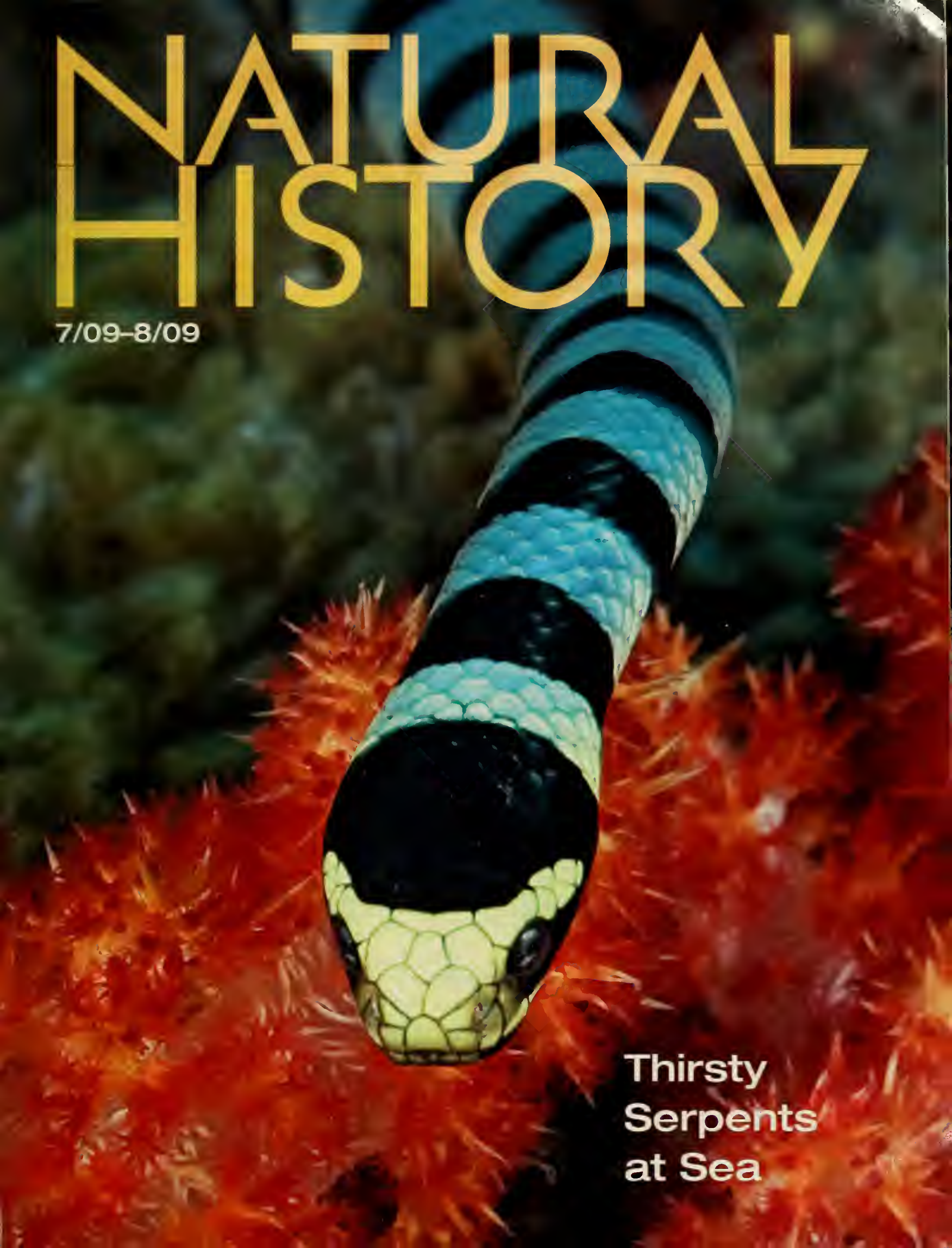


NATURAL HISTORY

7/09–8/09

Thirsty Serpents at Sea

Your Journey Begins

18,000 Years Ago

AT THE MASHANTUCKET PEQUOT MUSEUM

The world's largest, award-winning Native American museum, located in beautiful southeastern Connecticut.

- Life-size 16th c. Indian village
- 4 acres of interactive exhibits
- 18-story observation tower
- Souvenir gift shop
- Unique restaurant
- Educational Powwow, July 8 & 9

Powwow Event Sponsor: **Bank of America**

Associate Sponsor: **Troon Golf**

Promotional Sponsor: **Tribal Elder Mr. & Mrs. John E. Perry**

MASHANTUCKET PEQUOT MUSEUM & RESEARCH CENTER

110 Pequot Trail, Mashantucket, CT 06338

800-411-9671 • I-95, Exit 92

www.pequotmuseum.org

Smithsonian Affiliate

GEM AAA

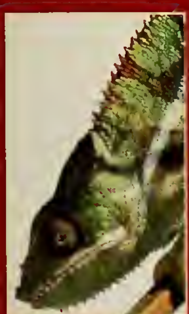
www.naturalhistorymag.com

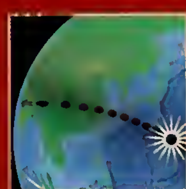
NATURAL HISTORY

JULY/AUGUST 2009 VOLUME 118 NUMBER 6

FEATURES

DEPARTMENTS





ON THE COVER: *Yellow-lipped sea krait (*Laticauda colubrina*) in Bunaken National Park, Indonesia*
Image by Mark Thomas

See preceding two pages

THE NATURAL EXPLANATION BY ERIN ESPELIE

On safari in Kenya's Masai Mara National Reserve, rule-abiding visitors must make mobile dens of their vehicles, hunkering down to view the action from a safe, respectful vantage. Big game barely bats an eye nowadays at the motors and the open mouths. But a few of the smaller denizens, such as the bat-eared foxes (*Otocyon megalotis*) pictured here, can't abide the noise or attention. To see these shyer creatures, one must go looking, outfitted with a truckload of patience.

Photographer Suzi Eszterhas spent several years in a Mara bush camp before "batties," as she calls them, ever came on her radar screen. She was studying hyena behavior when she happened upon and became enamored of a pair of adult bat-eared foxes. The next year she set out to habituate one or more of that species to her presence. Luckily, a female she chose to tail gave birth within a few weeks—and in a very shallow den, easily visible from a distance.

