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NATURAL HISTORY

DECEMBER 2001 – JANUARY 2002 VOLUME 110 NUMBER 10

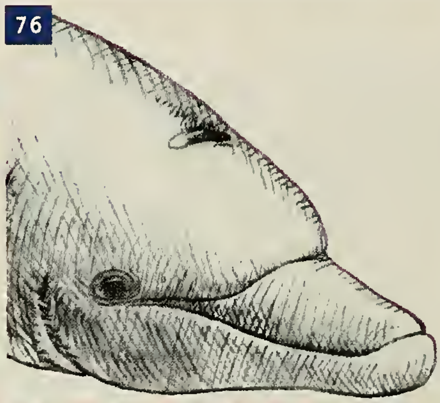
FEATURES

COVER The silkworm moth caterpillar, whose length may reach eight inches, deters some predators with its stinging spines.

STORY BEGINS ON PAGE 42

PHOTOGRAPH BY NIC BISHOP

DEPARTMENTS



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UP FRONT

Why Music?

If music be the food of love, play on
—William Shakespeare, *Twelfth Night*

Human beings are inherently and just about universally musical. Of course, salable musical talent is not given to us all—but musical responsiveness, a musical *sense,* certainly is. The person who is unmoved (neither uplifted nor cast down) by melody and rhythm is perhaps as rare as the person who (through injury or illness) has lost the sense of taste and no longer desires food. Whether one's musical palate is tempted by offerings from Laurie Anderson, the Backstreet Boys, Miles Davis, the Budapest String Quartet, or the Buena Vista Social Club is immaterial. Music is a common craving. Hundreds and hundreds of radio stations base their existence on that premise.

Although compositional cleverness—be it Mozart's or Mariah Carey's—may be appreciated intellectually, music appeals directly and almost exclusively to the emotions. The old adage has it that music can soothe our savage breasts, but it can also open up an unhealed psychic wound, incite us to action, or hijack our better judgment (a possibility that prompted Lodovico Settembrini, the character who represents Western rationalism in Thomas Mann's great novel *The Magic Mountain,* to call music a "politically suspect" art.)


JOHN VINK: MAGNUM PHOTOS

Is our musical capacity a meaningless by-product of our intelligence? Is it hardwired? Has it something to do with sexual selection, seduction, and mating? Or (and this is the argument I find most persuasive) does it have an essentially social function? To see what anthropologists, behavioral ecologists, and neurobiologists think, please turn to "Face the Music," by Susan Milius, on page 48.—*Ellen Goldensohn*

NATURAL HISTORY

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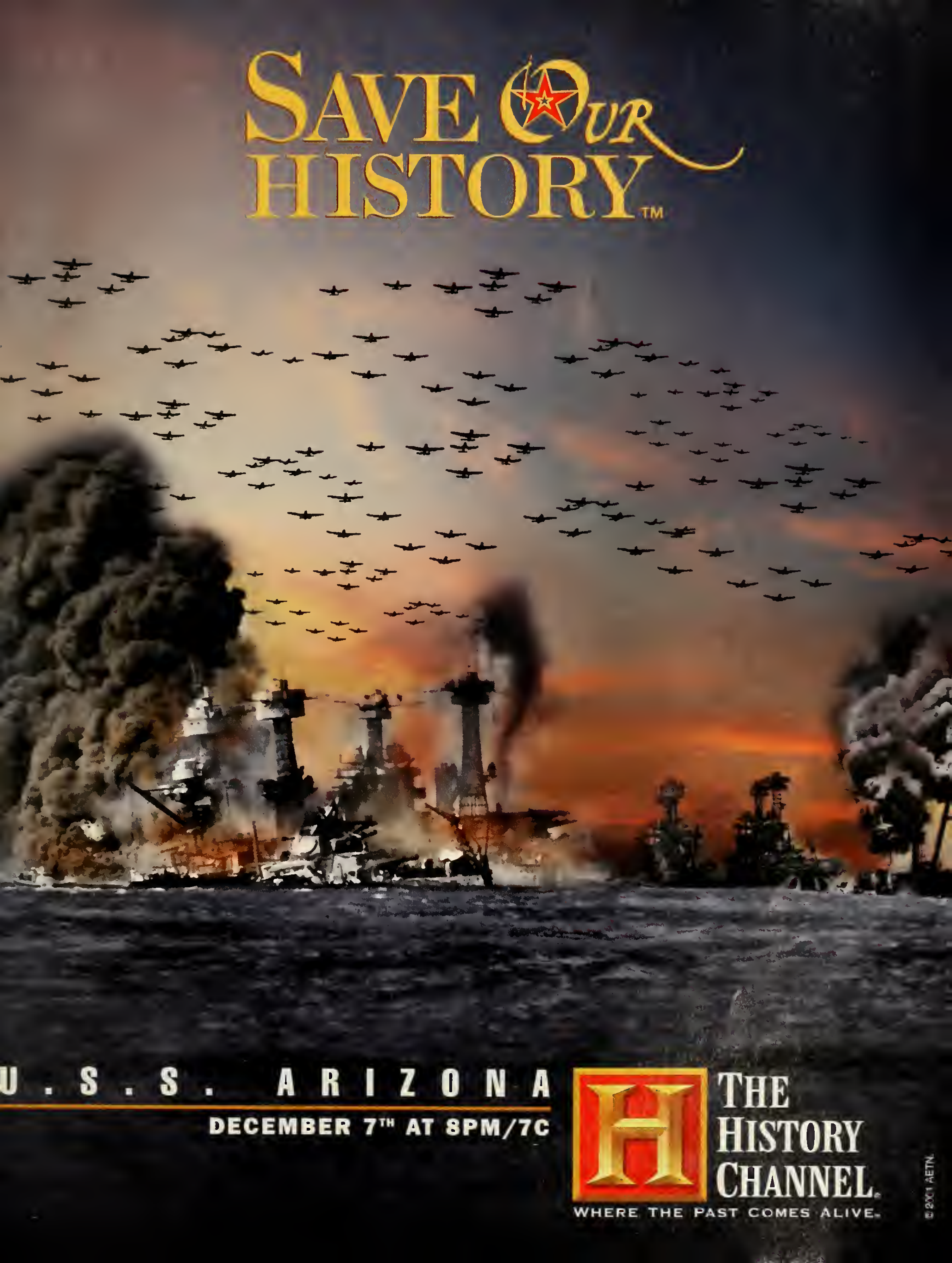
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LETTERS

A Date With a Blue Moon

I was wondering why Joe Rao did not mention, in his column "The Sky in October," that a Blue Moon occurred on October 31, 2001.

Mike Jacobs
Newport Beach, California

JOE RAO REPLIES: This was a rather unusual situation. The full Moon on November 1 occurred at 12:41 A.M. EST. Yet in the Central, Mountain, and Pacific time zones, this full Moon appeared before midnight, and hence on the previous calendar day. So for much of the country, in fact, the Blue Moon—the second full Moon in a calendar month—was in October (full Moons on October 2 and 31). At *Natural History* we have traditionally geared our Moon-phase times to the Eastern time zone, so we considered the Blue Moon to be occurring in November (full Moons on November 1 and 30). I mentioned this timing oddity in my November column.

Universal Praise

Neil deGrasse Tyson's column ("Universe") is consistently one of the best features of your magazine. I've been a *Natural History* subscriber for twenty years and a science editor for almost that long. I know great writing when I see it. Tyson makes obscure information relevant, dry material interesting, and complex details understandable. That's a tall order, given that his subject is astrophysics. "Over the Rainbow" (9/01) was a terrific example of this.

Barbara Ross
via e-mail

Fruit Fall

In "Engineering the Apple" (10/01), Sue Hubbell writes that the notion that apples caused illness "may well have been reinforced by the apple's association with the Fall in various translations of the Bible, including the King James Version (though in the oldest Hebrew and Greek texts, the Tree of Knowledge bears merely a generalized 'fruit')." As far as I can tell from *Strong's Exhaustive Concordance of the Bible,* neither "apple" nor "apples" appears in Genesis in the King James Version. However, apples are mentioned in the King James Version Hebrew Bible in Deuteronomy, Psalms, Proverbs, the Song of Solomon, Lamentations, Joel, and Zechariah. I find no reference by Strong to apples in the New Testament.

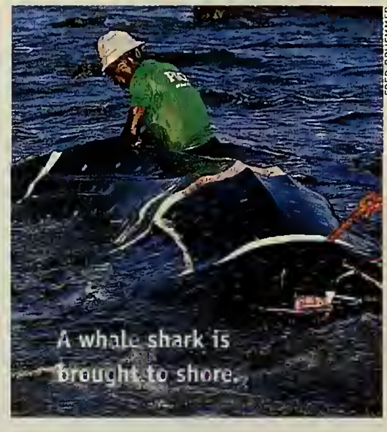
Evan B. Hazard
Bemidji, Minnesota

Good Catch

As a volunteer at a marine laboratory in Florida, I was surprised to see the animal in the photograph on page 56 of "Sea Hunters of Lamalera" (10/01) identified as a pilot whale; the patterns of ridges and spots tell me it is more likely to be a whale shark, the largest species of fish on earth.

I recently lived for four years in the Inupiat community of Barrow, Alaska. Having observed the whaling practices and traditions there, I was interested to read about Lamalera's whaling culture. The two indigenous populations are widely separated geographically, but the traditions of sharing the harvest and of concern for the prey's spirit are quite similar.

Ernie Whitney
Cortez, Florida

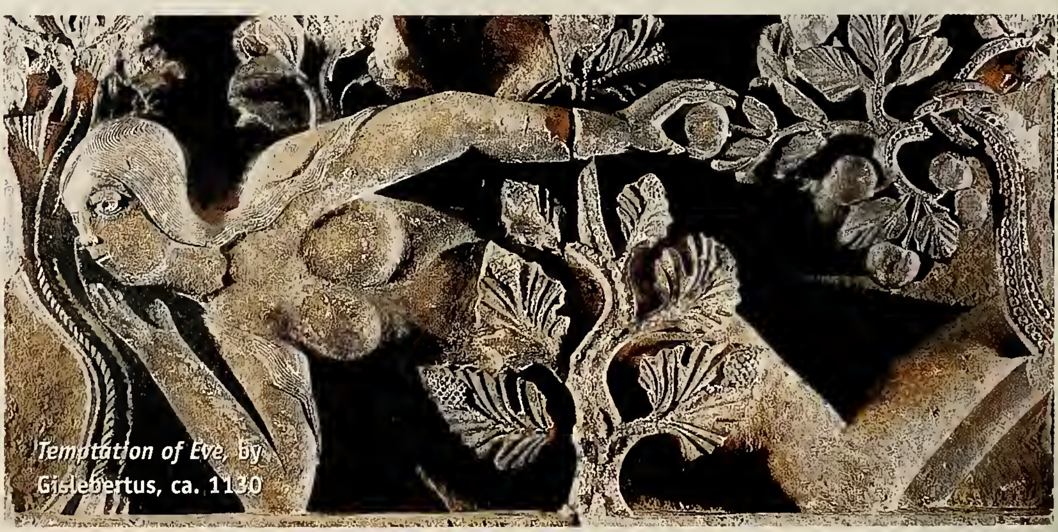


A whale shark is brought to shore.

FRED BRUEMMER

THE EDITORS REPLY: The photograph is indeed of a whale shark. The slide we worked from was captioned correctly by the photographer, but we mislabeled the photograph. We thank you and the other sharp-eyed readers who pointed out the error.

Natural History's e-mail address is nhmag@amnh.org.



Temptation of Eve, by Gislebertus, ca. 1130

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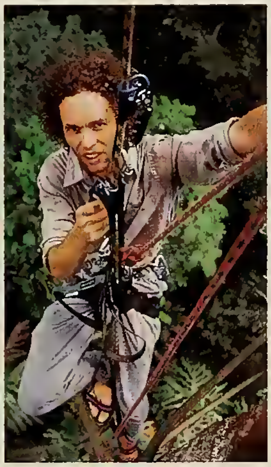

Although he started graduate school with the idea of studying the effects of cattle-grazing on public lands in the western United States, **Lee Dyer** ("In Defense of Caterpillars," page 42) soon concluded that caterpillars were more intriguing herbivores and that tropical forests were more alluring places. Dyer, left, is an assistant professor in the Department of Ecology and Evolutionary Biology at Tulane University in New Orleans. His long-term research projects in Costa Rica, Ecuador, and the state of Colorado—carried out with assistance from Earthwatch Institute volunteers—involve interactions among plants, caterpillars, predators, and parasitoids. **Nic Bishop,** who began taking photographs at the age of nine while living in Sudan, where his father worked for UNESCO, holds a doctorate in plant physiology. He is the author-photographer of about forty books, mostly for children, including *The Secrets of Animal Flight* (Houghton Mifflin, 1997), featuring high-speed photography, and *Digging for Bird-Dinosaurs: An Expedition to Madagascar* (Houghton Mifflin, 2000).

Susan Milius ("Face the Music," page 48) is a life sciences reporter for the weekly magazine *Science News.* She says that when she was growing up, her mother insisted the household keep quiet during broadcasts from New York City's Metropolitan Opera. "The singers sounded so miserable so much of the time," Milius remembers, that she often fled into the woods. As a result, she says, she owes much of her interest in nature to "the emotive powers of the Met's singers." Now, in addition to birdsongs and frog calls, Milius enjoys many kinds of music—from Chinese opera to her nephew's computer creations—but finds only certain recordings conducive to writing. The present article was written under the influence of Miles Davis's "Kind of Blue."

After growing up in Arizona and earning a Ph.D. in zoology at the University of California, Los Angeles, **Harvey B. Lillywhite** ("To Wipe and Wax," page 58) traded the arid Southwest for the southeast coast. Now a professor of zoology at the University of Florida and director of its Seahorse Key Marine Laboratory, he hasn't forgotten his "ecological roots"—his work with wiping frogs addresses a fascinating way of dealing with dry weather. But Lillywhite isn't ecologically constrained; he loves exploring "the raw outdoors," from mountains and deserts to islands and reefs. Currently he is studying the physiological ecology of snakes and frogs and is involved in ecology and conservation projects in northern Florida's Big Bend coastal region.

Joel Cracraft ("Gondwana Genesis," page 64) studies the evolution and biogeography of birds. His interest in the Southern Hemisphere distribution of living avian groups began three decades ago, when he was a graduate student at Columbia University and a postdoctoral fellow at the American Museum of Natural History. Since 1992, Cracraft has been a curator in the Museum's Department of Ornithology and has served as curator-in-charge since 1999. He has done fieldwork in South America and central Africa and conducted long-term studies of birds of paradise in New Guinea. Cracraft has written widely on phylogenetic theory and was co-curator of the Museum's Hall of Biodiversity.

Papua New Guinea, where marine wildlife photographer **Mike Parry** ("The Natural Moment," page 78) was born, abounds with beautiful, diminutive coral-reef creatures. Parry, though, prefers to concentrate on larger subjects and has traveled the world in search of them; two of his favorites are the great white shark and the humpback whale. A lover of blue-water free diving, Parry can spend hours trying to get just the right shot, one that he hopes "captures the animal's spirit on film." But for his photograph of a saltwater crocodile, he had little time to think before diving to within a couple of feet of the reptile.

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AT THE MUSEUM

American Icon

At the centenary of her birth, Margaret Mead is remembered as the world's most influential anthropologist.

By Nancy C. Lutkehaus

Margaret Mead arrived at the American Museum of Natural History in 1926. Having just completed her first significant ethnographic research in Samoa, she was appointed assistant curator in the Department of Anthropology. She was only twenty-five years old. Mead was given a temporary office in an attic room in the Museum's west tower. So well did she like this out-of-the-way office, with its views of the rooftops of New York City and its two stairways (ideal, she said, for creeping down one stairway while someone to be avoided, such as a too-solicitous elderly curator, was laboring up the other) that she stayed there the rest of her life.

Arriving at that same office in 1972 to be interviewed by Mead for a position as her assistant (I was an undergraduate anthropology major at Barnard College), I felt as though finding my way through the maze of the Museum and up the precipitously winding stairs to Mead's inner sanctum must have been a test she'd devised to determine my suitability. Like Mead, I soon grew fond of the office's remote location and the bird's-eye view of the busy streets below. In a way, the tower's position symbolizes Mead's relationship to the Museum and to anthropology: like the tower, which is both part of and set apart from the Museum's overall structure, Mead was part of the institution and the discipline of anthropology yet also apart from them. She felt strongly that both the Museum and her discipline must not just be a repository of artifacts but must engage in finding solutions to challenges facing society.

Over the course of her fifty-two-year association with the Museum, Margaret Mead was a scientist, curator, teacher, author, social activist, and media celebrity. The success of her first book, *Coming of Age in Samoa,* published in 1928, had thrust her into the media spotlight. The book's comparison of adolescence in the South Seas and in the United States made it a best-seller at a time when the public was concerned with the social transformations among Jazz Age youth. In the early 1950s, as television became widespread, Mead appeared on the CBS program *Adventure,* a series produced live from the Museum, to talk about trance among the Balinese and the impact of World War II on social change in remote societies of New Guinea.

Mead's flair for writing and public speaking, combined with her belief that anthropologists and museums should address contemporary social issues, led to her participation—as an expert in human behavior—in United Nations conferences and other international forums and to her acting as a consultant to institutions and organizations worldwide. She discussed the role of the scientist in society, the changing nature of the family, racial inequality, peaceful alternatives to war, population growth, environmental degradation, and the creation of humane human set-

KEN HEYMAN

Margaret Mead in the Museum's old sixth-floor storage area, 1959

tlements. Her wide-ranging concern for humanity led *Time,* in 1969, to declare Mead "mother to the world."

It is thus not surprising that when the Museum celebrated its 125th anniversary in 1995 by publishing a guidebook to fifty of its treasures, Margaret Mead herself is listed as treasure no. 38, right between the Folsom Point (treasure no. 37) and the Peregrine Falcon Diorama (treasure no. 39). The guidebook states that Mead "brought the serious work of anthropology into the public consciousness" through her books, the courses she taught at Columbia University, the articles she wrote in a monthly column for *Redbook,* and the frequent interviews with her that were published in magazines and newspapers and broadcast on radio and television.

When I visited the Museum last spring, the newly renovated Hall of the Peoples of the Pacific—which had opened in 1971, decades after Mead began planning it—had recently reopened. I was pleased to see that the hall now incorporates Mead in the exhibition. Continuous videotapes show interviews with her and about her. Photographs of Mead and the people she studied, quotes from her notes and lectures, and artifacts she collected give the viewer insights into the process of doing fieldwork and add a social and historical context to her life.

Artifacts of Mead's own life are also presented—the Presidential Medal of Freedom that she received posthumously from President Jimmy Carter, as well as her signature red cape and stick. The label reads: "In her later years, Margaret Mead regularly wore a cape and used a style of walking stick often called a thumbstick. Those two items became a familiar sight as Dr. Mead traveled about for her numerous lectures and conferences."

Margaret Mead used to joke that when she didn't want to be recognized, all she had to do was leave her cape and thumbstick at home. How fitting that she has become both a Museum treasure and an artifact.

Nancy C. Lutkehaus is chair of the gender studies program and an associate professor in the Department of Anthropology at the University of Southern California. She is the author of the forthcoming Margaret Mead and the Media: Anthropology and the Creation of an American Icon.

MUSEUM EVENTS

DECEMBER 3

Lecture: "Our Cosmic Habitat" (Distinguished Authors in Astronomy series). Astronomer Royal Martin Rees, Royal Society research professor, University of Cambridge. 7:30 P.M., Space Theater, Hayden Planetarium.

DECEMBER 4, 6, 7, 8, AND 11

Panel discussion: "Using the Genome to Understand Human Ancestry." Moderated by Nicholas Wade, *New York Times* science reporter, with anthropologist Ian Tattersall, AMNH; biologist Andrew Clark, Pennsylvania State University; Douglas Wallace, Center for Molecular Medicine, Emory University; and evolutionary biologist Joseph Graves Jr., Arizona State University West. December 4, 7:00 P.M., Kaufmann Theater. Presented in conjunction with the exhibition "The Genomic Revolution" (on view through January 1, 2002, in Gallery 3). Workshops on genetics: December 6 and 7, 9:00–11:00 A.M. and 7:00–9:00 P.M., and December 8, 9:00–11:00 A.M.; follow-up explanation session, December 11, 7:00 P.M.

DECEMBER 8

Roundtable presentation: "Border Crossing: Cultural Appropriation and Artistic Freedom in Arts, Media, and Literature of Indigenous and Latina Women" (Identities Beyond Borders series). Moderated by writer Helena Maria Viramontes, Cornell University, with artist participants Nadema Agard, Maria Dominguez, and Carol Kalafatic. 1:00–3:00 P.M., Linder Theater. Gallery visit to "Who Is the Virgin of Guadalupe? Women Artists Crossing Borders," Henry Street Settlement Abrons Art Center, 4:00–6:00 P.M. Shuttle from AMNH at 3:15 P.M. For reservations and information, call (212) 769-5315 or see www.amnh.org/programs.

DECEMBER 17

Lecture: "The Hubble Time Machine" (Frontiers in Astrophysics series). Astronomer James Lowenthal, University of Massachusetts, Amherst. 7:30 P.M., Space Theater, Hayden Planetarium.

DECEMBER 18 AND JANUARY 29

Lectures on upcoming sky events: "Celestial Highlights." Hayden lecturer and amateur astronomer Hank Bartol. 6:30 P.M., Space Theater, Hayden Planetarium.

DECEMBER 29

Kwanzaa celebration: Performances, workshops, and marketplace for this African American holiday. 12:00–6:00 P.M., Hall of Ocean Life. For a schedule of events, call (212) 769-5315 or visit www.amnh.org/programs.

JANUARY 7

Lecture: "The Riddle of the Compass" (Distinguished Authors in Astronomy series). Author and mathematician Amir D. Aczel. 7:30 P.M., Space Theater, Hayden Planetarium.

JANUARY 12–13 AND 26–27

Weekend programs: "America As Home." Arab American and South Asian community-based organizations present films, artist talks, panel discussions, and readings and performances. Leonhardt People Center.

