). It was then relatively easy for them to study Y chromosomes from various parts of the world to see if they shared any particular mutation. If they did, it would mark them as descendants of a common ancestor.

Like Wilson's group, the Stanford team has used their markers to draw an evolutionary tree of the human race, and they find that the oldest branches are exclusively African, confirming that Africa is the motherland of us all. Some Africans spread out to the other continents, a journey that the Y chromosome records in exquisite detail. It reveals individual waves of migration from Asia to Europe, from Asia to Polynesia, and from Asia to the New World.

But there's one important disparity between the findings based on the Y chromosome and those based on mitochondrial DNA. Underhill and his colleagues established a clock for the Y chromosome, and in the November 2000 issue of *Nature Genetics* they estimated that Y-chromosome Adam, the man from whom all living men descend, lived only 59,000 years ago.

How can we all descend from two people who lived thousands of generations apart? These scientists are calculating the antiquity of the various genes we share, not attempting to reconstruct the complete family tree of the people who carry them. Only our mitochondrial genes descend from a common female ancestor who lived 170,000 years ago, and only our Y chromosomes descend from a single Y chromosome dating back 59,000 years.

The men who were alive in mitochondrial Eve's day carried a number of different versions of the Y chromosome. They passed their chromosomes down to their sons, and over time, each version of Y went through its own ups and downs. Finally, about 59,000 years ago, a man was born with a newly mutated Y chromosome that would eventually dominate our entire species. Other versions of the Y gradually disappeared as men died without children or had only daughters.

Perhaps it was common 59,000 years ago for just a few men in each band to earn the privilege of fathering children.

It's intriguing that Y-chromosome Adam appears to have lived so much later than mitochondrial Eve. His Y chromosome apparently needed less time to overwhelm the human gene pool. One possible explanation for this speed is that one of the genes on Adam's Y chromosome had a mutation that gave it an evolutionary edge, and natural selection then drove its spread. But natural selection of a gene is not the only force capable of making it more widespread—culture might have been responsible. Perhaps it was common 59,000 years ago for only a few men in each band to earn the privilege of fathering children. If that was the case, Y-chromosome lineages might have gone extinct quickly, because most men would have been unable to pass on their genes. The Stanford team is now exploring these two possible explanations.

The findings from research on the Y chromosome and mitochondrial DNA are only a taste of the genealogical feast that will be served up in the next few years. Last year, government and private-sector scientists made a joint announcement that they had sequenced the entire human genome. Researchers will now be able to find markers far more quickly—and not just on the Y chromosome or on mitochondrial DNA but on any gene they want to study. Some of these genes will turn out to be hundreds of thousands of years old. Others will turn out to be much younger, having evolved in response to recent epidemics or similar challenges.

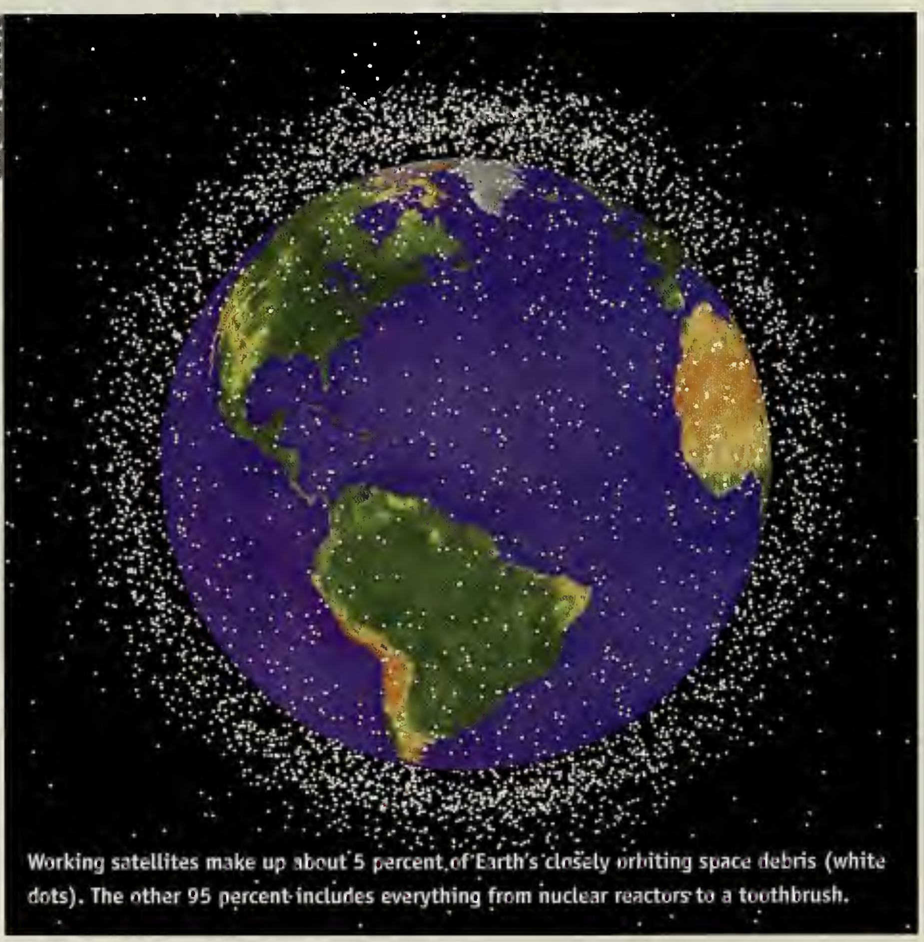
All this new research makes me think differently about our child. We are not simply giving him or her my nose or my wife's eyes. We are giving our child tens of thousands of histories combined into a single genome. And she or he will carry this record of human existence another generation into the future. Somehow, the mysteries of swaddling don't seem like such a big deal anymore. □

CELESTIAL EVENTS

Lost in Space

What goes up must come down. Or not.

By Richard Panek



NASA/JOHNSON SPACE CENTER

Working satellites make up about 5 percent of Earth's closely orbiting space debris (white dots). The other 95 percent includes everything from nuclear reactors to a toothbrush.

Every sky watcher knows that what's "up" in our nighttime skies isn't up at all. Celestial objects may look as though they're "up there" to observers "down here" on Earth, but we long ago adjusted our thinking and accepted that they're simply moving across the vast reaches of empty space, where directions like up and down have no meaning. And for the most part, that's true.

The exception is what we ourselves have sent up—for example, the International Space Station (ISS), now under construction in orbit. But artificial satellites such as the ISS won't stay up there forever, and one reminder of this basic fact of physics is the impending return of the *Mir* spacecraft to our blue planet.

If all goes according to plan (never a safe bet when it comes to space missions), *Mir* should be reentering Earth's atmosphere between February 26 and 28, or about a week after this issue of *Natural History* comes off the presses. Much of *Mir* should disintegrate on reentry; any remaining pieces should land in the Pacific Ocean, off the coast of Australia. That crash-and-burn will reduce the number of man-made objects in the heavens by one, but the total will still be nearly 8,000, and growing almost daily.

About 2,500 of those objects are genuine satellites—spacecraft specifically designed to orbit Earth. As for the other 5,000 or so out there, they're the celestial equivalent of roadside trash: hatch covers, rocket bodies, bits and pieces of payloads that have disintegrated or (at the rate of about six a year) unexpectedly exploded, even a glove that a *Gemini* astronaut lost back in the 1960s. And then there's the celestial equivalent of a roadside attraction: a one-third-sized working model of the *Sputnik 1* satellite, released by *Mir* cosmonauts in 1997 on the fortieth anniversary of the launch that initiated the space age.

Is anybody keeping track of all this stuff? Fortunately, yes: the U.S. Space Command's Space Control Center (SCC) near Colorado Springs, Colorado. The SCC continuously monitors the location of each object, not only to distinguish between friend and foe, but to facilitate navigation by determining what could potentially be in the way. When the bankrupt global satellite telephone company Iridium LLC needed to think about dumping

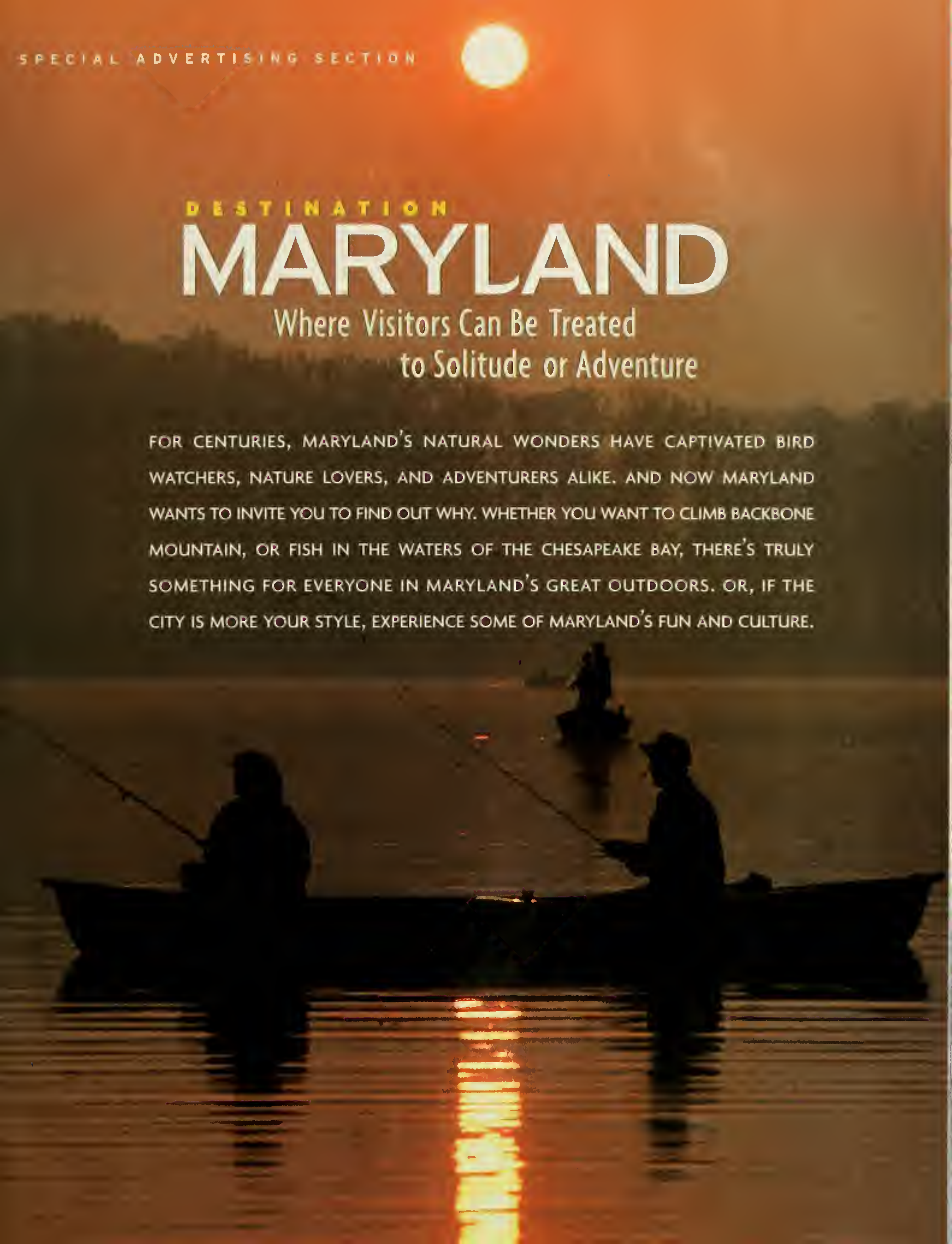
(Please turn to page 43)

DESTINATION

MARYLAND

Where Visitors Can Be Treated to Solitude or Adventure

FOR CENTURIES, MARYLAND'S NATURAL WONDERS HAVE CAPTIVATED BIRD WATCHERS, NATURE LOVERS, AND ADVENTURERS ALIKE. AND NOW MARYLAND WANTS TO INVITE YOU TO FIND OUT WHY. WHETHER YOU WANT TO CLIMB BACKBONE MOUNTAIN, OR FISH IN THE WATERS OF THE CHESAPEAKE BAY, THERE'S TRULY SOMETHING FOR EVERYONE IN MARYLAND'S GREAT OUTDOORS. OR, IF THE CITY IS MORE YOUR STYLE, EXPERIENCE SOME OF MARYLAND'S FUN AND CULTURE.



COME OUT AND PLAY

The wonderful thing about Maryland is that everything is within a 3-hour drive of its biggest city, Baltimore. That's why the state's tourism motto is *So many things to do. So close together.*

CENTRAL MARYLAND

If solitude is what you are looking for, visit Yachts Unlimited, located at Great Oak Landing Marina on Fairlee Creek. Yachts Unlimited offers you the unique opportunity to charter beautiful yachts. Rent a bike in Ashland or Monkton, because just an hour's drive from Baltimore you'll find the 40-mile Northern Central Rail Trail which winds through the countryside on its way to the Mason-Dixon line and beyond. Before you begin your trip, stop by your local book store and pick up some travel books covering the Chesapeake Bay area. Johns Hopkins University Press is a good place to start. Popular destinations in this region include Annapolis, Baltimore City, Columbia, Havre de Grace, Towson, Westminster, Ellicott City and Bel Air.

EXPLORE ONE OF THE EAST'S LAST REMAINING UNSPOILED WILDERNESSES.

WESTERN MARYLAND

Within the mountains of Western Maryland, adventure and natural beauty come together to help you enjoy a fun-filled weekend. If there's a touch of Roy Chapman Andrews in you, but you want to stay a little closer to home, then this is the perfect place for your next expedition. Experience the region's world-class trout fishing with one of the local guides along the Upper Youghiogheny River. Novice fishermen can take advantage of the Yough's gentler sections or the dramatic canyons of the Potomac's North Branch. Accomplished anglers can move to the heart of the action in the Savage River, a tailwater fishery and catch-and-release trophy area. At the end of your day, you can gaze upon the stars while camping at Garrett County's Big Run State Park in the heart of the Savage River State Forest. Western Maryland's most popular destinations include Antietam, Cumberland, Deep Creek Lake, the C&O Canal Park and Hagerstown.

CAPITAL REGION

The Capital Region of Frederick, Montgomery, and Prince George Counties is home to some wonderful state parks that offer everything from hiking to biking. Cunningham Falls State Park, 15 miles north of Frederick, in the Catoctin Mountains, is the home of the breathtakingly beautiful Cunningham Falls. This 78-foot cascading waterfall roars through a rocky gorge and a lake. If you want to take in some history, the Capital Region is the place to do it. A crucial Civil War battle was fought in Frederick County on July 9, 1864. At Monocacy National Battlefield, walk in the footsteps of a small Union force of 5,800 men who managed to stall the advance of an 18,000-strong Confederate army for a full day. This battle prevented an invasion of the nation's capital. Popular destinations in this region include Frederick, Bethesda, College Park, Gaithersburg, Laurel, Rockville, Thurmont and Upper Marlboro.

DESTINATION
MARYLAND

Maryland's 47 state parks, six forests and state public lands encompass more than 372,000 public acres.

SOUTHERN MARYLAND

Miles of magnificent shoreline along the Potomac River and rural scenery offer another treat in this diverse state. Explore the 288-acre Great Blue Heron Sanctuary, protected by the Nature Conservancy on the tranquil Nanjemoy Creek. There you can experience an amazing feat of nature as more than 1,100 breeding pairs of great blue herons return to this site each winter to mate and bear their young. Paddle up the Port Tobacco River, just south of the Nanjemoy, with a stop at Chapel Point State Park. Here you can hike to a scenic overlook for an impressive view of the river and St. Ignatius Church, which served as a stop on the Underground Railroad. Popular destinations include Calvert Cliffs, LaPlata, Leonardtown, Prince Frederick, Solomons, historic St. Mary's City and Waldorf.

EASTERN SHORE

The Eastern Shore of Maryland offers rolling hills, scenic shores and quaint towns—the recipe for a perfect weekend adventure. Begin your journey at Janes Island State Park. Easy paddling along 30 miles of marked water trails takes you through a 2,900-acre salt marsh that is abundant with wildlife—snowy egrets, diamond-back terrapins and herons, along with bluefish, rockfish, sea trout and flounder. The Eastern Shore is known for its mix of scenery and hospitality and is a seafood lover's paradise. Stop by one of the waterside restaurants and have a Maryland shore dinner. Popular destinations include Cambridge, Centerville, Chestertown, Crisfield, Denton, Easton, Fair Hill, Kent Narrows, Ocean City, Pokomoke City, Princess Anne, Rock Hall, Smith Island, Snow Hill, St. Michaels and surrounding towns. ❐

WITH ITS CELEBRATED WATERFRONT, CHARMING NEIGHBORHOODS AND FASCINATING MUSEUMS, BALTIMORE IS THE STARTING POINT FOR A PERFECT WEEKEND GETAWAY.

Explore Maryland

Maryland

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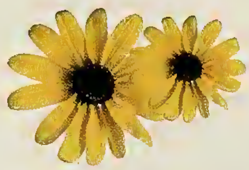
MARYLAND'S UNIQUE COUNTIES

WORCESTER COUNTY
The Wild Ponies of Assateague

When you come to Maryland, you certainly don't want to miss Assateague Island State Park and National Seashore, home to the famed wild ponies and so much more. Assateague is an uninhabited island running parallel to the shoreline with 37 mile of dunes, marshlands, and beaches. You'll be able to camp, fish, canoe, kayak, hike, or bike along paths that provide a glimpse of the ponies, waterfowl and other wildlife.



There's so much history to discover in Maryland and so much nature to admire.

Western Worcester provides visitors with its own type of outdoor adventure. The Pocomoke River State Forest and Park covers more than 13,000 acres of cypress swamps and loblolly pines. The river and its shoreline provided cover for escaped slaves traveling the Underground Railroad to the North. The Pocomoke River flows through one of the northernmost cypress swamps in the country. More than 27 species of mammals, 29 species of reptiles, 14 species of amphibians, and 172 species of birds have been seen in the wetlands that border the Pocomoke.

Of course Worcester has its share of history too. Visit the Mt. Zion One-Room School Museum and the Julia A. Purnell Museum in Snow Hill to get a glimpse of life from the pre-colonial days to the late 19th century. A walking-tour of Snow Hill offers some interesting historical details about eight churches and 52 homes.

FREDERICK COUNTY
History's Crossroads

The National Road, the first federally funded highway in the United States, follows a trail used by George Washington as a route to link the port of Baltimore with the interior of the United States. The National Road travels through the heart of Frederick, Maryland's historic district. This is where settlers bound for the wilderness began their journeys, and the winds of war brought Union and Confederate troops together in battle twice.