With entrée to the cubs' early growth, Eszterhas camped out from dawn until dusk in the passenger seat of her Suzuki, peering through a telephoto lens from her haven into the foxes'. She soon observed that, short of suckling, the father took on equal domestic duty. He's the one tending to the young in the photograph on the previous pages. And it is he that picked up the cubs and moved them to a new (less easily photographed) den after a few weeks. But it wasn't the photographer's attentions that bugged him. Odor builds up, Eszterhas explains, betraying the den's presence to predators; plus, the home gets overrun by fleas and ticks.

Ironic, in a way, that insects would be bothersome to bat-eared foxes, which are insectivores. Their birth season is timed to coincide with the arrival of the short rainy season, in October and November, when insect populations spike. Not coincidentally, the fox-filled area that Eszterhas frequented was rich with termite mounds.

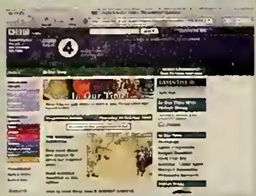
And the bat-eared foxes' hallmark ears, which measure about five inches on adults, are adapted to detecting the rustle of insects. Dung beetles, for instance, roll up balls of dung, bury them, and lay their eggs inside. When the larvae hatch, they feed on the dung ball. That is, unless a bat-eared fox hears the larvae hatch and, as Eszterhas has observed, digs it up, claws it open, and feasts on the larvae. "I've seen them go crazy over the dung balls," she says. "They'll fight over them. It's as if they've found the jackpot."

Bat-eared fox sniffs a dung ball.

California-based photographer **Suzi Eszterhas** spends nine months of the year shooting a variety of wildlife in the field. In recent years she has specialized in documenting family life and newborn animals. She has published widely and is a Fellow of the International League of Conservation Photographers. Visit www.suzieszterhas.com to see more of her work.

nature.net by robert anderson

CHINA SYNDROME



Recently I read Simon Winchester's *The Man Who Loved China*, a wonderful biography of Joseph Needham (1900-1995), the brilliant Cambridge scientist who devoted his life to uncovering the innovations that the ancient Chinese gave the world. The list includes far more than gunpowder, paper, printing presses, silk, and the compass. But all those marvels raise the question: Why did a culture that invented so much, long before the West, not undergo a scientific and industrial revolution? Three British scholars, interviewed on the BBC's online radio program *In Our Time* (www.bbc.co.uk/radio4/history/inourtime/inourtime_20061019.shtml), examine that intriguing historical puzzle. For my guide to Web sites exploring Needham's quest and the technological wonders of the Middle Kingdom, please visit the magazine online (www.naturalhistorymag.com).

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

WORD EXCHANGE

JOHN NORTON

The Color Purple

Olivia Judson's article on color vision ["Seeing the Light," 4/09] reminded me of an experience I had when I taught high school chemistry. In laboratory experiments measuring and calculating the wavelengths of light produced by hydrogen gas, my students—particularly the boys—had difficulty measuring the third emission line in the violet range (at 397 nanometers, it's right near the border between visible and ultraviolet light). One year I discovered that a couple of girls in my class could easily see and determine the position of three violet emission lines. We started calling them Super Girls, and from that time forward, I always asked the female students how many violet lines they could see before starting the measurements.

I now teach human anatomy part-time. The morning that I read Judson's article—where she mentions that mothers whose sons have a particular kind of colorblindness may be tetrachromats—one of my students asked me to explain colorblindness. Her son had just been diagnosed as colorblind. I was able to investigate whether she was one such Super Girl and a tetrachromat.

I borrowed a hydrogen emission setup and asked my student to describe the colors she saw. She said she saw only one violet line. I was disappointed. Then she realized she forgot to wear her glasses while looking through the diffraction grating. With her glasses, she saw three distinct violet lines.

In the next anatomy class, I asked if any of the women had colorblind-

Continued on page 37

NATURAL HISTORY

VITTORIO MAESTRO *Editor in Chief*

Steven R. Black *Art Director*

Erin Espelie *Executive Editor*

Senior Editors
Rebecca Kessler, Dolly Setton

Melisa Beveridge *Assistant Art Director*
Annie Gottlieb *Copy Chief*
Graciela Flores *Editor-at-Large*
Florence Brauner *Volunteer*
Natasha Thweatt *Intern*

Contributing Editors
Robert Anderson, Druin Burch, Olivia Judson, Avis Lang, Charles Liu, Laurence A. Marschall, Richard Milner, Robert H. Mohlenbrock, Joe Rao, Stéphan Reebs, Judy A. Rice, Adam Summers, Neil deGrasse Tyson

CHARLES E. HARRIS *Publisher*
Edgar L. Harrison *Advertising Director*
Maria Volpe *Promotion Director*
Sonia W. Paratore *National Advertising Manager*
Adam Cohen *Advertising Manager*
Meredith Miller *Production Manager*
Joe Sharkey *Manager, Publishing Services*

For advertising information
call 646-356-6508

Advertising Sales Representatives
Detroit—Barron Media Sales, LLC, 313-268-3996
Chicago—Robert Purdy & Associates, 312-726-7800
West Coast—On Course Media Sales, 310-710-7414
Toronto—American Publishers Representatives Ltd., 416-363-1388
Atlanta and Miami—Rickles and Co., 770-664-4567
South America—Netcorp Media, Ltd., 51-1-222-8038
National Direct Response—Smyth Media Group, 914-693-8700
Market Classified—Media Options, 800-442-6441

TODD HAPPER *Vice President, Science Education*

Educational Advisory Board
David Chesebrough *COSI Columbus*
Stephanie Ratcliffe *Natural History Museum of the Adirondacks*
Ronen Mir *MadaTech–Israel National Museum of Science*
Carol Valenta *Saint Louis Science Center*

NATURAL HISTORY MAGAZINE, INC.

Charles E. Harris *President, Chief Executive Officer*
Judy Buller *General Manager*
Cecile Washington *General Manager*
Charles Rodin *Publishing Advisor*
Jim Van Abbema *Webmaster*

To contact us regarding your subscription, to order a new subscription, or to change your address, please visit our Web site www.naturalhistorymag.com or write to us at

Natural History
P.O. Box 5000, Harlan, IA 51593-0257.

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

If you would like to contact us regarding your subscription or to enter a new subscription, please write to us at Natural History, P.O. Box 5000, Harlan, IA 51593-0257. Postmaster: Send address changes to *Natural History*, P. O. Box 5000, Harlan, IA 51537-5000. Printed in the U.S.A.

© Richard F Cox, 2009 Used under license from Shutterstock, Inc.; © Momatiuk - Eastcott/Corbis.

