

NATURAL HISTORY

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NATURAL HISTORY

OCTOBER 2002

VOLUME 111

NUMBER 8

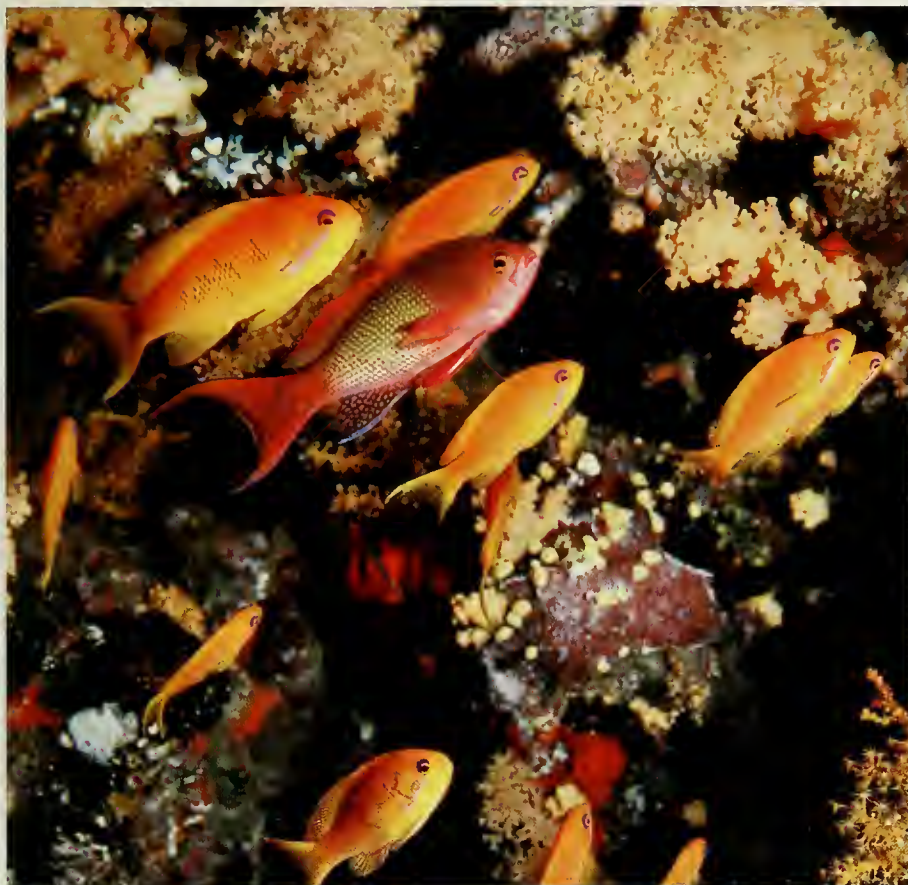
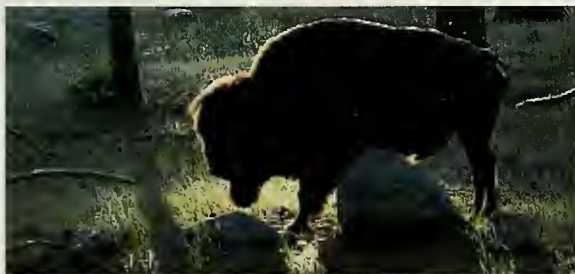
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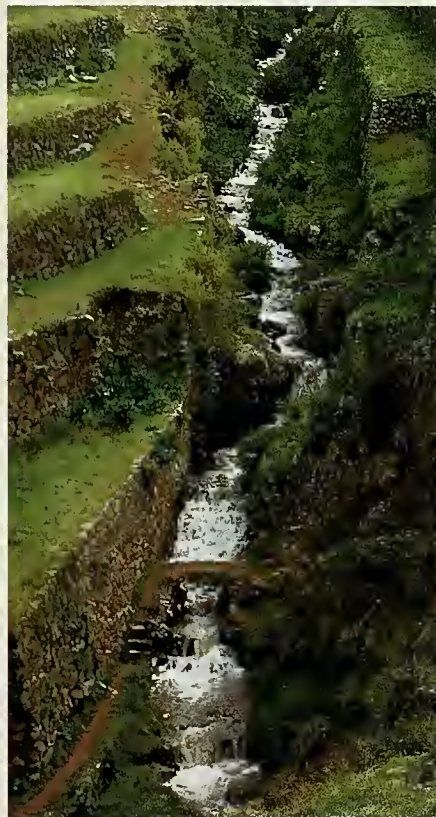
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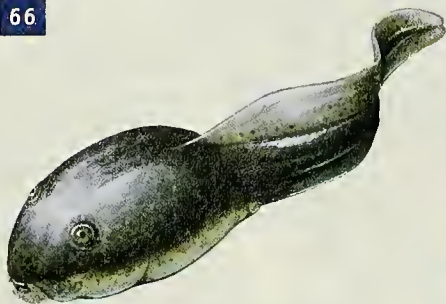
COVER In Yellowstone, a snow-covered bison faces the onset of winter.

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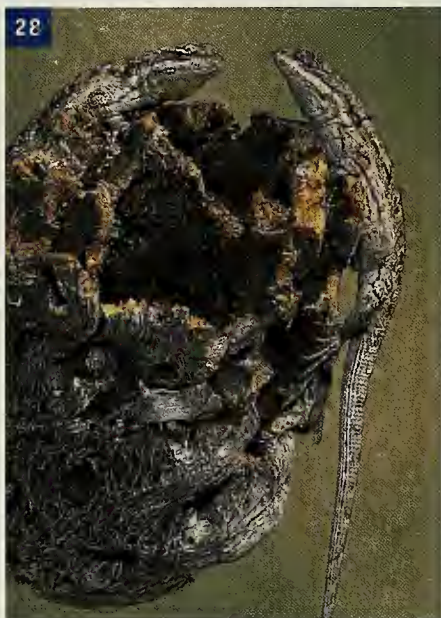
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UP FRONT

The Big Picture

Working at *Natural History* magazine for eighteen years has been nothing less than a re-education for me, not because it immersed me in new scientific findings (though it did that, of course) but because it slowly and surely revised my view of the world. I suspect that the magazine, being based on (and named for) a remarkable scientific discipline, has this effect on many readers. Science narrowly conceived can amount to little more than manipulating the natural world; natural history offers instead an encompassing and exhilarating way of understanding that world and one's place in it. The field of natural history, in other words, is more than the sum of its parts.

Looking at the world through *Natural History's* lens—through the eyes of anthropologists, astronomers, biologists, geologists, and paleontologists—regularly brings one face-to-face with a world of complexity, deep time, and, above all, constant change. For me, the view through that lens was so compelling that it reshaped my daily reality. I no longer live only in the here and now. And I no longer live securely within my own skin. I am aware that mastodons once walked where I walk, that the seemingly solid ground under my feet has frozen and thawed (and will re-freeze and re-thaw) over eons. I am aware that I live on a drifting continent. Many dry, cold lands once lay under warm, shallow seas. Not so long ago, green trees grew in the Sahara; further back in time, the badlands of the American West were verdant rainforest. I take quite seriously the notion that I am not an individual, a being tightly packaged in my own skin, but rather a colony of cells, perhaps more like a jellyfish or a sponge or a coral reef, the host to a universe of bacterial symbionts. I have learned that the perfect flesh and bone of a new baby is made of recycled elements released in the ancient explosions of stars.

In the pages of *Natural History* investigators from many disciplines have deflated our human pretensions to uniqueness: archaeologists have informed us that our hominid ancestors may well have had run-ins with perhaps a dozen quite similar species on the plains of Africa; molecular biologists have reported that viruses and parasitic segments of DNA have intruded themselves into our genome and made themselves at home there; anthropologists have demonstrated that such "cultural absolutes" as the nuclear family are actually highly variable and of recent, local vintage. Biogeographers and ecologists, physicists and climatologists have connected us and every other living being with the elements. Developmental geneticists have revamped the nature/nurture debate by explaining that the environment can act through genes to shape the individual organism. And throughout the magazine's history, field naturalists in the Darwinian tradition have provided other scientists with essential data—observations of whole organisms evolving within whole systems.

Magazines, too, evolve and change. Although I leave the editorship as of this issue, I am confident that *Natural History* will expand its reach and breadth under its new and skillful editorial stewardship. I know that my successor, Peter Brown, who was editor of the admirable publication *The Sciences*, will enjoy shaping, and being shaped by, the legacy of this century-old magazine.

—Ellen Goldensohn

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Natural History (ISSN 0028-0712) is published monthly, except for combined issues in July/August and December/January, by Natural History Magazine, Inc., at the American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024. E-mail: nhmag@amnh.org. Natural History Magazine, Inc., is solely responsible for editorial content and publishing practices. Subscriptions: \$30.00 a year, for Canada and all other countries: \$40.00 a year. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Copyright © 2002 by Natural History Magazine, Inc. All rights reserved. No part of this periodical may be reproduced without written consent of Natural History. Send subscription orders and undeliverable copies to the address below. For subscription information, call (800) 234-5252 or, from outside U.S., (515) 247-7631. Postmaster: Send address changes to *Natural History*, P.O. Box 5000, Harlan, IA 51537-5000. Printed in the U.S.A.

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LETTERS

Meteors and Magnitudes

I found Alan Burdick's "Now Hear This" column on noisy meteors ("Psst! Sounds Like a Meteor," 7/02–8/02) especially interesting, because years ago I saw and heard a very bright meteor while camping on a beach in Florida. It came out of the west over a thick covering of Australian pine trees. Burdick mentions pine needles as an example of small objects that can act as transducers for a meteor's electromagnetic waves.

In the same issue's "Universe" column, in a romp through chemistry's periodic table ("Cosmos on the Table"), Neil deGrasse Tyson claims that "every second of every day, 63 billion tons of fast-moving hydrogen atoms are turned into helium as they slam together within the 15,000,000°K core of the Sun." I believe this estimate of the mass of hydrogen atoms is two orders of magnitude too large. Every second, about 600 million tons of hydrogen are converted into 596 million tons of helium as the difference in mass—4 million tons—is converted into energy. These figures are consistent with the Sun's known luminosity and with Einstein's famous mass-energy equation.

Robert Fleck
Embry-Riddle Aeronautical
University
Daytona Beach, Florida

NEIL DEGRASSE TYSON
REPLIES: When I read the article, I, too, was puzzled by the 63 billion tons. A review of my calculations revealed a simple conversion error in units. The correct number is 630,000,000 (630 million) tons. Thanks for looking over my shoulder.

Knock, Knock

In Adam Summers's "Biomechanics" column about sperm whales ("Fat Heads Sink Ships," 9/02), he addresses the question of why a whale would seek out a collision with a ship. According to historians, whalers once called sperm whales "carpenter fish" because of the knocking noise they made. We now know the noise is used in echolocation. Whales may have sensed the hammering of the ship's carpenter at his never-ending task of keeping the wooden vessel seaworthy. Perhaps the ship was somehow perceived as a competitor, and that's why the whales attacked not just once but kept at it.

Priscilla Gadzinski
White River Junction, Vermont

Spare That Cicada Killer

I saw the September "Letters" and began a mad search for the preceding issue with Joe Coelho's story on cicada killers ("Findings," 7/02–8/02). I had been introduced to cicada killer wasps at a campground in

Pennsylvania just two weeks earlier. The little blighters had made their nests in the sand on the playground. The children and I watched one bring in a cicada and were impressed with the strength of these amazing wasps. I regret to say that I killed one before I found out how underaggressive they really are. After this, I'll leave them alone. Now, if I can only find that back issue of the magazine so I can read up on them.

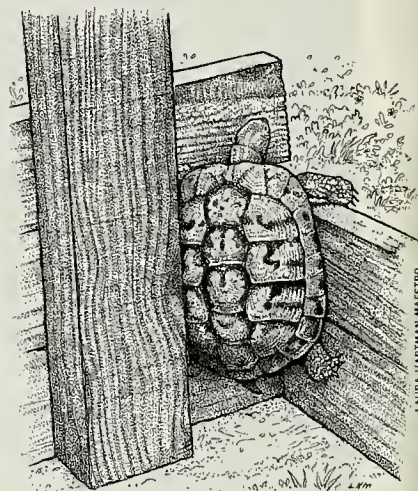
Lisa Pasquale
State College, Pennsylvania

Ninja Turtles

H. Robert Bustard's description of the tortoise that learned to escape over a wooden barrier ("Endpaper," 9/02) gave me a sense of déjà vu. We have a Russian tortoise that did the same thing, even though she has just a stump of a left rear leg (we call her Stumpy).

During warm weather, we kept her outdoors for a while in a four-foot-square enclosure, with 1 x 6 boards along the sides, bolted to 4 x 4 corner posts. Stumpy could hook her forefeet on the top edge of the board, but since she was only about six inches long, we did not think she had either the strength or the leverage to get her entire body up

and over the wall. But within a matter of a few weeks she focused her escape efforts on one corner of the pen. There she was able to gain a purchase on a bolt end, about three inches off the ground, with the claws of her right (and only) rear foot. By pulling with her front legs and pushing with the rear one, she got her center of gravity up to the top of the board. After many tries, she managed to topple out. Fortunately we were watching her at the time, or she might have escaped



Escape artist

into the surrounding neighborhood. (Her predecessor, a Russian tortoise named Speedy, escaped just that way.)
Edward Groth III
Pelham, New York

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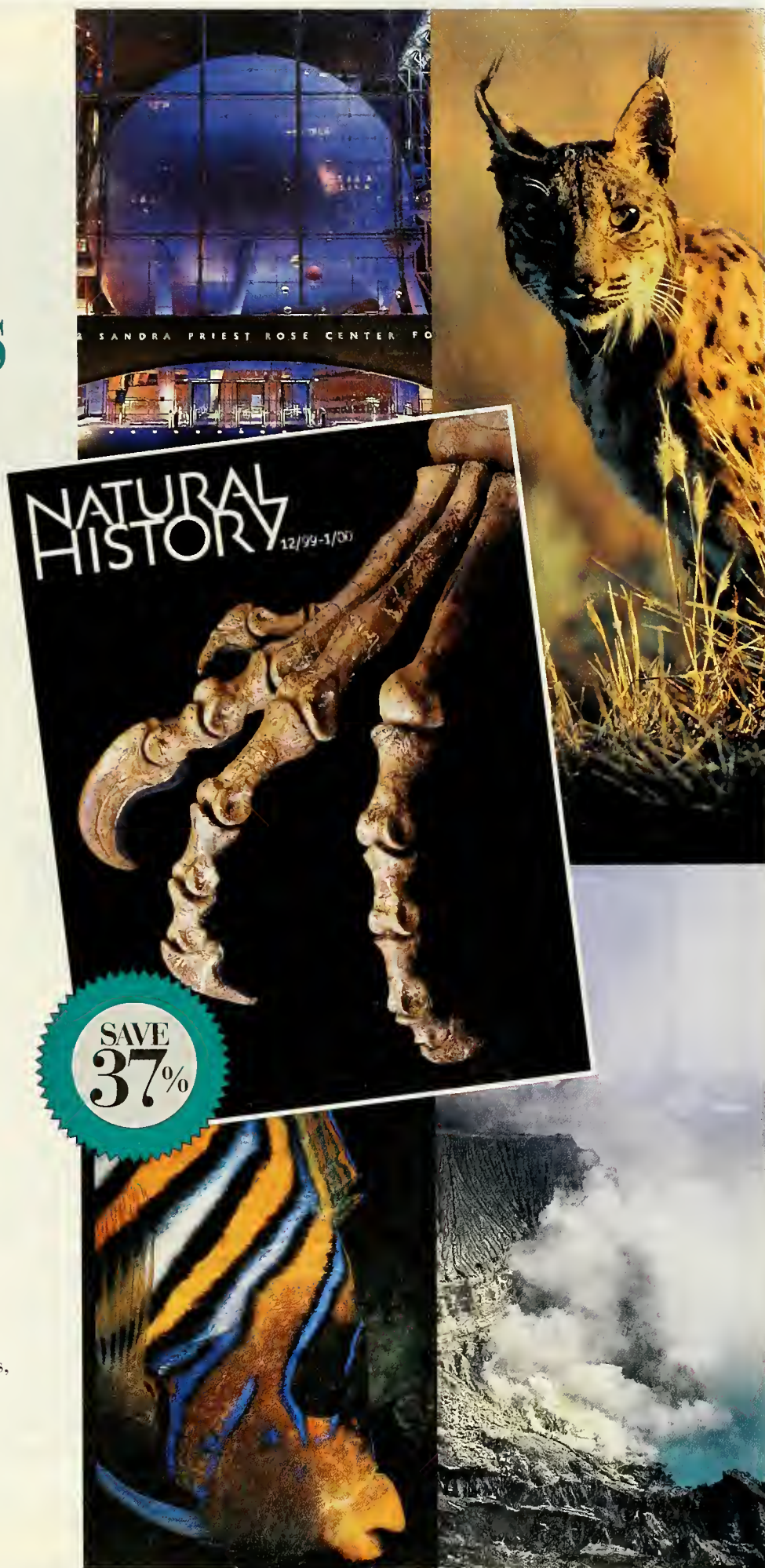
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CONTRIBUTORS



"It's hard to imagine," writes **Dale F. Lott** ("Plains Song," page 44), "but before East Africa became safari land, rich adventurers went on safari on the Great Plains." Lott (foreground), a bison expert and a professor emeritus of wildlife, fish, and conservation biology at the University of California, Davis, has had a lifelong connection with the nearly endless acres of America's breadbasket. He was born on western Montana's National Bison Range (of which his maternal grandfather was the superintendent) and spent the first six years of his life there; when he was ten, his family bought a ranch three miles away that had once been owned by his paternal grandfather. Lott majored in English as an undergraduate before turning to the behavioral endocrinology of rodents as a graduate student; it wasn't until he became a thirty-year-old assistant professor looking for a fieldwork subject that he once again turned his attention to bison, which at the time had scarcely been analyzed. His book about the species, *American Bison: A Natural History*, was published last month by the University of California Press.

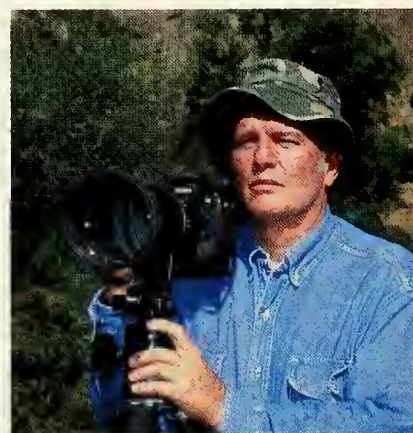
"I like to put things together," says **Jennie Dusheck** ("The Interpretation of Genes," page 52). In 1973 she built a reflecting telescope with a nine-inch mirror that she ground and polished herself. By the time she was in graduate school, in the 1980s, she had moved on to motorcycles, rebuilding the engine of a trashed 1973 Norton Commando, which she customized to fit her "relatively short stature." Today, she says, the telescope and bike sit in the garage gathering dust, while she spends her time fitting ideas together. Dusheck and co-author Allan J. Tobin are currently revising their award-winning college-level biology textbook, *Asking About Life*.



Paul Trawick ("Trickle-Down Theory, Andean Style," page 60) first got involved in water management issues as an undergraduate in the 1970s, when, as a representative of the Oregon Student Public Interest Research Group, he fought a plan by the U.S. Army Corps of Engineers to build a dam on the Rogue River. He later earned a doctorate in anthropology from Yale University for his research on the contrasting irrigation practices followed by diverse communities in the Peruvian Andes. As someone who has worked periodically for both the World Bank and the Inter-American Development Bank, Trawick is familiar with the call for reform in the handling of water resources. He suggests that policy makers in Peru and elsewhere have much to gain from an examination of the irrigation procedures and related customs that some of the Andean communities have maintained since ancient times. An assistant professor of anthropology at the University of Kentucky, Trawick is the author of *The Struggle for Water in Peru: Comedy and Tragedy in the Andean Commons* (Stanford University Press, October 2002).



For **David Welling** ("The Natural Moment," page 74), the quick strike of a rattlesnake on a jay was a bit of serendipity, giving him an opportunity to capture the scene and its aftermath. But it also came as something of a shock, "especially," he says, "since I had walked around the bush where the rattler was hidden just fifteen minutes prior to the strike." A nature photographer since 1988 and a professional one for the past four years, Welling grew up in Los Angeles, Reno, and Las Vegas. He counts as his favorite subjects "anything with fur, feathers, scales, or breathable skin (amphibians)" but adds that one of his greatest experiences was photographing the mountain gorillas in central Africa's Parc National des Virungas in the late 1980s. For sixteen years Welling has been active as a volunteer at a facility in the United States that rescues and cares for wild animals. For this month's photograph, he used a Nikon F5 35mm camera, a lens with a teleconverter, and a Fresnel lens for fill flash.





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AT THE MUSEUM

Tern, Tern, Tern

By Henry S.F. Cooper Jr.

Since 1969 Helen Hays, the tern lady of Great Gull Island, has helped conserve thousands of seabirds.



Hays and friends in their natural habitat

On May 22 I joined a small group from the American Museum of Natural History in a motor launch at Niantic, Connecticut. We chugged across Long Island Sound to Great Gull Island, a bird sanctuary jointly operated by the Museum and the Linnaean Society of New York (an ornithological group dedicated to natural history and conservation). Great Gull is a low rock-pile of an islet and the most successful breeding ground for common and roseate terns in North America. About 17,000 pairs of commons and more than 1,800 pairs of roseates breed there every summer, arriving in early May and departing with their young in August. This colony is the only one with a growing population (especially of roseates), partly because breeding grounds on Long Island and farther

south have been eliminated by relentless human development.

Terns are about two-thirds the size of gulls; a roseate tern is a little longer than a common tern and a little more elegant, with a whiter body (contrasting more sharply with its black head), a longer tail (extending beyond its folded wings), sometimes a blacker bill, and a faint, rosy blush on its breast. Listed as an endangered species by the federal government since 1987, roseates breed in large numbers in only two other places, Bird and Ram Islands, off the coast of Massachusetts. The terns feed on the abundant fish (sand eels and butterfish, for example) that are chased by such sport fish as bluefish and striped bass to the water's surface, where the terns, which can't dive more than a few feet underwater, can catch them. The three islands are also relatively free of

predators, except for the great black-backed gulls near Great Gull, which have learned to capture the terns in the air and swallow them whole.

But things can go wrong, and these tern colonies might easily disappear, as they once did on Great Gull. In the nineteenth century, plume hunters slaughtered the birds for their feathers, then popular for ladies' hats; 40,000 skins were taken in one year. But the coup de grâce occurred in 1897, just before the start of the Spanish-American War, when the army began building Fort Michie to guard the eastern approaches to Long Island Sound. Eventually, 500 men moved onto the seventeen-acre island; granite riprap and concrete fortifications invaded the sandy beaches and meadows where terns scraped out their nests. In 1949, when the government ceded the island to the Museum, most of the fortifications were destroyed, and the terns slowly began coming back.

By 1966 the colony was large enough and stable enough to study, and Helen Hays (self-described as "the ornithologist, not the actress") has spent every summer on the island since then. Soon after taking over in 1969, Hays made a name for the project by documenting the effects of PCBs and other toxins on the bird population (thin-shelled eggs and deformed chicks) and by lobbying successfully for the reduction of environmental contaminants.

At a slender wooden jetty with an off-putting sign reading Research Station—Do Not Land, the short, cheerful, energetic-looking Hays caught our rope and guided our group's boat in. As she led us through the ruined fortifica-

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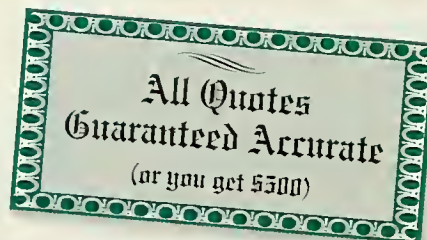
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tions of Fort Michie, with hundreds of crying terns soaring and swooping overhead, Hays explained that she had gotten into ornithology because of her wish, when she was at Wellesley College in the 1950s, to do fieldwork, and the only job available was studying ruddy ducks in Manitoba. After getting a master's in ornithology from Cornell University, she came to the Museum in 1956. When a friend took her to Great Gull to see the terns, Hays knew she did not want to be among solitary ruddy ducks anymore; she wanted to be in the social swirl of this colony.