Discover even more history with a visit to the National Museum of Civil War Medicine. Telling the medical story of the Civil War, the museum gives visitors a glimpse of the care and healing, courage and devotion of caregivers and patients on both sides of the war.

And then stop at two well-preserved Civil War battle fields where critical battles took place: the Battle of Monocacy and the engagement at South Mountain.

Before you leave downtown Frederick, don't miss the shops, restaurants and theaters that make these streets so special. You'll want to see each and every one of the trompe l'oeil murals decorating walls and bridges. The work of local artist William Cochran, the murals have become a symbol of Frederick's unique character.

ST. MARY'S COUNTY
A Bit of America's Storied Past

Historic St. Mary's City is the site of the state's first capital and now one the finest 17th century tourist attraction in North America. St. Mary's City boasts a stunning 800-acre outdoor history museum along the banks of the St. Mary's River. See a replica of the square-rigged *Dove*, one of the two ships that brought English settlers to the state in 1634. Before choosing St. Mary's City, the early settlers first landed at St. Clements Island, now a state park accessible by water-taxi. There you'll find a wonderful museum devoted

AT FORT McHENRY, FRANCIS SCOTT KEY WAS INSPIRED TO WRITE "THE STAR SPANGLED BANNER" AFTER THE SUCCESSFUL DEFENSE AGAINST THE BRITISH DURING THE WAR OF 1812.

CLUSTERED SPIRES OF DOWNTOWN FREDERICK IN THE HEART OF FREDERICK COUNTY.

to the island's history and importance.

Not too far away, on Piney Point you can take a picnic lunch and visit the Piney Point Lighthouse Museum and Park. The lighthouse, built in 1836, was the first permanent lighthouse built on the Potomac River and is the only remaining accessible lighthouse on its original location in Southern Maryland. The museum tells the story of a U-1105 German Submarine from WWII, which is on display. After the war, the Navy acquired ownership of the submarine and it was eventually scuttled off the coast of Piney Point. In November of 1994, the wreck was designated as Maryland's first historic shipwreck preserve.

Nature lovers will find more than 400 miles of shoreline to explore in St. Mary's County. To find more out about the region, take a sail aboard one of the several historic vessels in the area that offer scenic cruises or sails.

CALVERT COUNTY

Celebrate the Culture of the Chesapeake

A hike through Calvert Cliffs State Park brings you to the majestic Calvert Cliffs on the Chesapeake Bay. Formed over 15 million years ago, the cliffs contain more than 600 species of fossils. The park is ideal for hiking and walking, picnicking, fishing, and fossil hunting, and there is a 45-minute walk one-way (two miles) to the beach. The area under the cliffs is closed due to landslide activity, but fossil collecting can be done along the open beach where there are no cliffs.

In Calvert County, you can also take advantage of some wonderful ecological spots. The Battle Creek Cypress Swamp Sanctuary protects the country's northernmost naturally occurring stand of bald cypress. A boardwalk at Flag Ponds Nature Park leads through delicate wetlands. Three different scientific centers—the Academy of Natural Sciences' Estuarine Research Center, the American Chestnut Land Trust, and the Chesapeake Biological Laboratory—offer an introduction to this diverse and unique environment.

The rich maritime history and diversity of life found in the Chesapeake Bay come alive at the Calvert Marine Museum. Here you'll find boats, models, paintings, woodcarvings, aquariums and fossils. Outdoor exhibits include a boat basin, river otter habitat, and a re-created salt marsh. Enjoy a leisurely one-hour cruise around Solomons Harbor and the Patuxent River aboard the *Wm. B. Tennison*, the oldest Coast Guard licensed passenger-carrying vessel on the Chesapeake. Built in 1899, this nine-log chunk-built bugeye was later converted from sail to power, serving as an oyster buyboat. After your cruise, sample the fresh catches served at Solomon's excellent restaurants.

CHARLES COUNTY

Southern Maryland's Hidden Gem

Charles County is a destination that combines history, the outdoors, culture and fabulous

seafood into one unforgettable weekend. Explore the fossil hunting grounds of Purse State Park, or take in the forests and wetlands of the Mattawoman Natural Environment Area.

If you like history, you'll be intrigued by the small town of Benedict, the only spot in the United States where foreign troops have invaded our shores. The British army landed here on their way to Washington D.C. during the war of 1812. Two of the troops are buried at Old Fields Chapel Cemetery in Hughesville.

For a bit of exercise, you can take a 24-mile bike ride through history, following the trail of John Wilkes Booth. Your tour picks up his trail at the home of Samuel Mudd, the doctor who set Booth's leg before he continued his escape into Virginia. The route follows lightly traveled roads through rolling countryside and scenic farmland. Stop at the St. Mary's Catholic Church, built in 1848, where Dr. Mudd is buried. You will peddle around the Zekiah Swamp and end up in Pope's Creek on the Potomac River. Here, you can enjoy a Maryland crab dinner without any guilt.

After taking a vacation in Maryland, you will definitely understand why they say *So many things to do. So close together.* For more information about this extraordinary state, call 1-877-333-4455 to speak to a Maryland travel specialist. ❐

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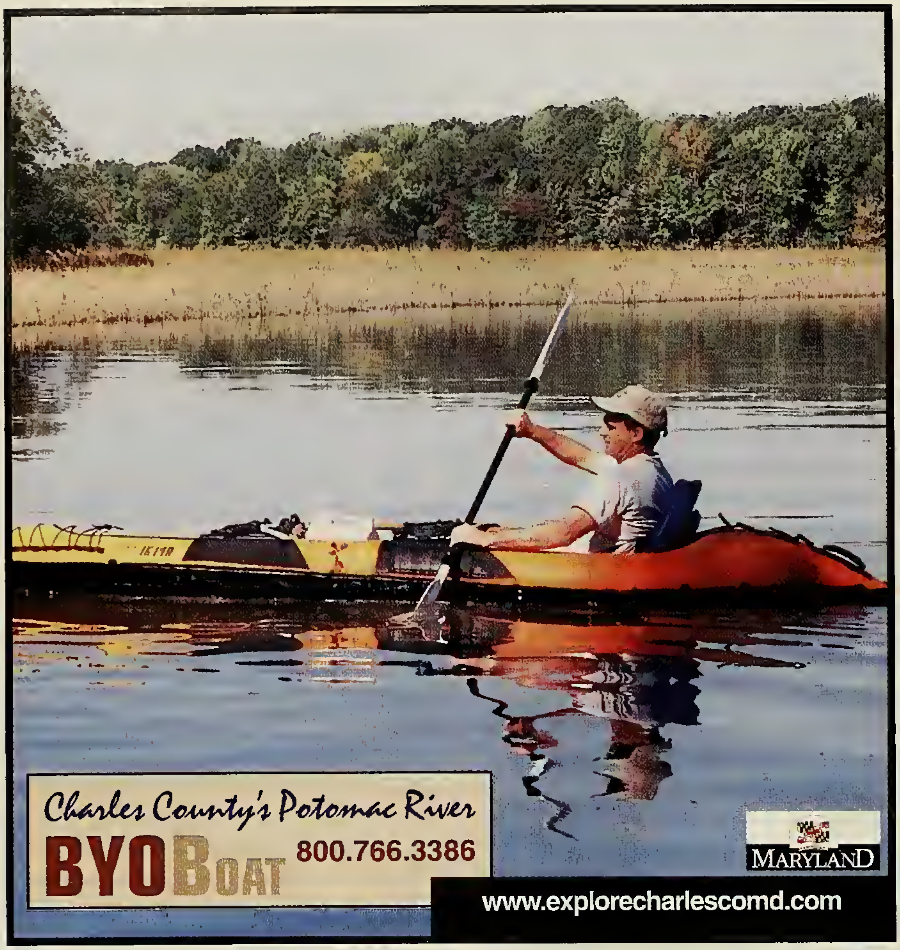
DESTINATION
MARYLAND



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(Continued from page 36)
its sixty-six satellites last year, it asked the SCC for guidance in steering its suddenly useless inventory safely to oblivion. (The Pentagon later decided to keep the satellites aloft for at least two more years.)

Many of us who were alive in the 1960s have memories of standing outside at night, straining for a glimpse of Telstar or some other primitive satellite as it slowly traveled across the backdrop of the so-called fixed stars. Whatever romantic visions of space exploration were inspired by that sight have long ago receded into collective nostalgia. But sky watchers can still get some kind of existential thrill from locating celestial objects that, unlike the Moon, planets, and stars, will probably vanish from the universe before they do.

Only a small proportion of orbiting objects are visible through even the most powerful backyard telescopes, but the recent addition of the ISS to the night sky now gives naked-eye observers something to see. It can reach the brightness of a first-magnitude star if it catches the light of the Sun just right. As the station itself grows, that radiance will also grow. To find out precisely when and in what part of the sky the space station is visible, you can visit spaceflight.nasa.gov/realdata/sightings/, which links to sighting opportunities for more than 200 locations worldwide.

As for *Mir*, it may be going but it's not gone yet. And until it is, you can determine the spacecraft's availability and visibility by checking a Web site established by *Sky & Telescope* magazine at www.skypub.com/sights/satellites/mir.shtml.

And then there's the *Gemini* glove. No, you can't see it, but surely it, too, deserves a dedicated Web site to inform us of its whereabouts. Forget the beeping *Sputnik 1* model. That glove is a more touching monument to the space age—a humble reminder that at any time, and despite all our technological wizardry, our reach can still exceed our grasp.

Richard Panek is author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

THE SKY IN MARCH

By Joe Rao

Mercury hugs the southeastern horizon before dawn in early March. Despite being far from the Sun (27.5° at greatest elongation on the 11th), it comes into view only for those willing to search diligently with binoculars.

Venus is the blazing evening "star" shining in the west at dusk for most of the month. On the 1st, Venus stands so high that it remains visible for three hours after sunset. By the 27th, however, it sets only about half an hour after sundown. During March, the planet swings closer to Earth and grows to an apparent diameter nearly 1/30 that of a full Moon. Venus's crescent is visible in telescopes, binoculars, and maybe with the naked eye. But the crescent also thins throughout the month, so its magnitude fades from -4.6 to -3.8. Its illuminated fraction narrows to a hairline one percent by March 27. Apparitions of Venus go through an eight-year cycle, so its appearance in 2001 closely duplicates that in 1993. At only one point in the cycle do those in the Northern Hemisphere get a chance to see Venus at both dusk and dawn within twenty-four hours, and March brings us this rare opportunity. The best chance to see Venus as both the evening and the morning "star" is immediately after sunset on the 27th and then just before sunrise the next morning; look for it very low on the eastern horizon.

Mars rises within an hour of midnight local time in March. As it continues to approach Earth, its brightness noticeably increases, from magnitude +0.5 on the 1st to -0.2 by month's end. On the night of March 2–3, it passes about 5° north of the first-magnitude star Antares, the "rival of Mars," though the planet will appear to shine nearly twice as bright.

Jupiter and Saturn continue to be prominent in the evening sky. Coming into view high in the southwest, Jupiter (in the constellation Taurus) is, next to Venus, by far the brightest "star" of the night. During early twilight, it lies about 30° to 40° above and to the left of Venus. Yellow Saturn and the red first-magnitude star Aldebaran (also in Taurus) soon emerge, flanking Jupiter in the deepening dark-blue sky. Use your binoculars for observing the Taurus get-together: even the most ordinary pair will show dozens of the Pleiades' and Hyades' stars and at least one of Jupiter's four bright moons. As evening progresses, the whole assemblage wheels lower in the west, setting by midnight.

The Moon is at first quarter on March 2 at 9:03 P.M. The full Moon comes on March 9 at 12:23 P.M., last quarter on the 16th at 3:45 P.M., and the new Moon on the 24th at 8:21 P.M.

The vernal equinox occurs at 8:31 A.M. on March 20. Spring begins in the Northern Hemisphere, fall in the Southern Hemisphere.

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

BIOMECHANICS

As it rocks from side to side, a walking penguin may look clumsy, but its movements are actually quite efficient.

When Tim Griffin and Rodger Kram set out to study how penguins walk, they didn't expect to be impressed. Compared with long-legged ostriches striding across a plain, waddling penguins come up short. Underwater they may be able to race like torpedoes in tuxedos, but on land they are more apt to evoke laughter than to inspire respect.

Previous research on penguins seemed to back up the laughter with hard numbers. Pound for pound, a penguin on land uses twice as much energy as other animals of its size to walk a given distance. Scientists laid the blame for this expense on waddling, the (presumably) energetically costly business of the bird's throwing its body first to one side and then to the other as it walks.

Griffin and Kram, both at the University of California, Berkeley, decided to test the assumption by measuring the work involved in waddling. So they filmed emperor penguins walking over a force-sensitive plate. Their data enabled them to calculate not just the force of each step but also the direction in which the force was acting and how fast the penguins were moving.

Similar studies on humans and other land animals have shown that walking is a surprisingly efficient way to move. Planting a foot in front of your body as you walk forward, you rise up slightly. Once your body is positioned directly above the foot, you start to fall forward and downward. In this process, much of the kinetic energy of your forward movement is turned into gravitational energy, which is then transformed into moving forward again. The same process occurs when a pendulum converts the energy it derives from moving side to side into moving upward against gravity. A walking person is like a pendulum turned upside down. Taking advantage of gravity this way saves lots of energy. Experiments have shown, for example, that a person's muscles need to supply only 35 percent of the work they would have to perform if there were no inverted pendulum involved. As the walker "falls" with each step, the muscles manage to recover 65 percent of the energy they put into a stride.

Griffin and Kram were amazed to discover that in this respect the penguins were actually superior to humans, recovering up to 80 percent of the energy they put into each step—among the highest rates ever recorded for any animal. How is this possible? Penguins not only rise and fall along the line in which they are walking (as we do); they also swing their bodies from side to side like pendulums. This side-to-side waddling provides additional energy for fighting gravity.

Waddling is not wasteful. The emperor penguin reuses some energy from one sway to make the next one.

Story by Carl Zimmer ~ Illustration by Sally J. Bensusen

The Fine Art

Energy from this sideways movement helps the penguin reach an upright position when only one leg is on the ground. As the bird swings back—or rather, falls—to the opposite side, it uses gravitational energy both to move sideways and to step forward.

Biologists have given waddling a bad rap, suggest Griffin and Kram. Penguins do pay a steep price to walk, but the researchers claim that waddling is not to blame. Instead, they propose, the trouble comes from having such short legs. Long-legged animals with longer strides maintain contact with the ground for more time during each step than do short-legged creatures. This allows a long-legged creature to use slower-working, more efficient muscle fibers. An emperor penguin is a hefty bird, weighing about forty pounds—in the same range as the flightless South American rhea, which is similar to an ostrich. But the emperor's legs are only one-third the length of the rhea's, or only about as long as those of the guinea fowl, a bird weighing only three pounds. Moving a rhea's body around on a guinea fowl's legs, a penguin has no choice but to use a lot of energy.

Like many animals, penguins are caught in a biomechanical bind. With their flipperlike wings, they are well adapted for swimming, and their short legs may help reduce drag underwater. But because they're birds and not fish, penguins cannot completely give up life on land, where they find mates, lay their eggs, and raise their chicks. Emperors are, in fact, champion walkers, traversing up to 150 miles of frozen sea ice to reach their winter rookeries. Far from wasting energy, waddling may help keep a penguin alive. □

# of Waddling

The Scavenging of "Peking Man"

New evidence shows that a venerable cave was neither hearth nor home.

By Noel T. Boaz and Russell L. Ciochon

China is filled with archaeological wonders, but few can rival the Peking Man Site at Zhoukoudian, which has been inscribed on UNESCO's World Heritage List. Located about thirty miles southwest of Beijing, the town of Zhoukoudian boasts several attractions, including ruins of Buddhist monasteries dating from the Ming Dynasty (1368–1644). But the town's main claim to fame is Longgushan, or Dragon Bone Hill, the site of the cave that yielded the first (and still the largest) cache of fossils of *Homo erectus pekinensis,* historically known as Peking man—a human relative who walked upright and whose thick skull bones and beetling brow housed a brain three-quarters the size of *H. sapiens*'s.

The remains of about forty-five individuals—more than half of them women and children—along with thousands of stone stools, debris from tool manufacturing, and thousands of animal bones, were contained within the hundred-foot-thick deposits that once completely filled the original cave. The task of excavation, initiated in 1921, was not completed until 1982. Some evidence unearthed at the site suggested that these creatures, who lived from about 600,000 to 300,000 years ago, had mastered the use of fire and practiced cannibalism. But despite years of excavation and analysis, little is certain about what occurred here long ago. In the past two years we have visited the cave site, reexamined the fossils, and carried out new tests in an effort to sort out the facts.

To most of the early excavators, such as

Franz Weidenreich, who in the 1930s studied the fossils of *Homo erectus* unearthed in China, is caricatured along with Ralph von Koenigswald (wielding the shovel), who found fossils of *H. erectus* in Java. The fanciful setting is, according to the artist, "any place where the dead are disturbed."

PAINTING BY FRED F. SCHERER. JACKIE BECKETT: AMNH

RECONSTRUCTION BY G.J. SAWYER AND IAN TATTERSALL. PHOTOGRAPH BY ROD MICKENS; AMNH

Above: A model of an *H. erectus* skull, based on fossils of several individuals from the Peking Man Site at Zhoukoudian. Most of the missing bones, represented in white, mirror existing parts on the opposite side of the skull.

AMNH

The early investigations at Zhoukoudian were coordinated by the Cenozoic Research Laboratory in Beijing. Staff members there included (left to right in foreground) Teilhard de Chardin, Franz Weidenreich, Yang Zhongjian, Pei Wenzhong, and Bian Meinian.

anatomist Davidson Black, paleontologist Pierre Teilhard de Chardin, and archaeologist Henri Breuil, the likely scenario was that these particular early humans lived in the cave where their bones and stone tools were found and that the animal bones were the remains of meals, proof of their hunting expertise. Excavation exposed ash in horizontal patches within the deposits or in vertical patches along the cave's walls; these looked very much like the residue of hearths built up over time.

A more sensational view, first advanced by Breuil in 1929, was that the cave contained evidence of cannibalism. If the animal bones at the site were leftovers from the cave dwellers' hunting forays, he argued, why not the human bones as well? And skulls were conspicuous among the remains, suggesting to him that these might be the trophies of headhunters. Perhaps, Breuil even proposed, the dull-witted *H. erectus* had been prey to a contemporary, advanced cousin, some ancestral form of *H. sapiens*. Most paleoanthropologists rejected this final twist, but the cannibalism hypothesis received considerable support.