Antique Explorers' Gear

Hermit crabs, a lineage some 200 million years old, may not have been the first to salvage mollusk shells for self-protection. Primitive arthropods were among the earliest animals to venture onto land—500 million years ago—and they too recycled shells, according to new research.

Fossil tracks of early beachcombers

WHITEY HAGADORN

James W. Hagadorn of Amherst College in Massachusetts and Adolf Seilacher of Yale University analyzed Cambrian-period fossil tracks left on a sand flat by ancient arthropods in what is now central Wisconsin. The small imprints are in remarkably good shape: a microbial mat permeating the beach probably saved them from obliteration by waves.

The tracks resemble those of present-day hermit crabs, complete with intermittent, off-center impressions—hallmarks of a borrowed shell touching the ground with each step. But the marks suggest that compared with hermit crabs, the ancient trekkers wore their shells upside down. So whereas hermit crabs' rear ends curl under toward their bellies, the early arthropods' tails must have curled upward, like scorpions'. Also in contrast with hermit crabs, the borrowed shells seem to have been too small to cover all. They may have just protected the gills from desiccation, thus overcoming a critical hurdle in the move from sea to land.

After all, guarding against land predators was pointless: there were none. Indeed, the winding tracks suggest a leisurely excursion. The arthropods probably came ashore at low tide to graze upon the same microbial mat that recorded their tracks so well. (*Geology*)

—*Stéphan Reebs*

Panther chameleon

JOUAN & RIUS/NATUREPL.COM

Light Meal

Vitamin D_3 is essential for good health, yet seldom can animals obtain enough of it from food. Fortunately, exposure to sunlight supplements the diet: ultraviolet B (UVB) rays convert a cholesterol-related molecule that's present in skin cells into vitamin D_3. Balancing the two sources might seem tricky, but a recent paper shows that chameleons are amazingly good at it.

Most people think reptiles bask in the sun just to warm up. To establish whether they also do it to get their vitamins, Kristopher B. Karsten and his graduate adviser at the time, Gary W. Ferguson of Texas Christian University in Fort Worth, along with two colleagues, studied panther chameleons, *Furcifer pardalis*. For two months, the team fed six chameleons crickets that were either enriched or low in vitamin D_3.

The team then set the chameleons in separate outdoor enclosures that had similar amounts of sun and shade for five days, and tracked where they spent their time. The three vitamin-deprived chameleons spent more time in the sun than did their three vitamin-fortified counterparts.

That behavior led to a mathematically optimum exposure to UVB, particularly in the vitamin-deprived bunch, the researchers calculated. The chameleons are thus pros at balancing diet and sunshine. The researchers suspect that a special brain receptor lets the reptiles determine when they're low on D_3 and how much sunning will make up for it. (*Physiological and Biochemical Zoology*) —*S.R.*

Wet Galaxy

Astronomers have reported the oldest and most distant sign of water in the universe: a cloud of water vapor near a supermassive black hole at the center of a faraway galaxy.

A team led by C.M. Violette Impellizzeri, at the time a doctoral student at the Max Planck Institute for Radio Astronomy in Bonn, Germany, first spotted it in 2007—apparently from 11.1 billion light years away.

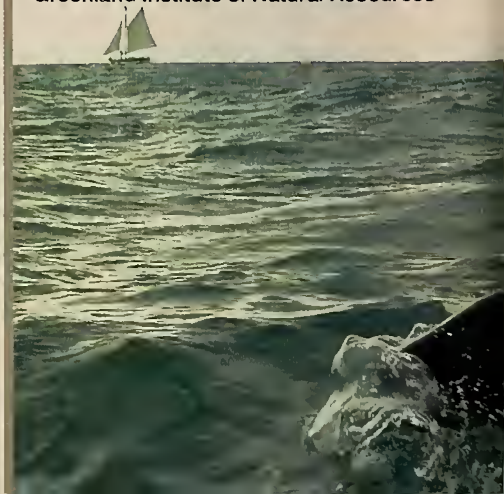
Molecular signals must be unusually strong to be detected from such a great distance. The astronomers inferred the presence of the water cloud after detecting an unusually powerful water maser—an amplified microwave signal produced by stimulated water molecules. A galaxy between Earth and the maser served as a gravitational lens by bending and further magnifying the microwave rays.

Water masers exist in galaxies close to home, but they are rare. Yet Impellizzeri's team found one

Back from the Wild

In 1998, with much fanfare, a twenty-year-old orca named Keiko took a one-way trip on an Air Force cargo plane from Oregon to Iceland. There, attended by dozens of biologists and trainers, and at a cost reportedly topping $20 million, the orca was gradually reintroduced to his native waters. Keiko, of course, had starred in three *Free Willy* movies, which sparked a public campaign to free him after nineteen years in captivity.

But things didn't quite turn out as planned. A team of his former caretakers, led by Malene J. Simon of the Greenland Institute of Natural Resources



FERNANDO UGARTE

JOHN MCKEAN HST ARCHIVE DATA

MG J0414+0534, a distant galaxy, appears four times (with red halos). The image was made possible by a second galaxy (center, white) closer to Earth, which acts as a magnifying and multiplying lens.

on their first look through a gravitational lens. Powerful water masers must therefore have been much more common in the early universe than they are now.

Were it possible to plan a trip to that wet galaxy (MG J0414+0534, it's called), remember that the universe has expanded considerably since the signal originated, 11.1 billion years ago. The water maser is now 19.8 billion light years away—so pack a lunch. (*Nature*) —*S.R.*

in Nuuk, has analyzed logs of Keiko's behavior and data from satellite tags recording his travels and dives. They point out that Keiko never managed to integrate with Icelandic orca pods and didn't seem to do much diving or fishing. He spent two several-week-long stretches on his own at sea, but ultimately chose to return to human care. Perhaps it was his affinity for frozen fish and human companionship that drew him back. He died of pneumonia in 2003, inside an open-access pen in a Norwegian inlet.

Simon's team concludes that Keiko was never a good candidate for reintroduction in the first place. Unlike the few captive marine mammals that have been successfully freed, Keiko had spent too long in captivity from too young an age, and was too strongly bonded with people, to have much chance at reentry. Even the best intentions, and plenty of cash, can't necessarily undo the taming of a giant, it seems. (*Marine Mammal Science*) —*Rebecca Kessler*

Keiko in home waters

TAKAHISA MIYATAKE

Adanson's house jumper examines a red flour beetle playing possum.

