NATURAL HISTORY

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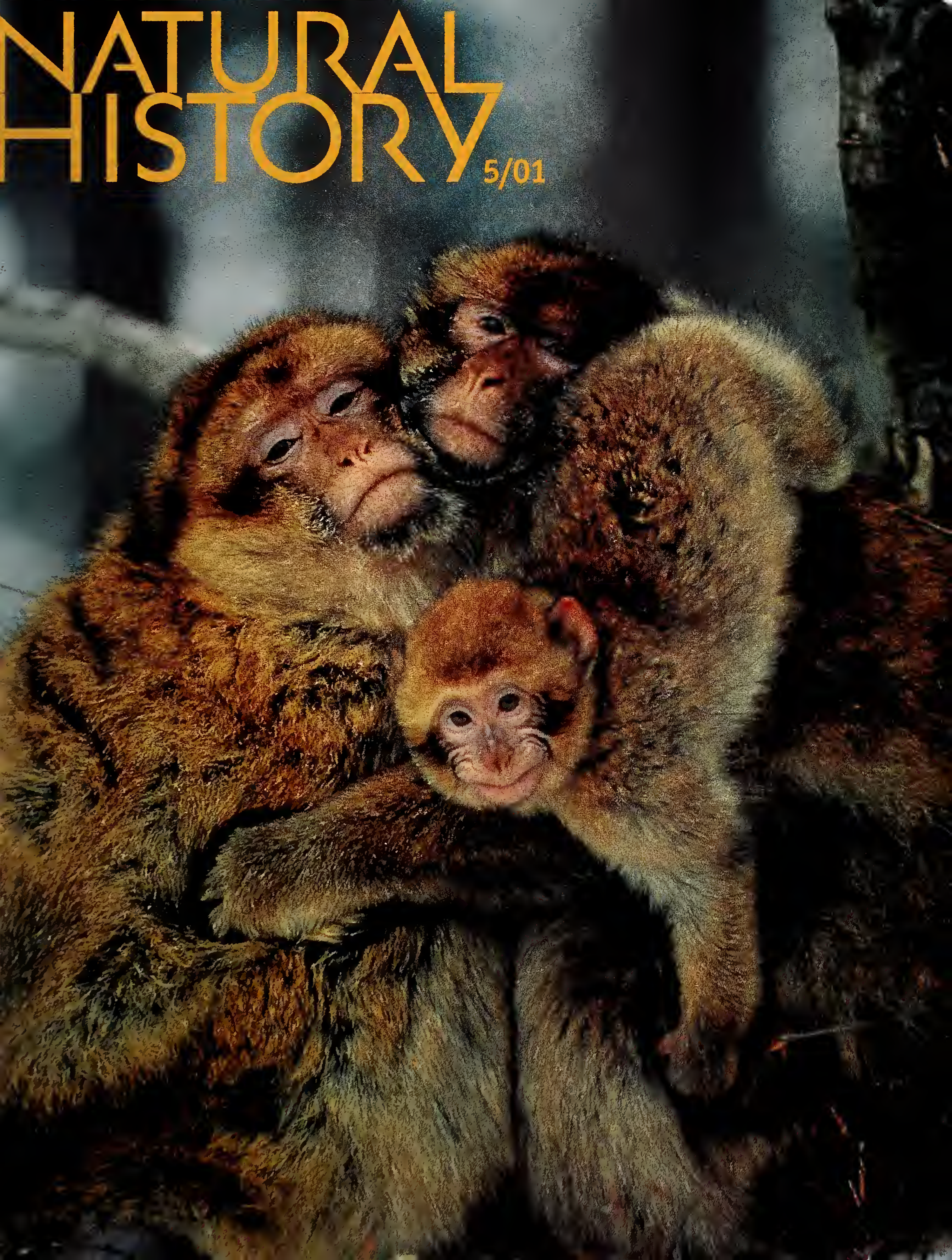

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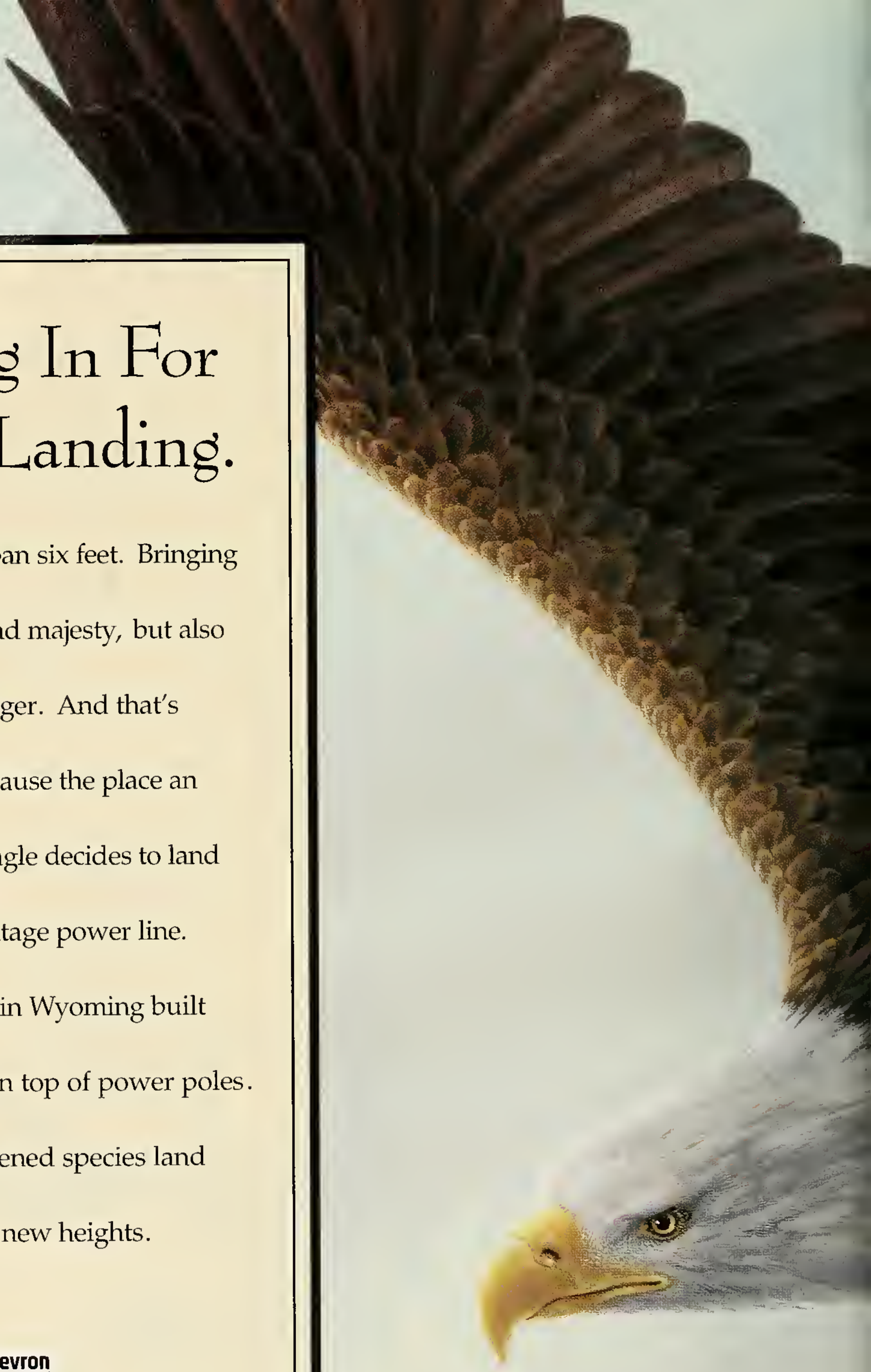

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NATURAL HISTORY

MAY 2001 VOLUME 110 NUMBER 4

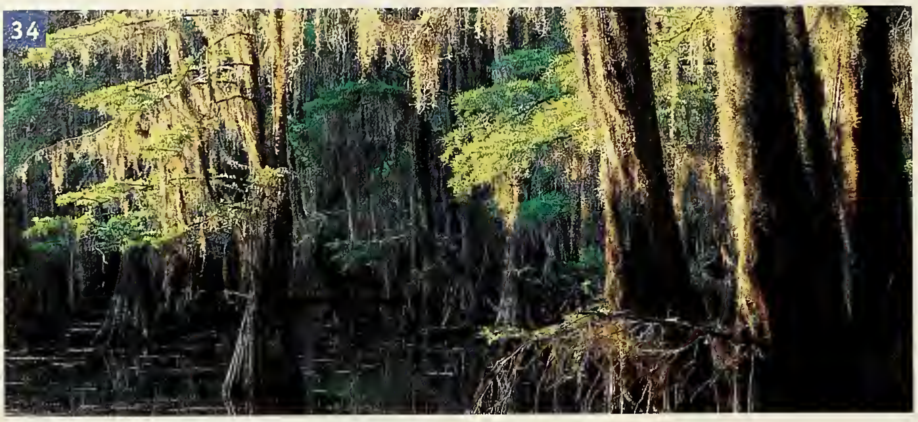
FEATURES

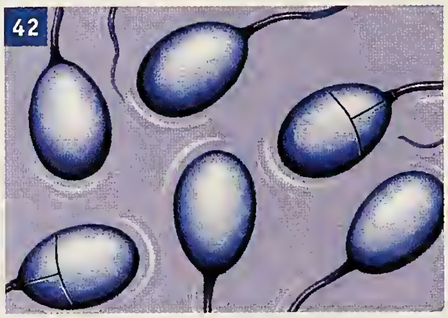
COVER
Female Barbary macaques with a baby. Primate mothering is, to varying degrees, a shared venture.

STORY BEGINS ON PAGE 50

PHOTOGRAPH BY CYRIL RUOSO/BIOS; PETER ARNOLD, INC.

DEPARTMENTS





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UP FRONT

Others' Day

Probably because I grew up in a part of the world where most families were small and nuclear, I often heard friends remark that nothing in their experience—not the baby-sitting jobs, certainly not complaints from their own overworked mothers, not all of Erma Bombeck's brilliant wisecracks—had quite prepared them for the night-and-day relentlessness of the task of caring for their first baby. (The only person among us who knew the score ahead of time was herself the oldest of eleven. It could truly be said that Kathy had already been a parent.)

A human infant is, of course, about as helpless a creature as one finds in nature. And it needs support for an extremely long time. Mothers and fathers are not born with the skills required. (Basic issues of caretaking sometimes stymie even the experts. Is crib death best prevented by putting the baby down on its back, side, or stomach? The most recent official answer from pediatricians is that the back is safest.) As soon as an infant can crawl, its moment-to-moment existence is threatened by physical dangers. Getting a child past infancy requires unending vigilance, and attending to its social and emotional education is one of life's most challenging long-term commitments. (The writer James Agee once observed that "begetting a child is at least as serious an act as murder." Yet for the most part, we cheerfully opt to reproduce.)

DANNY LYON; MAGNUM PHOTOS, INC.

Humans are flexible creatures, and what we consider the proper and most loving way to bring up a child varies with cultural background, financial circumstances, and individual experience. Yet we are not infinitely flexible. We are mammals, primates with a unique evolutionary history. If our offspring are to survive and behave as social creatures, we must toe a biological bottom line.

In this issue, anthropologist Sarah Blaffer Hrdy ("Mothers and Others," page 50) takes an extended look at that bottom line. Pulling together evidence from social anthropology, endocrinology, and studies of animal behavior, Hrdy bolsters her hunch that the original human family was far from nuclear. As Mother's Day approaches, we can pause to think about not just the traditional honorees but also fathers, siblings, grandparents, aunts, uncles, day-care workers, and foster parents. It may well be that the devoted labors of "others" made it possible for humans to evolve.—*Ellen Goldensohn*

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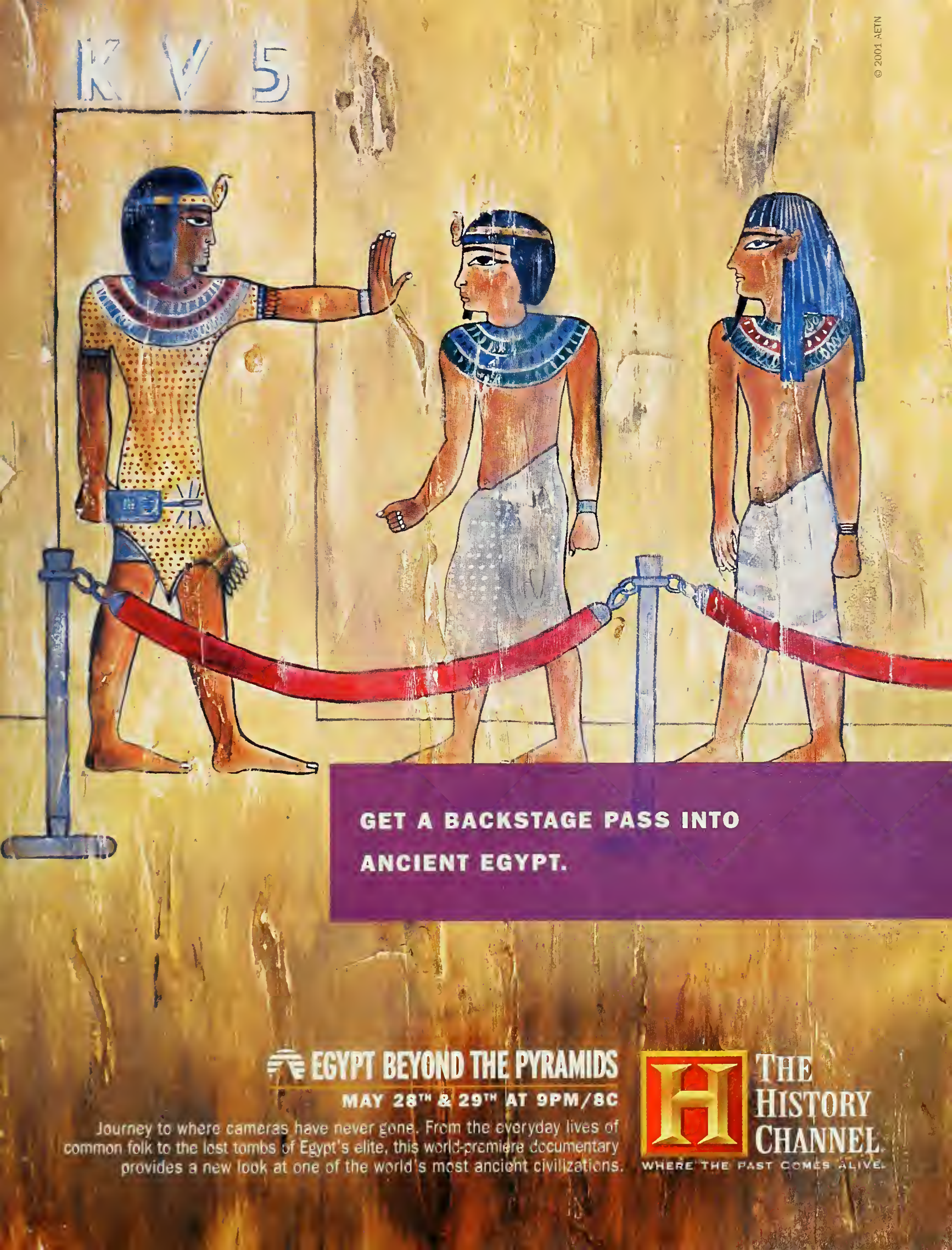
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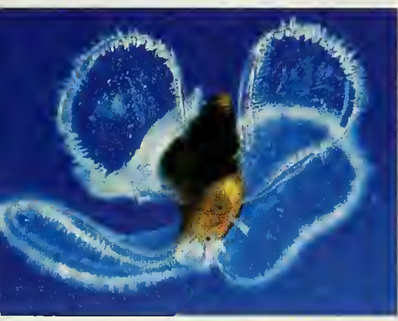
LETTERS

A Larva By Any Other Name

On page 56 of "A World Apart," by Gregory A. Wray (3/01), two photographs illustrate the drastic morphological change that occurs in a snail at metamorphosis. Unfortunately, the photographs are of two decidedly different types of snails. While the adult nudibranch is correctly identified, the veliger larva is not a nudibranch. Its multispiral, heavily sculptured, darkly colored shell, plus its large four-lobed velum, point to a different type of snail, one of the neogastropods.

Paula M. Mikkelsen, Ph.D.
Division of Invertebrate Zoology
American Museum of Natural History



PETER PARKS; IMAGE QUEST 3D

THE PHOTOGRAPHER, PETER PARKS, RESPONDS: Paula Mikkelsen is quite right. The original slide for this photo was mislabeled. It should have been captioned "prosobranch" (not "opistobranch").

Insect Allure

Erik L. Laurent's article on the Japanese fascination with insects ("Mushi," 3/01) was itself fascinating. The note about the author on page 13 ("Contributors") mentions the eating of insects, and I was reminded of an incident that happened in 1946 or '47. I was in the Scientific and Technical Division at MacArthur's headquarters, where we had the responsibility of overseeing Japanese research. One project was on the use of silkworm pupae after the silk had been unwound. Unfortunately, the research had to be discontinued because the young women doing the work ate all the pupae. Food was rather short at that time, and the pupae were essentially cooked in the water used to loosen the silk.

John H. McClendon
via e-mail

The author writes about Japan, but playing with insects is fairly universal in Asia. When I was a child in Hong Kong, we were always staging fights between belligerent insects, which were sold by vendors sitting outside the school gate.

A. Zee
Santa Barbara, California

Eve and Adam

In "The Evolutionary Front" (3/01), Carl Zimmer writes that "a father cannot contribute mitochondrial genes to a child, because mitochondria in sperm can't enter the egg cell." Yet in "Symbionts and Assassins" (7/00–8/00), Guy Brown writes, "When a sperm penetrates an egg cell during conception, it delivers a full load of nuclear DNA but only a few or no mitochondria." If Brown is correct and some mitochondria can be passed from father to child, does that shed doubt on the "mitochondrial Eve" date of 170,000 years?

Adam Klein
Jackson, New Jersey

GUY BROWN RESPONDS: There has been some scientific debate over the past ten years about whether any mitochondrial DNA is inherited paternally. It had been assumed that there was no paternal inheritance, but then some work on mice indicated there was a paternal contribution, and studies of egg fertilization showed that significant numbers of sperm mitochondria did enter the egg. More recent studies, however, have indicated that sperm mitochondria entering the egg are subsequently destroyed, and the pendulum of opinion has swung back. I was reflecting the current scientific uncertainty by saying that the sperm might deliver "only a few or no" mitochondria.

Hominid Bones

After reading "The Scavenging of 'Peking Man,'" by Noel T. Boaz and Russell L. Ciochon (3/01), I wondered if there were any planned or in-process efforts to replicate the DNA of *Homo erectus* and/or *Homo habilis,* as has recently been done with Neanderthal DNA.

Kathleen McVey
via e-mail

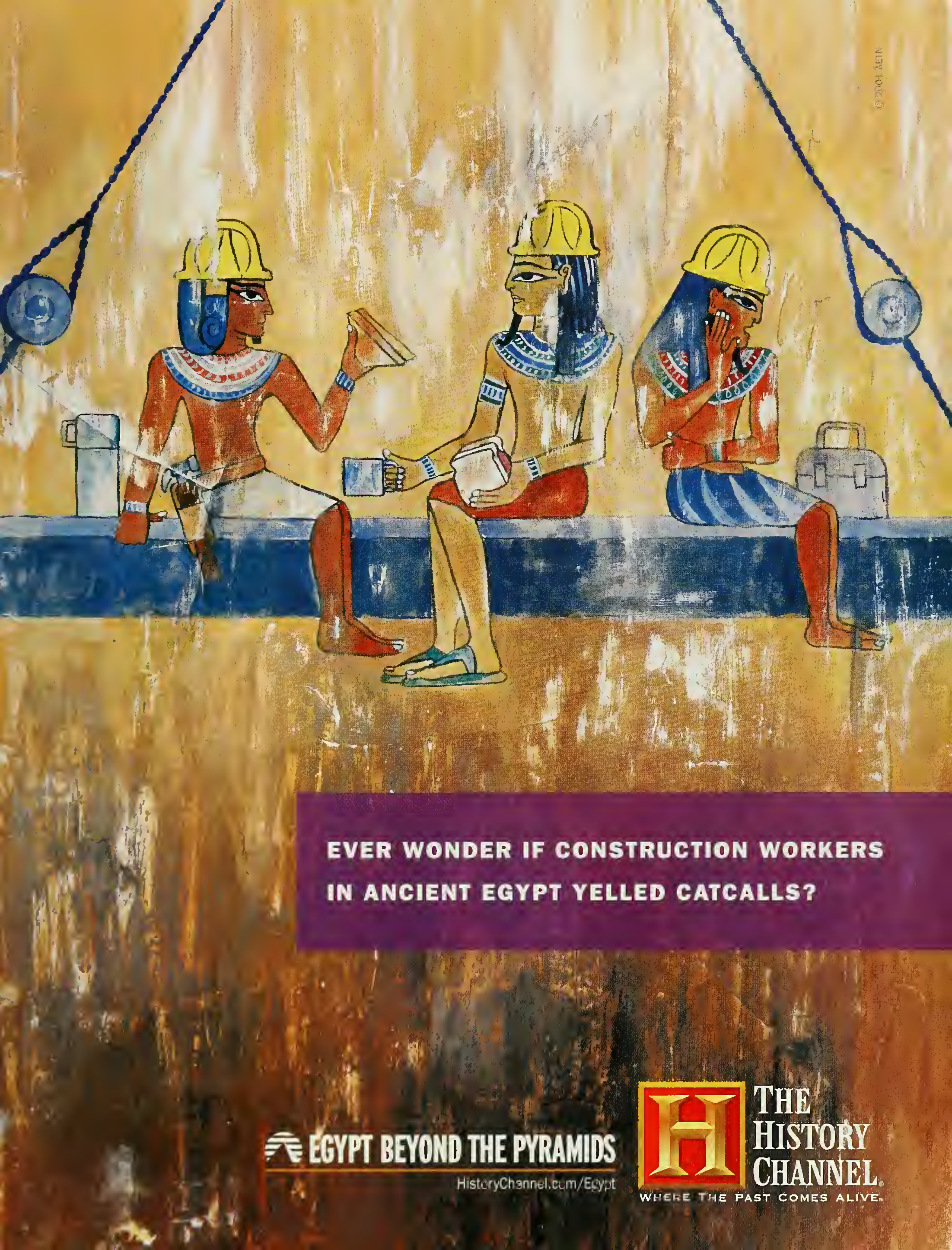
RUSSELL L. CIOCHON REPLIES: Chances for the preservation of DNA decrease with the specimen's age. Neanderthal fossils are all less than 100,000 years old, and even so, only two have yielded DNA. *Homo erectus* fossils are three to fifteen times older; in addition, none have been well enough preserved to provide any DNA. No fossils of "Peking man" are available for DNA testing, as all of the originals have been lost.

Dislodged Beavers

In "In the Field" (3/01), Peter J. Marchand writes that beavers "show little inclination to chisel through" the ice of a pond and emerge from their lodges during winter. Here on the U.S.-Canadian border along the Saint Lawrence River, I have been observing six beaver colonies this winter, and beavers from five of them have been out frequently to harvest trees and brush. The other colony happens to be the deepest. I suggest that beavers in shallower ponds, less than three feet deep, are more likely to make or find holes in the ice created by running waters that are, in turn, caused by holes in the dam that they or otters might make.

Bob Arnebeck
Wellesley Island, New York

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

It was a picture showing the bacterium *Vibrio harveyi* glowing in the dark that drew **Bonnie L. Bassler** ("Tiny Conspiracies," page 16) to study cell-to-cell communication in bacteria. At the time, she was just finishing her doctorate in biochemistry and wanted to do research in genetics. She thought *V. harveyi* would make an ideal subject because she could induce mutations that affected luminescence and then simply turn off the lights in the room to identify the interesting mutants. "After eleven years of studying the 'languages' of this species," she says, "I realize the phenomenon is slightly more complicated than I first suspected. However, making the mutants is still fun." Bassler is an associate professor in the department of molecular biology at Princeton University.

An anthropologist with a long-standing interest in the natural relationships among males, females, and their offspring, **Sarah Blaffer Hrdy** ("Mothers and Others," page 50) began her research in the 1970s with a nine-year study of Hanuman langurs, a species that Indians regard as sacred. Her evolutionary perspective on families has resulted in two previous major essays for *Natural History*: "Daughters or Sons" (April 1988) and "Natural-Born Mothers" (December 1995). Hrdy (pictured with her son, Niko) is professor emerita of anthropology at the University of California, Davis, and the author of four books, including, most recently, *Mother Nature: A History of Mothers, Infants, and Natural Selection* (Pantheon Books, 1999).

Laura Sessions ("New Zealand Sweet Stakes," page 64) first read E. O. Wilson's article "The Little Things That Run the World" as an undergraduate biology student and says she has been looking for examples ever since. Honeydew insects in the southern beech forests of New Zealand fill the bill. Sessions moved to New Zealand from the United States in 1996. After finishing her master's degree at the University of Canterbury in Christchurch—on the effects of Australian brush-tailed possums on New Zealand plants—she enrolled in a doctoral program there in science communication. Sessions leads natural history tours of New Zealand for American students and recently visited South Georgia and other subantarctic islands, where she had an opportunity to "play with the penguins and sea lions."

After writing his doctoral dissertation on slug slime, **Mark Denny** ("The Rewards of Chance," page 72) turned his attention to the plants and animals that live on wave-swept shores. Currently the DeNault Professor of Marine Sciences at Stanford University, Denny conducts fieldwork at Stanford's Hopkins Marine Station in Pacific Grove, California. Together with Steven Gaines, he wrote *Chance in Biology: Using Probability to Explore Nature* (Princeton University Press, 2000). Their interest in chance began while attempting to predict the toughest conditions intertidal organisms could tolerate. Denny reports that for a biologist (not a mathematician or statistician), it feels strange to have written a book about probability theory—especially, he says, when he mentions it to fellow biologists and then "observes them get a wary look in their eye and edge away."

John Serrao ("The Natural Moment," page 88) grew up in the borough of Queens, New York City, where he pursued his passion for living things by hunting black widow spiders around Jamaica Bay and collecting cicada-killing wasps in his backyard. After receiving an M.S. in Science and Environmental Education from Cornell University, Serrao (pictured here with a two-month-old black bear) began his career as a professional naturalist, leading nature programs for schools and communities near his home in the Pocono Mountains. His wildlife photography has appeared in dozens of magazines and field guides and in nearly a hundred nature books. Serrao's most recent book is a self-published photographic guide, *The Reptiles and Amphibians of the Poconos and Northeastern Pennsylvania* (J. S. Publications, 2000).

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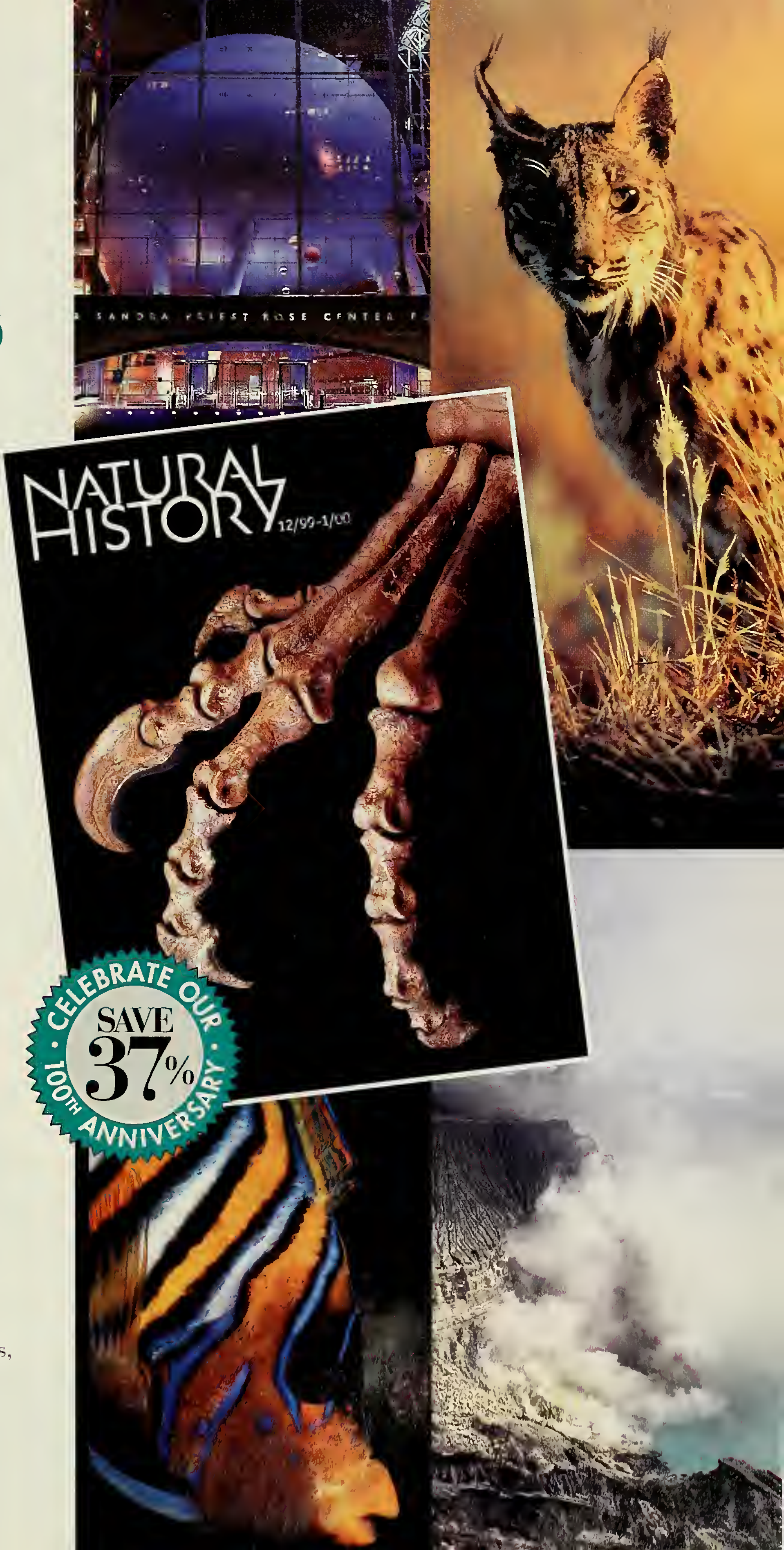


IN SUM

SIS'S CHICKS Brood parasitism—tricking another mother into incubating one's eggs—is particularly common in ducks. A female duck simply lays her eggs in the nest of another duck, leaving the host mother to care for them. It's a good deal for the parasitic bird: she avoids the energetically costly business of incubating and raising her own chicks and also avoids being a sitting duck for predators.


Goldeneye with chicks

VICTORIA MCCORMICK; ANIMALS ANIMALS

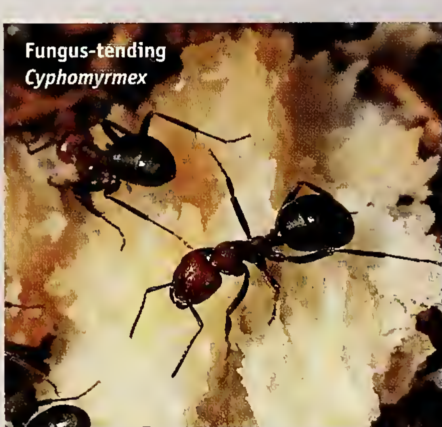
If the host and parasite are closely related, the cost of caring for these extra offspring would be outweighed by the genetic benefit to the group. Zoologists Malte Andersson and Matti Åhlund, of Sweden's Göteborg University, studied this kin-selection hypothesis among female goldeneye ducks *(Bucephala clangula)* by exploring whether the birds parasitize only individuals to which they are closely related.

Without harming the developing embryos, the researchers drew small albumen samples from goldeneye eggs and looked for genetic markers specific to each mother. Andersson and Åhlund found that the hosts and parasites were, in fact, more closely related than one would expect if nests were selected by chance. Female goldeneyes return to their birthplace to lay their eggs, so are they simply more likely to nest—and parasitize nests—in the same area, or do the ducks recognize and target their relatives? The scientists discovered that females most often parasitized the nests of their mothers and sisters and that female relatives spent more time together than random female pairs did. In addition, the more closely related the host-parasite pair, the greater the number of extra eggs a parasite laid in a host's nest—suggesting that a near-relative host was more amenable to the invasion. ("Host-Parasite Relatedness Shown by Protein Fingerprinting in a Brood Parasitic Bird," *Proceedings of the National Academy of Sciences* 97:24, 2000)—*Kirsten L. Weir*

POACHED FUNGI Processions of foliage-toting leaf-cutter ants are common in the rainforests of Central and South America. When the ants return to their nests, they don't eat the leaves they have collected but use them to feed the nutritious fungi that they cultivate in underground chambers. Now scientists have discovered a new ant species of the genus *Megalomyrmex* that is incapable of growing its own fungi but has evolved to steal the fungus farmers' carefully tended harvests.