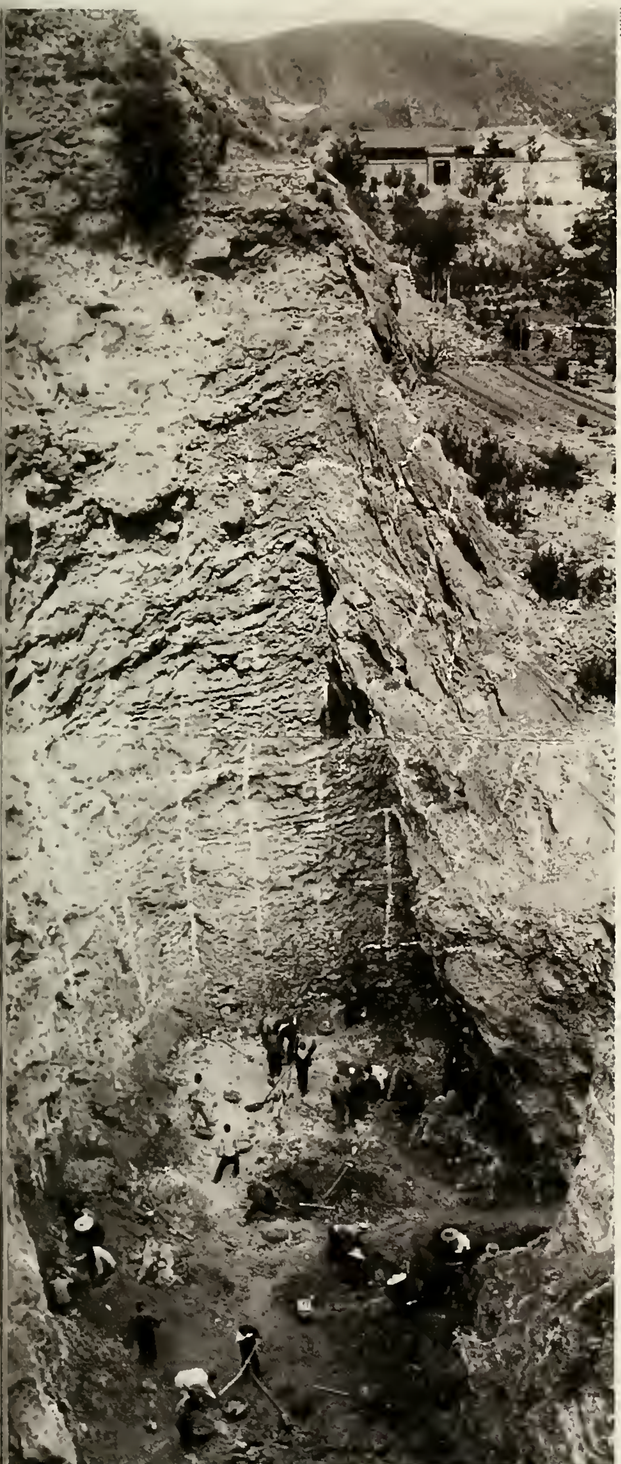
In the late 1930s Franz Weidenreich, an eminent German paleoanthropologist working at Peking Union Medical College, described the *H. erectus* remains in scientific detail. A trained anatomist and medical doctor, he concluded that some of the skulls showed signs of trauma, including scars and fresh injuries from attacks with both blunt and sharp instruments, such as clubs and stone tools. Most convincing to him and others was the systematic destruction of the skulls, apparently at the hands of humans who had decapitated the victims and then broken open the skull bases to retrieve the brains. Weidenreich also believed that the large longitudinal splits seen, for example, in some of the thighbones could only have been caused by humans and were probably made in an effort to extract the marrow.

Others held dissenting views. Chinese paleoanthropologist Pei Wenzhong, who codirected the early Zhoukoudian excavations, disagreed with Breuil and suggested in 1929 that the skulls had been chewed by hyenas. Some Western scientists also had doubts. In 1939 German paleontologist Helmuth Zapfe published his findings on the way hyenas at the Vienna zoo fed on cow bones. Echoing Pei's earlier observations, of which he was aware, Zapfe convincingly argued that many of the bones found at sites like Longgushan closely resembled modern bones broken up by hyenas. In fact, a new term, taphonomy, was coined shortly thereafter for the field Zapfe pioneered: the study of how, after death, animal and plant remains become modified, moved, buried, and fossilized. Franz Weidenreich soon revised his prior interpretation of several *H. erectus* bones whose condition he had attributed to human cannibalistic activity, but he continued to argue that the long-bone splinters and broken skull bases must have resulted from human action.

Following disruptions in fieldwork during World War II (including the loss of all the *H. erectus* fossils collected at Longgushan up to that time, leaving only the casts that had been made of them), Chinese paleoanthropologists resumed investigation of the site. While rejecting the idea of cannibalism, they continued to look upon the cave as a shelter used by early humans equipped with stone tools and fire, as reflected in the title of paleoanthropologist Jia Lanpo's book *The Cave Home of Peking Man*, published in 1975.

About this time, Western scientists began to appreciate and develop the field of taphonomy. A few scholars, notably U.S. archaeologist Lewis R. Binford, then reexamined the Longgushan evidence, but only from a distance, concluding that the burning of accumulated bat or bird guano may have accounted for the ash in the cave. With the founding in 1993 of the Zhoukoudian International Paleoanthropological Research Center at Beijing's Institute of Vertebrate Paleontology and Paleoanthropology, a new era of multidisciplinary and international research at Longgushan began. At the institute, we have been able to collaborate with paleontologists Xu Qinqi and Liu Jinyi and with other scholars in a reassessment of the excavations.

One of taphonomy's maxims is that the most common animals at a fossil site and/or the animals whose remains there are the most complete are most likely the ones to have inhabited the area in life. Standing in the Beijing institute amid row after row of museum cases filled with mammal fossils from the cave, we were immediately struck by how few belonged to *H. erectus*—perhaps only 0.5 percent. This suggests that most of the time, this species did not live in the cave. Furthermore, none of the *H. erectus* skeletons is complete. There is a dearth of limb bones, especially of forearms, hands, lower leg bones, and feet—indicating to us that these individuals died somewhere else and that their partial remains were subsequently brought to the cave. But how?

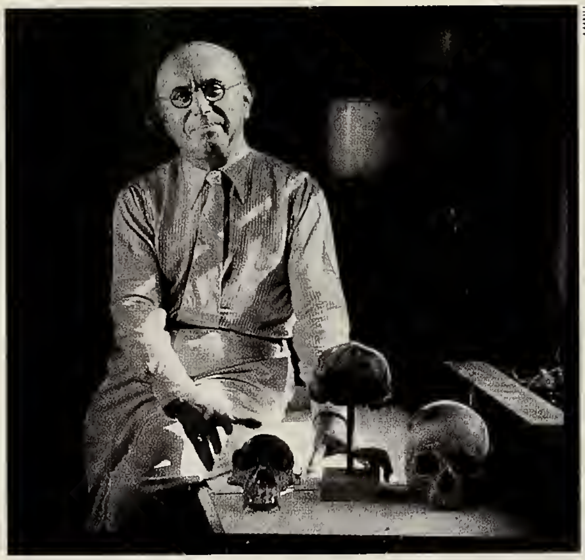

AMNH

During the 1930s, excavators dug down through the hundred-foot-thick deposits that contained the remains of "Peking man." The deposits, which also yielded animal bones, stone tools, and layers of ash, had completely filled an ancient cave.

The answer was suggested by the remains of the most common and complete animal skeletons in the cave deposit: those of the giant hyena, *Pachycrocuta brevirostris.* Had *H. erectus,* instead of being the mighty hunters of anthropological lore, simply met the same ignominious fate as the deer and other prey species in the cave? This possibility, which had been raised much earlier by Pei and Zapfe, drew backing from subsequent studies by others. In 1970, for example, British paleontologist Anthony J. Sutcliffe reported finding a modern hyena den in Kenya that contained a number of human bones, including skulls, which the animals had apparently obtained from a nearby hospital cemetery. In the same year, South African zoologist C. K. Brain published the findings of his extensive feeding experiments with captive carnivores, akin to those of Zapfe three decades earlier. One of Brain's conclusions was that carnivores tend to chew up and destroy the ends of the extremities, leaving, in the case of primates, very little of the hands and feet.

It looked as if H. erectus *had smashed open the skulls to cannibalize the brains.*

To test the giant hyena hypothesis, we examined all the fossil casts and the few actual fossils of *H. erectus* from Longgushan. We looked for both carnivore bite marks and the shallow, V-shaped straight cuts that would be left by stone tools (although we realized that cut marks would probably not be detectable on the casts). We also analyzed each sample's fracture patterns. Breaks at right angles indicate damage long after death, when the bone is fossilized or fossilizing; fractures in fresh bone tend to be irregular, following natural structural lines. Breakage due to crushing by cave rocks is usually massive, and



Franz Weidenreich at his laboratory at the American Museum of Natural History in the 1940s, with ape and human skulls

the fracture marks characteristically match rock fragments pushed into the bone.

We were surprised by our findings. Two-thirds of Longgushan's *H. erectus* fossils display what we are convinced are one or more of the following kinds of damage: puncture marks from a carnivore's large, pointed front teeth, most likely the canines of a hyena; long, scraping bite marks, typified by U-shaped grooves along the bone; and fracture patterns comparable to those created by modern hyenas when they chew bone. Moreover, we feel that

Two-thirds of the fossils show bite marks or fractures inflicted by carnivores.

the longitudinal splitting of large bones—a feature that Weidenreich considered evidence of human activity—can also be attributed to a hyena, especially one the size of the extinct *Pachycrocuta,* the largest hyena known, whose preferred prey was giant elk and woolly rhinoceros. One of the *H. erectus* bones, part of a femur, even reveals telltale surface etchings from stomach acid, indicating it was swallowed and then disgorged.

The pattern of damage on some of the skulls sheds light on how hyenas may have handled them. Bite marks on the brow ridge above the eyes indicate that this protrusion had been grasped and bitten by an animal in the course of chewing off the face. Most animals' facial bones are quite thin, and modern hyenas frequently attack or bite the face first; similarly, their ancient predecessors would likely have discovered this vulnerable region in *H. erectus*. Practically no such facial bones, whose structure is known to us from discoveries at other sites, have been found in the Longgushan cave.

The rest of the skull is a pretty tough nut to crack, however, even for *Pachycrocuta,* since it consists of bones half again as thick as those of a modern human, with massive mounds called tori above the eyes and ears and around the back of the skull. Puncture marks and elongated bite marks around the skulls reveal that the hyenas gnawed at and grappled with them, probably in an effort to crack open the cranium and consume the tasty, lipid-rich brain. We concluded that the hyenas probably succeeded best by chewing through the face, gaining a purchase on the bone surrounding the foramen magnum (the opening in the cranium where the spinal cord enters), and then gnawing away until the skull vault cracked apart or the opening was large enough to expose the brain. This is how we believe the skull bases were destroyed—not by the actions of cannibalistic *H. erectus*.

We know from geological studies of the cave that the animal bones found there could not have been washed in by rains or carried in by streams: the sediments in which the bones are found are either very fine-grained—indicating gradual deposition by wind or slow-moving water—or they contain angular, sharp-edged shards that would not have survived in a stream or flood. Some of the bones may have belonged to animals that died inside the cave during the course of living in it or frequenting it. Other bones were probably brought in and chewed on by hyenas and other carnivores.

Cut marks we observed on several mammal bones from the cave suggest that early humans did sometimes make use of Longgushan, even if they were not responsible for accumulating most of the bones. Stone tools left near the cave entrance also attest to their presence. Given its long history, the cave may have served a variety of occupants or at times have been configured as several separate, smaller shelters. Another possibility is that, in a form of time-sharing, early humans ventured partway into the cave during the day to scavenge on what the hyenas had not eaten and to find temporary shelter. They may not have realized that the animals, which roamed at twilight and at night, were sleeping in the dark recesses a couple of hundred feet away.

What about the ash in the cave, which has been taken as evidence that *H. erectus* used fire? Recently published work by geochemist Steve Weiner and his team at the Weizmann Institute of Science in Israel suggests that the fires were not from hearths. In detailed studies of the ash levels, they discovered no silica-rich layers, which would be left by the burning of wood. Wood (as well as grass and leaves) contains silica particles known as phytoliths—heat-resistant residues that are ubiquitous in archaeological hearth sites. The results indicate that fire was present in the cave but that its controlled use in hearths was not part of the story.

Still, a human hand may somehow be implicated in these fires. One possibility we are exploring in the next phase of our research is that Longgushan was a place where *Pachycrocuta* and *H. erectus* confronted each other as the early humans sought to snatch some of the meat brought back to the cave by the large hyenas. *Pachycrocuta* would have had the home court advantage, but *H. erectus,* perhaps using fire to hold the carnivore at bay, could have quickly sliced off slivers of meat. Although today we might turn up our noses at such carrion, it may have been a dependable and highly prized source of food during the Ice Age. □

RUSSELL L. CIOCHON

A composite image of the skulls of *Pachycrocuta* and *H. erectus,* left, shows how the giant hyena may have attacked the face. Beneath is a disgorged piece of an *H. erectus* thighbone. Below: An artist's depiction of the cave shows hyenas consuming the remains of an *H. erectus.*

WILL THOMSON

A WORLD AP

The larval lifestyle may seem alien to us terrestrial bipeds, but it comes quite naturally to most creatures—especially inhabitants of the world's oceans.

By Gregory A. Wray

A tiny larva, not much larger than a speck of dust, swims through the swirling soup of plankton in the cool waters of Puget Sound. Rows of minute cilia along the sides of its body pulsate continuously, pulling single-celled algae near before flicking them into its mouth. Fifty feet below the larva, an adult of the same species creeps across the rocky seafloor in search of a meal. Looking nothing like the larva and colossal by comparison (weighing about a million times more), this animal—a *Pisaster ochraceus* sea star, or starfish—is an active predator, searching out clams and mussels to pry open with its powerful arms. The larva and the adult lead lives that differ in almost every conceivable way: what they eat, how they move, what predators they must avoid, and the physical world they must negotiate.

From a human perspective, this may seem an odd arrangement. Even as embryos, we possess many anatomical features of our future adult bodies, albeit often in rudimentary form. Furthermore, only a few temporary structures appear during human development, most notably the transient gill slits that close when we are still early embryos, the placenta that feeds us in the womb, and the baby teeth that erupt soon after birth. Human development is quite direct, involving a fairly steady progression toward adult form.

Not so for most animals. The vast majority begin life as larvae that differ drastically from the corresponding adults. Many familiar animals have a larval form: caterpillars turn into butterflies, and tadpoles into frogs. But it is among the ocean's marine invertebrates that the larval lifestyle is most dramatically displayed. By one estimate, about 170,000 species of marine invertebrates exist worldwide, including not only sea stars but also sea

A spiny lobster larva hitches a ride on a jellyfish. After being at sea for two years, the larva will swim against the current back to coastal waters and undergo metamorphosis.

PETER PARKS; IMAGE QUEST 3D

ART

To see larvae in action, go to www.naturalhistory.com

And Then There Were Two

Cloning in Sea Star Larvae

By Elizabeth J. Balser and William B. Jaeckle

In 1989 scientists reported an astonishing discovery: cloning by sea star larvae. Isidro Bosch, of the State University of New York College at Geneseo, and several colleagues observed larvae with small growths, or buds, in place of one or more of their larval "arms." After separating from the primary, or "parent," larva, these buds developed into fully formed swimming larvae. Long before reaching adult form, let alone sexual maturity, these immature lifeforms were in essence giving birth to other, genetically identical individuals.

In the years since Bosch's discovery, we, too, have found instances of cloning among the larvae of several sea star species as well as among at least three species of brittle stars. Larvae of sea stars collected from the western Atlantic Ocean exhibit three distinct cloning methods. Most commonly, clones develop from the posterior arms of the parent larva (which, unlike the radially symmetrical adult, is bilaterally symmetrical, with a front and a back end). In the second method, all ten larval arms release buds that develop into independent larvae. In the third, the preoral lobe (a region in front of the mouth) separates from the primary larva, which then regenerates its preoral lobe, while the released lobe forms its own larval body.

From the mother sea star's point of view, larval cloning is a reproductive bonus: with no more investment on her part, she winds up with many more offspring. From the larva's perspective, cloning is a way for one "individual" (the primary larva and all the genetically identical larvae it produces) to extend the amount of time it has to find a suitable place (or, in this case, places) to settle and metamorphose into adult form. A longer period of dispersal tends to mean a wider dispersal as well, which may eventually help a species populate new areas. Less benignly, of course, a longer dispersal also increases the period of vulnerability to predators. Presumably, however, in order for larval cloning to have evolved, the benefits must, at least some of the time and under some circumstances, outweigh the costs (for instance, when suitable habitats for the adult are few and far between).

Once cloned, a larva develops no differently than an embryo arising from a fertilized egg. This suggests that cloning restarts the developmental process or, alternatively, begins some as-yet-undiscovered parallel developmental pathway. Understanding the patterns of gene expression during cloning could have far-reaching value in studies of the evolution and control of development—particularly since cloning by free-living larvae may turn out to be a characteristic typical of other invertebrate phyla. In the words of the renowned larval ecologist Gunnar Thorson, "Who knows? Nobody has ever looked for it!"

ELIZABETH BALSER

Two clones (white globes) develop from the rear "arms" of a sea star larva.

ELIZABETH BALSER

The preoral lobe (see box) of this larva will soon break free and form a new, independent larva, while the "parent" left behind will regenerate the lost lobe.

urchins, sea cucumbers, sea slugs, and sea lilies, as well as corals, clams, barnacles, and feather-duster worms. These animals typically spend days, weeks, or even months in larval form, mostly swimming in the top ten to twenty feet of water in the company of myriad other creatures. (One bucketful of seawater might contain the larvae of a dozen or so species of marine invertebrates.) At the end of the larval stage, the animals drop down to the seafloor and metamorphose into adults. There they live, grow, and eventually reproduce, releasing sperm and eggs into the water and beginning the cycle again.

The marine invertebrate larvae are so small that their discovery came only in the late 1700s, with the development of good microscopes. Samples of seawater examined through these new instruments revealed a world teeming with unfamiliar organisms. Early observers believed that these tiny creatures must be the adults of previously unknown species, and they named them according to the animals' often bizarre shapes—such as pilidium (from the Greek word for "hat") or auricularia (from the Latin for "ear").