Forfeit Thy Neighbor

Some beetles play possum, and for the same reason that possums do: to avoid attention from predators. A new study highlights the reason for the trick's success—it works by sacrificing the neighbors.

Takahisa Miyatake of Okayama University in Japan has long studied the red flour beetle, *Tribolium castaneum*, and its spider predator, Adanson's house jumper, *Hasarius adansoni*. When a spider attacks, the beetle feigns death by entering a state known as tonic immobility, which often averts real death. To figure out exactly why the tactic succeeds, Miyatake and three colleagues bred one beetle strain that feigns death for about twenty minutes and one that doesn't do it at all. Then they studied interactions between spiders and beetles of both strains.

Spiders prefer living prey, so they were less likely to devour beetles that feigned death after an attack, the researchers found. That was especially true if alternative prey was available. Spiders ate death-feigning beetles 38 percent of the time when the beetles were alone, but if the spider had a choice between a death-feigner and a nonfeigner, it bagged the nonfeigner almost every time. The results were comparable when spiders had a choice of death-feigning red flour beetles and nonfeigning beetles of a different species.

The researchers conclude that tonically immobile beetles enjoy improved odds of survival, especially when in the company of more mobile compatriots. (*Proceedings of the Royal Society* B) —*Harvey Leifert*

Clone Ranger

What you are about to read deals with alarm calls, eavesdropping on neighbors, and self-recognition. Now guess who the subjects are. Bet you're not thinking of plants, are you? Yet sagebrushes do all those things.

When an insect munches on a sagebrush leaf, the wound releases volatile compounds. They waft into the air and incite other leaves to mount a chemical defense in preparation for attack. (Internal signaling, via the stems, doesn't seem to communicate that particular message in sagebrushes.) The leaves of nearby sagebrush plants "overhear" and respond defensively, as do those of the damaged individual itself. But a plant's reaction is stronger to its own chemical warnings than to those issued by strangers, Richard Karban of the University of California, Davis, and Kaori Shiojiri of Kyoto University in Japan have just discovered.

The two biologists measured how much herbivory sagebrushes suffered when they spent a summer next to either a wounded clone of themselves or a wounded individual that wasn't related. Insect damage was 42 percent lower in plants that had received airborne messages from their clones.

Karban and Shiojiri conclude that the volatile cue has a chemical signature to which the sender is most sensitive. That signature may be determined genetically, so close relatives could also be more responsive to it. The biologists point out that the ability to distinguish self and family from others is an evolutionary prerequisite to favoring kin in competition—a further step so far observed only in plants whose roots are touching. (*Ecology Letters*) —*S.R.*

SAMPLINGS

Home Growth

MEGAN FREDERICKSON

Allomerus octoarticulatus ants on young *Cordia nodosa* leaves

Ants and ant-housing trees are a classic example of mutualism. The trees provide room and board for ants that ward off herbivores in return. But friends aren't always what they seem, a new study shows.

Cordia nodosa is a South American tree colonized by ants, and one of them, *Allomerus octoarticulatus*, turns out to be as much fiend as friend. Sure, the ants protect the tree, but they also prune off its flowers, sterilizing it. Hypothetically, they do so to force the tree to put its energy into growing rather than producing fruits and seeds. Inside hollow nodules in the branches called *domatia*, the ants both live and farm honeydew-producing scale insects for food. More growth creates more domatia, letting the ant colony expand.

To test the hypothesis, Megan E. Frederickson, an ecologist at Harvard University, went to Peru and selected *C. nodosa* trees that housed *Azteca* ants—true friends, by contrast. She snipped off all the trees' flowers to mimic *Allomerus*, and, sure enough, four months later found that the sterilized trees had grown four times as many domatia as untouched controls.

But occupation by flower-pruning ants doesn't necessarily end a *C. nodosa* tree's sex life. A tree can host a series of ant colonies during its lifetime. Eventually, *Azteca* ants—or other true friends like them—may move in and let the tree blossom. (*The American Naturalist*) —S.R.

No Lily-livered Rat

For thousands of years, desert woodrats (*Neotoma lepida*) of the southwestern United States lived on a diet rich in juniper, despite the plant's toxic compounds. Then, 18,700 years ago, the region's climate changed. In what is now the Mojave Desert, juniper gave way to creosote shrubs, while farther north in the Great Basin it remained plentiful. Creosote shrubs have a completely distinct arsenal of toxins, yet woodrats thrive in both areas today. How did woodrats in the Mojave adapt to their new staple?

To learn the genetic backstory, Elodie Magnanou and colleagues at the University of Utah in Salt Lake City captured woodrats from the Mojave and the Great Basin, and fed them controlled diets containing either juniper or creosote for several days. Next, the researchers compared messenger RNA extracted from their livers to find out which genes were being expressed there to process food. They used microarrays, molecular tools that can quickly highlight differences in gene expression between individuals of the same species. Innovatively, in this case they used microarrays specific to the common lab rat, *Rattus norvegicus*, to study the woodrat, a related wild species.

DENISE DEARING

Desert woodrat

In woodrats on the creosote diet, the team identified twenty-four genes that were much more active in the Mojave group than in the Great Basin group. Those genes make liver enzymes that help to detoxify creosote—allowing Mojave woodrats to prosper on seemingly inedible food. (*Molecular Ecology*) —H.L.

THE WARMING EARTH

Deactivating the Clathrate Bomb

Vast reserves of the greenhouse gas methane are sequestered in a solid form, called methane clathrate, in sediments under the sea and in permafrost. Clathrate is stable only at low temperatures; should global warming free just 10 percent of its sequestered methane into the atmosphere, the resulting greenhouse effect would equal that of a tenfold increase in carbon dioxide.

That's a climate scientist's worst worst-case scenario, and many have conjectured that something like it happened 11,600 years ago. Then, Earth emerged from an ice age and warmed up in a hurry—in some places by 18 Fahrenheit degrees in twenty years. Air bubbles trapped in Greenland ice at the time show a 50 percent increase in atmospheric methane. Did a clathrate meltdown take place?

Unlikely, says Vasilii V. Petrenko, now at the University of Colorado at Boulder. With colleagues, he measured levels of the isotope carbon-14 in the methane in those air bubbles. It was too high to have come from clathrate, the team found, and more in line with production by wetlands, which must have proliferated in the newly balmy climate. (Bacteria produce the gas as they break down organic matter.)

That warming 11,600 years ago took the Earth from cold to temperate. How clathrate will respond to the change underway from temperate to warm remains to be seen, though Petrenko is optimistic. As for the threat of methane emission from expanding wetlands, he calls it a "lesser evil," since wetlands can hold far less of the gas than clathrates do. (*Science*) —S.R.