Biologist Rachelle M. M. Adams, of the University of Texas at Austin, and colleagues studied this thievery-prone species both in the field and in the laboratory. Native to central Panama, it raids nests of *Cyphomyrmex longiscapus* ants, driving out the fungus growers and taking over the colony.

Some *Megalomyrmex* species invade colonies of fungus growers and live peacefully with them as parasites. But members of the newly discovered species invariably attack all the original inhabitants by pulling at their legs and antennae and perhaps by excreting venom.

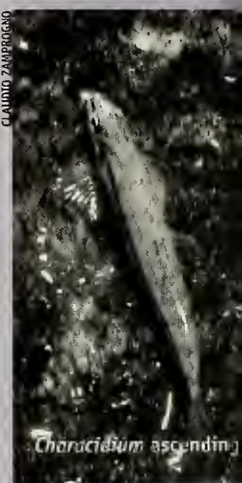

Fungus-tending *Cyphomyrmex*

ROBERT CARR; BRUCE COLEMAN INC.

Unable to defend themselves, the surviving *C. longiscopus* ants abandon their broods and flee the nest. The predaceous invaders consume the fungus and, researchers suspect, feed the stolen larvae to their own broods.

The nest raiders may do some light gardening, maintaining healthy fungus growth for a while. But they don't add necessary nutrients to the high-maintenance gardens, so the fungi eventually become depleted and the "agro-predators" must seek out and take over a new nest. ("Agro-Predation: Usurpation of Attine Fungus Gardens by *Megalomyrmex* Ants," *Naturwissenschaften* 87, 2000)—*Kirsten L. Weir*

ROCK-CLIMBING FISH Salmon swim upstream to spawn, sometimes leaping over low waterfalls, but can any fish climb a wet, slippery, five-story cliff? A team of Brazilian ichthyologists, headed by Paulo A. Buckup, of the Brazilian National Museum and the Federal University of Rio de Janeiro, has observed a species of the South American darter *(Characidium)* that routinely performs this seemingly impossible feat.


Characidium ascendin

CLAUDIO ZAMPROGNO

The researchers observed the waterfall-climbing abilities of the inch-and-a-half-long fish in the swift freshwater streams of Espírito Santo in eastern Brazil. Using their two large pairs of long, flat, stiff-rayed fins, the darters cling to the base of the vertical rock surface while still underwater, then inch themselves upward with strong lateral movements. Their flat, scaleless bellies and slender, elongated bodies facilitate the process. Resting for a few minutes between each effort, they are able to gradually ascend a fifty-foot cliff beneath a waterfall. The same adaptations that enable the darters to cling and climb also enable them to recolonize upstream areas after being washed downstream by flash floods. The scientists think this behavior helps maintain populations in the isolated uplands, where, it seems, more species of darters have evolved than in the lowlands.

Other kinds of fishes, notably some tropical gobies and Asian loaches, which also have the ability to climb tall waterfalls, have independently evolved fin and body shapes similar to those of the darters. ("Waterfall Climbing in *Characidium* (Crenuchidae: Characidiinae) From Eastern Brazil," *Ichthyological Exploration of Freshwaters* 11:3, 2000)—*Richard Milner*

FINDINGS

Tiny Conspiracies

Cell-to-cell communication allows bacteria to coordinate their activity.

By Bonnie L. Bassler

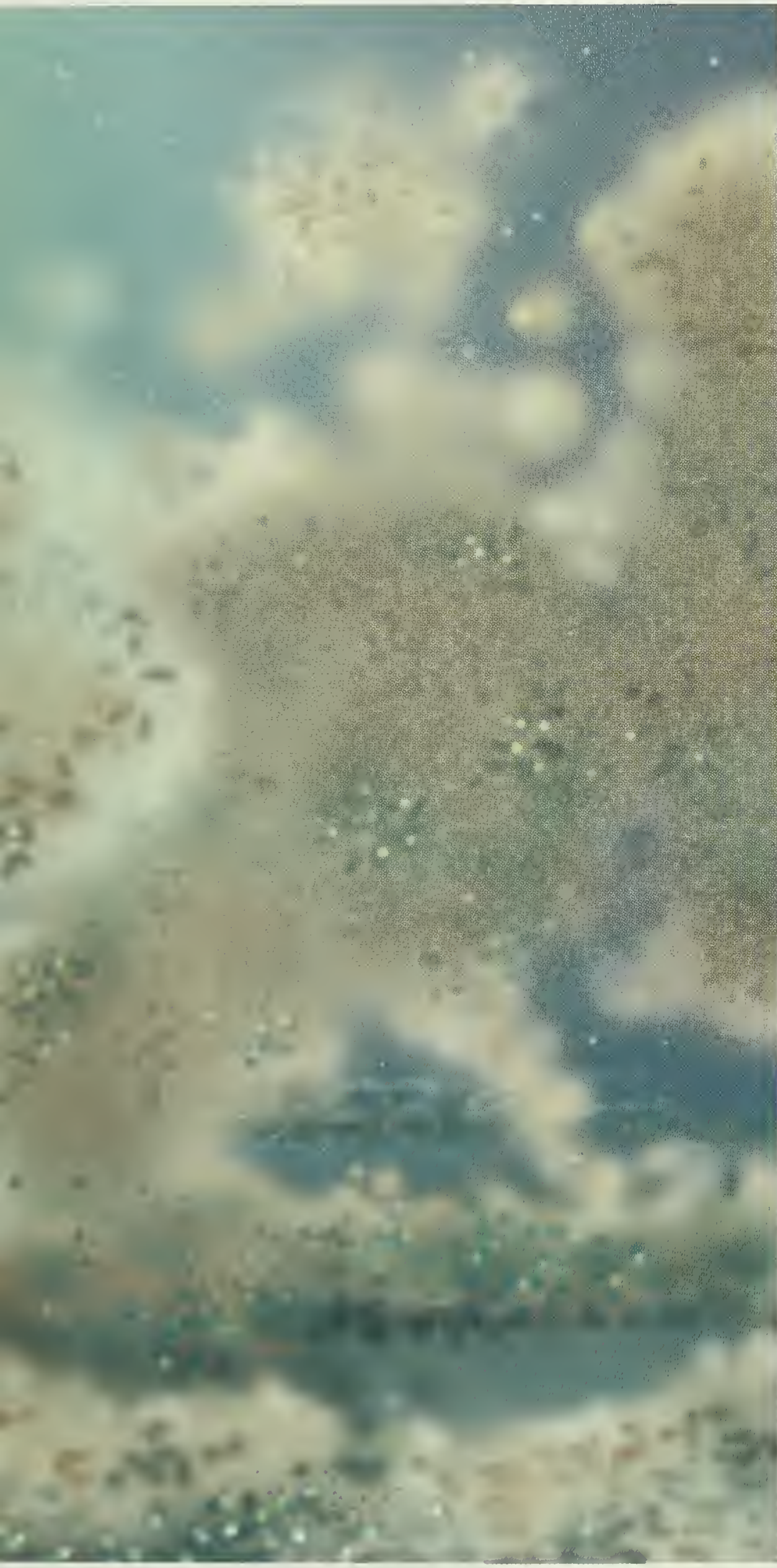
Bacteria have adapted to a huge range of environments on earth, surviving and multiplying in and on plants and animals, in rock layers deep beneath the surface, in searing desert soils, under polar ice, and under extremely high temperatures and pressures in thermal vents on the ocean floor. During the past decade, we have begun to realize that the success of these tiny, single-celled organisms may depend in large part on their ability to converse with one another using chemical signals. Cell-to-cell communication allows bacteria to coordinate their activity and thus enjoy benefits otherwise reserved for multicellular organisms.

By means of a process called quorum sensing, bacteria are able to detect when they are assembled in large numbers as opposed to when they are essentially alone. They may then adjust their behavior accordingly. Bacteria alert one another to their presence by releasing chemical molecules known as autoinducers. When a chemical of this type becomes sufficiently concentrated in the environment (for example, in an organ such as the lungs or intestinal tract), bacteria that are sensitive to it respond by turning on genes that regulate the production of certain proteins. The newly manufactured proteins, in turn, affect the behavior of the bacteria, which take advantage of one another's presence in their efforts to survive and proliferate.

Until recently, the exchange of chemical signals was assumed to be a trait characteristic of "higher," multicellular organisms. Researchers knew of only a few cases of bacterial cell-to-cell communication and considered them the exception rather than the rule. But now scientists are realizing that this capacity is not only common but critical for bacterial survival and interaction in natural habitats.

The phenomenon of quorum sens-

Artist's concept of a biofilm, a bacterial community that organizes itself in part through cell-to-cell chemical signals. Attached to such surfaces as intestinal linings, biofilms have channels that allow nutrients to reach the individual residents.


PEG DIRCKX; CENTER FOR BIOFILM ENGINEERING

ing was first discovered in two species of bioluminescent marine bacteria, *Vibrio fischeri* and *V. harveyi*. Both of these glow-in-the-dark organisms produce light only when their quorum-sensing ability notifies them that they have reached a high cell density. They then manufacture luciferase, an enzyme concoction that facilitates a light-producing biochemical reaction. Although the two species are quite closely related, they inhabit very different niches in the ocean. *V. fischeri* lives in symbiotic association with a number of marine animals, producing light that host animals use for such purposes as luring prey, scaring off predators, and attracting mates. In return, *V. fischeri* gets to reside in the hosts' specialized light organs, where it is provided with amino acids and other nutrients. *V. harveyi*, by contrast, is a free-living organism, and no

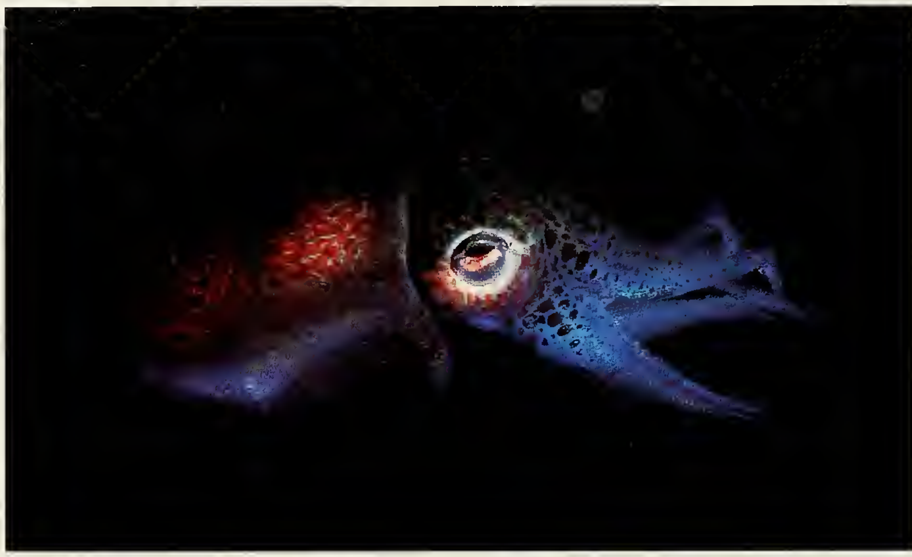
By means of a process called quorum sensing, bacteria are able to detect when their population has reached a high density.

one has yet figured out what advantage it derives from emitting light.

One of *V. fischeri*'s most fascinating associations is with certain bobtail squids of the genus *Euprymna*, the best studied being the Hawaiian bobtail squid. Living in knee-deep coastal waters, this small creature buries itself in the sand during the day and comes out to hunt after dark. Its lifestyle makes the squid especially vulnerable to predation on clear, bright nights, when light shining on the animal from the moon and stars could cause it to cast a shadow and tip off predators patrolling beneath it. But through an alliance with *V. fischeri*, the squid has evolved a light organ that serves as a camouflaging mechanism. The amount of light emitted from this organ, located on the underside of the creature's body, is controlled by an irislike structure. The squid senses the intensity of light from the sky and regulates its light organ accordingly, so that the animal, seen from below, more or less matches the background.

The squid's light is produced by the symbiotic bacteria inhabiting the light organ. After a baby squid hatches, *V. fischeri* bacteria in the seawater swim through ducts leading into the immature light organ, where the hospitable conditions enable them to multiply. There the bacteria live suspended in fluid and, as part of their normal behavior, secrete an autoinducer (the chemical that signals their presence) into it. The bacteria interpret a threshold concentration of this chemical as their cue to switch on the production of light. In effect, *V. fischeri* bacteria alert one another that they are inside a suitable host. When dispersed in the ocean water, however, the bacteria and their autoinducer chemicals never reach critical concentrations. Then again, the bacteria probably do not gain anything by emitting light outside the squid.

A remarkable part of this exquisite symbiosis is the way the squid keeps the bacterial culture fresh within its light organ. At sunrise, when the squid prepares to bury itself in the sand for a day of sleep, so many bacterial cells are living in its light organ that the animal cannot supply them all with adequate nutrients. The squid circumvents this problem by pumping out about 95 percent of the *V. fischeri*. This also reduces the level of autoinducer in the light organ below the critical threshold and causes the bacteria remaining within to stop producing light. The pumping is tuned to the squid's circadian rhythm and is activated only at sunrise. As the day goes by, the bacteria begin to divide, their numbers increase, and more autoinducer accumulates. By nightfall, the light organ is "on" again, ready to do its job.



MIKE SEVERNS

A Hawaiian bobtail squid owes its luminescence to *Vibrio fischeri* bacteria housed in an internal light organ. The bacteria secrete a chemical that, when it has accumulated in sufficient concentration, stimulates them to glow.

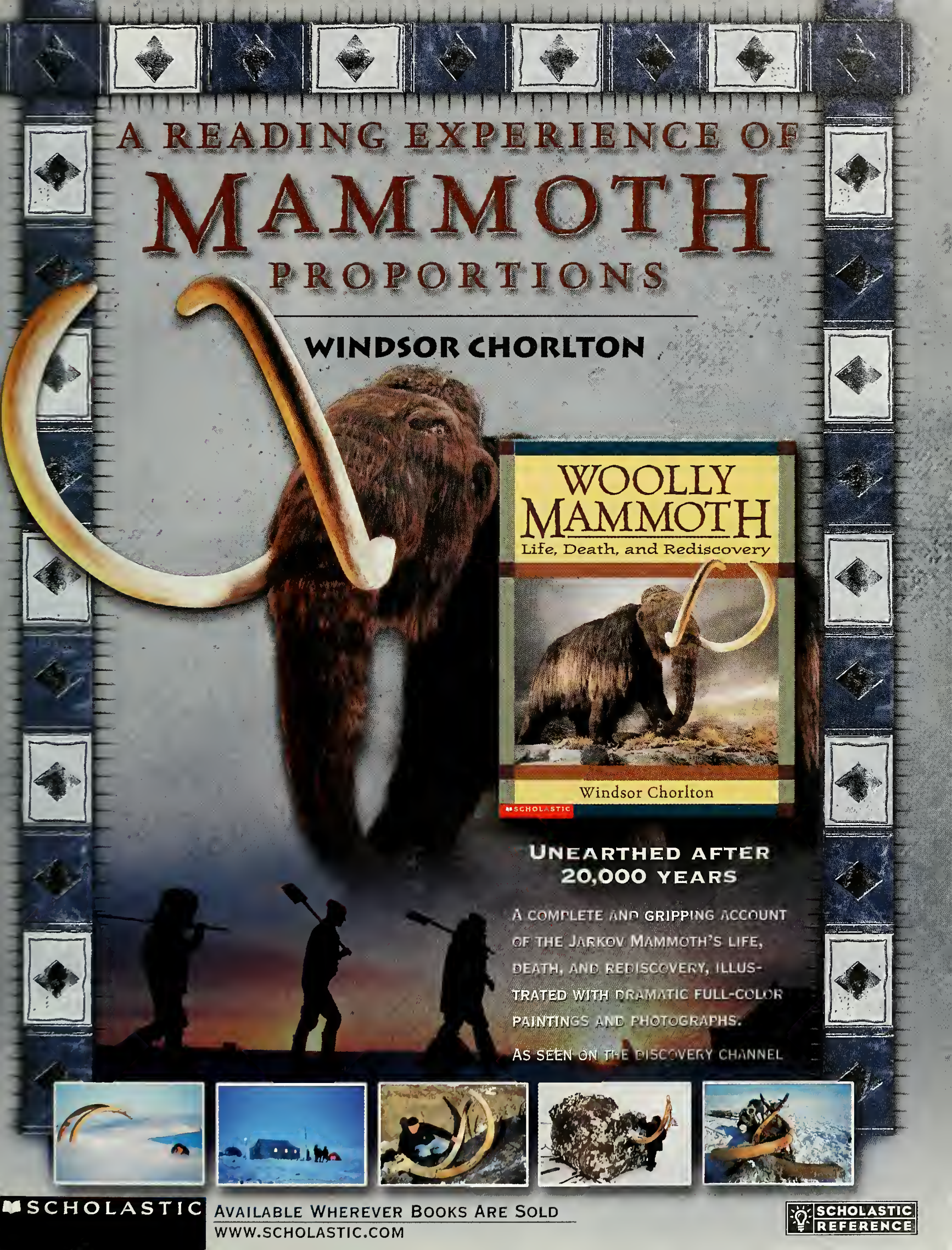
Quorum sensing is not restricted to glow-in-the-dark marine bacteria. In the past decade, scientists have found it in many other species, with variations in the autoinducer molecules secreted, the means by which they are detected, the biochemical reactions they trigger, and the behavior they regulate. For example, quorum sensing controls the production of virulence factors (toxins and other disease-causing agents) in numerous human and plant pathogens that have a clinical or agricultural impact. Invading bacteria may improve their odds of overcoming a host's defenses by releasing their virulence factors simultaneously and only when they are present in great numbers. A premature release might tip off the host's immune system.

In natural environments, bacterial species compete with one another for nutrients, for entry into hosts, and for survival under hostile conditions. Many bacterial species produce antibiotics—chemical compounds to which they themselves are immune but that kill their competitors or impede their growth. Quorum sensing enables the bacteria to coordinate the release of these antibiotics in high doses.

By releasing their toxins simultaneously, invading bacteria may improve their odds of overcoming host defenses.

Quorum sensing also enhances the ability of some bacteria to acquire DNA fragments that, because of the death of some of their fellows, are up for grabs in the environment. These DNA fragments are a useful resource for repairing mutated or damaged chromosomes. Only where there is a concentrated population of bacteria is there likely to be any substantial amount of free DNA available. In this case, quorum sensing turns on the machinery that enables cells to take in this DNA.

Bacterial mating, which creates a more diverse array of individuals and can spread advantageous genes through a species, seems to employ quorum sensing as well. The process involves donor cells and recipient cells. We know that in *Agrobacterium tumefaciens,* a species that causes tumors in susceptible plants, the donors communicate with one another through quorum sensing, but exactly what function this serves is not yet understood.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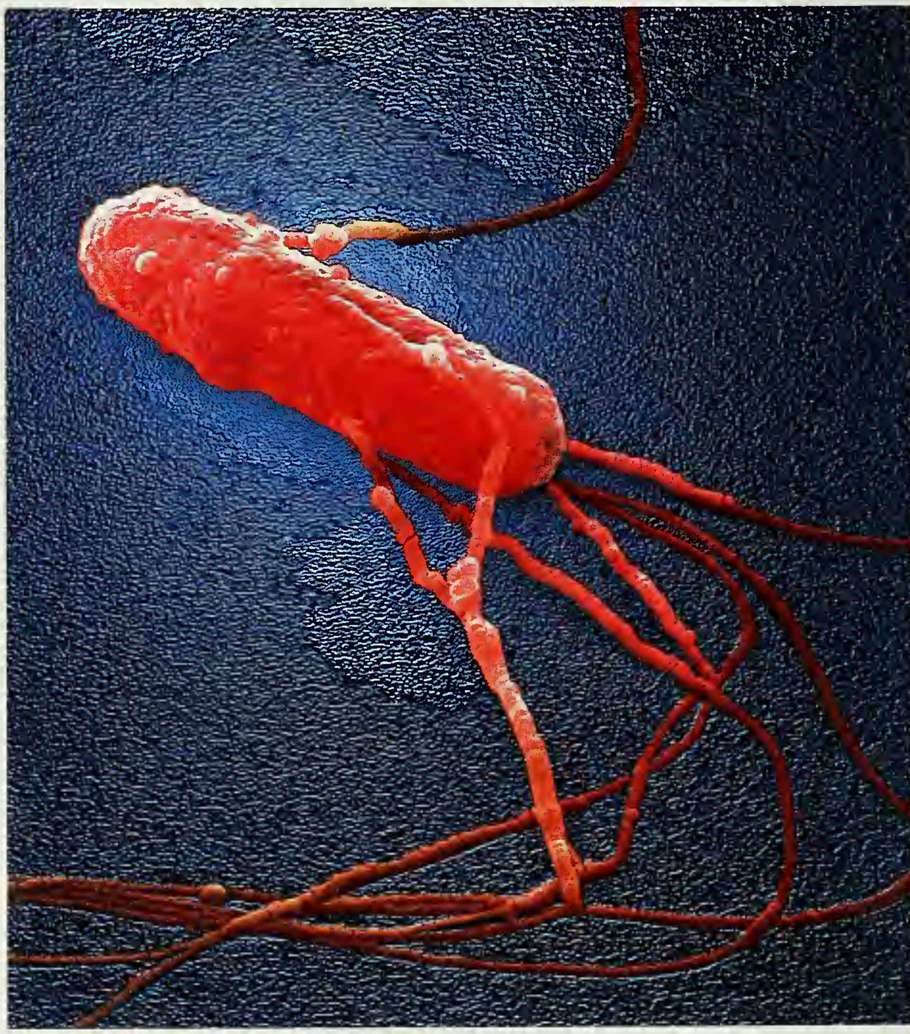
Often bacteria live in biofilms, or communities attached to a surface such as a rock in a pond or the lining of an intestine. A biofilm is surrounded by a polymer coating, or shield, that keeps the bacteria from drying out and that also resists antibiotics and other environmental assaults. The bacterial community is typically made up of several different species; as in a human metropolis, each member of the community—usually each species—has a specific job. One member, for example, may be responsible for producing the enzymes and molecular building blocks needed to create the polymer shield. Within the biofilm is a network of channels that allow water and nutrients to reach the resident bacteria and permit waste products to flow out. At least in some cases, proper formation of these channels has been shown to be dependent on quorum sensing, although the details of how this is controlled remain to be worked out.

Many bacteria are known to produce and detect several different autoinducers. For example, recent studies show that the free-living luminous bacterium *V. harveyi,* in addition to having the quorum-sensing system that enables it to "turn on" its glow, has a separate system that involves another autoinducer. This second chemical signal

***Yersinia pestis* (the bubonic plague bacterium), right, and *Salmonella typhimurium* (one cause of food poisoning), below, are among the bacterial species known to produce and recognize a type of interspecific chemical signal.**

BARRY DOWSETT/SCIENCE PHOTO LIBRARY; PHOTO RESEARCHERS, INC.



JUERGEN BERGER, MAX-PLANCK INSTITUTE/SCIENCE PHOTO LIBRARY; PHOTO RESEARCHERS, INC.

has been found in a variety of other bacteria as well. These and other findings have led to speculation that this widespread molecule is the basis of a common "language," a bacterial Esperanto providing communication between species.

The capacity to distinguish signals both from its own kind and—through a more universal code—from others could provide a population of a particular bacterial species with valuable information. It could learn not only the cell

Different species may be able to communicate with one another using a common "language," a bacterial Esperanto.

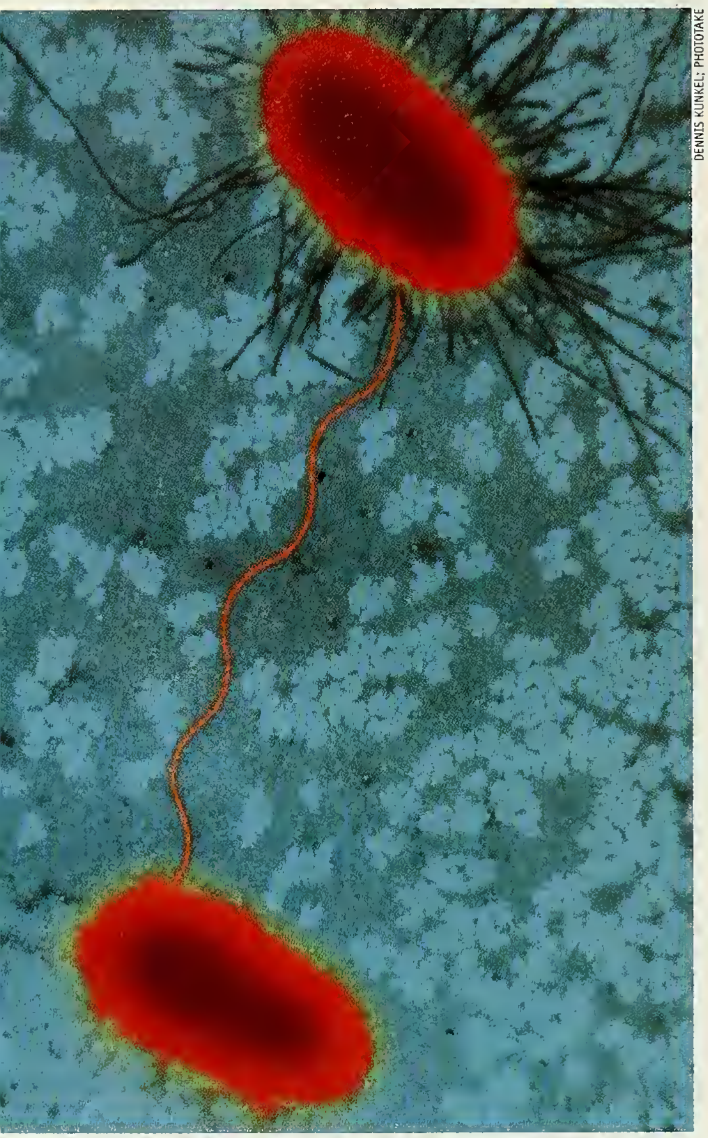
density of its own population but also whether or not it was sharing its habitat with other species and even whether its own kind was in a majority or a minority at any given time. By adjusting its behavior, this population could then make the most of the prevailing conditions.

Many bacteria that infect humans

have now been shown to produce the interspecies signal molecule. They include *Escherichia coli* (food poisoning), *Salmonella typhimurium* (food poisoning), *S. typhi* (typhoid fever), *Haemophilus influenzae* (pneumonia, meningitis, sepsis), *Helicobacter pylori* (peptic ulcers, stomach cancer), *Borrelia burgdorferi* (Lyme disease), *Neisseria meningitidis* (meningitis), *Yersinia pestis* (bubonic plague), *Campylobacter jejuni* (food poisoning), *Vibrio cholerae* (cholera), *Mycobacterium tuberculosis* (tuberculosis), *Enterococcus faecalis* (endocarditis, urinary tract infections), *Streptococcus pneumoniae* (pneumonia, ear inflammations), and *Staphylococcus aureus* (pneumonia, endocarditis, septicemia, toxic shock syndrome, meningitis, food poisoning). While for the most part the specific function served by the autoinducer in these bacteria is not yet known, there is mounting evidence that, at least in some cases, it increases virulence.

The explosion of research in quorum sensing, especially in pathogenic bacteria, is pointing the way to new biotechnological applications. If therapies could be developed that manipulate or disrupt quorum sensing, such drugs would constitute a new class of antibiotics. A new broad-spectrum antibiotic might result, for instance, if a way can be devised to undermine the interspecies signaling system.

Some novel research is focused on designing molecules that are structurally similar to autoinducers. The idea is to make a molecule that binds to the autoinducer detector of a particular bacterial species, blocking its ability to sense the appropriate signal molecule. This would prevent pathogenic bacteria from recognizing when they are assembled in great numbers and would thus avert the process that is normally triggered. Another approach is to design drugs that specifically interfere with the enzymes involved in synthesizing autoinducers, thus preventing the bacteria from sending out their signal molecules.


DENNIS KUNKEL; PHOTOTAKE

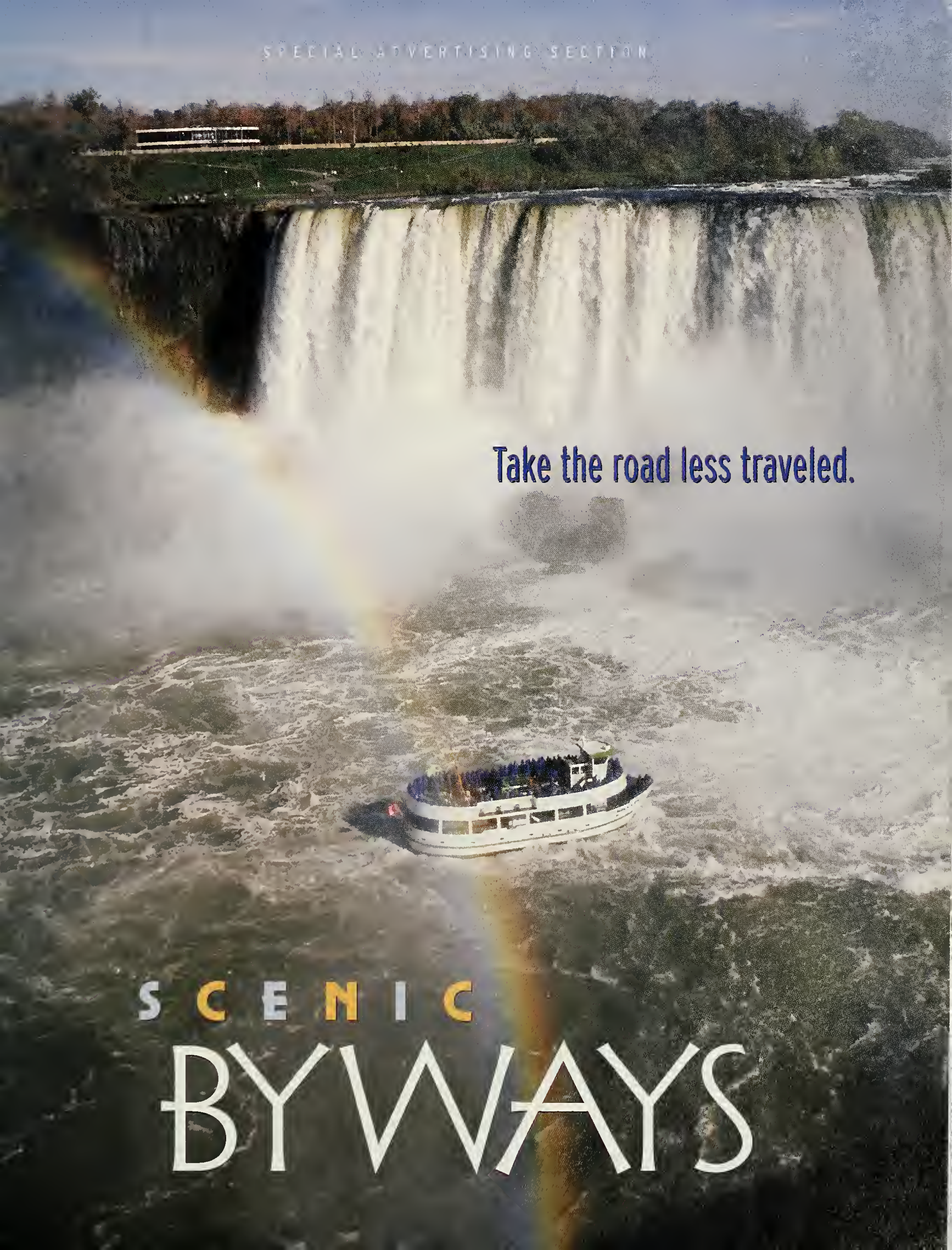
When bacteria mate, as shown here for *E. coli*, a donor cell transmits DNA through a tube. In some species, donor cells communicate with one another through chemical signals, but the function this serves is not understood.