JANUARY 15

Lecture: "One Universe." Neil deGrasse Tyson, the Frederick P. Rose Director of the Hayden Planetarium, and Charles Liu, AMNH Department of Astrophysics. 7:00 P.M., Kaufmann Theater.

JANUARY 19

Lecture/demonstration: "Through Time and Space" (Following the Beat series). Based on instruments in AMNH's Hall of African Peoples. Percussionists Neil and Ayanda Clarke. 1:00–3:30 P.M., Leonhardt People Center.

JANUARY 24

Lecture: "Aquagenesis: The Origin and Evolution of Life in the Sea." Marine biologist and artist Richard Ellis, AMNH Division of Paleontology. 7:00 P.M., Kaufmann Theater.

DURING DECEMBER/JANUARY

The Museum's Origami Holiday Tree, decorated with 1,500 folded-paper animals, is on display in the Theodore Roosevelt Memorial Hall.

Teachers resource: *Musings,* a Web newsletter for science educators, at www.amnh.org/learn/musings.

University Without Walls: Telephone courses on natural sciences and anthropology. The Museum's Department of Education and DOROT, a nonprofit serving the elderly. For information, call DOROT at (212) 769-2850 or toll-free (877) 819-9147.

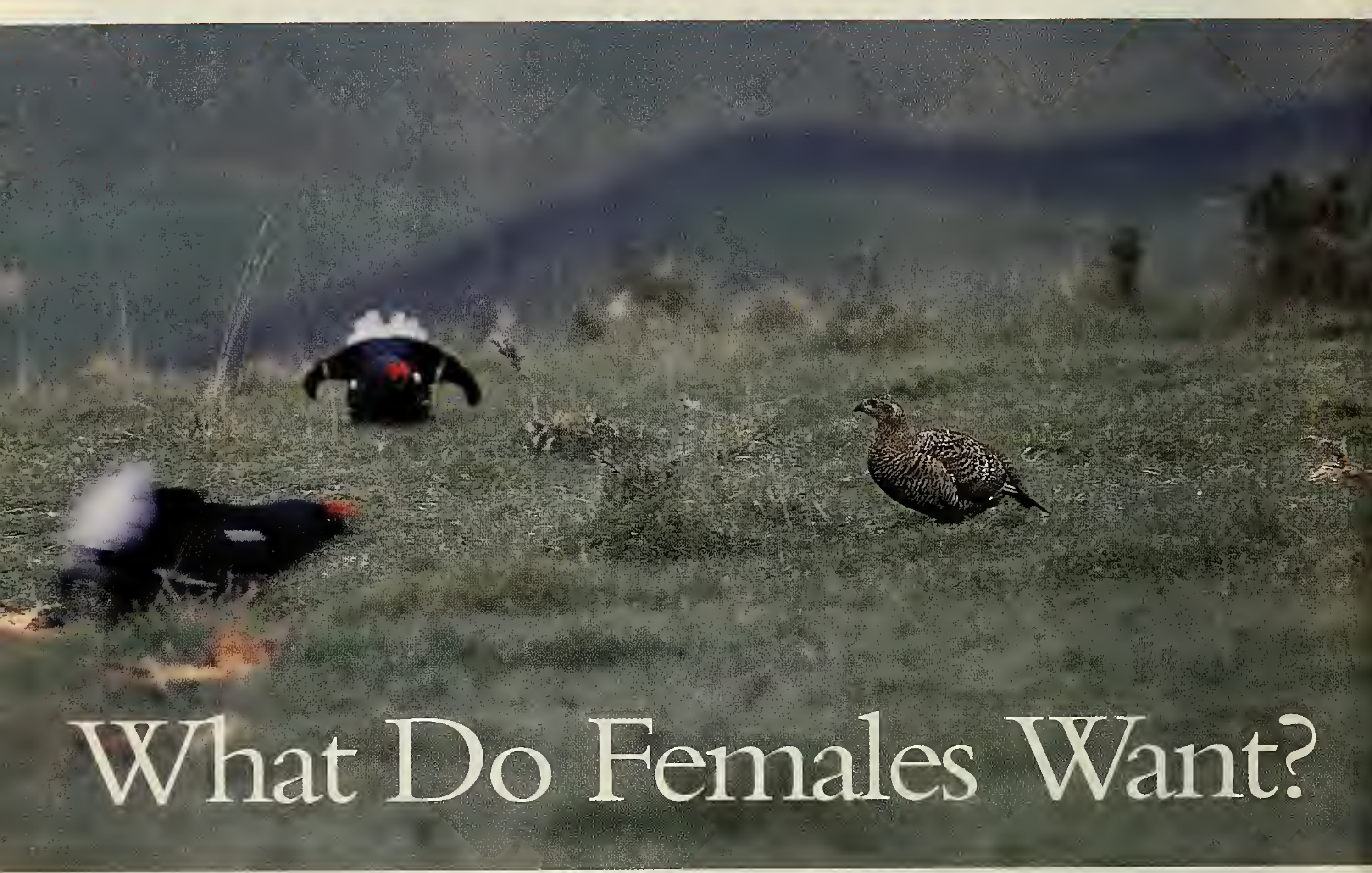
Field trips, walking tours, and workshops for children and adults, both inside and outside the Museum. Call (212) 769-5200 for information.

Planetarium courses (beginning in January): "How to Choose a Telescope," "Stars, Constellations, and Legends," and many others. For complete course descriptions, visit www.amnh.org/hayden/.

For news from the Center for Biodiversity and Conservation, go to research.amnh.org/biodiversity/center/newsletter/webletter.html.

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

FINDINGS



What Do Females Want?

Does a male's long tail or flashy coloration advertise his good genes? New research challenges the old answers.

By Robert M. Sapolsky

To readers of *Cosmo* and *Animal Behaviour*, it must be quite obvious that females the world over are concerned about finding the right mate. For females in pair-bonding species (such as swans, which mate for life, or monogamous South American monkeys), competency at fatherhood is a potential mate's most desirable quality. In many of these species, courting males display paternal skills: male lovebirds, for example, snatch worms and pretend to feed them to a desired female.

But selecting a good co-parent is also high on the list for female *Homo sapiens*—a species that hardly rates as a textbook pair-bonder. About a decade ago, psychologist David M. Buss published a celebrated study examining the attributes that men and women desire in a mate. He canvassed more than 10,000 people, from thirty-seven different cultures—people of different races, religions, and ethnicities; people living in urban and rural settings, Western and developing nations, capitalist and socialist economies, monogamous and polygamous family arrangements. And in every society Buss examined, he found that women were more likely than men to consider economic prospects a high priority in a mate. This was interpreted as a sign that human females universally want mates who will be effective breadwinners. (As one might imagine, Buss's study generated all sorts of unsettling accusations of political incorrectness.)

And even in social species that don't pair off to reproduce, females often choose a particular male on the basis of how well he is likely to treat them or their offspring. For a female olive baboon, for example, a prize catch would be a male that, when in a foul mood, directs his aggression toward some other female rather than toward her. But what about species in which a female isn't going to be getting any paternal assistance out of her mate or even having much contact with him down the line? In such species, males are not integrated into social groups. (The typical arrangement, such as that of golden hamsters, is a

Male black grouse attempt to impress a female.

BOBBY SMITH; ARDEA LONDON, LTD.

stable group of females with a single breeding male that is likely to be booted out by some other male long before his own young are born—a social structure that sociobiologists typically call a harem but that primatologist Alison Jolly suggests should instead be called a "gigolo group.") All the female gets out of the brief liaison with her mate is some sperm packed with genes. So what does such a female desire in a male? Good genes, of course. The age-old problem for these females is how to figure out which males have the good genes, and in species after species, males try to advertise theirs. Peacocks spread their gorgeous tail fans; male lions have their elaborate manes, elk their ornate antlers. But are such features merely ornamental, serving no useful purpose beyond sexual attraction? The question that has long vexed evolutionary biologists is whether these ornaments actually tell you anything about the genetic health of a male. In other words, is there truth in advertising?

In 1930 British statistician and geneticist Ronald Fisher, one of the most influential evolutionary thinkers of the past century, postulated that fancy ornamentation is actually something a female should *not* be attracted to, because a

The son of an attractive male guppy is significantly less likely to survive than the average male.

male animal's huge energy expenditure to grow and maintain it would have a price tag in terms of his survival—his Darwinian fitness. According to this view, if the male has spent a lot of calories on growing the biggest tail or antlers or whatever, he couldn't possibly have spent enough on something sensible, such as keeping his immune system well tuned. While Fisher's view has generally fallen out of favor, some striking support for it has recently emerged. Robert Brooks and John Endler, of James Cook University in Australia, studied sexual attractiveness in male guppies of the species *Poecilia reticulata*. They first showed that the males with the fanciest color patterns were considered the most attractive by females and that they sired sons that were likely to be especially attractive. Color patterning, the scientists determined, is heritable and may be sex-linked, coded for by a cluster of genes on the male's Y chromosome. Then Brooks found something that was surprising enough to get published in the journal *Nature* (6 July 2000): sons of attractive males are significantly *less* likely to survive than are average *P. reticulata* males. And it isn't even the case that once they get this ornamentation, they are more likely to be killed by a predator (a frequent cost of being flashy and conspicuous). Their survival rates are lower than average even *before* they reach sexual maturity and develop the coloration. So Brooks's guppy experiment stands as one example in support of the significant cost of attractive ornamentation.

Another view is that such decorations don't tell you much—good or bad—about a male's genes. Rather, they say something about fads. Jacob

A female guppy (left) and a male

PAUL ZAHL; PHOTO RESEARCHERS, INC.

Höglund and Arne Lundberg, of Uppsala University in Sweden, thought up an interesting experiment. Pair up female and male black grouse that have no chemistry—the female isn't interested in the male. Now use low-tech scientific artifice to turn him into a male that appears to be highly desirable—that is to say, surround him with ostensibly rapt females (a gaggle of stuffed female birds)—and that indifferent live female suddenly decides he's kinda cute after all. It's a bandwagon effect. This seems to mean that if all the other females of your social group decide that males with neon antlers are a hot commodity (even if you think they look ridiculous), it is to your fitness advantage to mate with someone like that. After all, if neon antlers on males are suddenly all the rage, you want your sons to have them in order to maximize the passing on of copies of your own genes. By this circular logic, a trait becomes attractive because it's attractive because it's attractive . . . even if it carries no information about the health or genes of the carrier.

Still another possibility is that attractive ornamentation really does translate into something meaningful and desirable about a male. Health may be the message: "You can bet I'm in good health if I can afford to waste all this energy growing these three-foot-long tail feathers." In 1982 Marlene Zuk and W. D. Hamilton, one of the gods of evolutionary biology, formalized this into the notion that conspicuous and expensive ornamentation in males signaled that they were free of parasites (see "A Charming Response to Parasites," April 1984). Why should a female find this appealing? Because it decreases the likelihood that *she'll* wind up with parasites after cozying up to the guy. All sexually reproducing organisms need to worry about sexually transmitted diseases; the more evolutionarily significant version of this basic theme is that attractive ornamentation signals not only good health but good genes to be passed on to the next generation. Evolutionary biologist Amotz Zahavi, of Tel Aviv University in Israel, posits that females have evolved the ability to differentiate between ornamentation that genuinely reflects good genes and the kind that instead suggests bad genes or an acquired trait.


Peacock and peahen

FRANS LANTING; MINDEN PICTURES

Does attractive ornamentation sometimes translate into good genes? Theoretically, at least two methods could give you the answer to this question. Using the first, you isolate the gene(s) responsible for the attractive trait in males of a certain species. You then look for other genes that are clustered nearby and that tend to be inherited along with the attractiveness gene(s) in a statistically reliable way. You figure out the function of the proteins coded for by those neighboring genes and whether these proteins are particularly advantageous. And soon you'll be part of some zillion-dollar race to sequence the animal's genome.

Or you can do it the old-fashioned way. Carry out a study in which females are mated and have offspring with males of differing attractiveness. Then see whether the attractive males father young that are more "fit"—that is, more likely to survive to adulthood and to produce their own offspring. If they do, you've got a pretty good reason to conclude that the more attractive males pass on a more adaptive assemblage of genes. And this is exactly what a number of studies have shown, casting a big vote in favor of the good-looks/good-genes hypothesis.

Yet some startling revisionism has recently crept into that hypothesis. One example is a study of ducks, done by Emma Cunningham and Andrew Russell, then of the University of Sheffield, and also published in *Nature* (2 March 2000). They found that the offspring of male mallards that were particularly attractive to females have a trait that considerably increases their likelihood of survival. So, more votes for the good-looks/good-genes hypothesis. What was that trait? When females mated with these males, they laid large eggs, a factor that definitely increases the fitness of the offspring. But wait—egg size is a trait determined by the *female,* not the male. When females mated with more attractive males, they apparently invested more energy in the resulting offspring, making it more likely that these young would survive. In fact, when Cunningham and Russell controlled for egg size, they found no difference in survival between the offspring of the most and the least attractive males.

When zebra finch females mated with attractive males, they produced eggs with more growth-promoting hormone.

In a similar study published in the journal *Science* (1 October 1999), Diego

WILLIAM PATTON/SURVIVAL ANGLIA; OXFORD SCIENTIFIC FILMS

Gil and colleagues at the University of Saint Andrews in Scotland studied zebra finches and found that the offspring of the more attractive males begged for more food, grew faster, and were more likely to be dominant once they fledged. Again, where is this coming from? The scientists found that when females mated with the more attractive males, they developed eggs that contained more growth-stimulating hormone. And then there's the work by Félix de Lope, of the Universidad de Extremadura in Spain, and Anders Moller, of Université Pierre et Marie Curie in France, showing that when female barn swallows mate with more attractive males, they take better care of the resulting chicks.

All this is actually a logical extension of the bandwagon effect uncovered by Höglund and Lundberg. For starters, if everyone in your species "wants" to mate with males that have some trait that doesn't necessarily seem attractive to you, it's still in your best genetic interest to mate with these males so that your sons have the desirable trait. And if everyone in your species "knows" that more attractive males make for offspring that carry better genes, and if you've mated with an attractive male, it's in your best genetic interest to invest as much as possible in the well-being of those offspring.

The challenge, of course, is to figure out how a female knows she has mated with a more attractive male and how this translates into the differential investment in her young. How does that "knowledge"—on whatever level it exists in the brain of a bird—translate into synthesizing more growth hormone in a gland or going the extra mile to find the offspring something to eat? We have here the classical dichotomy between a proximal and a distal level of explanation in biology. The distal level—large, evolutionary concerns—is simple. By investing more in offspring with traits that are more reproductively desirable, females can enhance the passing on of their genes. But the proximal level—how that evolutionary logic translates into the nuts and bolts of hormones and neural pathways in a particular animal—is a great mystery at this point.

Studies of egg size, the amount of growth hormone in eggs, and parental investment generate serious problems for the good-looks/good-genes hypothesis. When Cunningham and Russell found that females with attractive mates grew bigger eggs, at first it raised the possibility that the underlying logic was, "Everyone knows that more attractive males make kids with better genes, so I have to make sure these kids survive." But the researchers then found that the father's attractiveness had no effect on hatching success, survival, or growth. Maybe good genes really *don't* exist.

Findings such as Cunningham and Russell's do not disprove the theory that more attractive males have better genes; quite possibly they do, most of the time. But these findings have uncovered a major alternative explanation for what has been observed—one that must now be ruled out in every subsequent study on the subject: if the offspring of attractive males are more fit, is it because the female has invested more energy in their survival?

So lots more research is needed, both to see how much the parental investment factor confounds the supposed cases of good genes and to understand the physiology behind females' differential investment in offspring and how it relates to the attractiveness of the father. In the meantime, exasperation seems unavoidable. It's bad enough that males with longer tail feathers get more action, but they also get acclaimed for having better genes when this may not actually be the case.

Self-fulfilling prophecies spring up in all sorts of settings. Everyone "knows" that boys are biologically better at math than girls are, and studies have shown that teachers are more likely to praise young boys than young girls for the same math performance. And guess what? By the time they reach high school, boys score better than girls on standardized math tests. Is this due to a biological difference or to the different environment? Here's another example that has always amused me (it's from the medical anthropology literature): In certain traditional cultures, everyone "knows" that shamans are able to induce voodoo death (aka psychophysiological death). So when someone has a voodoo hex put on him, everyone knows he's a goner, and they withhold food from him—why waste a limited resource?—to the point of his weakening and dying from one ailment or another. Is such a death due to the efficacy of a voodoo curse or to this additional intervention? Not clear, but you can bet the shaman's hex fees go up.

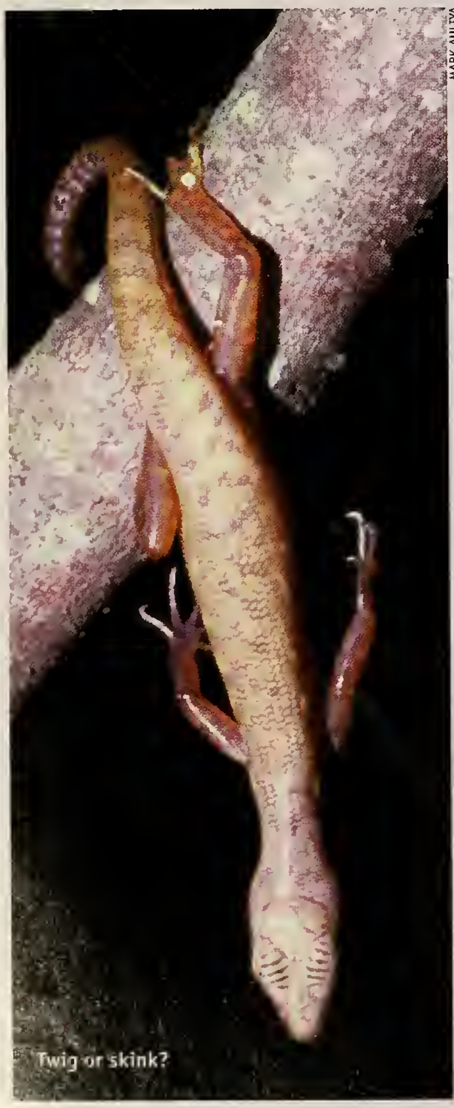
One sees such confusions popping up in all sorts of realms of human illogic. I'm just disappointed to see female mallards and zebra finches falling for something this obvious. They should know better than that.

Robert Sapolsky is a professor of biology and neurology at Stanford University. His latest book is A Primate's Memoir (Scribner, 2001).

IN SUM

TWIG MIMICS Reptiles have evolved an assortment of strategies for discouraging, avoiding, or escaping from predators. Certain snakes have bright colors that warn of venom; others feign death when threatened. Many lizards have sharp spines, and some attempt to frighten predators with sounds. Still others opt to run away and hide.

Andreas Schmitz and Mark Auliya, from the Zoologisches Forschungsinstitut und Museum Alexander Koenig in Bonn, Germany, recently described the unusual escape tactics of the shy diurnal skink *Sphenomorphus sabanus*. Auliya observed this behavior in a swampy forest in West Kalimantan, Indonesia, while he was studying another reptile species. One night he happened to see, by the glow of a flashlight, an *S. sabanus* scampering along the branch of a tree, attempting to flee. Then it stopped suddenly and hung upside down; clinging to the branch with its hind claws, the lizard resembled a small, dry twig. After a few moments, it stopped doing its twig impression and darted away. The finding was hardly a surprise to local villagers—they confirmed that these skinks use imitation to avoid detection.



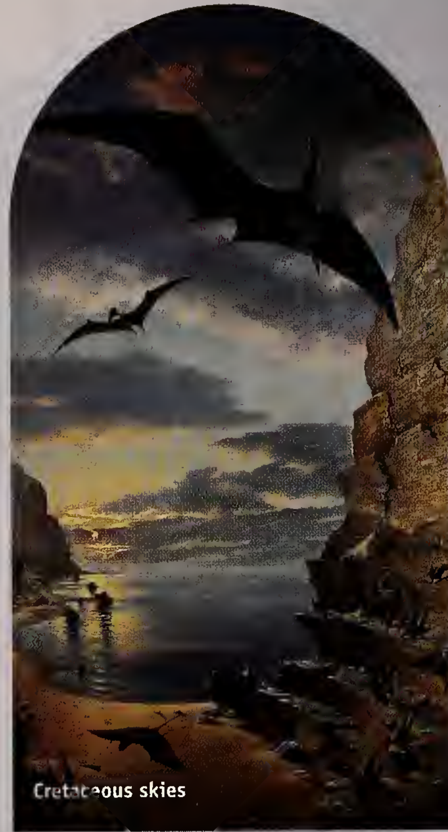
MARK AULIYA

Twig or skink?

Even though a few species of geckos also mimic twigs or leaves to avoid predators, the strategy is quite rare. Most lizards that reside in trees drop to the ground when threatened. The researchers suggest that the advantage of *S. sabanus*'s escape route may be its novelty. If predatory birds expect their prey to fall to the ground, Schmitz and Auliya's argument runs, they would be unlikely to notice a lizard still hanging from a branch. The cryptic posture might make these skinks invisible to tree-dwelling predators as well. ("An Unusual Escape Reaction Observed in *Sphenomorphus sabanus* [Reptilia: Scincidae] in Indonesia, With Taxonomic Comments," *Herpetological Bulletin* 76, 2001)—*Kirsten L. Weir*

PTREMENDOUS A recent dig near Valencia, Spain, has uncovered a previously unknown pterosaur that may be the largest animal ever to have taken wing. Workers digging in siltstone dating from the very late Cretaceous found vertebrae and limb bones indicative of a new species and genus of azhdarchid pterosaur, with the wingspan of individual adults ranging from sixteen to forty feet. This degree of variation is typical of several genera of flying reptiles, but the width is the greatest yet seen (the largest previously known specimen, *Quetzalcoatlus northropi*, had a wingspan of thirty-six feet). David Unwin, of Humboldt-Universität zu Berlin in Germany, one of the researchers who made the find, is suggesting that the variable and sometimes great size of these pterosaurs may be attributable to the animals' unusual sensitivity to their environment during growth.