Hays arrives on the island during the last week in April to watch the terns come in. This year, a group of about forty flew over the island on May 5 and the birds began landing on May 7, a little later than usual. By the time of our May 22 visit, about half of the expected 24,000 or so terns had arrived, bright and chipper and ready for courtship displays despite

their long trip. Most of the roseates come from the coast of Brazil; the commons come from there as well and also from the coast of Argentina—wintering grounds discovered by Hays and her associates during several expeditions undertaken in the past decade.

What was once the fort's mine-placement and detection center now serves as office, bird-banding laboratory, bird-processing room, kitchen, dining room, and sitting room. The detritus of more than thirty years of ongoing bird-watching is impressive: shelves of canned food, lots of battered pots and pans, maps, notebooks, bookcases crammed with pa-

perbacks, a gull skeleton, a wall clock with birds marking the hours and bird songs for chimes, and straw hats

speckled white with tern droppings and topped with long-stemmed cloth flowers—worn to deflect dive-bombing terns, which always attack the highest point. (Hays recounted how she and her helpers had originally worn pith helmets until they realized that the birds were bending their beaks on the hard hats.)

The banding would not start until the first chicks hatched, but

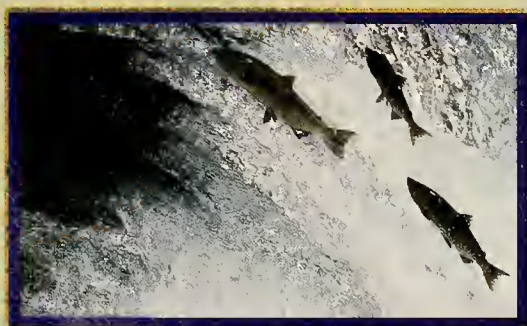
Hays was already setting up blinds from which the birds could be observed during the daytime for the



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A visiting common tern from Argentina is identified by an orange tag on its right leg.

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next six weeks. We headed toward the east end of the island, spreading out in a line across the meadow, heads down, looking for eggs. In April a small tractor had been used to disc-harrow much of the poison ivy, bittersweet, bayberry, and grass cover, leaving the soil soft and free of vegetation. In the past, grass, bayberry, and other weeds had taken over most areas used by the nesting commons. In 1981 meadow voles (*Microtus pennsylvanicus*) were reintroduced for lawn-mowing purposes. The voles successfully devoured the grass, but soon afterward, inedible weeds crept in, with the result that the vole population crashed. Hence, harrowing proved more effective than voles for removing invasive species.

From time to time, we stopped our egg search to put up blinds—tall, tapering wooden frames covered with canvas that overlooked all the nesting concentrations of common terns, as well as smaller structures (which looked like outhouses) placed around the periphery for keeping track of the roseates. When the first egg was discovered, we broke ranks to inspect it; it was slightly elongated, golf-ball-size, and camouflaged with dark green mottling on a light green field. Placed in a plastic bag and suspended from a pocket scale, the egg weighed in at twenty-two grams. Its shell was then numbered with a felt-tip pen and returned to the nest, which was marked by a numbered tongue-depressor stuck in the ground. Great Gull's tern chicks should have a long life: the oldest common tern tracked by Hays's project recently celebrated its twenty-sixth birthday, and the oldest roseate is twenty-five.

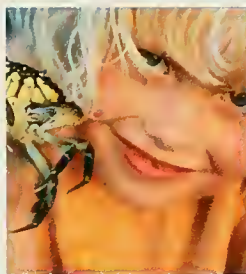
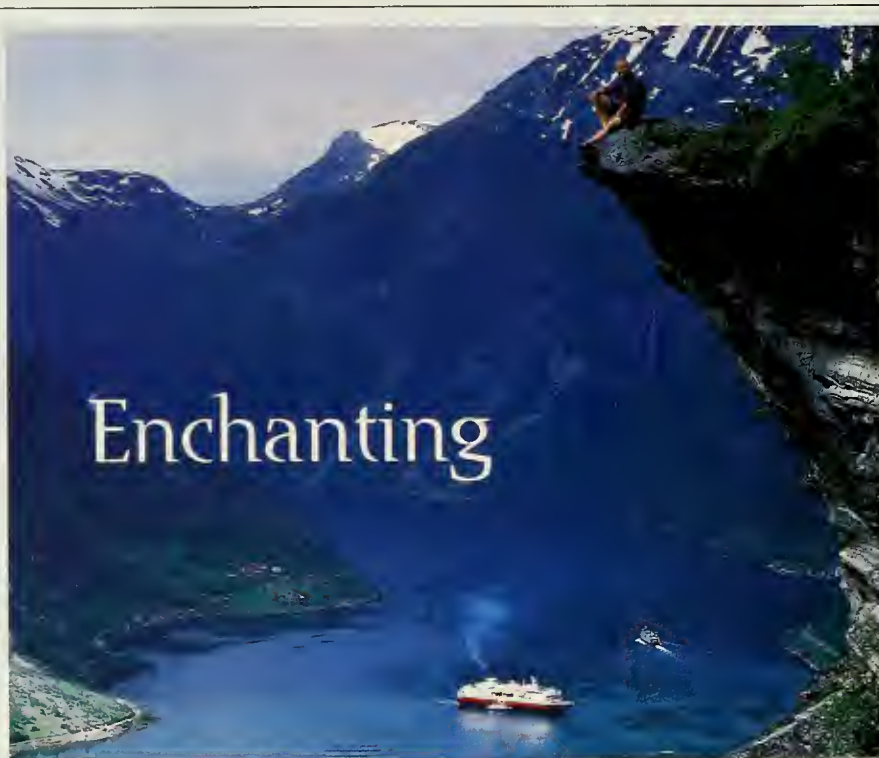
The project has also found that both kinds of terns tend to be monogamous, and the longest documented pairing to date is twelve years. Terns normally lay three eggs each spring, a day apart, and don't sit on the nests until after the second egg is laid. (The first egg hatches in about twenty-three days.)

A week or two later, when almost 12,000 breeding pairs are on the island, the egg laying, hatching, and observing would be in full swing, and Hays's team (as many as thirty people during the height of the season) would be busy banding the young, trapping adults on their nests, and entering the information into their computerized database.

As we were saying good-bye at the jetty, Hays said she was looking forward to the next few weeks and added, "Last year the terns were more syn-

chronous in their behavior than ever before—arriving, nesting, and departing closer together. You'd think, after the number of years we have worked on the island, we would know everything, but fortunately that is not true, and there are still things to discover."

Henry S.F. Cooper Jr., a former staff writer for the New Yorker, has been visiting the Museum since he was four years old, when his father sat him in a cavity of the Willamette meteorite.



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MUSEUM EVENTS IN OCTOBER

INSIDE AND OUTSIDE THE MUSEUM

Lecture 10/2 (Reports From the Field series): "Peterson Field Guides: The Legacy." Ornithologist Noble S. Proctor, Southern Connecticut State University. Orientation Theater (fourth floor), 7:00–8:30 P.M.

Lecture 10/3 (China Survey series): "Enduring Themes of Chinese Philosophy." John S. Major, China Institute senior lecturer and former director of the Asia Society's China Council. Kaufmann Theater, 6:30–8:00 P.M.

Exhibition reopening 10/5: "The Butterfly Conservatory: Tropical Butterflies Alive in Winter." Hall of Oceanic Birds. Through 5/26/03.

Lecture 10/8 (Hot Topics in Science & Culture series): "An Evening With Oliver Sacks." Neurologist Oliver

Scott Weidensaul. Portrait Room, 3:00–4:30 P.M.

Panel 10/15 (Hot Topics in Science & Culture series): "Urban Archaeology: An Examination of Slavery and the African Presence in the Northeast." Moderator: AMNH anthropologist David Hurst Thomas. Panelists: Michael L. Blakey, New York African Burial Ground Project; Cynthia Copeland, New-York Historical Society; Gerald F. Sawyer, Connecticut State University. Kaufmann Theater, 7:00–9:00 P.M.

Lecture 10/16 (Reports From the Field series): "Peterson Field Guides: Conservation and Renewal." Biologist John C. Kricher, Wheaton College, Massachusetts. Orientation Theater (fourth floor), 7:00–8:30 P.M.

Lecture 10/17 (China Survey series): "China in the 20th Century." Renqiu Yu, State University of New York, Purchase College. Kaufmann Theater, 6:30–8:00 P.M.

Lecture 10/22: "Rosalind Franklin: Dark Lady of DNA." Franklin biographer Brenda Maddox. Kaufmann Theater, 7:00–8:30 P.M.

Lecture 10/30 (Reports From the Field series): "Search for the Golden Moon Bear." Naturalist Sy Montgomery. Kaufmann Theater, 7:00–8:30 P.M.



CRAIG CHESER/AMNH

Sacks discusses his recently published memoir, *Uncle Tungsten: Memories of a Chemical Boyhood*. LeFrak Theater, 7:00–9:00 P.M.

Lecture 10/10 (China Survey series): "Chinese Literature." Zhang Xudong, New York University. Kaufmann Theater, 6:30–8:00 P.M.

Performance 10/13: Singer Yoojin Chung performs Korean *p'ansori*, a form of folk art opera and epic storytelling. Kaufmann Theater, 2:00–3:15 P.M.

AMNH Book Club 10/13: *The Ghost With Trembling Wings: Science, Wishful Thinking, and the Search for Lost Species*, by

Lipschutz. Advance registration only. Rose Center classroom, 6:30–8:30 P.M.

Lecture 10/21 (Distinguished Authors in Astronomy series): "The Biggest Bang." Jonathan I. Katz, Washington University in Saint Louis. Space Theater, Hayden Planetarium, 7:30–9:00 P.M.

Course 10/22–11/19 (four Tuesdays, except 10/29): "Virtual Universe." Hayden Planetarium instructors Carter Emmart, Brian Abbott, and Ryan Wyatt. Advance registration only. Space Theater, Hayden Planetarium, 6:30–8:30 P.M.

November's Celestial Highlights 10/29: Space Theater, Hayden Planetarium, 6:30–7:30 P.M.

Course 10/28–11/25 (four Mondays): "Using a Telescope." Don Neill, AMNH research fellow. Advance registration only. Rose Center classroom, 6:30–8:30 P.M.

Course 10/29–12/3 (six Tuesdays): "Fundamentals of the Cosmos." Hayden Planetarium instructor Stephanie L. Parello. Advance registration only. Rose Center classroom, 6:30–8:30 P.M.

Course 10/30–11/20 (four Wednesdays): "Stars, Constellations, and Legends." Consummate amateur astronomer Hank Bartol. Advance registration only. Space Theater, Hayden Planetarium, 6:30–8:00 P.M.

ASTRONOMY & COSMOLOGY

Course 10/3–11/14 (six Thursdays, except 10/31): "Scientific Revolution." Hayden Planetarium instructors Stephanie L. Parello and Ryan Wyatt. Advance registration only. Rose Center classroom, 6:30–8:30 P.M.

Lecture 10/7 (Frontiers in Astrophysics series): "NASA's New Horizons Mission to Pluto: A Mission to New Frontiers." Alan Stern, Southwest Research Institute. Space Theater, Hayden Planetarium, 7:30–9:00 P.M.

Course 10/7–10/21 (three Mondays): "Choosing a Telescope." Amateur astronomer and astrophotographer Peter

IMAX MOVIES

Kilimanjaro: To the Roof of Africa and *Pulse: A STOMP Odyssey*. Samuel J. and Ethel LeFrak Theater; daily screenings from 10:30 A.M. through 4:30 P.M.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online. To make reservations for programs and events, call (212) 769-5200.



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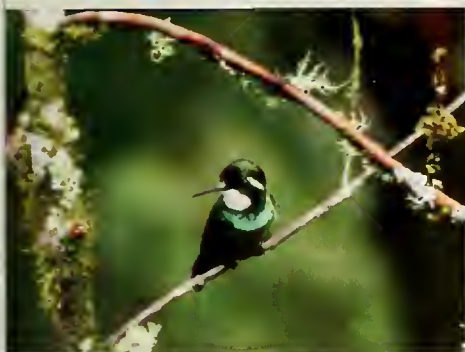
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Photos: Panama Tourist Board

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Millions of Neotropical migrants pass through Panama in the spring and fall, and it's possible to see a wintering grosbeak sharing the same tree with a keel-billed toucan.

For the best birding, head to the rainforest, where you may spot two of

the country's most famous inhabitants: the resplendent quetzal, with its thirty-inch-long iridescent blue-green tail feathers, and the harpy eagle, an unusually large and powerful raptor and the country's national bird.

Deep in the astonishingly large Darien National Park, a biosphere reserve with seven life zones, you will find dozens of endemic species and clusters of green, scarlet, blue, and yellow macaws. Here you stand a good chance of spotting such rare birds as the chestnut-fronted macaw and red-throated caracara.

At Volcan Baru, the country's most visited national park and its highest elevation, catch a glimpse of the quetzal or toucan. Near the Panama Canal, explore Pipeline Road, which passes through the rainforest of the Soberania National Park and is home to 380 species including trogons, caciques, woodpeckers, and many more. In the Panama Canal, visit Barro Colorado Island, home to the Smithsonian Tropical Research Institute. The Panama Canal watershed boasts 560 bird species including the rufescent tiger heron and chestnut-mandibled toucan.



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With more than 80,000 acres of state parks and 100,000 acres of forests, **West Virginia** offers a natural, peaceful setting for watching its native wildlife.

FROM THE POTOMAC Highlands in the northeastern part of the state to the New River Valley in the south, West Virginia is home to hundreds of species of birds that find sanctuary amid its breathtaking moun-

tains, valleys, forests, lakes, and streams.

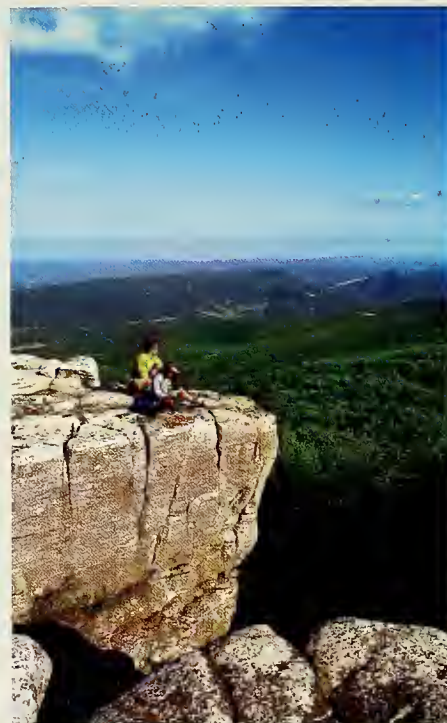
A variety of community groups as well as educational programs at most state parks are available to help guide both the casual observer and serious watcher plan an adventure to remember.

From wood and waterfowl to raptors and osprey, the wonders of wildlife await in Wild and Wonderful West Virginia. For more information and a free travel guide, call 1-800-CALL WVA or check out www.callwva.com.



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Photos: West Virginia Division of Tourism

WORCESTER COUNTY, MARYLAND

IN WORCESTER County, a birding vacation is a chance to experience an unspoiled wilderness. Located on Maryland's lower eastern shore, this small county didn't have a road to the mainland until 1952.

Perhaps as a result, the natural beauty of its native landscape remains unchanged. Worcester County's ecological diversity—you'll find a barrier island, a cypress swamp, centuries-old forest, tidal wetlands, and secluded fields, all easily accessible—makes it home to an impressive variety of birds, both resident and migratory.

Over 350 bird species have been recorded, more than in any other

county in Maryland. Stop anywhere along the road in Worcester County, look around, and you'll see an abundance of birds. To help you keep track of sightings, you may print out a birdwatching map from <http://www.visitworcester.org/birding/birdmap.html>.

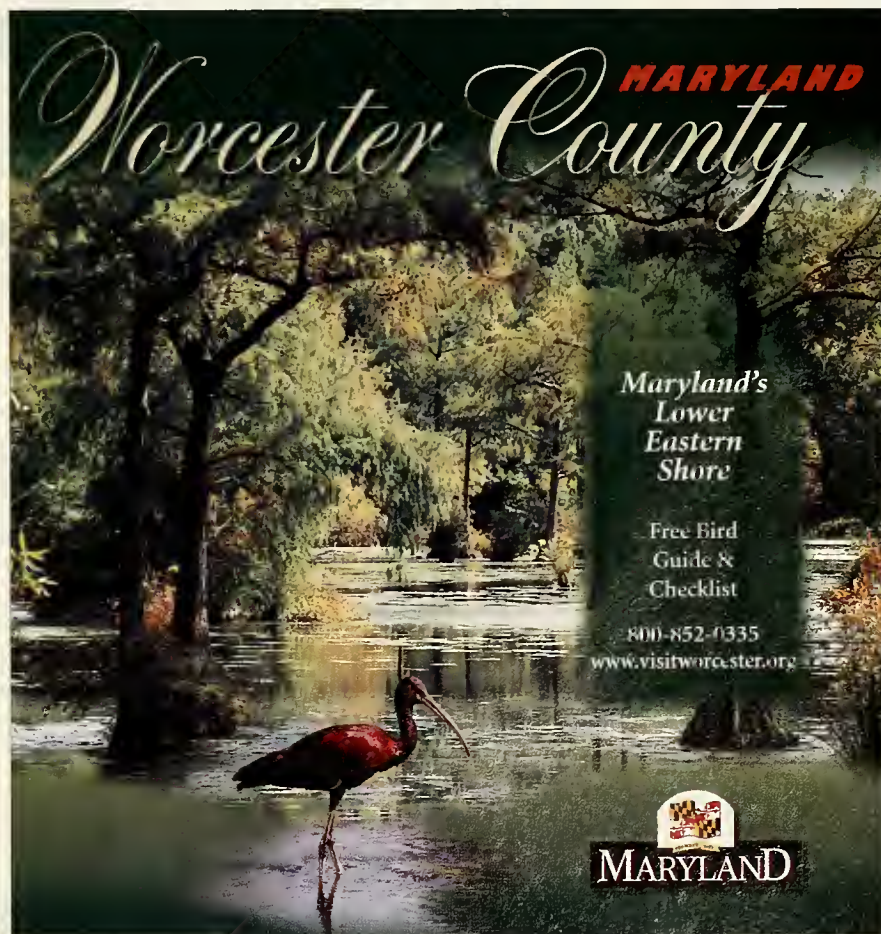
State and national parks in the county offer camping, nature trails, and guided tours. The wetlands of the Pocomoke River State Forest and Park are a sanctuary for birds: more than 127 species have been cited. Look for flocks of bald eagles, which roost in the Pocomoke Cypress Swamp on Hickory Point Road. And at Assateague Island National Seashore, try the "Life of the Marsh Trail," which courses its way through salt marshes where you can spot many wetland bird species and enjoy the panoramic view from the observation deck.

GARRETT COUNTY, MARYLAND

Tucked in the Allegheny Plateau of the Appalachian Mountains of western Maryland, Garrett County offers visitors a chance to reconnect with nature. This county's seven scenic lakes, protected forests and parks, open fields and grasslands, and boggy wetlands provide opportunities for nature-oriented activities in every season. And because of its high elevation, Garrett County harbors breeding birds rarely encountered elsewhere at this latitude. Visit here to see birds usually spotted only in Canada, the Great Lakes, and the Northeastern states.

Fall, when Garrett County is ablaze with colors, is a perfect time to visit. Discover the hermit thrush as you hike through shady maple and hemlock groves, or encounter bobolinks in golden hayfields and northern waterthrush in subarctic swamplands.

In the heart of the county lies Deep Creek Lake, Maryland's largest freshwater lake. Enjoy some birding from the perspective of a boat on this man-made lake, near the town of Wisp. From Herrington Manor, embark on a naturalist-led hayride through Garrett State Forest to a beautiful overlook above the brilliant foliage. Or follow the meandering trails of Swallow Falls State Park, nine miles north of Oakland, where the Youghiogheny River flows through shaded rocky gorges and creates rippling rapids. Here, you'll see the spectacular Muddy Creek Falls, a crashing 63-foot waterfall.




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CHARLES COUNTY, MARYLAND

CHARLES COUNTY IS only an hour away from Washington, D.C., but its natural beauty sets it apart from most suburbs. Situated on the coastal plain of southern Maryland, Charles boasts an abundance of undeveloped areas, including 150 miles of spectacular shoreline, acres of second-growth forests, large and small lakes, ponds, and extensive wetlands. It is bordered on the west and south by the Potomac River, on the east by the Wicomico River, and on the north by the Mattawoman Creek. Not surprisingly, it is a haven for birds and bird-watchers alike.

Visit the forests along Mattawoman to spot vibrantly colored songbirds or, early in the evening, to hear the call of barred owls. This fall, look for Charles County's official bird, the great blue heron, in its traditional breeding

grounds at the Nanjemoy Creek Great Blue Heron Sanctuary. To glimpse rare or endangered species such as the Louisiana thrush, hike on the mile-long nature path over the wetlands of the Naval Surface Warfare Center's Watchable Wildlife Center, part of the Chicamuxen Wildlife Management Area (301-743-5161).

For a change of pace, rent a kayak, canoe, or boat in Gilbert Run Park, in Nanjemoy Creek (301-932-3470), and explore miles of scenic marshes rich with wildlife. This winding creek has many high banks that serve as nesting sites for bald eagles; Charles County has the second largest population of bald eagles in Maryland.

Before you go on this outstanding birding trip, request a copy of the Charles County Bird Watchers Guide, available through <http://www.charles-county.org/tourism/brochures.html>.

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Tom Vargo

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and enjoy the unhurried pace of coastal living. More than 280 species of birds have been spotted on the island. Thirty-seven species of shorebirds forage and nest in its pristine habitat. Located along the Atlantic Migratory Flyway, Little St. Simons Island is a critical staging site for many of these birds.

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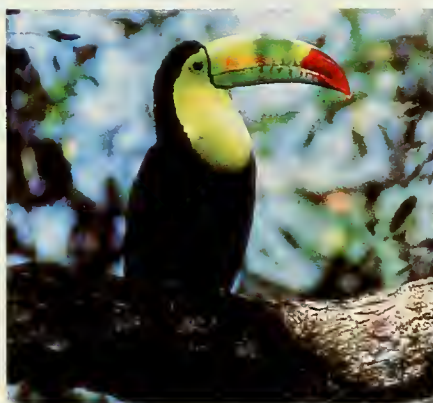
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The new 820 Swift Audubon binocular, designed by birders for birders, took two years to design, incorporating the comments and advice of the country's leading birders. This rugged, high-quality tool took a lot of care and effort to design, but it is nonetheless affordable. Swift's 825R, the Eaglet, is a compact, easy to hold binocular that focuses to ten feet.

Swift also makes an Ultra-Lite series of sharp, lightweight binoculars, which carry the Swift lifetime guarantee, as well as many economy models—affordable but dependable—with such fine features as waterproofing, rubber armor, and wide-angle optics.

For a detailed list of all Swift birdwatching binoculars, visit <http://www.swift-optics.com/birdwatching.htm>.

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In October more than 500 species, many of them migrants from the north, flock to Belize, which is located on the Central, Pacific, and Mississippi Flyways. You may glimpse such transients as the yellow-billed cuckoo, American redstart, or ruby-throated hummingbird, along with the indigenous scarlet macaw, king vulture, black catbird, or the keel-billed toucan, Belize's national bird.

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A pioneer in avian conservation, Zeiss was the proud sponsor, earlier this year, of the exciting search for the long-lost Ivory-billed Woodpecker in its original southeastern Louisiana habitat. Zeiss sent a team of searchers, joined by many other birders, to the



US Fish and Wildlife Service



Alex Westner, courtesy Pocono Mountains Vacation Bureau, Inc.

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Pearl River Wildlife Management Area. There, they conducted the most extensive search in decades for the woodpecker, believed to be extinct for at least fifty years. Although the Ivory-billed Woodpecker was not sighted, Zeiss team members reported that they saw signs of potential habitation and recommend further explorations of the area.

For more information about the Ivory-billed Woodpecker expedition, and for a complete listing and description of Zeiss products, visit www.zeiss.com/us.

POCONO MOUNTAINS, PENNSYLVANIA

Photos: Alex Westner, courtesy Pocono Mountains Vacation Bureau, Inc.



A YEAR-ROUND RESORT just a short drive from New York City, Pennsylvania's Pocono Mountains offer wooded peaks and valleys, sparkling lakes, rushing rivers, and some of the loveliest waterfalls in the east.

With seven state parks and miles of hiking trails, acres of forests, and the Delaware Water Gap National Recreation Area, the Poconos are a natural retreat and a favorite site for birds and birders alike. And with over one hundred

varieties of trees, creating a blazing landscape of red, orange, and gold, the Poconos are especially enticing in the fall.