In some cases, host organisms already seem capable of manipulating quorum-sensing systems to their own advantage. For example, *Pseudomonas aeruginosa,* a bacterium present in soils and wetland habitats, poses a threat of infection to people already debilitated by cystic fibrosis, burns, cancer, or other conditions. By detecting and responding to autoinducer signals, the victim's body may be able to hinder the secretion of this bacterium's toxins. In other cases, hosts appear to produce molecules that mimic, and in some way interfere with, the quorum-sensing signals. This has been observed in some plants and algae.

If therapies could be developed that manipulate or disrupt quorum sensing, such drugs would constitute a new class of antibiotics.

While much applied research is directed toward finding ways to disrupt quorum sensing, the process can also be exploited in a positive way. For example, cell-to-cell communication may enhance the production of antibiotics. By finding ways to promote quorum sensing, scientists may discover how to improve the commercial production of natural antibiotics, enzymes, and other biochemicals useful in the prevention and treatment of disease, for the protection of food sources, and in industrial processes.

Whatever the practical applications, the investigation of quorum sensing promises to provide biologists with insights into a key step in the evolution of multicellular organisms. An appreciation of the molecular mechanisms that govern this bacterial process will lay the foundation for a better understanding of the development of organs and of cell-to-cell interactions and information processing in higher organisms. □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The Bay of Fundy is also home to spectacular marine wonder! Take a whale watching tour and see more kinds of whales more often than anywhere else—playful humpbacks, giant finbacks, and maybe even the rare right whale! Watch hundreds of thousands of shorebirds reel off sable stretches. And from porpoises to plovers, seals to sea urchins, you'll see how the Bay of Fundy welcomes them all!

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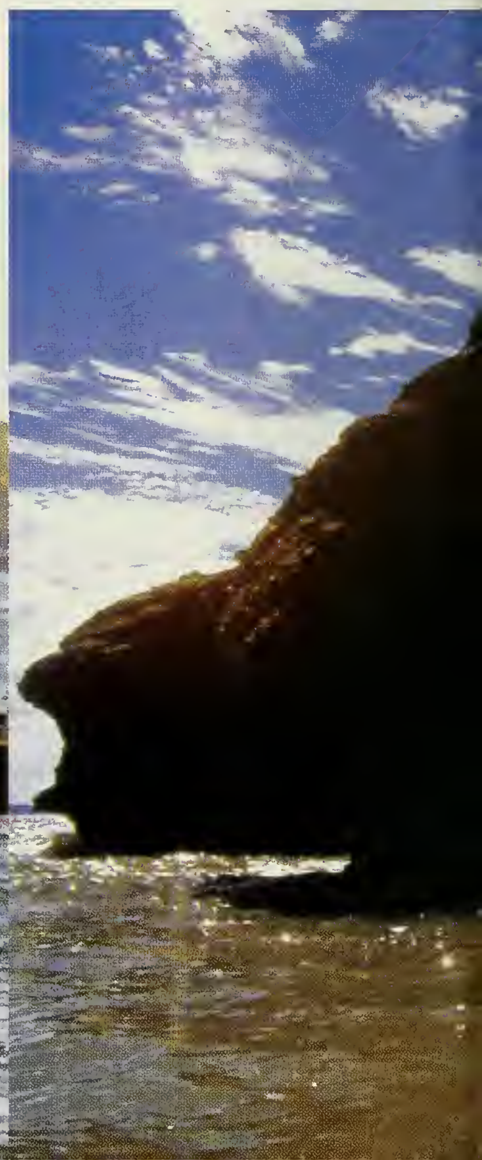
Take a whale watching or sea kayaking tour in the Bay of Fundy.
On the Cover: One of New York's scenic byways, the Seaway Trail parallels the Niagara River.



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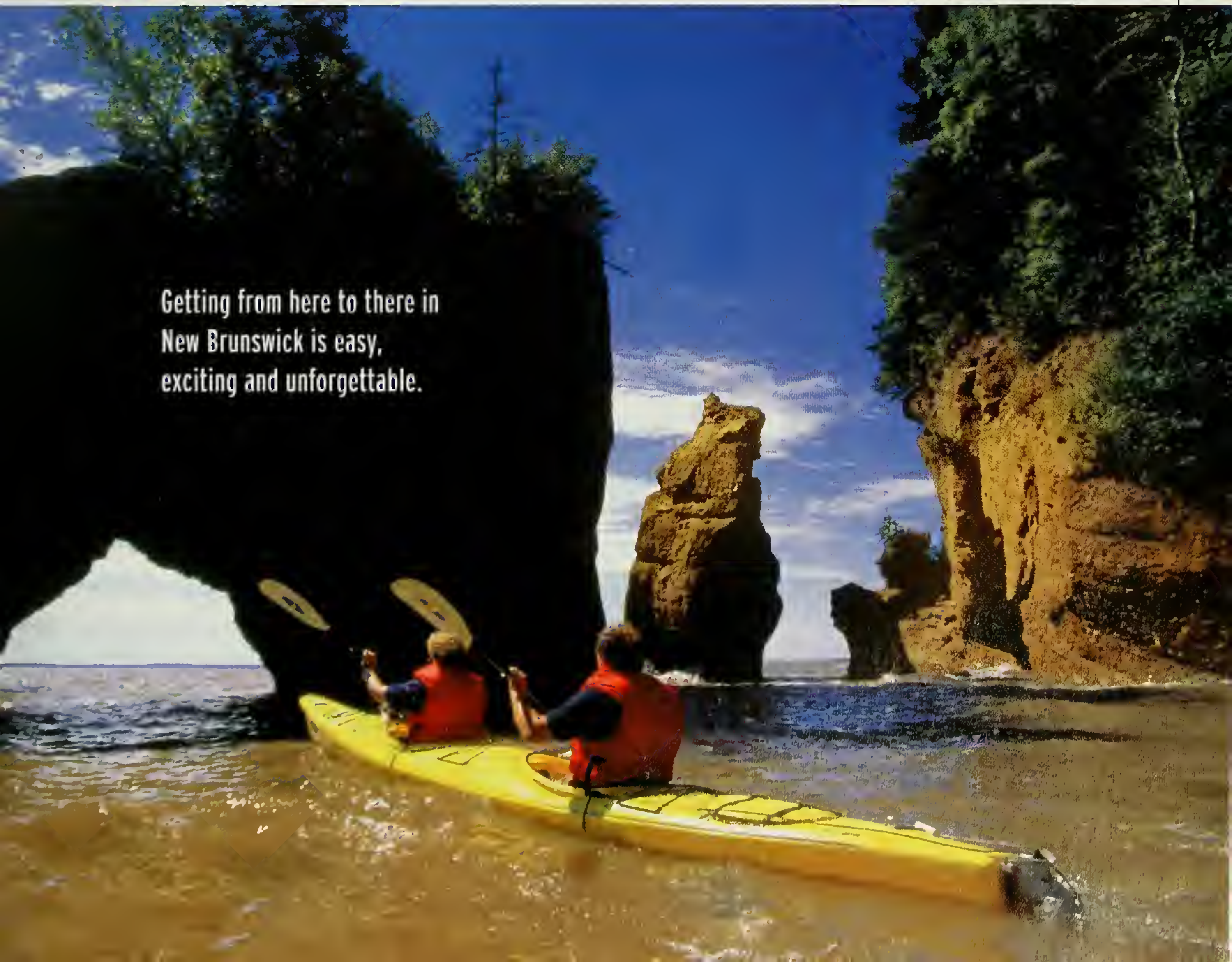
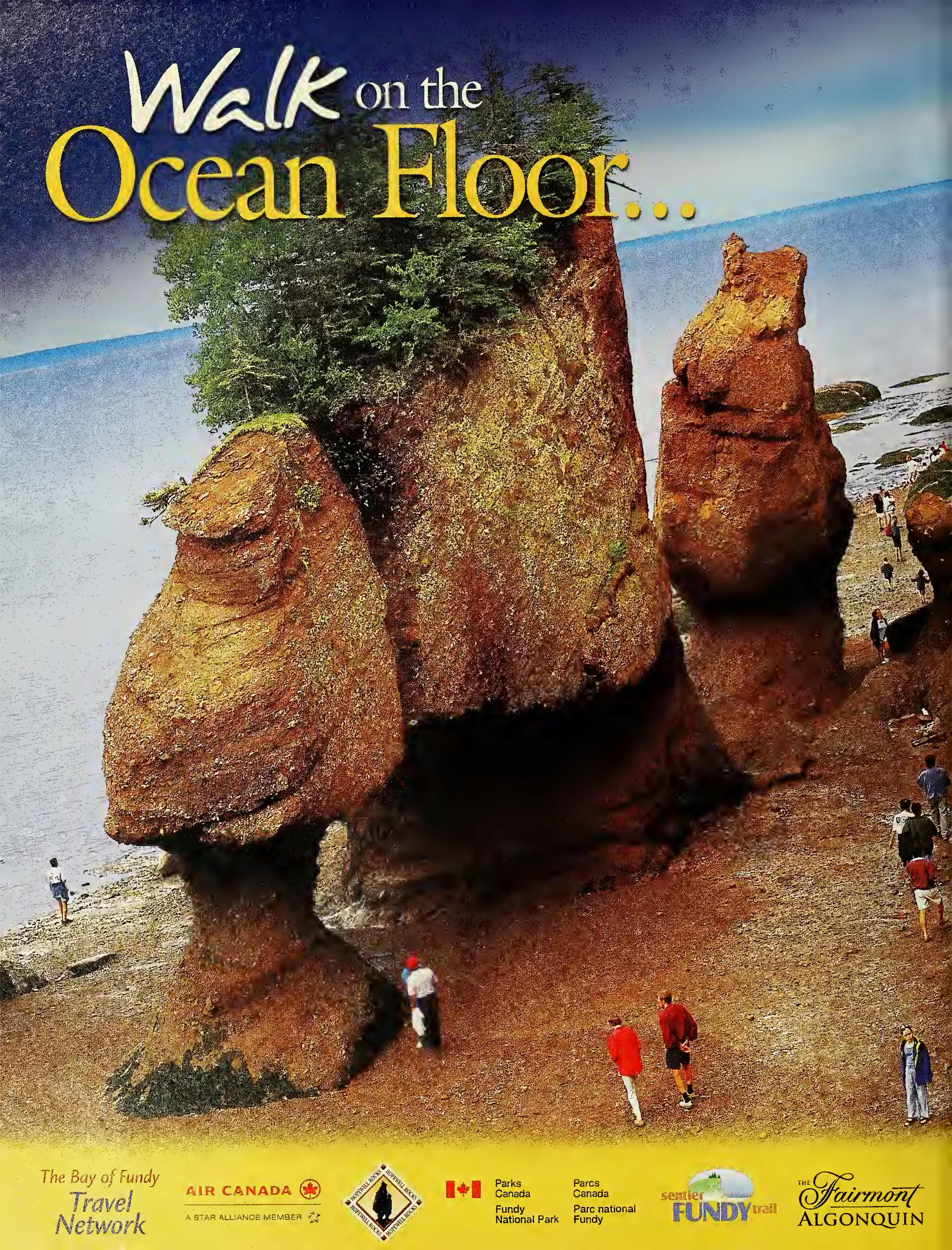
Fresh seafood dining, a vibrant nightlife, and spectacular shopping make Fundy a true New Brunswick adventure. From four-star hotels to cozy B&Bs, seaside resorts and country inns, they've got first-rate accommodations. Plus, did you know your dollar goes a lot further in New Brunswick? Two American dollars can equal as much as three Canadian dollars! You'll find it all in New Brunswick, Canada's Bay of Fundy—WOW!

Visit the New Brunswick website at **www.tourismnewbrunswick.com**, or call **1-800-561-0123** for more information on how you can get started on your New Brunswick adventure.

Saint John is known as the Fundy city.

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SCENIC BYWAYS

New York Make a Great Vacation Out of Getting There

New York is one of the most popular vacation destinations for visitors from across the country.




New York has hundreds of golf courses and miles of beaches. The Adirondacks, the state's highest mountains, are a favorite hiking and fishing area.

New York is teeming with scenic byways, from a 150-mile journey along the Hudson River Valley, to a leisurely 340-mile journey through the wineries and waterfalls of the Finger Lake region. You can truly make a vacation out of a single road trip.

The tour of the Hudson River Valley combines the natural beauty of the region with the homes of great Americans. Exit the Thruway (I-87) at Tarrytown. Follow Route 9 north, visiting historic Philipsburg Manor, to Peekskill and Route 6, which takes you along cliffs high above the Hudson River. Cross the Bear Mountain Bridge to Bear Mountain State Park, where you can hike, swim, or enjoy a picnic lunch. Then take Route 9W north to Route 218, which brings you into the village of Highland Falls. Don't miss a tour of the United States Military Academy at West Point.

Return to Route 9W north to Route 218, the Storm King Highway, for a winding drive leading to Storm King Art Center. Rejoin Route 9W through Newburgh, where General George Washington's Headquarters are located, and past several wineries, where you can stop for a tour and a tasting of some of the region's best wines.

Continue north to the Mid-Hudson Bridge (Route 44/55). Crossing the river again, head north on Route 9 to the Franklin D. Roosevelt and the Vanderbilt Mansion National Historic Sites and on to the Village of Rhinebeck. Travel north on Route 9G, and visit Montgomery Place and Olana State Historic Site.

Next turn east into the Taconics, taking Route 23B to Route 23. Take Route 22 south to Millerton. Follow Route 199 through winemaking country to Route 82 to Route 44 to the scenic Taconic Parkway, which leads to the Saw Mill River Parkway and, finally, back to Tarrytown and the Thruway (I-87).

The tour of the Finger Lakes region begins in Elmira, home of the Mark Twain Study and Exhibit; Woodlawn Cemetery, where Mark Twain is buried; and the National Soaring Museum, an impressive exhibition of sail planes and historic gliders.

Travel northeast on Route 13 to Ithaca, the city of waterfalls: dozens are within the city limits and hundreds more are within several miles. Stop and hike at hidden areas, such as Buttermilk Falls. While in Ithaca, don't miss Cornell University.

Follow Route 89 north along the shore of Cayuga Lake and drive to Taughannock Falls State Park, where the state's highest waterfall drops 215 feet into a rock amphitheater. The Cayuga Wine Trail (for more information call 1-800-732-1848) with eight wineries is located along Route 89.

Travel northwest to Geneva. Take Route 14 south along the shore of Seneca Lake—one of the 11 Finger Lakes, known for their deep clear waters. Travel to Dresden and follow Route 54 west to Penn Yan. You are still in wine country, so travel south on Route 54A along the shore of Keuka Lake to Hammondsport. Here are the excellent Glenn H. Curtiss Museum and numerous wineries. Next, drive to Bath on Route 54. Take Route 17 southeast to Corning, where you can explore 3,500 years of glassmaking at the Corning Glass Center.

From Corning, take Route 414 and visit Watkins Glen State Park, with its hiking paths and natural pools formed by the age-old waterfalls tumbling into stone basins. Take Route 14 south to the town of Montour Falls, where you can see Chequaqua Falls and visit Havana Glen Park, with a short scenic walk to Eagle Cliff Falls. Continuing south on Route 414 will take you back to Elmira.

For more information on these travel ideas or the other fabulous cities and great outdoors sites, call **1-800-CALL-NYS**, or visit **www.iloveny.com**.

SCENIC BYWAYS

US 212 Beartooth Scenic Byway is just one way to enter the Yellowstone National Park.

As you can imagine, Wyoming has some of the most beautiful and uncrowded scenic byways in the country. Because the state is so large, there is no better way to explore Wyoming's natural wonders than its Scenic Byways. Wyoming's Scenic Byways and Backways Program allows visitors to discover the amazing array of wildlife and scenery in this outstanding state.

These designated travel routes reflect the pride of the Wyoming people who live in the communities and work the ranches along these routes, and are committed to the preservation, protection, and enhancement of these special places. When traveling these roadways, take in the sense of adventure and freedom that first attracted people to this great state and discover why they fully deserve to be recognized with Byway and Backway status.

Three scenic byways cross the Big Horn Mountains in north-central Wyoming, the Cloud Peak Skyway (US 16), the Big Horn Scenic Byway (US 14), and the Medicine Wheel Passage (US 14A). All will get you safely to the other side of the mountains in about the same time.

Big Horn Scenic Byway connects Sheridan and surrounding communities with Greybull, Wyoming and includes 45 miles of scenic mountain driving. Look out over spectacular valley views from one of several roadside turnouts—on a clear day, you can see forever. Interesting stops include Shell Falls, Burgess Junction Visitor Center and Sand Turn.

The Cloud Peak Skyway traverses the southern Big Horn Mountains and offers breathtaking vistas of distant snowcapped peaks along its 45-mile length. This route connects the towns of Buffalo and Tensleep, Wyoming. Highlights include Hospital Hill, Powder Pass, Meadow Lark Lake and Tensleep Canyon.

The Medicine Wheel Passage rises sharply from the Big Horn Basin near Lovell, Wyoming and winds 25 miles through steep canyon terrain and high alpine meadows to Burgess Junction. This route provides primary access to the Medicine Wheel National Historic Landmark. This byway is open only from May to November, and its 10 percent grades may not be the best choice for those pulling trailers or driving a RV.

Of course all of these roads and more lead you on an adventure through the real Wyoming. To learn more about Wyoming's scenic highways and byways, go to the Wyoming web site at **www.wyomingtourism.org**. A new Wyoming Scenic Byways brochure will be available in Spring 2001. To order one, call **1-800-225-5996**.

West Virginia Wild and Wonderful

West Virginia has some beautiful byways from which to enjoy its countryside and history.

THE STATE OF WEST VIRGINIA HAS FOUR NATIONAL scenic byways designated by the FHWA national Scenic Byway Program. These are the Highland Scenic Highway, the Midland Trail, the Coal Heritage Trail, and the Washington Heritage Trail. All preserve the rich culture, heritage and beauty of the state.

The Highland Scenic Highway, a beautiful path through the Monongahela National Forest, takes visitors past mountainous terrain covered by hardwood forests. This scenic byway extends 43 miles from Richwood to US Route 219, seven miles north of Marlinton. The highway follows State Route 39/55 for 21 miles from Richwood to the Cranberry Mountain Visitor Center.

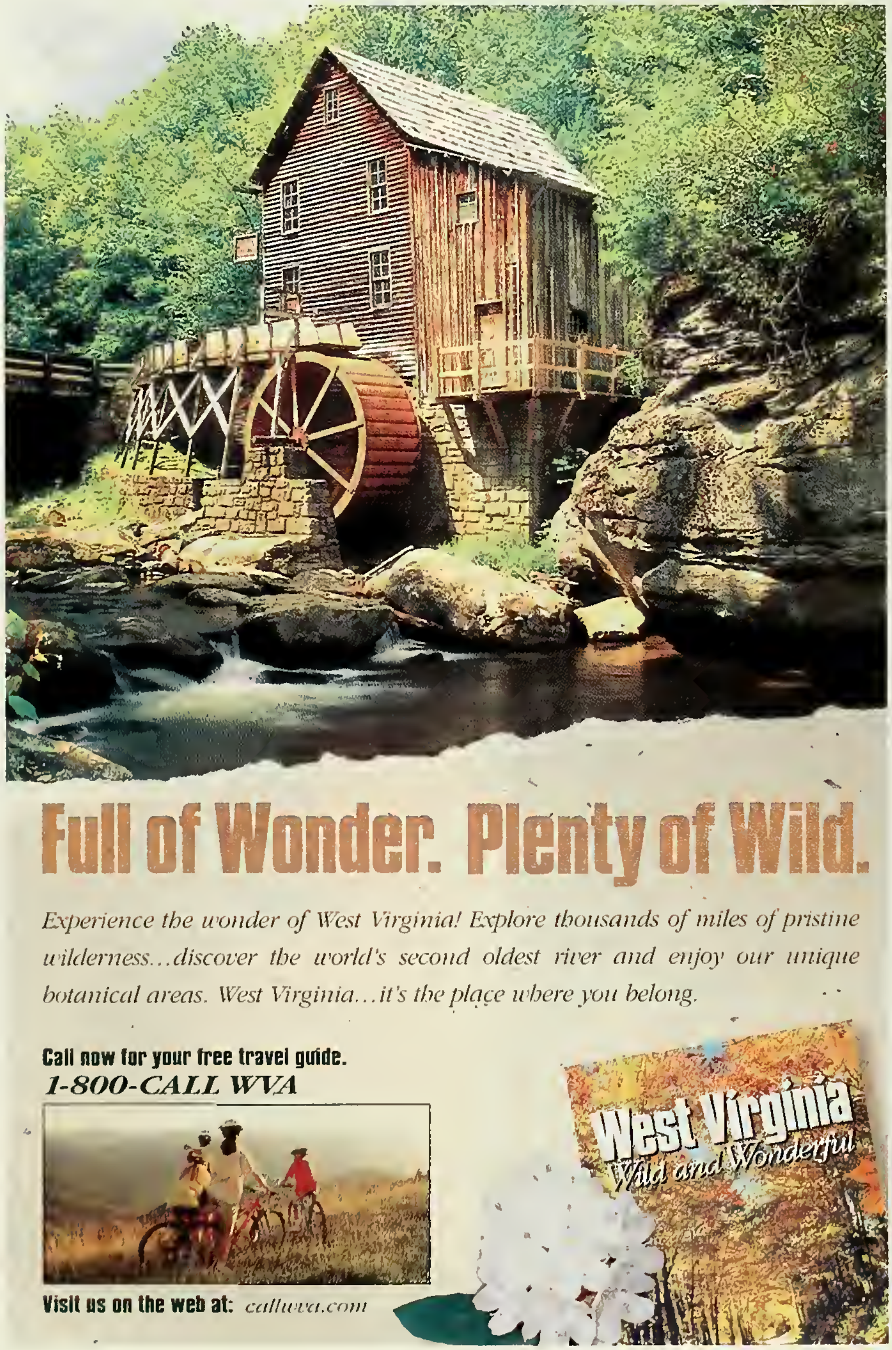
The Coal Heritage Trail winds through mountains and valleys, taking visitors through four of West Virginia's southern counties. As you travel along this byway, you can't help but notice West Virginia's industrial heritage. This area of Appalachia was America's most productive energy-producing region, and its abundant coal fields affected its physical, economic, and social climate.

The Midland Trail follows the same path that Native Americans and pioneers used to head west. The Midland Trail thus takes you on a timeline through colonial America, the Civil War, immigration, African-American history, and the industrial revolution. Before interstates, the Midland Trail was the main route through the West Virginia mountains.

West Virginia boasts having four national scenic byways.

The Washington Heritage Trail loops through three counties of West Virginia's Eastern Panhandle, crossing mountains, farmland, and historic towns. The Eastern Panhandle is significant to historians because George Washington and his family vacationed and built homes in this area. In fact, seven Washington family homes or estates can be seen from the trail.

For more information on West Virginia and its scenic byways, call **1-800-CALL-WVA**, or visit the state's website at **www.state.wv.us/tourism**.



SCENIC BYWAYS

Scenic Short Cuts

Some beautiful touring routes by land or by sea.

Pennsylvania Route 6

Route 6 is a true scenic byway. With over 400 miles of ground to cover, you'll have time to stop at all of the special places that make this byway such a gem. Pull over at a country store to buy authentic Pennsylvania crafts, take in that wonderful Pennsylvania fare at one of the many restaurants on the side of the road, and stop to photograph a scenic view within the Allegheny National Forest. By the end of your trip, you'll have added some wonderful additions to your "best of" lists—diners, bed and breakfasts, Victorian villages, and festivals from border to border.

But there are many more attractions to lure you to this scenic byway. In Warren County you'll drive by parts of the Allegheny National Forest. If you want to stretch your legs, there are 11 campgrounds and 600 miles of trails for hiking. And Crawford County includes the Commonwealth's largest natural lake, and one of the Nature Conservancy's "last great places in the U.S."

For a free Pennsylvania visitors guide—including a detailed road map and calendar of upcoming events call **1-814-435-7706**, or visit the state's website at **www.paroute6.com**.

American Cruise Lines

If you'd rather cruise through America's inland passages than ride along her scenic byways, take a cruise through New England's enchanting towns aboard the AMERICAN EAGLE on American Cruise Lines. The seven-night New England Islands Cruise takes you back to the maritime history of the world. Throughout the cruise, historians and naturalists will intrigue you with tales as you visit whaling museums and historic homes.

Other New England trips include cruises through Maine's coast and harbors, the Hudson River Cruise, and an East Coast inland passage

Enjoy harbor hopping through several of New England's enchanting towns.

cruise. You will cruise along rivers, bays, estuaries, and canals—waterways once traveled by Native Americans, explorers, and pirates.

For reservations call **1-800-814-6880** or visit the state's website at **www.americancruiselines.com**.

Swift Instruments

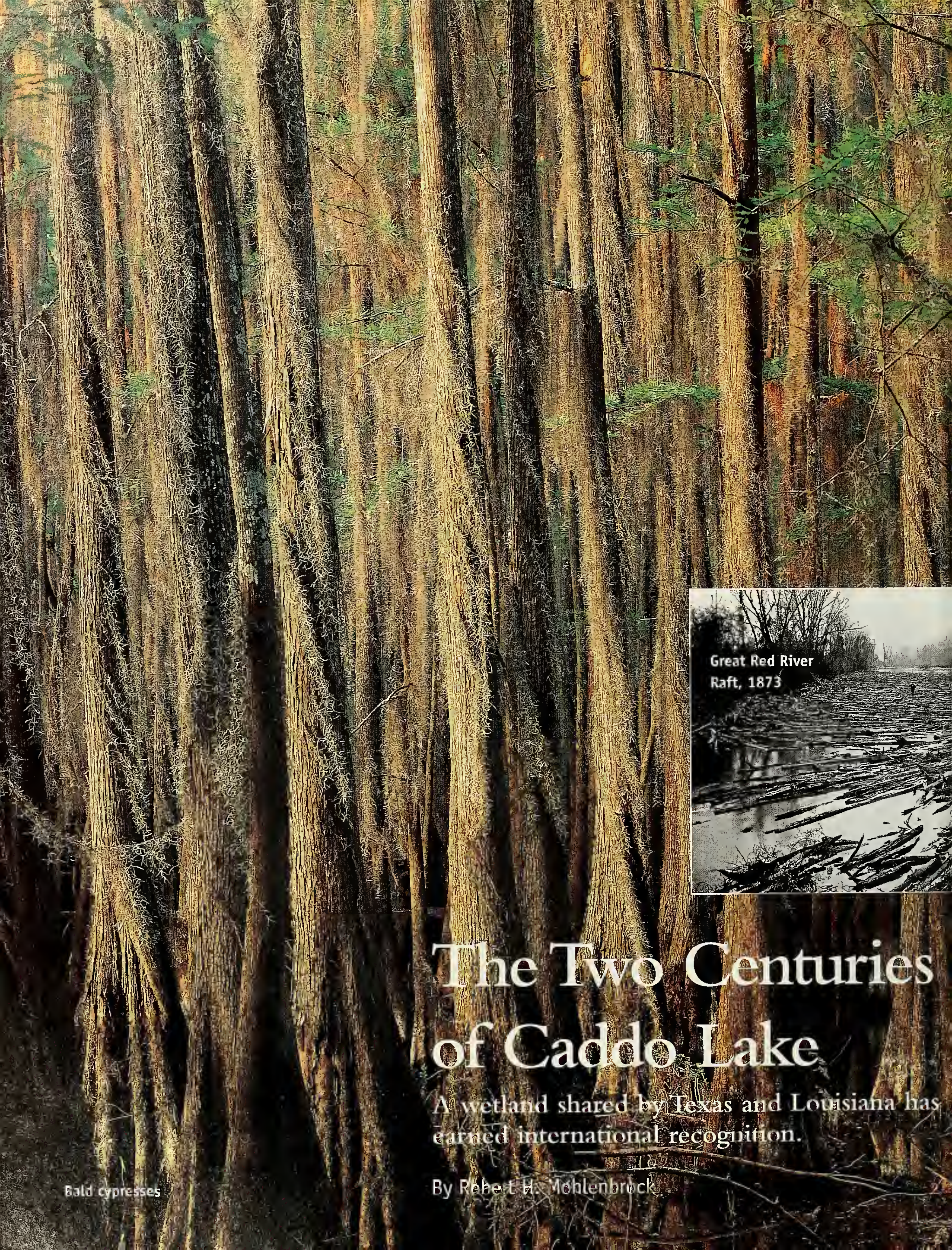
No matter if you're driving along the scenic byways or sailing through New England ports of call, you'll need to bring a good pair of binoculars with you, and Swift Instruments has been a leader in the optics field since 1926. In fact, for anyone who enjoys bird-watching, from the casual backyard birder to the professional ornithologist, Swift Instruments has been a leader in designing and manufacturing innovative bird watching optics for the past 40 years.

This year Swift is celebrating its 75th anniversary. The company has just introduced a new model, the 820 Swift Audubon, which is specifically designed for birders. Also available are compact binoculars for backpacking, hiking, biking, and mountain climbing, and waterproof binoculars for boaters.

Swift products are sold and serviced at finer optics, sporting, photo, and specialty stores throughout the world. For more information on Swift Instruments, call **1-617-436-2960**, or visit **www.swift-optics.com**.

To find out more about America's scenic byways, go to National Scenic Byways Online at **www.byways.org**.

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



Bald cypresses

Great Red River Raft, 1873

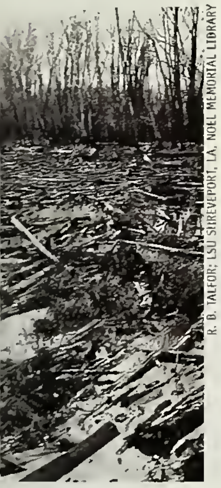
The Two Centuries of Caddo Lake

A wetland shared by Texas and Louisiana has earned international recognition.

By Robert H. Mohlenbrock

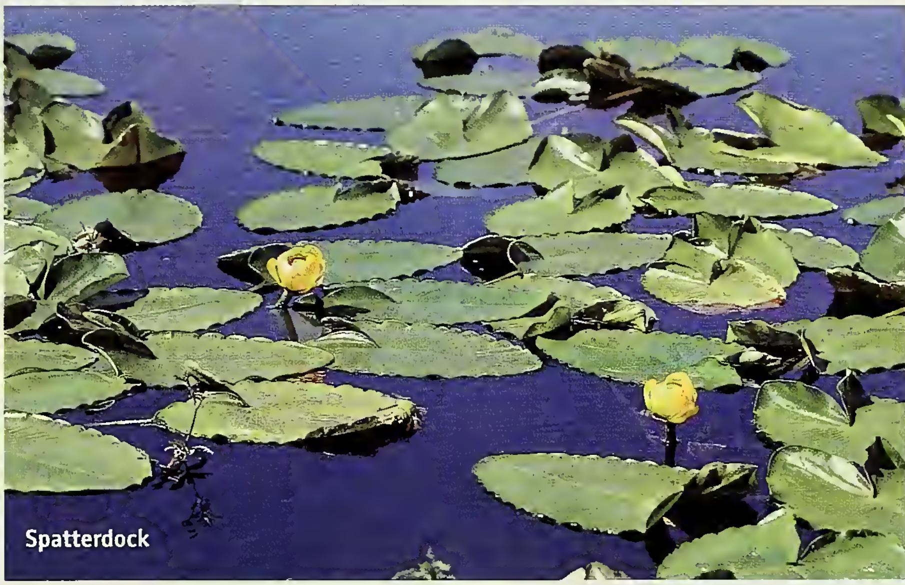
THIS LAND

About 200 years ago, a huge logjam formed in the Red River where it flows through northwestern Louisiana. Because of the buildup of logs, the river spilled into nearby Cypress Valley, creating Caddo Lake, a large body of freshwater that straddles the border between Texas and Louisiana. A legend recounted by the Caddo Indians attributed the lake's origins to an earthquake. In fact, Caddo Lake did develop close in time to the great New Madrid earthquakes of 1811–12, which formed Reelfoot Lake in Tennessee and altered the course of the Mississippi River. Archaeological evidence, however, reveals that Caddo Lake arose earlier, about 1800, and was simply the result of dead trees piling up in what was a relatively slow-flowing, shallow section of the river.


R. B. TALFOR; LSU SHREVEPORT, LA. NOEL MEMORIAL LIBRARY

The logjam, known locally as the Great Red River Raft, persisted and the lake continued to expand until the 1870s, when the federal government cleared the blockage with underwater explosives. This maneuver opened the river to navigation farther upstream and stopped the overflow of water into the lake. During the twentieth century, the lake was dammed for purposes of oil exploration, flood control, and water supply, and it now has a stable water level, with an average depth of eight to ten feet. Altogether, including its associated maze of bayous and cypress swamps, the lake covers fifty square miles. Its diverse habitats may be sampled in Texas's Caddo Lake State Park (established in 1934), whose recreational and camping facilities border Big Cypress Bayou.