Unwin's suggestion would account for both the variation within species and the size of the largest individuals. The duration and extent of

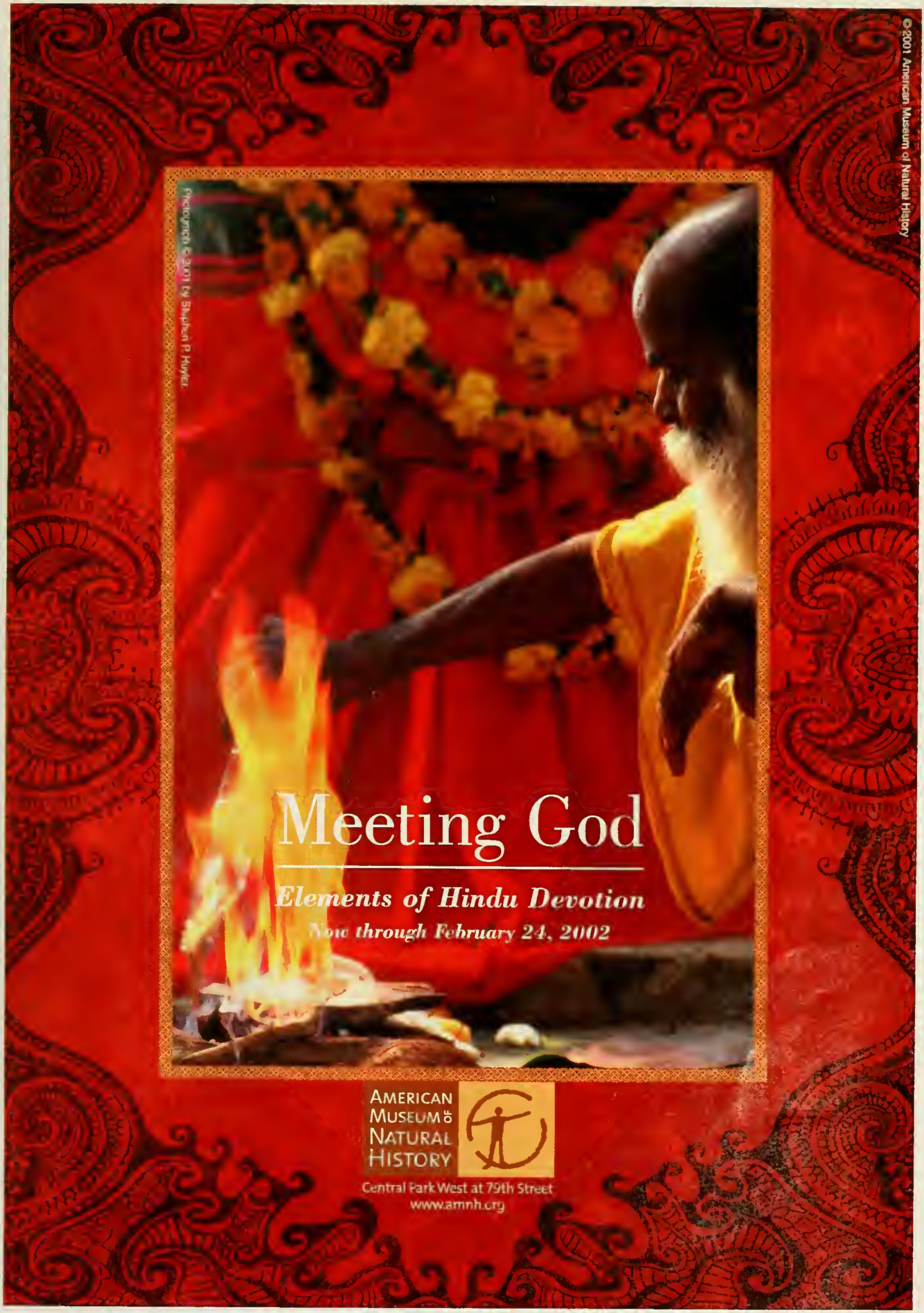


AMNH

Cretaceous skies

growth in modern turtles, crocodiles, and other groups related to the pterosaurs is heavily influenced by environment (temperature, food availability), and Unwin thinks that pterosaurs shared that susceptibility, even though adult body size in other groups of flying vertebrates, including both living and extinct bats and birds, varies little and is largely independent of environmental influences. (Abstracts of "A Giant Azhdarchid Pterosaur From the Latest Cretaceous of Valencia, Spain—The Largest Flying Creature Ever?" and "Variable Growth Rate and Delayed Maturation: Do They Explain 'Giant' Pterosaurs?" Sixty-First Annual Meeting of the Society of Vertebrate Paleontology, 2001)—*T. J. Kelleher*

HOME SWEET FOSSIL HOME Large or small, landlubbers or seafarers or both, hermit crabs have one feature in common: they generally spend their lives inside the empty shells of snails or other mollusks. When these crabs grow too large for one adopted home, they search for another. But if high-quality shells are in short supply, they must improvise. Some make do with a broken shell or even with a piece of bamboo or a hollow mangrove root. Now there is evidence that at least one type of hermit crab has found another solution.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Zoologist David K. A. Barnes, of University College Cork in Ireland, recently discovered that the large, semiterrestrial hermit crab *Coenobita rugosus* sometimes moves into fossilized marine snail shells that have fallen out of the eroding coastal limestone of southwestern Madagascar.

Barnes found that the crabs preferred the shells of local mollusks, but when these mod-

DAVID K.A. BARNES

Broken home

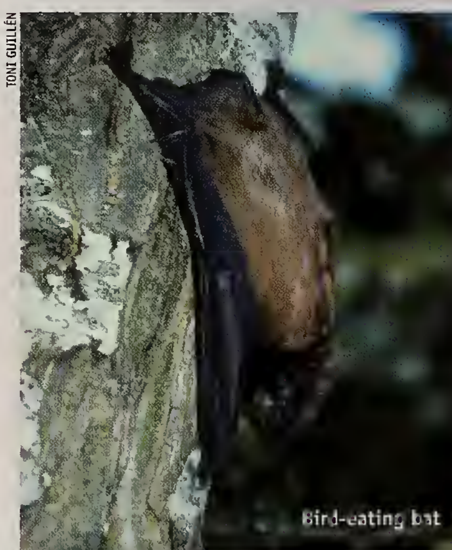
ern homes weren't available the hermits inspected fossil shells for suitability and sometimes moved into them (though nearly all the fossils Barnes examined had structural hindrances that made them unusable). He predicts that this curious behavior may eventually change, however. Local fishermen collect mollusks along the shore and, working at the high-tide mark, remove the living animals from their casings, leaving behind piles of empty shells. Most are too large for hermit crabs. But as fishermen increasingly exploit the local mollusk populations, they'll soon have to settle for smaller animals. In time, the discarded shells may be diminutive enough to provide homes for hermit crabs, freeing them from the need to survey the emerging fossils. ("Ancient Homes for Hard-up Hermit Crabs," *Nature* 412, 2001)—*Kirsten L. Weir*

IN-FLIGHT MEAL Though bats and birds are both aerial creatures, records of their interaction have been extremely rare. Carlos Ibáñez, of the Estación Biológica de Doñana in Seville, Spain, and fellow researchers have demonstrated that a large, carnivorous European bat is interacting regularly with certain groups of birds. In a massively messy undertaking, these scientists have sifted through 14,000 guano samples from the bat species known as the greater noctule *(Nyctalus lasiopterus)*, hoping to identify what the bats were feeding on every night: flies, moths . . . birds? They found that the bat droppings contained quite a few feathers, particularly during the two periods a year when flocks of small passerines make their seasonal migrations, mainly at night, through the bat's Mediterranean domain.

A few species of tropical bats occasionally capture and consume roosting birds, but *N. lasiopterus* is the only bat now known to regularly prey on birds in temperate climates. It may in fact hunt and attack a bird while both animals are in flight.

Ibáñez's group studied the wing shape and sonar patterns of the greater noctule and found that they differ significantly from those of other carnivorous bats. *N. lasiopterus* has a long, low-frequency echolocation call, making it well equipped for detecting airborne prey at considerable distances. In addition, the wings of the greater noctule—designed for speed—lack the maneuverability that would be required for hunting a bird in a confined nesting space. According to Ibáñez et al., this rare bat made an easy transition from hunting large insects to capturing small birds in midair. ("Bat

TONI GUILLÉN



Bird-eating bat

Predation on Nocturnally Migrating Birds," *Proceedings of the National Academy of Sciences* 98:17, 2001)—*Erin M. Espelie*

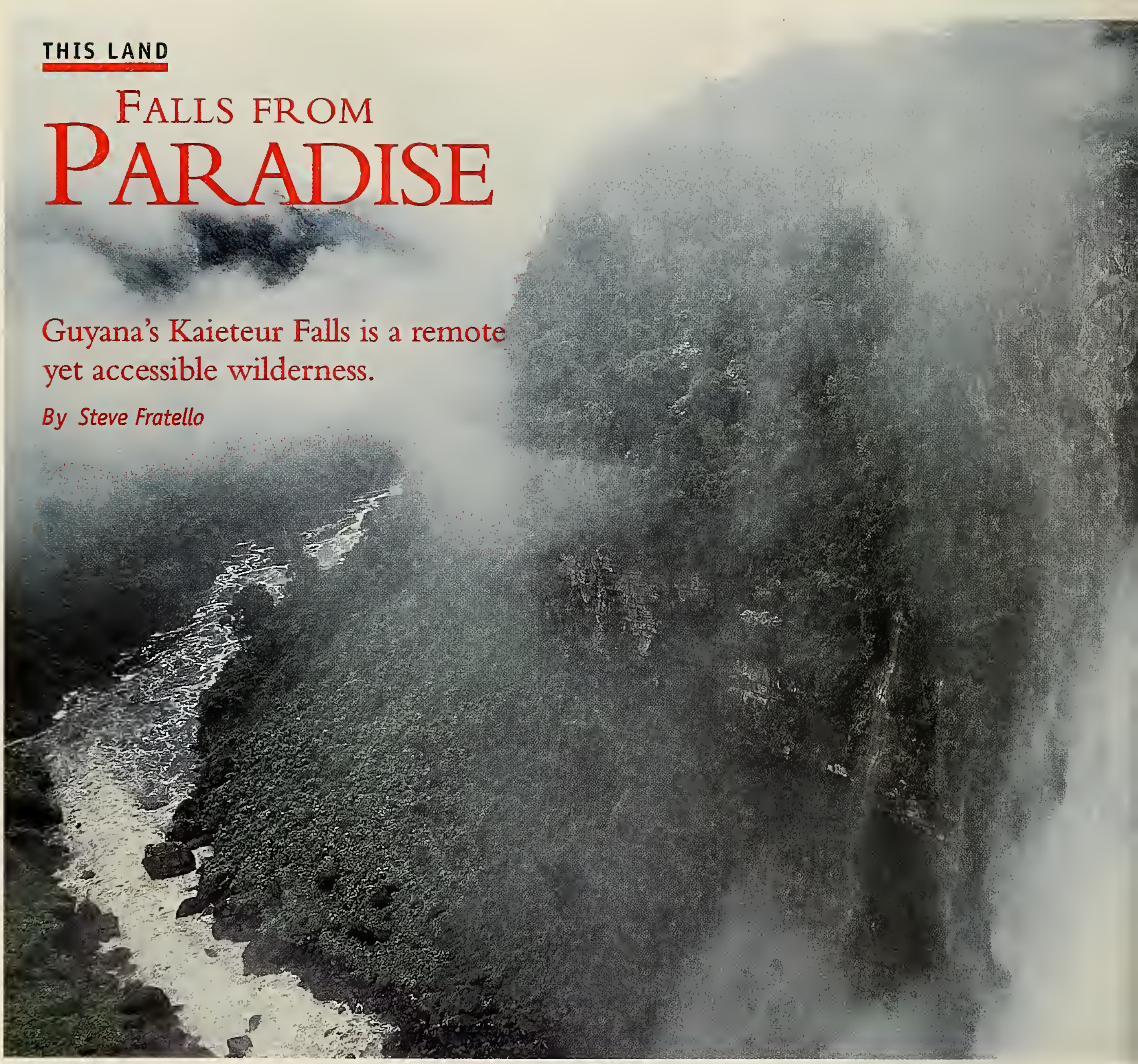
HOW TO SAY I LOVE YOU Firefly courtship is built on bioluminescence, but scientists are unsure what controls the glow. Fireflies are flashers, and their abdominal lantern, or light-producing organ—permeated by nerve cells and equipped with a trachea—is made up of cells containing luciferin, a protein that emits light in the presence of oxygen. Just inside the walls of these cells, called photocytes, are masses of mitochondria—the cells' powerhouses—which need oxygen to do their work. Normally they grab hold of any incoming oxygen. Until recently, no one knew how oxygen could pass deep into the photocytes, where the luciferin is, and cause the cells to glow.

KEITH KENT/SPL; PHOTO RESEARCHERS, INC.

Barry Trimmer, of Tufts University, and colleagues became interested in the process after noticing similarities between caterpillars' brain cells, which use nitric oxide (NO) as a signal, and the cells controlling the fireflies' lantern. They found that exposing live fireflies to NO gas caused the lantern to glow continuously. Many insects synthesize NO for use as a neurotransmitter; whether this molecule signals the fireflies' photocytes to glow wasn't clear. Even when the insects' nervous system was removed and the lantern exposed to NO, the organ still glowed—indicating that NO gas was not causing nerves to fire. Introduction of octopamine, a known firefly neurotransmitter, caused flashing, which was stopped by adding a substance that absorbed the NO. The scientists speculate that NO bonds more readily to the mitochondria than oxygen does; unable to bond there, oxygen drifts to the organelles that house the light-emitting luciferin. As for why the flash stops, they propose that either the increased oxygen accelerates degradation of NO or that the flash of light may reverse the bonding of the gas to the mitochondria. ("Nitric Oxide and the Control of Firefly Flashing" and "NO Helps Make Fireflies Flash," *Science* 292, 2001)—*T. J. Kelleher*

THIS LAND

FALLS FROM PARADISE



Guyana's Kaieteur Falls is a remote yet accessible wilderness.

By Steve Fratello

About 150 miles inland from the coast of Guyana (formerly British Guiana), the Potaro River plunges 741 feet in one drop over a sandstone cliff. This is Kaieteur Falls, one of the most spectacular cataracts in the world. According to a legend of the Patamona Indians, it was named for Kaie, a chief who saved his people by paddling over the falls in an act of self-sacrifice to Makonaima, the great spirit. Upriver from the falls, the Potaro Plateau stretches out to a distant escarpment of the Pakaraima Mountains, while below yawns the great Kaieteur Gorge, swathed in luxuriant rainforest.

As a naturalist who has visited Guyana's interior many times, I have had the good fortune to linger in this wilderness on several occasions. Although hiking down into the gorge presents something of a challenge, an airstrip on the plateau enables anyone to see the falls, a one-and-a-half-hour flight by small plane from Georgetown, the nation's capital. A national park was established in 1929 to protect the area, and recent legislation expanded the total coverage to 242 square miles. Although the park exists more on paper than in reality, plans are being drawn up to conserve its unique community of plants and animals and to develop ecotourism.

The 1,500-foot-high Potaro Plateau lies within the eastern Guiana Highlands, which cover most of southeastern Venezuela as well as the

BILL CURTSINGER

Kaieteur Falls' 741-foot drop

bordering territory in northern Brazil and western Guyana. In this huge area, more ancient rock is largely overlain by the Roraima Formation—rock (mostly layers of sandstone) that erodes relatively easily. This has resulted, particularly in Venezuela, in the creation of the famous *tepuis*—sheer-sided, table-topped mountains that, like islands, bear distinctive vegetation.

On the plateau, patches of sandy soil near the falls support both scrubby forest and savanna that contains grasses, sedges, scattered shrubs, some small trees, and areas of exposed rock where vegetation appears during the rainy season. Right next to the savanna, at the brink of the gorge, is a patch of low-elevation cloud forest. Sustained by the mist from the falls, it drips with epiphytes—mosses, ferns, aroids, orchids. Farther upriver the alluvial forest is dominated by the large-buttressed mora tree, while the forest in the gorge below is mixed or dominated by species of wallaba.

A number of terrestrial orchids live on the savanna, but the most eye-catching plant is *Brocchinia micrantha*, a thick-stalked terrestrial bromeliad that can grow twelve feet high. Found here and at some nearby areas, this plant collects water in a "tank" formed by the base of its leaves. The tank is often home to the small golden frog *(Colostethus beebei)* and to the world's largest bladderwort, *Utricularia humboldtii*. The bladderwort's lavender flowers adorn a stalk that may rise six feet above the bromeliad's tank.

Among the animals on the plateau is the savanna fox, a species widespread in South America and only distantly related to the foxes of the Northern Hemisphere. It is better known as the crab-eating fox—only because the first specimen described had a crab in its stomach. While sightings of this and other mammals are apt to be rare on a short visit, by sitting at the edge of the escarpment one might observe a troop of red howler monkeys moving quietly through the canopy far below.

More likely to be seen or heard on the plateau is the little chachalaca, a gallinaceous bird named in part for its noisy call. The rocky forest and rock outcrops near the falls provide the perfect habitat for the Guianan cock-of-the-rock, a medium-sized, flaming orange bird. During the breeding season, small groups of males gather in leks (courting areas), where they display for the females. I have seen four or five males together in one small, scrubby tree close to Johnson's Lookout, a vantage point that affords a picture-postcard view of the falls.

From the escarpment, one can also see birds flying across the gorge—such as red-and-green macaws. I've observed a pair of orange-breasted falcons that nest on the cliff face next to the falls. They probably prey mainly on the white-collared and other swifts that make their home on the cliffs and behind the falls. These insect-eating birds fill the air at dawn and dusk, and

FLIP DE NOOYER; FOTO NATURA

An aerial view

as night falls they sweep down at amazing speed to settle in their roosts.

Butterflies, including glorious morphos, abound in the gorge. In one ravine, within a few minutes, I've spied nearly all the seven or eight species of morphos present, among them *Morpho hecuba*, South America's largest butterfly, with wings that span eight inches. The upper side of this majestic glider is a rich dark brown, with a flamelike burst of russet and pearl. Blue morphos include *M. rhetenor*, whose glittering royal-blue wings are among the most brilliant sights on earth.

Standing deep in the gorge on a white sand beach, with the dark waters of the Potaro roiling by, I've surveyed lush green glades of grasses and sedges that line rocky side channels of the river. I've watched as the *Inga* trees at the river's edge, their contorted branches heavily laden with epiphytes, attracted myriad butterflies and skippers to their delicate blossoms.

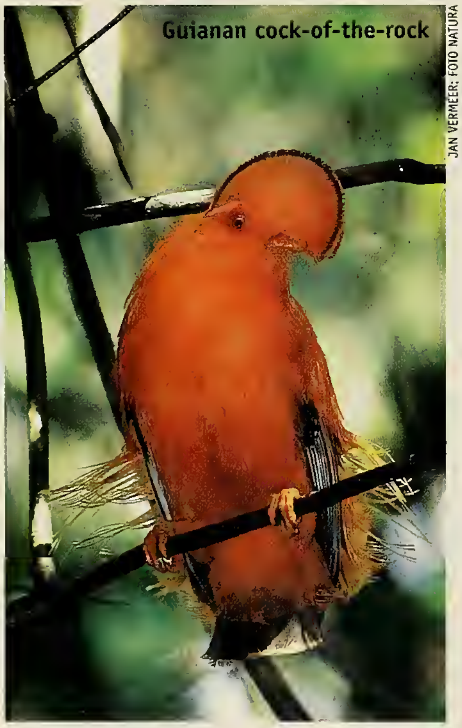
JOE LEMONNIER

Looking across the river to the billowing crowns of the mighty mora trees, I've let my gaze wander up the green slope to a smaller falls called Old Man's Beard, which cascades in tiers off the escarpment. All this plus Kaieteur Falls—if this isn't a paradise on earth, what is?

Naturalist Steve Fratello has explored various rainforests, especially within the Neotropics. During 2000 he led several butterfly- and moth-collecting expeditions into remote mountain regions of Guyana.

For visitor information, contact:
Tourism and Hospitality Association of Guyana
157 Waterloo Street
Georgetown, Guyana
(5922) 50807
www.exploreguyana.com

HABITATS


Guianan cock-of-the-rock
JAN VERMEER; FOTO NATURA

Savanna vegetation, in addition to the bromeliad *Brocchinia micrantha* and the bladderwort *Utricularia humboldtii,* includes such terrestrial orchids as the pale green and purple *Catasetum discolor* and the large pink *Sobralia liliastrum.* Common scrubby trees are *Erythroxylum citrifolium, Andira grandistipula,* and species of *Clusia.* Among the herbs are the insectivorous *Drosera kaieteurensis,* a sundew; the saprophytic *Burmannia bicolor;* and countless grasses and sedges.

Boggy areas are often dominated by *Brocchinia reducta,* a cousin of *B. micrantha.* This terrestrial species collects water in its tall, narrow, yellowish tank. Also at home here are plants of the Rapateaceae family, which is endemic to Guyana and neighboring regions. The Rapateaceae usually have long, straplike leaves and a small cluster of light yellow flowers topping a long stalk.

Forest trees prominent on the plateau and in the gorge include mora, wallaba (*Eperua falcata, E. grandiflora),* clump wallaba *(Dicymbe pharangophila),* and species of *Swartzia* and *Inga*—all legumes. The souari nut tree, *Caryocar nuciferum,* is also common. Well buttressed, it is easily recognized by its large fruit, pockmarked bark, and bright-green trifoliolate leaves.

Mammals, apart from the savanna (or crab-eating) fox, live mostly in the forested areas of the plateau or down in the gorge. Among the primate species are red howler and wedge-capped capuchin. Peccaries, tapirs, anteaters, armadillos, sloths, coatis, and others are around but hard to see. Southern river otters swim in the Potaro's dark, tea-colored water.

Birds easily encountered on the plateau near the falls include the little chachalaca and Guianan cock-of-the-rock, as well as honeycreepers, dacnises, and tanagers. The cliff face is home to the orange-breasted falcon and its prey—white-collared swifts, white-chinned swifts, and white-tipped swifts. In the gorge, red-and-green macaws and red-billed toucans are common sights, while occasionally spied down along the river are the white-necked jacobin and the crimson topaz, both hummingbirds. In one spot deep within the gorge, the pendulous nests of green oropendolas adorn the outer branches of a tall tree growing on one of the river's small islands. These nests and this large songbird's melodious, liquid calls are signatures of the Neotropical lowlands.