For birders, a trip to the Delaware Water Gap is always rewarding. More than 260 species have been sighted in this area, from American bald eagles soaring above the upper Delaware River, making their way southward, to the Louisiana waterthrush, which nests in cavities in the banks of swift-running streams. Golden eagles are less frequently sighted but are recorded nearly every winter. In the bottomland forests and ravines along the river, look for a variety of warblers, including cerulean, blackburnian, and black-throated green warblers, as well as acadian flycatchers and hermit thrush.

During the fall and spring, many birds migrate along the river valley, and the Kittatinny Ridge is an especially important migratory corridor for raptors. Wild turkeys can be spotted in the Poconos' open fields, bobolinks and grasshopper sparrows breed in the area's grasslands, and waterfowl, shorebirds, and herons wade in its wetlands. And the Poconos' deciduous forests harbor a wealth of birds, ranging from the scarlet tanager to the ruffed grouse.



View America's symbol—the bald eagle—in its natural habitat, the Pocono Mountains. Along the Upper Delaware River, Pike and Wayne counties host the largest population of bald eagles in the northeast. For your **FREE** Vacation Guide or for immediate reservations, visit **800poconos.com**.

For Eagle Watcher Etiquette, Visit **800poconos.com** and click on **Things To Do**.

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SAMPLINGS

By Stéphan Reeb

ACCOUNTING FOR TASTE People who consider the carrion-eating habits of vultures disgusting might want to stop reading right now. The Egyptian vulture (*Neophron percnopterus*), not content with rotten meat, also consumes cow and sheep feces. A good explanation has been proposed for the odd diet. Unique among vultures, the Egyptian sports a bright yellow face. The color yellow in the animal world comes from pigments called carotenoids, which vertebrates cannot synthesize and must therefore obtain directly from



RICK EDWARDS; ANIMALS ANIMALS

their diets. A recent study by J. J. Negro, of the Doñana Biological Station in Spain, and colleagues shows that though bones and carrion contain few yellow pigments, cow dung and sheep droppings have a fair amount of the stuff. The biologists looked at blood plasma in captive vultures and found that carotenoid concentration was low in birds that were fed on cow meat but went up after the menu was switched to cow dung. Perhaps, the investigators suggest, the bright yellow face that results from eating feces signals to potential mates or rivals that its owner is an especially fit individual. After all, any bird able to thrive on a diet that includes an item that is low in nutrition and likely to contain lots of parasites is apt to be in very good shape. ("Coprophagy: an unusual source of essential carotenoids," *Nature* 416, 2002)

OF A RIGHT MIND TO FIGHT

A male tree lizard is sunning itself on a rock by the side of U.S. Highway 80 in New Mexico. Suddenly a competitor, another male, appears a few feet away. Never mind that this intruder is in fact introduced by an experimenter working behind the scene; tempers may still flare and a lateral display (the lizard showing one side to its opponent) may ensue, perhaps even followed by a charge. The stage is set for a study by Diana K. Hews and R. Andrew Worthington, of Indiana State University. Their objective: to determine if aggression is controlled by one side of the brain more than by the other. Their results: lizards that spotted the intruder with their left eye were more likely to present with their left side, and lizards that displayed with their left side were twice as likely to charge. Since information from the left eye is processed first in the brain's right hemisphere, these findings provide



JOE McDONALD; ANIMALS ANIMALS

additional support for the idea that this hemisphere plays the greater role in aggression. (Previous studies on Siamese fighting fish and toads, as well as on humans and other primates, have yielded similar results.) Drawing conclusions about human behavior from such studies is always risky, but highway drivers should perhaps try to ignore cars aggressively passing on their left (don't succumb to road rage!). Far better instead to look for lizards sunning on the right side of the road. ("Fighting from the right side of the brain: left visual field preference during aggression in free-ranging male tree lizards [*Urosaurus ornatus*]," *Brain, Behavior and Evolution* 58, 2001)

NEW NARCS? Another animal could soon join sniffer dogs in the business of contraband detection. Rats have good noses, too, and as demonstrated by James Otto, of the University of Baltimore, and Michael F. Brown and William Long III, of Villanova University, they can be trained not only to recognize the smell of illicit drugs, prohibited foodstuffs, and dangerous explosives (as previous workers have found) but also to search actively for those odors and adopt a particular posture when the search is successful. The scientists taught rats to stand on their hind legs if they detected the smell of cocaine and also outfitted the animals with a harness and long cable designed to "report" their posture to a computer. Laboratory trials in an arena containing twenty-five



MICHAEL BROWN

cups filled with bedding material (only one of which was scented with a simulated cocaine powder) yielded a correct-hit rate of 95 percent. Although field trials were not run, the team suggests possible advantages of rats over dogs: (1) rats can squeeze into tight hiding places; (2) rats do not form strong social bonds with humans and wouldn't need specific human handlers nearby; (3) rats are inexpensive to breed and maintain, and large numbers can be trained through automated systems; and sadly, (4) rats might be seen as expendable and could be called upon in dangerous situations involving the detection of explosives and buried mines. ("Training rats to search and alert on contraband odors," *Applied Animal Behaviour Science* 77:3, 2002)

SOUNDS LIKE TROUBLE In Africa, terrestrial animals respond in one of two ways to advancing savanna fires: by burrowing into the ground or running for their lives. For those who try to flee but aren't very fast, a little forewarning can mean the difference between life

and death. One such animal is the West African reed frog (*Hyperolius nitidulus*). In summer, reed frogs cling to grass stems or dry leaves. They remain motionless to conserve water, but the sound of distant fire can rouse them to action. German biologists T. Ulmar Grafe, Stefanie

Döbler, and K. Eduard Linsenmair, of the University of Würzburg, played a recording of a savanna fire to reed frogs that were peacefully estivating in Ivory Coast's Comoé National Park. Eighteen out of twenty frogs listened for a few minutes and then took off in the direction of tall trees or dense bush at a forest edge (these critters are good climbers, and tall structures offer protection from ground fires). None of the frogs reacted to white noise, and only six moved in response to the fire sounds played backward. Why do the frogs spend precious moments listening before they leap toward safety? Perhaps, the biologists suggest, the frogs want to make certain that the crackling sounds are fire and not dry sticks breaking under a large animal's footsteps. Scientists

already knew that various nonhuman animals use smoke, heat, and visual information to perceive distant fire, but this is the first example of acoustic detection. ("Frogs flee from the sound of fire," *Proceedings of the Royal Society of London B* 269, 2002)



West African reed frog

E.R. DEGENGER/DEMBINSKY PHOTO ASSOC.

SEWAGE TREATMENT Aphids are well known for their production of honeydew, a sugary liquid excreted in great abundance by these sap-feeding insects. Free-living aphids need not worry about waste disposal: they can flick the honeydew away, give it to ants that "tend" them in exchange for the privilege of eating their waste, or simply move on to another feeding location. But for aphids living inside plant galls, the risk of getting stuck or even drowning in their own sticky waste is quite real. For more than a century scientists have known that gall-dwelling aphids solve this problem with water-repellent wax. Special glands near the insect's anus produce a pow-



An aphid dumps some honeydew marbles.

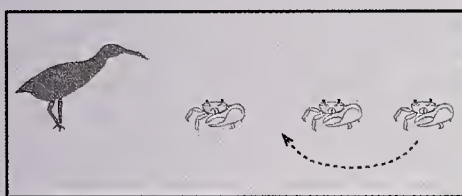
N. PIKE

dered wax that coats the honeydew droplets, creating little hydrophobic marbles that can be pushed along and kicked out of a gall through a tiny opening. Aphid wax also coats the inner surface of the gall, which has become the focus of recent research. Nathan Pike and colleagues at the University of Cambridge have observed that this waxy wall-covering resembles a bed of microscopic needles. Some of the needles adhere to the honeydew marbles, adding to their waxy coat. But the needle tips also keep the honeydew drops from sticking to the wall. This significantly improves the ease with which the aphids move the marbles around, making for efficient sewage transport. ("How aphids lose their marbles," *Proceedings of the Royal Society of London B* 269, 2002)

Stéphan Rees is a professor of biology at the Université de Moncton in New Brunswick, Canada, and the author of Fish Behavior in the Aquarium and in the Wild (Cornell University Press).

EXPERIMENT OF THE MONTH

When attacked by a predator, a group of animals often becomes more compact as each individual tries to reach



STÉPHAN REES

the relative safety of the center. Well documented in vertebrates, this so-called selfish herd effect has now been reported for an invertebrate, the fiddler crab (*Uca pugilator*). Equipped with a video camera, Steven V. Viscido and David S. Wetthey, of the University of South Carolina, ventured onto the mudflats of a small tidal creek to measure the cohesion of crab flocks before and after an attack. They mapped the position of individual crabs relative to a reference grid system made of white golf balls placed strategically

in the dark mud. When a natural predator (a clapper rail) or a simulated one (a person) ran toward a flock,

the crabs scurried about but always ended up forming a tighter aggregation. So strong was the pull of the center, with its "promise" of greater safety, that the crabs farthest away from the predator also rushed to join the group, even though this meant moving toward the source of danger. Obviously, for wary crabs, living on the edge is not considered a viable option. ("Quantitative analysis of fiddler crab flock movement: evidence for 'selfish herd' behaviour," *Animal Behaviour* 63, 2002)

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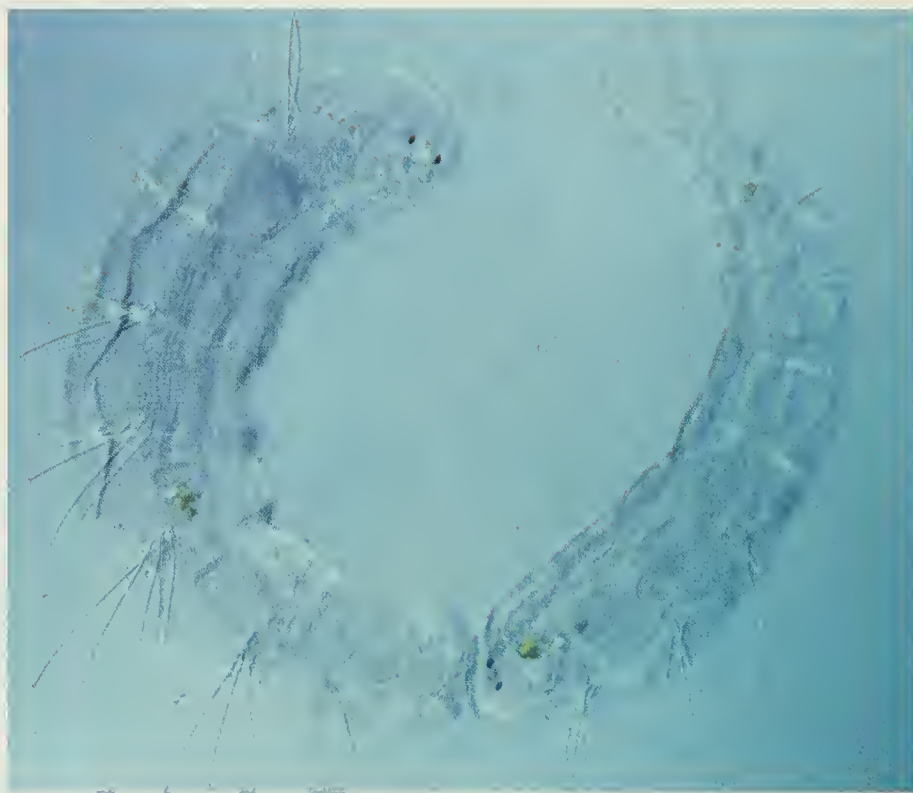
Getting a Head in the World

When the naidid worm reproduces, it grows a new front for its back half and a new tail for its front.

By Alexandra Bely
and Gregory Wray

We peer down at the tiny worm wriggling under the lens of our microscope. Four black eyes peer up at us: two from the creature's head and two from its . . . other head. Two-headed worms are common in our lab, and they're common outside the lab as well. If you've ever scratched the surface of a slimy rock in a pond or stream, you may even have taken one of these miniature beasts home with you, tucked away under your fingernail.

The bizarre worms we study are called naidids. They are members of the phylum Annelida, the group that includes segmented worms such as leeches, tube worms, and the familiar earthworm. Although naidids are widespread and abundant in ponds, streams, marshes, and other freshwater pools, we know relatively little about them, in part because of their size. Most are tiny; members of the largest species grow to about the size of a toothbrush bristle. A naidid's body is nearly transparent, allowing easy viewing of its inner workings: its bilobed brain, its pulsating blood vessels, its



ALEXANDRA BELY

A naidid worm is about to split into two. Note the two sets of eyes (black dots). Below: The act of separation (green and blue indicate new growth).

muscles and stomach, and even its lunch are plainly visible to anyone who cares to look. Also hard to miss, of course, are its two heads, complete with two pairs of eyes, two mouths, and two brains. One head is just where you would expect it, at the front end of the animal. The second head is right in the middle of its body.

Two-headed naidids are not abnormal mutants; rather, they are average worms that happen to be in the process of reproducing by a method known as paratomic fission (or paratomy). Growing a second head in the center of its body is a naidid's first step in propagating itself. Just in front of this head, new tail segments develop. The worm eventually splits into two complete animals (hence the term "fission"), one with the old head and a new tail, the other with the old tail and a new head. But why stop at two heads? Many nai-



ids develop five or more at once, ultimately breaking up into an equivalent number of worms. This curious mode of reproduction has arisen in several groups of annelids. How such an unusual reproductive method may have evolved has been the subject of our research for several years.

Annelids are certainly not the only members of the animal kingdom with unconventional reproductive habits. Take *Hydra*, a genus of freshwater invertebrates that commonly inhabit lakes and ponds. With one end of its body at-

tached to a rock or to submerged vegetation, a *Hydra* waves its tentacles in search of tiny aquatic prey, which it captures and stuffs into its mouth, located at the center of its ring of tentacles. To reproduce, a *Hydra* typically forms a bud that grows from the side of its body. The bud develops its own mouth and set of feeding tentacles but shares a gut, and hence its food, with its parent. Like a naeidid, a *Hydra* eventually splits into two or more complete individuals that go their separate ways.

Sea anemones such as the pink-tipped surf anemone, which is common along the Pacific coast of North America, have a particularly dramatic mode of reproduction. Opposite ends of the anemone slowly crawl away from each other, creating a tug-of-war that ultimately causes the animal to tear itself in two. Each half then regenerates the part that was lost, making the behavior an efficient, if peculiar, way of procreating.

And the list continues—sea stars that split in half, marine ribbon worms that break up into dozens of small pieces, sponges that fragment. All these creatures propagate by an asexual method known as asexual reproduction: offspring are produced by a single parent, and no gametes (eggs or sperm) are involved in the process. Although certainly not common, this kind of reproduction has evolved numerous times and in disparate kinds of invertebrates.

With the ability to reproduce asexually, the would-be parent has no need to find a mate. Even a single naeidid worm that makes its way to a new environment has the potential to quickly populate the entire body of water it inhabits. A well-fed naeidid can reproduce every two or three days. Assuming that the average worm reproduces every three days, in just three months it could in theory be the proud progenitor of more than a billion offspring! Viewed another way, if that average one-centimeter worm did not split after consecutive rounds of fission, after three months it would be more

than 6,000 miles long—roughly the distance from San Francisco to Paris. Given that reproduction is the currency of evolutionary success, naeidids are clearly doing something right. But how does an animal become capable of reproducing this way? New molecular tools have made it possible to study the genes involved in this unorthodox manner of generating offspring.

The worm we have been studying is a delicate little naeidid called *Pristina leidyi*. Rearing this species has proved to be surprisingly easy and inexpensive. Like most naeidids, *Pristina* are detritivores that ingest fine sediments and scrape diatoms and algae from rocks and aquatic plants. In the laboratory, we housed worms in glass bowls filled with spring water and added a few paper towel pieces as a substrate for them to crawl on. For food, the worms were content with a century-old lab recipe (originally developed for growing organisms such as *Paramecium*) that consists of boiled hay and wheat grains. In this simple microcosm the worms flourished.

With our subjects now in hand, we began our genetic studies by investigating homeobox genes, which in many animals play important roles during embryonic development. Specifically, we wanted to learn where and when two such genes—*orthodenticle* and *engrailed*—are turned on, or expressed, during paratomic fission in *Pristina*. To find out, we had a powerful chemical technique at our disposal, which causes cells to change color in the presence of RNA copies of the genes. Such copies would only be present if the genes were turned on.

After several days of painstakingly transferring our minute, nearly invisible worms from one chemical solution to the next, dark blue patches began to appear in the naeidids' bodies, revealing

the location of cells in which the two genes were being expressed—specifically, in the new heads and tails growing in the middle of reproducing worms. In other words, these two genes, typically involved in the development of sexually produced embryos, are also involved in the development of new tissues during paratomic fission.

We were delighted with our results, but we wondered how in the course of evolution these genes came to be expressed during paratomy. It is difficult to imagine paratomic fission arising in one giant evolutionary step, in which a whole suite of genes (including *orthodenticle* and *engrailed*) would simultaneously have acquired the ability to be deployed in the middle of a worm's body. It seemed likely that intermediate



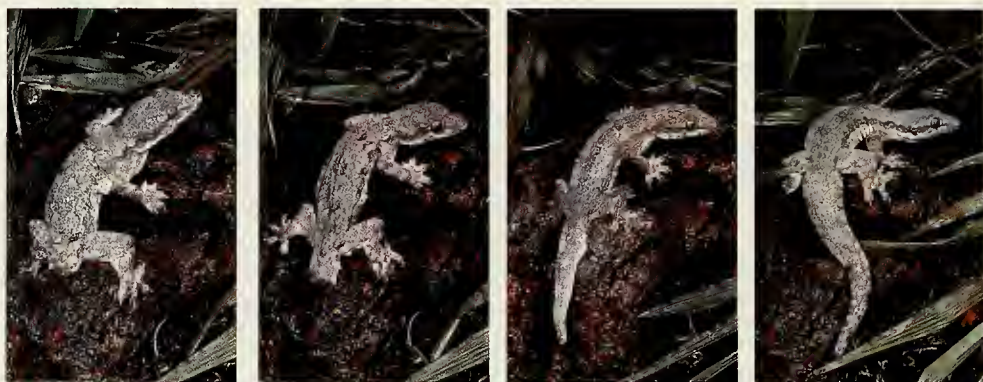
Like a naeidid, a hydra reproduces asexually, developing a bud that will eventually split from its parent.

steps were involved. Some evidence suggested that the process by which some animals regenerate lost or damaged body parts might be related to the process of paratomy. As long ago as 1916, French zoologist Lucienne Dehorne noted that the distribution and movement of naeidids' cells during paratomy bore a striking resemblance to that seen during regeneration. We were therefore eager to find out what was happening with our two homeo-

box genes while regeneration was taking place.

Pristina worms, it turns out, are great regenerators. When we removed the anterior or posterior end of a worm, the remaining piece grew a new head or tail within just a few days. We found that during regeneration, the expression patterns of the *orthodenticle* and *engrailed* genes were almost identical to the patterns seen during paratomy. In worms forming a new head or tail either by regeneration or by paratomy, both genes were turned on in regions of the developing nervous system. Additionally, in worms developing a head by either process, *orthodenticle* was turned on at the tip of the new head as well as in the foregut (specifically in the pharynx, the muscular "throat" of the worm).

The resemblance between regeneration and paratomy, then, is not merely superficial but extends to the underly-



Many vertebrates, including geckos, can regenerate lost body parts, such as a tail. In a handful of invertebrates this trait has led to reproduction by fission.

ing regeneration, much of it from the early 1900s, we found that most worms can regenerate missing segments, but only a small proportion are able to reproduce by fission. Moreover, with just a single known exception, all annelids capable of fission can also regenerate (a pattern that seems to hold for many other invertebrate groups as well, including flatworms, sea anemones, and starfish). So we believe that in annelids, the ability to regenerate came first and may even have been a necessary prerequisite for the evolution of fission.

The next question we wanted to explore was whether regeneration is completely novel or whether it, in turn, is based on yet another process, such as embryogenesis. To find out, we compared gene expression during paratomy and regeneration with that in a developing embryo. In this new endeavor, our *Pristina* worms proved uncooperative. Naidids are able to reproduce sexually, but they do so

very rarely in nature, and the environmental cues that prompt an individual to switch from asexual to sexual reproduction are not known. Despite our efforts to manipulate our naidids' lab environment to simulate what might be a natural trigger for sexual reproduction—such as a change in day length or temperature—our worms continued to reproduce only by fission.

Fortunately, the two genes we studied have been examined in the embryos of a closely related annelid group, the leeches. Although leeches neither regenerate nor undergo paratomic fission, their embryos are very similar to those of *Pristina*'s. When we compared our *Pristina* findings with the published data for *orthodenticle* and *engrailed* in leech embryos, we were pleasantly surprised. In leech embryos, just as in our fissioning and regenerating naidids, *orthodenticle* was expressed near the tip of the head and in the foregut, and both genes were turned on during the development of the leech's nervous system.

Evolution, it seems, is fond of recycling. Genes that control embryological development were co-opted to play a role in the regeneration of body parts, and the ability to regenerate was subsequently critical to the evolution of paratomy. Countless questions remain, of course, regarding the ways in which the astonishing diversity of reproductive modes has evolved. As our little *Pristina* worms have shown us, the answers may be lying humbly underfoot, beneath a slimy pondside rock just waiting to be turned over.

Alexandra Bely, a postdoctoral fellow in molecular and cell biology at the University of California, Berkeley, will soon be an assistant professor of biology at the University of Maryland. Gregory Wray is an associate professor of biology at Duke University.



Painted sea stars and other starfish regenerate missing arms—in this case, four out of five.

ing genetic machinery. Indeed, during paratomic fission, a naidid behaves as if it were broken in half (even though it has not been damaged), regenerating a new tail for its front end and a new head for its back end. Given the extensive similarities between regeneration and fission, an obvious question is, Which process came first in the course of evolution? Reviewing the literature on an-

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UNIVERSE

Let There Be Dark

To keep the cosmos in view, sky watchers must fight to keep the Earth from being enveloped in a fog of artificial light.

By Neil deGrasse Tyson

Astrophysics reigns as the most humbling of scientific disciplines. The astounding breadth and depth of the universe deflates our egos daily, and we are continually at the mercy of uncontrolled forces. A simple cloudy evening—one that would stop no other human activity—prevents us from making observations with a telescope that can cost \$20,000 a night to run, regardless of the weather. We are passive observers of the cosmos, acquiring data when, where, and how nature reveals itself to us. To know the cosmos requires that we have windows onto the universe that remain unfogged, untinted, and unpolluted. But the spread of what we call civilization, and the associated ubiquity of modern technology, is generally at odds with this mission. Unless something is done about it, people will soon bathe the Earth in a background glow of light that will block all access to the frontiers of cosmic discovery.

The most obvious and prevalent form of astropollution comes from streetlamps. All too often, they can be seen from your airplane window during night flights, which means that these streetlamps illuminate not only the streets below but the rest of the universe. Unshielded streetlights, such as those without downward-facing shades, are most to blame. Municipalities with these poorly designed lamp housings find themselves buying higher-wattage bulbs because half the lamplight points upward. This wasted light, shot forth into the night sky, has



rendered much of the world's real estate unsuitable for astronomical research. At a 1999 conference entitled "Preserving the Astronomical Sky," participants rightly moaned about the loss of dark skies around the globe. One paper reported that inefficient lighting costs the city of Vienna \$720,000 annually, London \$2.9 million, Washington, D.C., \$4.2 million, and New York City \$13.6 million. Note that London, with a population similar to that of New York

City, is more efficient in its inefficiency by nearly a factor of five.

The astrophysicist's dilemma is not that light escapes into space but that the lower atmosphere supports a mixture of water vapor, dust, and pollutants that bounce some of the upward-flowing photons back down to Earth, leaving the sky aglow with the signature of a city's nightlife. As cities become brighter and brighter, dim objects in the cosmos become less and

less visible, severing urban dwellers' access to the universe.

It's hard to exaggerate the magnitude of this effect. A penlight's beam, aimed at a wall across a darkened dining room, is easy to spot. But gradually brighten the overhead light, and watch how the beam gets harder and harder to see. Under light-polluted skies, fuzzy objects such as comets, nebulae, and galaxies become difficult or im-

A marketing executive wanted to project her company's logo onto the Moon. I explained why this was a bad idea.

possible to detect. I have never in my life seen the Milky Way galaxy from within the limits of New York City, and I was born and raised here. If you observe the night sky from light-drenched Times Square, you might see a dozen or so stars, compared with the thousands that were visible from the same spot when Peter Stuyvesant was hobbling around town. No wonder ancient peoples shared a culture of sky lore, whereas modern peoples, who know nothing of the night sky, instead share a culture of evening TV.