In the two centuries since Caddo Lake's formation, plant and animal life have adjusted to its presence. Alligators and water snakes—including venomous water moccasins—are common in and around the lake, which is a haven for several fishes and amphibians that are rare elsewhere in Texas and Louisiana. The lake's large aquatic plants include spatterdock, with yellow, club-shaped flowers; white water lily; and water lotus, with huge creamy flowers and woody fruits. Among its smaller aquatic plants is water shield, whose three-inch-wide, nearly circular leaves are enveloped in a protective coat of gelatinous slime.


Spatterdock
DPA; DEMBINSKY PHOTO ASSOCIATES

In the surrounding region, the terrain consists of low hills whose ridge tops are less than a hundred feet above the elevation of Caddo Lake. Next to the lake, in low-lying areas that often contain standing water year-round, are extensive bald cypress forests. With enlarged, buttressed bases and cone-shaped "knees" to anchor them in their watery habitat, bald cypresses may tower as high as a hundred feet. The knees also store food reserves in the form of starch. When a bald cypress does die and fall into the swampy waters, wildflower seeds become lodged in the decaying wood and sometimes germinate. A fallen log thus often nurtures considerable vegetation, especially species of beggar's-lice.

Bottomland forest grows where the elevation is slightly higher and water stands only some of the time. A still higher zone, which remains free of standing water, supports a mesic (moist) forest. This habitat extends partway up the adjacent slopes, while upland forest occupies the upper slopes and ridge tops.

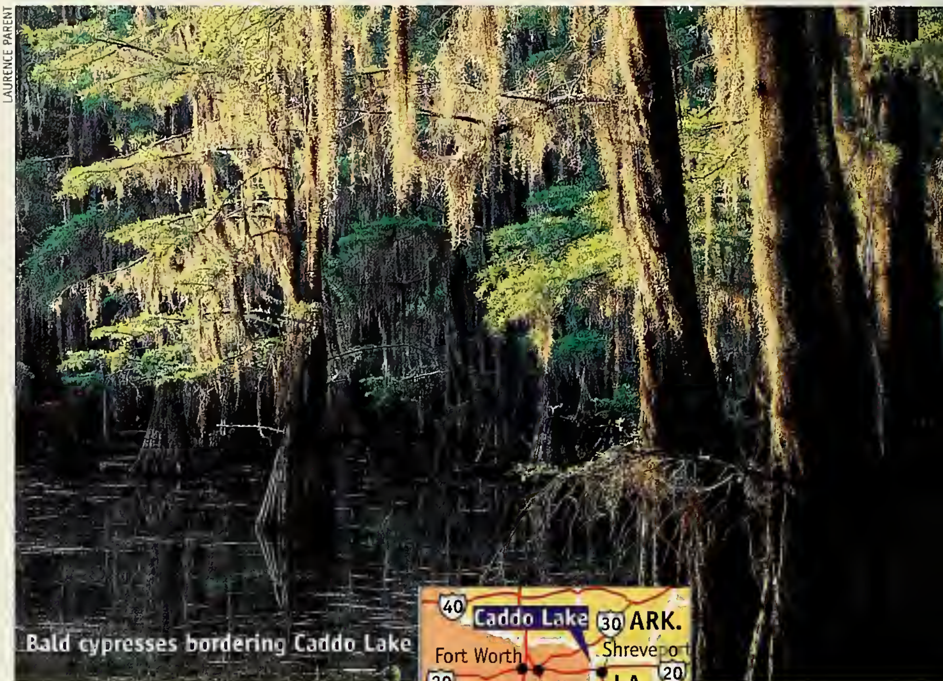
Caddo Lake is one of only seventeen wetlands in the United States that have been designated Ramsar sites, so named for the Convention on Wetlands, which resulted from a forum that took place in Ramsar, Iran, in 1971. The convention established guidelines for identifying "wetlands of international importance" and ensuring their conservation. More than 120 nations are now contracting parties to the convention. The United States ratified the Ramsar agreement in 1986, and Caddo Lake was listed in 1993, when nearly twelve square miles' worth of Texas-owned land parcels in and around the lake were designated for protection.

For a wetland to be a Ramsar site, it must do one of the following: (1) contain a representative, rare, or unique example of a wetland type; (2) support endangered species or threatened ecological communities; (3) support populations of plant and/or animal species important for maintaining the biological diversity of a particular region; (4) serve as a refuge for plant and/or animal species or support them at a critical stage in their life cycle; (5) regularly support 20,000 or more waterfowl; (6) regularly support 1 percent of the individuals in a population of one species of waterfowl; (7) support a significant proportion of indigenous fish species; or (8) provide fish stocks with an important spawning ground, nursery, migration path and/or source of food. Caddo Lake meets many of the Ramsar criteria. It is a good example of a bald cypress swamp; it supports a number of plants and animals that are rare for the region; it is home to more than 200 species of birds, 50 of mammals, 90 of reptiles and amphibians, 90 of fishes, and 500 of native plants; and it attracts well over 20,000 waterfowl. Conservation of this ecosystem is the responsibility of the Texas Parks and Wildlife Department and of the U.S. Fish and Wildlife Service and its offices in Texas. In 1999 the protected area was increased to thirty-three square miles.

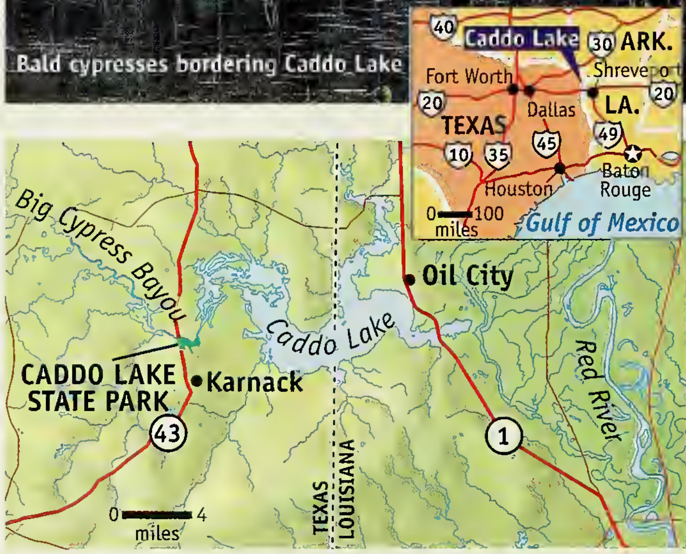
Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

For visitor information, contact:
Caddo Lake State Park
RR 2, Box 15
Karnack, TX 75661
(903) 679-3351
www.tpwd.state.tx.us/park/caddo/caddo.htm

LAURENCE PARENT



Bald cypresses bordering Caddo Lake



JOE LEMONNIER

HABITATS

Bald cypress forest contains the largest trees in the area. Growing with the bald cypress are two other species of trees that commonly have buttressed trunks but lack the cypress's "knees"—tupelo gum and pumpkin ash. Other species are water hickory, planer tree, and swamp red maple.

Virginia sweetspire and snowbell bush grow in the shrub layer. These two species, both bearing attractive white flowers, are commonly available from nurseries and garden centers. Plants that colonize fallen tree trunks include two varieties of pink St.-John's-wort, several kinds of beggar's-lice (or stick-tights) with yellowish flower heads, and two stingless members of the nettle family: false nettle and clearweed.

Bottomland forest trees often grow straight and tall, forming a dense canopy in summer and autumn. Common species in the seventy-five-foot range are sweet gum, overcup oak, cherrybark oak, and willow oak. Often growing below these is a secondary canopy of trees from twenty to fifty feet tall. Among them is box elder, a member of the maple family with compound leaves, and green haw, which has two-inch-long curved spines on some or all of its branches and sometimes even on its trunk.

Vegetation on the forest floor in this shaded habitat is often sparse but includes a diversity of species. Among the grasses are the bamboolike giant cane as well as lower-growing wood

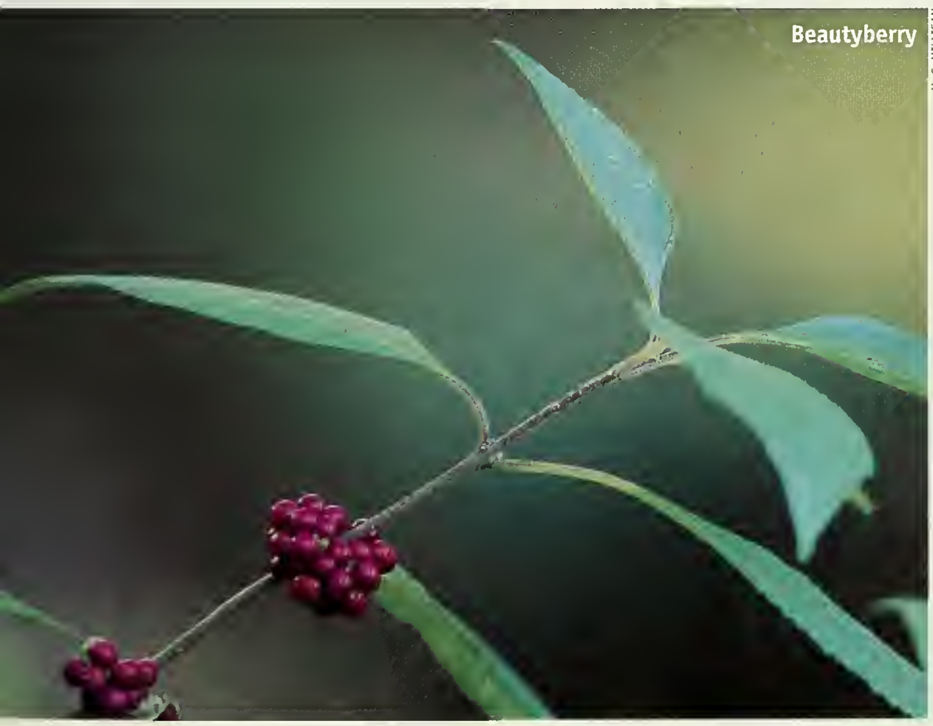

Jack-in-the-pulpit

FRED HABEGGER; GRANT HEILMAN PHOTOGRAPHY

reed grass and white grass. Wildflowers include water horehound, jack-in-the-pulpit, green dragon, and a triangular-leaved blue violet. Here and there are thickets of shrubs such as possum haw, a type of holly that loses its leaves during the autumn. Greenbrier vines and a vine known as supplejack (or rattan vine) climb over some of the vegetation.

Mesic forest tree cover is not as closed as that in bottomland forest. The most common species are water oak, bitternut hickory, and sugarberry (a type of hackberry). Black walnut trees appear in the more elevated tracts. A midcanopy layer is formed by hop hornbeam, musclewood, and pawpaw. Ferns are plentiful, among them rattlesnake fern, named for the tiny spherical spore cases arranged on a special tufted frond. Violets, wild geranium, mayapple, and blue phlox bloom in April and May. After a bit of a summer lull, the blues of woodland asters and the yellows of woodland goldenrods render the forest vibrant in late August.

Upland forest trees include large, sturdy black walnuts and southern red oaks, in addition to the somewhat shorter black gum, red mulberry, redbud, flowering dogwood, and sassafras trees. Here and there is the large-leaved, prickly stemmed Hercules' club, also known as the devil's walking-stick. The brilliant magenta-fruited beautyberry is the most common shrub. Asters, goldenrods, and sunflowers dominate the landscape from late summer to the end of the growing season.


Beautyberry

M. C. MILLIGAN

CELESTIAL EVENTS

Was there volcanism on Mercury?

The Mysterious Side of Mercury

The *MESSENGER* launch in 2004 promises to lead us out of the dark.

By Richard Panek

The dark side of the Moon? Been there, done that. Another dark side in our solar system, however, is beckoning to some astronomers today, much as the Moon's did to an earlier generation. In this case the dark side is Mercury's, and as always in such discussions, its very existence depends on the definition of "dark."

The dark side of the Moon, for one, *isn't*—dark that is, at least in any day-and-night sense of the word. Every crater on the Moon's surface gets some sun. In fact, during Earth's new Moon phase, it's the Moon's "dark" side that is fully in sunlight.

Still, that side is indeed dark to us, in the sense that we can't see it. As with many major satellites in the solar system, the Moon is in synchronous rotation with its host planet, meaning that it always shows the same face to Earth, never the other. That unseen frontier, perhaps more appropriately termed the far side, proved to be a most tempting target at the dawn of the space age.

Mercury's dark side is now starting to arouse a similar curiosity among astronomers. No, this dark side doesn't actually dwell in darkness either, although until the 1960s most astronomers believed that Mercury was in synchronous rotation with the Sun and that one side of the planet did indeed experience perpetual night. But in terms of what we know about the planet, just about half its surface remains, for all practical purposes, hidden.

Mariner 10 flew past Mercury three times: on March 29 and September 21, 1974, and on March 16, 1975. That's *it*. The photographs that the spacecraft sent back comprise just about the entire database of close or even reliable observations of the surface features of the innermost planet of our solar system—and they cover slightly less than half of Mercury's surface. The other half, though technically visible from Earth or from satellite observatories such as the Hubble Space Telescope, is still pretty much off-limits. The problem is the planet's proximity to the Sun—the same obstacle observers have always had to overcome when studying Mercury. Partly for that reason, observing the planet has historically served more as a means of gathering general astronomical information than as an end in itself. Transits of Mercury (when, from the point of view of an observer on Earth, the planet crosses the surface of the Sun) have been useful, for example, in determining the sizes of the planets relative to the Sun and the overall scale of the solar system (see "Celestial Events," November 1999). And a seeming anomaly in the planet's orbit around the Sun helped substantiate Einstein's general theory of relativity.

But Mercury itself? Consider: Recently when I logged on to Yahoo! and followed the Science topic trail from Astronomy to Solar System to Planets, I found that Mercury had the fewest number of entries among the planets—a mere 4. Even Pluto had double that number, while Mars weighed in with a whopping 143.

Now, however, Mercury's relative anonymity just may be nearing an end. What most surprised astronomers during the *Mariner 10* flybys some twenty-five years ago was the presence of a magnetic field, about 1/100 the strength of Earth's, possibly indicating an active interior. Now researchers revisiting that *Mariner 10* data have found evidence of volcanic activity on the surface of the planet. New radar observations of Mercury's north pole even indicate the possible presence of water in the form of ice.

For these reasons, a NASA mission that was already in the works—the *MESSENGER* (an acronym for Mercury: Surface, Space Environment, Geochemistry, and Ranging) spacecraft, due to launch in 2004 and rendezvous with the planet in 2009—has recently assumed new significance. Unlike *Mariner 10, MESSENGER* would map the entire surface of Mercury and, in the process, possibly resolve some questions about planet formation.

In the meantime, observers can continue to content themselves with those infrequent occasions when Mercury ventures far enough from the Sun to provide us with a clear, if fleeting, glimpse. This month, Mercury makes its brightest appearance of the year. Look for it at twilight, trailing the Sun over the horizon in the west-northwestern sky—but look quickly, because the planet will be setting one to two hours after the Sun. By the end of the first week in June, the wash of light from the Sun will render it unobservable, and Mercury will once more be there but not there, dark but not dark, gone but—especially among astronomers—nowhere near forgotten.

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

THE SKY IN MAY

By Joe Rao

Mercury is just above the west-northwestern horizon at midtwilight, climbing higher night after night. For observers at temperate northern latitudes, mid-May offers the year's best chance to see Mercury. It's at greatest eastern elongation from the Sun (22.5°) on the evening of the 22nd, rendering the "elusive planet" not so elusive at all. The only trick to seeing it is knowing when to look. Mercury will be positioned above and to the right of Saturn on the evening of May 6 and will appear nearly one full magnitude brighter. During the evenings of May 13–17, it rapidly tracks past the brighter Jupiter. A two-day-old crescent Moon sits off to the left of Mercury on the evening of the 24th. Thereafter, the planet dives back down to the horizon, fading rapidly into the sunset.

Venus is a dazzling diamond low in the east at early dawn's light. Technically it reaches its greatest brilliance on May 4 (magnitude -4.5) but will look about the same all month. Venus gains only a little altitude in May, continuing to rise at about the break of dawn. Seen through a telescope, the planet is dwindling in size. At the same time, because of its position vis-à-vis Earth and the Sun, its crescent is thickening. A waning crescent Moon slips well below and to the right of Venus on the morning of the 19th.

Mars, in the constellation Sagittarius, rises at about 11:30 P.M. local daylight time on the 1st but about two hours earlier by month's end, dominating the south-southeastern sky the rest of the night. Mars becomes everyone's object of fascination this month as its golden-orange glow brightens from magnitude -1.1 on May 1 to a dazzling -2.0 by the 31st. From May 13 through August 2, it will in fact surpass Sirius (the brightest of all stars) in brilliance. On May 11 the planet begins retrograde (westward) motion against the backdrop of stars. For observers with telescopes, the brightening Mars is a thrilling, though still challenging, planetary target. The Martian north pole is tilted well toward us this spring as the planet's northern-hemisphere summer draws to an end. Look for the shrinking northern polar ice cap as well as increasingly prominent surface features.

Jupiter is low in the west-northwest during twilight. It is still the brightest "star" at dusk in early May, despite being dimmed by its low altitude and its great distance from Earth (on the opposite side of the solar system). Jupiter has had a brilliant yearlong apparition, but sky watchers are running out of time to view it. The giant planet sets only about fifty minutes after the end of twilight on May 1, and two weeks later it sets with the fading twilight. By the 24th, Jupiter is gone completely, hidden behind the glare of the Sun.

Saturn might be glimpsed very low near the west-northwestern horizon about an hour after sundown during the first week of May. Use the brighter Mercury to guide you to Saturn on the evening of the 6th. For the rest of the month, Saturn lies too close to the Sun to be visible. Saturn's solar conjunction occurs on May 25.

The Moon is full on May 7 at 9:52 A.M. Last quarter comes on May 15 at 6:11 A.M., and the new Moon falls on May 22 at 10:46 P.M. First quarter is on May 29 at 6:09 P.M.

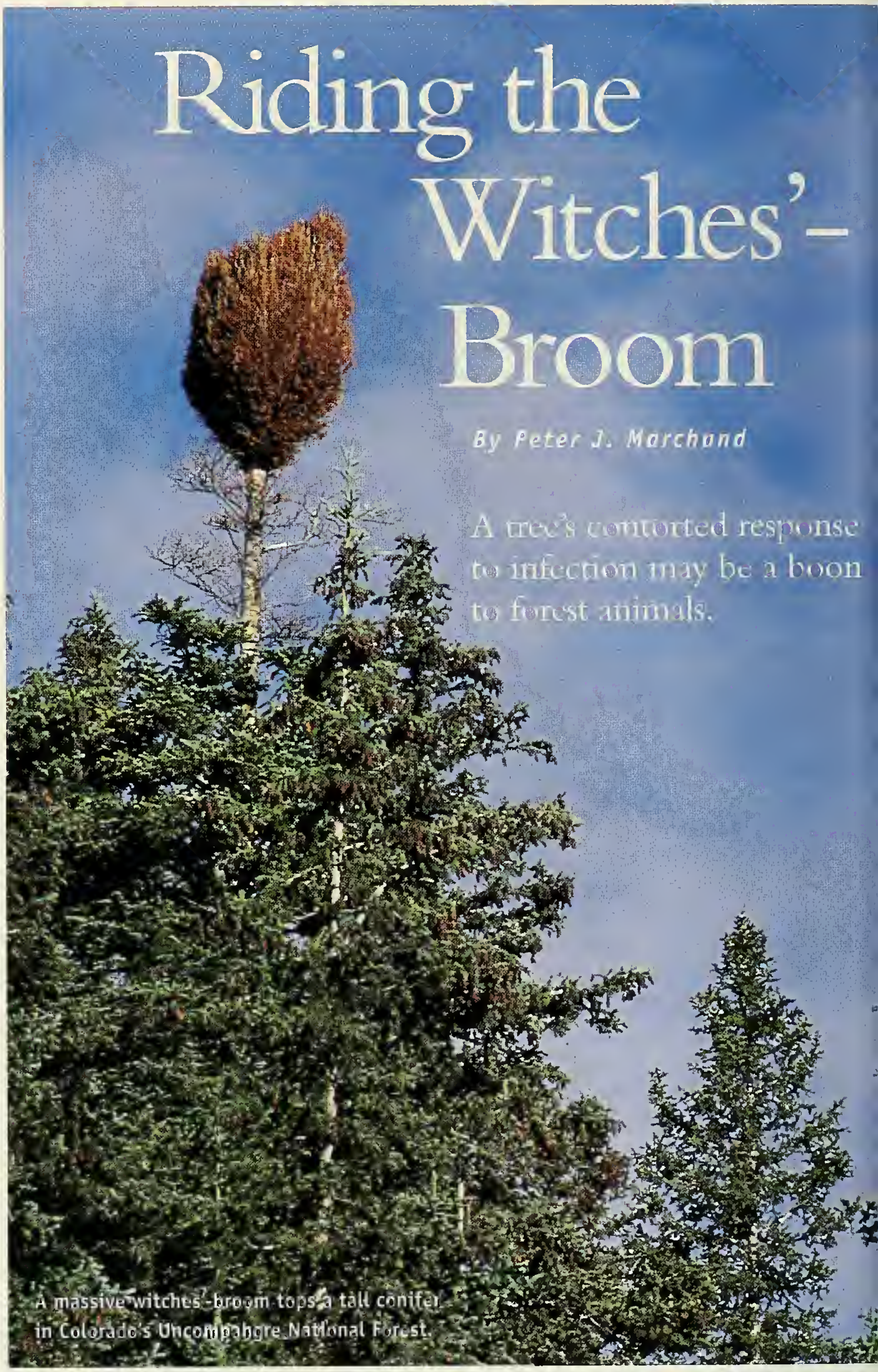
Unless otherwise noted, all times are given in Eastern Daylight Time.

IN THE FIELD

Riding the Witches'-Broom

By Peter J. Marchand

A tree's contorted response to infection may be a boon to forest animals.



A massive witches'-broom tops a tall conifer in Colorado's Uncompahgre National Forest.

I was tagging along with friends on a "hay ride" through Colorado's Arapaho National Forest when the old wrangler at the reins suddenly pulled his team to a halt. Interrupting his nonstop storytelling, he gestured toward a dark shape high in a lodgepole pine and drawled, "Porcupine nest," jerking his head upward in the general direction of the object. My eyes followed his motion to a dense tangle of twigs wedged between the trunk and an oddly twisted branch near the top of the tree. Recognizing the cluster as a large witches'-broom—and having never heard of porcupines nesting in trees—I wondered if this was just local folklore. Or did the old outdoorsman know something about witches'-brooms that I had missed?

Witches'-brooms are odd growths of stunted and closely packed branches. They occur sporadically in many different kinds of trees and shrubs, both broad-leaved and coniferous, and come in all sizes and shapes, from small spindly clusters to large globose masses. Many look like nests. Witches'-brooms result from prolific, localized growth, occasionally induced by genetic mutation but most often caused by parasitic organisms—ranging in size from microscopic to large and luxuriant—that manipulate the plants' own growth hormones.

Among the smallest agents of witches'-brooms are amoeba-shaped phytoplasmas, often no larger than a hundredth of a millimeter in diameter, that infect the phloem, or food-transporting, cells of many broad-leaved trees and shrubs. Though they possess only one-fifth the number of genes found in the typical bacterium, these simple pathogens can wreak havoc within their hosts, redirecting hormones and causing broom formation near branch tips, where plant sugars and nutrients become concentrated.

The most common architects of witches'-brooms in coniferous trees are certain rust fungi as well as the widespread, and photosynthetic, dwarf mistletoes. Both these organisms cause especially large and convoluted brooming (of the sort the old wrangler had pointed to), and few conifers are immune to their attack. The rusts, spread by tiny spores, induce a dense packing of branches with characteristic yellow foliage that is cast in the fall, though the broom itself keeps growing year-round. Spruce broom rust can infect almost any of the native North American spruces but is found only where the understory shrub bearberry is available as an alternate host (many parasites produce generations that alternate between two different host species, one of which it may not affect adversely). Fir rust produces similar tightly packed brooms in most of the true firs but is limited to areas where chickweed, its alternate host, also grows. By contrast, the forty or so species of New World dwarf mistletoes, collectively distributed from Honduras to the Pacific Northwest and across Canada to New England (with eight more found in the Old World), need no alternate host, and one or another of them attacks almost every coniferous tree species within their range. The sticky seeds of dwarf mistletoe are spread from one tree to another by exploding fruits, often aided by wind or birds; once the seed attaches and grows, it adds its own cluster of shoots to the profusion of abnormal branches promoted by the infection of its host.

Unlike most plant parasites, the broom-forming dwarf mistletoes may considerably benefit a forest community by creating additional food resources and habitat for many animals. A few months ago, I came across a huge, downed Engelmann spruce that held three large witches'-brooms, two of which contained recently occupied red-squirrel nests. One broom, situated close to the trunk about sixty feet above the base, consisted of many contorted branches, some four to five inches in diameter. Together with their dense tangle of twigs, they created a mass exceeding four feet in height. Within this broom was a three-tiered nest system—a veritable squirrel condominium. The floor of the bottom chamber consisted of partially decomposed, densely packed organic duff about two inches thick, overlying a bed of coarse spruce needles. Incorporated into this mass was a considerable amount of grass and animal hair, including a lone crimped guard hair of a deer or elk. Fecal pellets were buried within the floor to a depth exceeding one inch, indicating long usage of the nest.

DAVID LIEBMAN

MICHAEL QUINTON: MINDEN PICTURES

A parasite that distorts tree growth, dwarf mistletoe (above) is a treat for a porcupine (inset).

Red squirrels are not the only creatures that take advantage of large witches'-brooms—or of the parasites that produce them. Abert's and northern flying squirrels, as well as martens and bushy-tailed wood rats, are known to utilize witches'-brooms for nesting or protection. In addition, ten perching bird and eight raptor species, including Mexican spotted owls and goshawks, sometimes nest within these structures. One raptor, the long-eared owl in eastern Oregon, may be particularly dependent on witches'-brooms for nest sites. But the list of users doesn't end there. The shoots and fruits of dwarf mistletoes are fed upon by at least a dozen species of birds, including many grouse, and also by numerous insects—such as the thicket hairstreak butterfly, whose larvae feed solely on these mistletoes and mimic almost perfectly their color and shape. Add to this twenty-nine or so different fungi known to tap the concentrated resources of witches'-brooms (some parasitizing the mistletoe itself), and the list of species benefiting from the tree-parasite interaction is impressive.

What, then, of the old wrangler's "porcupine nest"? Porcupines feed heavily on the nutritious shoots of dwarf mistletoe, and one researcher has observed porcupines in the Pacific Northwest seeking shelter during winter within some of the larger brooms in Douglas firs. It seems that no end of organisms are ready to jump on the wagon—to ride the witches'-broom, as it were—and share in the spoils of competition between these diminutive parasites and their giant hosts.

Peter J. Marchand is currently a visiting scientist at the Carnegie Museum of Natural History's Powdermill Biological Station in the Allegheny Mountains of western Pennsylvania.

THE EVOLUTIONARY FRONT

Alternative Life Styles

Computer scientists and biologists are finding common ground in the evolution of artificial and natural organisms.

By Carl Zimmer

Do universal laws of evolution exist? There's no bigger question in biology, and none harder to answer. To discover a universal rule, you need more than a single case, and when it comes to life, we're stuck with a data set of one. All life on earth descends from a common ancestor, with every species storing its genetic information in DNA (or, in the case of some viruses, RNA). If scientists someday discover another form of life, perhaps lurking on a moon of Jupiter or in some distant solar system, they may be able to compare its evolution to our own and see if the two histories have followed the same playbook. But such an opportunity may be a long way off.

In 1992 the eminent biologist John Maynard Smith declared that the only way out of this quandary was to build a new form of life ourselves. "We badly need a comparative biology," he wrote. "So far, we have been able to study only one evolving system, and we cannot wait for interstellar flight to provide us with a second. If we want to discover generalizations about evolving systems, we will have to look at artificial ones."

In the nine years since Maynard Smith's call, computer scientists have done their best to answer it. They've tried to create a menagerie of artificial life-forms, from self-replicating software to "intelligent" robots, and they've set off plenty of breathless hype in the process. Some claim, for example, that computer processing speeds are climbing so quickly that within fifty years, robots with superhuman intelligence will be walking among us. Neuroscientists have countered that brains are much more than just masses of neurons: they consist of complex networks that communicate with one another using dozens of chemical signals. Even the simplest of these networks can take decades to decipher. Just figuring out the system of thirty neurons that lobsters use to push food through their stomachs has taken more than thirty years and the collective labor of fifteen research teams. At that rate, millions of years could pass before scientists fully comprehend the workings of the 100 billion neurons that make up the human brain.

But not all is hype and skepticism. Suitably humble experts on artificial life and suitably open-minded biologists are starting to work together. One promising collaboration is being led by Chris Adami, a physicist at the California Institute of Technology; Charles Ofria, a former student of Adami's who is now at Michigan State University; and Richard Lenski, a microbiologist at Michigan State. Building on pioneering work by Tom Ray (now at the University of Oklahoma), Adami and Ofria have created computer programs—digital creatures—that behave in remarkably lifelike ways. And working with Lenski, they've shown that these creatures, which they call *Digitalia,* evolve much the way biological life-forms do.

Each digitalian consists of a short program that can be run by a computer. The computer moves line by line through the program, methodically executing each command until it reaches the end, whereupon it loops back to the beginning and starts over. A program can reproduce by instructing the computer to make a copy of the program, and this duplicate then starts running on its own.

Adami and his colleagues conceive of the digitalia as organisms living on a two-dimensional plane divided up into thousands of cells. Each digitalian occupies a single cell, and when it reproduces, its offspring take up residence in the adjoining cells. Once a digitalian starts reproducing, its progeny can race across the plane like mold spreading over a slice of bread. (The researchers can watch their progress by means of a graphic display on a computer screen, although the screen itself isn't actually the habitat—there's no one-to-one correspondence between the pixels and the cells.)

Digitalia don't simply replicate; they also evolve. Every time a digitalian replicates, there's a small chance the copy will contain a mutation. Mutations in nature are random changes in a sequence of DNA; in the case of digitalia, mutations consist of certain kinds of random changes in a program. For example, the computer may copy part of a program twice instead of once or may switch one command for another.

As in the real world, most mutations are harmful to digitalia, inserting fatal bugs that prevent them from replicating. Other mutations have little or no effect, building up like junk through the generations. And some help digitalia replicate faster. Those so blessed come to dominate their artificial world, just as natural selection favors well-adapted biological life.

Adami and his associates have found that their digitalia consistently evolve in certain ways—ways that are similar to what biologists see in real life. In one experiment, they created several different strains of digitalia and let them evolve. They found that these programs consistently shrank down to sleek, short sequences of commands—as few as eleven command lines in some cases—that carried the minimum amount of information necessary for replicating. It takes less time to copy a short program than a long one, so the shorter the program, the more quickly it can multiply.

In the 1960s Sam Spiegelman and his colleagues at the University of Illinois got a similar result when they studied the evolution of RNA viruses. They put viruses into a beaker and supplied them with all the enzymes they needed to replicate. Twenty minutes later, the researchers transferred some of the newly replicated viruses to a new beaker and let them replicate again. After a few rounds, the scientists waited only fifteen minutes each time, and then only ten minutes, and finally only five. By the end of the experiment, the viral RNA had shrunk to 17 percent of its initial size. The viruses evolved into such small versions of themselves because they could shed genes they had used to invade and commandeer host cells. These had become unnecessary and now only slowed down the RNA's replication. As with digitalia, the most successful viruses under these conditions were the simplest.

Normally, however, life doesn't exist in a test tube, with all its needs taken care of by a technician. Organisms have to eat, or photosynthesize, or somehow consume the energy and matter around them. To make digitalia more lifelike, Adami and his colleagues require them to eat to survive. Numbers are their food.

Each organism is supplied with a random sequence of 1's and 0's. Just as some bacteria eat sugar and transform it into useful proteins, digitalia are required to read these numbers and transform them into meaningful outputs. With the right combinations of commands, for instance, they can determine whether three numbers in a row are identical, or they can turn a string of numbers into its opposite ("10101" becoming "01010"). The scientists reward the digitalia for evolving the ability to do these tasks. The programs of these lucky organisms start running faster, and as a result, they multiply faster. Soon their numbers overwhelm the less capable digitalia.

Under these complex conditions, the digitalia don't turn into stripped-down creatures. Instead, they evolve from simple replicators into sophisticated data processors that can crunch numbers in complicated ways. Human programmers, of course, can also write programs to carry out these tasks, but sometimes the digitalia evolve versions that are unlike anything ever conceived by a human designer.