JEFFREY SEVERINGHAUS

VASILII V. PETRENKO

To study past methane levels, geologists sample ice, above, at the Pakitsoq ice margin in western Greenland, left.

LIFE ZONE BY ROBERT R. DUNN

A Head in the Clouds

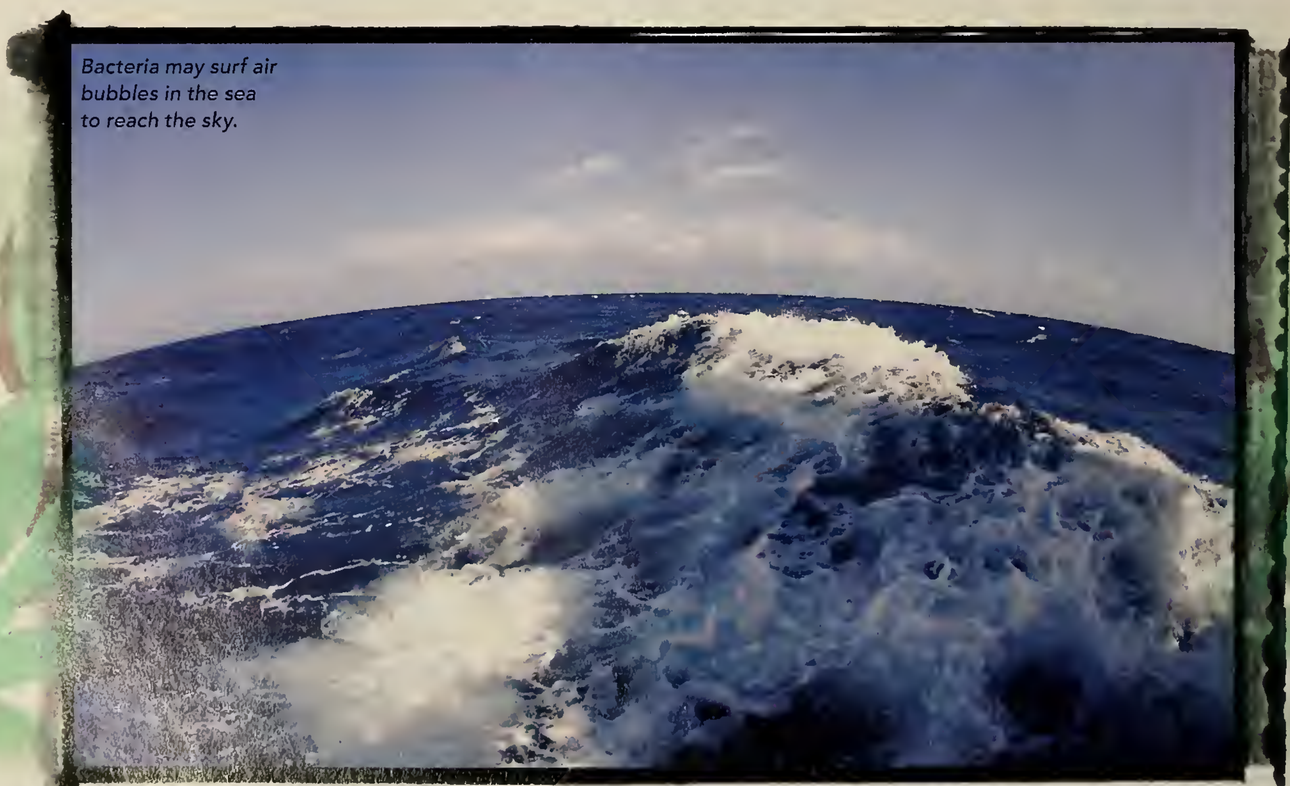
Do the microorganisms that circulate in the atmosphere get there by chance—or by contrivance?

Circumambulating his home near Oxford University, in the style of Charles Darwin treading his "thinking path," the evolutionary biologist William D. "Bill" Hamilton often thought about life—all of it. He imagined evolutionary scenarios, extravagant and daring theories. Much as a novelist might imagine characters, he imbued each with personality and possibility and then helped them into the world to meet their fate.

Just such a theory took him to the Congo at the beginning of 2000. It had been suggested that HIV had jumped from chimps to humans via a tainted polio vaccine. Hamilton thought the idea had merit. But rather than simply argue the possibility, Hamilton and two students climbed trees in the rainforest to gather poop from the stick nests of chimpanzees. They hoped to extract RNA and DNA to see which strains of HIV and related viruses plagued the chimps. It could be argued that any trip that involves climbing trees to collect poop has not started terribly well. But things got worse. One of the students stabbed himself on a palm-leaf spike and suffered blood poisoning, requiring his evacuation. Then Hamilton, who had not taken any malaria prophylactics, was bitten by an infected mosquito. Soon feverish, he was sent home to England. On January 30, 2000, the day after his return, he lapsed into a coma.

The HIV hypothesis Hamilton risked his life for was potentially consequential for human history and health. But it wasn't the most momentous idea he considered, nor the most unruly. Several of Hamilton's wild stories have survived initial disbelief and dismissal to become foundation stones in the understanding of evolution. He imagined, for example, that microorganisms might live in clouds, and even make them.

Clouds have traditionally been beyond the purview of biologists—too rarefied to be the stuff of life. But Hamilton looked up (often when it was imprudent, while hurtling headlong on his bicycle), and imagined them as biomes teeming like a river with life. Into the clouds he cast until he felt a bite, the tug of something as big and wild as anything



Bacteria may surf air bubbles in the sea to reach the sky.

www.xezo.com
Limited edition of 516 pieces
For a limited time, Xezo is offering the Architect limited-edition watch for just **$665.00** (shipping is free within the U.S.). To order this finely handcrafted timepiece, visit the manufacturer's Website at **www.Xezo.com**, or call 800-779-0102.
ETA 2000-1 SELF-WINDING AUTOMATIC MOVEMENT WITH SHOCK ABSORBER • STOP SECOND DEVICE • SAPPHIRE CRYSTAL GLASS FRONT & BACK
Architect 2001
Automatic
The Swiss-made, automatic Architect by Xezo - as unique as your environment
Crocodile leather
Surgical steel curved case
Size: 48mm x 35mm x 8mm
Luminous hands and markers
50m/165ft water-resistant
20 JEWELS
XEZO
SWISS MADE
CASEBACK VIEW
XEZO

he'd reeled in before. He had already made revolutionary leaps from selfish genes to self-sacrificing kin and from parasites to the evolution of sex. He could, in his speculation, afford to be a little bit reckless.