The expansion of electrically lit cities during the twentieth century created a technology fog that forced astronomers to move their hilltop observatories from the outskirts of towns to remote places such as the Canary Islands, the Chilean Andes, and Hawaii's Mauna Kea. One notable exception is Kitt Peak National Observatory in Arizona. Instead of running away from the spreading and brightening city of Tucson, fifty miles away, the astronomers stayed and fought. The battle is easier-won than you might think; all you have to do is convince people that their choice of outdoor lighting is a waste of money. In the end, the city gets efficient streetlamps and the astronomers get a dark sky. Ordinance No. 8210 of the Tucson/Pima County

Outdoor Lighting Code reads as though the mayor, the chief of police, and the prison warden were all astronomers at the time the code was passed. Section 1 identifies the intent of the ordinance:

The purpose of this Code is to provide standards for outdoor lighting so that its use does not unreasonably interfere with astronomical observations. It is the intent of this Code to encourage, through the regulation of the types, kinds, construction, installation, and uses of outdoor electrically powered illuminating devices, lighting practices and systems to conserve energy without decreasing safety, utility, security, and productivity while enhancing nighttime enjoyment of property within the jurisdiction.

And after thirteen other sections that give strict rules and regulations governing citizens' choice of outdoor lighting, we get to the best part, section 15:

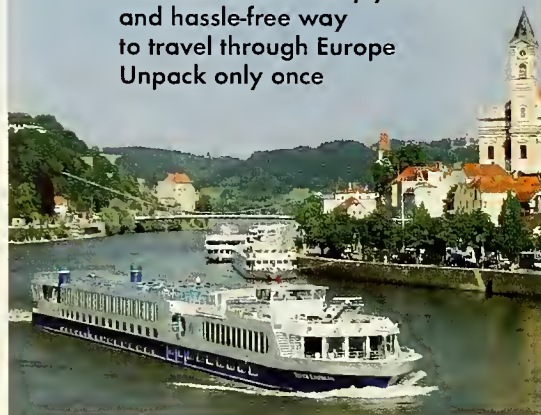
It shall be a civil infraction for any person to violate any of the provisions of this Code. Each and every day during which the violation continues shall constitute a separate offense.

As you can see, by shining light on an astronomer's telescope you can turn a peace-loving citizen into a Rambo. Think I'm joking? The International Dark-Sky Association (IDA) is an organization that fights upward-pointing light anywhere in the world. With an opening phrase reminiscent of the one painted on Los Angeles Police Department squad cars, the IDA's motto says it all: "To preserve and protect the nighttime environment and our heritage of dark skies through quality outdoor lighting." And, like the police, the IDA will come after you if you transgress.

I know. They came after me. Not a week after the Rose Center for Earth and Space first opened its doors to the

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public, I received a letter from the IDA's executive director, scolding me for the upward-pointing lights embedded in the pavement of our entrance plaza. We were justly accused—the plaza does have forty (very low wattage) lamps that help delineate and illuminate the Rose Center's granite-clad arched entryway. These lights are partly functional and partly decorative. The point of the letter was not to blame the bad viewing conditions across all of New York City on these itty-bitty lamps but to hold the Hayden Planetarium accountable for setting a good example for the rest of the world. I am embarrassed to say that the lights remain.

But all that's bad is not artificial. A full Moon is bright enough to reduce the number of stars visible to the unaided eye from thousands to hundreds. Indeed, the full Moon is more than 100,000 times brighter than the brightest nighttime stars. And the

physics of reflection angles endows the full Moon with more than ten times the brightness of a half Moon. This moonglow also greatly reduces the number of meteors visible during a meteor shower (though clouds would be worse), no matter where you are on

A cell-phone conversation between two astronauts on the Moon would be a bright spot in the radio sky.

Earth. So never wish a full Moon upon an astronomer who is headed off to a big telescope. True, the Moon's tidal force created tide pools and other dynamic habitats that contributed to the transition from marine to terrestrial life and ultimately made it possible for humans to thrive. Apart from this detail, most observational astronomers, especially cosmologists, would be happy if the Moon had never existed.

A few years ago I got a phone call from a marketing executive who wanted to light up the Moon with the logo of her company. She wanted to know how she might proceed. After slamming down the phone, I called her back and politely explained why it was a bad idea. Other corporate executives have asked me how to put into orbit mile-wide luminous banners with catchy slogans written across them, much like the sky-writing or flag-dragging airplanes you see at sports events or over the ocean from a crowded beach. I always threaten to send the light police after them.

Modern life's insidious link with light pollution extends to other parts of the electromagnetic spectrum. Next at risk is the astronomer's radiowave window to the cosmos, including microwaves. In modern times we are awash in the signals of such radiowave-emitting devices as cellular telephones, garage-door openers, keys that trigger "boip" sounds as they remotely lock and unlock car doors, microwave relay stations, radio and television transmitters, walkie-talkies, police radar guns, global positioning systems, and satellite communications networks. Earth's radiowave window to the universe lies cloaked in this technologically induced fog. And the few clear bands that remain within the radio spectrum are getting progressively narrower as the trappings of high-tech living grab more and more radiowave real estate. The detection and study of extremely faint celestial objects is being compromised as never before.

In the past half century radio astronomers discovered remarkable things, including pulsars, quasars, molecules in space, and the cosmic microwave background, the first evidence in support of the big bang itself. But even a wireless conversation can drown such faint radio signals: modern radio telescopes are so sensitive that a cell-phone encounter between two astronauts on the Moon would be one of the brightest sources in the radio

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sky. And if Martians used cell phones, our most powerful radio telescopes would easily nab them, too.

The Federal Communications Commission is not unmindful of the heavy, often conflicting demands that various segments of society place on the radio spectrum. The FCC's Spectrum Policy Task Force intends to review the policies that govern use of the electromagnetic spectrum, with the goal of improving efficiency and flexibility. FCC chairman Michael K. Powell told the *Washington Post* (June 19, 2002) that he wanted the FCC's philosophy to shift from a "command and control" approach to a "market-oriented" one. The commission will also review how it allocates and assigns bands of the radio spectrum, as well as how one allocation may interfere with another.

For its part, the American Astronomical Society, the professional organization of the nation's astrophysicists, has called on its members to be as vigilant as the IDA folks—a posture I endorse—in trying to convince policy makers that specially identified radio frequencies should be left clear for astronomers' use. To borrow vocabulary and concepts from the irrepressible Green movement, these bands should be considered a kind of "electromagnetic wilderness" or "electromagnetic national park." To eliminate interference, the geographic areas surrounding the protected observatories should also be kept clear of human-generated radio signals of any kind.

The most challenging problem may be that the farther an object is from the Milky Way, the longer the wavelength and the lower the frequency of its radio signals. This phenomenon, which is a cosmological Doppler effect, is the principal signature of our expanding universe. So it's not really possible to isolate a single range of "astro" frequencies and assert that the entire cosmos, from nearby galaxies to the edge of the observable universe, can be served through this window. The struggle continues.


Today, the best place to build telescopes for exploring all parts of the electromagnetic spectrum is the Moon. But not on the side that faces the Earth. Putting them there might be worse than looking out from the Earth's surface. When viewed from the Moon's near side, the Earth looks thirteen times bigger, and shines some fifty times brighter, than the Moon does when viewed from the Earth. And the Earth never sets. As you might suspect, civilization's chattering communication signals also make Earth the brightest object in the radiowave sky. The astronomer's heaven is, instead, the Moon's far side, where the Earth never rises, remaining forever buried below the horizon.

Without a view of Earth, telescopes built on the Moon could point in any skyward direction, without the risk of contamination from the Earth's electromagnetic emanations. Not only that, night on the Moon lasts nearly fifteen Earth days, which would enable astronomers to monitor objects in the sky for days on end, much longer than they could from the Earth. And because there is no lunar atmosphere, observations conducted from the Moon's surface would be as good as observations of the cosmos from Earth orbit. The Hubble Space Telescope would lose the bragging rights it now enjoys.

Furthermore, without an atmosphere to scatter sunlight, the Moon's daytime sky is almost as dark as its night, so everybody's favorite stars hover visibly in the sky, right alongside the disk of the Sun. A more pollution-free place has yet to be found.

On second thought, I retract my earlier callous remarks about the Moon. Maybe our neighbor in space will one day become the astronomer's best friend after all.

Neil deGrasse Tyson, an astrophysicist, is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.



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ENDS & MEANS

Can Nature Be Declawed?

Ecofeminists may be substituting one stereotype for another.

By Marlene Zuk

He stood outside the door of the museum, barefoot, very tan, and wearing only a faded pair of cutoffs. He was clutching a large bird to his chest. The bird was barely alive, its eyes shut, its black-and-white feathers moving slightly. "Can you help him?" said the young man, staring hopefully at me. Having finished my undergraduate degree, I was working in the vertebrate zoology research museum at the University of California, Santa Barbara, and such requests were not uncommon. Sometimes we took care of injured birds in the museum until they were ready to fly away.

Not this time, however. I pointed out that the bird, which I identified as a common loon, was too far gone to be helped but that I'd be happy to take it for the museum's collection. Stuffed birds were used both as research specimens and for teaching. By painstakingly examining taxidermy mounts during my vertebrate zoology course, I had learned how to identify many of the local species; I was now learning how to prepare specimens myself, and fresh material was always welcome.

The young man was horrified. How could I be so callous when the poor creature was still alive? While we were arguing, the loon died in his arms. After a little more persuasion, he agreed to donate the bird to our collection, and I started the paperwork. Skins are always more valuable if information about their collection is kept with the specimen, so I noted the date, the place on the beach where it had been found,

and then asked the man his name.

"Wing Bamboo," he said.

I paused. It was southern California, it was the 1970s, and while people named Rainbow and Runningwater were commonplace in the food co-op, you usually didn't see them in the museum, donating dead birds. Should I write "Bamboo, Wing"? "W. Bamboo"? Was it all one word? In the end, I wrote it down just as he'd said it, and told him to put the bird on the table. He gazed at it and put it down, but only after clutching it a little tighter and intoning, "Goodbye, brother loon."

Since then, I have thought about the encounter several times. Wing Bamboo, like many people, wanted to use an emotional connection with animals to forge an ideological link with nature. One recent such impulse comes from the ecofeminist movement, which connects two goals: ending inequality between the sexes and solving environmental problems by changing the human relationship to the natural world. It rose to prominence in the 1980s, associated with animal rights and radical environmental movements in the United States and Europe. As both a feminist and a champion of environmental causes, I was

predisposed to like the merging of the two. But invoking examples from the natural world in the service of a cause, no matter how worthy, is at best a risky venture. My own experience studying animals has led me to believe that such "nature-based" ideologies are likely to be seriously out of sync with the realities of nature itself.

One version of ecofeminism holds that women have more "connections to the primal," as Mary Morse, author of *Women Changing Science*, puts it. This belief is not new, of course. Because of their reproductive and caregiving functions, women have been traditionally regarded as less cerebral and more physical, and therefore more "natural," than men. But instead of rejecting this viewpoint (with its denigrating implication that women are incapable of detached analysis), eco-



feminism embraces the idea of the emotional, spiritual female who, by virtue of her gender, is better equipped than a man to attain a deep understanding of the earth. A related idea (also far from new) is that women are naturally more peace loving and less aggressive than men and are therefore better suited for making the world more compassionate. The popular formulation of this view is that if women ran the world, wars would end, gun control would be unnecessary, and we would all cooperate to achieve common goals for the good of society.

I hasten to point out that many (perhaps most) feminists are as uneasy as I am about the idea that women can save the planet simply by virtue of being women, or that if women are not inferior to men, they must be superior to them. Along with other scientists, I am particularly skeptical about the claim that female humans have a less aggressive nature than males, enabling us to empathize with other organisms. Presumably, this compassion is part of human nature, and we share it with other animals—where else, after all, could it have come from? But is there anything wrong with this idea? If we look at other species in the animal kingdom, can we conclude that the idea of the gentler female is well founded?

Take, for starters, a bird known as the great reed warbler. Migrating each spring from Africa to Europe, this species settles in reed beds of lakes to breed. The male may attract more than one female to settle on his territory. If this happens, he allocates his help with the offspring according to a first-come, first-served principle: the first, or primary, female he mates with gets a greater share of fatherly aid in the form of fetching insects for the babies. So life is good for primary females—unless they lose their clutch of eggs to a predator or to some other disaster, in which case the male turns his attention to other females on his territory. While

studying these birds, Swedish ecologists Bengt Hansson, Staffan Bensch, and Dennis Hasselquist, of Lund University, noticed something peculiar: primary females were three times more likely to lose their eggs to predators than were secondary females. To find out why, the scientists performed an ingenious experiment. They placed plasticine eggs in artificial nests in the warblers' territories and compared the marks left in the claylike surfaces with marks

Invoking examples from the natural world in the service of a cause, no matter how worthy, is at best a risky venture.

made by known species of birds and mammals. From the distinctive nibbles on the fake eggs, Hansson and his colleagues deduced that the embryos of primary females in each territory were being destroyed, not by prowling rats or snakes, but by other reed warblers—specifically, by secondary females in the same territory. This behavior on the part of secondary females increased the likelihood that they would gain more male parental care and thus improve the survival odds for their own chicks. In Darwinian terms, it makes perfect sense, yet avian infanticide is hardly an example of pacifism (or sisterhood) among females.

Such cases of female competition and aggression have been noted in many birds and other vertebrates. Even that classic symbol of cheery optimism, the bluebird, turns out to have a dark side. Ecologist Patricia Adair Gowaty, studying eastern bluebirds in the southeastern United States, found that females were so aggressive they sometimes fought to the death (see "Bluebird Belligerence," June 1985). Bluebirds build nests in holes that form in dead tree stumps. In nature, Gowaty pointed out, such nest sites are quite limited, and it is therefore logical that females battle fiercely over them. She was taken aback when her discovery was deemed

so sensational that it appeared in "Ripley's Believe It or Not!," an illustrated feature usually reserved for two-headed calves and 500-pound balls of string. Presumably, the bluebird finding was deemed extraordinary because reality did not conform to the stereotype—killer bluebirds were bad enough, but female killer bluebirds were the stuff of nightmares.

Females and males compete over the same things: resources that make it more likely an individual's genes will be passed on to the next generation. Sometimes, in this competition, a given female

will do better if females around her cannot reproduce. In the case of dwarf mongooses and a variety of other mammals, including some primates such as marmosets, dominant females exert so much control over the lives of subordinates that the subordinates become physically incapable of producing offspring, their estrous cycles stilled. From an evolutionary standpoint, this is indeed a fate worse than death.

The champion practitioners of female brutality, however, come from the species in which females rule in a monarchy so absolute that insubordination is seldom tolerated. I am talking about the social insects, among which females comprise the vast majority of individuals in the colony, and males play a small but crucial role by fertilizing the next generation of queens. Strife appears at several levels: In honeybees, the first queen to emerge from her pupal cell may kill the others as they lie in their virginal wax chambers. Or the female workers may indirectly rebel against the queen's reproductive tyranny by manipulating the number of males or females they rear in the hive. In many species of wasps, females battle fiercely for superiority when a colony is founded. These battles—resulting in limbs lost, antennae torn from their sockets, wings shredded

by mandibles—are among the most vicious in the animal kingdom.

Another notion common among ecofeminists is that thousands of years ago our species lived in benevolent societies that worshiped female deities, venerated female qualities, and were closely in tune with the natural world. According to this view, only when male-dominated, Judeo-Christian philosophy took over did humanity begin to be divorced from the earth. (This idea gets involved with another feminist issue, body image, since some of the support for such a scenario comes from comfortingly plump, Stone Age female figurines that supposedly represent the good old days before we had to worry about cellulite and tight jeans.)

As numerous anthropologists have argued, considerable doubt exists about the reality of a sexually egalitarian past. But why search for a model of female-dominated society in primordial communities? Nature provides us with several examples of female-dominated societies in the here and now, and I for one would not want to live in any of them. A land of milk and honey—at least the honey part—seems to come at the expense of having your head ripped off by another female.

Of course, we hardly need to model a female-friendly world after the behavior of wasps or honeybees. But that is precisely my point: looking for support in nature for cooperative, loving females is just as foolish as looking for support for an animal equivalent of Ozzie and Harriet. Although it is good to debunk the myth of the passive female, and good to look for positive images of women in nature and art, substituting one stereotype for another will only defeat the feminist goal of equality and, what is worse, can prevent us from learning about what animals really do.

But as numerous psychologists have noted, people like to divide the world into opposites. And nowhere is the us-versus-them litany as pervasive as in

comparisons between males and females. Males are aggressive, females are passive; males are exploratory, females are nest builders and caregivers. The first problem with such categorizations is that “male” attributes are too often the ones deemed necessary for worldly success. This division has been bad for women, because it associates them with characteristics not held in high esteem. Thus women are tempted either to counterclaim that they, too, are warriors and explorers or to keep the dualism intact by celebrating the very qualities that were denigrated (a goddess-woman rejoices in her earthy nature).

But the dualism itself is flawed. Yes, selection has acted differently on males and females of all animal species. The behaviors that benefit your average female wasp are different from those that benefit the average male

Even that classic symbol of cheery optimism, the bluebird, turns out to have a dark side: killer females.

wasp, and the same holds for bluebirds or pipefish. I, like many other scientists, have made a living out of exploring those differences, and I have no doubt that they are there, manifested in different ways under different circumstances. Gender-related selection often means that the sexes are in conflict, and that males and females compete not only among themselves but with each other. But it does not mean that the differences are fixed, with males and females of every species possessing the same extreme values for masculine and feminine characteristics. We should debunk the stereotype of the passive female not because aggressive female bluebirds are more our style but because it is wrong and because it prevents us from acknowledging that female bluebirds fight.

Some feminists believe that science itself is a fundamentally flawed undertaking because it is founded on anti-

female, antinature attitudes that emphasize domination and objectivity at the expense of harmony. The scientific revolution of the modern era thus paved the way for what Mary Mellor, a prominent ecofeminist author, calls “a disenchantment of Nature.” The question of whether science has separated us too much from the natural world emerged with the nineteenth-century Romantics, and this separation or lack of it affects how we think both about other organisms and about science as a way of knowing. Mary Morse states flatly that science “sanctions domination of both nature and women,” a view echoed by writers such as Carolyn Merchant, one of the founders of modern ecofeminism. Even the prominent MIT science historian Evelyn Fox Keller has drawn parallels between what she characterizes as the controlling behavior of scientists and such mental diseases as paranoia and obsessive-compulsive disorder. While hardly consigning all scientists to the psychiatrist’s couch, Keller does suggest that “a science that promises power and the exercise of dominion over nature selects for those individuals for whom power and control are central concerns. And a science that conceives of the pursuit of knowledge as an adversarial process selects for those who tend to feel themselves in adversarial relation to their natural environment.” Or to use the trendier term, we scientists are all “control freaks.”

As a scientist, and particularly as one who studies animal behavior, I find almost touching the faith that nonscientists have in my ability to control and predict natural phenomena. Let me tell you a secret: it’s a mess out there, with “out there” being the natural world we are all supposed to be trying to keep under our thumbs. The suggestion that we control nature contains the implicit assumption that we already understand

it, an assumption that becomes more and more wildly incorrect the longer we work on natural systems. It is not that we never learn anything; it is just that finding one small piece of the puzzle invariably suggests other puzzles, each with thousands of pieces lying in their own boxes underneath the one we are working on at the moment. Most of the scientists I know find the world more complex than nonscientists do. If you do not really look at something, it is easy to oversimplify it.

This is why Mellor's concern with disenchanted nature is so puzzling to me. Why should close observation and asking questions about how something works rob that thing of its vibrancy or its capacity to inspire awe? Nature is much more enchanting to me now than it was when I knew less about it.

Carolyn Merchant's suggested alternative to a science-dominated society is a "partnership ethic that treats humans (including male partners and female partners) as equals in personal, household, and political relations and humans as equal partners with (rather than controlled-by or dominant-over) nonhuman nature." This sounds fine, but for myself, I wouldn't recommend entering a partnership with someone I knew only slightly. I doubt that any self-respecting ecofeminist would think of sharing a household with a perfect stranger or of starting a business or raising a child with one. What kind of partnership can we have with creatures we know little about? And how can we get to know them if scientific study is rejected as a controlling patriarchy? If we simply rely on feelings of connection with animals but don't know how they breathe or reproduce or find food, we have learned more about ourselves than about them.

The risk of rejecting the study of nature is that we will idealize it. If we mythologize animals (not to mention plants, protozoa, and bacteria), we will have merely put a new twist on the eighteenth-century, Rousseauesque

idea of the "noble savage," a concept that idealized every member of *Homo sapiens* unexposed to the corrupting influences of civilization. If nature is automatically pure and good, what to make of predation? What to make of langurs that kill their young, of the cute little squirrel that is transformed into

*We need to talk not simply
about our relationship to nature
but about nature itself.*

hawk flesh? If we are not supposed to dominate nature or one another, what of domination within nature?

However reluctantly, most of us recognize that wolves, too, must eat, and sometimes they must eat Bambi. The wolf slitting the throat of a deer is at least reasonably quick about it. Predation may seem unpleasant but is sometimes a necessity. But it gets worse: what to do about parasitoids?

Parasitoids are both parasites and free-living predators; they spend part of their lives inside another animal and part on their own. Some of my research concerns one of these, a minuscule fly that hears a male cricket calling to attract a female and homes in on him. The fly then deposits sticky little larvae on and around the male. In minutes, one or a few will bore a hole through the outer skeleton into the cricket's body. The larvae feed and grow until, after about a week, two or three maggots may occupy the entire body cavity. From the outside, it looks like a cricket, walks like a cricket, and—until the end is quite near—even talks like a cricket, able to produce the deceptively cheerful chirps that signal summer. Except for this brittle shell, however, almost all the cricket flesh has been converted into fly. Finally, the larvae have grown enough to shatter a hole in the side of the still-living host, burst through, and dig into the soil, where they pupate and eventually emerge as adult flies. Only then, when it is no longer useful to its para-

site, does the cricket host die (see "Overhearing Cricket Love Songs," by Daniel Robert and Ronald R. Hoy, June 1994).

I have dissected hundreds of crickets over the past several years, and when I discover a maggot, white and pulsating, I am always shocked and amazed.

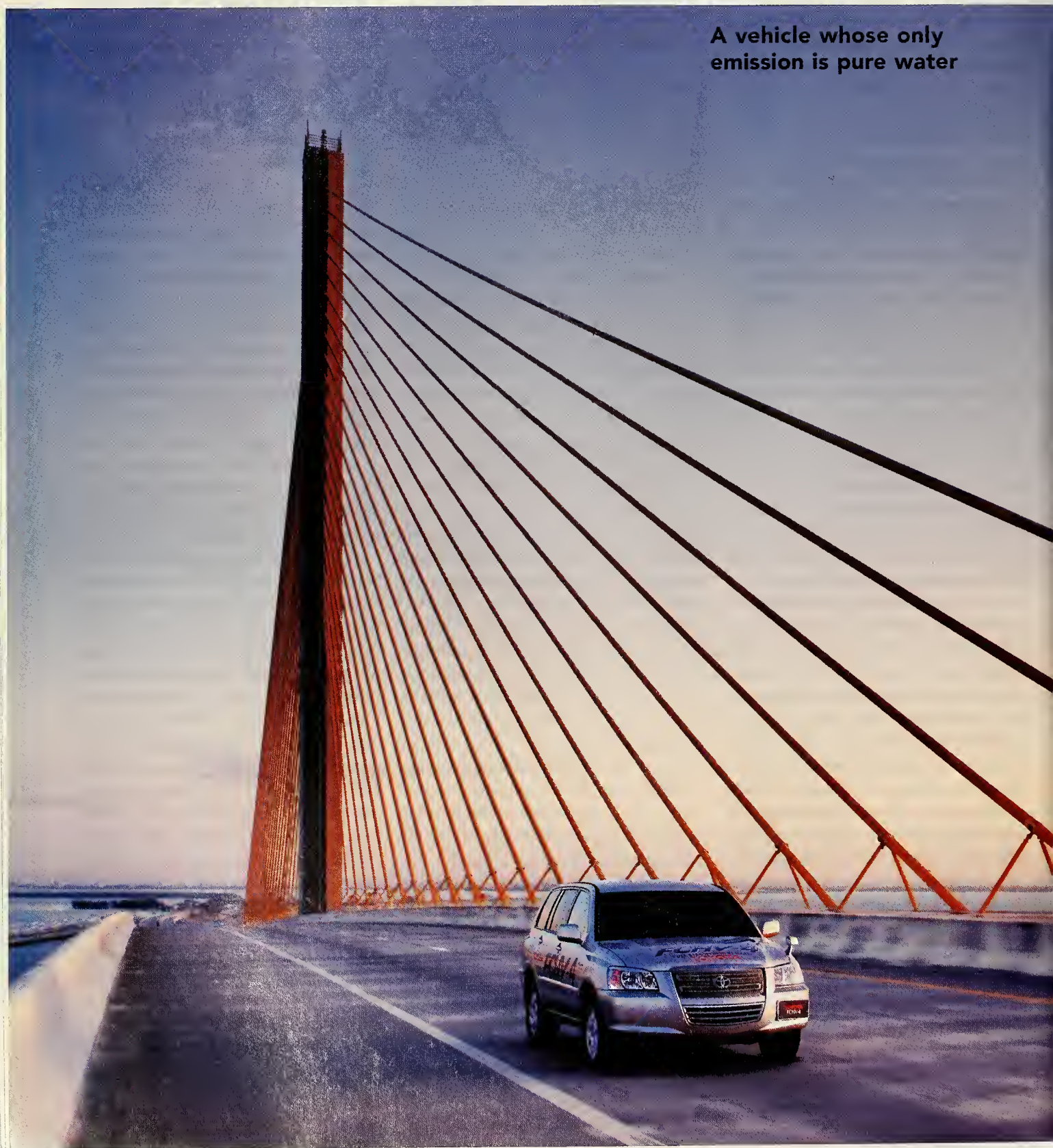
When I lecture on this research, I tell audiences that everyone, scientists and non-scientists alike, should open up an insect and see a parasitoid at least once in their lives. The audience always laughs, but I am not entirely joking. It is worth seeing something horrific because it forces you to reexamine that warm, fuzzy feeling about nature. I am not suggesting that we eschew Romanticism only to make up some equally self-serving story about cruelty and the law of the jungle. Nature is no more inherently evil than it is inherently good. I just want to make sure that while we discuss our relationship with nature, as feminists or as anything else, we actually talk about nature itself and not simply about the relationship.