To discover a universal rule, you need more than a single case. With life, we're stuck (so far) with a data set of one.

Someday this sort of evolution may produce new kinds of efficient, crash-proof software. But Adami and Ofria are not interested in the commercial possibilities of digitalia; they're too busy working with Richard Lenski, comparing their artificial life to biological life.

The partnership began after Lenski heard Adami give a talk about his digitalia. Adami showed the audience a graph charting the creatures' replication rate. The line on the graph rose for a while before reaching a plateau and then rose to still higher plateaus in a series of sudden jerks. Lenski was astonished. He and his colleagues had observed how *Escherichia coli* bacteria evolved over thousands of generations, acquiring mutations that helped them consume sugar more efficiently and reproduce faster. When Lenski had charted their evolution, he had found the same punctuated pattern that Adami identified. Digitalia and *E. coli* apparently had some profound things in common. The two teams of scientists joined forces in 1998.

Since then, they have found more similarities between digitalia and biological organisms. In 1995 Lenski and a student, Mike Travisano, ran an experiment to gauge the importance of chance, history, and adaptation to the evolution of bacteria. From a single *E. coli* they cloned twelve populations, which they regularly supplied with the simple sugar glucose. Over the course of 2,000 generations, all the colonies evolved, becoming better and better adapted to the glucose diet. Then Lenski's team switched the bacteria to a diet of a different sugar, maltose. Over the course of another 1,000 generations, the colonies adapted until they could grow almost as well on their new food.

But the evolution of the colonies was not just a simple story of adapting to food. Lenski and his colleagues also kept track of the size of the microbes as they adapted. Originally the colonies were identical, but by the time the scientists switched them from glucose to maltose, they had diverged into a range of different sizes. Then, as the bacteria adapted to their new diet, their size changed again. Some colonies changed from big to small, others from small to big. Overall, the researchers found, the bacteria's adaptation to their diet had nothing to do with their size change. Chance mutations could alter cell size with little effect on their fitness, that is, their success in survival and replication.

Adami and a student, Daniel Wagenaar, recently converted Lenski's experiment into one they could run with their computer creatures. They created eight copies of a single program, which they used to seed eight separate digitalia colonies. The organisms were rewarded for mastering a set of logical operations, but once they had become well adapted, the researchers changed the reward system so that an entirely different set of operations was favored—a digital version of switching from glucose to maltose.

Adami and Wagenaar observed that digitalia could evolve quickly and thrive in new conditions, just as *E. coli* had. They also monitored the length of the programs—a trait that proved relatively unimportant to their fitness, just as cell size was for the bacteria. Adami and Wagenaar found that the evolution of a program's length was determined mainly by its history and by chance mutations, rather than by the pressure to adapt.

These parallel experiments suggest, once again, that artificial and biological life evolve according to at least some of the same rules. When it comes to traits that experience intense natural selection—such as the mechanisms for finding food or crunching numbers—the end results may erase much of a trait's previous history. But in the case of traits that experience only weak selection—such as the size of a bacterium or the length of a computer program—chance mutations can send evolution off in unpredictable directions, and their effects can linger for a long time as historical vestiges.

One of the great attractions of digitalia is that they're so much easier to work with than biological life. You can create billions of different digitalia strains and watch them evolve for thousands of generations in a matter of hours. And every step of that complicated journey is preserved on a computer, instantly available for study—making it possible to ask questions about digitalia that can't be addressed in ordinary experiments.

For example, biological evolution has produced structures and organisms of awesome complexity, from termite colonies to the human brain. But does this mean that evolution has been dominated by a steady trend of rising complexity over time? A long line of thinkers have claimed that it does; one recent example is Robert Wright, in his book *Nonzero: The Logic of Human Destiny*. Stephen Jay Gould, on the other hand, has argued that what some people may interpret as an overall trend toward complexity is really the random rise and fall of complexity in different branches of the tree of life.

You can create billions of digital organisms and watch them evolve for thousands of generations in a few hours.

Though fascinating, this debate has stalled because scientists have yet to settle on a definition of complexity in biology or on a way to measure its change. Complexity is not unique to biology, however. Mathematicians have found precise ways to measure the complexity of information, whether it's a picture of Jupiter transmitted by the *Galileo* probe or the sound of a friend's voice on the telephone. Since digitalia genomes are strings of commands—in other words, information—Adami and his associates have been able to adapt mathematical methods to measure digitalia complexity as well.

To gauge how much of the information in a digitalia program is vital to the organism's survival, the researchers mutate each command in the program in every possible way and then see whether the organism can still function. A program may be stuffed with useless commands and turn out to be quite simple; even if you tamper with a lot of its code, it will still function. But another program of the same length may turn out to be complex, using most of its commands in precise ways that don't tolerate much tinkering.

Following this method, Adami and his coworkers have measured the complexity of digitalia colonies as they've evolved through 10,000 generations. Overall, the complexity consistently rises until it levels off. Its ascent is jagged but is an ascent nevertheless. For digitalia, at least, evolution does have an arrow pointing toward greater complexity.

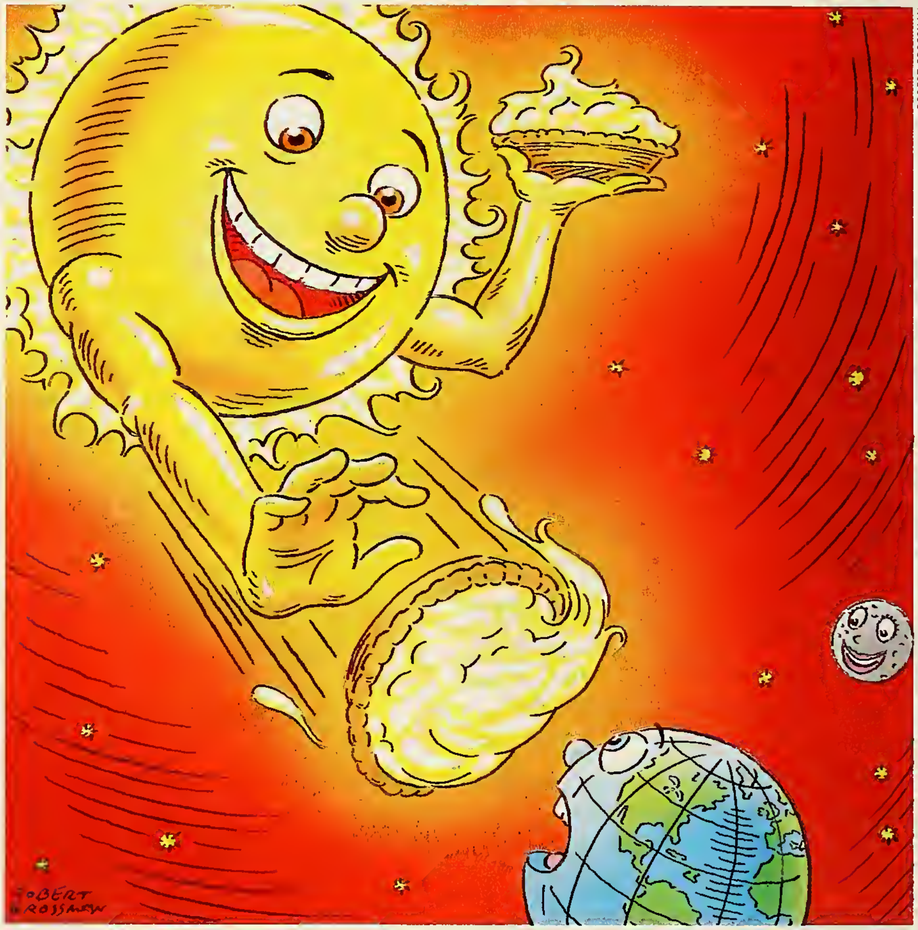
As interesting as these results are, any application to biological life comes with some important caveats. For one thing, the scientists only measured the information that was contained in the digitalia programs, which is akin to biologists measuring the complexity of information encoded in a genome. There's no simple equation that enables a biologist to use genetic complexity to calculate the complexity of the things a genome creates.

Another caveat to bear in mind is that the complexity of digitalia increases in a fixed environment—that is, the rewards for processing data don't change. In the natural world, conditions are always changing, with an endless flow of droughts, floods, outbreaks of disease, and other life-altering events. Every time conditions change, genes that were specialized to deal with the old conditions become useless. The obsolete genes may mutate or even disappear, and in the process, the complexity of a species' genome dwindles. Only as the species adapts to new conditions may complexity increase again.

In the natural world, the arrow of complexity may get turned back too often to have any significant effect on long-term evolution. But just finding that arrow is an admirable start. Indeed, everything about digitalia is, at the moment, a start—the start of a new kind of science and just maybe the start of a new kind of life.

Science writer Carl Zimmer is the author of At the Water's Edge *and* Parasite Rex.

UNIVERSE



ROBERT GROSSMAN

Cosmic Plasma

There's a lot of it out there but, thankfully, not too much of it down here.

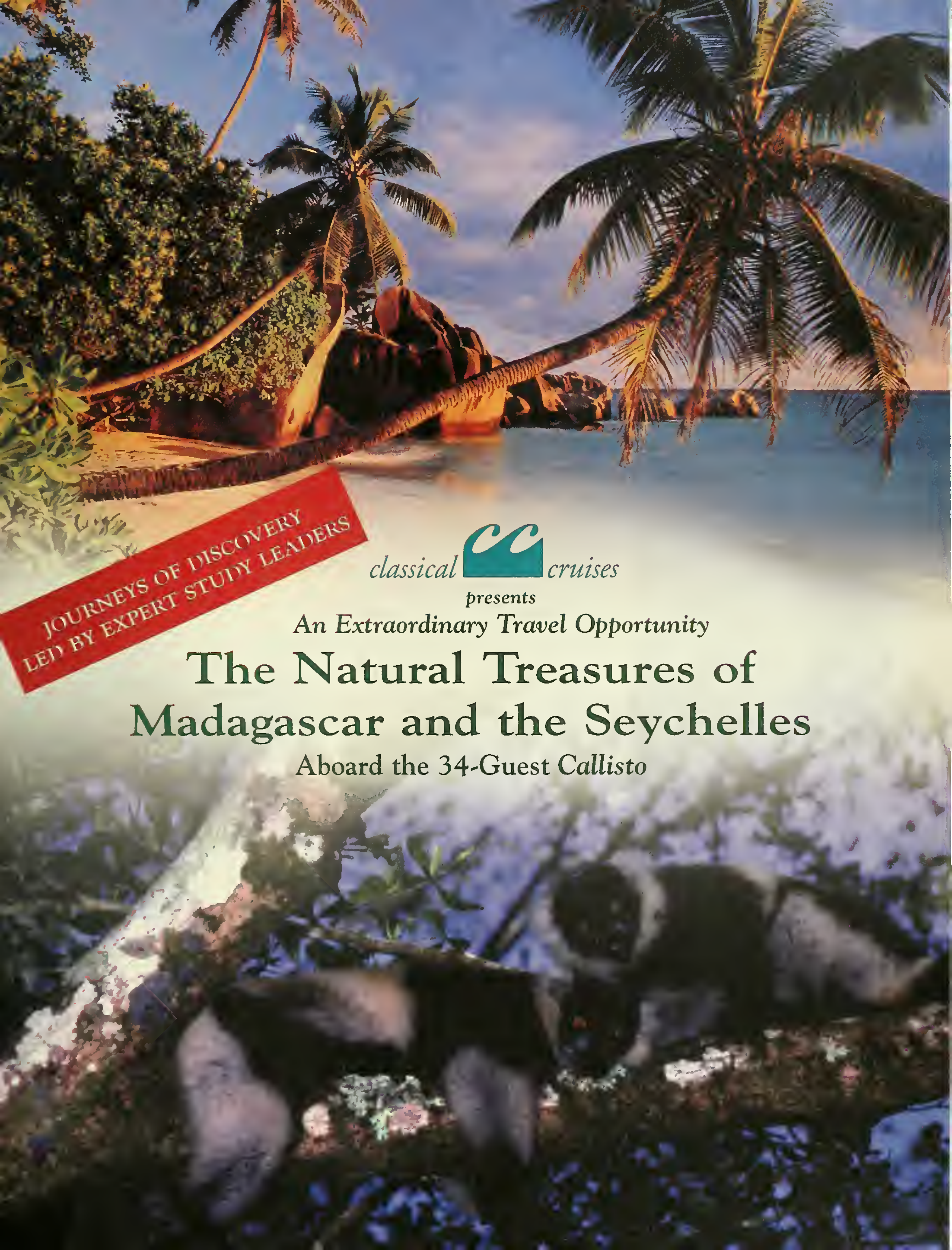
By Neil de Grasse Tyson

Only rarely does the medical doctor's vocabulary overlap with that of the astrophysicist. The human skull has two "orbits," the round cavities where your two eyeballs go; your "solar" plexus sits in the middle of your chest; and your eyes, of course, have "lenses"—though our bodies contain no quasars and no galaxies. For orbits and lenses, the medical and astrophysical usages resemble each other greatly; on the other hand, the term "plasma" is common to both disciplines, yet the two meanings have nothing whatever to do with each other. A transfusion of blood plasma can save your life, but a brief encounter with a glowing blob of million-degree plasma would leave a puff of smoke where you had just been standing.

Astrophysical plasmas are remarkable for their ubiquity, yet they're hardly ever discussed in introductory textbooks or in the press. Writers of science books often call plasmas the fourth state of matter because of a panoply of properties that sets them apart from the familiar solids, liquids, and gases. A plasma has freely moving particles, just as a gas does, but a plasma can conduct electricity as well as interact strongly with magnetic fields passing near it or through it. Atoms within a plasma have had some or all of their electrons stripped from them by one mechanism or another. And the combination of high temperature and low density in a plasma only occasionally allows electrons to recombine with their host atoms. Taken as a whole, the plasma remains electrically neutral, because the total number of electrons (which are negatively charged) equals the total number of protons (which are positively charged). But a plasma can seethe with electric currents and magnetic fields, so in many ways, it behaves nothing like the ideal gas we all learned about in high-school chemistry class.

The effects that electric and magnetic fields have on matter almost always dwarf the effects of gravity. The electrical attraction between a proton and an electron is forty powers of ten stronger than their gravitational attraction. So strong are electromagnetic forces that a child's magnet easily lifts a paper clip off a tabletop, despite Earth's formidable gravitational tug. Want a more interesting example? If you managed to extricate all the electrons from a cubic millimeter of atoms in the nose of a space shuttle and if you attached those electrons to the base of the launch pad, then the attractive force would inhibit the launch. All engines would fire, but the shuttle wouldn't budge. And if the Apollo astronauts had brought back to Earth all the electrons from a 100-inch cube of lunar dust (leaving behind the atoms from which they came), the force of attrac-

(Please turn to page 47)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The Natural Treasures of
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Aboard the 34-Guest Callisto

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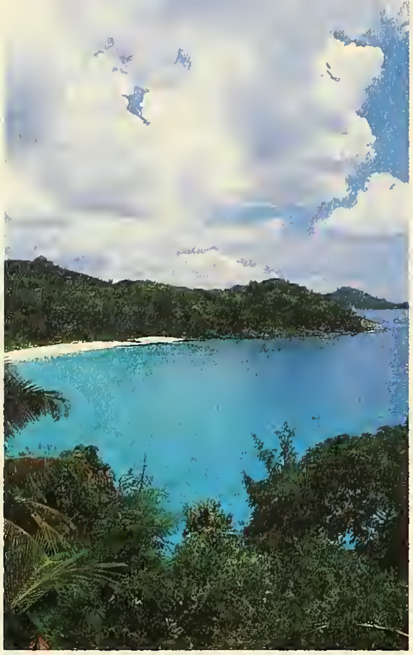


Mahe, Seychelles

Chameleon; Nosy Mangabe Reserve, Madagascar

Maroantsetra, Madagascar

HIDDEN AWAY IN THE INDIAN OCEAN, spread out over a vast expanse of sea, lies an incredible natural paradise, the islands of Madagascar and the Seychelles. Here Nature has developed a magical garden of rare plants and flowers and filled it with strange and wonderful wildlife. This winter, Classical Cruises invites you to discover the natural treasures of this remarkable island world with some of the world's leading naturalists and conservationists.

Created and preserved by continental shifts that occurred millions of years ago, the Seychelles and Madagascar are an ecological wonderland, filled with unique species of animals, birds, and plants. Here you'll find an array of unusual wildlife, including the Seychelles sunbird, the blue-barred parrotfish, the giant land tortoise, and more than 30 species of lemurs. You'll also encounter rare habitats, including the primeval rainforests in the high hills of Mahe and Silhouette, where tall and strangely twisted trees are festooned with tiny native begonias and miniature orchids and pitcher plants cling to the gnarled trunks.

On these voyages, as with every Classical Cruises program, we have engaged distinguished Study Leaders to introduce you to the natural wonders of the region. Explore the evolutionary history of the islands with renowned paleoanthropologist Dr. Donald Johanson and discover the extraordinary birdlife of the region with Dr. Donald F. Bruning, Curator and Chairman of Ornithology at the Wildlife Conservation Society. Examine the conservation issues affecting the area with prominent wildlife expert Joan Embery and noted ABC News correspondent Lynn Sherr.

For over 30 years, Classical Cruises has been offering unique voyages of discovery to some of the world's most fascinating and pristine places. We invite you to join us and discover for yourself our unique concept of "travel as a learning experience."

Study Leaders

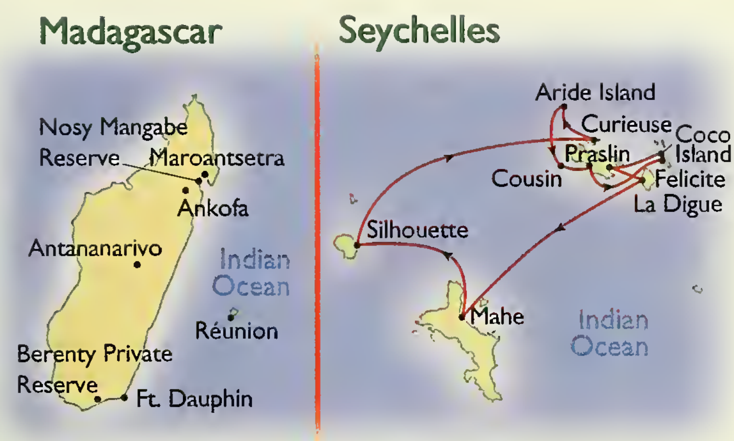
LYNN SHERR
Departure: *December 20 - January 7*
Award-winning ABC News correspondent Lynn Sherr has covered a wide range of stories and investigative reports in her journalism career, but it was a 1973 visit to Africa that led to her intense interest in giraffes. In her book *Tall Blondes*, Sherr chronicles the giraffe's cultural history as well as its links with science, geography, literature, art, and most importantly, conservation.

DR. DONALD C. JOHANSON
Departure: *January 15 - February 3*
A pioneer in the field of physical anthropology, Dr. Donald C. Johanson profoundly influenced the understanding of early hominid evolution with his discovery of the "Lucy" skeleton in Ethiopia in 1974. The author of numerous books, most recently *From Lucy to Language*, Dr. Johanson narrated the popular PBS/Nova series "In Search of Human Origins" and served as curator of physical anthropology at the Cleveland Museum of Natural History for many years.

JOAN EMBERY
Departure: *January 29 - February 17*
Nationally known for her appearances on late-night television with Johnny Carson, renowned conservationist and animal expert Joan Embery is dedicated to the preservation and understanding of the Earth's wildlife and habitats. Embery serves as Conservation Ambassador for the San Diego Zoo and the San Diego Wild Animal Park and in that role, captivates and inspires the public with her message of wildlife preservation. She is also the proud caretaker of a lemur.

DR. DONALD F. BRUNING
Departure: *February 12 - March 3*
Dr. Donald F. Bruning is curator and chairman of Ornithology at the Wildlife Conservation Society in New York. A distinguished birder, he is actively involved in conservation efforts worldwide.

Other departures available.
Please inquire with Classical Cruises.



Itinerary

Day 1
DEPART USA

Day 2
EUROPEAN CITY
Transfer to an airport hotel until the evening flight to Madagascar.

Day 3
ANTANANARIVO, MADAGASCAR
Morning arrival in Antananarivo. Transfer to the *Hotel Colbert.*

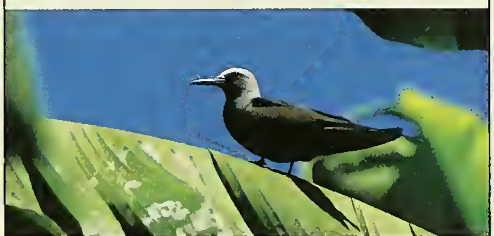
Days 4 & 5
ANTANANARIVO | FT. DAUPHIN | BERENTY PRIVATE RESERVE
On the morning of Day 4, fly to Ft. Dauphin. Transfer to the Berenty Private Reserve, on the banks of the Mandrare River. Found here are 115 plant species, 83 bird species, and several species of mammals, most prominently lemurs. Accommodations are at the *Gite d'Etape.*

Day 6
BERENTY PRIVATE RESERVE | FT. DAUPHIN | ANTANANARIVO
Fly from Ft. Dauphin to Antananarivo. Upon arrival, visit Ambohimanga, the old capital of the Merina royal family. Continue to Antananarivo and the *Hotel Colbert.*

Day 7
ANTANANARIVO | MAROANTSETRA
Morning flight to Maroantsetra. Travel to Andrifotra Private Reserve, created to protect the region's wildlife. Accommodations at *Relais du Masoala.*

Day 8
NOSY MANGABE RESERVE
Spend the day at Nosy Mangabe Reserve, home to the endangered aye-aye lemur, black-and-white, ruffed, and brown lemurs; and several species of chameleon.

Day 9
ANKOFA
This morning, cruise up the Antainambalana River by pirogue to Ankofa, where we experience the daily life of a typical Malagasy village.



Noddy Tern; Cousin, Seychelles

Day 10
MAROANTSETRA | ANTANANARIVO
Transfer to Maroantsetra's airport for the flight to Antananarivo. Transfer to the *Hotel Colbert.*

Day 11
ANTANANARIVO | RÉUNION
Tour Antananarivo, then fly to Réunion. Overnight at the *Hotel Meridien.*

Day 12
MAHE | EMBARKATION
Morning flight to Mahe, the main island in the Seychelles. Embark *Callisto.* Overnight aboard ship in Mahe.

Day 13
SILHOUETTE ISLAND AND CURIEUSE BAY
A hike through the pristine rain forest on Silhouette Island reveals several species of endemic orchids, bwa sandal, bwa rouz, kapisen, and other trees.

Day 14
CURIEUSE AND ARIDE ISLANDS
Visit Curieuse, home to giant land tortoises, the coco de mer, and several bird species. Afternoon at Aride, whose plant life includes the beautiful cream and magenta Wright's Gardenia and the recently discovered Aride Peponium, found nowhere else on earth.

Day 15
COUSIN ISLAND AND ANSE LAZIO, PRASLIN
Morning at uninhabited Cousin, home to Seychelles warblers, wedge-tailed shearwaters, fairy terns, lesser noddies, and others. Then sail to Praslin's Anse Lazio for swimming, snorkeling, and relaxing.

Day 16
FELICITE AND COCO ISLANDS
Morning at Felicite, covered with a profusion of palms and other plants. Afternoon swimming and snorkeling at tiny Coco isle.

Day 17
PRASLIN ISLAND
Explore the Vallee de Mai, believed by some to be the Garden of Eden. Watch for the Seychelles black parrot; the Seychelles blue pigeon; sunbirds; and Seychelles flying foxes.

Day 18
LA DIGUE
Call at La Digue for a tour of the forested nature reserve and a swim at Anse Source d'Argent. In the evening, dock in Mahe.

Day 19
MAHE | DISEMBARKATION
Disembark at Mahe for a tour of the island. Relax at the *Hotel Plantation* before the evening flight.

Day 20
EUROPEAN CITY | USA
Arrive in a European city to connect with the return flight to the USA.

Departures

Depart	Return
December 20, 2001	January 7, 2002 *
January 15, 2002	February 3, 2002
January 29, 2002	February 17, 2002
February 12, 2002	March 3, 2002

Other departures available. Please inquire with Classical Cruises.

* The Madagascar portion follows the cruise on this departure.

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- Three meals daily thoughout the program: breakfast, lunch, and dinner. Afternoon tea aboard ship
- House wine and soft drinks with lunch and dinner aboard ship.
- Welcome and farewell receptions aboard ship, hosted by the captain.
- Educational program of lectures and discussions provided by an accompanying study leader.
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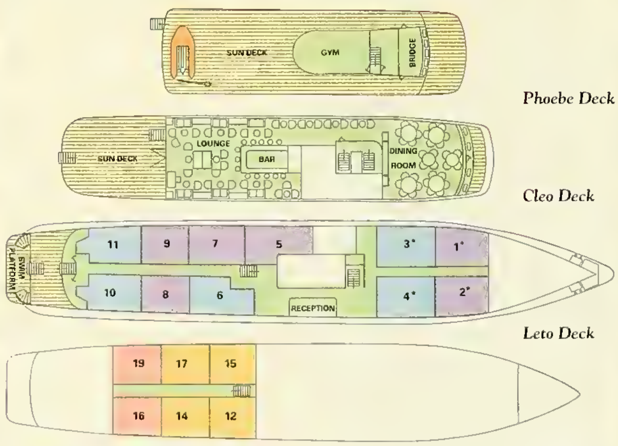
The New 34-Guest *Callisto*

THE YACHT CALLISTO, whose name means "most beautiful" in Greek, has become still more beautiful thanks to an extensive, recently completed renovation. This lovely oceangoing yacht offers a maximum of 34 guests a rare opportunity to experience some of the world's most undiscovered and pristine places. All 17 of *Callisto*'s staterooms are exterior, each with a large panoramic window (staterooms on Daphne Deck have three portholes each), so you can enjoy views of the sea and the various ports of call. All cabins are air-conditioned and feature a private bath, telephone, two-channel radio, TV/VCR, and refrigerator. The yacht's public areas include a spacious lounge ideal for lectures and presentations as well as quiet conversation; a dining room in which all guests are accommodated at a single unassigned seating; and a gym. There are two broad decks for sunbathing and dining alfresco and a swimming platform at the yacht's stern. *Callisto* flies the Greek flag and is served by a crew of 16.

Lounge

Dining alfresco

Deck Plan



* Cabin with full or queen-size bed

Gym

Marble-appointed cabin bathroom

Rates

Per Person, Double Occupancy

Cabin Category	D	C	B	A
Rate	$8,195	$8,595	$9,095	$9,495

Single Supplement: $2,500 (Categories C and B)

Airfare

Classical Cruises would be pleased to assist you with your air reservations. Please call us at 800-252-7745 for further information.

(Continued from page 46)
tion would exceed the gravitational attraction between Earth and the Moon.

Earth's most conspicuous plasmas are lightning, the trail of a shooting star, and the ordinary electric shock you get after shuffling around on your living-room carpet in your wool socks and then touching a doorknob. Electrical discharges are jagged columns of electrons that abruptly move through the air when too many collect in one place. Lightning, for instance, happens to strike Earth's surface thousands of times per hour. The centimeter-wide air column through which a bolt of lightning travels is turned into glowing plasma in a fraction of a second, having been raised to a temperature ten times that of the Sun's surface by these flowing electrons.

Every shooting star is a tiny particle of interplanetary debris moving so fast that it burns up in the air and descends to Earth as harmless cosmic dust. Almost the same thing happens to a spacecraft that reenters our atmosphere. Since its occupants don't want to land at the near-Earth orbital speed of 18,000 miles per hour (about five miles per second), the craft must slow down and its kinetic energy must go somewhere. Shock waves along the leading edge heat the craft during reentry. The heat is rapidly whisked away by protective shields. This is why the astronauts, unlike shooting stars, do not descend to Earth as dust. For several minutes during a descent, the heat is so intense that every molecule surrounding the space capsule becomes ionized, cloaking the astronauts in a temporary plasma barrier that none of our communication signals can penetrate. This is the infamous blackout period, when the craft is aglow and Mission Control knows nothing of the astronauts' well-being. The craft continues to slow down as it plows through the atmosphere. Along the way, the temperature drops, the air gets denser, and the plasma state can no longer be sustained. The electrons go back home to their atoms, and communication is quickly restored.

While relatively rare on Earth, plasmas comprise more than 99.99 percent of all the visible matter in the cosmos. This tally includes every glowing star and "gas" cloud. Nearly all the Hubble Space Telescope's beautiful photographs of nebulae in our galaxy depict colorful gas clouds in the form of plasma. The shape and density of some of these clouds are strongly influenced by the presence of magnetic fields from nearby sources such as pulsars. The plasma can lock a magnetic field into place and torque or otherwise shape the field to its whims.

Earth's most conspicuous plasma? Try lightning, or the trail of a shooting star.

This marriage of plasma and magnetic field is a major feature of the Sun's eleven-year cycle of activity. The plasma near the Sun's equator rotates slightly faster than the plasma near its poles. This differential is bad news for the Sun's complexion. With the Sun's magnetic field "frozen" into its plasma, the field gets stretched and twisted. Sunspots, flares, prominences, and other solar blemishes come and go as the gnarly magnetic field punches through the Sun's surface, carrying solar plasma along with it.

Because of all this hubbub, the Sun flings charged particles into space, up to a million tons of them per second—including electrons, protons, and bare helium nuclei. The resultant particle stream, sometimes a gale and sometimes a zephyr, is more commonly known as the solar wind. This most famous of plasmas ensures that comet tails point away from the Sun, no matter whether the comet is coming or going. By colliding with molecules in Earth's atmosphere near our magnetic poles, the solar wind is also the direct cause of the aurora borealis and aurora australis (the northern and southern lights), not only on Earth but on all planets with atmospheres and strong magnetic fields.

Depending on a plasma's temperature and its mix of atoms, some free electrons will recombine with needy atoms and cascade down the myriad energy levels within. En route, the electrons emit light in prescribed wavelengths. The auroras owe their beautiful colors to these electron hijinks, as do neon tubes, fluorescent lights, and those glowing plasma spheres offered for sale next to the lava lamps in tacky gift shops.

These days, satellite observatories give us an unprecedented capacity to monitor the Sun and report on the solar wind as though it was part of the day's weather forecast. My first-ever televised interview for the evening news was triggered by the report of a plasma pie hurled by the Sun, at 300 miles per second, directly at Earth. Everybody (or at least the reporters) was scared that bad things would happen to civilization when it hit. Severe plasma ejections can fry the circuits on satellites and knock out transformers at power stations. But this one was mild and innocent. I told the viewers not to worry—that Earth's magnetic field protects us—and I invited them to use the occasion to go north and enjoy the aurora that the solar wind would cause.

The Sun's rarefied corona, visible during total solar eclipses as a glowing halo around the silhouetted Moon, forms a five-million-degree plasma that is the outermost part of the solar atmosphere. With temperatures that high, the corona is the principal source of the Sun's X rays. Without the benefit of an eclipse to block the Sun's bright surface, the corona easily gets lost in the glare.

There's an entire layer of Earth's atmosphere where electrons have been kicked out of their host atoms by ultraviolet light from the Sun, creating a plasma blanket called the ionosphere. This layer reflects certain frequencies of radio waves, including those of the AM dial (which can reach hundreds of miles) and of shortwave (which can reach thousands of miles beyond the horizon). FM signals and those of broadcast television, however, pass right through the ionosphere, traveling out to space at the speed of light. Any eavesdropping alien civilization will know all about our TV programs (probably a bad thing), will hear all our FM music (probably a good thing), and will know nothing of the politics of AM talk-show hosts like Rush Limbaugh (probably a safe thing).

Most plasmas are not friendly to organic matter. The person with the most hazardous job on the *Star Trek* television series is the one who must investigate the glowing blobs of plasma on the uncharted planets they visit. (My memory tells me that this person always wore a red shirt.) Every time this crew member meets a plasma blob, he gets vaporized. Born in the twenty-third century, these space-faring, star-trekking people would, you'd think, have long ago learned to treat plasma with respect (or not to wear red). We in the twenty-first century know enough to treat plasma with respect, and we haven't been anywhere.

In the center of our thermonuclear fusion reactors, where plasmas are monitored at a safe distance, we attempt to slam together hydrogen nuclei at high speeds and turn them into heavier helium nuclei. By doing so, we liberate energy that could supply society's need for electricity. Problem is, we haven't yet succeeded in getting more energy out than we put in. To achieve such high collision speeds, a blob of hydrogen atoms must be raised to tens of millions of degrees—at least as hot as the center of the Sun, where thermonuclear fusion is a routine thing. No hope for attached electrons here. At these temperatures they've all been stripped from their hydrogen atoms and roam free. How might you hold a glowing blob of hydrogen plasma at millions of degrees? In what container would you place it? Even microwave-safe Tupperware will not do.