Barnacle larvae found crawling on adults, for instance, were thought to be parasites—a misconception not corrected until the 1820s, when Irish surgeon and amateur naturalist John Vaughn Thompson observed them metamorphosing into immature barnacles. Zoologists initially responded to his findings with disbelief: for centuries, many people had believed that goose barnacles were the young of real geese (hence the barnacle's common name), and zoologists were understandably wary of this new and seemingly equally fantastic claim.

Two decades after the publication of Thompson's findings, German physiologist Johannes Müller accidentally discovered a second example

PETER PARKS; IMAGE QUEST 3D

Equipped with long spines that it flares open when attacked, an early-stage larva of a marine worm, above, bears little resemblance to the adult it will become. The late-stage scale worm larva, left, is beginning to look like its adult self.

while studying a microscopic creature to which he had earlier given the scientific name *Pluteus paradoxus*, or "strange easel"—an apt name for a creature whose triangular profile and projecting "legs" gave it the general appearance of an artist's easel, albeit a nearly transparent one flecked with bright red spots. Müller was surprised to observe a miniature brittle star (a slender relative of sea stars) growing inside the body of this minute animal. His continuing patient observations revealed that the two creatures were in fact one and the same: the adult develops inside the swimming larva, whose body is cast away when the adult takes up residence on the seabed.

FRED BAVENDAM; MINDEN PICTURES

One by one, nearly all the creatures in the peculiar microscopic bestiary of ocean water were found to be the larval stages of familiar animals. By the beginning of the twentieth century, scientists could confidently assert that a complex life cycle with an extended larval "detour" is in fact the most common method of development in the animal kingdom. This newly discovered complexity raised several questions: Why is the larval stage such a widespread feature of animal life, and if it is advantageous, why don't all animals go through one? And why do larvae look so bizarre?

One key insight into these questions came during the 1920s from Walter Garstang, an English embryologist and amateur poet. Garstang was among the first to argue that larvae are intricately adapted to their planktonic world, a world so differ-

Right: The nudibranch, or sea slug, larva starts out with a shell and four ciliated feeding lobes. (The larva's eyes are visible as two black dots.) Above: At metamorphosis, nudibranchs crawl out of their shells, with many species trading armor for toxicity, which they advertise with bold markings.

Getting to the Point
Self-Defense in Crab Larvae

By Steven Morgan and Skyli McAfee

Of the many predators that crab larvae face, plankton-eating fishes (such as anchovies and silversides) pose the greatest threat. Female crabs living in the marshes, mangroves, and sea grass beds of estuaries and bays—the productive but perilous habitats where such fishes are especially abundant—brood their embryos beneath their bodies until the embryos have developed into larvae and are ready to be released. The release is timed carefully: it occurs under cover of darkness, when fish are least active, and during the strongest ebb tides of the month, when the vulnerable crabs-to-be have the best chance of being swept out to the relatively safer waters of the open continental shelf.

PETER PARKS; IMAGE QUEST 3D

The long spine of this porcelain crab larva may deter predatory fish.

Their conspicuousness already reduced by partial transparency, the larvae of many species further boost their chances of survival by descending into dimly lit waters during the daytime and ascending only at night to feed in the more productive surface waters. If approached by a fish, a crab larva generally does not attempt to avoid or escape attack. Instead it relies on a heavily armored exoskeleton and spines that effectively increase its size many times over. In addition, a pair of antennal spines flare upon attack, transforming the larva into a prickly ball, difficult for small-mouthed planktivorous fishes to swallow. Indeed, young fish sometimes die when larvae catch in their throats.

To avoid such a fate, a fish may attack a larva repeatedly before swallowing it, spitting it out each time in an attempt to break down the spines. After the initial strike, the larva plays dead: its antennal spines collapse, and it sinks quietly away. Remarkably, larvae can survive multiple strikes, regenerating broken spines during the next molt or two.

A similar set of defenses has arisen in other lineages of marine invertebrates. The larvae of polychaetes (segmented marine worms), for example, are also largely transparent and sink to safer depths during the daytime. Attacked, they roll into a ball and, like crab larvae, flare their bristles and play dead.

Some crab larvae complete their development in the estuaries and bays where their mothers released them. To help their young survive, the females in these species invest more energy per offspring than do other crab mothers—producing fewer, but larger, eggs and brooding them for a longer time. The result is larger and very long-spined larvae with a relatively short development time of about two weeks. Conversely, short brood times, small eggs, small body size, and short spines are common in species whose larvae migrate offshore and back during development.

When the time comes to metamorphose into adult form, the larvae (or more precisely, postlarvae) of coastal crabs must return to shore, regardless of how far they may have drifted. Riding a flood tide at night on this last journey, enough of them make it past the predatory fish to start the cycle anew.

ent from the seafloor habitat of adults that few features of anatomy could serve a useful purpose in both locations. Take, for example, cone snails (or cone shells, as they are known to collectors): the adults crawl about the seabed, while the larvae are swept along by currents near the ocean's surface; the adults are active predators, armed with potent neurotoxins, while the larvae are herbivores that capture single-celled algae with the aid of microscopic cilia; and the adults are preyed upon by octopuses, while small jellyfishes and a great variety of other tiny predators feed on the larvae. The contrasts are enormous.

Pointing to transient larval organs that form no part of the adult, Garstang argued that the rigors of life among the plankton drove the evolution of numerous and seemingly bizarre adaptations in the early part of the life cycle: the highly convoluted tracts of cilia on the larvae of clams and acorn worms, used for swimming and feeding; the long spines on some annelid worm larvae that flare in response to the slightest touch; and the specialized,

The Long and the Short of It
"Arm" Development in Sea Urchin Larvae

By Larry R. McEdward

Like sea star larvae, most sea urchin larvae have little "arms" lined with rows of cilia that gather nutritious particles suspended in the water. Remarkably, when food is scarce, a sea urchin larva's arms grow longer, thus providing more cilia with which the animal can capture food.

If long arms are beneficial, why would larvae ever have short ones? One possible advantage is that when food is abundant, nutritional intake is limited only by how much a larva can digest—arm length is irrelevant. In fact, smaller arms may allow a larva to devote more energy and materials to increasing the size or activity of its gut. Another advantage is that short-armed larvae start developing into juvenile sea urchins sooner than do long-armed individuals. These larvae will also metamorphose into adults sooner than their long-armed brethren and thus are vulnerable to planktonic predators for a shorter period of time.

PETER PARKS; IMAGE QUEST 3D

Many sea urchin larvae can modify their "arms" in response to food supply.

My graduate students and I are currently investigating several aspects of larval plasticity in sea urchins. (Plasticity is the ability to produce different body forms under different environmental conditions.) Though we have not yet isolated the specific cues that trigger modifications in structure, function, or development, we have learned that different species respond to different cues, with some larvae able to detect cues and alter arm length even before they have begun to feed. We also want to learn how this plasticity is related to other larval attributes. For example, not all species pack their eggs with the same amount of nutritional material. Larvae that develop from protein- and lipid-rich eggs have a greater capacity to modify their early development and to exhibit plasticity, even though larvae from poorly provisioned eggs are more dependent on food from the plankton and would thus, we might think, benefit more from an ability to modify their bodies in response to environmental conditions. One long-term hope of our team is that understanding the mechanisms by which short and long arms are generated in different species will help us determine if larval plasticity arose once, early in the evolutionary history of sea urchins, or numerous times.

suckerlike organs used by the larvae of sea squirts and sea stars to adhere to rocks or shells during metamorphosis.

Although Garstang's observations and conclusions may now seem almost obvious, they went against the then-prevailing view. Just half a century earlier, the German comparative anatomist Ernst Haeckel had forcefully argued that embryonic development retraces the course of evolutionary history. Haeckel, who interpreted larvae as vestiges of ancestral adults, remained influential well into the twentieth century. In arguing that its anatomy specifically adapts a larva for planktonic life, Garstang challenged Haeckel's paradigm and, indeed, played an important role in its eventual demise as a general principle. (Garstang's poetry remains popular among biologists today, in large part because it venomously satirizes Haeckel and other intellectual opponents.)

But why would young need a body plan and habitat different from those of adults? In Garstang's view, the answer was dispersal. Local habitats—whether a suitable rock, a chunk of coral reef, or a bit of sandy sea bottom—inevitably suffer periodic disruptions from silt deposition, unusually violent storms, disease outbreaks, and the like. Setting great numbers of offspring adrift in the ocean increases the chance that at least some will survive and be delivered to suitable locations, a strategy that contemporary ecologists call bet hedging.

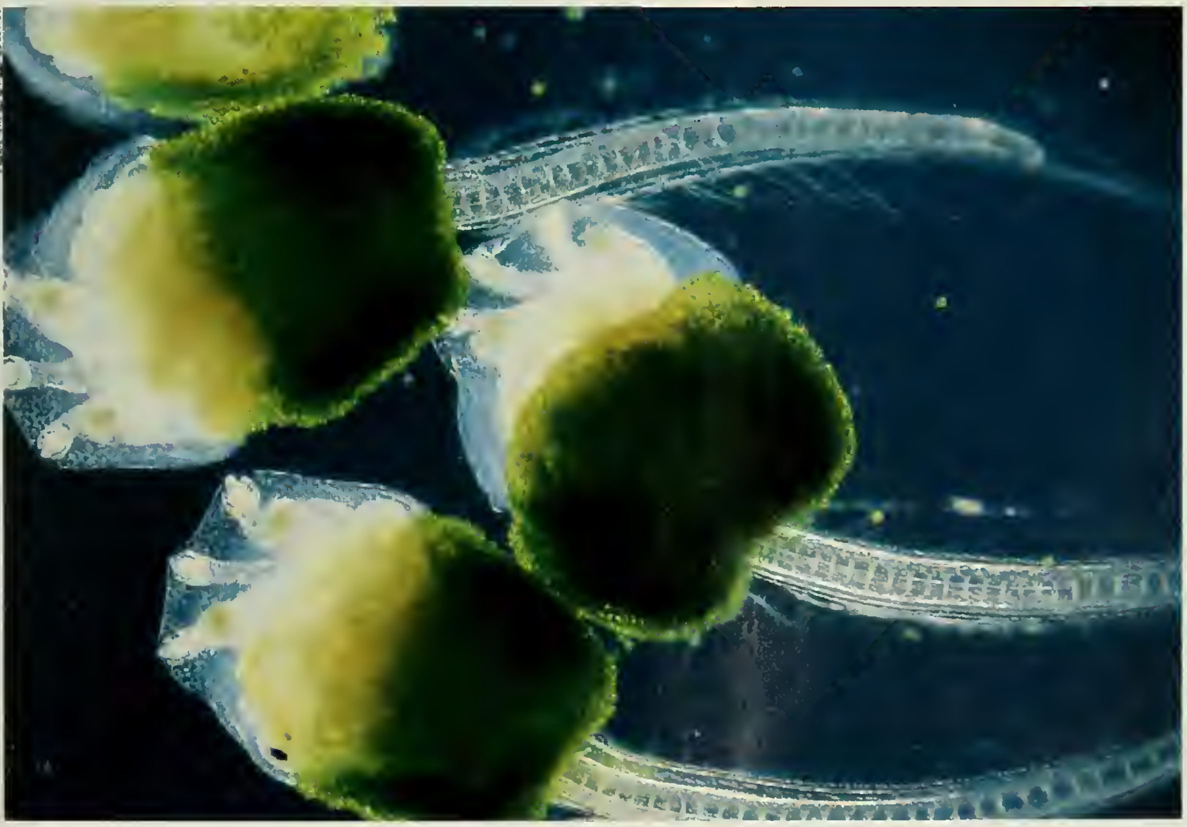
Larvae's ability to drift long distances also provides a mechanism for genetic mixing. Many adult marine invertebrates have only a limited ability to move, and some, such as corals and barnacles, do not move at all. Inbreeding is a real danger for creatures that are (quite literally, in some cases) stuck in one place. Widespread dispersal helps ensure that when larvae do settle down, their neighbors—and potential mates—will be unrelated.

Although dispersal provides tangible benefits, the cost is high. Among the plankton are numerous diminutive but voracious carnivores, including small jellyfishes and comb jellies, saber-toothed creatures called arrowworms or chaetognaths, and a host of crustaceans and small fishes. Larvae that are not eaten are still prey to the ocean currents, which can sweep them away from suitable habitats. And when "suitable habitat" means a coral reef in the Pacific Ocean—separated from the next reef by perhaps a thousand miles of open ocean—almost any current is likelier to move a larva away from safety than toward it.

Yet the broad geographical distribution of many species of marine invertebrates across the South Pacific is proof that larvae do sometimes successfully drift from reef to reef, crossing over abyssal depths that adults could never negotiate. Just how far from its birthplace a larva may drift became clear in the 1970s, when oceanographers, using fine-mesh nets similar to those invented by Thompson a century and a half earlier, began a systematic sampling of plankton in the middle of oceans. These plankton hauls often included the larvae of clams, sea stars, and other invertebrates whose adults live only in the relatively shallow water of continental shelves. We now know that the Gulf Stream sweeps countless larvae out of the Caribbean Sea and into the North Atlantic, where most perish and perhaps a tiny fraction survive long enough to ride the entire gyre to Europe and back across to the Caribbean.

PETER PARKS; IMAGE QUEST 3D

PETER PARKS; IMAGE QUEST 3D



Left: Sea squirts have a short larval life, swimming with the aid of a tadpolelike tail for just a few minutes before settling on the seafloor, to which they attach themselves with little "suckers" (visible at the front end). There they will transform into filter-feeding adults, above.

ELIZABETH BALSER

As a sea star larva prepares to settle on the seafloor, it grows an attachment organ with sticky "arms" and a central adhesive disk (see bracket). The adult-to-be (yellowish sac) forms from the lower part of the larval body. Eventually the rest of the larval body, except for the stomach (orange), is absorbed into the developing juvenile.

All these hazards take a heavy toll. Estimates of larval death rates range from 10 to 20 percent per day. Even at the lower rate, barely one-fifth of a brood will survive two weeks among the plankton, and only a few percent will last a month. (Most larvae must feed for weeks or months before they grow large enough to undergo metamorphosis.) Such heavy mortality suggests that natural selection will favor the evolution of well-defended larvae that eat efficiently, grow quickly, drop out of the plankton community in short order, and soon undergo metamorphosis—just as Garstang and others suggested nearly a hundred years ago. The idea has only recently been tested in detail, however.

Using time-lapse microscopy, Michael Hart, an evolutionary biologist at Dalhousie University, has observed echinoderm larvae capturing food particles and then quantified their feeding rates. Comparing the rates of sea urchin and sea star larvae, he found that those of sea urchins were higher and that these larvae reached metamorphosis sooner. Anatomically the two kinds of larvae are quite similar, and both use the cilia along the sides of their bodies to sweep algae toward their mouths, but the sea urchin larvae also develop long projections lined with hundreds of cilia, which help the larvae pull in even more food. Specializations for feeding abound among immature marine invertebrates. The cilia on the larvae of acorn worms capture algae; strings of mucus serve as "fishing" lines for some sponge larvae; and the larvae of lobsters and shrimp use powerful claws to grab unwary prey.

Well-fed or not, larvae face the problem of predation. The larvae of many groups defend themselves with spines and spikes, which can be impressive. Some shrimp larvae sport sharp spines extending more than five times their body length. Other defensive strategies include toxicity (some sea squirt larvae) and concealment (larval snails that hide in their shells). And nearly all marine invertebrate larvae enjoy the advantage of transparency.

To study how larvae defend themselves from predators, Steve Rumrill and Tim Pennington, then graduate students at the University of Alberta, set up aquariums with different combinations of predators (adult jellyfish and juvenile fish, for example) and prey (sea urchin embryos and larvae in various stages). They found that the embryos and younger larvae were especially vulnerable because they had not yet developed their feeding projections, inside of which are spiny spicules capable of deterring some predators, such as jellyfish. But nothing stopped the fish, whose mouths opened wide enough to swallow even late-stage urchin larvae whole.

Even if a larva manages to get enough to eat and to escape being eaten, it confronts the challenge of finding an appropriate place to settle and undergo metamorphosis. Those fortunate enough to drift near the right habitat at the right time must still select exactly the right site. Settling near a hungry snail could be disastrous for a peanut worm, and landing too far from kelp would doom a sea urchin to starvation. As the time for metamorphosis approaches, most larvae become acutely sensitive to chemical cues that signal the presence of food, conspecific adults, and potential hazards. The importance of finding a good place to land is underscored by the fact that the decision, once made, is often final: many larvae bear specialized structures that glue them to their chosen spot.

Metamorphosis itself must coincide with settlement on the seafloor, an environment so different from the surface that no larva would long survive unchanged—just as no adult could handle life in a planktonic world. Metamorphosis can be dramatic and literally gut-wrenching. Almost immediately

Out of the Frying Pan, Into the Freezer

Larvae at Deep-Sea Vents

By Craig M. Young

A quarter century ago, when scientists discovered lush colonies of organisms surrounding hot-water vents, such as black smokers, on the ocean floor, they began wondering how these animals maintained their populations. The giant tubeworms, specialized clams and mussels, and wide assortment of tiny snails, crabs, shrimps, and other worms that live around the vents are nourished by bacteria, which in turn obtain their energy from hydrogen sulfide in the hot water emanating from deep within the earth's crust. Completely dependent on vent water, these species cannot survive even a short distance away. Because the hot-water plumbing of the seafloor is controlled by unpredictable volcanic activity in the earth's interior, a vent may remain open and active for only limited periods—years or sometimes decades. Moreover, areas of active venting may lie hundreds of miles apart. Researchers suspected that many, if not most, of the vent animals must produce larvae capable of dispersing through cold ocean water to new sites.

Searching for larvae, researchers from the Woods Hole Oceanographic Institution towed plankton nets near vents on the East Pacific Rise. They captured relatively few—except in the buoyant plumes that rose directly above hot smokers. Here the larvae of various snails and polychaete worms were abundant, suggesting that some larvae may begin their voyage from one vent field to another by drifting in the slightly warmer waters near vents. On the other side of the world, larvae of the abundant shrimp found around vents on the Mid-Atlantic Ridge have been captured more than half a mile above the bottom and more than 900 miles from the nearest vent, suggesting that free-swimming larvae do indeed travel long distances.

CRAIG YOUNG

CRAIG YOUNG

Above: Adult giant tube worms at hydrothermal vents in the Pacific Ocean. Inset: An electron micrograph of the larva of a related species from cold methane seeps in the Gulf of Mexico.