Morpho menelaus
LUIZ MARIGO; PETER ARNOLD, INC.

Butterflies include *Morpho hecuba, M. rhetenor, M. menelaus,* and *M. achilles.* Among the innumerable other species are *Aphrissa statira, Phoebis argante,* and half a dozen *Parides.*

UNIVERSE

Mathematically challenged Americans suffer from . . .

Fear of Numbers

By Neil deGrasse Tyson

ROBERT GROSSMAN

We may never know the circuit diagram for all the electrochemical pathways within the human brain. But one thing is for sure, we are not wired for logical thinking. If we were, then mathematics would be the average person's easiest subject in school.

In this alternate universe, math might not be taught at all, because its foundations and principles would be self-evident even to slow-achieving students. But nowhere in the real world is this true. You can, of course, train most humans to be logical some of the time, and some humans to be logical all of the time; the brain is a marvelously flexible organ in this regard. But people hardly ever need training to be emotional. We laugh early in life, and we are born crying.

We do not emerge from the womb enumerating objects around us. People had to invent the concept of counting and build upon it when new needs arose because of the growing complexities of life and society. We all agree that $2 + 3 = 5$, but what is $2 - 3$? To answer this question without saying it has no meaning required that somebody invent negative numbers, another part of the number line. And we all know that half of ten is five, but what is half of five? To give meaning to this question, somebody had to invent fractions, yet another class of numbers. As the ascent through numberdom progressed, many more kinds of numbers were invented: imaginary, irrational, transcendental, and complex, to name a few. They each have specific and sometimes unique applications to our discoveries about the physical world.

Those who study the universe have been around from the beginning. As a member of this (second) oldest profession, I can attest that we actively use all parts of the number line for all manner of heavenly analyses. We also routinely invoke some of the smallest and, of course, largest numbers of any profession. One could argue strongly that astrophysicists do not fear numbers.

With thousands of years of culture behind us, what grade has humanity earned on its math report card? More to the point, what grade do we give Americans, members of the most technologically advanced culture the world has ever known?

Let's start with airplanes. Whoever lays out the seats for Continental Airlines seems to suffer from medieval

fears. I have yet to see a row 13 on any flights I have taken with them. How about buildings? Seventy percent of all high-rises along a three-mile stretch of Broadway in Manhattan have no thirteenth floor. While I have not compiled detailed statistics for everywhere in the nation, my experience walking in and out of buildings tells me that more than half of them skip the thirteenth floor. If you've ridden the elevators of these guilty high-rises, you've probably noticed that the fourteenth floor directly follows the twelfth. This trend exists for new buildings as well as old ones. Some buildings are self-conscious and try to conceal their superstitious ways by providing two separate elevator banks: one that goes from 1 to 12 and another that jumps straight to 14. The twenty-two-story apartment building in which I was raised (in the Bronx) has two separate banks of elevators. One bank stops on the even floors, the other on the odd floors. One of the mysteries of my childhood was why the odd bank of elevators went from floor 11 directly to floor 15 and the even bank from 12 to 16. Apparently, for my building, a single odd floor could not be skipped without throwing off the entire odd-even scheme. Hence the blatant omission of any reference to either the thirteenth *or* the fourteenth floor.

In one particular building that harbors an extensive subterranean world, the levels below the first floor are labeled B, SB, P, LB, and LL. Perhaps this is to give you something to think about while you are standing in the elevator doing nothing, but these floors are begging to become negative numbers. For the uninitiated, the abbreviations stand for Basement, Sub-Basement, Parking, Lower Basement, and Lower Level. We don't use such lingo for regular floors. Imagine a building with floors labeled not 1, 2, 3, 4, and 5 but Ground, Above Ground, High Ground, Very High Ground, and Sub-Roof. There should be nothing wrong, in principle, with floors called -1, -2, -3, or even 0.

Society's implicit denial of all that is less than zero shows up in many places. A mild case of this syndrome exists among car dealers who, instead of saying they will subtract $1,000 from the price of your car, promise you $1,000 "cash back." In corporate accounting reports, fear of the minus sign is pervasive. There it's common practice to enclose negative numbers in parentheses and not to display the negative symbol anywhere on the spreadsheet. Even the successful book and film *Less Than Zero,* which tracks the falling from grace of wealthy Los Angeles teens, could not be imagined with the logically equivalent title *Negative.*

Just as we hide from negative numbers, we hide from decimals, especially in America. This past year was the first time that all stocks were traded on the New York Stock Exchange in decimal dollars instead of in clunky fractions. And even though U.S. currency is decimal and therefore metric, we don't think of it that way. If something costs $1.25, we typically parse it and recite "a dollar twenty-five." This behavior is not fundamentally different from the way people recited prices in the old decimal-averse British system that combined pounds, shillings, and pence.

When my daughter turned fifteen months old, I took perverse pleasure in telling people she was "1.25." They would look back at me, heads tilted in silent puzzlement, the way dogs look when they hear a high-pitched sound.

Fear of decimals is also rampant when probabilities are communicated to the public. People usually report odds in the form of "something to 1," which makes intuitive sense to nearly everyone: The odds against the long shot winning the ninth race at Belmont are 28 to 1. The odds against the favorite are 2 to 1. Yet the odds against the second-favorite horse are 7 to 2. Why don't the track's oddsmakers say "something to 1"? Because if they did,

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Ellen Goldensohn, Editor in Chief

then the 7-to-2 odds would instead read "3.5 to 1," stupefying the decimal-challenged people of this nation.

I suppose I can live with missing decimals, missing floors in tall buildings, and floors that are named instead of numbered. A more serious problem is the limited capacity of the human mind to grasp the relative magnitudes of large numbers.

If you start counting by reciting one number per second, you will need 12 days to count to a million and 32 years to count to a billion. Counting to a trillion will take you 32,000 years, which is as much time as has elapsed since people first drew on cave walls. If laid end to end, the 100 billion (or so) hamburgers sold by the McDonald's restaurant chain would stretch around the Earth 275 times, with enough left over to make a stack from Earth to the Moon and back. And last I checked, Bill Gates was worth $50 billion. If the average home-owning adult would pick up a quarter from the sidewalk but not a dime, then the corresponding amount of money that Bill Gates would ignore if he saw it on the street is $25,000.

In corporate accounting reports, fear of the minus sign is pervasive.

These are entertaining brain exercises for the astrophysicist, and normal people do not think about these sorts of things. But at what cost? Beginning in 1967, NASA launched a series of space probes that shaped more than two decades of planetary reconnaissance in our solar system. The celebrated Pioneer, Voyager, and Viking missions were part of this era. So, too, was the *Mars Observer,* which was lost on arrival in the Martian atmosphere in 1993. Each probe took many years to plan and build. Each mission had broad and deep scientific objectives and cost taxpayers between $1 billion and $2 billion. After a 1990s change in administration, NASA introduced a "faster, cheaper, better" paradigm for a new class of $100 million space probes. Unlike previous probes, these could be planned and designed swiftly to fulfill missions with sharply defined objectives. Of course, that meant a mission failure would be less costly and less damaging to the overall program of exploration.

In 1999, however, two of these more economical Mars missions failed, with a hit to taxpayers of about $250 million. Yet public reaction was just as negative as it had been to the loss of the billion-dollar *Mars Observer*. The news media reported the $250 million as an unthinkably huge waste of money and proclaimed that something was wrong with NASA. The result was a congressional hearing.

Not to defend failure, but $250 million is not much more than the cost of producing Kevin Costner's film flop *Waterworld*. It's also the cost of about two days in orbit for the Space Shuttle, and it's one-fourth the cost of the lost *Mars Observer*. Without these comparisons, and without the reminder that these failures were consistent with the "faster, cheaper, better" paradigm, in which risks are spread among multiple missions, you would think that $1 million equals $1 billion equals $1 trillion.

Nobody announced that the $250 million loss amounts to less than one cent (0.01 dollars) per person in the United States. This many pennies are surely lying around in our streets, but people are just too busy to bend down and pick them up.

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

CELESTIAL EVENTS

Where the Action Is

If you don't like the weather on Jupiter, just wait.

By Richard Panek

Let's face it, the night sky doesn't do much. Sure, the stars appear to execute one rotation on the celestial sphere every twenty-three hours and fifty-six minutes. And yes, the planets, as the Greek derivation of the word suggests, wander slightly against the starry backdrop from one night to the next. And then there's the Moon, forever going through its fractional phases, over and over, unto eternity. But *action*? Put all these incremental changes together, and what you get is a drama of Noh-like minimalism, at most.

This helps explain why a favorite target of many amateur observers is the one telescopic object they know will actually change right before their eyes: Jupiter. Last month, this column described Galileo's discovery of the moons of Jupiter in January 1610, when the telescope was still in its infancy. Even that primitive telescope revealed the constant dance of Jupiter's four innermost moons, a piece of celestial choreography that visibly varies not only from night to night but over the course of a single evening. For amateur observers, Jupiter's moons offer the astronomical equivalent of an old saw, "If you don't like the weather, just wait." So does Jupiter itself—especially because part of what's always changing on the planet is, in fact, the weather.

Take the Great Red Spot. It's a cyclonic storm similar to a hurricane (though its 15,400-mile diameter is large enough to swallow two Earths). The spot churns counterclockwise at speeds of up to 270 miles per hour. A constant presence—at least during the four centuries since the invention of the telescope—the Great Red Spot undergoes visible changes in shape, size, and even color. In recent years, it has appeared not so much red as bleached orange.

And the spot is only the most famous manifestation of Jupiter's volatile meteorology. Other storms arise frequently, sometimes drifting across the planet's atmosphere, sometimes growing from one day to the next, and sometimes simply popping out of existence. Cloud formations, too, are constantly shifting. Dark bands such as the north and south equatorial belts reveal where gases are descending, while white zones show where gases are rising. But even if Jupiter's atmospheric conditions were as calm as Colin Powell, the planet would still reward observers looking for action.

Jupiter, with a diameter of 88,789 miles at its equator, is the largest planet in the solar system, but despite its size, its rate of rotation is the fastest: it completes one revolution every nine hours and fifty-five minutes. Under ideal circumstances, an observer could watch an entire day pass on Jupiter in the course of one night on Earth.

Such circumstances arise during December and January. At 1:00 A.M. Eastern Standard Time (EST) on New Year's Day, Jupiter reaches opposition—the point in a planet's orbit at which


Capricious Jupiter

JET PROPULSION LAB; NASA

Earth lies between it and the Sun. When that happens, observers on Earth can see a planet "in front of" them only when the Sun is "behind" them. Because Jupiter will be rising at sunset and setting at sunrise—a length of time that on some of the longest nights of winter happens to pretty much coincide with the planet's orbital period—observers will be able to see Jupiter's full rotation. What's more, this particular opposition of Jupiter finds the planet passing just about as close to Earth as it ever does, providing amateur observers with a generous target, forty-seven arc seconds wide.

The best opportunities to monitor the passage of a Jovian day in its entirety arise during the week before and the week after opposition—in this case, the last week of December and the first week of January. During that period, the planet will be high enough above the horizon throughout the crucial dusk-to-dawn time frame that watchers shouldn't be hindered by the significant blurring created by Earth's atmosphere when objects are low in the sky. Select a feature to monitor (a band, a belt, a storm), then follow it as it moves across the planet's visible disk, slips out of view, eventually reappears, and returns to its initial position. On New Year's Eve, for instance, the Great Red Spot will be crossing the planet's central meridian (the imaginary vertical line running from pole to pole down the center of the disk) at 7:06 P.M. EST and returning to the meridian at 5:01 A.M. EST on New Year's Day.

As always, the only obstacle standing between you and a good round of observations is the weather. Not there; here. But, hey, if you don't like the weather—well, you know what to do.

Richard Panek's next book, *The Invisible Century: Einstein, Freud, and Our Search for Hidden Universes,* will be published in 2003 by Viking.

THE SKY IN DECEMBER AND JANUARY

By Joe Rao

Mercury is scarcely visible until the last several days of December, when it creeps above the southwestern horizon about half an hour after sunset. During the first half of January, the planet shows up there more clearly near the end of evening twilight. Mercury reaches its greatest eastern elongation from the Sun (19°) on January 11, shining at a moderately favorable magnitude of -0.6 but fading rapidly to magnitude +0.3 by the 17th and to +1.3 by the 20th. It then swings down in front

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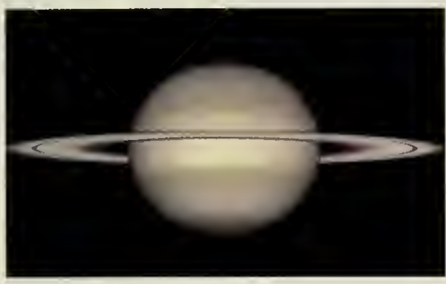
of the Sun, reaching inferior conjunction on the 27th.

Venus briefly appears very low in the east-southeast just before sunrise during the first few days of December. It then moves behind the Sun, reaching superior conjunction on January 14, and won't be readily visible again after sunset until at least late February.

Mars moves from Capricornus into Aquarius on December 4, crossing the meridian at about sunset. Look for it in the southwestern sky during the late evening hours. On the 20th, the planet is about 5° above the slim crescent Moon; a month later, on the evening of January 18, it returns to a similar position. Throughout January, Mars crosses the meridian about an hour before sunset and is visible low in the southwestern sky until about 10:00 P.M. local time. Indeed, the red planet sets at nearly this hour until the end of May. As of mid-January, Mars is 149 million miles from Earth and thus presents a rather tiny telescopic disk (last June, when it was unusually close to Earth, the planet looked four times as large). Mars gradually fades from magnitude +0.4 on December 1 to +0.8 on January 1 and finally to +1.0 on January 31.

Jupiter, in Gemini, arrives at opposition to the Sun on New Year's Day, shining at a dazzling -2.7 magnitude. In December it rises during evening twilight and remains in the sky all night. By January the planet is already shining in the east when darkness falls; passing overhead before midnight, it sets before sunup. Jupiter is the silvery "star" hovering about 5° below and to the left of the Moon on the evening of December 2. The planet is roughly the same distance above and to the right of the Moon on December 30 but appears much closer by January 26.

Saturn, at opposition, is above the horizon from sunset to sunrise on the night of December 3, passing north of the bright orange star Aldebaran. Over the course of the month, it appears to move westward several degrees. Approaching perihelion (on July 26, 2003) with its rings tipped 26° to our line of sight, Saturn shines at magnitude -0.5, the brightest it has been in nearly three decades. During January, Saturn is well up in the east-northeast at dusk; by month's end, it



NASA AND THE HUBBLE HERITAGE TEAM

sets in the west-northwest at about 3:00 A.M. local time. Observers in the continental United States and parts of southern Canada get to see a nearly full Moon occult Saturn on December 28 at about 4:05 A.M. in the East and at roughly 12:15 A.M. local time on the West Coast. For Hawaii, occultation occurs the previous evening at 8:42 P.M. local time.

The Moon is at last quarter on December 7 at 2:52 P.M. and new on the 14th at 3:47 P.M. First-quarter Moon falls on the 22nd at 3:56 P.M. On December 30 the Moon is full at 5:41 A.M.; a few minutes earlier, the Moon is partially eclipsed, resulting in a brief, slight darkening of its lower rim at 5:29 A.M. In January, last-quarter Moon comes on the 5th at 10:54 P.M., new Moon on the 13th at 8:29 A.M., first quarter on the 21st at 12:46 P.M., and full Moon on the 28th at 5:50 P.M. On January 14 the sliver of a very young Moon hovers less than 6° below Mercury in the west-southwest. The following evening, it is well to the east of Mercury and much easier to spot.

The Geminid meteor shower promises a fine display, at least for those willing to brave the chill. These meteors can be seen all night long for a week or so, with no Moon to spoil the view with its glare. Peak activity is expected December 13–14 from evening through morning, when a Geminid meteor should burst across the sky about every minute, especially in the predawn hours. Past displays have featured a richness of both fireballs and faint meteors but have included fewer objects of medium brightness. The meteors appear to originate near the bright star Castor, in Gemini.

The Sun will undergo an annular, or ring-shaped, eclipse on December 14. The eclipse path first strikes Earth over the middle of the Pacific Ocean. Heading east, it passes 300 miles south of the Hawaiian Islands, producing an 84 percent eclipse over Honolulu at 9:27 A.M. Hawaiian time. Veering northeast, the path goes over parts of Nicaragua and Costa Rica, where the Sun will mimic a dazzling ring of fire near sunset. Over most of the United States—except for upstate New York, portions of New England, and Alaska—a partial solar eclipse will be visible. Depending on your location, between 1 and 40 percent of the Sun's diameter may be covered, with the greater coverage visible toward the south. East of the Mississippi River, sunset comes before the eclipse is finished, but the western half of the country has an uninterrupted view.

Earth reaches perihelion—at 91,402,515 miles, the point on its orbit nearest the Sun—at 9:00 A.M. on January 2.

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

IN THE FIELD

O Tannenbaum

Father Christmas may be at odds with Mother Nature.

By Bernd Heinrich

Along with its religious significance, the Christmas season offers those of us who live in northern latitudes a more secular, but also traditional, cause to celebrate. We have once again endured the longest nights of the year and can look forward to coasting down on ever longer days from the winter solstice to spring. To mark this event, people of northern Europe and North America have customarily gone into the forest and cut down a young evergreen tree to bring home.

For my family in New England, the holiday doesn't begin until Christmas Eve. We go into a nearby woods where the trees grow thickly, fell a six- to ten-foot conifer, and carry or drag it back to the house. We always select either a spruce or balsam fir that is not too tall and skinny from struggling to reach the sunlight. Our preferred tree is broad at the base, evenly conical, and well filled in with branches in successive whorls.

While its needles (actually modified leaves) are still alive and fresh, we decorate the tree with colorful glass globes, tinsel, red winterberries from a deciduous holly, spruce and fir cones, and cotton to simulate snow. The long, thin limbs bend slightly under their ornamental load the same way they bow, rather than break, under accumulations of snow and ice in the woods. The top is crowned with a star.

We enjoy choosing our wild tree as much as we do decorating it. But

Young spruce au naturel

PHOTOGRAPHS BY NATHAN FARB

increasingly, going into the woods to find just the right specimen is a family ritual out of reach for most people. While city dwellers and suburbanites can make an annual tradition of selecting and purchasing a tree from a vendor, I wonder if this may lead us to forget what an authentic evergreen looks like. Farmed Christmas trees can be manicured with clippers or power saws into any desired shape. Ironically, the shape that is most in demand in a commercial tree is what we think a Christmas tree is supposed to look like when left to grow on its own. That is, the trees are pruned in an attempt to improve on nature. To me, that seems somewhat like painting roses red.

An unaltered conifer is unmistakable if one is aware of how its shape is achieved naturally. And shaping starts at the top. By late summer and on through fall and winter, each fir, spruce, or other conifer is topped by a single, pencil-like vertical twig bearing a cluster of buds. This twig is the "leader" that will eventually become part of the trunk of the tree. (The trunk below the young leader consists of a series of previous annual leaders.) While any bud—or any twig resulting from it—has the potential to become a leader, usually the centermost one will have assumed leadership by spring. The buds on the sides of the same top cluster will end up becoming one whorl of the horizontal branches of the tree. How these arboreal leader/lateral decisions are made is a matter of physiological checks and balances that involve a host of plant hormones interacting in response to the position of the tree in the forest and to resources such as light.

The leader releases auxins, hormones that work in conjunction with others called gibberellins to promote elongation in the leader while inhibiting the growth of nearby buds and twigs. This shunting of resources to the leader is known as apical dominance, and without it, an evergreen would burgeon equally in all directions. In a shaded forest, where each young tree competes with thousands of other seedlings, such indiscriminate growth would spell suicide. The evergreens next to it, growing conically and relatively straight up, would rob it of light. The only way any one conifer can survive the competition—and only a tiny percentage make it—is to come to a narrow point at the top and to extend sideways only far enough to capture the sun's energy. The tree's priority is to allocate energy to the

The growth of the leader, or topmost vertical twig, is vital to the health of a conifer.

leader so that the whole organism can outstretch the other trees in the race toward the light.

Leadership, however, is not irreversible. Changes occur routinely, due for the most part to deer or moose nipping off the succulent tops of young trees (in winter I have also seen red squirrels feeding on the buds of the leading twigs) or to breakage caused by storms and fallen branches. In such cases, one might expect chaotic growth in all directions, but a corrective mechanism kicks in to prevent it. In a tree left leaderless and with newly uninhibited lateral growth, several shoots from the top cluster engage in a competition to become the new leader. It is a slow process, sometimes taking a few years to complete. Eventually one or another of the contenders gets a slight upper hand, so to speak: it produces more auxins than the others do, and these accumulate on the twig's lower side, causing the cells to elongate. This favored twig then bends toward the vertical to take on the role of leader. Coniferous symmetry can be restored, and the tree can again stretch skyward and compete with its evergreen neighbors.

A commercial Christmas tree starts out like any other conifer, but the tips of both its leader and lateral branches are clipped off. Such trimming removes the growth inhibition of buds and twiglets farther in on the branch. The trees direct less energy upward and outward and become bushier. With its natural branching patterns disrupted, the tree is, strictly speaking, no longer a wild specimen. To a pagan purist like me, that spoils the effect. The evergreen tree, once symbolic of forest wildness, has been tamed into a bush.

Should I care if this representation of the natural world that we bring into our living rooms is altered to suit human expectations? Probably not. But we may come to prefer and even insist on a domesticated tree with the "perfect" shape, a tree we would never see in nature. Which leads me to wonder: If our ignorance of how conifers grow can allow us to do this to a Christmas tree, how much more might we alter Nature at large without caring, or even knowing, that it has been changed?

Bernd Heinrich is a professor of biology at the University of Vermont, Burlington.