In the ecofeminist anthology *Reweaving the World*, Brian Swimme writes, "My own hope is that what is happening in our time is the emergence of the common myth necessary for us to feel and act as kin to everything." This is well and good, except that it takes us back to Wing Bamboo and his kinship with the loon. What does it mean to feel and act as kin? At best the statement is vague, at worst misleading. It tells us something, perhaps, about Wing Bamboo. But it says nothing about the loon.

Marlene Zuk is a professor of biology at the University of California, Riverside. This essay is adapted with permission from her most recent book, Sexual Selections: What We Can and Can't Learn About Sex From Animals, published by the University of California Press. © 2002 The Regents of the University of California.

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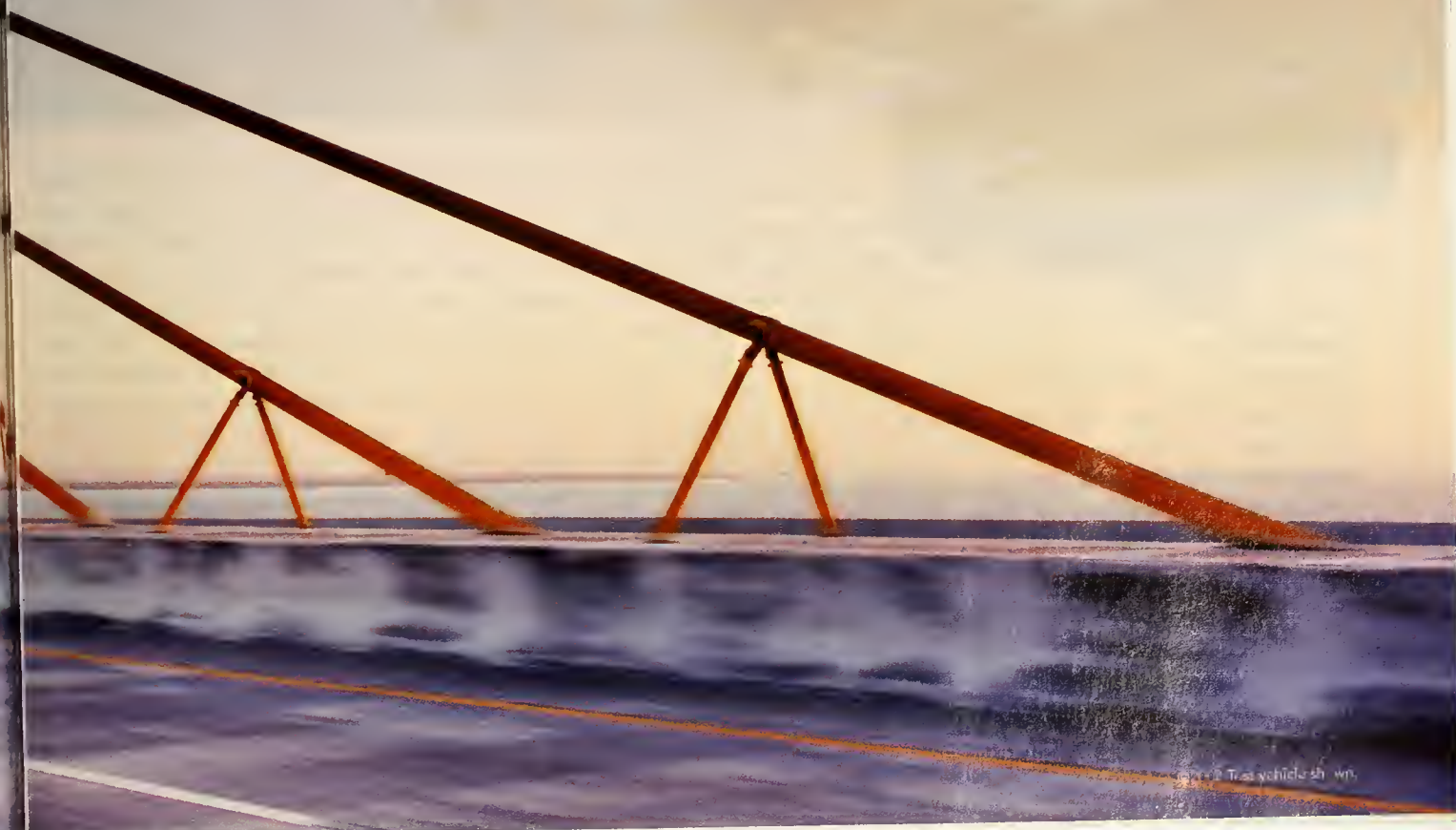
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Plains Song

Bison and life on the "American Serengeti"

By Dale F. Lott

After decades of field observation, zoologist Dale F. Lott turned to literary portraiture to capture what he had seen. What follows are sketches from Lott's *American Bison*, a book that captures far more of the natural and cultural history of the bison and of the Great Plains than one would find in a purely scientific monograph. Ranging over the animal's life and death, as well as its neighbors and its protectors, these sketches address the overarching question that

Lott says has always driven his work: *How do bison get on in the world?*—THE EDITORS



A prehistoric North American bison effigy of unknown provenance. Plains tribes probably began hunting buffalo around A.D. 1300, perhaps prompting the creation of such objects.

Bison Athletics

I'm watching a mature, one-ton bull standing alone on a dirt road on the National Bison Range. He's the only buffalo around, and I have set up my movie camera, so I'm watching him through the viewfinder—finger on the shutter button—wishing, as a man with a movie camera will, that the subject would do something footage-worthy. He stands broadside to the road's line of travel, his front feet at the bottom of the cutbank where the road is in a trough sliced through a low hill to ease the

WILLIAM J. HAYS; AMON CARTER MUSEUM, FORT WORTH



grade. His right horn slips into the earth and cuts a horizontal groove. He glances up to the top of the slope six feet above the road, makes a second groove with his left horn, glances up again—and without seeming to gather himself—leaps to the top of the cutbank, lands upright on all four feet, and calmly surveys his new view. My finger is still on the shutter button, and I still haven't pressed it.

Social Relations

Bulls test the urine of cows, seeking the ones about to enter estrus. When they find one, they are likely to try to spend the next few hours with her. That's not easy to do. Pre-estrous cows become restless—breaking away from a tending bull and running through the herd. A running cow attracts bulls, and a string of them are soon following her, just as a tail follows its comet. When she stops, they gather and



quickly sort out who among the present company gets to stand by his cow.

Most fights involve hooking uppercuts or a cautious locking of horns or shoving head to head, ending when one animal signals submission and the winner lets him go. But not always. This time the bulls hurl themselves at each other, elongating their bulky bodies into animated battering rams as they launch themselves for the first blow. Their heads come together with a terrific shock. It ripples through their bodies in a visible wave. I once saw a bull somersaulted backward by such a charge: 2,000 pounds of bull flipped upside down like a lawn chair in a gust of wind.

The bulls lock horns and push hard, their hooves plowing soil as each tries to drive his opponent back. The old bull is pushed backward

and a little sideways, dust spurting from beneath his skidding feet. Suddenly a foot catches on a rock and he trips and falls onto his side. The younger bull strikes down and forward with his horns, slamming them into the old bull's flank and hooking right and left. The curves of his horns make most of the contact and deliver bruising, possibly rib-breaking, but not fatal, blows. Then the tip of one horn plunges through skin and muscle and into his opponent's abdomen. Only one horn penetrates, and it penetrates only once, but the wound will be mortal.

The younger bull ends his attack and returns to his cow. In a few minutes the old bull will rise to walk away. He will graze again, drink again, sleep again. But an infection will send matter oozing down his ribs in a few days, and in a few weeks it will kill him.

A stampede stretches to the horizon in a lithograph done in 1862, when millions of bison still roamed North America. Twenty years later, only about a thousand remained here.

Adapted from American Bison: A Natural History, by Dale F. Lott, published by the University of California Press. Copyright © 2002 The Regents of the University of California.

Youth

On the National Bison Range, calves are born in April and May. The snow has melted and the earth is warming. The vibrant green of new grass growth is eclipsing the browns of the grasses dried over the winter. The golden yellow of arrowleaf balsamroot and the purple of lupine contrast intensely with the new grass. I have watched dozens of calves emerge into this idyllic world. It's a setting to encourage relaxation, even lassitude—I feel it, but the calves don't seem to. Take the one I'm watching just now. Within a minute or two, as soon as his mother has freed him from the membrane that surrounded him in the womb, he begins a frantic struggle to get to his feet. He gets halfway up several times and falls forward, backward, and sideways. I think, "Take it easy, little one, rest a minute. There's no rush." But the brain that has guided calves to adulthood for thousands of generations knows better. The calf hasn't got a minute to spare. Wolves may arrive any second. A late winter storm could drop six inches of snow tonight, and winter returns in a few months.

An hour-old calf can scamper pretty well. This is

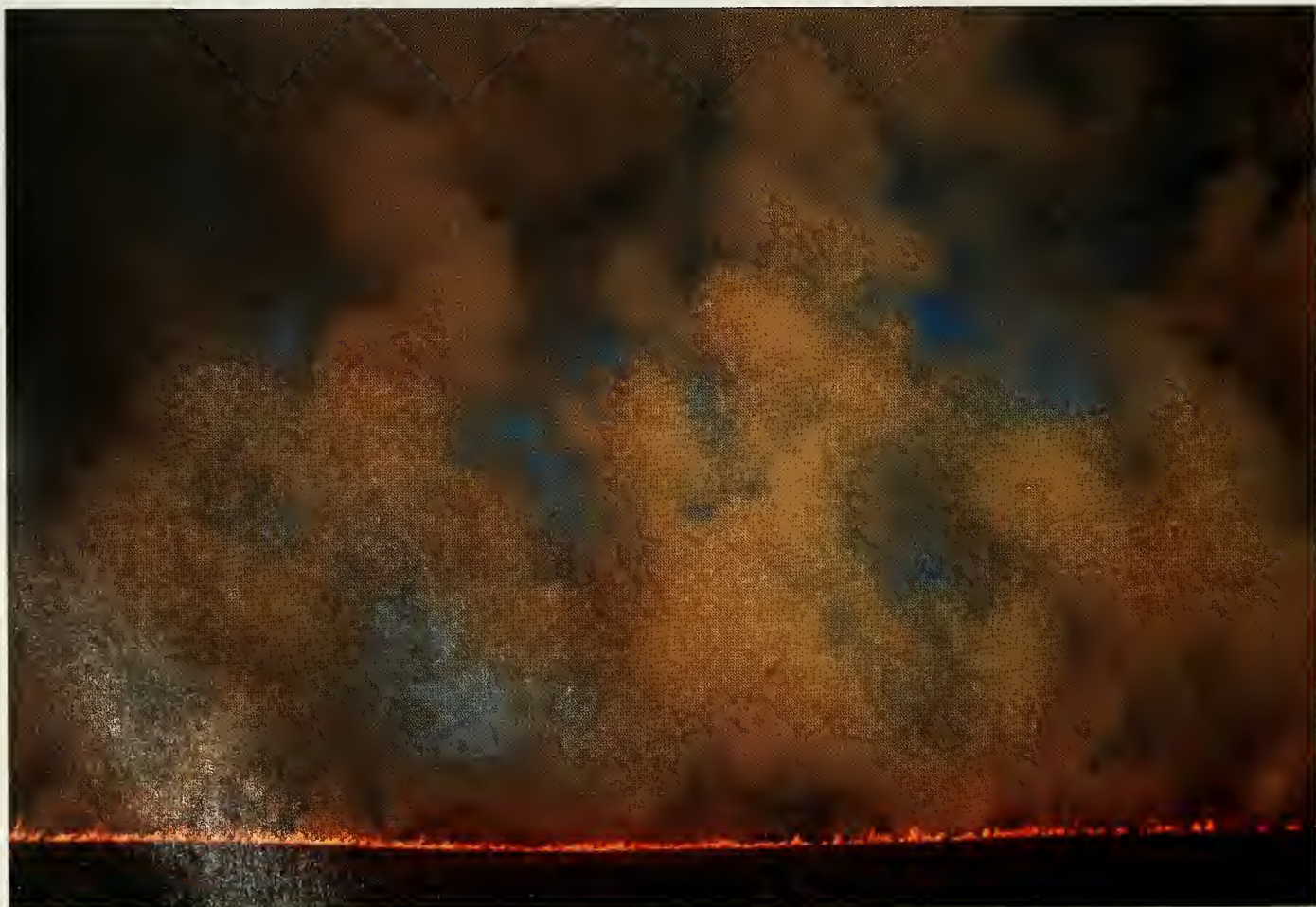
a wonderful adaptation to being born in plain sight on a prairie with wolves about, but it makes the calf a challenge to keep in touch with—like a ball that never stops bouncing.

The bouncing baby bison doesn't bounce aimlessly. It bounces toward something big and close. Mom is big and close, and the ball usually bounces her way. But sometimes it fixes its eye on some other bison that passes by and rushes after it. Then mother chases both of them down and retrieves her young. A calf a few months old that loses its mother will attach itself to anything large and moving. An orphan calf followed Captain Meriwether Lewis one afternoon as he walked west beside the Missouri River.

The Neighborhood

Ah, family! With all its idealized connotations of safety, nurturing, tenderness, altruism, loyalty, and love, the very word warms us and so warms our feelings toward the wolf. Wild dogs, especially the big wild dogs, are famously family oriented, and wolves are no exception. Hunting parties are made up of families collaborating in the hunt, sharing in

Prairie fires—whether caused by lightning or hunters—burn quickly across a sea of grass, bringing new growth and, in the past, attracting bison.



JIM BRANDENBURG, KINDEN PICTURES

the kill, and, if the pack has pups at home, carrying food to them in their stomachs. Family is valuable and so is valued. Among dogs, the family that preys together stays together. Still, wolf social life little resembles the American dream family. Idealized American family life is about happiness. Wolf family life is about survival and reproduction. In most circumstances, each family stakes out and defends dozens of square miles to hunt in. Trespassing wolves will be challenged, pursued, perhaps killed.

There *are* affectionate greetings and nudging and grooming among pack members; they even share food. But life within the pack is intensely, even relentlessly, structured, and all attempts to deviate from the established order are punished severely. Relationships are adjusted through physical, sometimes deadly, force. It puzzles me a bit that we

I once saw 2,000 pounds of bull flipped upside down like a lawn chair by a gust of wind.

nature-loving Americans, who for the most part treasure political equality, have such affection for an animal whose social organization is basically a cruel despotism. There's no equality among wolves. One member of each dyad will be the tyrant, and the other will be the tyrannized.

No human has ever seen a ferret at work in a burrow that a prairie dog dug. What we can see only in our imaginations must also take place in the prairie dog's nightmares. Is the dog awakened in its pitch-black burrow by a presence—sound? smell?—and if so, is it ready to resist or escape? Or is it taken in its sleep? In either case, the unseen presence finds the prairie dog's throat and opens it. The dog's body, denied breath and blood, quickly becomes a meal, to be eaten on the spot. Or perhaps it is dragged out under the prairie night sky to a nearby ferret burrow, where two or three young nightmares wait to be fed.

The Four Elements

On the Great Plains, they say, trees lean east and people lean west. Wind tilts every aspect of Great Plains weather. Spinning winds become tornadoes. Vertical winds pile up thunderheads. These negatively charged clouds may connect to earth via fire-starting lightning and may release either hail or refreshing rain. Winter winds blow snowflakes



A black-footed ferret, left. This predator stalks black-tailed prairie dogs in their burrows, below.



sideways for miles, making the world ten feet away invisible at high noon in a blizzard. Cattle, descended from wild stock native to warmer, calmer climes, turn their backs on this onslaught and drift until a fence or another barrier stops them. There they remain imprisoned until either they or the winds die.

An individual buffalo is affected little by these kinds of winds. Yet to bison as a species, winds made a big difference. Warm chinook winds from over the mountains to the west created the first open pastures as winter waned. But the most important wind for bison was one they never felt: the polar jet stream. This jet stream marks the northern limit to warm, moist air pushed north from the Gulf of Mexico by Bermuda highs, and it sometimes creates low-pressure, storm-inducing areas.

In the past, when warm, wet air from the Gulf of Mexico saturated the plains, grass grew abun-



JIM BRANDREURG; MINDEN PICTURES

In 1923, the tallgrass prairie of what is now South Dakota's Wind Cave National Park, above, became a refuge for bison.

dantly, bison ate heartily, and the populations rose. But sometimes for a year or so the jet stream was well to the south, bringing dry air over the plains. Every five to ten years, eastern Montana endured (as it does today) fifty or more consecutive days in the growing season without rain. The grass would retrain; the bison dependent on it would suffer.

It seems hard. For each buffalo the shift in weather meant hunger, less chance of reproducing, more chance of dying. For the bison as a species, it meant a shrinking population. But the dry years were what kept the prairie a grassland. If every year were wet, trees would grow, the grass would go, and the bison would follow. That's not to say that those who suffered in the droughts did so for the greater good of bisonhood; they were just unlucky. But their bad luck was an inescapable part of the boom-and-bust cycle of all temperate grasslands. And it's the bust part of that cycle that ensured that the minerals from their bones nourished a grassland covered with living bison and not a woodland haunted by their ghosts.

The wind-rippled grassland whose surface undulates from horizon to horizon strongly evokes a sea, but it's a sea that can burn. For millions of

years, lightning alone caused the fires. But several thousand years ago, people began to burn the prairie—often with buffalo in mind. Sometimes they used the flames to drive the bison someplace for easier and safer killing by people on foot. Sometimes they burned the grass so that new growth would attract bison to a more convenient killing place.

Fire interacts with grazing. In the mixed-grass prairie, the grass known as little bluestem presents grazers with an in-your-face defense: stiff tillers, or stalks, that a grazer must push through to get to the green leaves. Bison avoid little bluestem with tillers, but fire removes these stalks. Bison graze the new-growing little bluestem as readily as they do other grasses. The fire that consumed little bluestem's defenses thus helped this grass's competitors, through the mechanism of bison grazing. The grasslands are as much creatures of the grazers as the grazers are creatures of the grasslands.

Bison affect the composition of plants on the plains in two ways. First, they wander. When they had the whole prairie to wander over, particular patches of grass probably had two-year rests fairly regularly, especially because bison chose areas where grasses were growing most vigorously. When the tallgrass canopy is grazed off, sunlight reaches the earth and the shorter plants do better.

There's no equality among wolves. In every pair, one is the tyrant, the other the tyrannized.

There are fewer individuals of more species after grazing—just as after fire. But grazing-stimulated growth in the western short grasses tends to eclipse other, smaller plants. Grazed short-grass prairie has more individuals of fewer species.

Second, bison don't just take away. They give something back: fertilizer. From a prairie plant's point of view, urine is a bath of nitrogen dissolved in water—the answer to its prayers. The grasses' leaves and stems would have eventually decomposed and returned the nitrogen to the soil, but only after a longer delay and in a form that the plant would spend more energy using. Bison are drawn to the close-clipped, nitrogen-rich grass growing around colonies of black-tailed prairie dogs (which graze the same few square yards every day), and they leave a disproportionate amount of their diges-

tive by-products there, transferring nitrogen from the rest of the prairie soil to prairie dog towns.

Bison don't just graze and eliminate on a prairie; they also wallow. Wallowing probably gets rid of some insects, possibly reduces the bison's heat load, and certainly alters 75 to 150 square feet of habitat for the prairie plants. Wallowing also lays the soil bare and compacts it. The compacted bowl of soil holds rainwater, creating a microenvironment in which seedlings that are otherwise rare in tallgrass prairie—sedges and rushes—can grow. Some of these seeds are blown in by prairie winds; others are carried there in the coats of the wallowing bison—perhaps picked up in another wallow.

The Hunt

Be a bison. A bison cow on the run, adrenaline soaring, heart racing, hooves flying. On the run from what? From whatever the bison all around you are fleeing. Running with the herd has meant safety for thousands of generations.

But not this time. This time the predator is man, and unlike all the other predators, he wants you to notice him before he is beside you, wants you not to lag behind the running herd. This morning, men waved and shouted as they approached the herd and started the cows and young bulls around you running from them, and as you ran with the herd, more men rose to the left and right, guiding the running herd down a funnel of strange sounds and movements. This predator has turned your ancestor's hard-earned knowledge of predators to its own advantage. It has turned your best defense into a deadly weapon. Your escaping will be the death of you.

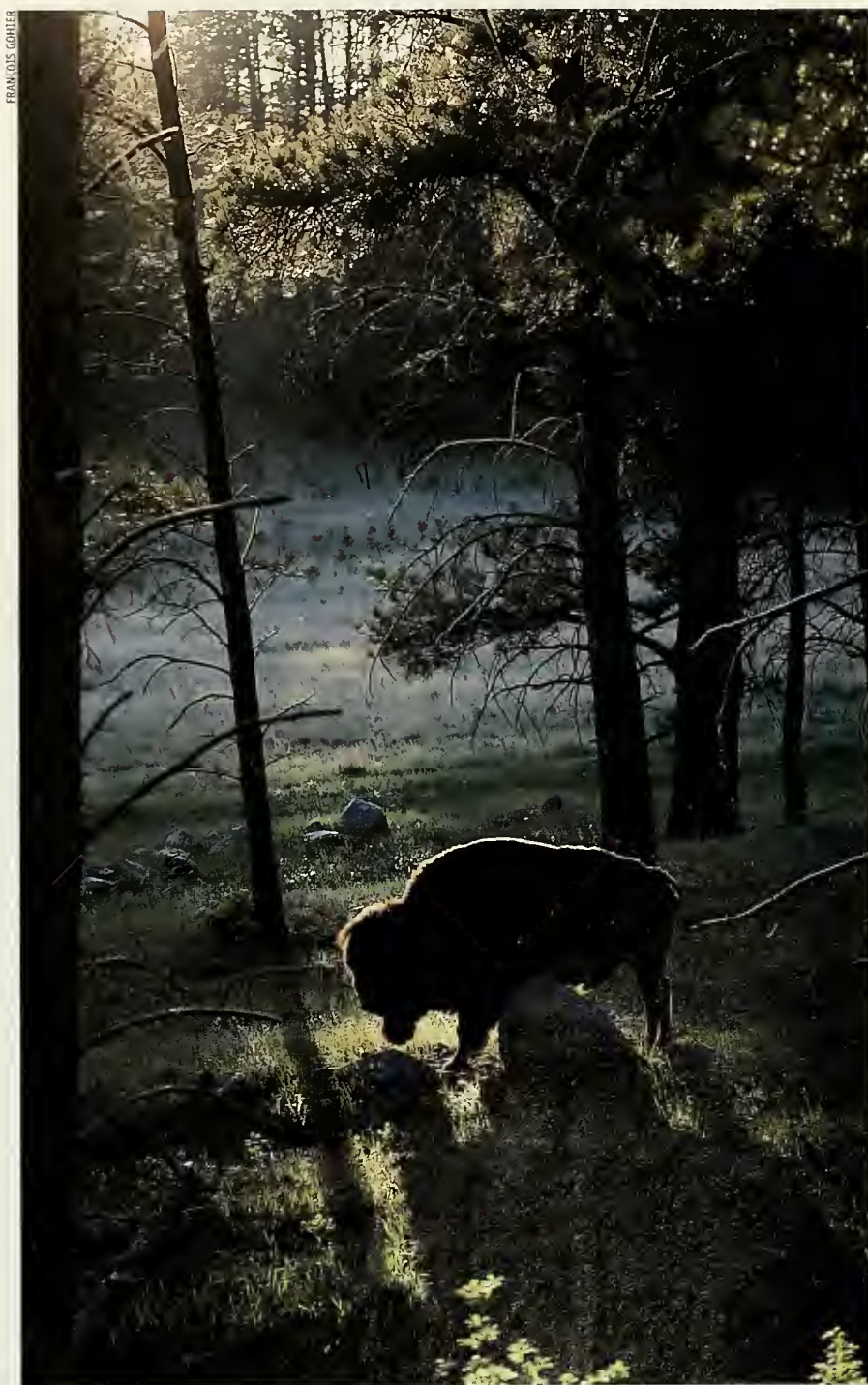
But that's not what your phylogeny whispers, and so you follow the cow in front to. . . Suddenly, where she ran, there is only empty ground, and in a moment, not even that. The plain has ended mid-stride and you are running in space. Your feet flail at the sky as your body tumbles; then your breath is gone and your ribs and spine are breaking as the cow behind you falls on you, the way you fell on the cow in front. Your body becomes part of the maimed mass at the bottom of a cliff.