Because vent animals live at such great depths and under tremendous pressure, the details of their development and ecology have been difficult to determine. Only recently, after years of work, have we reared tubeworm larvae in our laboratory. The first ones we succeeded in raising came not from vents but from shallower, 2,000-foot-deep communities at cold methane seeps on the Louisiana continental slope. Now, with colleagues from the University of Southern California, we have also cultured the larvae of giant tubeworms from deep Pacific vents, and they are gradually yielding the details of their dispersal mechanism.

Tubeworm eggs and embryos are richly endowed with all the lipids and protein needed for embryonic development and larval dispersal. And because lipids are less dense than seawater, they also aid dispersal by causing the larvae to rise toward the surface. After drifting for several weeks, the embryos develop into ciliated larvae and swim actively for about two weeks before locating a suitable habitat and transforming themselves into small worms. We don't yet know what precipitates the larval migrations of giant tubeworms or other vent animals back to the ocean floor, nor do we know how they locate suitable habitats. We suspect that they cue in on certain attributes unique to vents: the presence of sulfide, hot water, or perhaps other vent organisms.

A Method for the Masses

Oxygen Delivery for Stay-at-Home Embryos

By Richard Strathmann

Most marine invertebrates set their young adrift. Some, however, produce masses of embryos that remain at the bottom of the sea, where they may be protected by tough capsules, by layers of gel, or by the body of a parent. Though these embryos are safe from the many planktonic predators, life in an embryo mass is not without its challenges.

Perhaps the most vital challenge is getting enough oxygen. Not very soluble in water, oxygen diffuses in it at about 1/10,000 the rate oxygen diffuses in air. For free-swimming larvae, this presents no problem. But for embryos packed together in a mass—with no circulatory system and no way to force oxygen-bearing water rapidly through the tiny spaces between small eggs—the problem can be severe.

One solution is to keep the mass small and thus the need for oxygen relatively low. Accordingly, species in which mothers brood their embryos on or in their bodies tend to be the smaller species of sea stars, sea cucumbers, clams, and feather-duster worms. Larger species of marine invertebrates that brood their young have evolved special ventilation mechanisms. A large crab or lobster may incubate more than 100,000 embryos, but each one is held loosely on a separate strand. Oxygenated water is forced through the mass of embryos by the mother's movements; to increase circulation around her brood, a mother crab waves her abdomen up and down.


RICHARD STRATHMANN

A nudibranch laying its gelatinous, ribbonlike egg mass

Other species, including many snails, secrete strong, flexible, thin-walled capsules around their eggs and attach each capsule to a rock or to seaweed in moving water. Some snails, sea slugs, and worms embed embryos in gel, often in the form of thin strings or beautiful coiled ribbons that undulate gracefully in the current. Even within a thin ribbon, however, embryos will die if packed too tightly. The thicker the mass, the more of it must be devoted to gel, thus lowering the demand for oxygen within a given volume.

Sometimes these embryo masses are thick and globose and are anchored in the sand by a buried strand of gel. Masses of this type range from a quarter inch to several inches in diameter and have a high proportion of gel. Embryos in the center of the mass receive less oxygen than those at the periphery and, as a result, develop more slowly. In some masses, the central embryos die; in others, as the peripheral embryos hatch and leave, those in the center start receiving more oxygen and are able to complete their development.

Some of these protective measures have their costs, of course. The capsule walls of cone snails and the gel around nudibranch eggs constitute between one-quarter and one-half of the organic material in the mass. If the mother produced only eggs, and not the additional protective coats or spacing gel, she could produce up to twice as many. What makes the trade-off worthwhile is the increased survival of her young.

after attaching to a rock or a blade of kelp, for instance, the larva of a bryozoan begins a violent rearrangement of its internal organs and external appearance. Pockets of sticky cells evert, securing the animal in place; other cells evert to form the outside of the adult; still others secrete a tough shell; and muscles quickly fold the former larval body wall inside the newly forming adult, where it is resorbed. In many ribbon worms and echinoderms, metamorphosis is remarkably rapid, with the major changes from larval to adult body form taking less than half an hour.

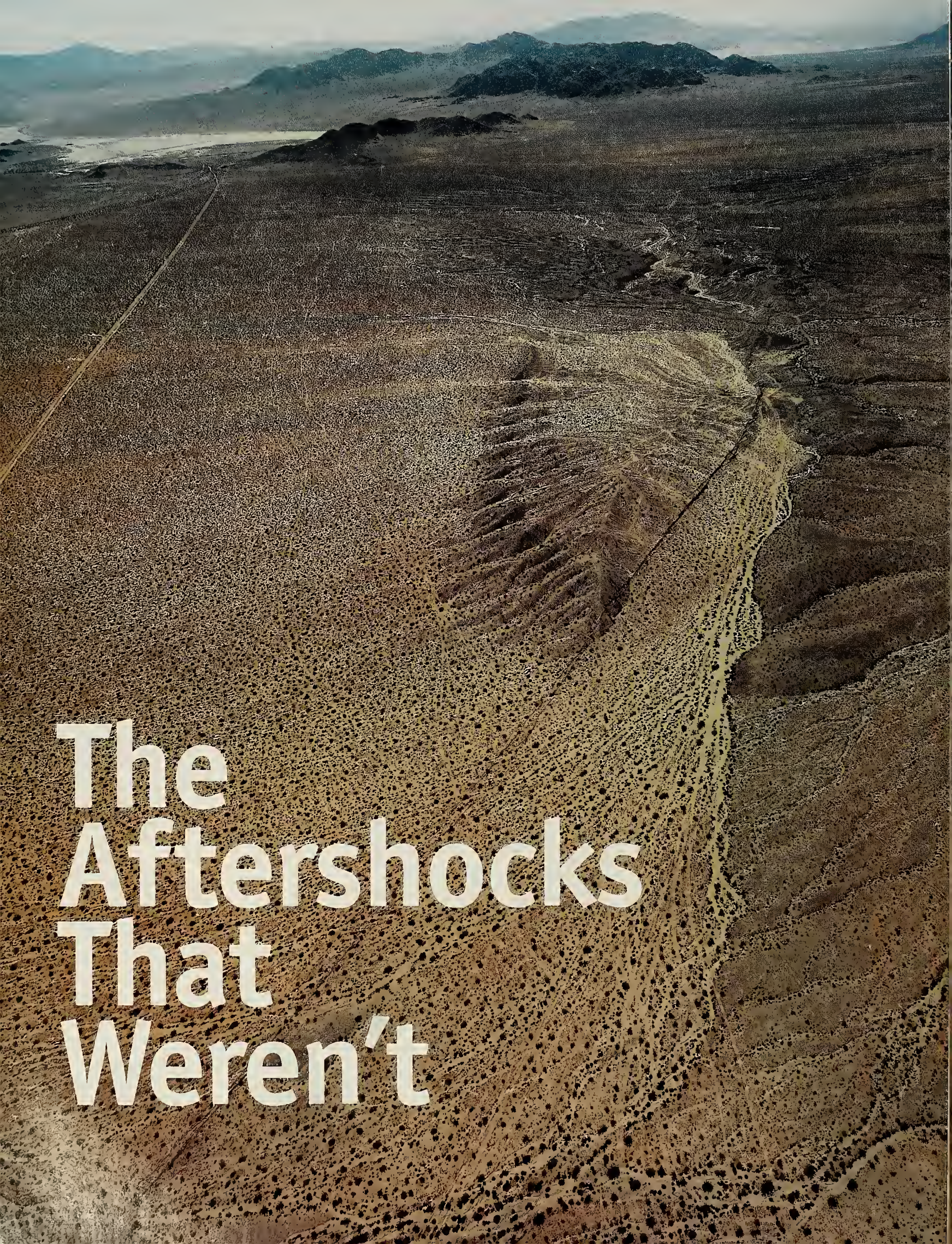
And then there are larvae that have no need to feed at all—including those of some clams, snails, sea stars, and annelid worms. Nonfeeding larvae are generally much simpler anatomically than the feeding larvae of related species, having jettisoned useless feeding structures and significantly accelerated the events leading to metamorphosis. In these species, eggs are provisioned with enough protein and fat to fuel development all the way through metamorphosis. This shift to dependence on maternally provided food reserves has evolved within most groups of animals and at many junctures in the history of life. In the most extreme cases, a distinct larval stage is lost altogether, and embryos develop directly into miniature versions of adults. This evolutionary shift, too, has occurred many times—groups as diverse as squids, roundworms, and most vertebrates develop without the benefit of larvae.

Why don't all species adopt this trick of minimizing or even bypassing the larval stage? Because neither having nor lacking a larva is inherently superior. Each has costs and benefits, and the balance shifts among groups of animals and across the myriad habitats of the marine realm. Species with feeding larvae, for example, produce small eggs and consequently can afford to have much larger broods, whereas species with nonfeeding larvae or direct development tend to produce larger eggs or to have placentas and therefore much smaller brood sizes. Predators may also affect the duration of larval development: species heavily preyed on as small juveniles may be better off prolonging their time among the plankton, but others may do better to settle on the seafloor as quickly as possible and thus avoid planktonic predators. Understanding the particular ecological contexts that favor the evolutionary retention, reduction, or loss of larvae represents one of the outstanding challenges facing biologists today. For now, however, we can say that although larvae don't offer the only road to adulthood, for most animals they provide a good way to get there. □

Some marine invertebrates—like these young octopuses peering out of their egg cases—skip the free-living larval stage and develop directly from embryo to adult.

FRED BAVENDAM; MINDEN PICTURES

The Aftershocks That Weren't



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By Susan Elizabeth Hough

Before dawn on June 28, 1992, residents of southern California were jolted from their sleep by a magnitude 7.3 earthquake. The temblor started beneath the tiny Mojave desert town of Landers, but its effects were felt in Los Angeles, ninety miles to the west, as well as in northern California, southern Nevada, and at the Mexican border.

Earthquakes are not unusual for California, of course. The state is riddled with both large and small faults at the boundary between two tectonic plates: the North American Plate and the Pacific Plate. These two enormous pieces of the earth's crust are constantly sliding past and grinding against each other, creating an active and complicated boundary zone. Sections of faults often rupture here, earning California its reputation as earthquake country. So the powerful Landers temblor was not unusual in itself. Its far-reaching aftereffects, however, revealed some surprises.

Nearly half a century ago, seismologist Charles Richter, of Richter scale fame, observed that "an earthquake of consequence is never an isolated event." He was referring to the aftershocks that invariably follow a large temblor, or main shock. As earthquakes go, aftershocks are remarkably well behaved. In time, space, and magnitude, they follow predictable patterns that have been recognized by seismologists for decades. As a general rule, they are small, more frequent in the immediate aftermath of a main shock, and usually clustered no farther from the site of the main shock than the length of the rupture it created.

An aerial view looking southeast across the Mojave Desert shows a rupture (running from the lower left toward the upper right of the photo) created by the 1992 Landers, California, earthquake.

New evidence from California—and old reports from the Midwest—indicate that some earthquakes can trigger others hundreds of miles away.

The Landers temblor, however, permanently changed the established view of earthquake sequences. In the minutes and days that followed the quake, a substantial number of smaller seismic events occurred well beyond its aftershock zone—as far away as the Lassen Peak area and at the Geysers, about sixty miles north of San Francisco. The largest of these distant events, with a magnitude of 5.4, struck in western Nevada twenty-two hours after the Landers event. Quickly dubbed remotely triggered earthquakes, these outlying seismic events seemed to be different beasts from anything seismologists had previously encountered.

Because the Landers quake was one of the first magnitude 7.0 events to be recorded by state-of-the-art seismic stations throughout California, it yielded the first solid evidence of distant earthquake triggering. The authors of one research paper commented that "no previous experience would have led us to anticipate the observations of remotely triggered [earthquakes]." Earth scientists began to realize that large quakes could perturb the crust in complex ways that earlier theories could not explain.

The powerful Landers earthquake of 1992 triggered hundreds of distant events, many clustered in four areas in California and Nevada, and all far beyond the aftershock zone.

Almost immediately after Landers, researchers began to focus on these puzzling quakes. Not only were they located too far from the main shock to be classified as aftershocks, they also couldn't even be associated with the same physical mechanisms. As the Landers earthquake helped seismologists understand, conventional aftershocks appear to result primarily from local, mechanical factors—changes in stress caused by large-scale movement of a crustal block. But as seismologist Joan Gomberg and others have shown, the outlying earthquakes of 1992 were apparently set off solely by waves, or shaking, emanating from the Landers main shock. Such waves, it seems, were capable of engendering—that is, triggering—new quakes as far as 700 miles away.

Using data not only from Landers but also from Greece and Mexico, seismologists attempted to characterize the geology of vulnerable areas and to define a threshold level of shaking needed to trigger remote events. The first models implicated something curious: bubbles. Most of the triggered quakes identified in the immediate aftermath of Landers had taken place in regions with active volcanoes or geothermal features such as geysers. A couple of models showed that disruption of the bubbles within fluid reservoirs can indeed raise stress on faults, which, the researchers argued, could then set off earthquakes. According to this scenario, triggered earthquakes were rather exotic events occurring only in highly unusual geological zones.

The first computer studies of triggered quakes implicated the disruption of gas bubbles in subterranean reservoirs of fluid.

Last year, however, I took a new look at evidence from an unlikely time and place, and my investigation has revealed that the triggered earthquakes of 1992 were not as unprecedented—or as exotic—as they first seemed. Nearly two centuries ago, settlers along the Ohio River valley wrote reports that (had they been fully appreciated) might have helped scientists interpret what happened after the Landers earthquake. In the wee hours of the morning on December 16, 1811, the usually stable U.S. midcontinent was rocked by an earthquake so large that it caused damage as far away as coastal South Carolina. Now estimated to have had a magnitude upwards of 7.3, the temblor was the first event in an extraordinary sequence. Centered at the southeast corner of Missouri—the Bootheel region, adjoining the Tennessee-Kentucky border—the sequence was named New Madrid, after a town close to the event. The area experienced two more quakes after December 1811: events of comparable magnitude jolted the region on the mornings of January 23, 1812, and again on February 7, 1812. Historical accounts peg the final quake as the largest of the three; some refer to it as the "hard shock." Immediately following it, a section of the Mississippi River in the vicinity of New Madrid reversed course for several hours.

Starting in the 1970s and early 1980s, seismologists Otto Nuttli, Ronald Street, and Arch Johnston compiled and interpreted the available accounts of the New Madrid sequence, including reports of half a dozen "large aftershocks" on the Atlantic coast. Settlers left descriptions of thousands of perceptible aftershocks, most not large enough to rattle anything more than people's nerves, but some so strong they cracked chimneys and split stone houses.

Recently my own attention was drawn to historical accounts of the effects of the New Madrid sequence. I was especially struck by passages concerning three particularly large "aftershocks": one that occurred four days after the January 23 event and two others on the night of the February 7 "hard shock." These supposed aftershocks were apparently centered near the Ohio-Kentucky border; no accounts exist from within 200 miles of New Madrid. To a seismologist reviewing the evidence, this absence of reports in the region of the main shocks is contrary to expectation. Moreover, descriptions of the shaking in Ohio and Kentucky differ significantly from accounts of the New Madrid main shocks. Daniel Drake of Cincinnati stated that one of these "aftershocks" caused "a very sensible degree of trembling, but no oscillation." Jared Brooks of Louisville wrote that another was "violent in the first degree" but "of too short duration to do much injury." These accounts were exciting to read. Brooks and Drake—an engineer and a physician, respectively—seemed to be describing "jerky" motions of higher frequency than those generated in the region by the distant New Madrid main shocks. Such high-frequency energy is usually damped out as the waves move through the crust and away from the main shock.

I then used a computer mapmaking program to plot the reported distribution of effects from the three major "aftershocks." The results were striking: they revealed a bull's-eye pattern centered in northern Kentucky. I could only conclude that what Brooks and Drake and others had described were remotely triggered earthquakes—the same type of event that took earth scientists by surprise 180 years later.

The New Madrid observations suggest that the "bubbles theory" of the early models may have been a red herring. Yes, the remotely triggered earthquakes documented in recent years occurred disproportionately in regions of active volcanic or geothermal processes—regions where fluid reservoirs are in fact found at the depths at which earth-

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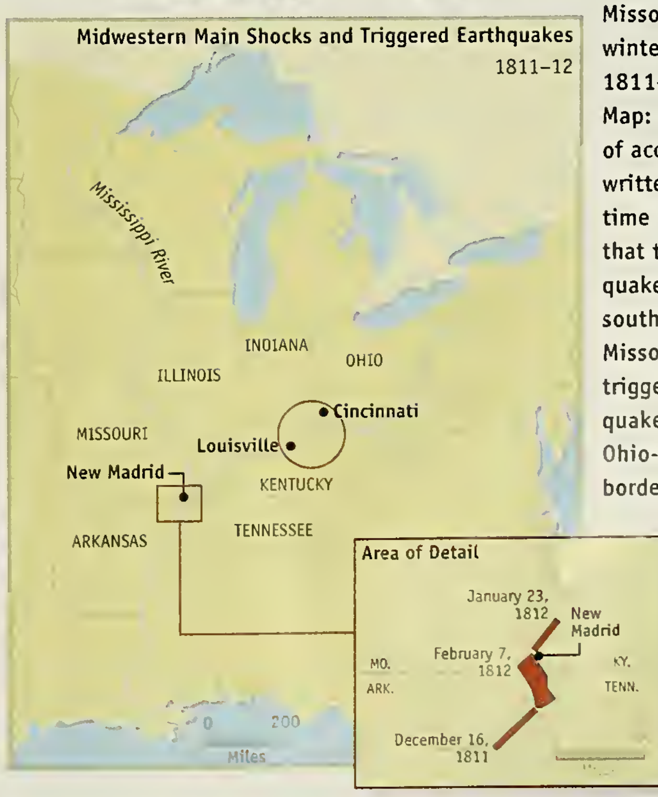

A contemporary woodcut, left, pictures earthquake devastation in New Madrid, Missouri, in the winter of 1811–12. Map: An analysis of accounts written at the time indicates that the three quakes in southeastern Missouri triggered other quakes near the Ohio-Kentucky border.

quakes occur (typically three to twelve miles below the surface). But northern Kentucky has no active volcanic or geothermal features, nor are earthquakes common there.