TODAY

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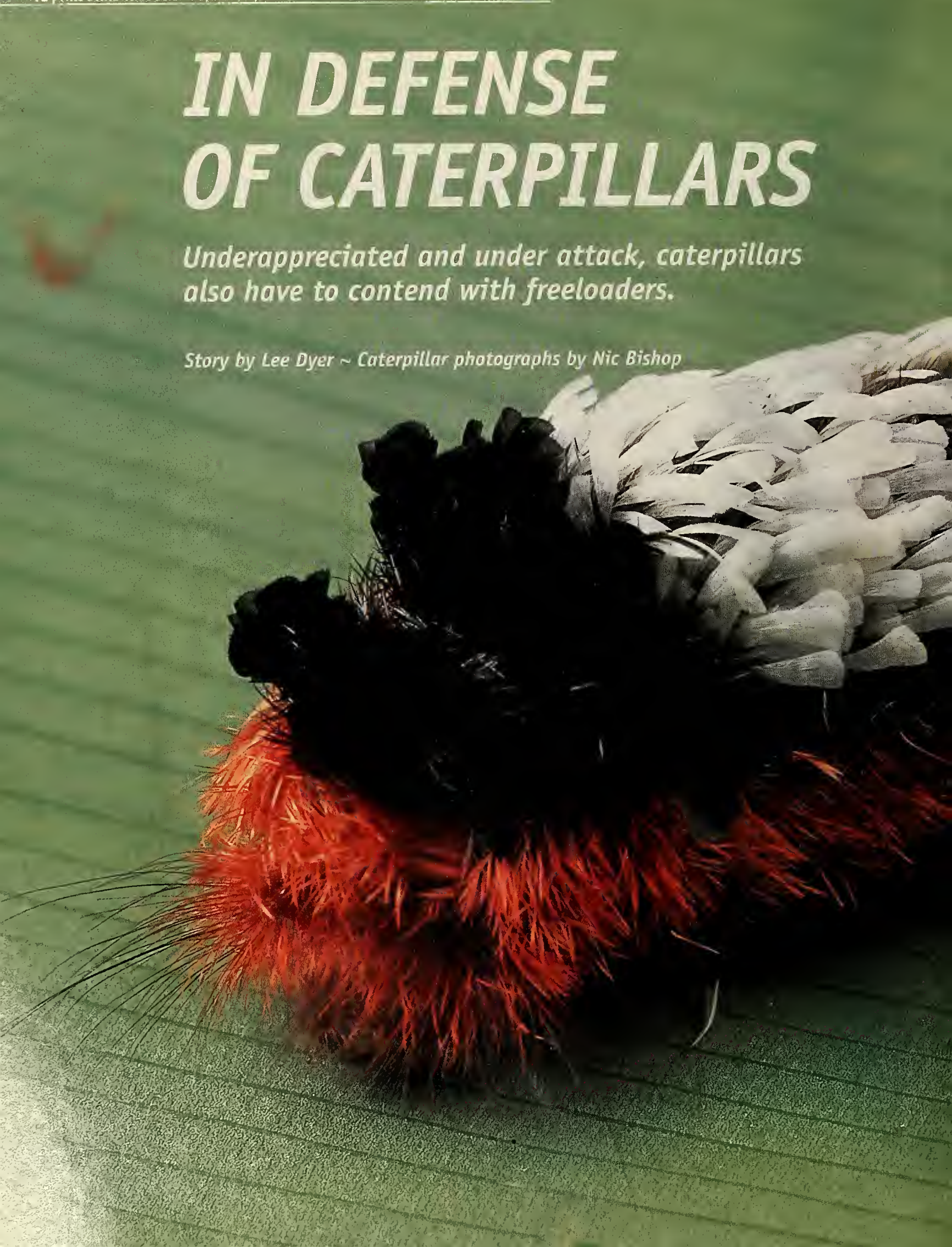
IN DEFENSE OF CATERPILLARS

Underappreciated and under attack, caterpillars also have to contend with freeloaders.

Story by Lee Dyer ~ Caterpillar photographs by Nic Bishop



Sticky hairs help protect a moth caterpillar from its enemies. Some other caterpillars have hairs or spines bearing chemical compounds that keep away a variety of predators. Long hairs also act as early-warning systems, giving caterpillars an opportunity to drop to the ground, thrash, or jump away when approached by an enemy.

A giant tropical ant *(Paraponera clavata)* can inflict a vicious sting, strong enough to immobilize prey. But the sticky hairs on a *Tarchon* moth larva prevent the ant from properly grasping its prey and delivering its stinging message.

The mandibles of *P. clavata* are rendered temporarily useless by a mouthful of sticky hairs, courtesy of the intended prey. Sticky hairs don't work as well against most parasitoids, whose larvae grow inside and ultimately kill their caterpillar hosts.

Heliconius hecale zuleika, a caterpillar in the long-winged butterfly family, stores toxins from the plants that it eats; it also advertises its toxicity to experienced predators in black and white. An enemy that ignores the conspicuous warning is liable to be met with a nasty blast of regurgitated plant compounds.

Agaraea larvae feed en masse: Group feeding can reduce an individual caterpillar's exposure to predators and enhance defenses such as thrashing and biting. One downside of group dining is that chemical signals from the larvae and their frass (excreta) can attract parasitoids. Some species of larvae eject their frass great distances to avoid discovery.

Many caterpillars are cryptically colored to match their host plants, making it difficult for birds and reptiles to spot them. But those predatory insects that locate prey through chemical sensing are not deterred. Using caterpillars such as this well-camouflaged *Adelpha,* the author and his collaborators have reared a plethora of fly, wasp, and nematode parasitoids.

The protagonist of Eric Carle's illustrated children's book *The Very Hungry Caterpillar* is what we all expect a caterpillar to be: a green, wormy eating machine that someday will be transformed into something better, such as a butterfly. Most people's attitudes toward caterpillars are based on this sort of lowly image and range from distaste (for, say, large hornworms munching on tomatoes in the garden) to indifference (toward, say, buckeye larvae chomping on weeds). The truth is that most leaf-eating caterpillars are not little green slugs. The amazing array of caterpillar colors, shapes, appendages, and behavior rivals that of their adult counterparts, and in many cases the immature organisms are far more pleasing to the eye.

Caterpillars evolved in response to a wide variety of selective pressures, but perhaps their most interesting features are adaptations against natural enemies. The value of defenses such as spines or sticky hairs, the regurgitation of plant toxins on an enemy, and the ability to mimic a snake is easy to imagine. But investigations into just how effective these defenses are—and against which enemies—reveal complex, unexpected patterns.

The vast and varied cast of characters that make their living by eating insect larval tissue includes a wide range of organisms, from microbes to primates. Two well-studied groups of caterpillar enemies are predators (many birds, wasps, ants, and true bugs) and, more obscure but no less abundant or important, parasitoids—certain wasps, flies, and nematodes whose immature stages live inside the caterpillar host, where they feed on nonessential tissues until they are ready to burst out of the devastated body and complete their life cycle as free-living organisms. Their gruesome predilection makes parasitoids great fodder for science fiction movies, but they benefit some plants by controlling populations of caterpillars.

Given the damage this sort of parasitism can cause, I expected that many defenses in the caterpillars' repertoire would have evolved in response to it. Surprisingly, however, my research, done at Tulane University with my former postdoctoral collaborator Grant Gentry, suggests this is not the case. While sticky hairs that glue an ant's mandibles together and toxic chemicals that make birds vomit can effectively deter predators, it turns out that parasitoids are actually attracted to caterpillar hosts with these attributes.

At first this finding confused us, because some of these larval defenses are formidable and have been demonstrated to affect parasitoids. Closely spaced spines, for instance, can make it harder for a parasitic wasp to lay its eggs on the caterpillar's body. And the toxins with which some caterpillars defend themselves against predators can also slow the development of, or even kill, parasitic larvae.

But we soon realized that the parasitoids' attraction to well-armed hosts makes good sense. Any parasitoid inhabiting a defenseless caterpillar becomes just as vulnerable to predators as its host is: if the larva is eaten, the parasite will be consumed right along with it. Far better, then, to parasitize a well-defended host, despite the cost. Thus, it appears that as long as caterpillars are challenged by both attackers from without and freeloaders from within, the perfect defense may elude them.

Acharia ophelians, a saddleback caterpillar, has stinging spines and perhaps other chemical defenses that are advertised by its bright coloration. Brush up against a group of these, and you could have a painful rash for more than a week.

CHRIS KNIGHTS; ARDEA LONDON LTD.

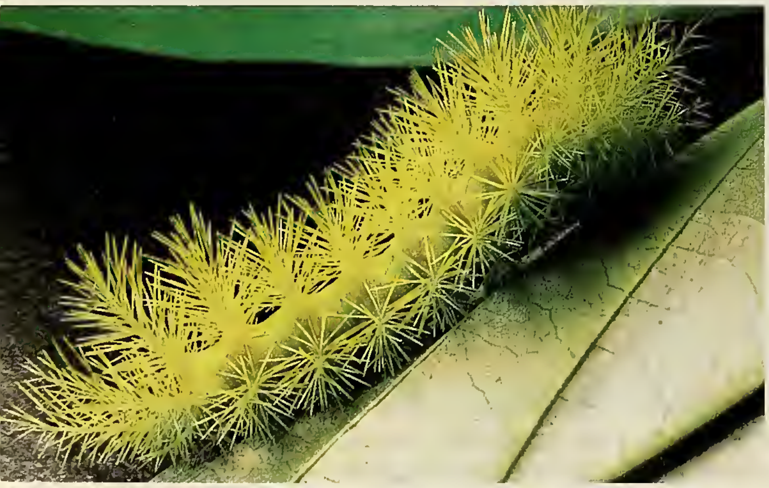
A whitethroat has caught a caterpillar. From the point of view of a parasitoid that spends part of its life cycle inside a caterpillar, a species that is vulnerable to predators is not the most desirable host.

A member of the puss caterpillar family, *Megalopyge albicollis* has extremely painful stinging spines and hairs that seem to protect it even from parasitoids. The caterpillar's nickname in Costa Rica, *gusano ratón* (vermin worm), reflects the bad experiences humans have had with it.

A leafy shelter has been cut away to reveal the cocoons spun by braconid wasp parasitoids after they emerged from an *Oecophorid* caterpillar. Because they are well protected, larvae that create shelters from the leaves they feed on may be attractive hosts for parasitoids.

ELECTRONIC CATERPILLAR COLLECTIONS Insect larvae are abundant and easy to find in all terrestrial ecosystems, but they are very hard to preserve. If simply pinned, as are their adult counterparts, they shrivel and fade; when prepared with various fixatives, killing solutions, or preservatives, they often lose their bright colors and other diagnostic characters. Partly as a result of such drawbacks, good museum reference collections are almost nonexistent, and keys outlining species characteristics are unavailable for most groups. The Internet has proved an invaluable tool for circumventing these problems. Larvae can be reared to adulthood in laboratories, taxonomists can identify the adults, and electronic images of both stages can then be placed into a collection that is readily accessible via computer. Two examples of digital collections are the Dyer-Gentry databases and key, at www.caterpillars.org, and the Janzen-Hallwachs database, at janzen.sas.upenn.edu.—*L. D.*

***Opsiphanes tamarindi* cannot easily remove the tachinid fly eggs from its head. Once the eggs hatch, the larvae burrow inside the host and begin consuming nonessential tissues.**



As big as a hot dog, *Automeris*, a giant silkworm moth caterpillar, discourages some predators by its size, strong bite, and array of spines.

The hag moth larva (genus *Phobetron*) has small stinging spines and large lobes that detach when a predator grabs them. Nonetheless, it is parasitized by wasps, flies, and nematodes.

When disturbed, *Hemeroplanes ornatus* inflates and displays the underside of its front end, startling predators with its close resemblance to a pit viper. At rest, this very large caterpillar, a member of the hawk moth family (whose larvae are called hornworms), resembles a lichen-covered stick.

Face the Music

Why are we such a musical species —and does it matter?

By Susan Milius

"In our village there was a man who had a daughter, and a guy wanted to marry her," reminisces Dadie Aime Loh, from southwestern Ivory Coast. The suitor was of another religion, however. "The father said the guy must change his religion. He did. They made a song about it in the village, and everybody was singing it. They were making fun of him: 'Just to have a wife, you gave up your religion.' People back home make songs about everything."

For the Dida people, Loh asserts, music is not the same thing it is for most contemporary Westerners, and not just because the drums and bells, calls and responses, sound a different beat. Loh, who demonstrates and teaches Dida music at the University of California, Santa Barbara, conjures up a world in which gifted singers may be celebrated but the talents of a few don't silence the voices of everyone else. "If you can speak, if you can think, you can make a song," he says.

The truth is that just about everybody everywhere is musical. The most off-key croakers among us respond to music, feeling the chill in a dirge, quickening to the frolic in a reel, or waiting nervously for a twenty-foot spider to jump out of the darkness when a movie soundtrack turns jittery. Human beings appear to be musical beings—but why? Does music have a biological function? Has musicality mattered in the evolution of our species?

On the streets of Paris in 1935, a young accordion player puts his heart into his music.

The first challenge faced by any theory about the origins of our musical capacity, emphasizes David Huron, head of the Cognitive and Systematic Musicology Laboratory at Ohio State University, is to explain why music is not just widespread but truly universal. Every culture that anthropologists have observed has its own music. (Music may be forbidden in some cultures at some points in their history, but repression of music is not the same as the absence of the desire to make it.) Styles of singing and types of instruments vary enormously—to the delight of fans of "world music"—but some form of music is present, often as part of important cultural traditions, from the arctic tundra to the tropical rainforests, whether for pursuing seals or for communicating with the spirits of birds.

Pervasiveness alone, of course, does not mean that a trait matters a lot in evolution. Music could be just a happy accident, notes psychologist Steven Pinker, of the Massachusetts Institute of Technology. Think about food. The vagaries of prehistoric nutrition may have favored hominids with a taste for fruit or for calorie-packed fats. Nowadays we can titillate those tastes whenever we want, but it's hard to argue that survival advantages drove humanity to evolve an enthusiasm for strawberry cheesecake. In theory, Pinker maintains, music, too, could tickle pleasure out of cognitive circuitry that evolved for more practical purposes, such as sorting out individual sounds from a noisy environment. In his 1997 book *How the Mind Works,* he writes, "I suspect that music is auditory cheesecake."


LUDWIG
ACCORDEON

So far, that has been a hard statement to prove or disprove. But it is a view that Ian Cross, university lecturer in music at the University of Cambridge, disputes. Cross argues that dismissing music as a useless frill smacks of ethnocentricity. He concedes that the view is perhaps a fair description of "what music has become over the last hundred years within technologized and capitalistic Western society," in which a booming industry for recording and selling sounds has turned music into "a commodity to be consumed, dispensable on demand." But elsewhere in the world, people turn to music for reasons other than entertainment—from keeping workers on task to powering spiritual events.

David Huron agrees, pointing to the Mekranoti Indians in the Amazon rainforest of Brazil as an example. Mekranoti women settle down on palm leaves and sing during months-long naming ceremonies. The men typically gather to sing in the predawn hours; their singing helps keep them roused and ready for any attack. Slugabeds get roundly taunted.

Huron describes himself as open minded on the question of an evolutionary value for music. "I think we should investigate matters further before we dismiss the notion," he says. But where to look? If music is indeed a universal human trait, then clues about its functions and origin may reside in our brains. One optimist searching for brain tissue devoted to musical matters is neuropsychologist Isabelle Peretz, of the University of Montreal. Peretz has studied people who suffered brain injuries that shut down their musicality but left other mental faculties intact. For instance, she has tested three people who, after recovering from ruptured aneurysms, were able to speak normally and even to recognize sounds in the environment (barking dogs, cars rumbling by) but could

If music is indeed a universal human trait, then clues about its origin may reside in our brains.

CHIEN-CHI CHANG: MAGNUM PHOTOS

not recognize the tunes of songs they once knew, such as Christmas carols or "Happy Birthday." One of these people said she still enjoyed music, however, and Peretz found that even though the woman couldn't recognize a tune, she was able to rate the happiness or sadness of a composition as readily as an uninjured listener could. (A different misfortune struck Russian composer Vissarion Shebalin: a severe stroke deprived him of almost all his language ability, yet he went on to compose his Fifth Symphony.)

Recently Peretz has begun to work with ten people who have no visible sign of brain injury but who describe themselves as profoundly tone deaf. Indeed, her tests have confirmed that these individuals cannot discriminate among pitches well enough to distinguish one tune from another. Such a limitation should not influence their conversation, Peretz points out, since speech, while often inflected and modulated, does not require the fine distinctions that music does. Peretz suspects, based on memoirs, that Latin American revolutionary leader Che Guevara shared their condition. Despite remarkable abilities in other areas, he remained unable to distinguish one musical piece from another—an awkward problem when it came to standing up for the national anthem.

Another intriguing line of inquiry focuses on babies' considerable responsiveness to music. Much of this research takes advantage of their tendency to react to something novel—by turning their head or body toward it—but to get bored with and stop responding to the familiar. Sandra Trehub, of the University of Toronto, for example, has found that infants can distinguish very small changes in musical patterns. Interestingly, six-month-olds react much as adults do to changes in pitch and pitch relations.

Jenny Saffran, of the University of Wisconsin–Madison, has explored babies' sense of pitch. She and her colleagues tested both adults and eight-month-olds with a series of bell tones. The infants proved far sharper than the adults at noticing sequences with the same relative pitches but different absolute pitches. Saffran proposes that people may be born with perfect pitch but lose the ability as they mature.

If such research does confirm built-in musicality, we're back to asking why. Charles Darwin addressed this question in his 1871 *Descent of Man*: "As neither the enjoyment nor the capacity of producing musical notes are faculties of the least use to man in reference to his daily habits of life, they must be ranked amongst the most mysterious with which he is endowed." Darwin suggested one answer: that music evolved as part of courtship. Initially he proposed to explain birdsong as a display, enabling a discerning female to select a mate from among a number of males. "They charm the female by vocal or instrumental music of the most varied kinds," he wrote. This process, which Darwin called sexual selection, enabled traits for the sexiest display to spread through the population. Darwin

Opposite page: Members of a Taiwanese marching band are undeterred by rain. Below: A teenage boy plays a homemade "viola" in a camp for displaced persons in Angola.

CRISPIN HUGHES: PANOS PICTURES

DAVID HURN: MAGNUM PHOTOS

Left: A young audience registers its approval at a 1964 Beatles concert in Great Britain.

JOHN VINK; MAGNUM PHOTOS

French rugby players, right, enjoy a team victory. Below: A street musician sings during *carnaval* in Brazil's eastern state of Bahia.

MIGUEL RIO BRANCO; MAGNUM PHOTOS

then extended his idea to the origins of human music: "[I]t appears probably that the progenitors of man, either the males or females or both sexes, before acquiring the power of expressing their mutual love in articulate language, endeavoured to charm each other with musical notes and rhythm."

In recent years, evolutionary psychologist Geoffrey Miller, of the University of New Mexico, has taken a fresh look at Darwin's notion that music arose through sexual selection. If Darwin was right, music might have evolved as a display, bursting forth naturally. And, claims Miller, so it does: "Music differs clearly from other human abilities such as proving mathematical theorems, writing legal contracts, or piloting helicopters, which depend on a tiny minority of individuals being able to acquire counterintuitive skills through years of difficult training." Ultimately, Miller says, he's trying to explain why "music is so primordially sexy. A wonderful musician is just more compelling than the world's best tax accountant or a man who's assembled the world's largest ball of string."

While understanding the visceral messages of music and developing enough skill to warble a recognizable "Happy Birthday" may be easy for most people, reaching the heights of musical prowess takes time and effort and, Miller suggests, special genetic gifts. As a result, music might serve as an opportunity for sexual competition.

Ellen Dissanayake, an independent scholar in Seattle who writes on the origins of artistic elaboration (see "Birth of the Arts," December 2000/January 2001), agrees but says, "Geoffrey's argument doesn't explain enough." She finds a much stronger case for music's origins in its power to foster cooperation. The cradle of music, she argues, literally was the cradle, and in human evolution, music came from the bonding duets between mothers and infants. Modern humans evolved to bear especially helpless young, compared with those of other primates, so anything that strengthened the bond between mother and infant would have had strong, immediate survival benefits and would have spread widely.

Dissanayake sees evidence for this hypothesis in the tendency of caregivers around the world to engage infants in cooing, crowing, and peekabooing interactions that display many of the components of music. In many cultures, adults playing with babies tend to pump up the high inflections and drop the lows, so that the sounds they make take on a melodic quality. Think, for example, of simple statements such as "Look at YOU-oooo" and of many nursery games, such as the one that ends with "THIS little piggy went WEE-WEE-WEE all the way home." In addition, phrases are repeated, and adult and baby fall into rhythms.

Experiments have shown how important this timing can be. In one experiment, mothers and babies were in separate rooms but able to see and hear each other via closed-circuit television. All proceeded smoothly—mother and baby happily gazing and chirping back and forth—until the researchers manipulated the tapes so that the baby was watching a replay of an earlier reaction from its mother. When the rhythms of the mother's actions and reactions were out of sync with the baby's reactions, the baby showed signs of distress by fussing and frowning. As soon as the researchers restored real-time communication, the baby resumed gurgling and kicking its feet contentedly. The motions in such duets matter as much as the sounds, Dissanayake says.

Might music have evolved as a sexual display or from duets between mothers and infants?

Perhaps the most sweeping view of music's benefits for emerging humanity comes from Cross. He proposes that music evolved as what he calls a "play-space" for the mind. Cross offers due respect to our predecessor species, some of which had superb skills in certain domains, such as understanding inanimate materials well enough to shape them

Singing's a Hoot

Lest we humans get too smug about our standing as a musical species, consider the gibbons, our most distant living ape relatives. All twelve species sing, and in ten of them, mated pairs engage in duets. (To hear gibbons sing, go to www.gibbons.de.)

To qualify as a singer, an animal must repeat several series of notes in a recognizable temporal pattern, explains zoologist Thomas Geissmann, of the Tierärzliche Hochschule Hannover in Germany. He's analyzed singing in nonhuman primates and proposes that their "music" might have developed along an evolutionary path that human ancestors wandered down too.

Siamang gibbon

Singing evolved independently at least four times among nonhuman primates, contends Geissmann. Depending on which classification scheme is used, some twenty-six species sing. Besides gibbons, singing primates include the Madagascan lemurs called indris, the tarsiers of Sulawesi, and the titi monkeys of South America. None of these groups perch particularly close together on the primate family tree.