Bison react to things they can see, hear, or smell that seem dangerous. The stand hunter—so called because he pursued standing bison—nullified smell by coming from downwind. He crawled on his belly and kept his distance. But then he fired his .50-caliber Sharps rifle. A sudden cloud of black smoke rose on the crest of the hill where he lay, fol-

lowed in an instant by a boom that would reach any ear within half a mile.

Nearly every wild thing fears the unknown and flees from it. It's a reasonable rule of thumb. If the unknown thing was not deadly dangerous, you've wasted a bit of time and energy. If it was deadly dangerous, you've saved your life. The possibility of one huge payoff like that justifies a lot of small investments. Call it the lottery principle of predation

Now that the prairie habitat is largely lost, bison live in more marginal habitats, such as the woodlands of Wind Cave National Park.



FRANÇOIS GONIER

prevention. It's sometimes called the life-dinner principle. The predator's dinner is at stake; the prey's life is at stake.

Why, then, did the herd stand for the slaughter? Perhaps because the rifle's report filled the ear too much like a thunderclap. A grazing herd is as indifferent to thunder as it is to the rain that usually follows. They simply graze on, their ears filled with thunderclaps and their coats filling with raindrops. Thunderclaps signaled rain, not death, and maybe that's why, while the rifle boomed, they grazed on. . . and died.

Decline and Fall

Many of North America's buffalo were already gone by the time the notorious hide hunt started on the Great Plains. When Europeans came to North America, bison reached the Atlantic coast

in the Carolinas and lived in every state east of the Mississippi but Connecticut, Rhode Island, New Hampshire, Vermont, and Maine. The openings in the woods where they grazed owed their existence to active management by Native Americans using fire.

There were still some buffalo left in Kentucky when Daniel Boone explored there in the late 1760s. But their numbers were shrinking in the land behind him. This eastern population withered and vanished under pressures familiar to wildlife biologists today: a combination of mortality—hunters of all races killed them for the table—and shrinking habitat. Europe's diseases spread like a great conflagration among the Native Americans, killing many, shattering communities, disrupting their habitat management. Without regular fire, woody plants invaded the meadows, displacing the grass. The

JIM BRANDENBURG; MINDEN PICTURES



combination of more firearms and less fire sent the eastern bison population on a long, slow slide to oblivion. By 1833, a little more than 200 years after the Pilgrims landed, there were no bison left east of

**Imagine your best defense
turned into a deadly weapon.
Escape becomes the death of you.**

the Mississippi. But from the Mississippi River to the Rocky Mountains, from the future El Paso to the future Edmonton, a vast sea of grass was still grazed by millions of bison. The bison, however, were soon to prove finite.

George Catlin, who traveled, wrote about, and painted the plains between 1832 and 1839, proposed a Great Plains park, created by the national

government, where herds of elk and buffalo would be protected in perpetuity. Catlin was writing more than thirty years before Yellowstone became the world's first national park. And he was extolling the beauty of the Great Plains biological community, not the spectacle of geysers, boiling mud, and rivers running in dramatic canyons they had worn through thousands of feet of rock. Catlin was way ahead of his time.

The federal government already owns large short-grass and mixed-grass tracts, and many more of both are for sale. A grassland park in the United States is possible and would not even be difficult to accomplish. We and our prairie heritage deserve, need, and surely will someday have at least one Great Plains National Park. Catlin called for one in the first part of the nineteenth century. Perhaps we can have one early in the twenty-first. □

**Bison shake
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and by a
shrunkened
gene pool.**



The Interpretation

The “expression” of a genome is best understood as a dialogue with an organism’s environment. That dialogue, not the genes alone, determines which ant becomes a queen, which fish becomes a male.



of Genes

By Jennie Dusheck



GARY MESAROS, PHOTO RESEARCHERS, INC.

We sometimes think of the environment as “out there,” a place separate from us, a place we can enter and leave at will. But the environment is, quite simply, the context for all of life; it is what makes us what we are. Plants in dry soil grow deeper roots than those in wet soil. Turtle eggs become male or female depending on temperature. A fish may become female in one social environment, male in another. Genes not only direct, they also take orders. In a sense, our genes are the means by which the environment regulates our development.

Everything about us—from the shape of a toe to the shape of a protein, from the year we enter puberty to the amount of stress hormone we release when another car gets our parking space—is a manifestation of an ongoing conversation between genome and environment. This conversation started billions of years ago, when life began, and goes on every minute of our lives. Yet, strangely, it’s a conversation to which most biologists turned a deaf ear for decades, starting in the 1940s, when the focus of biological research became overwhelmingly genetic. We’ve all read or been told repeatedly that genes provide a “blueprint” for the body, that genes “program” development, that we are “products of our genes.” A 1996 introductory biology text used by more than half of all college biology majors in the United States asserts: “An organism’s development is largely determined by the genome of [the fertilized egg] and the organization of the cytoplasm of the egg cell.” No mention is made of any influences outside the egg.

How did biologists come to snub so thoroughly one partner in the developmental conversation? The answers lie deep in the political and scientific history of biology. Decades before the advent of genetics in 1900, biologists sought to understand heredity by studying development, the process by

Leopard frogs (*Rana pipiens*) in duckweed. The common herbicide atrazine causes eggs to develop in the testes of male tadpoles of the species, making them incapable of reproducing.



ROUSSET PHOTO LIBRARY

Soviet biologist (and Stalinist ideologue) Trofim Lysenko, above, thought the environment alone shaped an organism. Western scientists held a view just as extreme: their experiments with phenotypically inflexible organisms—fruit flies, below, among others—led them to virtually ignore developmental plasticity in all species.

which organisms take shape from seemingly formless fertilized eggs. Indeed, for the first experimental embryologists, the most obvious place to look for answers to the mysteries of heredity was not deep in the genome—an entity whose existence they barely suspected—but within the environment of the embryo. During the latter half of the nineteenth century, biologists showed, for example, how different color morphs of the same butterfly species resulted from changes in temperature. Others examined the effects of ion or nutrient levels on development or looked at how environmental factors such as temperature could determine sex.

Then, in the early twentieth century, a confluence of discoveries and new technologies turned the attention of most biologists to genetics and physiology. Increasingly, in the West, biologists saw every individual as a self-contained unit whose study could answer virtually every biological question. Developmental biologists focused their attention on laboratory experiments in which the role of the environment was deliberately eliminated.

In the Soviet Union, however, biologist Trofim Lysenko believed that environment determined phenotype—that is, all of an organism's observable attributes, both structural and functional. As a student, Lysenko had been laughed at by geneticists; once he rose to power, he denounced old acquaintances and even mentors. Under Stalin and Lysenko, an entire generation of Soviet geneticists was exiled or murdered. Those who survived fled to Europe or to North or South America.

Biologists in the West recoiled violently from Lysenkoism. Many had lost personal friends in the purge or were themselves expatriate Soviets who had fled. The very idea that the environment influences phenotype became associated with the worst aspects of Stalin's bloodthirsty reign, with Communism, and with left-wing politics in general—but not with science.

In the 1940s and 1950s, a handful of Europeans and Americans attempted to reintroduce environmental considerations into developmental biology but met with little success. The molecular genetics revolution of the 1960s swept up many of the brightest young minds. Throughout the 1960s and

1970s, biologists interested in the effects of environment on development, survival, and reproduction worked primarily in ecology, agriculture, conservation biology, and related fields.

As developmental biologists increasingly focused on how genes “determine” phenotype, they turned to just a handful of “model” organisms that would reproduce rapidly and easily, primarily in the laboratory. Studies of the development of six animals—nematode worms, *Drosophila* fruit flies, zebra fish, African clawed frogs, domestic chickens, and house mice—formed the basis for nearly all we know about the genetics of development in animals. All six share certain traits, such as rapid development and early sexual maturation, that tend to minimize the effects of environment.

The biological focus on mice and fruit flies tended to obscure environmental effects.

Jessica Bolker, an evolutionary developmental biologist at the University of New Hampshire, has argued that biologists, in choosing organisms little affected by the environment, have unwittingly reinforced assumptions about the primacy of genes. All six of these lab organisms give molecular genetics the answer it expects, namely, that genes rigidly program development, independent of the environment of the embryo. As Bolker says, “Most of our models are small and fast and hardwired. . . . And so we think of development as being hardwired.”

But in the past decade biologists have come to realize that development is far from hardwired; instead, organisms show enormous developmental plasticity. Very recently, a new field of study—called ecological developmental biology, or eco-devo—has emerged. Eco-devo examines how developing individuals integrate environmental and genetic information, as well as how this process of integration influences the direction of evolution.

A basic tenet of eco-devo is that individuals with the same genes can turn out differently, depending on the environment in which the embryos find themselves. This plasticity, however, is not a general trait covering everything an organism does and is. Instead, plasticity itself varies across traits and species.

Sonia Sultan, of Wesleyan University in Middletown, Connecticut, has studied plasticity in four closely related species of buckwheat in the genus *Polygonum*. One of the four produced different-size



DAVID SCHARE; PETER ARNOLO, INC.

leaves in response to changes in light intensity, whereas another species did not adapt to light at all. Sultan has also shown that a species that is plastic with respect to one trait, such as leaf size, may show little plasticity with respect to another.

Her four species of buckwheat differed in the magnitude, direction, and timing of plasticity in traits as varied as leaf size, root length and form, and rate of photosynthesis. These differences corresponded roughly to the ecological distribution of the plants. For instance, the generalist species *Polygonum persicaria* was quite plastic. It reproduced well in poor conditions (doubling its leaf tissue in low light, for instance) but did better than the other three species in environments rich in light, water, or nutrients. By contrast, *P. hydropiper*, a more specialized species, showed far less plasticity. In poor, shady conditions it increased leaf tissue very little, and it only slightly increased its reproductive output—as measured by the number and size of its fruits—even in the most resource-rich environments. The species apparently could not take advantage of a bonanza.

Clearly, the environment somehow influences the genetic pathways that guide the development of the phenotype. British biologist C. H. Waddington considered how that might happen. He found that two distinct triggers—one environmental and one genetic—can activate the same molecular pathway during development. In the 1940s he was struck by the fact that ostriches hatch with calluses on their chests and abdomens, in just those places where contact with the ground later abrades the skin. Skin that is rubbed regularly becomes thicker and tougher as skin cells proliferate, as a glance at our heels and toes will confirm. But our own calluses are triggered by the abrasion itself. Waddington suggested that in ostriches, the trigger for making calluses had been transformed from an environmental switch to a genetic one—a process he called “genetic assimilation.”

Such developmental switches can be found anywhere in the network of genes involved in the formation of a trait. Ehab Abouheif, now at the University of Chicago, has demonstrated this idea beautifully in wingless ants. Most ant species have several castes. *Pheidole morrisi* has four: two with wings (queens and males) and two wingless (soldiers and workers). The network of six genes that regulates wing formation in these ants does the same thing in fruit flies (*Drosophila melanogaster*). And the winged ant castes express the six genes controlling wing formation in almost exactly the same way as



fruit flies express them. These genes constitute a sort of gene “cascade,” with one gene coding for a protein that in turn regulates the next gene. In soldiers, the first five genes are expressed normally, just as in the winged queens, but the most downstream gene in the cascade is not. So at the last moment, genetically speaking, the soldier ants shut off wing formation. In the workers, wing formation is interrupted farther upstream in the gene cascade.

Sisters in an anthill are 75 percent genetically identical. But whether they become soldiers, workers, or queens depends not on any differences in their genes, but on a set of environmental switches. At the first switch, the right light and temperature cause the ant embryos to release a burst of juvenile hormone, setting them on the path to becoming queens. Otherwise they become soldiers or workers.

The desert “plague” locust has two environmentally influenced forms. At low population densities the insect is green, with small wings and legs; at higher densities its colors become mottled and brighter, and its appendages larger.



When a species of social wasp attacks red-eyed tree frog eggs, some of the eggs save themselves by hatching prematurely.

Another Silent Spring?

That frogs are disappearing all over the world is hardly news. But that minute amounts of a common herbicide can demasculinize frogs was front-page news for days last spring, thanks to the work of developmental biologist Tyrone Hayes, of the University of California, Berkeley. Atrazine, considered harmless because it breaks down in a few days, is the most commonly used herbicide in the world. Farmers make up for its rapid breakdown by applying it in huge quantities. In the United States alone, farmers spray more than 60 million pounds of it each year, on corn, soybeans, and other crops. Rivers and streams in agricultural areas may contain 100 to 2,300 parts per billion (ppb). The ubiquitous herbicide even falls in rainwater—1 ppb in non-agricultural areas and up to 40 ppb in agricultural areas.

Early laboratory studies showed gross malformations in amphibians exposed to atrazine, but this effect occurred only at concentrations that animals in the wild would rarely encounter. Investigators did not look for subtler effects, so atrazine was declared safe for the environment, and the safe level for drinking water was set at 3 ppb. But Hayes's lab has shown that doses as low as 0.1 ppb turned male *Xenopus laevis* tadpoles into hermaphrodites, with three ovaries and three testes; doses of 1 ppb reduced the size of muscles of the larynx, which frogs depend on to call and attract their mates.

Hayes and his coworkers backed up their lab study with a dramatic field study of leopard frogs (*Rana pipiens*). Starting in California, the biologists drove east across the United States, collecting tadpoles and water samples from Utah to Illinois. The wild frogs were being hit even harder than their lab cousins: nearly fully formed eggs containing large amounts of yolk were found in the testes of male tadpoles. (Normally, eggs do not develop in tadpoles of either sex.) And the more atrazine in the water, says Hayes, the worse the malformation.

How can a chemical manufactured to kill plants by interfering with photosynthesis have such profound effects on animals? Atrazine is a potent endocrine disrupter because it boosts levels of an enzyme that normally transforms testosterone into estrogen. The result in male tadpoles is dramatically reduced testosterone levels and elevated estrogen levels, an effect Hayes and his colleagues measured in both *R. pipiens* and *X. laevis*.

Biologists have known for years that amphibian numbers are dropping precipitously, with populations winking out one by one. Yet no single cause seemed to explain more than a few regional declines. Hayes's work suggests a major contributing factor in the eighty countries that use atrazine. Beyond that, his work suggests the importance, when evaluating potentially harmful molecules, of looking at the internal morphology of developing embryos. Endocrine disrupters may be capable of destroying entire populations and species, but such compounds will not necessarily reveal their effects through extra legs or other malformations obvious to a layperson.

At a second switch, a protein-rich diet can trigger another pulse of juvenile hormone, turning the embryos into soldiers; on a poorer diet, they become workers. Both switches operate by means of a hormone, but the triggers that throw the switch—food, temperature, and light—are purely environmental.

In three other ant species, Abouheif found, wing formation was interrupted at a different point in every caste. He concludes that although the network of genes for wing formation is evolutionarily stable—conserved in various insects over some 300 million years—ants can turn off wing formation anywhere in the network. Making wings is a conservative process, but not making them is a flexible one. Abouheif hypothesizes that such evolutionary flexibility may be a general characteristic of organisms that have more than one form.

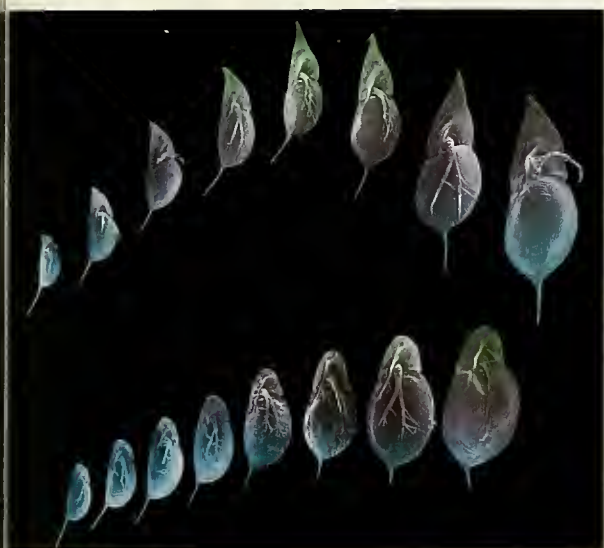
The idea that traits can be controlled by multiple triggers, both endogenous (originating within the organism) and exogenous (originating outside it), is generalizable and useful. The more medical investigators understand the triggers that instruct juvenile brain cells to multiply and form healthy new brain tissue, for example, the more success they may have turning on this activity in adults

*Without symbiotic bacteria,
neither mice nor squid
nor humans develop normally.*

whose brains have been damaged (ultimately, with a drug that mimics the endogenous trigger). And understanding exogenous triggers in development can help identify which synthetic compounds are likely to wreak havoc on humans and other organisms when released into the environment.

The mechanisms for these triggers will almost certainly lie among the signaling molecules (hormones and neurotransmitters, for instance) that cells use to talk among themselves. Signaling molecules appear to be the means by which an organism converses with its environment, both during early development and throughout life. Other molecules called “heat-shock proteins” also seem to act as switches that can decrease or increase plasticity, especially when an organism is under stress.

As we have seen, signals from the environment can be physical: temperature, light, pressure, abrasion. They can also be molecular (when, for example, a compound that mimics a hormone alters gene expression) or social. Social milieus can in-



CHRISTIAN LAPORSCH; PHOTO RESEARCHERS INC.

nate the squid's body so that it does not appear to predators as a conspicuous dark silhouette against the brightly lit surface of the ocean.

The immature light organs of a young squid develop a field of ciliated cells, which help draw *Vibrio* in from ocean water, as well as a series of deep pockets, or crypts, in which these bacteria will live. Within just a few hours, the new arrivals induce the cells of the light organs to swell and to grow tiny, hairlike microvilli. These changes help the bacteria flourish within the light organs. Young squid raised experimentally in water without *Vibrio* don't receive the right molecular signals and thus fail to go through normal development.

Invertebrates aren't the only organisms to have coevolved with bacteria. Mammals and other vertebrates are walking ecosystems. We humans normally carry hundreds of kinds of bacteria in our mouths alone. And these symbiotic organisms are not merely the inevitable result of living in a microbe-ridden world. Colonizing the body soon after birth, they are in fact essential for normal development, as has been shown in laboratory studies of mice raised in sterile environments. Development of nearly all the major organ systems is aberrant in these "germ-free" mice, says McFall-Ngai. The lining of the intestines, for instance, appears to have evolved to interact with bacteria. A few days before mice are weaned, when bacteria normally first appear in the gut, the intestinal cells cover themselves with a sugar called fucose, on which some symbiotic bacteria can live. If none of the right bacteria show up, the fucose disappears. But if

Left: Predatory midges alter the development of the water flea *Daphnia cucullata*. In the top sequence, a water flea exposed to these predators develops a long, pointed "helmet" and a spiky tail; in the bottom sequence, a water flea grows in the absence of predators.

duce many fish to change from male to female and back again. Take the Japanese goby *Trimma okinauvae*. If the resident male in a group leaves or dies, one of the group's females can become a male. But if a larger male then shows up, the recently remodeled "he" reverts to a "she." Such transformations can take place in as little as four days.

The development of some animals is influenced by predators. A substance released by predatory dragonfly larvae causes wood frog (*Rana sylvatica*) tadpoles to grow smaller than usual and to develop a deeper tail musculature (which seems to enable faster swimming and sharper turns). To effect these changes, the dragonfly larvae need only be in the water; they needn't actually be attacking the tadpoles. Similarly, the tiny water flea (*Daphnia cucullata*) develops a large protective "helmet" when predaceous larvae of the *Chaoborus* fly are present in the water nearby. And *Daphnia* is a predator in its own right, capable of inducing changes in its prey: green algae. Chemicals released by grazing water fleas cause the algae to give up the single-celled life and form colonies.

Relations between symbiotic bacteria and their hosts are another major strand of the eco-devo tapestry. The most detailed work in this area comes from the laboratory of Margaret McFall-Ngai at the University of Hawaii, where biologists study codevelopment in the squid *Euprymna scolopes* and the luminescent bacterium *Vibrio fischeri*. The bacterium guides normal development of the squid's light organs, which illumi-



BOTH PHOTOS BY ERICK GREENE AND ADAM EHMER

As the caterpillar *Nemoria darwiniata* feeds, it adopts the color of its host plant. The white insect, far left, is feeding on the pale flowers of *Ceanothus velutinus*, an evergreen shrub in the buckthorn family; the same caterpillar turns purple-red, left, when it enjoys *Amelanchier alnifolia*, a relative of apples and roses.



DAVID HALL; PHOTO RESEARCHERS, INC.

When a school of scalefin anthias (*Pseudanthias squamipinnis*), above, lacks a male, the dominant female turns into one (mauve fish with yellow flanks). Right: The queen and worker ants shown here are sisters and 75 percent genetically identical. Their obvious differences arise out of differing diets, which lead to a cascade of genetic effects.

the right ones do show up, they induce the gut cells to make more fucose. "The host tissues," writes McFall-Ngai, "are poised for interaction with the symbiont." Germ-free mice, which never encounter their coevolved symbionts, need 30 percent more calories to live than do mice with a full complement of gut bacteria, because vertebrates generally depend on such bacteria to help digest food and even to synthesize vitamins.

One of the best-known examples of how environment can influence development comes from research on endocrine disrupters—molecules in the environment that bind to receptors that normally link to the body's own hormones. Some of these molecules are natural substances, such as the plant estrogens in soy-based baby formula and other soy products. Many others are human made, including the plastic stabilizers in baby bottles, pacifiers, dental sealants, plumbing pipes, and gallon milk jugs, not to mention dispersants used to spread pesticides or to keep the spots off dishes in dishwashers.



MARK ROFFETT; MINDEN PICTURES

Some of the most disturbing news on endocrine disrupters recently emerged from the laboratory of Tyrone Hayes, a developmental endocrinologist at the University of California, Berkeley. Hayes's lab showed that minute amounts of atrazine, a nearly ubiquitous herbicide, can derail reproduction in natural populations of leopard frogs by causing males to make eggs (see "Another Silent Spring?," page 56).

Why is the study of eco-devo blossoming now? One reason is concern over the increasingly obvious effects of endocrine disrupters. Another, say several investigators, is the infectious zeal of developmental biologist Scott Gilbert, who in the past two years added a chapter on eco-devo to his best-selling developmental biology textbook. Gilbert recently published an influential review article in the journal *Developmental Biology* describing and naming the new field, and organized, with Jessica Bolker, a symposium on the subject. Converts to eco-devo, who come from every area of biology, are extraordinarily enthusiastic.