In 1997, Hamilton shared his cloud hunches with Timothy M. Lenton, then a PhD student at the University of Norwich in East Anglia, and the two launched into a collaboration to explore the possibility that microbes both make and fly in clouds.

The theory began with overcrowded microbes in the sea. When their populations become too dense, individuals that can escape will have an advantage. But how can they do that? What if, Hamilton imagined, they could get up into clouds and ride to greener pastures? Yet single-celled creatures are seemingly at the mercy of the fates. Here came the novelty: maybe microbes produce chemicals that cause clouds to form, ride those clouds, and then produce a second kind of chemical to cause the clouds to rain or snow them back to the ground. The idea seemed better suited to a children's book than to big science. And yet it was also somehow evidence of what a great mind, left to wander, can conjure—and what an eager graduate student can be roped into. Hamilton and Lenton published their story in 1998.

On its own, the idea that microbial life could be found in clouds was not entirely new. Earlier biologists had thrust an occasional vial or Petri dish out of a plane window or off a hot-air balloon or mountaintop (among them F.C. Meier, who disappeared in 1938 in his mid-forties while flying into dense clouds, searching for life). The vials those "aerobiologists" brought back down were chock-full of microscopic life. What was new was Hamilton and Lenton's concept that microbes had, by natural selection, evolved adaptations for making clouds rather the way beavers have evolved adaptations for making ponds.

JEFFREY JOY

Hamilton in the Congo

The paper was ahead of its time. The question it raised was too big for microbiologists, too biological for climatologists, and too airy for oceanographers. No one, not even Hamilton and Lenton, knew enough about all of the elements they discussed—clouds, bacteria, oceans, sea bubbles, and ice storms, to name a few. And then Bill Hamilton went to the Congo, caught malaria, and after five weeks in a coma, died. He was sixty-three.

As a child, Hamilton lost the tips of two fingers by playing with a bomb. As an adult, he got into a fight with a knife-wielding man in Brazil. While looking for ants in Rwanda, he was taken for a spy. He is said to have been hit quite a few times by cars while riding his bike at high speeds to his office at Oxford University. At his funeral, everyone recalled both Hamilton's brilliance and his near-pathological disregard for his own safety. Together those two traits had flung him into the far corners of the world, and, it seemed implicit, to an untimely death. He was buried quietly at the edge of Wytham Wood near Oxford, though he had requested that his remains be left in the Amazon to be pulled to pieces by beetles and buried for their young.

When Hamilton died, his ideas about clouds were discussed as an example of his beautiful mind, and promptly dismissed. Then a funny thing happened. Scientists began to examine parts of his cloud theory. First they tested, more rigorously, whether clouds really contained life. (They did.) Samples from clouds were scooped up, frozen, and later run through modern genetic analyses. Each and every sample seemed to be full of protein and DNA—and, implicitly, of life. An average cloud, if there is such a thing, contains tens of thousands of living cells in every milliliter of water. That's many fewer cells than in a milliliter of swamp water, but many more than you might expect to find in wisps of air. Algae, bacteria, and lots of fungi not only ride in clouds, but actually live in them, taking up residence, surviving, and reproducing on the "foods"—organic acids and alcohols, sulfur, and nitrogen—that float above us on the wind. A recent study found three species of bacteria way up in the stratosphere, more than twelve miles above Earth and above all but the thinnest, most attenuated clouds. None of those species has ever been collected anywhere else, leaving open the possibility that some species live only and always in the clouds. In this new, post-Hamilton view, clouds are their own biological realms—as Thoreau called them, "drifting meadow[s] of the air."

Yet the key to Hamilton and Lenton's hypothesis was not simply that microbes occur in clouds, but that they have evolved specific traits—tiny chemical "wings"—to take them there. In forests and deserts, microorganisms might not need any special adaptations to arrive in clouds. Winds, dust storms, fires, and thunderstorms may be sufficient to

blow them into the air. But for marine microbes to get airborne, they must escape the surface tension of water—no easy task. And yet clouds, as it turns out, are full of such minute sea creatures.

Hamilton and Lenton imagined how bacteria and other unicellular organisms might take advantage of rising air bubbles in wind-whipped whitecaps. It was already known that such air bubbles "scavenge" bacteria and other unicellular organisms as they rise to the water's surface. A bubble can accumulate microbes in densities several hundredfold greater than in the surrounding water. Once at the surface, the microbes might be popped into the air by the bubbles' bursts. Perhaps that would be enough to get microbes airborne, but Hamilton and Lenton envisioned something more specific.

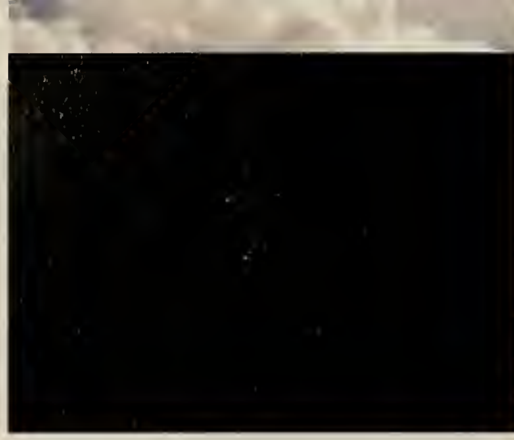
They knew that marine microbes (particularly algae) produce an immediate precursor to dimethyl sulfide (DMS), a flammable, water-insoluble byproduct of bacterial metabolism. Moreover, they knew that the DMS generated by those microbes could initiate the process of cloud formation, and that therefore, many a cloud that rolls over your house, whether in the shape of a dog, a popsicle, or a piano, likely had its start in the products of microbes. Water droplets form around microbially produced DMS molecules, which thus catalyze condensation. That much is not in contention, at least not anymore. The question is whether an individual microbe's genes benefit by producing DMS (a requirement for natural selection to act). Did a microbe that produced more DMS as it was flung into the air stand a better chance of survival? Would it be more likely to be drawn up into a new cloud, which would act as transportation to a patch of sea where its offspring would thrive and multiply? Hamilton and Lenton thought so. They imagined that DMS was, for microbes, like a kind of sail, extended when they needed to ride up into the air and catch the wind.