Geissmann proposes that the songs of all these species may have evolved from common primate vocalizations known as loud calls. Many primates, particularly adult males, belt out characteristic notes when groups meet or when something alarming happens. The singing routines of modern species are more elaborate than these calls, but there are some suggestive similarities. All songs and many calls, for example, contain runs of relatively pure notes.

Oddly enough, all the singing primates Geissmann has studied fall into the exclusive club of monogamous mammals (only 3 percent or so of all mammals tend to have one mate at a time). Whereas singing may originally have evolved in order to attract a mate or to help defend resources, Geissmann muses that duet singing in primates might have arisen along with monogamy. He imagines that a mate might have found it beneficial to repeatedly interrupt a partner's ongoing "song bout" with little phrases of his (or her) own to let potential home wreckers know that the partner was already taken. As more complex duetting evolved, singing might have strengthened pair bonds. At least in siamang gibbons, new mates have to learn the fine coordination between his part and hers.

Because our closest living relatives, the apes, give loud calls, Geissmann suspects our distant primate ancestors did too. Chimpanzees pant-hoot. Gorillas produce short bursts of notes, often while thumping their chests. Orangutans have a loud call. In fact, says Geissmann, "the only apes without loud calls are humans." Maybe these calls turned into our songs.—*S. M.*

into tools. But modern humans seem to possess a trait found in no other species—immense mental flexibility. As Cross puts it, modern humans can transfer insights from one domain to another, often to a domain that is metaphoric or symbolic. As a result, a tool is no longer just a tool. Take a knife, for example. It can slice through a slab of meat, but it can also suggest purely mental operations, such as cutting through an argument to the main point.

RHODRI JONES; PANOS PICTURES

Right: Crew members from a riverboat take a karaoke break by the Yangtze River, China. Below: To the accompaniment of a horse-head fiddle, a woman sings at dusk in Inner Mongolia.

If music played any kind of conceptual role for our ancestors, it must have deep roots in the evolution of our species. Archaeological evidence now suggests such roots. The earliest unambiguously musical object that Cross recognizes is a bone pipe found in southern Germany. (He discounts another flutelike find, from Slovenia, as being not clearly musical. Besides, he points out, it is from a Neanderthal site.) The German pipe, which was found along with other signs of modern humans, dates back to about 36,000 years ago—toward the end, Cross has written, "of the sudden efflorescence of visual art and symbolic artifacts that marks the undoubted emergence of modern human capacities."

Cross has also begun a quest for other kinds of early musical instruments. He was intrigued by stalagmite structures in some of the caves in France, Spain, and Portugal that were frequented by people some 30,000 years ago. These stalagmites—some of which show signs of ancient decorations, such as red ocher dots, as well as chipped spots and other traces of wear—ring with resonant tones when

struck. Cross proposes that ancient peoples may have "played" stalagmites like chimes. He and two archaeologist colleagues suggest that flint tools of this era might likewise have served early rock musicians. Inspired by the pleasant ringing sound that many tools make when struck, the researchers experimentally tapped a lot of rocks to get an idea of the kinds of wear marks that music-making would leave. Now Cross and his colleagues will be looking for those marks on ancient tools.

Regardless of the outcome of the rock project, the old German flute has already convinced Cross that "musicality is human and ancient"—so ancient, he says, that it could easily have played a role in that quantum leap in mental flexibility. The reason music might be an excellent promoter of mental flexibility, says Cross, is that it isn't inherently *about* anything, the way language is. Play around with language . . . *ooglu, oggli, ugly* . . . and you might be in big trouble if your word play gets overheard by someone big and cranky. Stick to instruments or meaningless sounds such as *la la la,* however, and you're safe.

EVE ARNOLD/MAGNUM PHOTOS

Looked at slightly differently, Cross observes, music can be about many things. A musician might muse about how a melody that rises and falls is like a wave breaking on a beach or a bird soaring and then diving for a fish. That's a shift from one domain to another. The melody has led the musician through a bit of cognitive acrobatics. And therein lies the value of the musical playspace: it provides opportunities to experiment with conceptual leaps while incurring little risk that anyone will spear you for doing so.

That's a difficult hypothesis to test, Cross admits. "Music leaves few traces except in the minds of those who engage in it." Of course, the agility of human thought and the ability to take one kind of idea and recast it for another domain might be just the sorts of traces he's hoping to find. "Without music," he says, "it could be that we would never have become human."

But maybe looking at how music benefits individuals is narrowing the focus too much, says Steven Brown, of the University of Texas Health Science Center at San Antonio. Like Dissanayake, Brown holds music's salient feature to be its fostering of strong bonds, although he focuses not on the mother-infant duo but on groups of people.

LENNOX MCLENDON/AP WIDE WORLD PHOTO

Rock singer Tina Turner (center) performs in Las Vegas in 1997 before a sold-out audience of more than 13,000 fans.

Singing together, dancing, even listening to the same music can help weld individuals into a team, a village, a nation. Before anybody gets too sentimental about the blessings of music, however, Brown points out that music can also transform crowds into a dangerous mob. But whatever kind of solidarity music promotes, he argues, members of such groups

Music may have helped humans acquire the immense mental flexibility unique to our species.

are more likely to survive and reproduce than are members of ragtag assemblages prone to infighting.

That train of thought assumes that evolution operates at the level of the group as well as that of the gene or the individual. The idea of group selection has been much criticized as woolly thinking in the past. Brown is not deterred, finding the evidence convincing that evolution plays favorites at many levels: "Multilevel selection is a fact of biology," he says.

One of group selection's longtime proponents, David Sloan Wilson, of Binghamton University in New York, says that he sees modern formulations of the idea increasingly invoked in studies of sex ratios and of disease virulence. "Now, *denying* the role of group selection is beginning to appear like woolly thinking," he says.

Wilson heartily endorses Brown's assertion that group-level benefits might have driven the evolution of musicality. "I think it's entirely plausible," he says. Music strikes Wilson as a particularly promising place to look for group selection, because (unlike Geoffrey Miller) he finds the evidence for individual-level selection weak. "Music is employed in many ways that seem to benefit the whole group more than the relative fitness of the individual musician within the group," he says.

The salient feature of music may be its "groupishness," its power to function as social glue.

Brown agrees, drawing support for his hypothesis from what he calls the "groupishness" of music, especially outside Western societies. "In the rest of the world, there's not this 'I love you so much I can't live without you' stuff," he says. Instead of

ROBERT CAPA; MAGNUM PHOTOS

American soldiers and French citizens celebrate France's liberation from the Nazis, right. Opposite page: Saxophone player Bill Clinton (then President-elect) is in tune with members of the Central High School Sugar Bear Band in Macon, Georgia.

emphasizing individual travail, especially in romance, much of the planet's music addresses group concerns. The Aka pygmies of central Africa, for example, sing some two dozen kinds of music, each for a different occasion. Brown lists categories of songs—for hunting, for gathering, for the death of an elephant—and points out the predominance of topics that affect the welfare of the group.

Even in Western societies, Brown finds, music often functions as social glue. In 1941 Dmitri Shostakovich composed a work, now called the Leningrad Symphony, to rally support for the city's 872-day resistance to the German siege. A live radio broadcast of the piece in 1942 was considered so important that soldiers with musical training were temporarily excused from front-line duty so they could play in the concert. A recognition of music's bonding power led Nazi occupiers in Poland and Czechoslovakia to issue a very different order—the disbanding of the national symphonies.

Solidifying membership within a group fulfills only one of music's roles, however, Brown maintains.

DAVID LONGSTREATH; AP WIDE WORLD PHOTO

Music also conveys information, with goose bumps added. It creates the visceral rush solemnifying the news that a child has reached adulthood, that a man and a woman are now one couple, that a community prays for healing. Loh offers examples from his village. "We sing when someone dies. The singing is about the life of the person, what he did bad, what was good. Also when we have a baby, there is special music, praying for him, telling him to be polite."

Catharsis is another group use of music. Brown argues that it channels grief or rage or other nearly overwhelming emotions for shared public release. Just ask people who watched the collapse of the World Trade Center towers how it felt to sing the national anthem in the following days. Most—even those who are neither religious nor nationalistic and who may be against the use of military force—are likely to say that singing with others who were going through the same experience brought some sort of relief.

Such groupish powers arise from the very structure of music, Brown maintains. "Conversation is about one person speaking and then the other," he says. "Music is about blending pitches, entraining to rhythms." If divided we fall, united we sing. □

By Harvey B. Lillywhite

TO WIPE AND WAX

IN DRY TIMES, SOME FROGS EMPLOY A CURIOUS METHOD FOR SAVING WATER.

The skin is a large and prominent organ, but we often take it for granted. While we think of our other important organs—heart, liver, kidneys, and the like—as securely placed inside us, doing complex and hidden things, we regard our skin as little more than a covering. Indeed, the principal function of skin is protective, but in various animals this role has given rise to myriad devices. Although the skin of all vertebrates has common properties, evolution has produced great variation in its shape, size, and functions and in its scales, claws, feathers, fur, spines, horns, and other appendages. Not all skin is created equal. The varied functions performed by the skin—including respiration, sensation, control of body temperature, transport of ions and water—reflect both phylogeny, or lineage, and evolutionary adaptation to a wide spectrum of different habitats.

Because amphibians were the first vertebrates to venture onto dry land, their skin has long been a subject of fascination to scientists. Amphibian skin is very different from—and, in some respects, simpler than—that of other vertebrates. It generally lacks appendages such as scales or hair and is comparatively thin and quite permeable to moisture. As a result, amphibians face an increased risk of drying out and have evolved behavioral specializations for maintaining water balance on land. In dry weather they retire to burrows, dense vegetation, or other protective places. Some amphibian species have adopted a nocturnal lifestyle to avoid

the drying rays of the sun; others seldom stray far from sources of moisture with which they can replenish body water after bouts of activity. Surprisingly, some of the world's driest deserts harbor one or more species of frogs or toads, though they are seldom seen except during the rainy season, when they form breeding aggregations at temporary pools. During the remainder of the year, these animals burrow into the soil and remain there in a state of dormancy, often surrounded by a protective cocoon: multiple layers of shed epidermis (the outermost skin) interspersed with layers of mucus or other secretions.

Some amphibians living above ground in arid regions are especially challenged by drying conditions and have developed some novel adaptations to conserve water. One well-known example is the South American painted belly monkey frog, *Phyllomedusa sauvagii*, which was investigated during the 1970s by Rodolfo Ruibal, Vaughan Shoemaker, and their students at the University of California, Riverside. Monkey frogs secrete waxes from spe-

The orange-legged leaf frog, common to South America's dry Chaco region, is one of several frogs that secrete waxes and spread them by wiping to avoid drying out.

Barking tree frogs spend time at ground level (such as in water-filled pitcher plants) and in dry treetops, where waxing and wiping keep them moist.

cialized glands in their skin, then wipe themselves in a stereotypic manner to spread the waxes over the body. A typical wax layer produced by wiping is fifty to a hundred molecules thick—comparable to the thickness of protective waxes secreted onto the cuticle of beetles and spiders.

Reports of wiping behavior in several species of phyllomedusine frogs (members of the family Hylidae) were preceded by reports that certain African tree frogs of the genus *Chiromantis* (family Rhacophoridae) were highly resistant to drying out.

J.H. ROBINSON; PHOTO RESEARCHERS, INC.

However, wiping itself was first noted by Charles McCann. In a 1940 issue of the *Journal of the Bombay Natural History Society,* he described the wiping behavior of *Polypedates maculatus,* a rhacophorid species known as the common Indian tree frog. During dry weather, some of these frogs took refuge in McCann's bungalow in Andheri, near Mumbai (formerly Bombay), providing him with a perfect opportunity to observe their curious mannerisms. At night they emerged from their hiding places, moved to a wet spot where they sat to absorb moisture for a while, and then ventured out in search of food. When the frogs returned in the morning, McCann witnessed each frog go through what he called "a process of 'self-massage,' a somewhat ludicrous performance." His description continues: "The head is first rubbed down from the top over the snout, by the forelegs, and then down the throat and thorax as far as the limbs will reach. This is followed by a 'massage' of the back, flanks, and abdomen, by the hind legs. The hindlimbs then massage one another. When all this 'toilet' is over, the limbs are collected under the body and the frog 'retires.'"

During the 1970s, when scientists began publishing reports on the self-waterproofing of South American phyllomedusine frogs, McCann's observations went unnoticed, as did his speculations on the purpose of wiping. "I have tried to figure out the reason for this performance," he had written, "and can only ascribe it to the possibility that the animal tries to clear its body of foreign matter adhering to its skin, perhaps also, an even coating of slime, when dry, acts as a sort of film, to prevent further evaporation of moisture." The latter interpretation turned out to be correct.

I learned about McCann's publication and became intrigued with Indian tree frogs during a visit to India roughly ten years ago, and I later returned there for a formal investigation of their wiping behavior. My collaborator, Ajay Kumar Mittal, a professor of biology at Banaras Hindu University in Varanasi, and I initially found that, like the South American *Phyllomedusa,* common Indian tree frogs could be stimulated to wipe themselves if we handled them. We next conducted some experiments in which frogs were subjected to repeated cycles of moderate but harmless dehydration before being handled. Under these conditions, the incidence of wiping increased markedly. It appeared that wiping was an adaptive response to water deprivation, but we needed to establish just how it worked.

During our investigations we uncovered an important connection between wiping and glandular secretion. As a frog wipes, the tactile stimulation of its limbs pressing against its body elicits a nerve reflex that causes muscle cells to contract around secretory glands in the skin. Wax secretions produced in these glands are thereby expelled onto the skin surface, and the frog's body becomes visibly wet. Following a bout of wiping, the frog rests motionless in a water-conserving posture—head and body low to the ground, limbs tucked tight against the body, and digits folded inward. After a few minutes the secretions dry, and the body takes on a waxy sheen. If water drips onto the back of a waxed frog, it forms beads (just as it would on a stick of butter), because the waxed skin is hydrophobic—both repelling water and retarding evaporative water loss. But if dirt or debris is dropped onto wax-coated frogs, they do not wipe it off. We surmise that grooming disrupts the integrity of the protective wax layer and is therefore detrimental to waxed frogs. Handling probably also disturbs the wax layer, which seems to explain why frogs are more likely to wipe themselves after being held.

WATER DRIPPED ONTO WAXED FROGS BEADS UP THE WAY IT WOULD ON A STICK OF BUTTER.

Both butterfat and frog wax owe their water-repellent properties to organic compounds called lipids—the key components of the water barriers present in a variety of plants, arthropods, and vertebrates. Reptiles and mammals generally lose less water through their skin than do amphibians, thanks to lipid structures within the epidermis. In these animals, lipids are deposited into spaces between cells, where they become organized into distinct sandwiched layers within the epidermis's corneous tissues (consisting primarily of fibrous keratin proteins). These sandwiched layers are also present in the skin of some birds. Although various frog species also produce lipids in their skin, either inside or outside their glands, they have only one or two layers of corneous epidermal cells—too few to provide the strong mechanical support that multiple layers supply to reptiles and mammals. Without this keratin-rich structure, the lipid layer is easily breached by movement or physical disruption. Amphibian skin thus appears to have limited options for waterproofing, because it is thin, poorly keratinized, and therefore supple. For reasons not well understood, these traits have persisted in modern amphibians, whose skin permits respiratory gas exchange while imposing the problem of water loss.

External lipid barriers spread by wiping provide a logical means of waterproofing when the skin doesn't do the job on its own. Indeed, recent studies have shown that wiping is more widespread than biologists once thought. The behavior has now been reported in several lineages of tree-dwelling frogs, from two distinct families and five continents. Our studies of the common Indian tree frog have revealed some important differences between it and the phyllomedusine frogs of South America. Wiping and waxing provide the Indian frog with only modest water resistance, so the species must also rely on behavior to avoid drying out. During hot, dry weather, the frogs hide in the sheaths of banana plants, in cracks and holes in the ground, and often in people's homes. By contrast, *Phyllomedusa*—whose skin is several hundredfold more water resistant than the Indian tree frog's—can rest in the open air on exposed branches during dry weather. It appears that differences in skin permeability are related to the glands in which the lipids are produced. In the Indian frogs, lipids are secreted from mucous glands and are therefore diluted by a mu-

HARVEY B. LILLYWHITE

Assuming nearly acrobatic postures to execute a typical waxing sequence, the orange-legged leaf frog first wipes its head, then its sides, and finally its legs and rear.

cous "carrier." In *Phyllomedusa,* on the other hand, secretions are produced in specialized lipid-producing glands that evidently contain undiluted waxes.

These varied mechanisms for secreting wax bolster the hypothesis that waxing evolved along several evolutionary pathways. Tamatha Barbeau, a former graduate student in my laboratory, discovered that six species of hylid tree frogs in Florida wipe themselves with lipids that are produced inside serous, or granular, glands. After mucous glands, these are the second most prominent type of gland in amphibian skin and are usually associated with the production of defensive compounds such as amines, peptides,

EACH FROG WENT THROUGH A SOMEWHAT LUDICROUS "SELF-MASSAGE."

and alkaloids. However, granular glands vary greatly in their structure and contents, and those of a wiping Australian hylid, *Litoria caerulea,* or White's tree frog, also have been shown to contain lipids. Perhaps the lipid-producing glands of modern South American phyllomedusine frogs evolved from the granular glands of their hylid ancestors.

One could also speculate that in some lineages, wiping evolved first as a means of stimulating secretions (either purely mucous or granular). By itself, mucus helps keep skin moist. The American bullfrog, for example, discharges copious amounts of mucus when basking in the drying rays of the sun. Water evaporates from the film of mucus, protecting the underlying skin from dehydration, though only as long as the body water lost to evaporation can be replenished, say from wet soil, a stream, or a pond's edge. Perhaps some of today's waxing and wiping frogs had similar mucus-secreting ancestors.

ROBERT AND LINDA MITCHELL

HARVEY B. LILLYWHITE

The painted belly monkey frog of South America, above, wipes its skin with wax from specialized lipid glands. The common Indian tree frog, right, secretes mucus along with the waxes and must adopt a water-conserving crouch after wiping.

As these ancestral frogs progressively invaded drier habitats, the evolution of a lipid film from a mucous film would have prevented the drying-out of both the underlying skin and the entire animal when water was scarce or absent.

All species of frogs thus far known to wipe themselves with secreted lipids reside in trees or in shrubbery and also have a geographic distribution that includes arid or semiarid environments. The Indian tree frog *Polypedates maculatus* is widely distributed throughout India but absent from rainforests, while a closely related sister species, *P. leucomystax,* the common Southeast Asian tree frog, lives exclusively in the moist rainforests of India and avoids dry places. Preliminary observations suggest that the latter species neither secretes lipids nor wipes itself. The secretion of lipids and the wiping behavior of the common Indian tree frog therefore appear to be linked to survival in comparatively dry regions.

DAVID LIEBMAN

Many dry, low-latitude habitats experience high temperatures, so overheating can also be a problem for tree frogs. Several species of frogs, including the tree frogs that engage in wiping, sweat in response to increasing body temperature. The sweat secretion, which is largely mucus and water, cools the skin by evaporation, much like human sweat. So, in the case of the Indian tree frog, mucous secretions are used in two different ways: at higher body temperatures they provide water for evaporation, while at lower temperatures they deliver lipids to the skin for waterproofing. This species begins to sweat at a body temperature of about 86° F, whereas the more waterproof painted belly monkey frog does not sweat until its body temperature reaches 102–104° F. In both species, once a lipid barrier is established by wiping, the mucous glands don't discharge their contents unless the body temperature exceeds the threshold for sweating. By tolerating higher body temperatures, the monkey frog—with an intact lipid barrier on its skin—can better withstand exposure to hot, dry weather without risk of glandular water loss.

Amphibians are regarded as sentinel vertebrates in the current drama of global extinctions. Environment-induced stresses appear to pose particular risks to them, partly due to the sensitive nature of their skin. Wiping and waxing adaptations are extraordinary biological phenomena that integrate behavior with biochemistry, physiology, and ecology. We know very little about the origins of wiping and waxing or how rapidly these behaviors might evolve. Nevertheless, they are likely to play some role in the overall repertoire of important adjustments that amphibians will need to make in response to the localized droughts and temperature changes predicted to result from global climate change. □

One of a pair of red-eyed tree frogs from Central America wipes its face, a behavior shared with several other species of the family Hylidae.

The flightless kagu, right, which lives only on the South Pacific island of New Caledonia, is the closest living relative of the sun bittern, opposite, of Central and South American rainforests.

JEAN-PAUL FERRERO; AUSCAPE

MICHAEL & PATRICIA FOGDEN

GONDWANA GENESIS

A combination of molecular data, anatomical evidence, and knowledge of ancient geography is providing new answers to the contentious issue of when—and where—modern birds arose.

By Joel Cracraft

About 65 million years ago a giant asteroid, perhaps six miles in diameter, tore through Earth's atmosphere and slammed into the Gulf of Mexico, carving a crater nearly a hundred miles in diameter. The impact released billions of megatons of energy. Smoke and dust from the ensuing firestorms cast a sooty blanket over much of Earth, blocking sunlight and widely disrupting terrestrial and marine ecosystems. With this cataclysm came the mass extinction event that marks the boundary between the Cretaceous and Tertiary Periods—the K-T, as it is called by geologists.

The K-T mass extinction has captured our imagination because of claims that it brought about the end of the dinosaurs. Yet as most people know, the descendants of dinosaurs—birds—survived and are with us today. The common ancestor of modern birds, which are known technically as Neornithes, and of bipedal maniraptoran dinosaurs (think *Velociraptor*) lived sometime during the Jurassic, more than

Both the sun bittern and the kagu are quick to spread their wings in threat displays. The sun bittern above is defending its nest by a stream in Costa Rica.

150 million years ago. Many lineages of premodern birds subsequently branched off the avian tree, including one of the most famous and important fossils, *Archaeopteryx*, recovered from the Upper Jurassic Solenhofen limestone quarries of Bavaria. After *Archaeopteryx*, numerous Cretaceous forms evolved. These were less advanced anatomically than modern birds, and all are now extinct. As far as we know, none survived the K-T asteroid event.