All the enthusiasm in the world wouldn't have sufficed, however, without the major advances in genetics of the past decade. Abouheif's research on developmental switches in wingless ants is a good example of how developmental genetics (including the many studies already done on fruit flies) provided the basis and tools to do eco-devo. The new tools—which include polymerase chain reaction, a technique for multiplying traces of DNA, and microarray analysis, a method for simultaneously studying the expression of tens of thousands of genes—are enabling scientists to ask and answer whole new sets of questions. Many bacteria that live in animals, for instance, cannot be cultured in the lab, and they occur in numbers too low to detect by conventional methods. Only recently, with the advent of microarray analysis, have biologists been able to sample and characterize whole communities of microorganisms, whether in the mouth, the gut, or the soil.

Just as important as the new technologies is an increasing emphasis on cross-disciplinary work. Hayes recalls that when he was in graduate school, biologists knew everything about the genetics of

Xenopus laevis, the African clawed frog, but little about the animal itself. "Everything was so specialized," he says. Now he sees entire fields as tools to ask larger questions: "I used to think of endocrinology as a field, and now I think of it as a tool to

understand something else, to understand biology.”

Ecological developmental biology may lead to fundamental changes in the way biologists think. For example, an assumption of standard evolutionary theory has been that genetic differences rigidly determine the relative success or failure of organisms. But phenotypic plasticity implies a degree of play, or looseness, in selection processes. Biologist Philip Yund, of the University of

Both environmental and genetic triggers can activate the same molecular pathway.

Maine, says that when biologists better understand how environmental information is incorporated into developmental processes, they will have a much more sophisticated understanding of how

selective pressures form the phenotype over evolutionary time.

Hayes points out that leopard frog populations have now been exposed to atrazine for some forty years, long enough for selective forces to have changed their biology. “Effectively, we’ve done a pretty awful experiment,” says Hayes, who speculates that a population of frogs living in a pond with high levels of the herbicide might evolve toward early metamorphosis and delayed sexual maturity. If they can get out of the pond soon enough, he reasons, their gonads could complete development away from the influence of the atrazine. In the future, Hayes will be looking for signs that leopard frogs are evolving in response to this herbicide.

Just as our environment is the context for how we become who we are, we are also the context for the development of other organisms—a conversation of which we are only now becoming fully aware. □

Calluses usually form only when external abrasion turns on the right genes, but ostriches hatch with calluses on their abdomens and chests. Evolution can “genetically assimilate” an environmentally induced trait.





Inca terraced fields on the slopes above Peru's Urubamba River

As we looked out over a vast basin in the southern Peruvian Andes, I asked my host the reason for the terracing I saw all around me. "The field always has to be flat so that the soil will absorb all the water," Eusebio Quispe told me. This was just the sort of straightforward lesson that an anthropologist hopes to learn through ethnographic fieldwork. What about conserving the soil, minimizing erosion? That was another benefit of terracing, Quispe acknowledged, but evidently he considered it secondary, and also obvious. The important point was that in this rugged environment, you cannot irrigate efficiently unless you radically alter the landscape.

I had come to the remote village of Huaynacotas to study its system of irrigation and water management, planning to compare it with others in the same province. Quispe spoke to me in Quechua, the language of the Incas, and although I did not yet realize it, the tradition I would learn about in his village dated back centuries, to the Inca empire and even earlier. But I could already see that the sculpted landscape was very old. The village sits at an elevation of nearly 12,000 feet, in the middle of a mountain bowl that tilts southward, facing out over cliffs that plunge down to the banks of a river far below. The stairways and zigzag footpaths I hiked up on my way to the community were cut into the stone cliffs and mountainsides, clearly in ancient times, and the terracing represented countless generations of hard work.

Huaynacotas has a reputation for being a remarkable place. Although Spanish colonists founded settlements along the river in the lower part of the valley, establishing their haciendas, or agricultural estates, on land taken from nearby

indigenous villages, this community was largely able to resist the takeover of its lands. A visitor in 1704 marveled at how the villagers operated their own gold mine so that they could pay the tribute owed to the Spanish Crown directly, without having to acquire money by selling crops and other goods to outsiders, as most Andean people did. Present-day residents of the lower valley—Spanish-speakers who trace their descent from the original colonists—regard Huaynacotas's inhabitants as purely "Indian," exceptionally tough and proud, and they say that the villagers have maintained many of their Inca traditions up to the present day.

The reputation is well deserved, but the history turns out to be more complicated than this. Huaynacotas is a place where people have struggled to hold on to their indigenous identity and their peasant way of life while maintaining some control over the direction and pace of change, but it is not a backwater relic of the distant past. The villagers are part of the modern world and are comfortable migrating to and dealing with its urban centers. The Quispe family, for example, like nearly all the other households in this village of 1,080, has one foot in Huaynacotas and one in Arequipa, the third largest city in Peru, and the Quispes depend on both ways of life for survival. Two family members live and work in Arequipa; they receive food crops from

PAUL TRAWICK



Scarce but carefully apportioned irrigation water from two alpine springs enables the villagers of Huaynacotas to stretch the maize-growing season to nine months, just enough for their staple crop.

Trickle-Down Theory, Andean Style

Traditional irrigation practices provide a lesson in sharing.

BY PAUL TRAWICK



PAUL TRAVICK

Canal cleaning in Huaynacotas, above and right, is an annual communal affair, a combination of hard work, drinking, feasting, and prayer.



LOREN MCINTYRE

In another Andean community, a woman mounds sod and rocks to divert a flow of irrigation water.

the village to help lower their cost of living and, in turn, send cash remittances back home.

Nevertheless, the people of Huaynacotas have preserved their traditional means of conserving and sharing water for several hundred years, and I was fortunate to start my research in such a community. I set out to learn primarily by doing, helping the Quispes and other families irrigate their parcels of land and, most of all, accompanying the village's water distributors on their rounds as they measured out the water and saw to it that the resource was used properly by each household. These experiences showed me that physically controlling water is one thing, conserving it and maximizing its availability is another, and sharing it effectively among people without generating conflict is still another. I was very interested in all three, but especially in irrigation as a social and moral challenge.

The local tradition of water distribution is based on the concept of equity, or fairness. As I ultimately came to understand it, this amounts to the notions that everyone has a right to a proportional share of this vital communal resource, provided they fulfill the corresponding duties to the community, and that everyone should be affected by the prevailing scarcity in the same basic way. Interestingly enough, the sixteenth-century chroniclers Garcilaso de la Vega and Felipe Guaman Poma de Ayala emphasized the principles of proportionality and fairness in their brief descriptions of what they said was the Inca system of water management. I had not looked very closely at their accounts before I began my fieldwork, but when I set about writing up my research a few years later, I immediately noticed this and other striking parallels. Modern scholars had



doubted the accuracy of these early descriptions—in part because after five centuries of change, there appeared to be little consistency in Andean irrigation practices in different locales.

Huaynacotas has two main water sources (large alpine springs), two reservoirs for accumulating their output at night, and two separate networks of

In the rugged Andean terrain, you cannot irrigate efficiently unless you terrace the fields.

canals to carry the water down to the fields. Each network serves roughly 500 acres, and archaeological studies indicate that much of this land has been under continuous cultivation for at least a thousand years, dating back to an early Andean empire known as the Huari. The fields—each of which, as a rule, comprises several levels of terracing—range in elevation from 10,000 to 13,000 feet. Some of the highest fields are primarily rain-fed rather than irrigated and are devoted to tuber production; the others are intensively cultivated with maize (the villagers' primary staple food) and various other subsistence crops.

The village is made up of three extended kinship units known as *ayllus*, whose members generally have small plots of land scattered throughout the ir-



PAUL TRAWICK

irrigated territory. This pattern is probably the result of a long history of intermarriage between the three groups, along with the gradual fragmentation of landholdings through inheritance and population growth. Like all Andean peasant villages, Huaynacotas includes both large and small landowners, but social and economic stratification is much less evident than it is in the large number of provincial villages that were once closely connected with the Spanish hacienda tradition.

No family in Huaynacotas today has more than a dozen acres of cultivated land, of which at most seven or eight are irrigated.

Each of the two irrigation networks is overseen by a water official called a *kampu*. The position rotates each year to two different men from the village and is considered a form of obligatory service to the community (the men usually volunteer, although sometimes under pressure). In September, men prepare the fields with plows pulled by oxen while women do the sowing. The *kampu* then routes the water to the various sectors of irrigated land, following a fixed sequence that reflects the planting order and crop maturation times. The individual villagers on the receiving end then direct the flow onto their parcels, one by one.

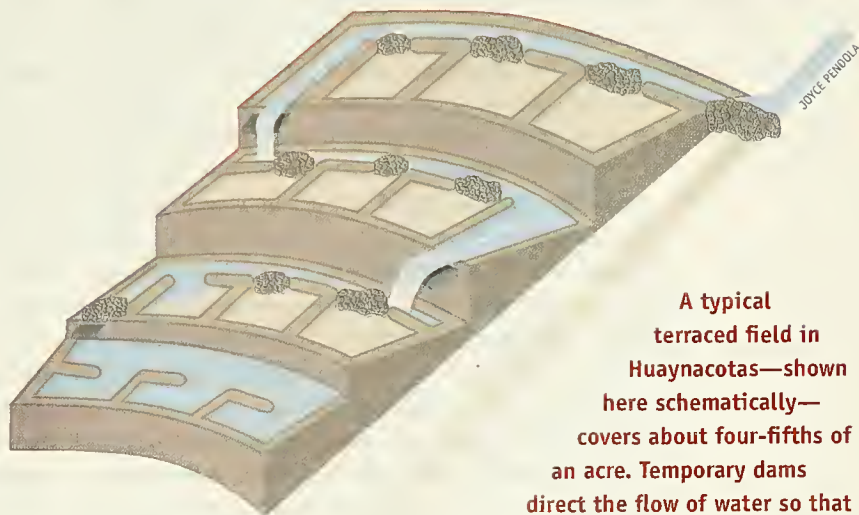
In a normal year, rain falls almost every afternoon and evening throughout the rainy season, which lasts from January through April. Nevertheless, irrigation is essential, because at this high altitude, maize requires nine months to mature. The irrigation sequence is determined by the fact that some sectors are significantly colder than others, owing in part to altitude but also to daily exposure to sun and wind. Maize plants sprout and develop more slowly in such locations and have to be given a head start to protect them from

the frosts that come at the end of the growing season. All sectors under production at a given time are irrigated, however, and water reaches every parcel, before the process begins again at the top of the sequence. Each complete cycle takes two to three months, depending on seasonal and long-term fluctuations in the supply. Even at best, a field is irrigated no more than three or four times a year.

Each reservoir refills overnight. The next morning, the *kampu* opens a wooden gate, releasing a flow of water that provides about nine hours of daytime irrigation. A dam made of large rocks and sod splits the stream from the reservoir and main canal in half. The two separate flows, called *rakis*, are diverted in this way through branch canals to reach the fields. Each *raki* is considered sufficient to water about four-fifths of an acre (a standard-size field known as a *topo*) in roughly two hours. When the water flow is high, therefore, each *raki* irrigates about four fields per day.

Within each sector, the *kampu* allocates water shares to individual parcels of land in a fixed contiguous order, starting at the bottom of the sector and proceeding upward, parcel by parcel. This contrasts with the practice in other villages nearby, especially those where irrigation is overseen by the state. There the bigger landowners and those growing crops that state officials consider more valuable to the economy (alfalfa, for example, which is fed to cattle being fattened for sale in urban markets) are able to get water more often than anyone else, through both licit and illicit means.

IRRIGATION OF A TERRACED FIELD



A typical terraced field in Huaynacotas—shown here schematically—covers about four-fifths of an acre. Temporary dams direct the flow of water so that the subdivisions (*atus*) on each terrace fill to the same depth.



A reservoir in Huaynacotas stores springwater that accumulates overnight. During the day, enough water is released from it into the village canal network to irrigate as many as eight fields.

The springs that supply Huaynacotas are the most vulnerable ones in the valley to droughts, which have happened with alarming frequency in the southern Peruvian Andes during the past thirty years. Water for irrigation is extremely scarce, even under normal conditions. Nevertheless, conflict over the resource is far less prevalent here than in other villages in the province. The tradition followed in Huaynacotas ensures that people absorb the impact of shortages fairly equally and that the uniform frequency of irrigation is preserved. If the flows dwindle, the *kampus* get the consent of the community to take some of the higher sectors of land in each half of the system out of production. Because all the families have land in these upper sectors, everyone makes a sacrifice (not a small one) for the common good.

The way each parcel is irrigated also contributes to maintaining a basic proportionality or equity among people's water rights. Earthen ridges or dikes of a standard height—about fifteen inches—divide the field into sections called *atus*, each covering perhaps 200 square feet. The water is pooled in these to the same depth over the entire surface of the field, starting with the bottom terrace and working upward. Once all the *atus* have been filled, irrigation is considered complete, and the flow must then move on to the next parcel and the next household, with no duplication allowed. The *kampu* allows no departures from this arrangement—such as the destruction of terracing and the irrigation of slopes, wasteful practices that are common elsewhere in the highlands, especially in areas formerly dominated by haciendas.

The contiguous sequence of distribution helps minimize waste. My research assistant and best village informant, Jesús Chirinos, who had already done his stint as water distributor, filled me in on the reason. As in most highland communities, the

canals are lined only with gravel, and a lot of water is lost because it soaks into the ground. Once the soil beneath has become saturated, however, the rate of loss decreases dramatically. Consequently, it is best to concentrate irrigation in one small area at a time, rather than jump around. In other Andean communities, most of whose traditions are quite different, the waste is much greater.

Just as important, the contiguous pattern makes irrigation a thoroughly public affair. Everyone knows the order of distribution, and since adjoining parcels are likely to be irrigated on the same day, their owners are normally waiting and watching, preparing their fields for irrigation, while their neighbors finish their turns. This routine monitoring provides restraints on theft, favoritism by water officials, and other forms of corruption.

The system's transparency enables people to see that under local rules and procedures, there is a direct link between their own self-interest and the

By giving up the irrigation of some fields, all landowners share the hardship of a drought.

common good. This essential compatibility has enabled them to avoid the well-known “tragedy of the commons”—the tendency of people to over-exploit and abuse any resources that they hold in common. Indeed, everyone in the village knows not only the rules but even how to operate the entire canal and reservoir system, because the male heads-of-household do this in rotation, serving as water distributors and sponsoring the yearly cleaning of the canals.

Conducted on the 16th and 18th of August to prepare the two halves of the system, the Yarka Aspiy (Canal Cleaning) is an intensive communal work project. The men carry it out in an atmosphere of celebration and always under the influence of a lot of drink, softened somewhat by a special meal prepared by the women. The distinction between work and play is completely blurred (it's literally a work party). On the day designated for the cleaning of his half of the system, the *kampu* begins by making burnt offerings to the alpine spring and saying special prayers to the mountain deities that bring the rain, after which cane alcohol and corn beer are consumed by everyone present. The men then work and drink their way back down to the

village, shoveling silt out of the reservoir and removing rocks, weeds, and other debris from the main canal. Along the way, they say other prayers at the junctions with the secondary canals. The work is done so enthusiastically that half the irrigation system is cleaned, sanctified, and thanked from top to bottom in a single day.

This kind of cooperation is made possible by a basic proportionality in the maintenance duties that people must fulfill in order to preserve their water rights. Because large landowners derive a greater benefit, their contributions to the canal cleaning are required to be greater—in terms of labor, food, and especially drink—than are those of the smallholder majority. This contrasts with the situation in the villages lower down in the valley, and in many other places throughout the highlands today, where the large landowners contribute the same amount as any smallholder, usually by hiring someone else to work in their place—a practice generally not allowed in Huaynacotas. During the past several decades, the breakdown of communal work traditions elsewhere in the Andes and in many other parts of the world has been widely noted, but in my opinion, the main reason for it—a lack of proportionality and the resentment and conflict that this lack engenders—has never been fully appreciated.

I believe that the water management system practiced today in Huaynacotas is the Inca system, just as the local people say it is. Studies done recently in other parts of the Andes show that this tradition has survived elsewhere as well. In fact, I think this type of system had emerged in various localities and become widely established in the Andes before the time of the Inca empire. Because the practices had proved to be effective and sustainable, the Incas may have adopted them and even endorsed them as official policy.

The national government in Lima would be wise to follow the Incas' precedent today. The Peruvian state has long been heavily involved in resource management in many places, since it is technically the legal owner and steward of all of the country's irrigation water. But like other governments in the so-called developing world, Peru's now faces downsizing because of heavy foreign debt. Organizations such as the International Monetary Fund and the World Bank are urging Peru's leaders to get out of the business of managing water, because the state's methods are seen as wasteful, costly, and rife with conflict.



LOREN MCINTYRE

Peru's government would now like to turn over responsibility for the operation and maintenance of local irrigation systems—and even ownership of the resource itself—to local water-user groups, and it is searching for a management model that will accomplish this shift without leading to a tragic outcome. Fortunately, Peruvian officials don't have to look very far. The best policy alternative does not come from a Washington think tank or from some land-grant agricultural research institution in the United States, consultants that Peru has always turned to in the past for such models. It comes from the Andes—from the Incas and their predecessors—and is similar to the solutions worked out by indigenous peoples facing the same challenge in other parts of the world. Because it works, the tradition has been handed down for hundreds of years, reaffirmed and ratified by people who knew their very livelihood was at stake. □

Terraced fields surround the Colca River, which flows to Peru's Pacific coast.

BIOMECHANICS

Lip-O-Suction

With teeth in its lips and its mouth open to 180°, a hungry tadpole turns a scrape into a close shave.

Story by Adam Summers ~ Illustrations by Shawn Gould

Though the leap from frog to prince gets all the press, I would argue that the metamorphosis from tadpole to frog is just as impressive—even more so when you think about how often it has to happen. The transformation from frog to prince is no mean feat, requiring rapid weight gain, change of coloration, and some minor rearrangement of facial features. But pollywogs must grow legs, lose a tail, and completely reconfigure their jaws and digestive tract to prepare for a life of eating flies.

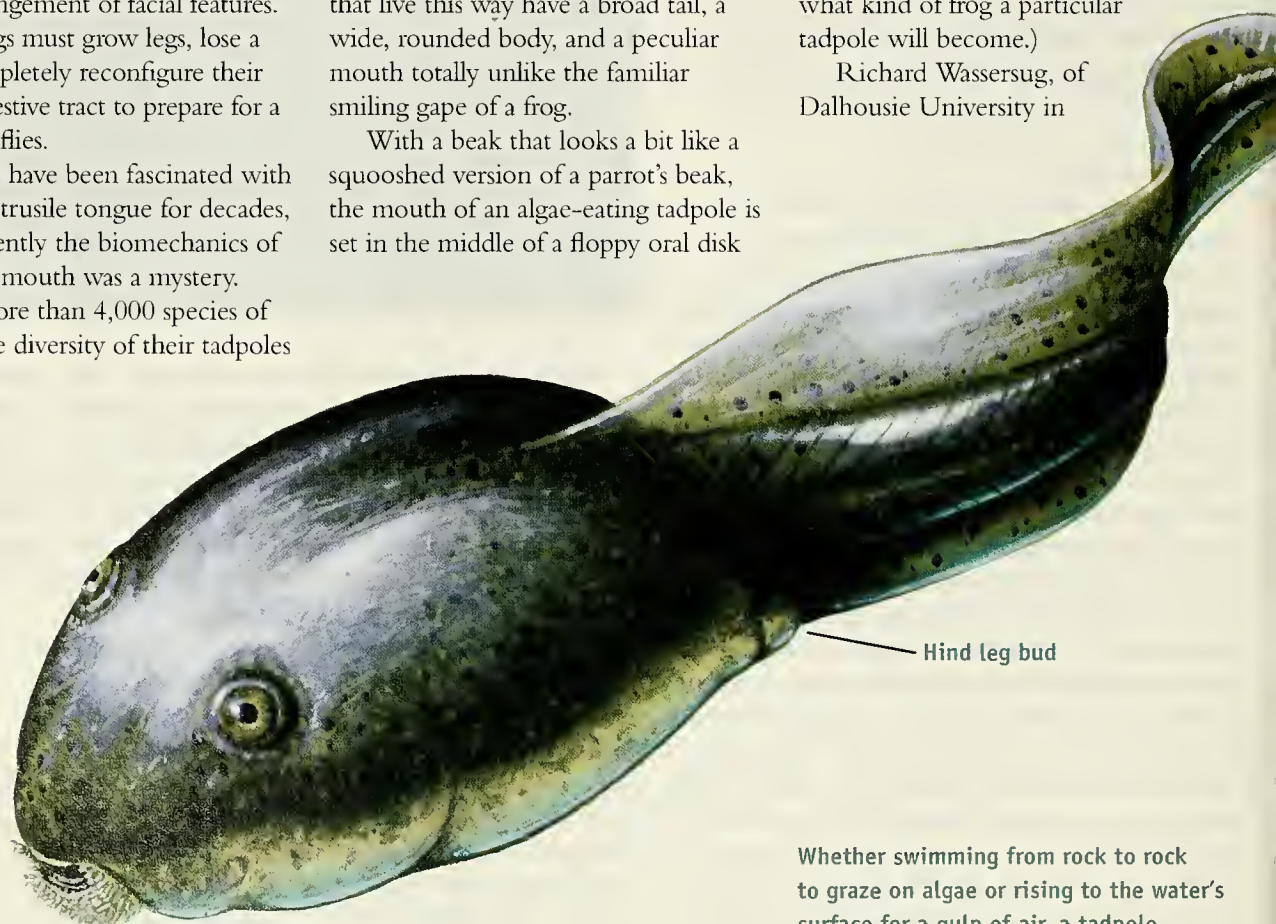
Biologists have been fascinated with the frog's protrusile tongue for decades, but until recently the biomechanics of the tadpole's mouth was a mystery. There are more than 4,000 species of frogs, and the diversity of their tadpoles

is nothing short of astonishing. Plankton-eating tadpoles spend much of their time hanging motionless in the water. Other kinds inhabit temporary ponds, where they dine on their fellow tadpoles. But by far the most common way of tadpole life involves harvesting algae and microbes from rocks and mud at the bottom of ponds. Tadpoles that live this way have a broad tail, a wide, rounded body, and a peculiar mouth totally unlike the familiar smiling gape of a frog.

With a beak that looks a bit like a squooshed version of a parrot's beak, the mouth of an algae-eating tadpole is set in the middle of a floppy oral disk

(see illustration on opposite page). Embellishing the disk, above and below the beak, are close-set rows of tiny teeth. Both beak and teeth are made of keratin, the stuff of fingernails and hair. (Except for their mouths, tadpoles tend to look an awful lot alike, and the number and arrangement of the tooth rows are important for determining what kind of frog a particular tadpole will become.)

Richard Wassersug, of Dalhousie University in



Whether swimming from rock to rock to graze on algae or rising to the water's surface for a gulp of air, a tadpole propels itself with its long, undulating tail.

Nova Scotia, has devoted his career to understanding tadpoles. He and his colleague Masamichi Yamashita, of the Institute of Space and Astronautical Science in Japan, recently described the biomechanics involved in two tasks for which tadpoles use their mouths: breathing and feeding.

Early in its development a tadpole breathes with gills. But as it starts the transition to froghood, it develops lungs—forcing the tadpole to swim frequently to the surface to gulp air. That makes simple breathing a dangerous business, because the average tadpole can become a tasty treat for any number of fish, reptiles, and birds. Hence survival puts a premium on being able to rush to the surface, take a speedy swig of air, then dash back to the safety of the pond bottom.

If you have ever watched a water strider scoot gracefully across a pond, or floated a needle on the surface of the water in a glass, you have observed surface tension: the “desire” of the molecules at the surface of a liquid to stick to those below. For the water strider, this cohesion is a good thing; it enables the insect to walk on, rather than fall through, the water surface. But for a tiny-mouthed tadpole in a big hurry to take a breath, surface tension is an obstacle to be overcome. High-speed video footage by Wassersug and Yamashita shows how the bullfrog tadpole manages the trick. When the tadpole is not breathing, its oral disk is closed, folded into the shape of a half-moon. But as the tadpole speeds close to the surface of the water, it flips the disk forward, throwing water away from its beak in the process. As the disk unfolds, little papillae at its corners stick up, further blocking the water from flooding in.

The unfolded disk is now flush with the pond surface, with the beak projecting into the air just above it. The tadpole opens its beak, takes a quick gasp of air, slams the beak shut,

and turns for the bottom. All this happens in not much more than a hundred milliseconds, hardly time for any but the luckiest predator to take advantage of the situation.