If the production of DMS is an adaptation of microbes that allows them to trigger cloud formation, it would be among the most magnificent and consequential adaptations of any lineage of life. Beavers may make ponds and wetlands, but microbes that build clouds alter Earth's conditions vastly more. If microbes did not produce DMS, cloud cover would be reduced dramatically. We, among other species, would probably not be able to survive. But did the bacteria evolve specifically to do this, or is it just a chance byproduct?

The answer to that question is now testable, as Lenton outlined recently in an email to me: one could study the evolution of the genes for the production of DMS and whether those genes were found preferentially in microbes that travel in clouds. One could also look at whether the genes for DMS production are selectively "turned on" by microbes when they approach the water's surface, where the DMS might most usefully propel them upward. We await an answer, but, I suspect, not for long. Lenton does not plan to do the work, but someone will—perhaps you.

After microbes get into clouds, how do they get down? With the exception of the three new bacterial species known so far only from the stratosphere, most of the microbes flying around above us appear to need to get down to Earth to prosper. Hamilton and Lenton proposed that microbes in clouds produce a second set of compounds, any of a group of proteins that cause ice to form around them. The frozen creatures begin to free fall to the Earth, and, if things go well, eventually melt, grow, and begin to divide. There was precedent for such a hypothesis, if a somewhat obscure one.

In 1976, David C. Sands was hired at Montana State University during an outbreak on wheat of *Pseudomonas syringae*. That bacterium was known to produce a protein that raises the freezing temperature of water, and in doing so, causes frost damage to plants' leaves at relatively warm temperatures. The frozen plant cells burst, and some strains of the bacteria then take advantage of the damage by consuming the cells' contents. Sands had a mystery on his hands, though. He could not understand where the infections were coming from. Sands sterilized some wheat seeds and planted the sterilized seeds in



BRENT C. CHRISTNER

Three separate ice crystals, grown in the laboratory, contain Pseudomonas syringae *(green dots).*

experimental plots. Amazingly, the infection raged on. It was as though the bacteria dropped straight out of the sky—and so he decided to consider that possibility. He got in a plane with a petri dish and, at cruising altitude, hung it out the window. His hand must have nearly frozen off. But when he brought the petri dish back to the lab, *P. syringae* grew. The bacteria had been floating above his wheat fields in the clouds and, somehow, descending onto his sterilized plants.

Many of the details of how *P. syringae* raises the freezing temperature of water were eventually resolved by Sands and others. The structure of the special protein the pathogen produces mimics the structure of an ice crystal, and that causes water molecules in liquid or vapor form to congregate on it and freeze. Initially, it seemed as though the bacteria's only use for this protein was in freezing plant cells. But those who paid attention noticed a strange pattern. The protein was present not only in *P. syringae,* or in plant pathogens more generally; it was also present in microbial lineages that did not infect plants at all. What other purpose might it serve?

Sands and others would soon reveal that *P. syringae* bacteria use the same protein that allows them to freeze plant cells to drop out of the sky, swaddled in the disguise of snowflakes. It seemed and seems possible that the proteins evolved because they help the microbes drop out of clouds, and then were secondarily co-opted to help some pathogenic varieties of the bacteria to eat plants. In 1976 Russell C. Schnell of the University of Colorado suggested that hailstones, at least in Kenya, very often had *P. syringae* at their core. Then in 2008, Brent C. Christner at Louisiana State University and colleagues, including Sands, collected snow from Antarctica, France, and Montana to see what, at the center of snowflakes, had initially enabled them to form. At each site a large proportion of the snow harbored evidence of ice-nucleating life. That finding was confirmed this year by a team of atmospheric scientists led by Kerri A. Pratt, a PhD student at the University of California, San Diego, who detected such life *in situ,* by analyzing ice crystals in clouds aboard a specially-equipped plane. All around us, as it rains or snows, one might, upon close inspection, find such collections of life—bacteria, algae, and fungi—falling toward us in great densities. It is not raining cats and dogs, but it is, more often than not, snowing bacteria.

Just as in the case of DMS, it is not fully resolved whether the cloud-riding microbes that cause rain and snow to fall "mean" to do it (which is to say, whether the proteins they produce evolved as adaptations for initiating snow and rain), or whether such consequences are incidental. None of the many details that have accumulated since Hamilton and Lenton's paper have ruled out their hypothesis. Meanwhile, around the seed of their speculation, the possibilities have grown more complex and wonderful than even Hamilton and Lenton might have imagined: a troposphere filled with life doing things we have yet to understand, things that affect the formation and dissolution of clouds and that ultimately, by stabilizing Earth's climate, may have had a hand in the origin of terrestrial multicellular life.

Hamilton is deeply missed by those who knew and loved him.

Continued on page 37

A Long Drink o

For thirsty sea snakes, the ocean can be a desert.

IMAGEBROKER/FLPA

"Look at this! How really weird," I exclaimed to a colleague. We were standing on the tilted deck of an old, wrecked merchant ship partly submerged off the coast of Papua New Guinea, near the capital city of Port Moresby. At my feet, a hundred or more sea snakes lay on the rusty deck, some stretched out side by side, others in tangled clusters. All were more or less still. Yellow-lipped sea kraits they were (*Laticauda colubrina*) [*see photograph at left*], their two- or three-foot-long bodies dressed in alternating bands of gray-blue and black. It wasn't their aggregation on dry land, as it were, that surprised me—sea kraits are amphibious and known to gather in large groups occasionally. But, like shipwrecked sailors, nearly all of them appeared emaciated, and I could not imagine the reason. It would be more than passing strange for so many in a single population to be unable to find enough fish to eat.

f Water

Flat-tail sea snake, Laticauda schistorhyncus, *above, is one of seven sea kraits, amphibious species that come ashore to rest and to lay eggs. Other sea snakes give birth to live young in the water. Below left: Yellow-lipped sea krait,* L. colubrina, *is a species the author showed is dependent upon freshwater to maintain water balance, though it spends much of its time in the ocean.*

BY HARVEY B. LILLYWHITE

That was in 1975. In the intervening decades I've replayed the scene in my mind now and then, each time returning to the question: what was wrong with those sea snakes? In hindsight, and with the benefit of additional research into sea snake physiology, I'm almost certain it wasn't hunger plaguing them. Although surrounded by the vast waters of the Pacific Ocean, they were most likely severely dehydrated. They might even have been early harbingers of climate change.