Although most of the attention given to bird evolution has focused on birds' relationships to dinosaurs, crucial questions about the origin and early evolution of modern birds have largely gone unanswered. When and where did they arise? How and when did they diversify and spread around the world? And what influence, if any, did the K-T mass extinction have on their history?

In recent years, ornithologists have sought to investigate these questions using very different kinds of evidence. Taking a traditional approach, some pa-

JEAN-PAUL FERRERO; AUSCAPE

BIOS (A. COMPOST); PETER ARNOLD, INC.

Ratites—big, flightless ground birds including the emu, rhea, ostrich, and cassowary—are true Southern Hemisphere specialties. Above: An emu with chicks forages in Australia's Northern Territory. Right: Marked by a horny head ornament called a casque and by particularly lethal clawed toes, the cassowary inhabits forests of New Guinea and northern Australia.

leontologists point to the virtual absence of modern birds in the Late Cretaceous and their abundance in the Early Tertiary in North America and Europe. From this they conclude that the evolutionary history of modern birds began in the Northern Hemisphere after the K-T extinction event.

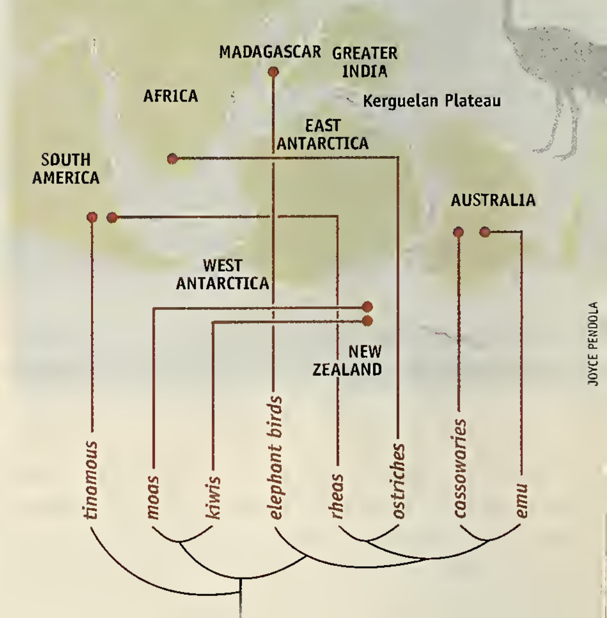
A contrasting view of modern bird beginnings comes from the expanding science of molecular systematics, which uses comparative DNA data to illuminate genealogical relationships. By correlating the amount of genetic difference between pairs of species with their presumed time of divergence from each other based on fossil evidence, some scientists believe they can calibrate a molecular "clock." The clock allows them to date the divergence of species pairs having no fossil record: the

Many lineages of modern birds existed prior to, and therefore must have survived, the K-T extinction event.

greater the difference in DNA sequence between two organisms, the farther back in time their evolutionary separation is thought to have occurred.

Several studies have independently examined sequence differences for a handful of genes in a small number of bird groups. The various investigators calibrated their clocks using different fossils and somewhat different methods of analysis, yet each concluded that these groups are so different genetically that they must have diverged sometime in the Cretaceous—that is, before the asteroid hit. According to this view, the pattern of the fossil record is biased: the large Tertiary record of birds exists only because sediments of that age are abundant

Ratites and Tinamous (Palaeognaths)



JOYCE PENDOLA

compared with those of the Cretaceous, and the fossils are found mostly in the Northern Hemisphere because that's where paleontologists do most of their work.

DES BARTLETT; BRUCE COLEMAN, INC.

Such scientific debates are often frustrating because they are unlikely to be resolved easily. Each side is relying primarily on one kind of evidence (here, either fossils or molecules), and too much time is spent dismissing the views of the opposing side. One way out of the conundrum is to obtain yet another kind of evidence and see how it fits together with the other data.

Research in my laboratory at the American Museum of Natural History has done just that. Employing new data—both molecular and anatomical—we have attempted to reconstruct the genealogy of modern birds and to use those findings to understand their past geographical distributions. This method of mapping reveals that many groups of modern birds were widely distributed on the ancient Southern Hemisphere supercontinent known as Gondwana and that they attained their present-day distributions as that landmass rifted and drifted during the Cretaceous and Early Tertiary. Combining knowledge about the breakup of Earth's early landmasses with our understanding of avian relationships and the fossil record, we have concluded that many lineages of modern birds existed prior to, and therefore survived, the K-T mass extinction event, thus supporting the conclusion derived from molecular clocks.

To understand this story, it helps to envision how Earth's landmasses fit together in the Early to mid-Cretaceous, about 120 to 100 million years ago. North America, Europe, and Asia formed a large supercontinent called Laurasia. Far to the south, Gondwana was beginning to separate into the continents we recognize today. The South Atlantic Ocean was forming and was continuous with another newly created ocean that extended eastward around the southern and eastern coasts of Africa. Yet Africa and South America maintained a connection across their midsections and probably did so until about 100 to 105 million years ago.

The heart of Gondwana was Antarctica, composed of two distinct geological sections: massive East Antarctica and long, narrow, mountainous West Antarctica. Southern Africa was merged with the margin of East Antarctica until they drifted apart about 140 million years ago. A combined continent of Madagascar and India was also sutured to East Antarctica, and farther east still was Australia. Southern South America had a connection across East Antarctica to Australia, and the rising Andean mountains had a nearly linear connection across West Antarctica to the continental block of proto-New Zealand and lands to the north, including the Norfolk Ridge and New Caledonia. A period of global warmth and moisture prevailed, and tropical or subtropical vegetation covered much of Gondwana. It was a favorable time for the dawn of modern birds.

For more than two decades a few ornithologists, including me, have proposed that various lineages of modern birds were distributed across Gondwana at the time of continental breakup. But today a clearer understanding of the very early history of modern birds allows us to pose an even bolder hypothesis: birds not only inhabited Gondwana from an early date, they originated there.

The strongest case for this conclusion emerges when we examine the earliest modern birds, which can be divided into three major lineages. First are

The largest of the world's birds, ostriches speed across their present African habitat.

the palaeognaths, or "old jaw" birds, so called because they share a particular configuration of bones in their palate. Palaeognaths include tinamous—small, chickenlike birds of tropical America that are capable of flight—and ratites, large flightless birds such as the ostriches of Africa, rheas of South America, emus and cassowaries of Australia, kiwis and extinct moas of New Zealand, and the extinct elephant birds of Madagascar.

All remaining birds are termed neognaths ("new jaws") and are subdivided into the other two major lineages of modern birds. One of these is the Galloanserae, including the galliform birds (chickens, pheasants, the curassows and guans of tropical America, and the megapodes, or mound builders, of Australasia) and their close relatives, the anseriforms (ducks, geese, swans). All other birds, from loons and penguins to woodpeckers and sparrows, are placed together in the third main lineage, the Neoaves.

When the evolutionary trees of these birds are plotted on a map of Cretaceous Earth, their Gondwanan distributions become apparent. Thus, within the palaeognaths, tinamous are in South America, kiwis and moas extend across West Antarctica to New Zealand, and emus and cassowaries span East Antarctica to Australia. Moreover, if ostriches and rheas are indeed related to each other, as some evidence seems to suggest, then they represent a historical connection across the South Atlantic between Africa and South America. The Galloanserae have similar trans-Antarctic distributions. The most primitive relatives of chickens and pheasants are the megapodes in Australasia and the guans and curassows in tropical America; likewise, two of the most

The most primitive relatives of chickens and pheasants live in Australasia and tropical America.

JEAN-PAUL FERRERO; AUSCAPE

A venerable line: Australia's magpie goose, below, belongs to one of the most ancient lineages of the anseriforms, the avian group that encompasses all ducks, geese, and swans.

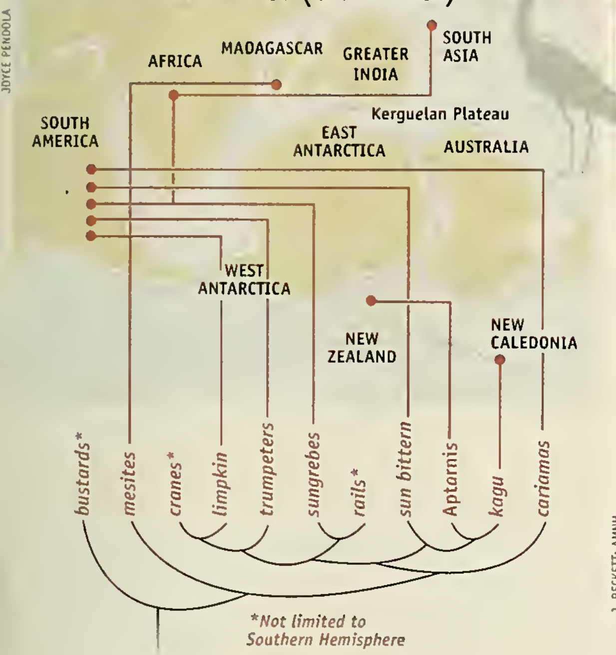
ancient lineages of the anseriform birds, the screamers and the magpie goose, are found in South America and Australia, respectively.

As I will shortly describe, the third great basal lineage—the Neoaves—also shows Gondwanan roots. If we combine this with the fact that all members of the Neoaves branched off the avian tree later than the palaeognaths and Galloanserae, we must conclude that even these advanced birds are older than some paleontologists have thought.

JOHN CANCALOSI; PETER ARNOLD, INC.

Cranes and Their Allies (Gruiformes)

JOYCE PENDOLA



Perhaps the most spectacular example of a trans-Antarctic distribution pattern within the Neoaves involves a medium-sized flightless bird—the kagu—that inhabits the remote island of New Caledonia in the southwestern Pacific. The kagu has long been classified with the gruiform birds, a grab bag of anatomically diverse families such as the familiar cranes and rails. Thanks to the detailed anatomical work of Bradley Livezey, a curator at the Carnegie Museum of Natural History in Pittsburgh, we now have strong evidence that most of these groups are indeed related. Livezey's findings, moreover, confirm a conclusion that I came to nearly fifteen years ago, also based on anatomical similarities—namely, that the closest living relative of the kagu is the sun bittern, an inhabitant of rainforests of Central and South America, half a world distant from New Caledonia. Comparisons of DNA sequences in our laboratory strengthen the evidence for this remarkable relationship.

J. BECKETT; AMNH

The malleefowl, above, builds nest mounds of sand and vegetation, which serve as temperature-controlled incubators for its eggs. Left: A reconstruction of *Aptornis*, a flightless New Zealand bird that went extinct after the islands were first settled by humans some 1,200 years ago.

How do two birds, one flightless and one barely capable of flight, evolve a distribution pattern like this? The answer can be found by deducing where their common ancestor was living 85 million years ago. Prior to that time, the southern continental blocks fit together in such a way that we could draw

J. BECKETT; AMNH

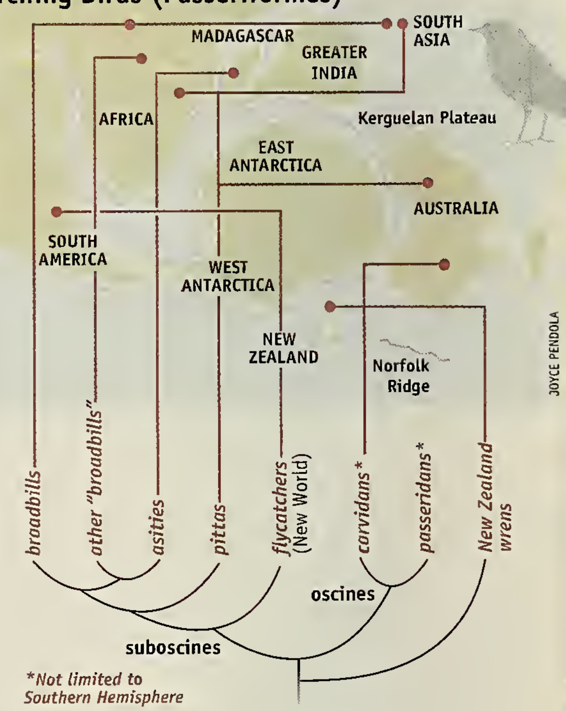
Molecular evidence has shown that the extinct Stephens Island wren, above, along with three extant species of enigmatic New Zealand wrens, are the oldest of all passerines, or perching birds.

a near-straight line from South America, across West Antarctica, onto the New Zealand landmass, and then northward along the now submerged Norfolk Ridge to New Caledonia. The kagu–sun bittern ancestor would have had no need to fly to what is now a remote island. It could have walked.

This scenario is further strengthened by another neat bit of information. Although the closest *living* relative of the kagu is the sun bittern, the kagu's actual closest relatives are two large, now extinct New Zealand species classified in the genus *Aptornis*. A finding such as this is the greatest thing since sliced bread to a biogeographer like me, but the story gets even better: both species of *Aptornis* were flightless. Like the unfortunate moas, with whom they shared the New Zealand forests, the two species of *Aptornis* were killed off for culinary purposes by the Polynesians sometime after these seafarers arrived on the islands, around A.D. 750–900. Thus, if two close relatives (in this case, *Aptornis* and the kagu) are flightless, then the simplest hypothesis is that their common ancestor was also flightless. Add to this the fact that the sun bittern is a very poor flyer, and we can see that species in this lineage were not well suited for crossing open oceans. This historical scenario is made more compelling by recent geological evidence that the Norfolk Ridge, which except for Norfolk Island runs submerged between New Zealand and New Caledonia, is itself continental crust and was exposed and covered with forest during at least part of the Late Cretaceous and Early Tertiary.

Other gruiforms are also distributed on former pieces of Gondwana. There are trumpeters, cariamas, and the limpkin in South America; sungrebes in South America, Africa, and southeastern Asia; and mesites on Madagascar. Mesites, small terrestrial birds with poor powers of flight, are especially noteworthy because they are one of the very oldest branches of the gruiform tree. How and when they arrived on Madagascar has always been something of a mystery, but I will propose a new answer to this puzzle after we've looked at another group of Neoaves—the Passeriformes, or passerines—which also appear to tell us something important about the history of Madagascar and the other southern continents.

Perching Birds (Passeriformes)



JOYCE PENDOLA

Passerines, or perching birds, are a hugely diverse group encompassing 60 percent of all living bird species. Ornithologists subdivide these 6,000 or so species into two large assemblages, based on anatomical differences in their syrinx—a vocal organ of muscle and cartilage located along the windpipe, or trachea. The suboscines have a relatively simple syrinx, whereas the oscines (the songbirds) have a more complex structure and, in general, a more elaborate vocal repertoire. More pertinent to this discussion, both groups apparently originated in Gondwana.

Suboscines, which include flycatchers, antbirds, woodcreepers, and ovenbirds, are now diverse in the New World, with about 1,100 species, nearly all of them in South America. The Old World has only about 50 species of suboscines, and these fall into three small groups: the outrageously colorful, short-legged, plump pittas; the broadbills; and the asities. Pittas and broadbills are found primarily in southern and southeastern Asia, but a small number of species from both groups are

Both Old and New World suboscines have geographical distributions that point back to Gondwana.

found in Africa, and two species of pittas have reached Australia from the north. The asities are the peculiar ones. Restricted to Madagascar, the four species—with their short, sharp bills—look nothing like broadbills. However, Richard Prum, an ornithologist at the University of Kansas, examined their anatomy and proposed that asities are simply modified broadbills. The exact relationship between broadbills and asities is still an open question, but there seems little doubt that the two groups are related to each other and to pittas. All of these suboscines—both Old World and New—thus have geographical distributions that point back to Gondwana, and their beginnings there make even more sense once their close relatives, the songbirds, are taken into account.

The evolutionary history of the songbirds is still incompletely understood, but current thinking holds that there are two major groups with complex interrelationships. One of these lineages, called the Corvida, contains all the crowlike birds, including crows and a large number of distinctive Australian groups, such as honeyeaters, bowerbirds, lyrebirds, and my own favorites, the splendidly adorned birds of paradise. DNA sequences determined in our laboratory show that all the most primitive corvidans are indeed Australian and that they diversified long ago, thus firmly anchoring the origins of the entire lineage in Gondwana.

The other main branch of the songbirds, called the Passerida, is hugely diverse; among its nearly 3,500 species are counted the finches, sparrows, thrushes, warblers, blackbirds, tanagers, and many others. Passeridans are distributed nearly worldwide. The current view is that they arose in the Northern Hemisphere and later dispersed to South America, Africa, and Australasia. This idea will have to be modified, however, because of new molecular evidence developed independently by Keith Barker, a postdoctoral fellow in our laboratory, and by my own research group. Some of the very primitive lineages assigned to the corvidans, we have learned, are actually more closely related to passeridans. This means the passeridans also had their beginnings on Gondwana.

These new findings raise the question of how the ancestors of the Northern Hemisphere passeridans reached there in the first place. Given our current state of knowledge, any answer to that question is going to be speculative, but it has to do with passeridans being related to corvidans as well as, somewhat more distantly, to the suboscines, which are all Gondwanan. And to seal matters, there are the enigmatic New Zealand wrens, which I have conveniently ignored until now. These tiny little birds, with short tails and sharply pointed bills, include only three species. (A fourth, the Stephens Island wren, was apparently exterminated by a lighthouse keeper's cat at the end of the nineteenth century.) Molecular sequencing results from both our lab and that of George Barrowclough, my fellow curator at the American Museum of Natural History, indicate the New Zealand wrens are at the very base of the passerine tree. Clearly these birds

Representing the New World suboscines: A dot-backed antbird perches in the Peruvian understory. Antbirds of various species are known for their habit of following columns of ants through tropical forests.

JOHN S. DUNNING; PHOTO RESEARCHERS, INC.

are very old inhabitants of New Zealand and provide another bit of evidence that the whole passerine group arose in Gondwana.

Now the story is at a point where the loose ends can be tied up—I hope—into a neat general hypothesis that explains why birds are distributed as they are and that resolves, at least partially, the debate over when the modern birds evolved. The many trans-Antarctic distribution patterns I have described for palaeognaths, Galloanserae, gruiforms, and passerines—and other groups such as parrots as well as swifts, hummingbirds, and their relatives the owls and the nightjars—strongly indicate that Gondwana harbored a diverse bird fauna. We can infer minimum ages for some of these lineages by correlating the time they were presumably isolated on fragments of Gondwana with the time of continental drift. New Zealand drifted north from West Antarctica beginning about 85 million years ago, which implies that kiwis, moas, the common ancestor of *Aptornis* and the kagu, and the New Zealand wrens as well are at least that old and that their lineages were in existence about 20 million years before the K-T extinction event. Likewise, if rheas and ostriches share a common ancestor, then the separation time of Africa and South America indicates that those birds have been evolving apart for 100–105 million years.

Trans-Antarctic distribution patterns indicate that ancient Gondwana harbored a diverse bird fauna.

Southeastern Asia is home to the majority of Old World suboscines, including the blue-winged pitta, below, and the lesser green broadbill, opposite page. Broadbills are related to another group, the asities, which are found only on Madagascar.

KEVIN SCHAFER; PETER ARNOLD, INC.

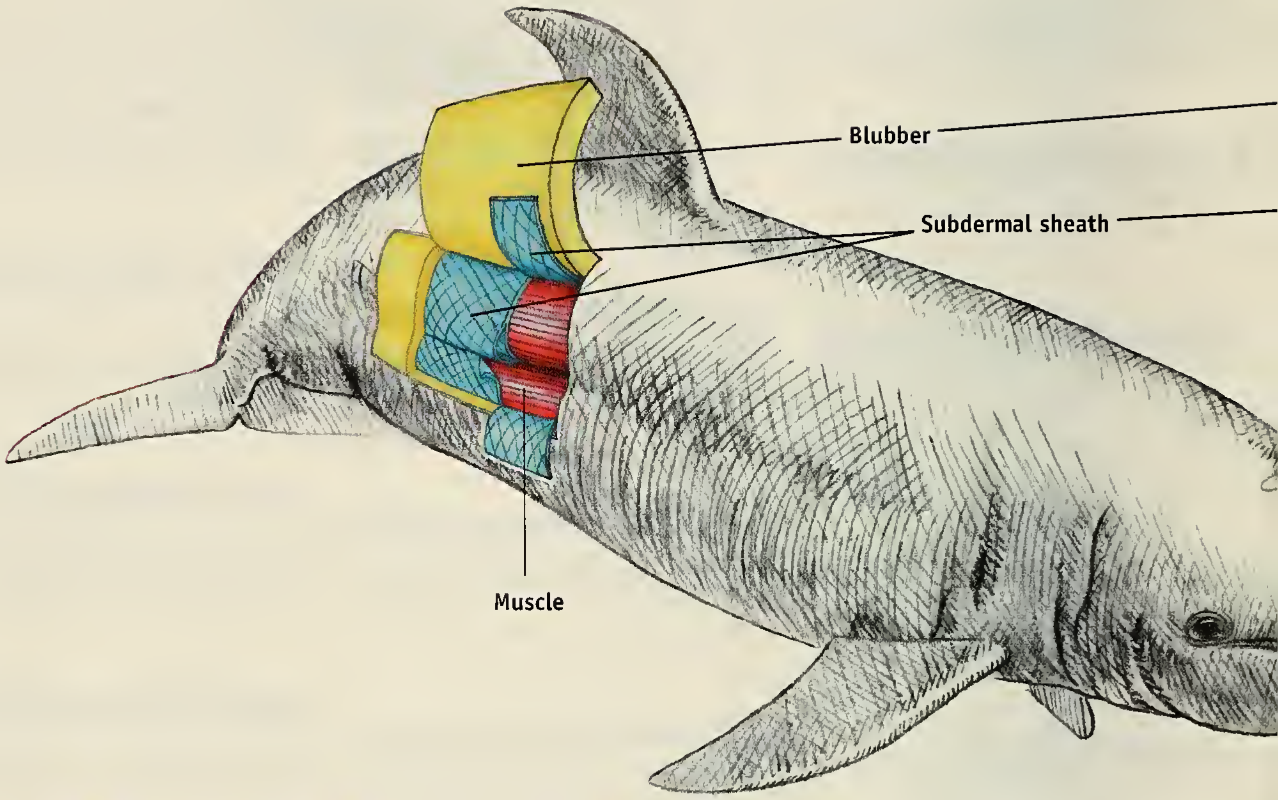
And what about Madagascar? That island continent drifted from Africa and moved south and east beginning about 165 million years ago, far too early for any group of modern birds to have gone along for the ride. Yet Madagascar had another connection with the rest of the world: Until 84 million years ago, Madagascar and the Seychelles Islands were connected to what geologists call Greater India, a continental block nearly twice the size of peninsular India today (Greater India drifted north and collided with Asia about 65 million years ago). This Madagascar–Seychelles–India megacontinent was once joined to East Antarctica, and for a time after they began separating, a land connection was apparently maintained via the Kerguelan Plateau, a large volcanic platform that formed 110 to 115 million years ago (only Kerguelan Island is now above water). Dredging from the top of this platform has revealed that a tropical forest once existed there, and no doubt it extended across much of Madagascar and Greater India. Late Cretaceous fossils of dinosaurs, crocodiles, and other vertebrates on Madagascar, nearly all of which have affinities to groups in India and South America, suggest that a land connection to Antarctica existed perhaps as recently as 85 to 95 million years ago. That seems late enough to explain the presence of elephant birds, mesites, and asities on Madagascar and perhaps—and I confess this is bald speculation—late enough for India to have carried the ancestors of the songbirds (and who knows what else) northward to dump them on the shores of Asia in the Early Tertiary.