Of course, the mouth is also for feeding. To get enough to eat, algae feeders must forage quickly and thoroughly, because surface algae generally grow in a thin layer. Most algae eaters, a diverse group that includes marine iguanas and some

vertebrate. The teeth then anchor the disk to the surface, while the beak nips off long pieces of algae. As the beak closes, the rows of teeth perform a scraping operation on any shorter algae it missed. The operation resembles the action of a multibladed shaving razor. As the rows of teeth immediately bordering the beak start to scrape, those next in line remain anchored to the algae until they slip and follow behind, scraping some algae and



When a tadpole eats, all parts of its oral disk come into play: the papillae provide friction to facilitate attachment, the beak snaps off long pieces of algae, and the tooth rows—working like a multibladed razor—scrape off shorter bits of algae.

cichlids and catfish, have fine, spatulate teeth (made, like ours, of enamel and dentin) that are used for scraping, as well as soft lips used for scooping up and holding the particles of algae loosened by the scraping. Tadpoles, rather than having separate teeth and lips, combine the two: the rows of tiny keratin scrapers are embedded in the floppy disk, which serves as lips. Wassersug and Yamashita—once again using high-speed video, this time of tadpoles feeding on algae-covered glass slides—revealed the importance of the multiple rows.

When feeding, the tadpole's first task is to place its oral disk flat on the algae-covered surface. To do this, the little frog-to-be opens its mouth to an astonishing 180°—the oral equivalent of a gymnastic split and, by a large margin, the widest gape of any

further trimming the “stubble.” As row after row of teeth pops into action, the algal surface is shaved closer and closer. By the time the last rows have done their scraping, the beak is completely closed, leaving the algae trimmings to be sucked in during the next chomp. The tadpole performs six of these all-in-one chomps per second.

Some stream-dwelling tadpoles have more than twenty rows of teeth. The extra rows may hold the tiny creatures in place during feeding, or perhaps they ensure a closer shave—a possibility that might interest razor manufacturers, whose offerings so far have been limited to triple-bladed models.

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

OUT THERE

Starry Weather

Partly cloudy, with a chance of flares?

By Charles Liu

Like all stars, the Sun is a seething ball of heat, light, and magnetic energy. Some of this energy regularly erupts from the Sun's surface, forming beautiful prominences, loops, and solar flares. Particularly powerful events eject millions of tons of protons and electrons into space at millions of miles per hour. When such an outburst points toward Earth, some of this Sun-stuff arrives in our vicinity a day or so later, often causing auroras—the northern and southern lights—as the stream of solar particles crashes into Earth's upper atmosphere. Sometimes the consequences are less innocuous; the particles' electromagnetic effects, for instance, can overload power grids and damage orbiting satellites.

Public awareness of Sun-induced phenomena has increased as our Earth-bound lives have become ever more intertwined with cellular phones, satellite TV, and other space-borne technology. Scientists have even coined a term for this stuff: "space weather." But the name is a little imprecise, since we're really talking about "star weather"—the star being, of course, our Sun. Whatever it's called, it certainly doesn't seem to resemble the wind, clouds, rain, and snow that we're familiar with down here. So, do stars have weather as we do on Earth?

Let's tackle this question by thinking first about the difference between terrestrial weather and space weather. Down here, particles do affect our weather—lightning, for example. But at sea level, Earth's atmosphere has a density of about one kilogram per cubic meter, or roughly

6,000,000,000,000,000,000,000 molecules per cupful of air. Interplanetary space, on the other hand, contains only a few thousand particles per cupful. So the motion of ionized particles dominates weather in space, while the movement of heat—hot and cold air and water, flowing from place to place—drives weather on Earth. Weather patterns readily appear on any planet with a steady energy source—on Earth, that'd be sunlight—and a substantial atmosphere.

Stars have both abundant atmospheres and energy. This suggests they should have planet-like weather.

Recently a team of astronomers, led by Adam Burgasser at UCLA, has provided new evidence—what appears to be Earth-like weather in the atmospheres of brown dwarfs—to support this conclusion. (See my column, "When a Star Isn't Born," September 2002, about these so-called failed stars.)

Just as the coils in a toaster glow brighter as they heat up, hotter brown dwarfs should be more luminous than cooler ones. Yet infrared measurements show a puzzling conflict between theory and

observation: brighter brown dwarfs appear to be too cool and dimmer ones too hot. Some astronomers have argued that the discrepancy comes from assuming that brown dwarfs have undifferentiated atmospheres, marred only occasionally by flares and prominences. This prompted Burgasser and his colleagues to create a model that assumes the top layers of brown-dwarf atmospheres are patchy, with thick clouds—laden with droplets of liquefied metal-bearing minerals and molten iron—floating atop an otherwise clear "sky."

According to this hypothesis, the



The eruption of a prominence (orange-red feature at upper left) hints at the roiling solar weather below.

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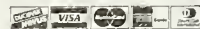
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clouds obscure part of the brighter dwarfs' light, leading observers to infer that the brown dwarf is cooler than it actually is. As brown dwarfs age, they cool; the clouds on the dwarfs turn into heavy, metallic precipitation. The sky then clears up, allowing more infrared radiation to escape and making the dimmer brown dwarfs appear misleadingly warm. The researchers' new model matches the observations well, suggesting that weather is indeed at work on these almost-stars.

Although brown dwarfs don't fuse hydrogen into helium, they have a lot of other things in common with low-mass stars. So if brown dwarfs have planet-like surface weather, there's a good chance that the faintest stars do too. That's not the whole story, however. The plasma in the guts of stars carries tremendous amounts of heat generated during nuclear fusion, and it can swirl and flow as easily as heat does in Earth's atmosphere. It makes sense to speculate, then, that stars might have weather in their interior as well as near their surface.

Do we have anything to support this remarkable prediction? Yes, indeed. By combining nearly six years of Doppler imaging data from the SOHO (Solar and Heliospheric Observatory) satellite, solar astronomers have now seen tantalizing suggestions of horizontal wind patterns and cyclonic flows deep below the Sun's outer layers. Of course, there's a great deal we don't understand about this result. But with more discoveries like SOHO's, astronomers may one day be able to forecast the imminent clearing of the mysteries of stellar weather.

Charles Liu is an astrophysicist with the Hayden Planetarium. He is also affiliated with Barnard College as a research scientist in the Department of Physics and Astronomy.

THE SKY IN OCTOBER

By Joe Rao

Mercury rises ahead of the Sun all month. It's best seen during the second and third weeks of October, just above the eastern horizon about half an hour before sunrise. Also around this time, the much dimmer Mars is nearby. The two planets are closest on the 10th, when Mars hovers less than 3° above and to the right of Mercury. Shining at magnitude -0.3 , Mercury reaches greatest elongation, 18° west of the Sun, on October 13. Mercury continues to brighten steadily thereafter; on October 27 it reaches magnitude -1.0 . Also on this date, Mercury passes 4° north of the bluish first-magnitude star Spica, in Virgo.

Venus starts the month low in the west-southwest during evening twilight. It sets only about seventy minutes after the Sun on the 1st and about three minutes earlier each evening thereafter. By the 13th, Venus sets only half an hour after the Sun. Venus is now a narrow crescent, visible with a small telescope or even with good, firmly braced binoculars. Look for the enormous slender crescent as soon as the planet appears, while it is still set against a bright sky. Because Venus is so brilliant (at magnitude -4.3), it may be visible at, or even before, sundown.

Mars treads the dawn in early October. It's in the east one and a half hours before sunrise. By month's end, it rises half an hour earlier in a fully dark sky. On the morning of the 4th, the planet will be roughly 10° below a slender crescent Moon. The red planet also has a rendezvous with Mercury on the morning of the 10th. At the beginning of October, Mars is 242 million miles from Earth and, at magnitude $+1.8$, is relatively dim.

Nonetheless, this marks the start of a most dramatic and spectacular Martian apparition. By late August 2003, it will be 208 million miles closer, appear more than six times larger, and shine some forty-six times brighter than it does this month.

Jupiter, in Cancer, the Crab, rises about five hours before sunrise early in October. By the end of the month—when standard time resumes—it rises at about 11:30 P.M. local time. The Moon passes well north of Jupiter on the morning of October 2.

Saturn is still prominent in the faint club of Orion, the Hunter. The planet appears in the east-northeast about four hours after sunset on October 1 and about ninety minutes earlier by month's end. At dawn, it stands high in the south-southwest. The Moon slides 3° north of Saturn on the morning of the 26th.

The Moon wanes to new on October 6 at 7:18 A.M. Less than two hours later, our satellite arrives at perigee (its position closest to Earth), 221,789 miles away. Abnormally large ocean tides should result for a few days around the event. The Moon is at first quarter on the 13th at 1:33 A.M. and waxes full on the 21st at 3:20 A.M. Last-quarter Moon occurs on October 29 at 12:28 A.M. EST.

"Spring ahead, fall back." October 27, the last Sunday of the month, is the day on which clocks must be set back one hour in most areas of the United States and Canada. On this date, the clock hour from 1:00 A.M. to 2:00 A.M. officially repeats.

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

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THE NATURAL MOMENT

A Sudden Death





Life tends to converge around water. In a desert, especially, a water hole can be a setting for congregation and confrontation, rest and action. Here the scene is a small pond in the Rio Grande Valley of south Texas, where photographer David Welling set up his blind at dawn on a March day. Wildlife soon arrived, seeking water and the shade of a big ebony tree and smaller mesquite bushes. Among the visitors were a ground squirrel, cotton rats, cardinals, a pyrrhuloxia, a green towhee, and a trio of green jays. Brightly plumaged, these jays range just north of the Mexican border, in areas such as Hidalgo County, Texas, home of sizable rattlers. When the attack came, at midmorning, it was a surprise to all but the snake.

The green jay had simply been sitting on a branch as Welling took its photo.



Then, says the photographer, the bird “hopped to another branch and was immediately struck by a rattler that was hiding in the bushes. I was so surprised by the action that I almost didn’t get this image.” The western diamondback rattlesnake held on as the bird, voiceless, beat the air yellow with its wings, one foot still grasping the perch, its face a small mask. With his bird portrait abruptly transformed into a drama, Welling wielded his camera and captured both violence and beauty. The venom did its work in three or four minutes; the reptile then slowly devoured its prey whole.—*Judy Rice*

Photographs by **David Welling**

REVIEW

Sifting Truth From Pelée's Ashes

How the real causes of a famous disaster, long misunderstood, became key elements in the modern science of volcanology

By Steven Soter

On the morning of May 8, 1902, the volcano Mount Pelée, on the Caribbean island of Martinique, vomited a superheated cloud of gas loaded with dust and rock. The turbulent cloud, impelled by its own weight, raced down the mountain faster than a hurricane, hugging the ground and heading for the coastal city of Saint-Pierre, about five miles away. It blasted everything in its path and left a blazing inferno. Within minutes, nearly 30,000 people lay dead—crushed, incinerated, asphyxiated by the scalding gas. The victims included the governor of the island and members of a “scientific commission” assembled to assess the volcanic threat. Only two people within the city survived.

Founded in the seventeenth century, Saint-Pierre had been the cultural and commercial capital of the French West Indies, with a prosperous economy built

on sugarcane and rum. American writer Lafcadio Hearn, who lived there for two years, found it enchanting—“the quaintest, queerest, and prettiest withal, among West Indian cities, all stone built and stone flagged,” adorned with palm trees, gardens, and fountains, and “a population fantastic, astonishing,” which he regarded as the handsomest in the West Indies. In 1902, Saint-Pierre was also the bastion of a white supremacy whose power was being challenged by a populist opposition. Louis Percin, a Radical-Socialist lawyer, was running against Fernand Clerc, a wealthy industrialist, in a highly charged election for a seat in France’s Chamber of Deputies, scheduled for May 11. But the inexorable natural agenda of the volcano would render all that irrelevant for Saint-Pierre.

Today we know that Mount Pelée has erupted catastrophically many times

in the past 10,000 years. The now-extinct Carib population even called it “the mountain of fire.” But in 1902 the people of Saint-Pierre could recall only a single eruption, in 1851, and it had left the city unscathed. Memories of that harmless event contributed to a false sense of security among some of the older residents.

In the week preceding the 1902 catastrophe, the volcano had become increasingly violent. To the accompaniment of thunderous explosions, the crater sent lightning-riven columns of ash towering above the city; a mantle of fine volcanic ash settled over everything; a steaming torrent of mud obliterated a sugar refinery near Saint-Pierre, killing two dozen people; telegraph cables connecting the island to the outside world were severed.

The reaction of the authorities was to prove disastrous. The mayor posted



Left: The city of Saint-Pierre, Martinique, before the 1902 eruption of Mount Pelée. Above: The ruined city, after the eruption.

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a reassuring proclamation. The leading newspaper derided those who were fleeing in panic. And on the evening of May 7—the last for the doomed city—Governor Louis Mouttet's commission announced that Saint-Pierre was not in danger.

Why had the government not evacuated the city? After the catastrophe, the finger-pointing began. Fernand Clerc, who had gotten out of Saint-Pierre at the last moment, charged that Governor Mouttet had instructions from Paris to keep the population in the city to avoid disrupting the elections. A rumor spread that troops had even prevented people from leaving. But with most of the principals dead, the truth remained obscure. Exploiting the tragedy, several sensational books were rushed into print in 1902, mixing fact and rumor with pure invention.

In 1969, Gordon Thomas and Max Morgan-Witts published *The Day the World Ended*, presenting it as a nonfiction account of the disaster. They blamed the tragedy on the apathy and duplicity of the governor. Adding to the list of ignored forewarnings from the volcano, they reported that poisonous centipedes and snakes had swarmed over the outskirts of the city and that people had been dying from an epidemic triggered by volcanic pollution. All this, like much else in their book, never happened.

Thomas and Morgan-Witts loaded their narrative with melodramatic fabrications, which so appalled Jacques Petitjean Roget, then president of the Historical Society of Martinique, that in 1972 he published a detailed and scathing critique to expose the nonsense. Unfortunately, his scholarly

analysis remained largely unknown outside the French West Indies. Consequently, most subsequent accounts of the tragedy have relied on Thomas and Morgan-Witts, and the mythology continues to propagate.

This year, marking the centennial of the disaster, three books retell the Mount Pelée story. In *Volcanoes in Human History*, geologists Jelle Zeilenga de Boer and Donald Theodore Sanders cite the 1902 eruption as one with far-reaching effects. Their book is generally good on the

La Catastrophe: *The Eruption of Mount Pelée, the Worst Volcanic Disaster of the 20th Century*, by Alwyn Scarth (Oxford University Press)

The Last Days of St. Pierre: *The Volcanic Disaster That Claimed Thirty Thousand Lives*, by Ernest Zebrowski Jr. (Rutgers University Press)

Volcanoes in Human History: *The Far-Reaching Effects of Major Eruptions*, by Jelle Zeilenga de Boer and Donald Theodore Sanders (Princeton University Press)

geology of volcanoes and the consequences of major eruptions; in their account of what happened in Saint-Pierre, however, they rely on the wrong sources and make a hash of the politics.

In *The Last Days of St. Pierre*, physics professor Ernest Zebrowski Jr. also

uses some unreliable sources but at least attempts to set the record straight. He gives a balanced and sympathetic description of bewildered authorities out of their depth in confronting an unpredictable menace. Even if Governor Mouttet could have imagined what was to happen, he had no means of evacuating 30,000 people. For dramatic effect, Zebrowski contrives detailed conversations among the characters in the unfolding drama, a technique I found distracting.

By far the best book in English on the tragedy is *La Catastrophe*, by Alwyn Scarth, formerly a professor of geography at Scotland's University of Dundee. Basing his book on meticulous research, Scarth has assembled the most revealing and reliable testimony, together with a collection of vivid photographs. He carefully probes and exposes "the lies and innuendos" that followed the disaster. We learn that far

from being apathetic or duplicitous, Governor Mouttet courageously tried to cope with the crisis and paid with his life. No evidence exists that the pending election played any role in his decisions. The election never threatened the French government in any case, because the parties of both candidates in Martinique (an "overseas department" of France) already belonged to the governing coalition.

The real problem was that no one on the island knew much about volcanoes, and no geologist in the world then knew anything about the kind of eruption that Mount Pelée was about to unleash. The people of Saint-Pierre feared an earthquake, or an inundation from the sea, or streams of lava flowing down the river valleys. The death cloud that actually burst from the volcano was beyond their ability to imagine. The tragedy of Saint-Pierre was more the result of ignorance and apallingly bad luck than of incompetence or malfeasance.

After the disaster, the geologist Alfred Lacroix came to Martinique to study the wreckage. After piecing together the evidence, he named the phenomenon *nuée ardente* (fiery cloud), also known today as pyroclastic flow. When internal gas pressure disintegrates the viscous lava blocking a volcanic vent, it can produce a cloud of hot gas full of dust and rock that spills like an avalanche down the side of the mountain. Although eruptions of this type are not rare, none had previously been studied. Lacroix's book on Mount Pelée became a classic in the new science of volcanology, and the dangers are now well understood. Today, in part because of the Saint-Pierre tragedy, governments take very seriously the threat of an awakening volcano.

Steven Soter, an astronomer in the Museum's Department of Astrophysics, is researching seismic precursory phenomena and the geoarchaeology of ancient Helike, a Greek city destroyed by an earthquake in 373 B.C.

Some of the fall's best reads involve quests. Japanese explorer Daisuke Takahashi has written **In Search of Robinson Crusoe** (Cooper Square Press), about his seven-year journey looking for traces of Daniel Defoe's real-life inspiration, Alexander Selkirk. In **Search for the Golden Moon Bear: Science and Adventure in Pursuit of a New Species** (Simon & Schuster), naturalist Sy Montgomery recounts her travels through Southeast Asia with evolutionary biologist Gary Galbreath and others. Andromeda Romano-Lax, sailing in a twenty-four-foot boat with her husband and two children, observes the dazzling array of natural life in **Searching for Steinbeck's Sea of Cortez: A Makeshift Expedition Along Baja's Desert Coast** (Sasquatch Books). Journalist Tony Horwitz, in **Blue Latitudes: Boldly Going Where Captain Cook Has Gone Before** (Henry

Year Quest for the Giant Sable Antelope of Angola (Atlantic Monthly Press).

In **Pacific High: Adventures in the Coast Ranges From Baja to Alaska** (Island Press), naturalist Tim Palmer investigates how the estimated 36 million people who inhabit this vast region have affected its environmental health. Journalists Marq de Villiers and Sheila Hirtle describe diverse peoples and elemental forces of sand, wind, and weather in **Sahara: A Natural History** (Walker Publishing). Anthropologist Ben Orlove travels to the world's highest lake, which lies between Peru and Bolivia, in **Lines in the Water: Nature and Culture at Lake Titicaca** (University of California Press). In **The Shaman's Coat: A Native History of Siberia** (Walker Publishing), journalist Anna Reid visits indigenous people of nine nationalities and finds their identities strengthened since the collapse of Communism. Closer to home, the American Southwest is what inspires both Craig Childs, in **Soul of Nowhere: Traversing Grace in a Rugged Land** (Sasquatch Books), and Ellen Meloy, in **The Anthropology of Turquoise: Meditations on Landscape, Art, and Spirit** (Pantheon Books).

Outstanding reference books include the National Audubon Society's **Guide to Marine Mammals of the World** (Alfred A. Knopf), illus-

trated by Pieter Folkens; the **Encyclopedia of Marine Mammals** (Academic Press), edited by William F. Perrin, Bernd Würsig, and J.G.M. Thewissen; and the **Encyclopedia of Evolution** (Oxford University Press).

These books are usually available in the Museum Shop, (212) 769-5150.

Shifting Ground

By Robert Anderson

Having studied geology in the early 1980s, I have trouble imagining the time, only a decade or so earlier, when plate tectonics—the unifying theory of our planet's inner workings—was not generally accepted. Perhaps that's why I so enjoyed the Web site "This Dynamic Earth" (pubs.usgs.gov/publications/text/dynamic.html). The site's authors W. Jacquelyne Kious and Robert I. Tillings, both at the U.S. Geological Survey, not only present a concise explanation of the theory, they also tell us a bit about the scientists who finally pieced it together.

The site clarifies the often fuzzy distinction between the older theory of continental drift and its more recent reincarnation, plate tectonics. Under "Historical Perspective," I discovered that the former had been around since 1596, when Flemish mapmaker Abraham Ortelius recorded his belief that the continents had not always been fixed in their present positions. And in 1858, geographer Antonio Snider-Pellegrini showed how the continents had once fit together. Then there was the visionary German scientist Alfred Lothar Wegener, who might have brought us the modern theory of plate tectonics decades before the 1960s had he not perished in 1930 during a trek across the Greenland ice cap.

Under "Plate Tectonics and People," the authors touch on the hazards of living on a restless planet—with its earthquakes, tsunamis, and volcanic eruptions—but they also list benefits, such as fertile soils, rich ore deposits, and geothermal energy. A world without plate tectonics would be poor indeed.

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



JULIAN DIMOCK; AMNH LIBRARY SPECIAL COLLECTIONS

Camera Man's Journey: Julian Dimock's South, edited by Thomas L. Johnson and Nina J. Root (University of Georgia Press)

Holt), signs on as a working crewman aboard a replica of Cook's first vessel, retracing the routes of the great navigator who "helped to make the world one." Finally, John Frederick Walker journeys to war-torn Angola to find a living giant sable antelope specimen and recounts some dramatic history in **A Certain Curve of Horn: The Hundred-**

ENDPAPER

Costa Rica's La Selva Field Station is a gathering place for some of tropical biology's most brilliant minds. Its research facilities, which give easy access to the jungle, harbor lethal snakes, wild pigs, snapping turtles—and mad scientists. The scientists happily spend their days plucking the wings off aerial insects and crucifying them on Styrofoam boards, molding poison-dart frogs out of Play-Doh, or shooting climbing ropes into the forest canopy with crossbows. I arrived at the station with little understanding of what compelled this scientific tribe to seek increasingly peculiar forms of academic exercise.

I'd come to La Selva to work with the dreaded bala ant (*Paraponera clavata*), also known as the bullet ant. These in-

would chill the manic ants to a manageable speed. By gluing two long rubber hoses to the cap of a small flask filled with crushed ice, I could create a vacuum in one tube by inhaling on the other. Thus equipped, I ran through the forest sucking up thousands of unsuspecting, benign leaf-cutting ants—convincing myself that the contraption was uniquely suited to the task. Then I tried to collect the balas. These ants were so big (or so smart) that they could brace themselves against the lip of the collection tube by stretching out their appendages. The Cryogenic Ant Sucker was doomed.

Instead, my comrades and I resorted to inserting a long stick deep into a bala nest and thrashing madly. When the furious ants charged up the stick, we'd smack it smartly against the top edge of an ice-filled chest, and the ants would drop inside. After they were chilled, we'd paint their motionless bodies psychedelic colors and return them to the forest.

Early each morning for several weeks we ventured into the forest to perform our nest thrashing and ant painting, but the ants caught on to us. They began to cling to the stick, refusing to drop into the ice chest. Only at the stick's rebound did they release their tenacious grip, which made them into dangerous missiles. Inevitably, one of my colleagues fell victim to an ant sting that confined him to bed with an ice pack, immobile, for thirty-six hours. A few days later another colleague succumbed to the same fate.

One evening toward the end of our study, we began antagonizing a new nest and couldn't figure out why no ants were emerging. Then some ants darted out a back exit at my feet, and soon a moving blanket of black began crawling up my socks. By furiously jumping up and down, I dislodged all but one, which made its way to my knee, clearly heading for my shorts.

Panicked, I tried to flatten it with my quadruple D-cell flashlight, completely missing the mark but successfully bashing my shin. Although I eventually knocked the ant off, my leg swelled horrendously, and I realized I might just as well have let the bala have its way with me. Still, in my misery I was consoled: This was my initiation. I had joined the scientific tribe.

Nathan Welton will shortly receive a master's degree from Boston University's Knight Center for Science and Medical Journalism.



Bala ants carve up dinner.

MICHAEL J. DOOLITTLE: PETER ARNOLD, INC.

Bites of Passage

By Nathan Welton

sects are inch-long behemoths whose stings feel like gunshots. One finds them on trees throughout the jungle, effortlessly toting the body parts of recently dismembered victims—grasshopper heads, frog legs, beetle thoraxes—down toward large black holes in the ground.

Whether or not the primitive balas use a caste system to accomplish their grim work was a mystery my colleagues and I wanted to solve, and our mark-and-recapture methodology required us to handle the beasts. Our plan was to collect arboreal foragers and underground nest tenders; compare body lengths, head sizes, and weights; and then paint the foragers one color and the nest tenders another. If afterward we consistently spotted, say, green ants in the trees and red ants on the ground, we would have found a caste.

To collect the balas, I invented a masterful piece of equipment I called the Cryogenic Ant Sucker, which, theoretically,

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


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