What you need is a bottle that will not melt, vaporize, or decompose. To design it, we'd use the relationship between plasma and magnetic fields to our advantage, creating a container whose walls are intense magnetic fields that the plasma cannot cross. One of the pesky problems with the confinement of plasma is that if you squeeze it in one place, it tends to pop out someplace else. It's like trying to squeeze a balloon to make it smaller. The economic return from a successful fusion reactor will rest in part on the design of this magnetic "bottle" and on our understanding of how the plasma interacts with it.

You'd think those *Star Trek* people would have learned to treat plasma with respect.

Among the most exotic forms of matter ever concocted is the quark-gluon plasma, newly created by physicists at the Brookhaven National Laboratory, a particle-accelerator facility on New York's Long Island. Rather than being filled with atoms stripped of their electrons, a quark-gluon plasma comprises a mixture of some of the most basic constituents of matter: fractionally charged quarks along with the gluons that normally hold them together to form protons and neutrons. This unusual form of plasma greatly resembles the state of our trillion-degree cosmos a few microseconds after the big bang—about the time the observable universe was not much larger than our solar system. Indeed, in one form or another, every cubic inch of the universe was in a plasma state until a half-million years had elapsed.

A half-million years into its history, the universe had cooled down to a few thousand degrees. Before then, all light was getting scattered to and fro by the free electrons in the plasma—a phenomenon that greatly resembles what happens to light as it passes through frosted glass or through the Sun's interior. Light can travel through neither without scattering, and this renders both of them translucent instead of transparent. As the universe cooled to below a few thousand degrees, each electron in the cosmos combined with an atomic nucleus, creating complete atoms of hydrogen and helium and trace amounts of lithium.

As soon as every electron had found a home, the pervasive plasma state no longer existed. And that's the way it would stay for hundreds of millions of years, at least until quasars were born, with their central black holes that dine on swirling gases. Just before the gas falls in, it releases ionizing ultraviolet light that travels across the universe, kicking electrons back out of their atoms with abandon. Until the emergence of quasars, the universe enjoyed the only interval of time (before or since) when plasma was nowhere to be found. We call this era the dark ages and look upon it as a time when gravity was silently and invisibly assembling matter into the plasma balls that became the first generation of stars.

Neil de Grasse Tyson, an astrophysicist, is the Frederick P. Rose Director of New York City's Hayden Planetarium. He is (along with Steven Soter) coeditor of, as well as a contributor to, Cosmic Horizons: Astronomy at the Cutting Edge, *a collection of essays written by astrophysicists working on the frontiers of cosmological research.*

Gifted ideas for Mother's Day

Elegant pieces of the season. Straw flower shoulder bag with leather straps, $35. Cream/green polka-dot 100% silk neckerchief by Echo, $17.50. Also available in turquoise/purple or black/tan. Flower glass pins with crystals. Blue, pink or green, $50.

A selection of our new jewelry collection, just in time for spring . . .

22kt gold-plated bronze, bee design with aventurine, handmade by Jaded. Necklace, $125. Clip earrings, $85.

Riverstone mother of pearl and amazonite. Necklace, $116. Cluster earrings, $55. Freshwater pearl earrings, $48.

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By Sarah Blaffer Hrdy

Mothers and Others

FROM QUEEN BEES TO ELEPHANT MATRIARCHS, MANY ANIMAL MOTHERS ARE ASSISTED BY OTHERS IN REARING OFFSPRING. ANTHROPOLOGIST SARAH BLAFFER HRDY MAINTAINS THAT OUR HUMAN ANCESTORS, TOO, WERE "COOPERATIVE BREEDERS"—A MODE OF LIFE THAT ENABLED THEM TO THRIVE IN MANY NEW ENVIRONMENTS. TODAY, ARGUES HRDY, OUR CONTINUED ABILITY TO RAISE EMOTIONALLY HEALTHY CHILDREN MAY WELL DEPEND ON HOW WELL WE UNDERSTAND THE COOPERATIVE ASPECT OF OUR EVOLUTIONARY HERITAGE.

Her child on her back, a mother fishes with a basket in the Okavango River in Botswana.

Mother apes—chimpanzees, gorillas, orangutans, humans—dote on their babies. And why not? They give birth to an infant after a long gestation and, in most cases, suckle it for years. With humans, however, the job of providing for a juvenile goes on and on. Unlike all other ape babies, ours mature slowly and reach independence late. A mother in a foraging society may give birth every four years or so, and her first few children remain dependent long after each new baby arrives; among nomadic foragers, grown-ups may provide food to children for eighteen or more years. To come up with the 10–13 million calories that anthropologists such as Hillard Kaplan calculate are needed to rear a young human to independence, a mother needs help.

So how did our prehuman and early human ancestresses living in the Pleistocene Epoch (from 1.6 million until roughly 10,000 years ago) manage to get those calories? And under what conditions would natural selection allow a female ape to produce babies so large and slow to develop that they are beyond her means to rear on her own?

The old answer was that fathers helped out by hunting. And so they do. But hunting is a risky occupation, and fathers may die or defect or take up with other females. And when they do, what then? New evidence from surviving traditional cultures suggests that mothers in the Pleistocene may have had a significant degree of help—from men who thought they just might have been the

fathers, from grandmothers and great-aunts, from older children.

These helpers other than the mother, called allomothers by sociobiologists, do not just protect and provision youngsters. In groups such as the Efe and Aka Pygmies of central Africa, allomothers actually hold children and carry them about. In these tight-knit communities of communal foragers—within which men, women, and children still hunt with nets, much as humans are thought to have done tens of thousands of years ago—siblings, aunts, uncles, fathers, and grandmothers hold newborns on the first day of life. When University of New Mexico anthropologist Paula Ivey asked an Efe woman, "Who cares for babies?" the immediate answer was, "We all do!" By three weeks of age, the babies are in contact with allomothers 40 percent of the time. By eighteen weeks, infants actually spend more time with allomothers than with their gestational mothers. On average, Efe babies have fourteen different caretakers, most of whom are close kin. According to Washington State University anthropologist Barry Hewlett, Aka babies are within arm's reach of their fathers for more than half of every day.

Accustomed to celebrating the antiquity and naturalness of mother-centered models of child care, as well as the nuclear family in which the mother nurtures while the father provides, we Westerners tend to regard the practices of the Efe and the Aka as exotic. But to sociobiologists, whose stock in trade is comparisons across species, all this helping has a familiar ring. It's called cooperative breeding. During the past quarter century, as anthropologists and sociobiologists started to compare notes, one of the spectacular surprises has been how much allomaternal care goes on, not just within various human societies but among animals generally. Evidently, diverse organisms have converged on cooperative breeding for the best of evolutionary reasons.

A broad look at the most recent evidence has

Cooperative breeding allows many members of the dog family to rear large litters. Below: An arctic wolf and her puppies.

convinced me that cooperative breeding was the strategy that permitted our own ancestors to produce costly, slow-maturing infants at shorter intervals, to take advantage of new kinds of resources in habitats other than the mixed savanna-woodland of tropical Africa, and to spread more widely and swiftly than any primate had before. We already know that animal mothers who delegate some of the costs of infant care to others are thereby freed to produce more or larger young or to breed more frequently. Consider the case of silver-backed jackals. Patricia Moehlman, of the World Conservation Union, has shown that for every extra helper bringing back food, jackal parents rear one extra pup per litter. Cooperative breeding also helps various species expand into habitats in which they would normally not be able to rear any young at all. Florida scrub-jays, for example, breed in an exposed landscape where unrelenting predation from hawks and snakes usually precludes the fledging of young; survival in this habitat is possible only because older siblings help guard and feed the young. Such cooperative arrangements permit animals as different as naked mole rats (the social insects of the mammal world) and wolves to move into new habitats and sometimes to spread over vast areas.

WHEN ANIMAL MOTHERS DELEGATE SOME INFANT-CARE COSTS TO OTHERS, THEY CAN PRODUCE MORE OR LARGER YOUNG AND RAISE THEM IN LESS-THAN-IDEAL HABITATS.

What does it take to become a cooperative breeder? Obviously, this lifestyle is an option only for creatures capable of living in groups. It is facilitated when young but fully mature individuals (such as young Florida scrub-jays) do not or cannot immediately leave their natal group to breed on their own and instead remain among kin in their natal location. As with delayed maturation, delayed dispersal of young means that teenagers, "spinster" aunts, real and honorary uncles will be on hand to help their kin rear young. Flexibility is another criterion for cooperative breeders. Helpers must be ready to shift to breeding mode should the opportunity arise. In marmosets and tamarins—the little South American monkeys that are, besides us, the only full-fledged cooperative breeders among primates—a female has to be ready to be a helper this year and a mother the next. She may have one mate or several. In canids such as wolves or wild dogs, usually only the dominant, or alpha, male and female in a pack reproduce, but younger group members hunt with the mother and return to the den to regurgitate predigested meat into the mouths of her pups. In a fascinating instance of physiological flexibility, a subordinate female may actually undergo hormonal transformations similar to those of a real pregnancy: her belly swells, and she begins to manufacture milk and may help nurse the pups of the alpha pair. Vestiges of cooperative breeding crop up as well in domestic dogs, the distant descendants of wolves. After undergoing a pseudopregnancy, my neighbors' Jack Russell terrier chased away the family's cat and adopted and suckled her kittens. To suckle the young of another species is hardly what Darwinians call an adaptive trait (because it does not contribute to the surrogate's own survival). But in the environment in which the dog family evolved, a female's tendency to respond when infants signaled their need—combined with her capacity for pseudopregnancy—would have increased the survival chances for large litters born to the dominant female.

According to the late W. D. Hamilton, evolutionary logic predicts that an animal with poor prospects of reproducing on his or her own should be predisposed to assist kin with better prospects so that at least some of their shared genes will be perpetuated. Among wolves, for example, both male and female helpers in the pack are likely to be genetically related to the alpha litter and to have good reasons for not trying to reproduce on their own: in a number of cooperatively breeding species (wild dogs, wolves, hyenas, dingoes, dwarf mongooses, marmosets), the helpers do try, but the dominant female is likely to bite their babies to death. The threat of coercion makes postponing ovulation the better part of valor, the least-bad option for females who must wait to breed until their circumstances improve, either through the death of a higher-ranking female or by finding a mate with an unoccupied territory.

One primate strategy is to line up extra fathers. Among common marmosets and several species of tamarins, females mate with several males, all of which help rear her young. As primatologist Charles T. Snowdon points out, in three of the four genera of Callitrichidae (*Callithrix*, *Saguinus*, and

The meerkats of southwestern Africa's Kalahari Desert are cooperative breeders par excellence. Here, a subordinate "baby-sits" for another female's litter.

DAVID MACDONALD; OXFORD SCIENTIFIC FILMS

Leontopithecus), the more adult males the group has available to help, the more young survive. Among many of these species, females ovulate just after giving birth, perhaps encouraging males to stick around until after babies are born. (In cotton-top tamarins, males also undergo hormonal changes that prepare them to care for infants at the time of birth.) Among cooperative breeders of certain other species, such as wolves and jackals, pups born in the same litter can be sired by different fathers.

Human mothers, by contrast, don't ovulate again right after birth, nor do they produce offspring with more than one genetic father at a time. Ever inventive, though, humans solve the problem of enlisting help from several adult males by other means. In some cultures, mothers rely on a peculiar belief that anthropologists call partible paternity—the notion that a fetus is built up by contributions of semen from all the men with whom women have had sex in the ten months or so prior to giving birth. Among the Canela, a matrilineal tribe in Brazil studied for many years by William Crocker of the Smithsonian Institution, publicly sanctioned intercourse between women and men other than their husbands—sometimes many men—takes place during villagewide ceremonies. What might lead to marital disaster elsewhere works among the Canela because the men believe in partible paternity. Across a broad swath of South America—from Paraguay up into Brazil, westward to Peru, and northward to Venezuela—mothers rely on this convenient folk wisdom to line up multiple honorary fathers to help them provision both themselves and their children. Over hundreds of generations, this belief has helped children thrive in a part of the world where food sources are unpredictable and where husbands are as likely as not to return from the hunt empty-handed.

KONRAD WOTHE; MINDEN PICTURES

Two African elephant females tend a newborn calf. The larger social group facilitates the mother's task of rearing a single, large, slow-maturing offspring.

The Bari people of Venezuela are among those who believe in shared paternity, and according to anthropologist Stephen Beckerman, Bari children with more than one father do especially well. In Beckerman's study of 822 children, 80 percent of those who had both a "primary" father (the man married to their mother) and a "secondary" father survived to age fifteen, compared with 64 percent survival for those with a primary father alone. Not surprisingly, as soon as a Bari woman suspects she is pregnant, she accepts sexual advances from the more successful fishermen or hunters in her group. Belief that fatherhood can be shared draws more men into the web of possible paternity, which effectively translates into more food and more protection.

But for human mothers, extra mates aren't the only source of effective help. Older children, too, play a significant role in family survival. University of Nebraska anthropologists Patricia Draper and Raymond Hames have just shown that among !Kung hunters and gatherers living in the Kalahari Desert, there is a significant correlation between how many children a parent successfully raises and how many older siblings were on hand to help during that person's own childhood.

ONE PRIMATE STRATEGY IS TO LINE UP EXTRA "FATHERS." IN SOME SPECIES OF MARMOSETS, FEMALES MATE WITH SEVERAL MALES, ALL OF WHICH HELP HER RAISE HER YOUNG.

Older matrilineal kin may be the most valuable helpers of all. University of Utah anthropologists Kristen Hawkes and James O'Connell and their UCLA colleague Nicholas Blurton Jones, who have demonstrated the important food-gathering role of older women among Hazda hunter-gatherers in Tanzania, delight in explaining that since human life spans may extend for a few decades after menopause, older women become available to care for—and to provide vital food for—children born to younger kin. Hawkes, O'Connell, and Blurton Jones further believe that dating from the earliest days of *Homo erectus,* the survival of weaned children during food shortages may have depended on tubers dug up by older kin.

At various times in human history, people have also relied on a range of customs, as well as on coercion, to line up allomaternal assistance—for example, by using slaves or hiring poor women as wet nurses. But all the helpers in the world are of no use if they're not motivated to protect, carry, or provision babies. For both humans and nonhumans, this motivation arises in three main ways: through the manipulation of information about kinship; through appealing signals coming from the babies themselves; and, at the heart of it all, from the endocrinological and neural processes that induce individuals to respond to infants' signals. Indeed, all primates and many other mammals eventually respond to infants in a nurturing way if exposed long enough to their signals. Trouble is, "long enough" can mean very different things in males and females, with their very different response thresholds.

For decades, animal behaviorists have been aware of the phenomenon known as priming. A mouse or rat encountering a strange pup is likely to respond by either ignoring the pup or eating it. But presented with pup after pup, rodents of either sex eventually become sensitized to the baby and start caring for it. Even a male may gather pups into a nest and lick or huddle over them. Although nurturing is not a routine part of a male's repertoire, when sufficiently primed he behaves as a mother would. Hormonal change is an obvious candidate for explaining this transformation. Consider the case of the cooperatively breeding Florida scrub-jays studied by Stephan Schoech, of the University of Memphis. Prolactin, a protein hormone that initiates the secretion of milk in female mammals, is also present in male mammals and in birds of both sexes. Schoech showed that levels of prolactin go up in a male and female jay as they build their nest and incubate eggs and that these levels reach a peak when they feed their young. Moreover, prolactin levels rise in the jays' nonbreeding helpers and are also at their highest when they assist in feeding nestlings.

As it happens, male, as well as immature and nonbreeding female, primates can respond to infants' signals, although quite different levels of exposure and stimulation are required to get them going. Twenty years ago, when elevated prolactin levels were first reported in common marmoset males (by Alan Dixson, for *Callithrix jacchus*), many scientists refused to believe it. Later, when the finding was confirmed, scientists assumed this effect would be found only in fathers. But based on work by Scott Nunes, Jeffrey Fite, Jeffrey French, Charles Snowdon, Lucille Roberts, and many others—work that deals with a variety of species of marmosets and tamarins—we now know that all sorts of hormonal changes are associated with increased nurturing in males. For example, in the tufted-eared marmosets studied by French and colleagues, testosterone levels in males went down as they engaged in caretaking after the birth of an infant.

CARLA V. BOE

JOE MCDONALD; ANIMALS ANIMALS

Adult mammals are adapted to recognize and respond to infant signals, sometimes even across species. Left: A male pygmy marmoset with twin daughters. Below: A house cat nurses an orphaned eastern gray squirrel.

Yoruba girls in Benin: In many human societies, older siblings play a key role as mothers' helpers.

Testosterone levels tended to be lowest in those with the most paternal experience.

The biggest surprise, however, has been that something similar goes on in males of our own species. Anne Storey and colleagues in Canada have reported that prolactin levels in men who were living with pregnant women went up toward the end of the pregnancy. But the most significant finding was a 30 percent drop in testosterone in men right after the birth. (Some endocrinologically literate wags have proposed that this drop in testosterone levels is due to sleep deprivation, but this would probably not explain the parallel testosterone drop in marmoset males housed with parturient females.) Hormonal changes during pregnancy and lactation are, of course, indisputably more pronounced in mothers than in the men consorting with them, and no one is suggesting that male consorts are equivalent to mothers. But both sexes are surprisingly susceptible to infant signals—explaining why fathers, adoptive parents, wet

GENETIC RELATEDNESS ALONE IS A SURPRISINGLY UNRELIABLE PREDICTOR OF LOVE. WHAT MATTERS ARE CUES FROM INFANTS AND HOW WE PROCESS THESE CUES EMOTIONALLY.

VICTOR ENGLEBERT

nurses, and day-care workers can become deeply involved with the infants they care for.

Genetic relatedness alone, in fact, is a surprisingly unreliable predictor of love. What matters are cues from infants and how these cues are processed emotionally. The capacity for becoming emotionally hooked—or primed—also explains how a fully engaged father who is in frequent contact with his infant can become more committed to the infant's well-being than a detached mother will.

But we can't forget the real protagonist of this story: the baby. From birth, newborns are powerfully motivated to stay close, to root—even to creep—in quest of nipples, which they instinctively suck on. These are the first innate behaviors that any of us engage in. But maintaining contact is harder for little humans to do than it is for other primates. One problem is that human mothers are not very hairy, so a human mother not only has to position the baby on her breast but also has to keep him there. She must be motivated to pick up her baby even *before* her milk comes in, bringing with it a host of hormonal transformations.

Within minutes of birth, human babies can cry and vocalize just as other primates do, but human newborns can also read facial expressions and make a few of their own. Even with blurry vision, they engage in eye-to-eye contact with the people around them. Newborn babies, when alert, can see about eighteen inches away. When people put their faces within range, babies may reward this attention by looking back or even imitating facial expressions. Orang and chimp babies, too, are strongly attached to and interested in their mothers' faces. But unlike humans, other ape mothers and infants do not get absorbed in gazing deeply into each other's eyes.

To the extent that psychiatrists and pediatricians have thought about this difference between us and the other apes, they tend to attribute it to human mental agility and our ability to use language. Interactions between mother and baby, including vocal play and babbling, have been interpreted as protoconversations: revving up the baby to learn to talk. Yet even babies who lack face-to-face stimulation—babies born blind, say—learn to talk. Furthermore, humans are not the only primates to engage in the continuous rhythmic streams of vocalization known as babbling. Interestingly, marmoset and tamarin babies also babble. It may be that the infants of cooperative breeders are specially equipped to communicate with caretakers. This is

A !Kung-San mother with her children: Among traditional foragers, having extra helpers may be what enables human mothers to supply enough of the millions of calories required to bring each child from infancy to independence.

MELVIN KONNER; ANTHRO PHOTOS

Mother and child in a day care center: A major study showed no ill effects from day care if the care was of high quality and infants had a secure relationship with parents to begin with.

not to say that babbling is not an important part of learning to talk, only to question which came first—babbling so as to develop into a talker, or a predisposition to evolve into a talker because among cooperative breeders, babies that babble are better tended and more likely to survive.

If humans evolved as cooperative breeders, the degree of a human mother's commitment to her infant should be linked to how much social support she herself can expect. Mothers in cooperatively breeding primate species can afford to bear and rear such costly offspring as they do only if they have help on hand. Maternal abandonment and abuse are very rarely observed among primates in the wild. In fact, the only primate species in which mothers are anywhere near as likely to abandon infants at birth as mothers in our own species are the other cooperative breeders. A study of cotton-top tamarins at the New England Regional Primate Research Center showed a 12 percent chance of abandonment if mothers had older siblings on hand to help them rear twins, but a 57 percent chance when no help was available. Overburdened mothers abandoned infants within seventy-two hours of birth.

This new way of thinking about our species' history, with its implications for children, has made me concerned about the future. So far, most Western researchers studying infant development have presumed that living in a nuclear family with a fixed division of labor (mom nurturing, dad providing) is the normal human adaptation. Most contemporary research on children's psychosocial development is derived from John Bowlby's theories of attachment and has focused on such variables as how available and responsive the mother is, whether the father is present or absent, and whether the child is in the mother's care or in day care. Sure enough, studies done with this model in mind always show that children with less responsive mothers are at greater risk.

It is the baby, first and foremost, who senses how available and how committed its mother is. But I know of no studies that take into account the possibility that humans evolved as cooperative

IN COOPERATIVE BREEDERS, THE DEGREE OF A MOTHER'S COMMITMENT TO HER INFANT SHOULD CORRELATE WITH HOW MUCH SOCIAL SUPPORT SHE HERSELF CAN EXPECT.

breeders and that a mother's responsiveness also happens to be a good indicator of her social supports. In terms of developmental outcomes, the most relevant factor might not be how securely or insecurely attached to the mother the baby is—the variable that developmental psychologists are trained to measure—but rather how secure the baby is in relation to *all* the people caring for him or her. Measuring attachment this way might help explain why even children whose relations with their mother suggest they are at extreme risk manage to do fine because of the interventions of a committed father, an older sibling, or a there-when-you-need-her grandmother.

The most comprehensive study ever done on how nonmaternal care affects kids is compatible with both the hypothesis that humans evolved as cooperative breeders and the conventional hypothesis that human babies are adapted to be reared exclusively by mothers. Undertaken by the National Institute of Child Health and Human Development (NICHD) in 1991, the seven-year study included 1,364 children and their families (from diverse ethnic and economic backgrounds) and was conducted in ten different U.S. locations. This extraordinarily ambitious study was launched because statistics showed that 62 percent of U.S. mothers with children under age six were working outside the home and that the majority of them (willingly or unwillingly) were back at work within three to five months of giving birth. Because this was an entirely new social phenomenon, no one really knew what the NICHD's research would reveal.

SUSAN MEISELAS: MAGNUM PHOTOS, INC.

Because of our long life spans, we humans may be uniquely able to supplement the child-rearing efforts of younger kin.

The study's main finding was that both maternal and hired caretakers' sensitivity to infant needs was a better predictor of a child's subsequent development and behavior (such traits as social "compliance," respect for others, and self-control were measured) than was actual time spent apart from the mother. In other words, the critical variable was not the continuous presence of the mother herself but rather how secure infants felt when cared for by someone else. People who had been convinced that babies need full-time care from mothers to develop normally were stunned by these results, while advocates of day care felt vindicated. But do these and other, similar findings mean that day care is not something we need to worry about anymore?

Not at all. We should keep worrying. The NICHD study showed only that day care was better than mother care if the mother was neglectful or abusive. But excluding such worst-case scenarios, the study showed no detectable ill effects from day care *only* when infants had a secure relationship with parents to begin with (which I take to mean that babies felt wanted) and *only* when the day care was of high quality. And in this study's context, "high quality" meant that the facility had a high ratio of caretakers to babies, that it had the same caretakers all the time, and that the caretakers were sensitive to infants' needs—in other words, that the day care staff acted like committed kin.

Bluntly put, this kind of day care is almost impossible to find. Where it exists at all, it's expensive. Waiting lists are long, even for cheap or inadequate care. The average rate of staff turnover in day care centers is 30 percent per year, primarily because these workers are paid barely the minimum wage (usually less, in fact, than parking-lot attendants). Furthermore, day care tends to be age-graded, so even at centers where staff members stay put, kids move annually to new teachers. This kind of day care is unlikely to foster trusting relationships.

CHIEN-CHI CHANG; MAGNUM PHOTOS, INC.

Children at a garment-industry day care center in New York City: For a developing child, the most practical way to behave might vary drastically, depending upon the commitment and sensitivity of its earliest caretakers.

What conclusion can we draw from all this? Instead of arguing over "mother care" versus "other care," we need to make day care better. And this is where I think today's evolution-minded researchers have something to say. Impressed by just how variable child-rearing conditions can be in human societies, several anthropologists and psychologists (including Michael Lamb, Patricia Draper, Henry Harpending, and James Chisholm) have suggested that babies are up to more than just maintaining the relationship with their mothers. These researchers propose that babies actually monitor mothers to gain information about the world they have been born into. Babies ask, in effect, Is this world filled with people who are going to provide for me and help me survive? Can I count on them to care about me? If the answer to those questions is yes, they begin to sense that developing a conscience and a capacity for compassion would be a great idea. If the answer is no, they may then be asking, Can I not afford to count on others? Would I be better off just grabbing what I need, however I can? In this case, empathy, or thinking about others' needs, would be more of a hindrance than a help.

For a developing baby and child, the most practical way to behave might vary drastically, depending on whether the mother has kin who help, whether the father is around, whether foster parents are well-meaning or exploitative. These factors, however unconsciously perceived by the child, affect important developmental decisions. Being extremely self-centered or selfish, being oblivious to others or lacking in conscience—traits that psychologists and child-development theorists may view as pathological—are probably quite adaptive traits for an individual who is short on support from other group members.

DANNY LYON; MAGNUM PHOTOS, INC.

If I am right that humans evolved as cooperative breeders, Pleistocene babies whose mothers lacked social support and were less than fully committed to infant care would have been unlikely to survive. But once people started to settle down—10,000 or 20,000 or perhaps 30,000 years ago—the picture changed. Ironically, survival chances for neglected children increased. As people lingered longer in one place, eliminated predators, built walled houses, stored food—not to mention inventing things such as rubber nipples and pasteurized milk—infant survival became decoupled from continuous contact with a caregiver.

Since the end of the Pleistocene, whether in preindustrial or industrialized environments, some children have been surviving levels of social neglect that previously would have meant certain death. Some children get very little attention,

IN EFFECT, BABIES ASK: IS THIS WORLD FILLED WITH PEOPLE WHO ARE GOING TO PROVIDE FOR ME AND HELP ME SURVIVE? CAN I COUNT ON THEM TO CARE ABOUT ME?

A boy and his younger sister

even in the most benign of contemporary homes. In the industrialized world, children routinely survive caretaking practices that an Efe or a !Kung mother would find appallingly negligent. In traditional societies, no decent mother leaves her baby alone at any time, and traditional mothers are shocked to learn that Western mothers leave infants unattended in a crib all night.

Without passing judgment, one may point out that only in the recent history of humankind could infants deprived of supportive human contact survive to reproduce themselves. Certainly there are a lot of humanitarian reasons to worry about this situation: one wants each baby, each child, to be lovingly cared for. From my evolutionary perspective, though, even more is at stake.

Even if we manage to survive what most people are worrying about—global warming, emergent diseases, rogue viruses, meteorites crashing into earth—will we still be human thousands of years down the line? By that I mean human in the way we currently define ourselves. The reason our species has managed to survive and proliferate to the extent that 6 billion people currently occupy the planet has to do with how readily we can learn to cooperate when we want to. And our capacity for empathy is one of the things that made us good at doing that.

At a rudimentary level, of course, all sorts of creatures are good at reading intentions and movements and anticipating what other animals are going to do. Predators from gopher snakes to lions have to be able to anticipate where their quarry will dart. Chimps and gorillas can figure out what another individual is likely to know or not know. But compared with that of humans, this capacity to entertain the psychological perspective of other individuals is crude.

Below: Woman and grandchild in Himachal Pradesh, India. Opposite: Pregnant mother with child, United States.

The capacity for empathy is uniquely well developed in our species, so much so that many people (including me) believe that along with language and symbolic thought, it is what makes us human. We are capable of compassion, of understanding other people's "fears and motives, their longings and griefs and vanities," as novelist Edmund White puts it. We spend time and energy worrying about people we have never even met, about babies left in dumpsters, about the existence of more than 12 million AIDS orphans in Africa.

SEAN SPRAGUE; PANOS PICTURES

Psychologists know that there is a heritable component to emotional capacity and that this affects the development of compassion among individuals. By fourteen months of age, identical twins (who share all genes) are more alike in how they react to an experimenter who pretends to painfully pinch her finger on a clipboard than are fraternal twins (who share only half their genes). But empathy also has a learned component, which has more to do with analytical skills. During the first years of life, within the context of early relationships with mothers and other committed caretakers, each individual learns to look at the world from someone else's perspective.

And this is why I get so worried. Just because humans have evolved to be smart enough to chronicle our species' histories, to speculate about its origins, and to figure out that we have about 30,000 genes in our genome is no reason to assume that evolution has come to a standstill. As gene frequencies change, natural selection acts on the outcome, the expression of those genes. No one doubts, for instance, that fish benefit from being able to see. Yet species reared in total darkness—as are the small, cave-dwelling characin of Mexico—fail to develop their visual capacity. Through evolutionary time, traits that are unexpressed are eventually lost. If populations of these fish are isolated in caves long enough, youngsters descended from those original populations will no longer be able to develop eyesight at all, even if reared in sunlight.

DURING EARLY CHILDHOOD, THROUGH RELATIONSHIPS WITH MOTHERS AND OTHER CARETAKERS, INDIVIDUALS LEARN TO LOOK AT THE WORLD FROM SOMEONE ELSE'S PERSPECTIVE.

If human compassion develops only under particular rearing conditions, and if an increasing proportion of the species survives to breeding age without developing compassion, it won't make any difference how useful this trait was among our ancestors. It will become like sight in cave-dwelling fish.

No doubt our descendants thousands of years from now (should our species survive) will still be bipedal, symbol-generating apes. Most likely they will be adept at using sophisticated technologies. But will they still be human in the way we, shaped by a long heritage of cooperative breeding, currently define ourselves? □

This article was adapted from "Cooperation, Empathy, and the Needs of Human Infants," a Tanner Lecture delivered at the University of Utah. It is used with the permission of the Tanner Lectures on Human Values, a Corporation, University of Utah, Salt Lake City.

New Zealand Sweet Stakes

Sugar was a shared resource in a forest community until a greedy newcomer moved in.

By Laura Sessions

Biologist E. O. Wilson has called invertebrates "little things that run the world," because of their numbers, variety, and influence on larger organisms and even entire ecosystems. New Zealand is home to "little things" that, while each only a few millimeters long, have benignly modified about 250 million acres of the country's beech forests. Known as sooty beech scale insects, these agents turn the resources of the beech trees into a substance crucial to their own survival and to that of other forest dwellers, from fungi to birds. The association of the insects and the trees is an ancient one, and the expansive food web in which they are actors was, until recently, intact.

Sooty beech scale insects (*Ultracoelostoma assimile* and *U. brittini*) are sap suckers, or homopterans, that grow in the furrowed bark of four species of southern beech trees *(Nothofagus)* in New Zealand. During its complex life cycle, the beech scale insect goes through several developmental stages called instars. The females pass through four stages, the males five. Second- and third-instar females insert their long mouthparts into the cells of a beech's phloem—the tissues that carry nutrients through the tree—and suck up sugars. After satisfying their appetites, they excrete the excess sap and wastes through a waxy anal tube. A sweet liquid, called honeydew, accumulates one drop at a time at the tip of this tube, which looks like a thin white thread.

Homopterans are common and widespread. Most of the world's 33,000 species produce honeydew, but few can match the beech scale's enormous and constant output of the substance. In the Northern Hemisphere, honeydew producers such as aphids are active only seasonally, but beech scale insects draw off and convert energy from beech trees year-round, and they do so copiously during the

B. W. THOMAS; LANDCARE RESEARCH

A tiny sap-sucking invertebrate, the sooty beech scale insect (in early developmental stage, right) has a big impact on millions of acres of New Zealand's beech trees, opposite.

austral summer. From January to April, the tree trunks in a southern beech forest often shimmer with a thick coat of honeydew, and the droplets' heady, sweet smell fills the air.