Finally, many of the early lineages of modern birds may have escaped the K-T asteroid calamity because they were to be found mainly on Gondwana. Over the past decade, geologists have accumulated evidence that terrestrial ecosystems on the southern continents were not as badly disrupted, or subject to as much extinction, as were their Northern Hemisphere counterparts. All of this goes a long way toward explaining why modern birds appear to be so old (as suggested by the molecular evidence) and why they were not present in the Laurasian fossil record until the Tertiary.

Is this storytelling? Not really. Ornithologists can get out in the field and dig up fossils, hunker down over a microscope to understand bird anatomy better, or work in the lab and sequence more DNA. All of their new evidence can be used to test and refine—or reject—these scenarios. But one thing seems to be emerging from recent studies: relatives of our backyard feathered friends are older than many of us previously suspected, and they were flying—and walking—around on the ancient southern supercontinent of Gondwana. □

ROLAND SEITRE; PETER ARNOLD, INC.

BIOMECHANICS



Spring-Loaded

Every beat of a dolphin's tail stores elastic energy that helps propel the animal forward.

Story by Adam Summers ~ Illustrations by Sally J. Bensusen

The two Pacific white-sided dolphins riding the bow wave of our boat are a paean to power and a testament to biomechanical efficiency. Though the boat motors along at eighteen knots, the dolphins keep pace without visible effort, their tail flukes barely beating in the clear blue water. When they slide off the wave, moving away from the boat, they increase their pace to an easy lope more akin to the stride of a long-distance runner than that of a sprinter. Besides symbolizing grace, speed, and exuberance, dolphins are a wonderful aquatic example of an important principle of locomotion: the temporary storage of energy in a spring.

To experience the benefits of spring-loaded locomotion, just hop on one of the icons of 1950s popular culture, a pogo stick. The downward part of each bounce compresses a spring at the bottom of the stick; energy stored there is then converted into the upward thrust of the next bounce. To bounce higher (or farther), all you have to do is push down a little harder on the spring; a small investment of energy produces a significant increase in jumping power. Kangaroos capitalize on this principle when they hop.

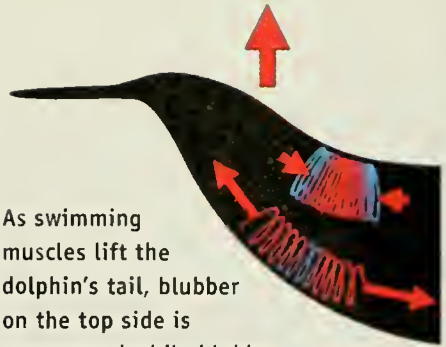
A clue that dolphins (and probably many other cetaceans) use biological springs to store energy lies in data collected by Terrie Williams, of the University of California, Santa Cruz. She trained bottlenose dolphins to swim in place against a stationary target designed to register the force with which they were pushing. The

The subdermal sheath attaches some of the dolphin's muscles to its skeleton and provides some of the "spring" in the animal's movements.

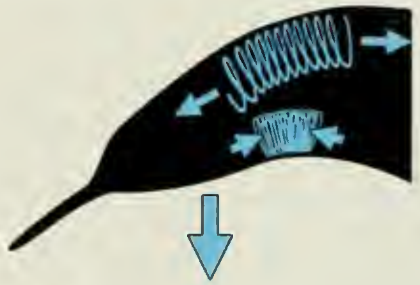
faster they beat their tails, the harder they pushed (and the faster they would have swum if they had been unrestrained). Responding to signals, the dolphins willingly maintained several different tail-beat frequencies, even though all that churning got them nowhere. Meanwhile, Williams measured how much oxygen the animals consumed while generating the force, since oxygen consumption is an indication of energy used. She found that even when the dolphins nearly doubled the force they were producing, their metabolic rate—as well as the frequency with which they popped above the surface to breathe—did not change.

The biomechanics of marine mammals, and particularly how they store elastic energy, is the subject of research in the lab of Ann Pabst and William McLellan at the University of North Carolina at Wilmington. Much of their work focuses on the animals' hind end, which in whales and dolphins tapers to a narrow tailstock that is higher than it is wide. The tailstock ends in the flukes; locomotion is powered by the up-and-down motion of these broad, flattened, propulsive blades. Muscles contract to pull the tail up, but at some point the tail must stop, reverse direction, and go down again. This reversal could be accomplished actively, through the contraction of opposing muscles, or passively, by the action of springs.

Pabst and McLellan's studies have led them to speculate that blubber and a connective tissue called the subdermal sheath are the springs in the dolphin's pogo stick. A stiff, helically wound membrane, the subdermal sheath surrounds the entire tailstock and attaches some of the underlying muscles to the skeleton. When the tail is on its way up, the sheath on the bottom side of the tail is stretched, storing some energy for the downstroke. On the way down, energy gets stored on the tail's top side. Perhaps even more important is the role of the blubber, a thick layer of fat that lies beneath the skin and, unlike the fat of your next-door neighbor's beer belly, is reinforced with a highly organized, three-dimensional weave of collagen fibers. This fibrous material gives dolphin blubber a stiffness and resilience not found in other forms of fat. Specialized triangular wedges of blubber run along both the top and the bottom of the tailstock. When a swimming dolphin flips its tail up, the top wedge compresses and the bottom wedge stretches. Once the tail can go no higher, the wedge of blubber on the top pushes it (and the wedge on the bottom pulls it) back down.



As swimming muscles lift the dolphin's tail, blubber on the top side is compressed while blubber and the fibers of the subdermal sheath on the bottom are stretched, storing energy for the downstroke.



As the muscles relax, the previously compressed blubber springs back and may help push the tail down. The now compressed blubber and sheath on the tail's underside may also contribute to the downward pull on the tail.

The combination of these two biological springs—the blubber and the sheath—may be what helps propel the dolphin at speeds greater than twenty miles per hour, making them the envy of swimmers and engineers alike. Perhaps our Olympians are on the wrong track, losing body fat to go faster. The trick might be to acquire better-designed fat, not less of it.

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

THE NATURAL MOMENT

Saline Away

Photograph by
Mike Parry MINDEN PICTURES

Photographer Mike Parry was taking a break between dives in shallow water off New Britain Island in Papua New Guinea when he saw a log floating close to his boat. A guide set him straight: that was no log, that was a saltwater crocodile. Would it be safe, Parry wondered, to get closer? His was no idle rumination—the saltwater crocodile, *Crocodylus porosus* (called a "salty" in Australia), has been known to include *Homo sapiens* in its diet.

The largest living reptile (males can grow to twenty-three feet long, females to ten), *C. porosus* is found throughout the tropical regions of Asia and the Pacific. Although the species is still threatened by the loss of its freshwater breeding habitat, conservation and breeding programs have reduced the pressures brought to bear on it by hide hunters.

All crocodiles are equipped with modified salivary glands that allow them to tolerate saline water; it's no surprise, then, that *C. porosus* can wander several hundred miles from shore with no trouble. For most individual animals, though, seafaring is more forced than elective. Adults hog good breeding territory in freshwater swamps and near coastlines, pushing younger and weaker animals to saltier regions. Unable to establish their own territory, the castaways—perhaps like the young salty that Parry spotted—often strike out in search of hospitable river systems.

Quickly shoving on fins, mask, and snorkel, the photographer grabbed his camera, slipped overboard, and swam to within a few feet of the crocodile. He remembers the mesmerizing stirring of its tail, the blue of the semitransparent membrane covering its eyes. The crocodile dived to the grassy seafloor. Parry followed and was able to take a few shots before the animal disappeared.

REVIEW

Reading the Heavens

By George Saliba

Astrology—an amalgam of myth, mathematics, philosophy, and astronomy—has mirrored social history through the ages.

Scarcely a culture, ancient or modern, has not produced people who have wondered at one time or another about the order of the universe in which we live and the likely laws that govern it. Their answers often range from pure myth, fantasy, and free association to supposedly universally testable rules that can account for the natural phenomena we all observe. The case of astrology is of special importance because it speaks to the basic human anxiety about the order of the universe and purports to endow its practitioners with the power to predict a person's character and destiny from the arrangement of the planets at the specific moment of birth. This kind of speculation goes back to the earliest texts of ancient civilizations, such as those of Mesopotamia, Egypt, India, and China. A glance at modern magazines will convince anyone who needs convincing that such astrological speculations persist right up to the present.

SCALA/ART RESOURCE, N.Y.

A page from a twelfth-century work authored by Hildegard of Bingen depicts man as the focus of celestial forces—the basic tenet of astrology.

Astrology: A History, *by Peter Whitfield (Abrams, 2001; $35)*

Sumptuously illustrated with reproductions of manuscript pages from volumes still found in collections of rare books, *Astrology: A History* covers the field's documented beginnings in Babylonia, its assignment to the celestial sphere during Greek and Roman times, its diffusion and adaptation in India, China, and the Middle East, its eclipse and reemergence in Western Europe during the Middle Ages, its revival during the Renaissance, and its increasing marginalization as the pure sciences became more widespread and accepted.

Peter Whitfield, an authority on maps and the author of a number of books on different aspects of the history of ideas, touches on some of astrology's great proponents: Greek philosopher Aristotle, Alexandrian astronomer Ptolemy, Islamic astrologer Abu Ma'shar, medieval philosopher Albertus Magnus, Elizabethan cosmologist and astronomer John Dee. In elaborating how astrology has permeated social and intellectual history, Whitfield looks at the astrological subtext of Chaucer's *Canterbury Tales,* for example, as well as Shakespeare's seven-ages-of-man soliloquy in *As You Like It.* He describes the Zodiac Man—each of the zodiac's twelve signs was thought to influence a different part of the body (a concept first described in Latin poet Marcus Manilius's first century A.D. *Astronomicon*)—and discusses the development of astrological medicine. Whitfield also explains the astrolabe, a two-dimensional model of the heavens that allowed an astrologer to determine, for any required date, the position of the ascendant zodiac sign.

A reader who is interested in the subject but not necessarily ready to roll up his or her sleeves and start delving into the technical details of astrology can peruse this book with pleasure. For an in-depth history of the subject, one would do better to dust off the century-old volumes of Auguste Bouché-Leclercq, *Les Précurseurs de l'Astrologie Grecque* (1897) and *L'Astrologie Grecque* (1899), which are not mentioned in Whitfield's bibliographical note at the end of the book. To read Leclercq's great works, one has to have the patience to cover close to a thousand pages of dense French prose. Whoever goes through that experience, however, will not be disappointed and will appreciate the intricate philosophical questions that the ancients were dealing with.

The questions and evidence first examined by astrology are deceptively simple: Why, for example, do seeds germinate only during the spring, and why do leaves fall in the autumn? Were these phenomena caused by the Sun, which was believed to rotate around Earth? Since the Sun's yearly path coincided rather well with events in spring and fall, could the other planets and the Moon have similar effects?

For the venerable Aristotle and his followers, who laid the intellectual foundations of astrology, all the manifestations of change—in particular, those of coming-to-be and decay—are the by-products of cyclical motions of the celestial bodies and the inclination of the solar path. This inclination, or ecliptic, along and around which all the other planets also seem to move (adjusting for the effects of the planets themselves), would later be elaborated on by Ptolemy. Once the celestial and the earthly realms were connected, it was a relatively small step to use this process to answer such elusive questions as, What kind of life will a child turn out to have? Lucky and wealthy, or destitute? And if it is the latter, could one take any steps to avert this destiny? The answers that succeeding generations provide to such questions are worth studying for what they say about the social history of an era.

Whitfield is right to conclude that the "rationalization" of astrology (using it to make unverified cause-and-effect connections similar in structure to the ones usually made in a scientific statement) took place at the hands of the Greek philosophers, especially Aristotle. Subsequently, Ptolemy formulated astrology as a natural system, a set of physical laws operating without any reference to the mythological gods of Greek antiquity. But Whitfield does not note that astrology's rationalization by the Greeks almost five centuries later is nowhere free of the mythological substratum upon which it was erected. Otherwise, why would Ptolemy (as well as modern astrologers) ascribe to the planet Mars all the maleficence pertaining to the Greek god of war and bloodshed, and to the planet Venus all the beneficence pertaining to the Greek goddess of love and romance?

The fact that astrologers tried their very best—and still do—to cloak their discipline in complicated mathematical constructions does not validate it as science. It is true that the computation of the point of the Sun's path that happens to be rising over the eastern horizon at a specific moment (a point called the horoscope or the ascendant in astrological parlance) is indeed a rather sophisticated exercise in spherical trigonometry. But its significance for the kind of life a child will turn out to have is speculation. Modern defenders of these computations assert that science cannot answer a whole host of questions—but neither can astrology or, for that matter, magic, geomancy, palmistry, or sheer guessing.

George Saliba, a professor in the Department of Middle East and Asian Languages and Cultures at Columbia University, is the author of numerous publications and books, most recently A History of Arabic Astronomy: Planetary Theories During the Golden Age of Islam *(New York University Press, 1994).*

nature.net

Jumping Genes and More

By Robert Anderson

When it comes to teaching science, the Internet has one clear advantage over textbooks: it can incorporate a full range of media to bring lessons to life. One of the best examples I have found is DNA From the Beginning, a site produced by the Dolan DNA Learning Center at Cold Spring Harbor Laboratory in New York (vector.cshl.org/dnaftb/). Billed as "an animated primer on the basics of DNA, genes, and heredity," the site is also a wonderful place to learn about the men and women who made the key discoveries. This is not surprising, given the laboratory's central role in much of that history.

The primer presents forty-one concepts, each including a video interview with a scientist, biographies of the important players, a gallery of relevant photos, a problem, and links for further study. But what most impressed me were the animated clips that illustrate the concepts. They require Flash Player to view, but seeing the molecules in motion makes it much easier to understand what is going on. Without a doubt, genetic information is dynamic. Take concept 32, "Some DNA can jump." The animation shows how, in Barbara McClintock's famous experiments with corn, genes can flip from one part of a chromosome to another.

Although some may find certain concepts challenging, the history that accompanies them is fascinating enough to keep one reading. If you've never read James D. Watson's 1968 classic, *The Double Helix*, concept 19 is a must. You'll get a fantastic, concise explanation of how Watson and Francis Crick (with some help from others) figured out the twisted ladder shape of DNA.

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

BOOKSHELF

The Birds of Heaven: Travels With Cranes, *by Peter Matthiessen; paintings and drawings by Robert Bateman (North Point Press, 2001; $27)*
In many cultures, cranes are regarded as symbols of longevity, good fortune, and harmony. Matthiessen journeys from Mongolia and Siberia to Sudan and South Africa to track the dwindling populations of the world's fifteen species of cranes.

The Monkey in the Mirror: Essays on the Science of What Makes Us Human, *by Ian Tattersall (Harcourt, 2002; $25)*
Writing in a lively, engaging style, American Museum of Natural History anthropology curator Tattersall muses on the nature of science and the multifarious processes of evolution, raising a host of intriguing questions about the biological and cultural histories of our own hominid family.

Darwin, His Daughter & Human Evolution, *by Randal Keynes (Riverhead Books, 2001; $26.95)*
Keynes, a great-great-grandson of Charles Darwin, found—in a chest of drawers inherited from his grandmother—the memorabilia-filled writing case of Darwin's beloved daughter Annie (who died at age ten). The discovery prompted him to write about Darwin's home life and the personal experiences that shaped his deepest ideas.

The Bone Museum: Travels in the Lost Worlds of Dinosaurs and Birds, *by Wayne Grady (Four Walls Eight Windows, 2001; $24.95)*
Grady, former science editor for the magazine *Equinox*, chronicles his travels with Canadian vertebrate paleontologist Philip Currie to dig for fossils on three continents. The author gains insight into not only the nature of evolution but also the drudgery and frustration of fieldwork.

Coming Home to Eat: The Pleasures and Politics of Local Foods, *by Gary Paul Nabhan (W. W. Norton, 2001; $24.95)*
Nabhan, director of the Center for Sustainable Environments at Northern Arizona University, devoted a year to eating only foods grown or caught within 200 miles of his home.

Aging Well: Surprising Guideposts to a Happier Life From the Landmark Harvard Study of Adult Development, *by George E. Vaillant (Little, Brown, 2002; $24.95)*
In an unprecedented series of studies, Harvard Medical School has followed 824 subjects—men and women from different economic backgrounds—from their teens to old age. Vaillant, the project's director, uses these studies to illustrate the variables involved in reaching a happy, healthy old age, explaining how natural resilience is affected by lifestyle choices and by factors such as marriage, divorce, and negative personality changes.

The Aging Brain, *by Lawrence Whalley (Columbia University Press, 2001; $22.95)*
As scientists tease apart the influence on the brain of environmental (diet, stress) and biological (genes, brain injuries) factors, they are developing a range of therapeutic and preventive measures that can help ensure the sustained vitality of our mental faculties.

Origins: The Evolution of Continents, Oceans and Life, *text and photographs by Ron Redfern (University of Oklahoma Press, 2001; $49.95)*
This unique survey of Earth—the formation and movements of its landmasses, seas, and mountains, as well as the emergence of its inhabitants—includes not only breathtaking photographs and excellent illustrations but also highly readable commentaries by a pioneer of, and authority on, interpretive landscape photography.

What Evolution Is, *by Ernst Mayr (Basic Books, 2001; $26)*
Largely responsible for shaping the modern synthesis of genetics and evolutionary theory, Mayr—now ninety-six and still professionally active—has written an elegant primer on evolution, in which he gives a spirited defense of Darwinian explanations of biology.

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

PHOTOGRAPHY


ART WOLFE

The High Himalaya, *photographs by Art Wolfe; text by Peter Potterfield (The Mountaineers Books, 2001; $44.95)*

EXPLORER GUIDE

ENDPAPER

Flag Waving

By Michel Pastoureau

In the Western world, the wearing of stripes originally constituted a handicap or liability. Medieval society, literature, and iconography endow a great number of individuals—real or imaginary—with striped clothing. In various ways they are all outcasts and reprobates: ranging from the heretic to the clown, the gamut includes not only the leper, the hangman, and the prostitute but also the disloyal knight of the Round Table, the madman of the Book of Psalms, and the character of Judas. They all disturb the established order; they all have more or less to do with the devil.

At the end of the Middle Ages, stripes make a very rapid transition from the diabolic to the domestic (though perhaps retaining their old connotation of impurity) and gradually become the sign of a servile condition or subordinate function, such as that of a lord's household staff. Parallel to the development of the domestic stripe is the evolution of another category—the aristocratic stripe, sometimes sophisticated, always in good taste. This stripe triumphs during the second half of the eighteenth century, the first period of romanticism and revolution.

ATTRIBUTED TO STUDENT OF GIOTTO, CA. 1340, SAN DOMENICO CHURCH, BOLZANO, ITALY

The ignominious stripe: In a fourteenth-century mural, three young women are saved by Saint Nicholas from a life of prostitution.

In the late 1770s a rage for stripes is found among the Americanophiles in France and in other countries hostile to England. The American Revolution was an offshoot of the Enlightenment; the flag, with the thirteen red and white stripes for the thirteen American colonies rebelling against the British crown, appears as the image of Liberty and the symbol of new ideas. The stripe quickly acquires an ideological and political status: wearing it, adorning oneself with it, displaying it at home or outside can proclaim one's Anglophobia or one's support of the movement for freedom. But it also becomes, quite clearly, a fashion trend.

Everywhere on the continent, there is an unfurling of stripes. Dresses, jackets, jerkins, coats, frock coats, waistcoats, petticoats, blouses, stockings, pants, trousers, aprons, ribbons, scarves: as much in court as in villages, most pieces of clothing are, or can be, striped. The aristocratic stripe and the peasant stripe meet up with each other and sometimes merge, as in the country and shepherd scenes of which painters and engravers have left so many examples. This rage for stripes lasts more than half a century, involving all social classes. Gradually the fashion in stripes extends to fabric for interiors and furniture.

It is difficult to say precisely why the French Revolution made such wide use of stripes and striped surfaces, to the point where they end up in its emblematic repertoire side by side with the fasces, the pike, the tricolor rosette, and the liberty cap. For two centuries, in paintings, engravings, picture books, theater—and later in film, television, and comic strips—all Revolutionary decor is striped decor, and every patriot or sansculotte is a figure wearing striped pants or vest.

Is it going too far to see in the French Revolutionary stripe a vestige of the image of the devil, juggler, or madman, all transgressors against the established order? Is it going too far to establish an *a posteriori* connection, at once dreamlike and geometric, between the bars of the Bastille, those prisons of the Reign of Terror, and the striped clothing so prized by the men of the French Revolution?

At the end of the eighteenth century, however, the Revolutionary stripe is neither a creation nor a monopoly of the French. Having come from America, it retains—even up to our own times—its American connotation.

Michel Pastoureau is an authority on medieval heraldry and a professor of history at the Sorbonne. He is also the author of Blue: The History of a Color *(Princeton University Press, 2001).*