Some of the most recent observations of remotely triggered quakes also suggest that bubbles and crustal fluids do not play a direct role in the triggering process. The October 16, 1999, magnitude 7.1 quake at Hector Mine, California, triggered events well outside its aftershock zone—in particular, a pronounced sequence near the Salton Sea, a large, low-lying saline lake just north of the California-Mexico border. Because the Salton Sea events occurred within a few miles of a modern seismometer, scientists had excellent data to analyze. And because the area is volcanically and geothermally active, the Salton Sea events also provided seismologists with an ideal opportunity to look for evidence of an exotic, fluid-controlled source in the event recordings. The results of my own recent analyses of the Salton Sea events suggest that, notwithstanding their association with unusual geophysical features, such remotely triggered quakes are nothing more than garden-variety temblors occuring on somewhat weak faults. In active volcanic and geothermal regions, myriad fragile faults may behave somewhat like a delicately balanced pile of pickup sticks—even a small disturbance can disrupt the system. Heat and crustal fluids may therefore facilitate triggering, but only indirectly, by creating an environment in which faults are weak.

MARK ZALESKI; SAN BERNADINO SUN

A ruptured piece of highway in the desert near Landers, California, after the 1992 quake

But if recent triggered earthquakes have generally happened where faults fail easily, what does one make of the New Madrid results? In parts of the crust that are relatively inactive, faults may be numerous, but they are expected to be strong. Recent studies suggest, however, that at any given time in such regions, a relatively large number of faults are probably close to failure. Thus a fairly small disturbance might trigger remote earthquakes in quiet parts of the crust, not because faults are especially weak there, but because where a great many faults exist, some are likely to be only a nudge away from failure.

Newly recognized phenomena, triggered earthquakes can provide important information about fault failure.

What, then, can triggered earthquakes tell us about earthquake processes in general? Scientists do not yet have a complete answer to this question. However, the observations from 1812 to 1999 all seem to carry the same message: that triggered earthquakes are ordinary earthquakes but that they stand to provide us with important new information about fault failure.

One possibility is that earthquakes—all earthquakes—represent nothing more than cracks in the earth that grow very, very slowly in response to the forces applied on them, until the cracking process accelerates into a runaway failure. Such a phenomenon would be analogous to cracking in rocks, a process that can be studied in detail in laboratory experiments. The final kick that initiates the runaway process might be infinitesimally small—perhaps nothing more than the final grain of sand landing atop the increasingly unstable sandpile. Or, as in the case of triggered events, it might be an abrupt kick, delivered by the shaking from a distant earthquake.

The idea of earthquakes as the culmination of runaway crack growth is not new. What is new is that we can now quantify the type of shaking that does, and does not, produce additional earthquakes at distant points. Preliminary results suggest that only quakes close to or above magnitude 7.0 will produce remotely triggered events. Seismologists are able to make rocks crack in the laboratory, but we have a very limited ability to test the conditions under which actual faults in the crust rupture. We now know that, at least once in a while, the ground beneath our feet performs its own experiments, giving us important new information about how earthquake ruptures occur. And some of these experiments have been available to us all along. The old data just had to wait for new eyes—eyes aided by years of accumulated scientific understanding.

Shortly after the New Madrid quakes, geologist and congressman Samuel L. Mitchill set out to compile and interpret local accounts of those events. His narrative, published in 1815, is among the most valuable sources of information available to modern seismologists for the 1811–12 sequence. After lamenting his failure to formulate a satisfactory theory to explain what had happened, Mitchill notes, "I console myself, however, that the history which I have written will give valuable information to the curious on these subjects, and assist some more happy inquirer into nature, to deduce a full and adequate theory of earthquakes." One hundred and seventy-seven years later, the Landers quake helped put earth scientists in a position to fulfill his hopes. ☐

California is earthquake country. The San Andreas Fault is easily visible at the surface of the Carrizo Plain.

Mushi

By Erik L. Laurent

Every summer and fall, Japanese children spend hours catching and playing with insects.

From *Companion Animals and Us: Exploring the Relationships Between People and Pets,* edited by A. L. Podberscek, E. S. Paul, and J. A. Serpell.
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Each summer and fall, many Japanese children (mostly boys) spend hours catching and playing with insects, or *mushi*. Live *mushi* are also sold in Japanese department stores and post offices, along with implements for catching and breeding them. Caged "autumn-singing" insects (primarily crickets and grasshoppers) have for centuries been welcome seasonal gifts in the countryside. Although in recent years the tradition of giving children rhinoceros beetles and stag beetles as gifts has lost ground to purchasing tiny electronic creature toys, children still flock to Japan's insectariums, or arthropod zoos. And as homework over summer vacation, many rural schools still assign their eight- to ten-year-old students the task of preparing a collection of live insects.

The first written reference to the selling of autumn-singing insects dates to 1685 in Kyoto. At that time, vendors carried their crickets in big square baskets suspended from poles worn across the shoulders, and they also sold small cages. Many children used to catch their own *mushi,* but insects began to be commercially bred as their popularity increased. Owned by fishermen or peasants, the first pushcarts that sold *mushi* appeared in about 1820. Beginning in the Meiji period (1868–1912), *mushiya,* or shops that sold singing insects, fireflies, and jewel beetles as well as cages and trapping devices, began to spring up. Lafcadio Hearn, the renowned writer on Japan, gives a price list for the twelve most popular species in a chapter on insect musicians in his 1898 book *Exotics and Retrospective*. During the 1930s *mushi* sales began to decline, and by the end of World War II the *mushiya* had almost completely disappeared.

Opposite: A child stalks a dragonfly in a field. Below: A katydid *(Gampsoclesis buergeri),* one of the singing insects favored by young Japanese collectors.

SHINJI KUSANO; NATURE PRODUCTION

The tradition did not die, however. In the 1960s department stores experienced a boom in rhinoceros beetle sales, fueled by the enthusiasm of young boys. Since then, rhinoceros and stag beetles have become the best-selling *mushi*. Several million are now bred and sold during the warmer months.

I recently interviewed a rhinoceros beetle breeder, Akahane-San, who lives in the town of Takatô on the island of Honshū. Akahane had been raising mushrooms but in 1985 switched to breeding beetles. Even though initially only one store in the nearby city of Ina sold his *mushi,* his business prospered and he has expanded the operation. Now his *mushi* are sold in the local post office and several department stores and are also bought by visitors to his farm.

"It's not a very hard job, quite suitable for old people," says Akahane, who keeps thousands of rhinoceros beetles in a fenced breeding enclosure on his farm. He carefully monitors soil conditions but basically leaves the beetles alone. At the end of August they lay their eggs, and the following summer the adults molt. To correct genetic problems that arise from inbreeding, Akahane introduces "new blood" every two or three years by adding wild-caught beetles to the breeding population. He now raises 4,000 rhinoceros beetles each year for the market.

Two major traits that seem to account for the popularity of these creatures are their inoffensive character and their spectacular appearance. Indeed, the black and horny rhinoceros beetle is one of the largest members of the order Coleoptera. Today in the Japanese countryside one sometimes still sees children pulling small carts full of rhinoceros beetles—a pastime that goes back hundreds of years. Little boys will induce the rhinoceros beetles to fight each other for a small piece of watermelon or will make them pull weights.

Each species of *mushi* is associated with a season of the year, and some even with a particular time of day. Traditional *mushi* games, likewise, are seasonal. In the spring children catch butterflies, and in the summer they play with aquatic whirligig beetles,

The bell cricket *(Homoeogryllus japonicus)*, right, is prized for its musical chirping. Below: An insect imprisoned in a cage made of a hollowed-out *kobocha*, or pumpkin.

true water beetles, and snails. Summer is also the time to catch fireflies and cicadas and to adopt rhinoceros and stag beetles as pets. Catching dragonflies, collecting *tsuchibachi* wasps' larvae, playing with ant lions and *batta* locusts, and learning to make *mushi* cages from straw are all traditional summer activities. In autumn children listen to singing insects, observe and play with red dragonflies, collect *inago* locusts, stage spider fights, watch mantises, and collect wasps' nests. Because most insects either die or enter dormancy in winter, that is a season without *mushi*.

Once a year, in autumn, *suzumushi* (bell crickets) and *kirigirisu* (singing grasshoppers) are offered for

MITSUHIKO IMAMORI; NATURE PRODUCTION

RYUKICHI KAMEDA; NATURE PRODUCTION

sale in nearly every post office in Japan and sent all over the country in special packages. When summer arrives in rural areas, many village shops feature butterfly nets, rhinoceros beetle cages, and packs of soft humus "mattresses" for keeping stag beetles. Department stores in larger towns and cities, however, remain the best places to buy *mushi*. Their summer displays feature live *mushi*, along with breeding and catching equipment, side by side with various insecticides. Revenue from sales of *mushi* alone climbed to 5 billion yen in 1992.

From spring to autumn, *minmin* cicadas are perhaps the most often caught *mushi* in Japan. Living everywhere—even in the centers of cities, clinging to tree trunks or to walls—they are not difficult prey for tree-climbing children armed with nets and cages. Seemingly of great interest to these children are the cries cicadas make when caught, as well as the tricks used for catching them.

Tombo tori (dragonfly catching) dates back to the first half of the eighteenth century. Dragonflies can

Mushi *introduce children to biological diversity, mortality, and the progression of the seasons.*

be caught by hand or with a net, but the traditional way of catching them is with a tool called a *buri* in western Japan or a *toriko* in Tokyo. Similar to a miniature bola, it is made of two small balls, stones, or shells wrapped in red cloth or paper and tied to a silk thread. The *toriko* is hurled about three feet ahead of the dragonfly, which then flies right into it; the thread becomes tangled in the insect's wings, and the dragonfly falls to the ground. Although popular until the 1960s among boys in the Japanese countryside, catching dragonflies no longer interests most children today. A related activity—catching fireflies—is not as easy as it used to be, because the species is now officially protected and its catchers may be fined.

Spider fighting, too, was very popular until about thirty years ago but is no longer in vogue. In Yokohama in the 1930s, all the twelve-year-old boys used to own spiders. They made the creatures fight by throwing one spider into another's web or by putting two spiders together in a miniature arena fenced in by wood chips. The fights were allowed to continue until one of the arachnids was killed.

Japanese children gain a great deal from their involvement with *mushi*. Among other things, they develop a feeling for the seasons, a sensibility pervasive in Japanese culture. They learn very early, for instance, that fireflies, rhinoceros beetles, and other creatures appear and then die during a limited period of the year. *Mushi* give children concrete material for their experimental dialogue with nature and introduce them to biological diversity. An insect's relatively short life span also teaches them about ontogenetic development and the cycles of life. Feeding and keeping *mushi* requires personal observation, reflection, and even experimentation. A post office leaflet that advertises the selling of *suzumushi* crickets tells children: "While observing, let's write a diary with pictures!" *Mushi* are usually looked after every day by the child, who keeps them until they die.

Traditionally the transmission of knowledge concerning *mushi* used to occur orally, passed from grandfather to grandchild. Although the traditions

YOHEI NAKAMOTO: NATURE PRODUCTION

KYODO NEWS PHOTO

Containers in a *mushi* store, left, are filled with beetle larvae for sale. Below: Boys buy beetles from an automatic vending machine.

KAZUO UNNO: NATURE PRODUCTION

A youngster stages a fight between a rhinoceros beetle and a stag beetle.

MITSUHIKO IMAMORI; NATURE PRODUCTION

A boy allows his rhinoceros beetle to walk up his arm, right. Below: A stag beetle more than three inches long was bought for $90,000 by a Tokyo shop in 1999. The record-size beetle drew thousands of young *mushi* enthusiasts into the store.

KYODO NEWS PHOTO

surrounding *mushi* could easily have been forgotten in modern industrialized Japan, insects have instead been turned into media phenomena, with stories featuring slick, *mushi*-related gear, games, and books. In addition, Japan's contemporary craze for little "virtual" animals that mimic *mushi* constitutes a technological transformation of real animals into "animaltronics." *Tamagochi,* for instance, are electronic toys that metamorphose into various shapes and even "die" if they are not cared for. Understanding growth and change is central to the manipulation of *tamagochi*. For Japanese children, creatures that undergo metamorphosis are a source of fascina-

MITSUHIKO IMAMORI; NATURE PRODUCTION

tion that is culturally reinforced. Pokémon toys are based on characters that continually change into other forms. ("Pokémon," of course, is "Japlish" for "pocket monster"—a computer toy, cartoon, television, and movie craze that has jumped cross-culturally to the West.) The very idea of imagining pocket-sized monsters, or bird-egg-sized pets like *tamagochi*, seems to be connected with the Japanese delight in miniatures, whether bonsai trees, computer chips, or *mushi*. Some of the body forms of Pokémon are clearly based on those of insects. The most obvious example is Caterpie, which resembles a caterpillar, then changes into Metapod, and finally becomes Butterfree. And much more so than any other group of animals, insects appear as secondary characters or as part of the scenery in the television and comic-book versions of Pokémon stories.

Despite the overwhelming mass-market success of these electronic and cartoon "insectoids," however, a sizable number of Japanese children continue to spend time with the genuine article. The fact that the many traditions associated with *mushi* have managed to survive in such a competitive market shows their remarkable vitality and the valued role of these diminutive ambassadors of nature in the education of children in Japan. ☐

Youngsters combing the fields with their insect nets are a sure sign of spring in rural Japan.

AT THE MUSEUM

The *Helicoprion* Mystery

Where were the teeth situated on this ancient shark? In its jaw? On its tail? On its back?

By *Richard Ellis*

ROD MICKENS; AMNH

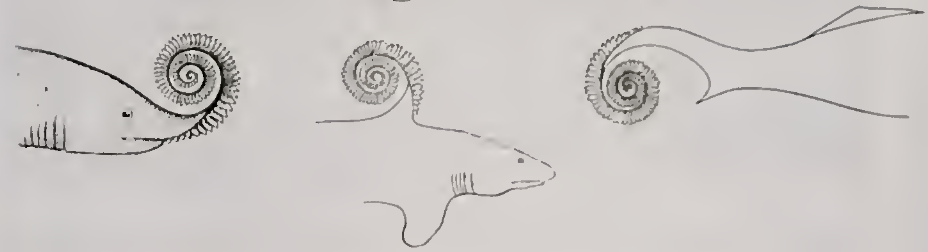
***Helicoprion* fossil**

As painted by Ray Troll, *Helicoprion's* tooth whorl may have been located on the lower jaw.

In the Museum's Hall of Vertebrate Origins is a most intriguing object, tucked away where few people see it. The object appears to be a perfect spiral of teeth, and the label below it reads, "What is this fossil?" This seems a curious question to be asking of Museum visitors, but the label provides the answer: "Many isolated tooth whorls of *Helicoprion* have been found, such as this specimen, but complete fossil skeletons are unknown." The specimen came from a phosphate mine in Idaho, but others like it have been unearthed in Wyoming as well as in Norway, Russia, Japan, Greenland, and Australia. Paleoichthyologists have categorized the teeth as sharklike and therefore identified the specimen as having belonged to certain primitive cartilaginous fishes—a group that includes the sharks and chimaeras living some 300 million years ago.

Helico- comes from the Greek for "spiral" or "whorl," and *-prion* from the Greek for "saw." *Helicoprion* thus means "spiral saw." But what was this saw used for? Russian paleontologist A. P. Karpinsky was the first to find and describe a specimen, which he collected in 1899 in the Ural Mountains. He puzzled over where to place it on the shark—the lower jaw, the upper jaw, both jaws, the tail, the dorsal fin, the middle of the back? Only a year after Karpinsky's de-

Positioning the Whorl



Above: Paleontologist A. P. Karpinsky found the first specimen of *Helicoprion*'s tooth whorl in 1899, but he could not decide where it might fit on the shark. Almost a century later, Australian paleontologist John A. Long visualized a seemingly extensible apparatus, illustrated below by Ivy Rutzky, of the Museum's Division of Paleontology.

scription appeared in print, American paleontologist C. R. Eastman wrote: "Of the two leading theories as to the position of . . . 'spines,' the first ascribes them to the jaws of a shark or skate, and the other to the median line of the back, some distance in advance of the dorsal fin." In a 1952 analysis of the tooth whorl, Russian paleoichthyologist Dimitri Obruchev decided that a location in the lower jaw "would only prevent the fish from feeding." He therefore placed the whorl in the upper jaw, "where it could serve as effective protection," acting as a shock absorber for the animal's head.

In his 1995 book *The Rise of Fishes: 500 Million Years of Evolution*, John A. Long, curator of vertebrate paleontology at the Western Australian Museum in Perth, includes a hypothetical illustration of *Helicoprion* that shows the shark's lower jaw curling downward into a tooth-studded spiral. One could imagine that the shark uncoiled its jaw and lashed at prey with a sort of toothed whip. Another theory is that *Helicoprion*'s tooth spiral mimicked coiled shellfish called ammonites (especially abundant at the time) in order to attract these ammonites, the shark's prey. "It seems more likely," Long writes, "that these sharks used the jagged tooth-whorls when charging into a school of fish or ammonites and thrashing about to snag prey on the projecting array of teeth."

Richard Lund, a paleoichthyologist at Adelphi University and an expert on sharks from the Devonian Period, points out two of *Helicoprion*'s radical features: the disproportionate size of the teeth making up the whorl, and the bases of the teeth being locked together during growth, a feature that prevented the shedding of the teeth. "Thus the smaller and older teeth are just shoved out and down, sort of like an ingrown toenail, only with teeth." Lund also believes the spiral must have been proportional to the size of the jaw that supported it: "Any reconstruction of the fish itself must be big enough to accommodate, smoothly, a buzz-saw-like gadget that got up to three feet in diameter. This yields a fish of very impressive size as well as impressive dentures."

A veritable cottage industry is devoted to the solution of the *Helicoprion* tooth-whorl mystery, and the tenor of some of the publications it inspires is unmistakably tongue-in-cheek. In the April 1, 1973—note the date—issue of the *Journal of Insignificant Research*, paleontologists Michael Williams and Kathy Elbaum, quoting from a 1966 paper by Danish paleontologist Svend Erik Bendix-Almgreen ("On the Significance of Karpinsky's Reconstruction") demonstrate that *Helicoprion*'s

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whorl was the biomechanical equivalent of a New Year's Eve noisemaker. It could be extended by hydraulic force, releasing "in effect a lethal raspberry."