In some forests, ten and a half square feet of tree

GRANT STIRLING; HEDGEHOG HOUSE, NEW ZEALAND

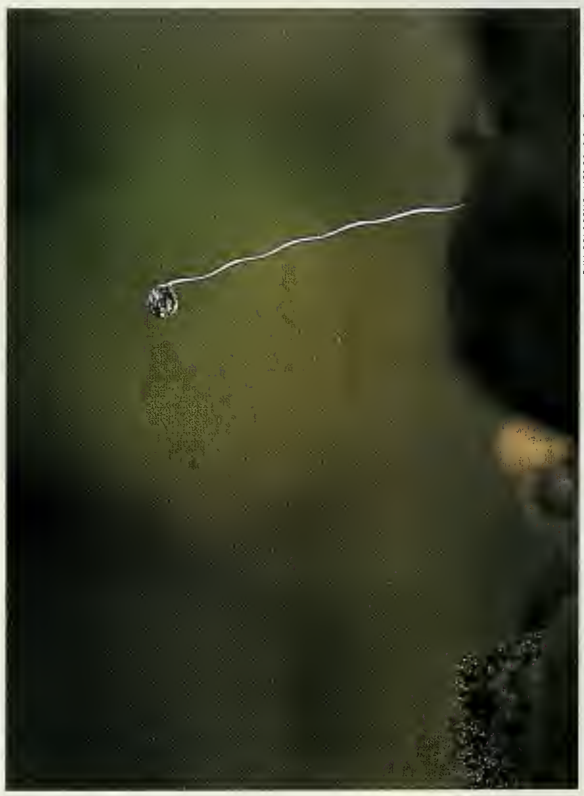
Right: A drop of honeydew—a sugary liquid excreted through a threadlike tube by a scale insect—is poised to fall. Drops are avidly eaten by forest dwellers such as the introduced honeybee, above, and the kaka, a native parrot, opposite page.

trunk (think of the top of an average card table) may support as many as 2,000 scale insects. More than 40 percent of the food the trees have produced through photosynthesis may be lost to sooty beech scale insects. These beeches do not appear to be harmed, although for most plants, losses of much less than 40 percent of their energy reserves would be insupportable. Currently, scientists can only guess how the trees are able to withstand such a drain, but various theories are being explored. Possibly only the more vigorous and faster-growing beech trees are tapped by beech scale insects. Fallen drops may recycle sugars to the soil and thence to trees, or the insects may promote extra photosynthesis in host trees.

Researchers have a better understanding of honeydew's huge importance to other organisms that live in southern beech forests. Because these forests are less diverse than many other forest types and because few of the resident plants provide fleshy fruits or abundant nectar, many native birds, lizards, insects, and other invertebrates rely on honeydew for a high-energy food, sipping drops directly from the threadlike tubes. (The beech scale itself benefits from honeydew feeders; removal of the sticky honeydew stimulates the flow of sap through the insect's digestive system, preventing "constipation.")

In the Northern Hemisphere, more than 250 invertebrate species—ants in particular—have been recorded feeding on honeydew. In European forests, for example, ants consume about two-thirds of the honeydew produced by aphids and other sap-sucking insects. New Zealand has only a few native ant species; here it is birds, rather than invertebrates, that avidly feed on the honeydew. While some New Zealand caterpillars and beetles do rely on honeydew for food, invertebrates more often benefit indirectly from a fungus that grows on the sticky drops. The fungus provides invertebrates with food and with lodging in its spongy interior and fissured surface. Aptly named the sooty mold fungus, this organism coats any surface where honeydew lands after falling from the insects' anal tubes—tree trunks, roots, shrubs, saplings, and even the forest floor. It may cover beech trees so thoroughly that their pale gray bark turns as black as charcoal, with new honeydew drops shining on top.

Often solitary during the day as they forage for insect larvae, kaka tend to gather at dusk at honeydew-rich sites, and the forest then rings with squawks and whistles as they socialize.



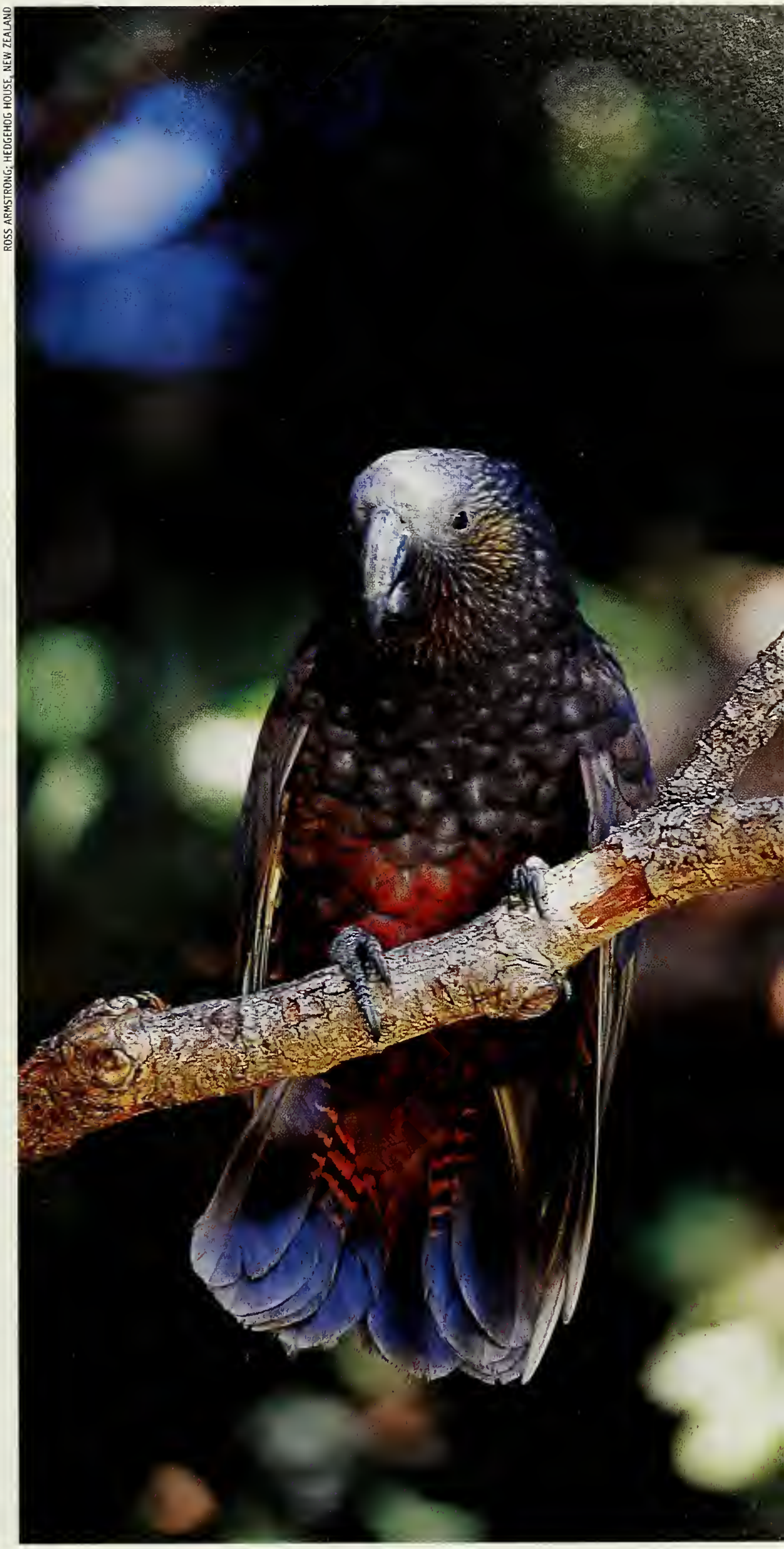
RAY GOLDRING; HEDGEHOG HOUSE, NEW ZEALAND

Caterpillars, beetle larvae, and other invertebrates find a home in sooty mold and become a source of protein for foraging birds, but the honeydew provides the birds with essential energy. Bellbirds and tuis—forest birds in the nectar-feeding family called honeyeaters—have brushlike tongues that enable them to lap up honeydew drops easily. They hop up the beech trunks, licking as they go and occasionally pausing to clean the sticky sugars from their feathers. Most frequently they feed on the branches in the canopy, possibly because more honeydew is found in the higher limbs of the tree than near ground level. Honeyeaters spend more time in forests with honeydew than in forests without it. The birds will flock to beech forests during the winter, when fruit and nectar are scarce; tuis may spend more than 80 percent of their feeding time harvesting honeydew when it is plentiful. Without the scale insect and its sugary excretions, these birds would be much less common in beech forests, to the detriment of some resident plants. Honeyeaters are the primary pollinators for native mistletoes and certain other nectar-producing plants. If these birds decline, the plants will no longer be able to produce new seeds. (See "A Floral Twist of Fate," September 2000.)

Also reliant on honeydew are the threatened New Zealand parrots known as kaka. These large forest birds nest in holes in old trees and spend about a third of their feeding time collecting honeydew when it is abundant. Kaka can obtain enough energy for a whole day in just three hours of honeydew foraging. This fuel then allows the birds to exert themselves digging out beetle larvae, a vital source of protein, from under beech tree bark. Larvae of kanuka longhorn beetles are harvested only by the males, while females collect other kinds, usually from rotting trees. Often solitary during the day, kaka can become quite social when they forage on honeydew. They often gather at dusk at honeydew-rich sites, and the forest then rings with squawks and whistles as they interact. Now surviving only in remnant populations, kaka also congregate at the beginning of the breeding season, but today these gatherings may be only a weak reflection of their sociability a century ago, when flocks of more than a hundred could be seen.

In the late 1970s a new "little thing" entered the southern beech forest—an interloper that threatens to ruin the intricate honeydew food web. Accidentally introduced into New Zealand, common wasps *(Vespula vulgaris)* found the conditions perfect. With

ROSS ARMSTRONG; HEDGEHOG HOUSE, NEW ZEALAND



the warm climate, abundant honeydew, and lack of natural enemies, the wasps flourished and their numbers exploded. Before their arrival, other exotic social insects, such as honeybees, bumblebees, and German wasps (*Vespula germanica,* which entered via aircraft parts at the end of World War II), had diminished honeydew supplies to a degree, but common wasps have proved to be ruthlessly efficient. On average, thirty of their hives, most on the ground, can be found per acre. And whereas insects such as feral honeybees reach densities of 22 insects per ten and a half square feet of tree trunk (bear in mind the card table with 2,000 honeydew insects), more than 300 common wasps can occupy the same space. The yellow-and-black, bee-sized common wasps are also found in other types of forests but are most concentrated in honeydew beech forest, where, thanks to their voracity, they have largely displaced German wasps. In these forests, the biomass of common wasps exceeds that of many other creatures added together; if one were to collect all the common wasps and put them on a scale, they would outweigh all the resident birds, rodents, and stoats combined.

Experiments using devices that prevented wasps from landing on beech trees have shown that the large numbers of common wasps in beech forests are responsible for a reduction of up to 70 percent of annual, and fully 99 percent of austral summer, honeydew production. By removing such vast quantities of honeydew, wasps may alter nutrient cycles and perhaps decrease the soil quality for beech trees. Furthermore, because common wasps constantly revisit

TONY BRUNT; HEDGEHOG HOUSE, NEW ZEALAND

Stoats are among the rogues' gallery of introduced creatures wreaking havoc on native wildlife. The juveniles below are in a clump of speargrass on the South Island.

the same areas of beech trunk, they do not allow the honeydew drops time to fully re-form and thus reduce the drops' size and sugar content. To fulfill their energy requirements, birds must eat many more of these smaller, less sweet drops and spend more time in search of them. If the drops become too small and scarce, birds may abandon honeydew altogether and try to search out whatever fruit, nectar, and other sugar sources may be available.

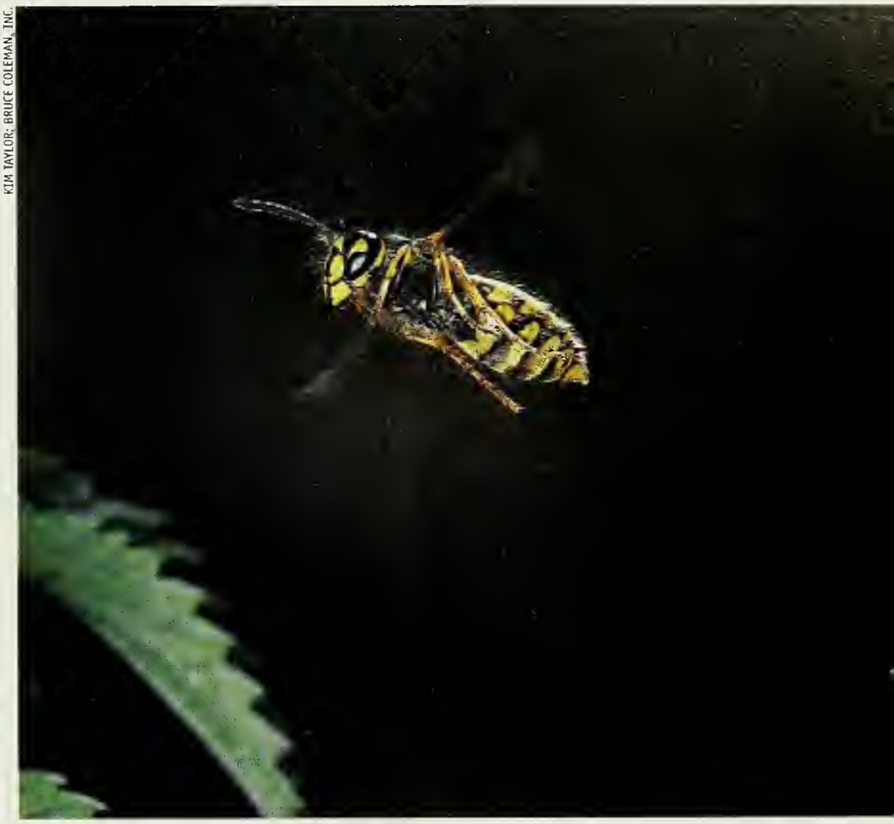
A scientist at Landcare Research in Nelson, New Zealand, Jacqueline Beggs has spent the past decade studying the effects of wasps in honeydew forests. She believes that the wasp-induced shortage of honeydew could contribute to a decline of native birds over the long term. Beggs has shown that when wasps reduce the number and size of drops below a certain level—a threshold reached when the insects revisit drops every six and a half hours—kaka give up even trying to feed on honeydew. Similarly, Henrik Moller, now at the University of Otago in Dunedin, New Zealand, and other colleagues at Landcare Research have shown that honeyeaters are even more sensitive. If wasps visit drops

If one were to collect all the introduced common wasps and put them on a scale, they would outweigh all of a honeydew beech forest's resident birds, rodents, and stoats combined.

at a rate of once every three hours, honeydew will be depleted to the point that bellbirds and tuis will switch to other food sources or be forced to conserve energy by spending less time on vital activities such as mating and nesting. Furthermore, when the bellbirds, tuis, kaka, and native insectivorous birds attempt to feed on native invertebrates, they again face competition from wasps, which devour spiders, caterpillars, ants, bees, and flies. Populations of these invertebrates have been decimated or even eradicated in areas where wasps are common.

Unfortunately, scientists do not know precisely how wasps may affect native species in the long run, partly because no one fully understands the organisms involved, especially the invertebrates, and partly because their interactions are so varied and complex. Land mammals are also a major problem. New Zealand has no native terrestrial mammals, but a raft of mammals has been introduced in the

KIM TAYLOR; BRUCE COLEMAN, INC.



HENRIK MOLLER; LANDCARE RESEARCH

The common wasp, above, first appeared in New Zealand in the late 1970s. Its numbers have since exploded. Left: A beech tree infested with honeydew-hungry wasps.

DON HADDEN; HEDGEHOG HOUSE, NEW ZEALAND

MARK A. CHAPPELL; ANIMALS ANIMALS

With nectar in short supply in the southern beech forest, two native species of honeyeaters (the bellbird, right, and tui, below) get their energy from honeydew.

last 100 to 150 years. Cats, rats, stoats, possums, and ferrets have had drastic effects on native plants and bird species, many of which are flightless and have few defenses against the invaders. It is therefore difficult to separate the "bottom-up" effects of little things like beech scale insects and wasps from the "top-down" effects of larger predators.

Wasps and mammals may interact to cause more serious harm than either group would alone. Possums, for example, eat many of the same things (such as mistletoe) that honeyeaters do, so the birds often cannot switch to other food types when wasps deplete the honeydew stores. Other effects of immigrant species have proved difficult to tease apart. During a long-term research project on the South Island of New Zealand, Beggs and Peter Wilson, also of Landcare Research, noted that kaka changed how they foraged and fed in response to competition with wasps for honeydew. However, the scientists could not test the overall effect of food shortage on the kaka's ability to raise young, because stoats had raided most of the nests, killing more than 70 percent of the kaka chicks and, even more dire, four of the seven nesting females. Female kaka incubate their clutches of one to five eggs for about twenty-four days; fledging takes a further seventy days. During these three months, both mother and chicks are at high risk of a stoat attack. Moreover, the death of females on their nests leads to a serious imbalance in the population; many breeding-aged males are unable to find a mate. Beggs and Wilson estimated that the kaka population they studied for ten years suffered 7 percent mortality, a rate that could cause this South Island population to become extinct in less than thirty years.

Scientists estimate that if wasps visit honeydew drops at a rate of once every three hours, the honeydew will be so depleted that bellbirds and tuis will have to switch to other sources of energy.

For native residents of southern beech forests to recover, New Zealanders have to play an active role. No pest-control measures currently available can turn the situation around, but various tools are being developed, such as the poisoning of wasp nests and the use of biological controls. This year, one operation succeeded in eradicating 90 percent of the wasp nests within a 740-acre area, enough to restore the honeydew to natural levels and to protect other invertebrates from wasp predation. If, at last, this little invader and its mammalian counterparts are restrained, the reward will be southern beech forests once again alive with the songs of honeydew-collecting birds rather than the drone of invading wasps. □

The Rewards of Chance

By Mark Denny

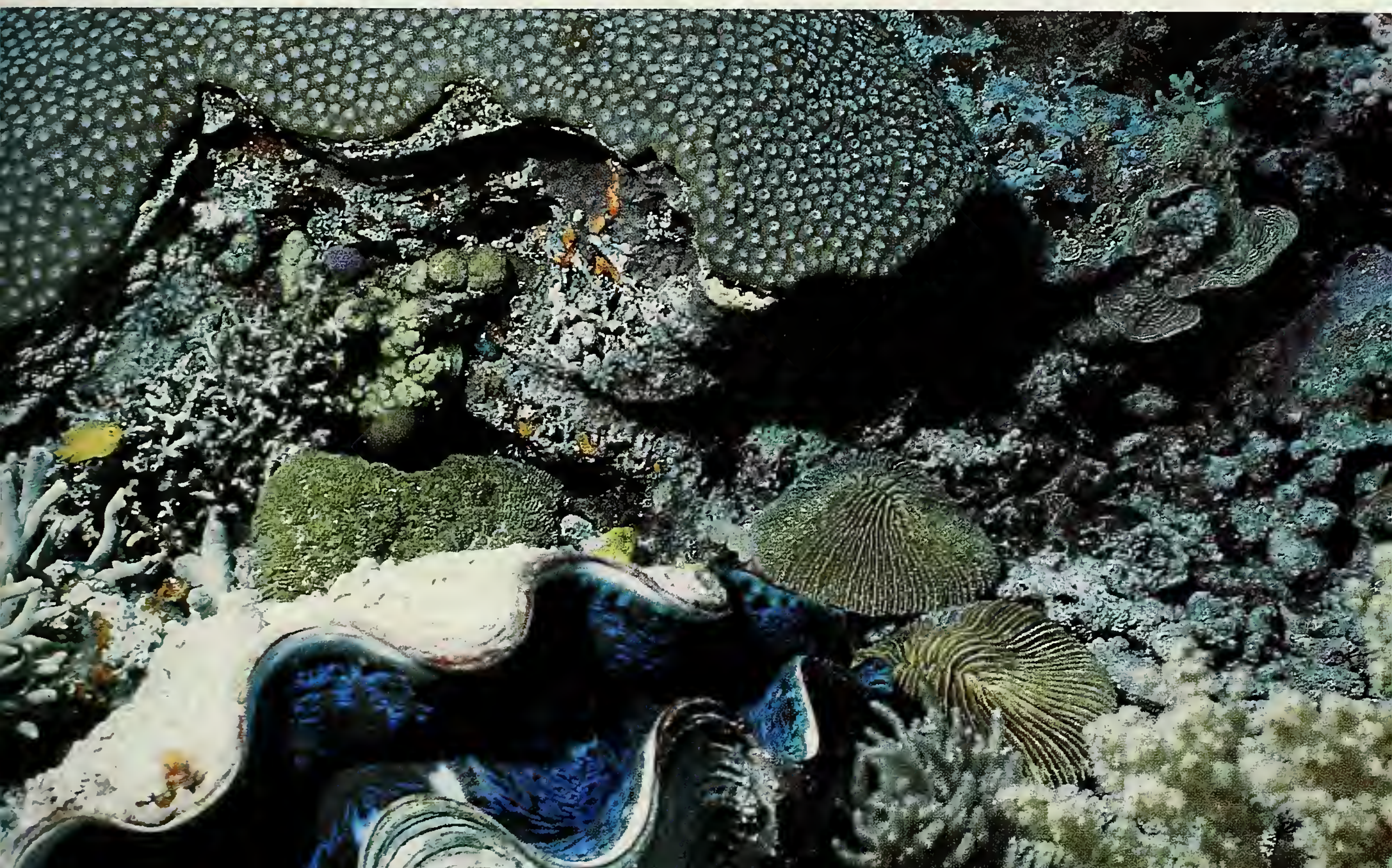
Sometimes the most profound messages in biology reside in the most pedestrian creatures. Consider the lowly clam. Slow afoot and very tasty, clams are attractive to a wide variety of predators. When threatened, a clam uses its strong adductor muscles to clamp its armorlike shells together, leaving no living material exposed and presenting a daunting task for any predator trying to gain entry. A serious difficulty arises, however, when the animal needs to open its shell again to breathe or feed. The muscles that caused the shell to "clam up" can't help, since they're effective at pulling but useless when it comes to pushing the shell open. To open up, the clam instead employs a peculiar material incorporated into the shell's hinge. As the shell closes, this material (a protein rubber called abductin) deforms—either stretching or compressing, depending on the species of clam. In the process, it stores mechanical energy, much as a garage-door spring stores energy. Later, when this energy is released, it provides the force needed to reopen the shell.

Rubbery materials are found in many animals besides clams. The wing supports of beetles, the neck ligaments of buffaloes, and the knees of fleas all contain structural elements made from materials akin to the man-made rubber in automobile tires and rubber bands. The walls of mammalian arteries provide a pertinent example. A mammalian heart is a pulsatile pump: during contractions, it squirts blood into the arteries, but it must then wait to refill before delivering the next pulse of fluid. Pumping in this intermittent fashion requires much more power than would be needed to move the same amount of blood in a steady stream. Fortunately, as the heart contracts, some of its power is used to stretch a protein rubber called elastin, found in the walls of the large arteries, thereby storing mechanical energy. As the heart refills, these arteries relax, releasing the energy. In essence, the arteries act as a

J. W. MOWBRAY; PHOTO RESEARCHERS, INC.

GIANT CLAM
A rubber protein in the hinges of its shell enables a clam to open up; muscles help it shut tight again.

Thanks to the random movements of agitated molecules, biological rubber allows clams to open wide and insects to fly efficiently.



secondary pump, smoothing out the uneven flow of blood and allowing our hearts to beat more efficiently. The circulatory systems of other vertebrates, as well as those of squids and octopuses, employ similar rubbery materials.

What gives rubbers this special ability to store mechanical energy? Surprisingly, perhaps, the answer is randomness. Biologists often bemoan chance events in nature, lamenting that if the world were just a bit more orderly, they would have an easier time understanding how life works. In fact, however, randomness can tell us a great deal about how plants and animals function.

Physicists long ago recognized the value of randomness. At room temperature, molecules of gas

The stiffness and extensibility of rubber tissue in animals comes from random movements of proteins.

STEPHEN DALTON; NHPA

HARLEQUIN BEETLE
In many flying insects, rubbery materials provide the elasticity that helps the wing flap and fold.

move at high speeds (a thousand feet or so per second), changing the direction of their flight frequently and at random as they bounce off one another. The random motion of gas molecules (the vigor of this motion being, as physicists would tell us, proportional to the temperature of the gas) is known as thermal agitation. This wild game of molecular billiards makes it impossible to predict exactly where any individual molecule will be at a given time or exactly what speed it will have, but physicists can use thermal agitation to make precise predictions about the behavior of the gas as a whole.

For example, we speak of a gas in a container as being under pressure. The pressure comes from the impact of individual gas molecules on the container's walls. Because the motion of molecules is randomized by collisions, we can predict that the pressure is the same in all directions. Similar considerations allow us to predict how gases diffuse. Again, it is impossible to know exactly where any individual gas molecule will roam, but as long as all motion is random, we can accurately predict how the average location of molecules shifts through time.

By the same token, the random behavior of rubbery proteins allows us to predict how much mechanical energy they can store. In mathematical terms, the amount of energy that a bit of material can store is proportional to the material's stiffness multiplied by its extensibility. Bone, for example, is very stiff (a lot of force is required to deform it) but not very extensible (it can deform only 2 to 3 percent before breaking). As a result, bone is relatively poor at storing energy. At the other end of the spectrum, mucus (such as that underlying the foot of a snail) is very extensible (it can easily stretch by 500 percent) but not at all stiff. So it, too, is poor at storing energy. The biological rubbers in animals, however, epitomize the happy medium. They are both reasonably stiff and highly extensible and, weight for weight, can store nearly a hundred times as much energy as high-tensile-strength steel.

Their secret? A complex, three-dimensional network of protein chains. In many respects, a protein chain (and what works for one chain holds for the material as a whole) is analogous to the kind of bead-link chain that one finds attached to old-fashioned bathtub stoppers. The overall length of such a chain is set by the number of beads, and although the beads cannot be stretched apart, they can rotate relative to their neighbors. As a result, the chain is flexible. Similarly, each amino acid in a protein chain is a "bead" that can rotate around the peptide bonds that link the amino acids into the chain. Like the bead-link chain, the protein chain combines flexibility and a fixed length (in this case, a fixed number of amino acids).

Imagine holding the ends of a bead-link chain, one in each hand, and pulling the chain taut. With the chain fully extended, each link is in line with its neighbors, and the chain as a whole has a very orderly arrangement. There is, in fact, one and only one arrangement of links that allows the chain to be stretched to its full length. Now, allow your hands to move together a bit. With its ends closer together, the chain is free to take on new configurations, and if you shake it at random, it will rattle around among these configurations. The closer together your hands are, the more arrangements the chain can adopt and the more freedom it has to rattle around. The concept works the other way as well: if we somehow knew how many arrangements the chain could take, we could infer how close together its ends must be.

If you were to extend a protein chain to its full length, all the amino acid "beads" would be in a straight line, and the chain would be entirely ordered. In reality, however, this kind of order is unlikely. At the temperatures at which life occurs on earth, thermal agitation, including the agitation of amino-acid molecules, is constantly occurring. Consequently, as individual amino acids in a protein chain move about randomly, the chain becomes disordered. And just as with the bead-link chain, the more disordered the molecular chain becomes, the closer together (on average) its ends are.

Put another way, a rubbery protein chain tends to assume a disordered shape. Because the motion of the chain is random, we can never say for sure what this shape will be at any moment. But precisely because the motion is random, we can use statistics to describe the probability that the chain is in a particular configuration. Knowing these probabilities, we can then calculate the average shape of the molecule. In mathematical terms, that is because the average end-to-end distance of a fully disordered chain turns out to be proportional to the square root of the number of its links. For example, if a hypothetical rubber has 100 amino-acid links, then in its natural, disordered state the ends of the chain will be only about 10 amino-acid lengths apart.

What does all this have to do with the ability of clams to open wide, beetles to fly, and fleas to jump? Everything, as it turns out. In the hypothetical example cited above, a 100-link amino-acid chain can be extended tenfold before it is pulled taut. For similar reasons, most actual rubbers have no trouble extending three to four times their resting length. The stiffness of biological rubbers comes from the natural tendency of rubber protein chains to coil, requiring force to extend them. This stiffness, coupled with the chains' great extensibil-

AMERICAN BISON Made in part of rubber protein, a huge ligament in the neck of a bison (or a cow, horse, or wildebeest) provides most of the force necessary to hold up the animal's massive head.

PAUL AND LINDAMARIE AMBROSE; FPG

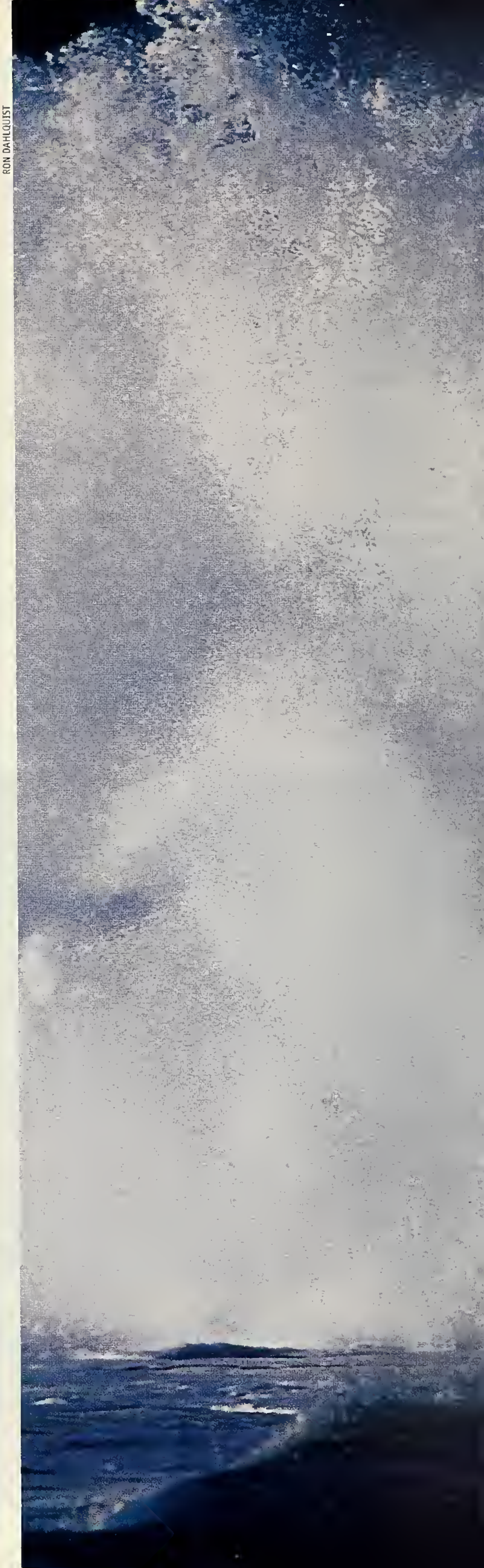
ity, accounts for the special ability of rubbery proteins to store mechanical energy.

Demonstrating that random molecular motion plays a necessary role in the mechanical properties of rubbers is easy. If a bit of rubber is cooled, the motion of its molecules is reduced and the material begins to lose its elasticity. For example, a rubber band that is resilient at room temperature becomes leathery and relatively inextensible when cooled in a kitchen freezer. This effect is, in large part, what doomed the space shuttle *Challenger*. *Challenger* was launched on an unusually cold day, and one of the rubber seals in its solid-fuel boosters was too stiff to function properly. Taken to an extreme, rubber cooled by liquid nitrogen behaves very much like glass: it is brittle and has very little capacity to store energy. Without random motion—that is, in the absence of heat—rubber is simply not rubbery. And without rubbery materials, neither clams nor human beings would operate as effectively as they do.

Only a few proteins are rubbery, however. In most of them, at least some of the amino acids are held rigidly together—by bonds between sulfur atoms in cystine molecules and by the hydrogen bonds and hydrophobic interactions among the so-called side chains of other amino acids. In addition, these side chains are often too bulky to permit them to move relative to their neighbors. Only when a protein is constructed from the right amino acids connected in the right order does the resulting chain have the flexibility necessary for rubbery behavior.

Paradoxically, randomness enables scientists to predict much about how nature works.

As important as rubbers are for animals, they are only one example of the utility of random behavior in nature. The same type of statistics that allows us to determine the average shape of protein chains can be used to predict a wide range of phenomena—from the force of waves breaking on a beach to the reason people are not deafened by the noise at a cocktail party. In these cases, the amplitude of ocean and sound waves, rather than the flexibility of protein chains, is involved, but the principle is the same. The message of the gaping clam is clear: far from being a frustrating obstacle, chance in nature is cause for celebration. □



RON DAHLQUIST

BREAKING WAVE Chance is a powerful force in the physical, as well as the biological, world. As waves converge at sea, their crests and troughs combine randomly, determining the height and force of the waves that reach the shore.

TONY BRAIN/SPL; PHOTO RESEARCHERS, INC.

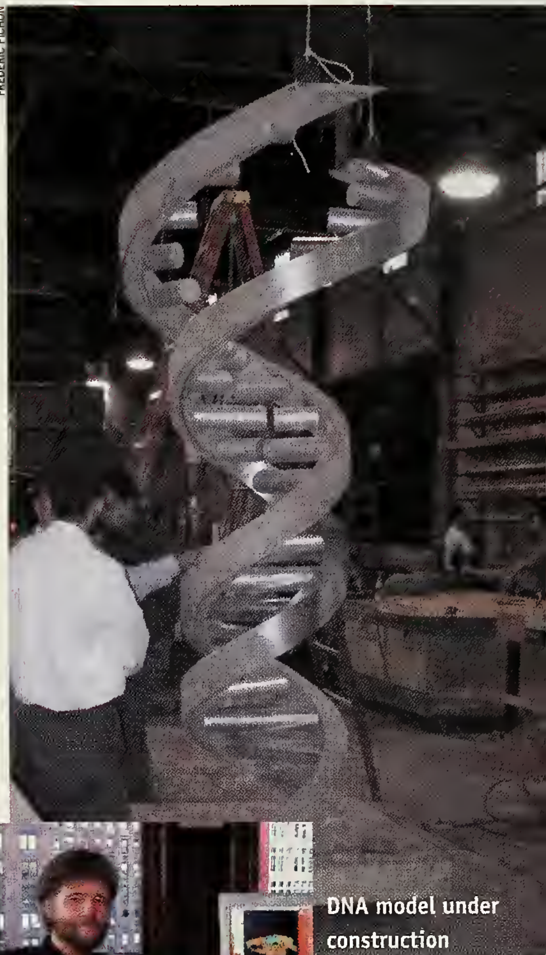
FLEA Fleas are great jumpers, some leaping 200 times the length of their own bodies. This impressive ability is due to rubbery material that is compressed when the insect cocks its "knees" (the joints between its hind legs and its body).

AT THE MUSEUM

The Genome Writ Large

A new exhibition unravels the wonder, the promise, and the potential dangers of human DNA research.

By Henry S. F. Cooper Jr.


FRÉDÉRIC PICHON
DNA model under construction


DENIS FINNIN; AMNH
Michael J. Novacek


DENIS FINNIN; AMNH
Rob DeSalle

This past February 12, Charles Darwin's birthday, two versions of the human genome were announced—one produced by a public organization, the International Human Genome Sequencing Consortium, based in Cambridge, England, and the other by a private company, Celera Genomics in Rockville, Maryland. Now, on May 26, the Museum opens the exhibition "The Genomic Revolution." Dealing largely with invisible matter, the exhibition relies on models that gleam like jewels under spotlights and on glowing images projected across computer monitors and high-definition plasma screens, while LED displays spell out news of the genome direct from the laboratory in bright, ever-flowing letters.

Just past the entrance is a small installation devoted to James D. Watson and Francis H. C. Crick's revolutionary 1953 double-helix model of the structure of the DNA molecule. And straight ahead is a brand-new, floor-to-ceiling rendering of the double helix as an organic, undulating, slightly metallic serpent of the night. It's a long way from Watson and Crick's mechanical, tinker-toy affair.

Also near the entrance, in an encased glass vial, is a sample of the real thing: a single strand of DNA replicated thousands of times and forming a white mush. A parabolic mirror inside the case makes the DNA material appear to float overhead like a hologram. Three and a quarter billion nucleotides—the structural units of DNA—on twenty-three pairs of chromosomes are contained in the nucleus of each human cell. If teased apart and laid end to end, the molecules would form an invisible thread nearly six feet long. The information in such a thread, if printed out, would fill 140 Manhattan phone books—and nearby, in three stacks, are exactly that number of them.

In a small theater close to the big DNA model is a five-minute animation loop that explains the uses of genomics in medicine, both to treat disease and to prolong human life. The hope is that in decades to come, as genes that cause various diseases are identified and as ways of removing them or splicing in new ones are perfected, many illnesses will be treated genetically or even prevented altogether. Already the genes for many diseases, from sickle-cell anemia to heart disease, have been pinpointed, though genetic means of treating them are still in their infancy.

Genomic research has raised all sorts of ethical issues, and a number of displays reflect how closely science and ethics are intertwined—not unlike the double helix itself, according to Rob DeSalle, the exhibition's curator as well as codirector of the Museum's Molecular Systematics Laboratory and a curator in the Division of Invertebrates. "Most people would agree that curing disease is a good use of genetics. But what about changing the color of eyes from brown to blue—what we call genetic enhancement? Harmless, perhaps? But then the next step after that is, 'Well, I'd like my child to be a little smarter than normal.' Or 'Gosh, I'd like her to be able to slam-dunk a basketball.' Before you know it, you're into designer babies. These are ethical questions we'll all face sooner or later."

If you carry the genes for an incurable disease, would you want that information made available to you? To insurance companies? To the government? What about cloning? And would you eat genetically modified corn? Bananas? Salmon? At three computer polling stations in the exhibition, visitors can register their opinions. They can then see how their answers tally with those of people sampled in a Harris Poll.

Genome research also focuses on the concepts of continuity and variation, another pair of intertwining themes incorporated into the displays. Seven percent of our genes are the same as those of *Escherichia coli* bacteria, and we share 90 percent with mice and more than 98 percent with chimpanzees. "This is continuity; the other side of the coin is variation," says DeSalle. "The difference between, say, you and me, is small but it exists: for every thousand base pairs of DNA we share, there's one change, meaning a 0.1 percent difference. There is more variation *within* than *between* racial groups. Humans are 99.9 percent alike—truly a single entity—and that is an important point of the exhibition."

Another point concerns the number of genes in the human genome. This number turns out to be only about one-fourth the initial projection: between 30,000 and 40,000, compared with an earlier estimate of more than 140,000. Fruit flies, by comparison, have between 13,000 and 14,000 genes, and roundworms have 19,000. "The lower number fortifies the whole notion of evolution and of our connectedness with all other organisms," says Michael J. Novacek, the Museum's provost of science.

Ten years ago, the Museum might have been less enthusiastic about mounting an exhibition on genomics, as its traditional mandate has been natural history—the study of organisms at a higher level of complexity than that of the gene. "We care for vast collections and sponsor a hundred expeditions a year, a thousand through a decade," Novacek says. "We wanted to protect all that. Some of us wondered why we should bring molecular biology to a museum, when that kind of work might readily be done at a university. But our mission is to understand the diversity and evolution of life and all the tips of its many branches, so we felt we needed that extra depth of knowledge for a very similar mission: to understand the map of life and the evolutionary process of life."

The Genomic Revolution
The exhibition opens May 26 in Gallery 3 and runs through January 1, 2002.

According to DeSalle, Novacek "led the charge" toward bringing molecular biology into the Museum, though Novacek points out that he was supported by several visionary curators, among them Niles Eldredge, who was already beginning to recruit molecular researchers for the invertebrate department. In 1990 the Museum opened its Molecular Systematics Laboratory, codirected by DeSalle and Ward C. Wheeler. A second molecular laboratory opened in 1995, headed by Joel Cracraft, of the ornithology department. This year, under the management of molecular biologist Bob Hanner, the Ambrose Monell Collection for Molecular and Microbial Research—a repository that will eventually hold 750,000 frozen samples of organic tissue and DNA from a host of species—begins operations.

Now, drawing on the breadth of its research in natural history, its laboratories, and its collections, the Museum is in a strong position to contribute to the field of molecular biology. It has, in fact, been catapulted into the forefront of a new molecular specialty called comparative genomics: the comparison of DNA throughout the animal kingdom.

One goal of comparative genomics is to identify which sequences of genes in the human genome are associated with which traits. "We take a DNA sequence from our genome and search for it in a mouse, a fruit fly, a worm, a nematode, and yeast—all of whose genomes have been either completely sequenced or nearly so. If we locate it in some of them and we identify its function, chances are that the function in the human genome is the same," DeSalle says. "The process is difficult, but it's where the really neat work is going to happen in the near future, and this is where I think the Museum comes in."

Another goal of comparative genomics is to plot evolutionary relationships. Evolution can be tracked back across the eons by comparing genomes and using as yardsticks the similarities and mutations of genes for the same traits in different species—whether the traits are a backbone, two eyes, or four legs. Using molecular biology as well as traditional morphology, Museum scientists can compare and contrast the evidence. The two approaches do not always agree. In the mammalogy department, for example, molecular research projects are causing fur to fly. Morphologists long thought that the primitive mammalian order Monotremata, which includes the platypus, branched off during the Cretaceous Period (between 140 and 70 million years ago). This would make the marsupial and placental mammals—thought to have branched off later—closely related. But molecular evidence now suggests that the marsupials and the monotremes branched off much earlier than the placentals did and that they are therefore the closer relatives.

Following the demise of the dinosaurs at the end of the Cretaceous, there occurred a great radiation—a "star burst," as Novacek calls it—of

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mammals, particularly of placentals, and molecular biology is proving a valuable and controversial tool in finding out what happened. Based on morphology, most mammalogists of the last century agreed that rabbits, for instance, are not closely related to rodents. Today molecular studies at the Museum suggest they are.

For any visitor to the exhibition who wants to know more about the nitty-gritty of DNA—and maybe even have a hands-on experience—a small laboratory near the exit permits people to learn about genetic applications in forensics or even to produce and analyze a sample of their own genes. And on the way out, you walk through a small gallery where your image is picked up on a video camera, processed digitally by computer software, and projected onto the gallery walls—except that instead of the image being formed of pixels, it's made of the letters A, C, G, and T, representing the four basic nucleotides in the DNA molecule. The idea is to produce one's image out of the elements of the genome, a graphic expression of its pervasiveness and relevance.

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

MUSEUM EVENTS

MAY 1, 8, 15, AND 22

Four lectures: "Genetics and the Brain," neuropsychiatrist Richard Mayeux, May 1; "Learning and Memory," neurobiologist Eric R. Kandel (Nobelist, 2000), May 8; "Development and Cognition," developmental psychobiologist Michael Posner, May 15; "Brain Imagery," neuropsychiatrist David Silbersweig, May 22 (Revolutionizing Medicine in the 21st Century series). 7:00 P.M., IMAX Theater.

MAY 3 AND 10

Two lectures: "Making of Precious Stones," Peter Vreeland, senior Museum instructor, May 3; "Four Wings and a Prayer: Caught in the Mystery of the Monarch Butterfly," entomologist and author Sue Halpern, May 10 (Thursday Afternoons at the Museum series). 3:00 P.M., Linder Theater.

MAY 8

Lecture: "The Eternal Frontier: An Ecological History of North America and Its Peoples." Mammalogist and paleontologist Tim Flannery, director of the South Australian Museum. 7:00 P.M., Kaufmann Theater.

MAY 10

Lecture: "Uncovering the Origins of Dinosaurs in Argentina's Ischigualasto Valley" (Earthwatch at the Museum series). Paleontologist Oscar Alcober. 7:00 P.M., Kaufmann Theater.

MAY 14

Lecture: "The Multiwavelength Universe" (Frontiers in Astrophysics series). Astronomer Alyssa Goodman. 7:30 P.M., Space Theater, Hayden Planetarium.

Bronze African termite mound by sculptor Steve Tobin, on the Museum grounds

MAY 18

Concert: "An Evening with Mary Redhouse." Navajo jazz vocalist. 7:30 P.M., Kaufmann Theater.

Young Naturalist Awards ceremony and luncheon. Noon, Astor Turret.

MAY 21

Lecture: "Time Travel in Einstein's Universe" (Distinguished Authors in Astronomy series). Astronomer J. Richard Gott. 7:30 P.M., Space Theater, Hayden Planetarium.

MAY 29

Lecture: "Wild Nights: Nature Returns to the City." Science writer Anne Matthews. 7:00 P.M., Kaufmann Theater.

DURING MAY

"Indigenous Peoples: Perspectives and Perceptions." Free weekend programs, including films, lectures, performances, and workshops. 1:00–5:00 P.M., Leonhardt People Center and the Linder and Kaufmann Theaters. For information and a complete schedule, call (212) 769-5315.

Musings: The Educators' Connection to the American Museum of Natural History (www.amnh.org/learn/musings/), a free Web newsletter for science educators, is being launched. Published three times a year by the Museum's National Center for Science Literacy, Education, and Technology.

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

Most Excellent of Fishes

In the annals of piscine diversity, cichlids break all records.

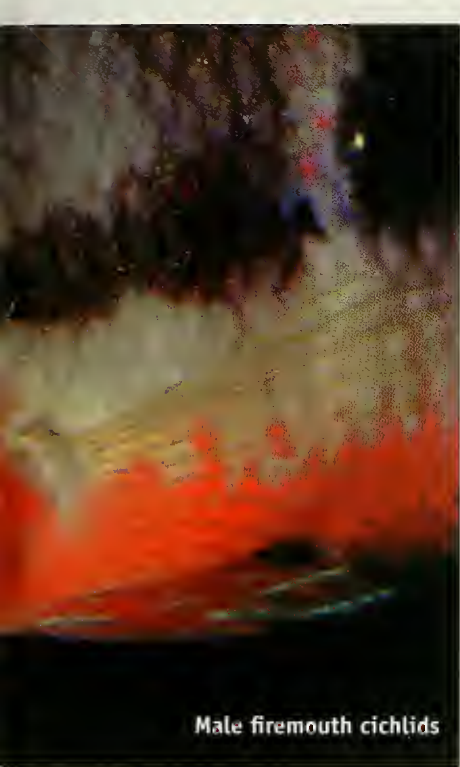
By Les Kaufman

Almost all living things, even the obscure and distinctly unromantic, have their human enthusiasts. Fleas have their Rothschild; barnacles, their Darwin; and now cichlids, their Barlow. Cichlids are large, tasty, colorful, and endearingly nasty creatures, familiar to fishermen, aquarium hobbyists, and diners worldwide. Never mind that most people seem constitutionally unable to pronounce their name ("sick-lids") in any other way than as a brand of chewing gum. Anyone who reads this book will not forget these fishes, in large part due to the narrative skills of the famously cichlid-smitten ethologist George W. Barlow, of the University of California, Berkeley.

Because of their behavior (which makes them seem far more inquisitive and intelligent than most other fishes) and their brilliant, protean garb (which makes them come across as sensitive and emotive to anybody watching them for more than a few seconds), cichlids occupy a place among fish comparable to that of parrots among birds or cephalopods among mollusks. But cichlids' biggest claim to fame is that, individually and collectively, they exhibit legendary diversity in both behavior and appearance. They are, for evolutionary biologists, the maddest of all eruptions out of Santa's workshop. Depending on who's doing the counting, cichlids may turn out to be *the most* diverse of all vertebrate families—or just about. But the differences among them can be subtle, and it takes a master to bring them to life on the printed page.

The Cichlid Fishes: Nature's Grand Experiment in Evolution, *by George W. Barlow (Perseus Publishing, 2001; $28)*

In his introduction, Barlow makes clear that cichlid hyperbole is not mere hype. Up to 1,000 species of this one family live in a single African lake, while only 2,800 species of fishes of all families live in the world's seas, 215 in the freshwater lakes and rivers of Europe, and 235 in the immensity of the Laurentian Great Lakes. The first chapter begins with the best popular account yet given of what cichlids are and how they fit into the broad scheme of fish evolution. In the next chapter, "Jaws Two," Barlow tackles with gusto the rich palate of cichlid feeding habits, which are determined by the varied shapes and deployments of their jaws and teeth. Chapter 3, "Plastic Sex," leaves behind morphological oral obsessions to examine the realms of sex deter-



AD KONINGS

Male firemouth cichlids

mination, sex ratios, sexual domination, and other trappings of sexual conquest.

The bulk of the book is devoted to Barlow's real forte—the events in a cichlid's life history that transpire between parental pairing and the young setting off with bag and pole. Monogamy, sexual subterfuge, mouth brooding, isosexuality (bet you haven't heard *that* term for homosexuality before), and secretocyte ingestion (parental skin cells nibbled off by their fry) are among the many topics that are carefully explained, illustrated, and discussed. Even more intriguing, however, is Barlow's treatment of long-standing myths about cichlid reproduction. Do the egg-shaped spots on the anal fin of some male mouth brooders really make females hot? Barlow's vivid accounts of cichlid family life in all its amazing variants—illustrated by clear, appealing line art throughout—is nonpareil.

In chapter 12, "Cichlid Factories," Barlow discusses how all these cichlid species might have come to be. His overview of speciation hypotheses and cichlid radiations is as good as anything I've seen. Barlow is clearly an adherent of the parsimonious allopatric model (differentiation into separate species because of geographic isolation); proponents of the sympatric model (speciation that is not dependent on geographic isolation) will be disappointed. An endemic species in a tiny sinkhole in South Africa, according to Barlow—and here he refers to one of my own favorites, *Tilapia guinasana*—"may be a window into the process of speciation," because its population of 250 to 400 exists in five distinct color morphs. In the end, however, Barlow says we don't comprehend the basis of cichlid diversity very well. But his "pretty good outline"—a wonderful introduction (for those who might not have spent the last thirty years of their lives obsessing about it) to the whole issue of cichlid species flocks—is about as complete as anybody will be getting for a while.

The book's last chapter, "Fish At Risk," deals with cichlid conservation. It's got diversity, balance, and a good parting shot. That may sound more like a wine than a book chapter, but it has become so formulaic to end books, television shows, and newspaper articles about nature with maudlin stories of anthropogenic destruction that we may as well judge "words in closing" as a genre unto itself. In that context, Barlow has pulled off the end of his book with panache.

Mouth brooding is just one of the behaviors that make cichlid parents so remarkable.

I wish there had been more mention of cichlids in the wild. Most of us temperate-zone Westerners, living where cichlids are notably scarce (except in pet stores and supermarkets), lack the means to hop to the Tropics for a month or two to find out more about them, so we settle instead for nature shows—and indeed, Barlow does mention the spectacular 1996 National Geographic film about cichlids in Lake Tanganyika. Also oddly missing from his account is any detailed treatment of the Texas cichlid *(Cichlasoma cyanoguttatum)*, the only native cichlid in U.S. waters. He mentions the cichlids in warm southern waters only in terms of the evils of human introduction, but these alien fishes can now be observed doing cool things not far from folks' front doors in Florida.

There are a few minor glitches here and there in the text. *Haplochromis elegans* and *Astatotilapia elegans* are referred to as two different species, but P. Humphrey Greenwood's groundbreaking work in the 1960s and 1970s changed that nomenclature. But this is just another illustration of how confusing cichlid taxonomy can be, even to a cichlid biologist. The book itself is attractive and has a nice, old-fashioned heft. It also has a great index, a wonderful and very useful bibliography, and (thank goodness, for many of us) a glossary. And the book is well bound and pretty rugged, as indicated by my copy's capacity to absorb several cups of coffee with only a slight stain on its attractive off-white pages.

In sum, *The Cichlid Fishes* is a marvelous narrative about an extraordinary family of creatures. Barlow's fertile synthesis belongs in the pantheon of natural history classics: G. E. Hutchinson's famous essay "The Cream in the Gooseberry Fool," Konrad Lorenz's *King Solomon's Ring,* Niko Tinbergen's *Curious Naturalists,* and Howard Ensign Evans's *Life on a Little-Known Planet.*

In his Aquatic Conservation and Ecology Laboratory at Boston University, Les Kaufman studies aquatic biological diversity. His favorite workhorses are the labroids, which include cichlids, and for the past dozen years he has analyzed the evolution of fish species flocks in Africa's Great Lakes.

nature.net

Trilobitophilia

By Robert Anderson

For nearly 300 million years, trilobites flourished in the world's oceans. It took the worst mass extinction, at the end of the Permian Period, to stop their long run. Just as dinosaurs and mammals are icons for the following eras, these hard-shelled, crustacean-like animals have come to represent the Paleozoic.

Recently I renewed my childhood fascination with these fossil critters by a visit to the Web site A Guide to the Orders of Trilobites (www.aloha.net/~smgon/ordersoftrilobites.htm), maintained by Sam M. Gon III, a biologist with the Nature Conservancy in Hawaii (a state where, ironically, no fossils have been found, let alone trilobites). An "enthusiastic amateur," Gon studies current biodiversity issues and was drawn to trilobites by their numbers: with more than 15,000 species, they are the most diverse group in the fossil record.

Gon's site is very well done. Offerings on the main menu range from information on the eight orders of trilobites to sections on what the living animals were like. Animations illustrate how they molted and "enrolled" (a term used to describe their defensive posture). Perhaps the most interesting section is "Evolutionary Trends" (click under "Classification"). Trilobites filled a wide range of ecological niches—from free-swimming pelagic feeders to deep-sea, thermal-vent symbionts—and left a remarkably detailed record of their transformation from one form to another.

If you find yourself converted into a trilobite enthusiast, you might want to try another site, this one maintained by sculptor George W. Hart (www.georgehart.com/trilobites/trilobite.html). Here you find a great recipe for edible trilobites. Hart, neither a gastronome nor a paleontologist, says he just likes the cookies. So do I.

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

BOOKSHELF

The Biodiversity Crisis: Losing What Counts, *edited by Michael J. Novacek, $19.95;* **Earth: Inside and Out,** *edited by Edmond A. Mathez, $19.95; and* **Cosmic Horizons: Astronomy at the Cutting Edge,** *edited by Steven Soter and Neil de Grasse Tyson, $24.95 (New Press/American Museum of Natural History, 2001)*

Three books of essays related to the Museum's halls cover such topics as mass global extinctions and how to preserve wildlands (the Hall of Biodiversity), the evolution of continents and mountain ranges (the Gottesman Hall of Planet Earth), and cosmological discoveries and hypotheses (the Rose Center for Earth and Space and the Cullman Hall of the Universe).

Racing the Antelope: What Animals Can Teach Us About Running and Life, *by Bernd Heinrich (HarperCollins, 2001; $23)*

"For millions of years, our ultimate form of locomotion was running," writes zoologist Heinrich, who examines animal physiology and behavior and applies these insights to his own long-distance running.

Evolution's Workshop: God and Science on the Galápagos Islands, *by Edward J. Larson (Basic Books/Perseus, 2001; $27.50)*

"An archipelago of aridities, without inhabitant, history, or hope of either in all time to come," wrote Herman Melville after a visit to the Galápagos in 1841. In Larson's intriguing scientific history, the islands are seen instead as a "field laboratory for the study of evolution in action, their harsh environment an opportunity rather than a curse."

Kids: How Biology and Culture Shape the Way We Raise Our Children, *by Meredith F. Small (Doubleday, 2001; $24.95)*

Anthropologist Small follows the various strands of nature and nurture that determine the fate of our children. Treating us to wide-ranging and informative research about kids in the larger context of human evolution and culture, she also offers astute and lively observations of her own daughter.

Dragon Hunter: Roy Chapman Andrews and the Central Asiatic Expeditions, *by Charles Gallenkamp (Viking, 2001; $29.95)*

This biography of the real-life inspiration for the fictional Indiana Jones shows how a "passionate single-minded man converted his mad dream of unlocking the secrets of central Asia into a triumphant scientific quest," says Museum paleontologist Michael J. Novacek.

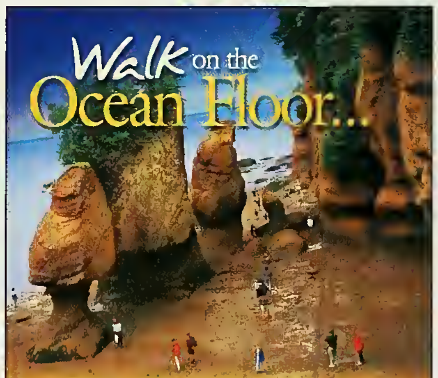
The Energy of Nature, *by E. C. Pielou (University of Chicago Press, 2001; $25)*

A mathematical ecologist takes a systematic look at the myriad ways in which energy and its transfer affect the earth and its inhabitants.

The Dragon Seekers: How an Extraordinary Circle of Fossilists Discovered the Dinosaurs and Paved the Way for Darwin, *by Christopher McGowan (Perseus Publishing, 2001; $26)*

The word "dinosaur" was coined by anatomist Richard Owen in 1842. This and other paleontological "firsts" are chronicled in an engaging book by the senior curator of paleobiology at the Royal Ontario Museum.

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



THE NATURAL MOMENT

Circle of Life

Photograph by John Serrao

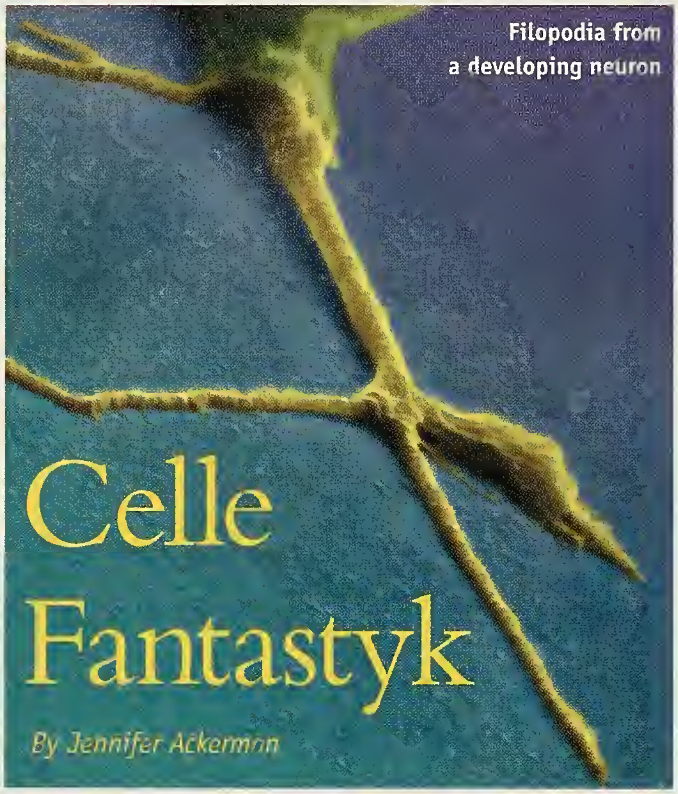
Last July, while strolling through mixed hemlock-hardwood forest in Pennsylvania's Pocono Mountains, photographer John Serrao gently turned over a rotting log. To his delight, he was treated to a rare glimpse of arthropod maternal behavior: a centipede coiled around her eggs.

This brooding female belongs to the scolopendrid family—most common in the Tropics but also found in parts of the United States. Scolopendrids have more than twenty pairs of legs and are usually two to four inches long. Here, what appears to be the centipede's head is really her hind end: she has tucked her head beneath the clutch to make it less vulnerable to enemies.

Centipedes' modified front legs are poison claws, which they use to inject a highly toxic venom. While the small U.S. species prey on worms, insects, and slugs, their foot-long tropical cousins feed on small lizards or mice and can deliver a painful sting to humans.

Scolopendrids reproduce without copulating. The male weaves a silken web on the ground, and in it he deposits a tiny, lemon-shaped spermatophore, or sealed packet of sperm. The female picks up the packet and places it inside her body. Several weeks later, she lays twenty or so eggs and curls herself around them. Fasting for two months, she cares for them intensively and defends them fiercely. She frequently licks the eggs to keep them moist and even coats them with a fungicidal chemical that she secretes from a gland in her head. Without these ministrations, the eggs would become infected with fungi and die.—*Richard Milner*

ENDPAPER



Filopodia from a developing neuron

SEM (X6000) BY DENNIS KUNKEL; PHOTOTAKE

Celle Fantastyk

By Jennifer Ackerman

Once, finding himself bleeding profusely after a bad fall, the naturalist Loren Eiseley apologized to his doomed blood cells: "Oh, don't go. I'm sorry." The words were spoken to no one, he wrote, but addressed to all the "crawling, living, independent" entities that had been part of him, and now, through his "folly and lack of care, were dying like beached fish on the hot pavement."

I'm not sure I could summon such compassion for my individual cells, not sure I could think of them as creatures with a wit and wisdom of their own. Just as a single molecule of H_2O doesn't make water, a single cell from the brain of a mouse sliding over its petri dish contains no thought; only when the cell links up with millions of others in an electrochemical network does thought emerge.

Still, Eiseley was on the right track.

One afternoon not long ago, I watched a film of what looked for all the world like a little squid thrusting forward a slender foot, as if to test the possibility of moving in one direction. Then the little creature slowly pulled back the foot, paused for a moment, and sprouted a new foot. This thin, twitching new limb poked out in a different direction, again searching like a tongue or antenna.

But all was not as it appeared in the film. Neither time nor scale was real. It was time-lapse video microscopy, with the small made large beneath a high-power lens, and hours squeezed into seconds—the same kind of compressed-time photography that makes clouds boil across the sky and the tendrils of a growing vine snake around the trellis. Accelerated or not, the movement of the little beast looked willful, no mere amoebic slithering or crawling about, but a delicate, precise, silvery motion invested with intelligence.

The star of the film—made by Diane Hoffman-Kim, a cell biologist then at Harvard—was no mollusk but the amoeba-like growth cone at the tip of an axon, a slender fiber that extends from a nerve cell—this one isolated from the spinal cord of a chick embryo. The "feet" were filopodia, Hoffman-Kim told me, dynamic little extensions of the cell membrane thrusting out from the growth cone, the leading edge of a growing axon, which the cell uses to sniff out connections with other nerve cells.

Hoffman-Kim was studying the way cells find one another to create the netted wiring of the brain, not just during embryonic development but all through life as the body learns new skills. She was interested in the molecules outside the cell that steer the tentative axon to its quarry, telling it where to go as it tunnels through tissues, in this direction or that. Once it finds exactly the right cell to hook up with, a link is formed. Somehow the cell initiates the connection and is itself altered by its accomplishment. If a skill is used again and again, the link hardens; if it's used only once, the filopodia soon shrink back, triggering a change in the brain cell, a thinning of the grip that may explain forgetting.

I was fascinated by the disembodied cell itself, which seemed to act as its own creature. On the scale of biological complexity, a single cell is said to occupy a spot roughly midway between the microcosmic world of genes and proteins and the visible world of the organism. My cells may have subsumed their individual identity by joining a larger community, but each still has its independent existence and contains a similar, if simpler, version of the mystery hidden in my head. Each is an immensely competent being, holding my whole genome, capable of subtle movement, rhythm, and sophisticated talk, adept at sucking energy out of life, and—when sufficiently full of zip—doubling and redoubling to make the world a fecund place.

Who's to say that each does not enjoy its own life?

Jennifer Ackerman's Chance in the House of Fate: A Natural History of Heredity *will be published in June by Houghton Mifflin. Her previous book is* Notes From the Shore *(Viking Penguin, 1995).*

Museum Friends Support Science Education *and* Increase Their Retirement Income

Looking back on his career as an executive at Simon and Schuster, Jason Berger says, "One of my proudest achievements was the distribution of Little Golden Books to supermarkets and pharmacies across the country, where they found their way into the hands of millions of young children who otherwise might have had little exposure to children's literature."

Several years ago, their wish to support science education prompted Jason and his wife Susanna to include the American Museum of Natural History in their wills. Then, last year, they discovered charitable gift annuities.

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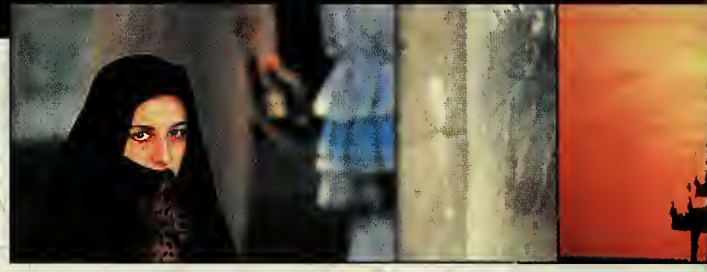
AMERICAN MUSEUM OF



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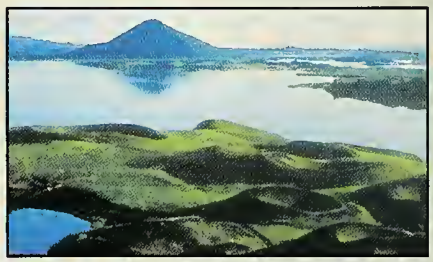

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