In their 1994 book *Planet Ocean: A Story of Life, the Sea, and Dancing to the Fossil Record*, author Brad Matsen and artist Ray Troll devote an entire page to the "vexing fossil shark." Troll admits to an obsession with *Helicoprion*'s tooth whorl, and he recently made a model of it. "There was no upper-half whorl of sharp teeth for the whorl to cut against," says Troll, "only rows of small crushing teeth. In all of the whorls and skulls Bendix-Almgreen examined, no other upper teeth were found besides the crushing teeth. . . . I could begin to 'see' the outline of the skull: long and extremely narrow. I realized this thing had a long nose on it much like a modern-day goblin shark. . . . As it grew, it produced bigger teeth, so what you're seeing is really a fossilized growth ring." Troll has drawn a new version of *Helicoprion*, but like all such reconstructions, whether by artists or paleontologists, it is at best an educated guess. *Helicoprion*'s secrets are still locked in the 280-million-year-old rocks.

Marine expert Richard Ellis's latest book is Encyclopedia of the Sea *(Knopf, 2000).*

MUSEUM EVENTS

MARCH 1
Lecture: "Impact of Global Warming on Polar Bears and Tundra Ecosystems" (Earthwatch at the Museum series). Ecologist Peter Scott, of the Churchill Northern Studies Centre. 7:00 P.M., Kaufmann Theater.

MARCH 5
Lecture: "Quasar Absorption Lines: Seeing Ghosts in the Universe" (Frontiers in Astrophysics series). Astronomer Jane Charlton. 7:30 P.M., Space Theater, Hayden Planetarium.

MARCH 5, 12, 19, AND 26
Four lectures: Biodiversity and Seaside Plants series. William Schiller, Museum botany lecturer. 2:30 P.M., Kaufmann Theater. (The series is repeated on four consecutive Thursdays at 7:00 P.M., starting March 8.)

MARCH 7
Preview clips and panel discussion: *Land of the Mammoth*, Discovery Channel's second documentary about the Jarkov mammoth and other Ice Age species in Siberia. 7:00 P.M., IMAX Theater.

MARCH 7, 14, AND 21
Three lectures: "Nonzero: The Logic of Human Destiny," science writer Robert Wright, March 7; "The History of Time," Museum astrophysicist Charles Liu, March 14; "Ecology and History of the Hudson River," Museum ecologist Jay Holmes, March 21 (Natural History and Life: AARP series). 2:00 P.M., Kaufmann Theater.

MARCH 8, 15, AND 22
Three lectures: Geology of the Revolutionary War in Metropolitan New York series. Geologist Sidney S. Horenstein, coordinator of the Museum's environmental public programs. 7:00 P.M., Kaufmann Theater.

D. FINNIN; AMNH

Chinese sundial, from exhibition of historical instruments at Weston Pavilion entrance, Columbus Avenue

MARCH 13
71st James Arthur Lecture on the Evolution of the Human Brain: "Evolution of Neocortex: Lessons From Embryo-Archaeology." Neurobiologist Pasko Rakic, of the Yale University School of Medicine. 6:00 P.M., Kaufmann Theater.

MARCH 19
Lecture: "The 23rd Cycle: Learning To Live With a Stormy Star" (Distinguished Authors in Astronomy series). Astronomer Sten Odenwald. 7:30 P.M., Space Theater, Hayden Planetarium.

DURING MARCH
International Women's History Month: "Everyday Heroines." Free weekend films, lectures, performances, and workshops. 1:00–5:00 P.M., March 3–18, Leonhardt People Center. For information, call (212) 769-5315.

Symposium registration: "Conservation Genetics in the Age of Genomics." April 4 keynote speaker: author and activist Jeremy Rifkin. April 5–6: scientific presentations. Sponsored by the Museum's Center for Biodiversity and Conservation and the Bronx Zoo–based Wildlife Conservation Society. Call (212) 769-5200 or visit research.amnh.org/biodiversity/.

Films at the IMAX Theater: *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition) and *Ocean Oasis* (the biodiversity of the Baja California peninsula).

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Cosmic Chemists

Gazing out at the far reaches of the universe led scientists back into the microworld of matter.

By Martin J. Rees

NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

Planetary Nebula NGC 6751

The unity of nature isn't just a poetic phrase. Ever since Isaac Newton showed that the same gravitational force that pins us to Earth holds the planets in their orbits, we have become more mindful that cosmos and microworld are intricately linked.

Science writer Marcus Chown expresses this theme beautifully. He recounts how scientists had to understand atoms before they could understand what made the stars shine, and how this led to the realization that the atoms on Earth were themselves forged in ancient stars. In tracing this intellectual quest, Chown highlights the advances made by many important but underappreciated pioneers in the field.

French philosopher Auguste Comte famously averred in 1835 that while we might learn the sizes and motions of stars, we would never know what they are made of. Within twenty years, Comte would be proved wrong. German chemist Robert Bunsen and a compatriot, physicist Gustav Kirchhoff, showed that dark lines previously discovered in sunlight's spectrum were caused by elements such as sodium, whose glowing emissions could be analyzed in the laboratory. Later, English amateur astronomer William Huggins, using newly available photographic techniques, found that the much fainter spectra of stars displayed the same line patterns as those of the solar spectrum. The Sun, Earth, and stars were made of the same stuff.

The Magic Furnace: The Search for the Origins of Atoms, *by Marcus Chown (Oxford University Press, 2001; $25)*

All this was achieved before atoms were understood. Indeed, until 1900 the reality of atoms was in serious doubt, despite compelling indirect arguments that the building blocks of matter came in discrete units. Stellar spectra had revealed the "bar codes" of many different elements. But since there is no straightforward relation between the strength of a spectral feature and the abundance of the element that causes it, twentieth-century physics would be needed to clarify the situation. Indeed, until the 1920s it wasn't appreciated that hydrogen and helium—the two lightest elements—were overwhelmingly the most abundant. Much credit here goes to British astronomer Cecilia Payne, whose 1925 Ph.D. thesis at Radcliffe College presented evidence that these two elements amount to 98 percent of the mass of the Sun. Sadly, the skepticism of the influential astrophysicist Henry Norris Russell led her to downplay what was actually her greatest discovery and to declare in a journal article that this inferred abundance of both hydrogen and helium in stars was "improbably high and is almost certainly not real."

Another mystery was what kept the Sun and stars shining. Nineteenth-century geologists, basing their estimate on sedimentary rock strata, gauged Earth's age to be hundreds of millions of years. Charles Darwin, in proposing his ideas about natural selection, concurred with the estimate, while England's leading physicist, William Thomson (Lord Kelvin), dogmatically argued that the Sun could not have been shining for much longer than 10 million years. U.S. geologist Thomas Chamberlain responded—in words that should resonate with some of today's theorists—that "there is perhaps no beguilement more insidious and dangerous than an elaborate and elegant mathematical process built upon unfortified premises." A detailed understanding of the reactions that have allowed the Sun to shine for 4.5 billion years as a "gravitationally confined fusion reactor" didn't come about until the late 1930s, through the insights of two U.S. physicists, Russian-born George Gamow and German-born Hans Bethe, and those of German physicist and philosopher Friedrich Carl von Weizsäcker.

If nuclei can fuse inside stars, could the entire periodic table of 92 elements be the outcome of nuclear transmutations in stars? Beginning in the mid-1940s, British astronomer Fred Hoyle was the dominant figure promulgating this idea. The most efficient processing occurs in heavy stars, which shine more brightly than the Sun and burn their hydrogen more rapidly. Gravity then squeezes them further, and the centers get still hotter, until the helium nuclei fuse into the nuclei of heavier atoms. When all their fuel has been consumed, big stars face a catastrophic collapse that can compress their cores to a state 1,000,000,000,000,000 times denser than an ordinary solid, transforming them into neutron stars or perhaps black holes.

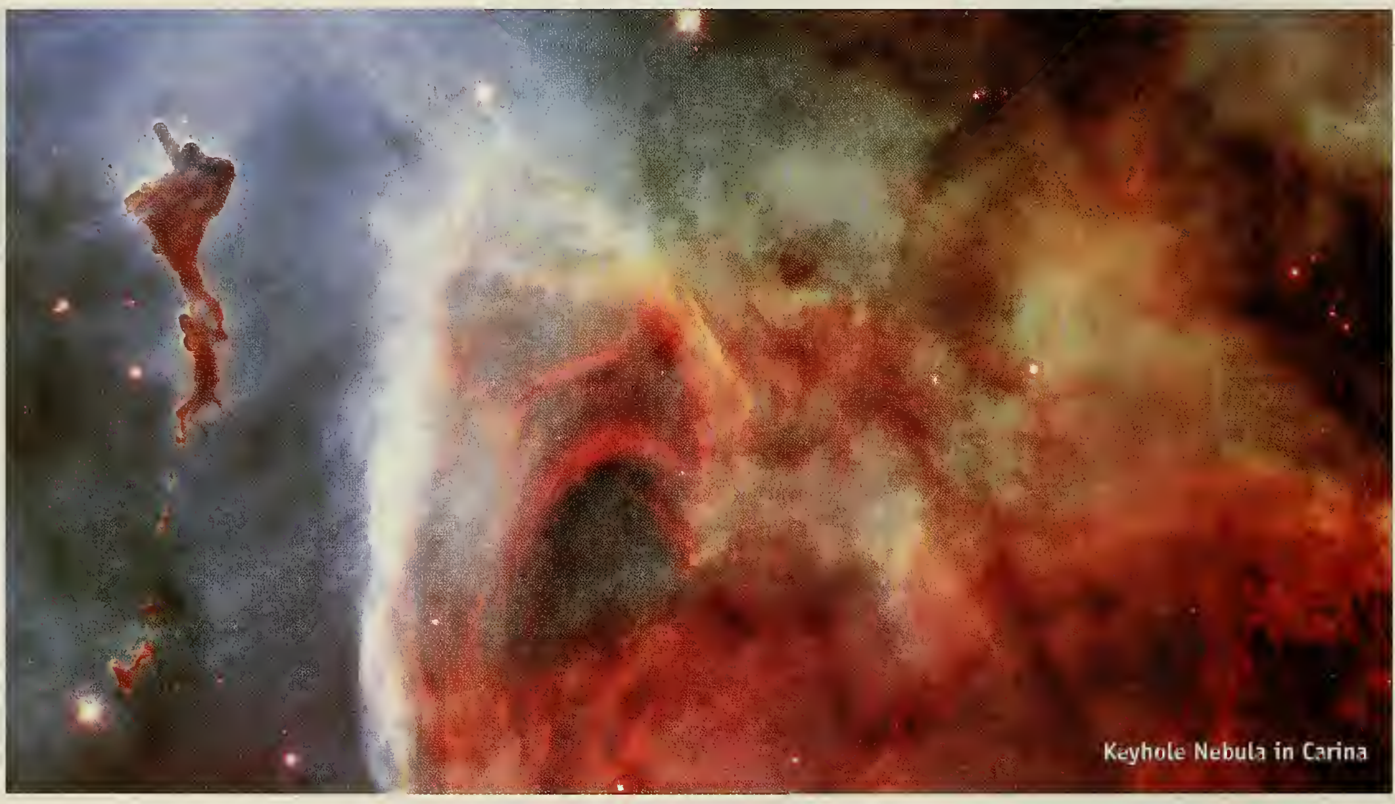
But this collapse also releases enough energy to trigger a colossal explosion—a supernova—that blows off the star's outer layers. These layers have by then developed an onionskin structure. Through nuclear alchemy, hydrogen has burned into helium, helium into carbon, carbon into nitrogen, and so on through the periodic table, up to and including iron—the main element in the core of these doomed stars.

The formation of elements higher up the periodic table requires a further input of energy. Thorium and uranium, for instance, are forged in the heat of a supernova, and barium and bismuth via the capture of neutrons within red giant stars. By 1957 these processes were codified in a classic paper that Hoyle coauthored with U.S. nuclear astrophysicist William Fowler and English astronomers Geoffrey and Margaret Burbidge. Canadian physicist Alastair Cameron developed some key ideas independently.

The galaxy is like an ecosystem. An oxygen atom expelled from a massive star may have wandered for hundreds of millions of years in interstellar space. It may then have found itself in a dense cloud, contracting under its own gravity to make a new star, surrounded by a dusty disk. That star might have been our Sun; that particular atom could have ended up on Earth and perhaps been cycled through a human cell. We are stardust—or the nuclear waste from the fuel that makes stars shine.

This scenario disappointed George Gamow. He thought that all elements emerged from the big bang, but this wasn't borne out by detailed calculations. When Albert Einstein's theory of relativity was used to model an expanding universe, it turned out that the temperature dropped so quickly following the big bang that there was no time for the network of reactions needed to produce all the elements. Moreover, observations showed that younger stars contained more heavy elements than older stars—corroborating the idea that stars formed from interstellar gas that became "polluted" over time. But Gamow was partially vindicated; he proved to be right about the origins of the light elements deuterium, helium, and lithium. Even the oldest stars are 23 percent helium—precisely the proportion that emerges from the big bang.

Seeking the true origins of atoms has been an interdisciplinary quest stretching back more than 200 years. Its pioneers deserve the same acclaim that is rightly given to those who proposed biological evolution. Through their insights, we now view Earth and its constituent atoms in a grand cosmic context. Marcus Chown's fascinating chronicle of their achievements deserves to be widely read.



Keyhole Nebula in Carina

NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

Martin J. Rees is a Royal Society Professor at the University of Cambridge and England's Astronomer Royal. His most recent book is Just Six Numbers: The Deep Forces That Shape the Universe *(Perseus Press, 1999).*

nature.net

Gems of the Universe

By Robert Anderson

Last month I revisited one of the first Internet sites reviewed in this column, the one created to post the latest images from NASA's Hubble Space Telescope. I was drawn to a wonderful new extension of the site called Hubble Heritage Project (heritage.stsci.edu/index.html).

The project's astronomers have refined the telescope's scientific images by paying close attention to such details as composition and color. While maintaining the accuracy of the originals, the resulting images are far more striking and often reveal details previously hidden from the unaided eye. These spectacular photographs are works of art worthy of their subject—the universe.

In the gallery, you'll find stunning images of everything from planets to merging galaxies. But they are more than just pretty pictures; the purpose of the project is to pique our curiosity about the universe. Each image tells a remarkable story, augmented by lengthy explanations and links to other sites.

Galaxy M87 (NGC 4486)

NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

My favorite is Planetary Nebula IC 418, a sunlike star that in its death throes became a red giant and then ejected its outer layers into space, forming the nebula. The stellar remnant at its core floods the surrounding gas with ultraviolet radiation, causing it to fluoresce, "glowing like a multifaceted jewel."

But they are all gems. Take NGC 3314, a spiral galaxy pair. The two are aligned so that one is silhouetted against the other, giving us the rare chance to view the light-absorbing dust clouds darkening the spiral arms of a distant galaxy. Or how about Galaxy M87 (NGC 4486), with its bluish jet of electrons and other subatomic particles streaming from the black hole at its center? Every image is magnificent.

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

BOOKSHELF

The 23rd Cycle: Learning To Live With a Stormy Star, *by Sten Odenwald (Columbia University Press, 2001; $27.95)*
Tracing the recent history of the Sun's destructive power, astronomer Odenwald warns us about the coming cycle of solar flares and storms, which may cause blackouts, satellite malfunctions, and other kinds of havoc.

Cosmic Evolution: The Rise of Complexity in Nature, *by Eric Chaisson (Harvard University Press, 2001; $27.95)*
"From galaxies to snowflakes," writes astrophysicist Chaisson, "from stars and planets to life itself, we are beginning to identify an underlying, ubiquitous pattern penetrating the fabric of all the natural sciences."

The Neptune File: A Story of Astronomical Rivalry and the Pioneers of Planet Hunting, *by Tom Standage (Walker, 2000; $24)*
Neptune was "discovered" in 1845 by mathematical calculation (not with a telescope), setting a precedent for a method of extrasolar planet hunting that has, to date, turned up more than forty.

Spacefaring: The Human Dimension, *by Albert A. Harrison (University of California Press, 2001; $27.50)*
A psychologist offers an overview of humans in space, covering such topics as motives for leaving Earth, group dynamics, and habitability of spacecraft.

Designs on Space: Blueprints for 21st Century Space Exploration, *by Richard Wagner, illustrated by Howard Cook (Simon & Schuster, 2001; $24)*
Elucidating blueprints for rockets, robotic arms, solar sails, and the $30 billion International Space Station, science writer Wagner shows us the equipment we'll be using to investigate the neighborhood of planet Earth.

A Thin Cosmic Rain: Particles From Outer Space, *by Michael W. Friedlander (Harvard University Press, 2000; $29.95)*
A physicist explains the phenomenon of cosmic rays and reveals what they tell us about the universe, the solar system, and Earth, as well as their role in the discovery of subnuclear particles.

Stardust: Supernovae and Life—The Cosmic Connection, *by John Gribbin with Mary Gribbin (Yale University Press, 2000; $24.95)*
The Gribbins discuss the formation of chemical elements—how they are processed inside stars, scattered across the universe in great stellar explosions, and recycled to become new stars, planets, and parts of ourselves.

Einstein's Unfinished Symphony: Listening to the Sounds of Space-Time, *by Marcia Bartusiak (Joseph Henry Press, 2000; $24.95)*
Science writer Bartusiak explains how sophisticated instruments allow scientists to hear gravity waves—vibrations in space-time first postulated by Einstein.

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.

UNIVERSE

Coming to Our Senses

By Neil de Grasse Tyson

ROBERT GROSSMAN

Equipped with his five senses, man explores the universe around him and calls the adventure science.

—Edwin P. Hubble, 1948

Our eyes are special organs. They allow us to register information not only from across the room but from across the universe. Without human eyesight, the science of astronomy would never have been born, and our capacity to measure our place in the universe would have been hopelessly stunted. Think of bats. Whatever bat wisdom gets passed from one generation to the next, you can bet that none of it is based on the appearance of the night sky.

When thought of as an ensemble of experimental tools for exploring the world, our senses have an astonishing acuity and range of sensitivity: Your ears can register the thunderous launch of the space shuttle, yet they can also hear a mosquito buzzing a foot away from your head. Your sense of touch allows you to feel not only a bowling ball dropped on your big toe but also a one-milligram bug crawling up your arm. Some people enjoy munching on habanero peppers, while other people can taste (and rebel against) the habanero on the level of parts per trillion. And your eyes can register the bright, sandy terrain on a sunny beach yet have no trouble spotting a lone match, freshly lit, hundreds of feet away in a darkened auditorium.

Before we get carried away in praise of ourselves, note that we gain in breadth what we lose in precision, because we register the world's stimuli in logarithmic rather than linear increments. For example, if you increase a sound's energy by a factor of two, you will barely take notice. Increase it by a factor of ten, and the change will be apparent. Our eyes perceive light the same way. If you have ever viewed a total solar eclipse, you may have noticed that the Sun's disk must be at least 90 percent covered by the Moon before anybody comments that the sky has darkened. The magnitude scale of stellar brightness, the well-known acoustic decibel scale, the seismic scale for earthquake severity—each is logarithmic, in part because of our biological propensity to see, hear, and feel the world that way.

What, if anything, lies beyond our senses? Does there exist a way of knowing that isn't limited by these biological connections with our earthly environment?

Consider that the human machine, while good at decoding the basics of the immediate environment (if it's day or night, if a creature is about to eat us), has very little talent for decoding how the rest of nature works. For that, we need the tools of science. If we want to know what's out there, then we must resort to detectors other than the ones we are born with. The job is to extend and, when we can, transcend the breadth and depth of our senses.

Some people boast of having a sixth sense, professing to know or see things that others cannot. Fortune-tellers, mind readers, and mystics top the list of those who lay claim to these mysterious powers. In so doing, they elicit widespread fascination in others, especially book publishers and television producers. The questionable field of parapsychology is founded on the belief that at least some people actually possess this talent. To me, the biggest mystery of all is why so many fortune-tellers choose to work the phones on TV psychic hotlines instead of becoming insanely wealthy futures traders on Wall Street. Apart from this inexplicable fact, the persistent failure of controlled, double-blind experiments to support the claims of parapsychology suggests that what's going on is nonsense rather than sixth sense.

Sacrificing precision for breadth, we register the world's stimuli in logarithmic rather than linear increments.

Modern science wields dozens of "senses," yet scientists do not claim to have special powers, just special hardware. In the end, of course, the hardware converts the information it gleans into simple tables, charts, diagrams, or images that our innate senses can interpret. In the original *Star Trek* sci-fi series, the crew that beamed down from their starship to an uncharted planet always brought with them a "tricorder," a handheld device that could analyze the basic properties of anything they encountered, living or inanimate. As you waved the tricorder over the object in question, it made a spacey sound that was interpreted by the user.

Suppose a glowing blob of some unknown substance were parked right in front of you. Without some diagnostic tool like a tricorder, you would be clueless about the blob's chemical or nuclear composition. Nor could you know whether it has an electromagnetic field or whether it is strongly emitting gamma rays, X rays, ultraviolet radiation, microwaves, or radio waves. If the blob were far out in space, appearing as an unresolved point of light in the sky, your five senses would offer no hint of its distance, its velocity through space, or its rate of rotation. You would have no capacity to see the spectrum of colors that compose its emitted light, nor could you know (as bees do) whether or not the light was polarized. Without any hardware to help your analysis—and lacking the urge to lick the stuff—all you could report back to the starship would be, "Captain, it's a blob."

Apologies to Edwin P. Hubble, but his words at the top of this essay, while poignant and poetic, should have read more like this:

> *Equipped with our five senses—along with telescopes and microscopes and mass spectrometers and seismographs and magnetometers and particle accelerators and detectors sensitive to the entire electromagnetic spectrum—we explore the universe around us and call the adventure science.*

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Imagine how much richer the world would appear to us and how much earlier the nature of the universe would have been figured out if we were born with high-precision, tunable eyeballs: Tune into the radio-wave part of the spectrum, and the daytime sky is as dark as night, except in some choice locations, such as the center of our galaxy (visible behind some of the principal stars of the constellation Sagittarius). Dial up microwaves, and the entire cosmos is aglow with a remnant from the early universe, a wall of light that hails from 300,000 years after the big bang. Flip the dial to X rays, and the locations of nearby black holes, with matter spiraling into them, pop immediately into view. Tune into gamma rays, and see titanic explosions scattered throughout the universe at a rate of about one per day. Watch the effect of these explosions on the surrounding material as it heats up and glows in other bands of light.

Our senses, honed from infancy, allow us as adults to pass judgment on events and phenomena in our lives, telling us whether or not they "make sense."

If we were born with magnetic detectors, the compass would never have been invented, because we wouldn't need one. We could just tune into Earth's magnetic field lines (as some bacteria do), and the magnetic north pole would call to us from beyond the horizon. If we had gas analyzers within our retinas, we wouldn't have to wonder what was in the air we were breathing. We could just check the analyzer to see whether the air contained sufficient oxygen to sustain human life. And we would have learned thousands of years ago that the stars in the Milky Way contain the same chemical elements found here on Earth.

If we were born with big eyes and built-in Doppler motion detectors, we would have seen immediately, even as grunting troglodytes, that all distant galaxies are receding from us—that the entire universe is expanding.

If our eyes had the resolution of high-performance microscopes, nobody would ever have blamed the plague and other illnesses on divine wrath. The bacteria and viruses that make us sick would be in plain view as they crawled on our food or slid through open wounds on our skin. With simple experiments, we could easily tell which bugs were bad and which were good. And, of course, the problem of postoperative infection would have been identified and solved hundreds of years earlier.

If we could detect high-energy particles, we would be able to spot radioactive substances from great distances—no Geiger counters necessary. You could even watch radon gas seep through the basement floor of your home and not have to pay somebody to tell you about it.

Honed from infancy, our senses allow us as adults to pass judgment on events and phenomena in our lives, to determine whether or not they "make sense." Problem is, hardly any scientific discoveries of the past century flowed from the direct application of our five senses. They flowed instead from sense-transcendent mathematics and hardware. This simple fact explains why relativity, particle physics, and ten-dimensional string theory make no sense to the average person. Neither do black holes, wormholes, and the big bang. Actually, these things don't make much sense to scientists either. At least not until they acquire a new and higher level of "common sense" from long study of the math and physics of the universe. This allows for creative thinking and enables us to pass judgment in the unfamiliar underworld of the atom or in the mind-bending domain of higher-dimensional space. The German physicist Max Planck, who won a Nobel Prize in 1918, made a similar observation about the discovery of quantum mechanics:

> *Modern Physics impresses us particularly with the truth of the old doctrine which teaches that there are realities existing apart from our sense-perceptions, and that there are problems and conflicts where these realities are of greater value for us than the richest treasures of the world of experience.*

Our five senses even interfere with sensible answers to stupid metaphysical questions, such as "If a tree falls in the forest and nobody is around to hear it, did it fall?" My best answer is, "How do you know it fell?" But that just gets people angry. So I offer a senseless analogy: "Q: If you can't smell the carbon monoxide, how do you know it's there? A: You drop dead." (Natural gas, too, is odorless to the human nose. For our protection, a pungent smell is added so that gas leaks can be safely identified and located.) In modern times, if the sole measure of what's out there flows from your senses, then a precarious life awaits you.

New ways of knowing are new windows on the universe, new detectors we can add to our growing list of nonbiological senses. Whenever this happens, a new level of majesty and complexity in the universe reveals itself to us, as though we were technologically evolving into supersentient beings, always coming to our senses.

Neil de Grasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium. This semester he is teaching astrophysics at Princeton University.

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THE NATURAL MOMENT

Photograph by **James Warwick**

Pier Revue

Built in 1866, the West Pier at Brighton, on the south coast of England, has long been a place for socializing. Seaside visitors flocked to its pavilion and concert hall until the pier closed in 1975. Although the empty buildings on the now derelict structure are silent by day, they come noisily alive on winter nights with the chirps, whistles, and varied murmurings of starlings—tens of thousands of them. As their natural roosts in woods and reed beds become scarce, starlings, which seek safety in numbers, readily adapt to buildings and bridges. Photographer James Warwick, himself a Brighton native, notes that small flocks from miles around arrive each evening, then coalesce into a huge roosting congregation. Before settling in for the night, the starlings indulge in an almost silent aerial display. One can hear only their "wings ripping the air" as they change direction en masse, like "iron filings in a magnetized sky."—*Judy Rice*

ENDPAPER

Informed Consent

A muckraking book spotlights the ethics of anthropological fieldwork.

By Samuel M. Wilson

Early last September, an ominous message addressed to the president of the American Anthropological Association (AAA) began making the rounds of the e-mail grapevine. "We write to inform you," it began, "of an impending scandal that will affect the American anthropological profession as a whole in the eyes of the public, and arouse intense indignation and calls for action among members of the Association." Prompting this warning was the imminent publication of *Darkness in El Dorado: How Scientists and Journalists Devastated the Amazon* (W. W. Norton). The book's author, freelance journalist Patrick Tierney, was charging anthropologists and other outsiders who worked in Amazonia in the 1960s with a wide range of misdeeds and ethical violations, the most horrifying of which was that they had intentionally introduced a devastating measles epidemic among the Yanomami. One of those singled out was Napoleon A. Chagnon, who published a vivid account of his fieldwork, "Yanomamö—The Fierce People," in *Natural History* way back in January 1967.

Yanomami, 1989

CHRIS STEELE-PERKINS; MAGNUM

When news of the book first hit, the reaction of many anthropologists was a quiet dread that it represented only the start of an unpleasant airing of the profession's less defensible acts and practices in the past. Anthropology emerged late in the nineteenth century, when many traditional societies were vanishing or being forever changed by colonial expansion and modernization. Anthropologists felt it was their mission to record what remained of the languages, knowledge, and worldviews of disintegrating cultures. They did not necessarily pause to consider that their presence in the field or the dissemination of the knowledge they gained might harm the people they studied. In fact, their work often aided colonial administrators and occasionally served as a cover for espionage.

By the 1960s, anthropologists had begun to agonize over their ability to be impartial observers. With the social upheavals of the Vietnam War, the belief that science was politically neutral came sharply into question. When some social scientists provided cultural information in support of the U.S. war effort, they were called to account by members of the AAA. At the same time, a feminist critique of science emerged, challenging long-held, deeply biased interpretations. Ethnographers also reconsidered what they owed their "informants" in terms of shared credit and editorial control over what was being written about them, and reassessed the condescending assumption that they knew what was right for "their" tribe.

Among the results of this soul-searching was that in 1965 the AAA impaneled a Committee on Research Problems and Ethics and, in 1967, adopted a code of ethics. Much amended over the years, the current code includes the following wording: "Anthropological researchers have primary ethical obligations to the people, species, and materials they study and to the people with whom they work. These obligations can supersede the goal of seeking new knowledge."

The claims made in *Darkness in El Dorado* are now being carefully reviewed and debated. The most damning accusations appear to be unsupported or false. Nevertheless, past research among the Yanomami was not ethically untainted, particularly in that acts of violence may have been instigated to study the supposedly violent nature of men. Long before the book's publication, in fact, criticism against some anthropologists was expressed within the field. (Web sites that document the charges and countercharges include www.tamu.edu/anthropology/Neel.html and www.anth.ucsb.edu/chagnon.html.)

The practice of anthropology will always be ethically complex, simply because the researcher is caught between different cultural systems. The *El Dorado* scandal, however, highlights the sea change that has occurred over the past forty years. Although some research from the 1960s and before was of the highest ethical standards and some research being carried out today is still questionable, on the whole the discipline has become more self-aware. And while at one time seeking the "informed consent" of the studied was unknown, proceeding without it now is almost unthinkable.

Samuel M. Wilson is an associate professor of anthropology at the University of Texas at Austin.

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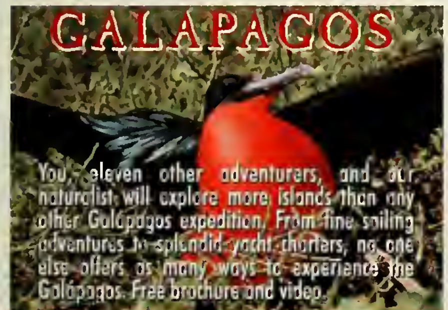

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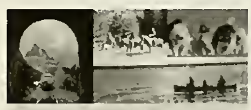

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- DAY 13 Shanghai
- DAY 14 Shanghai
- DAY 15 Shanghai/Tokyo/USA

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- DAY 3 Galápagos Islands/North Seymour Island
- DAY 4 Bartolomé Island/Santiago Island
- DAY 5 Genovesa Island
- DAY 6 Santa Cruz Island
- DAY 7 Isabela Island/Fernandina Island
- DAY 8 Isabela Island
- DAY 9 Española Island
- DAY 10 Galápagos/Quito
- DAY 11 Quito/USA

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- DAY 4 Grand Valley/Douglas Pass
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- DAY 6 Colorado River/Ruby Canyon/Horseshoe Canyon
- DAY 7 Depart Grand Junction

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- DAY 5 Burren Center/Newtown Castle/Cliffs of Moher
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- DAY 7 Aran Islands
- DAY 8 Ennis
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- DAY 3 Naples/Pompeii
- DAY 4 Messina, Sicily/Taormina
- DAY 5 Katakolon, Greece/Olympia
- DAY 6 Heraklion/Knossos, Crete
- DAY 7 Lindos/Rhodes
- DAY 8 Patmos, Greece/Kusadasi, Turkey
- DAY 9 Santorini, Greece
- DAY 10 Piraeus/Disembark *Clelia III* Athens/Vouliagmeni
- DAY 11 Vouliagmeni/Athens
- DAY 12 Vouliagmeni/Cape Sounion
- DAY 13 Vouliagmeni/ Athens/USA

Tuscany: A Summer Family Adventure

AUGUST 10 – 18, 2001

$3,750 – $5,290

- DAY 1 Depart USA
- DAY 2 Zurich/Rome/Sarteano, Italy
- DAY 3 Montepulciano/Pienza
- DAY 4 Siena
- DAY 5 Florence
- DAY 6 Giostra Del Seracino
- DAY 7 Trasimeno/Cortona
- DAY 8 Sarteano/Rome
- DAY 9 Rome/USA

Family Alaska Expedition: Aboard the Wilderness Adventurer

AUGUST 14 – 21, 2001

$2,790 – $4,890

- DAY 1 Arrive Juneau
- DAY 2 Juneau
- DAY 3 Point Adolphus and Icy Strait
- DAY 4 Glacier Bay
- DAY 5 Chichagof Island/Baranof Island
- DAY 6 Admiralty Island
- DAY 7 Tracy Arm Fjord
- DAY 8 Depart Juneau

Nepal: A Himalayan Family Adventure

DECEMBER 20, 2001 – JANUARY 3, 2002

$4,490 – $4,690

- DAY 1-3 Depart USA/Bangkok, Thailand/Kathmandu, Nepal
- DAY 4 Kathmandu
- DAY 5 Kathmandu/Pokhara
- DAY 6 Pokhara/Birethanti
- DAY 7 Birethanti
- DAY 8 Birethanti/Dhampus
- DAY 9 Dhampus/Pokhara
- DAY 10 Pokhara/Seti River
- DAY 11 Seti River/Royal Chitwan National Park
- DAY 12 Royal Chitwan National Park
- DAY 13 Royal Chitwan National Park/Bharatpur/Kathmandu
- DAY 14 Kathmandu/Bangkok, Thailand
- DAY 15 Bangkok/USA

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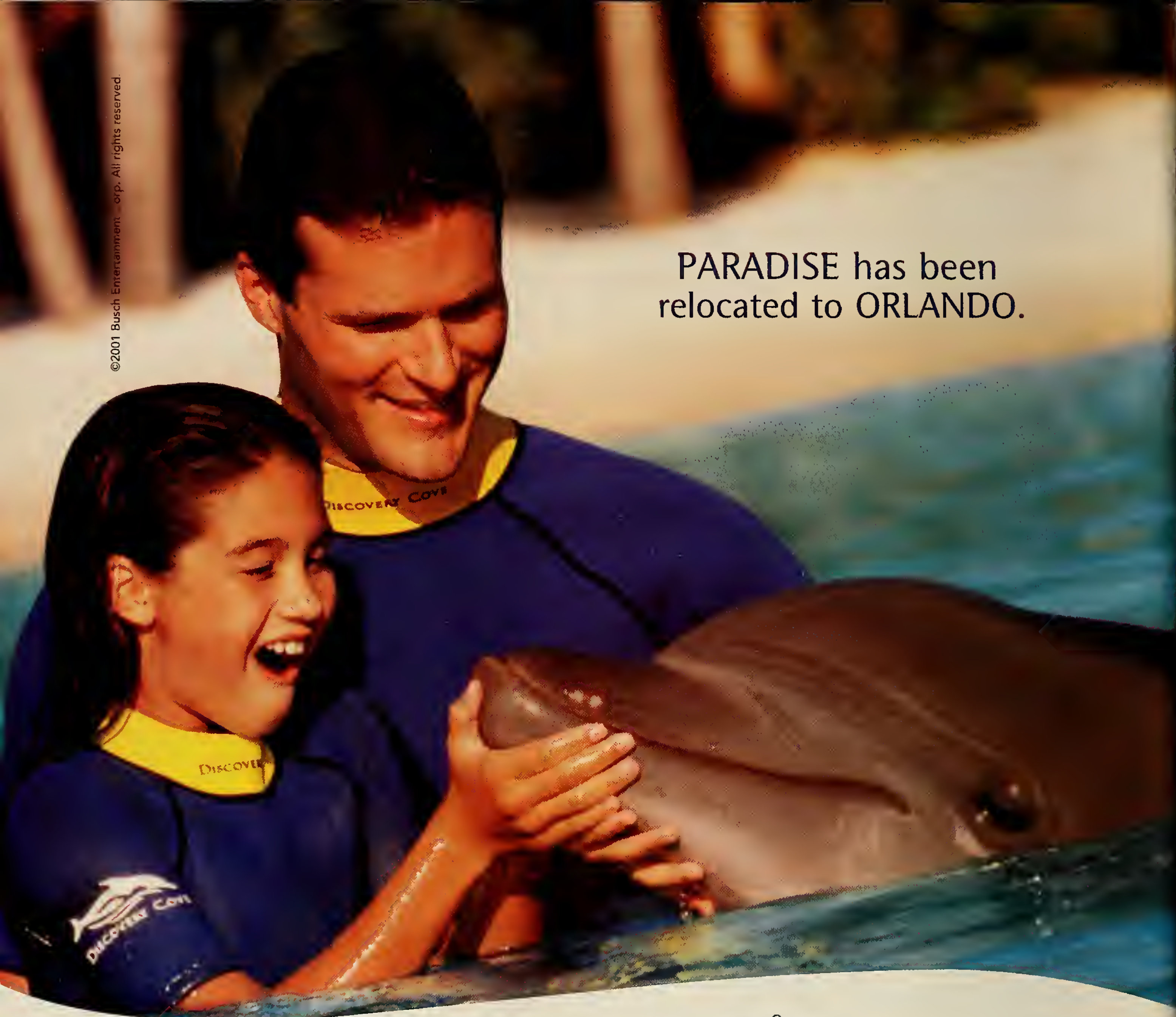

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