Of the myriad and diverse creatures of the sea, most evolved right there in the saltwater. But a handful of them, including sea snakes, are secondarily marine, having evolved from terrestrial ancestors. The evolutionary transition from one medium to another is difficult, and the switch from air on land to seawater presents special problems. Chief among them is obtaining enough water to stay properly hydrated: the high concentration of salts in seawater poses a challenge to maintaining the less-salty body fluid that most terrestrial organisms and their marine descendants possess.

Ancient mariners learned that we humans become seriously dehydrated if we drink seawater (an act called "mariposa"). Our kidneys cannot concentrate urine sufficiently to conserve enough water while eliminating the excess ingested salt. Marine mammals, by contrast, can excrete more concentrated urine than ours, and they have digestive-system adaptations that enable them to extract the maximum liquid from their food. As a result, marine mammals have no need for freshwater. It remains unknown whether they, and most other marine vertebrates, drink seawater directly.

Marine birds and reptiles have come up with a different solution for eliminating excess salt: specialized glands that secrete concentrated fluids of sodium chloride, the principal salt constituent of seawater. Desert animals, too, are subjected to osmotic stresses, and some excrete potassium salts as well. The list of species known to possess salt glands includes desert birds and reptiles, along with seabirds, marine turtles, the marine iguana, some crocodilians, sea snakes, and terrestrial reptiles living in coastal zones. In marine birds and iguanas a salt gland near each eye excretes through the nostrils; in marine turtles the gland is in the eye socket and excretes salty tears; crocodilians have salt glands in the tongue; and sea snakes have them beneath the tongue.

Salt glands have been studied almost exclusively in the laboratory, largely by infusing excess salt into an animal—either intravenously, or by pumping saltwater into the stomach—and demonstrating that salt glands secrete highly concentrated salt solutions in response. But there is little information concerning when and how effectively salt glands work in free-ranging animals. Physiologists have assumed that animals possessing salt glands are able to maintain water balance by excreting excess salts ingested in salty substances, such as marine prey or seawater—no freshwater required. It has been standard textbook dogma, for example, that sea snakes drink seawater and, in essence, distill it with their salt glands. But there is always drama in science, and my recent work shows that at least some sea snakes' salt glands are insufficient to that task, and their water balancing act more complicated than expected.

Blue-banded sea krait

In the 1990s, my colleagues and I studied an unusual marine reptile called the little file snake (*Acrochordus granulatus*) [*see bottom photograph at left*]. It is the sole marine species in the file snake family, the Acrochordidae, which also contains two freshwater species. The file snakes are only distantly related to the group herpetologists call sea snakes, which includes the sea kraits. Through a series of observations and experiments, we discovered that the little file snake not only drinks freshwater but requires it to maintain water balance. Most populations of little file snakes live in tropical southern Asia among mangroves or in other nearshore marine habitats. They spend their entire lives in seawater, where they can potentially dehydrate despite possessing a functional salt gland.

We further demonstrated that little file snakes eliminate much of their nitrogenous waste in the form of ammonia or ammonium rather than uric acid, as terrestrial reptiles typically do. That is important because the ammonia—a product of protein metabolism—is highly toxic and cannot be allowed to accumulate in body fluids. Nor can it be concentrated or precipitated, as uric acid can be, and it requires comparatively more water to eliminate via the kidneys. Thus the high protein load of the little file snakes' diet of fish exacerbates their need for freshwater. Indeed, little file snakes that are partly dehydrated cease to eat, presumably to conserve water that they would otherwise expend ridding the body of ammonia.

The unexpected freshwater requirement of marine file snakes piqued my curiosity about how sea snakes manage to stay hydrated—particularly in light of that oddly emaciated group on the Port Moresby wreck. Whereas the little file snake is the only marine species in its family, sea snakes have diversified considerably in the sea. Scientists recognize about sixty species in two

ALEJANDRO SOLORZANO

Yellow-bellied sea snake, above, a pelagic species that occasionally becomes stranded on land, as shown here. Some evidence hints that it and its relatives require freshwater; the author plans to test that hypothesis. Little file snake, left, shown here in captivity, is a marine species only distantly related to sea snakes; it also requires freshwater, the author determined.

BLUE-BANDED SEA KRAIT: PGS 24-26: COLEMAN SHEEHY III distinct lineages. The taxonomy is somewhat in dispute, but here, for simplicity, I'll follow a popular classification that regards those two lineages as subfamilies within the family Elapidae. Sea snakes are thought to have evolved from terrestrial elapids, which today include cobras, land kraits, coral snakes, and numerous other venomous species in Australia. The subfamily Hydrophiinae contains more than fifty sea snake species that are entirely marine. A few are pelagic, but most live near shore, and they all give birth to live young in the water. The subfamily Laticaudinae contains another seven species, all in the genus *Laticauda* and called sea kraits. The group is amphibious: sea kraits come ashore to rest and to lay eggs in moist, rocky places along the seashore.

BOTH PHOTOS: HARVEY B. LILLYWHITE

Dimpling of a yellow-lipped sea krait's scales, above left, is a symptom of dehydration. The author studied three sea krait species along the shore of Orchid Island, Taiwan, above right.

Sea snakes are widely distributed throughout much of the world's marine tropics, primarily along coastlines and islands of the Indian and western Pacific oceans. A single species also occurs along the Pacific coast of the Americas between Baja California and Ecuador. In addition to their salt glands, sea snakes have other morphological adaptations to life in the sea. Valvular nostrils prevent the entry of water, and reduced ventral scales let the body compress laterally—which, in conjunction with a paddle-shaped tail, aids swimming. All sea snakes possess a single functional lung. They surface to breathe air, though certain species can also exchange a moderate amount of oxygen and carbon dioxide through the skin. Some species that feed or rest on the seafloor can dive as deep as 350 feet and can remain submerged for more than two hours. Sea snakes have highly toxic venom that most species use to immobilize their prey of fish or eels, and many are important top predators on coral reefs. A few species specialize on fish eggs.

Some intriguing clues hinted that sea snakes might need freshwater in their diet. In the 1970s, William A. Dunson, a biologist (now emeritus) at Pennsylvania State University in University Park, had observed the yellow-bellied sea snake, *Pelamis platurus* [*see top photograph on opposite page*], a fully marine species in the subfamily Hydrophiinae, drinking freshwater in the laboratory. And in 1991, Michael L. Guinea, a biologist at Northern Territory University (now part of Charles Darwin University) in Darwin, Australia, reported observing yellow-lipped sea kraits drinking rainwater in Fiji; they would lick the water from vegetation or gulp it from depressions in coconut leaves. Snakes drinking freshwater in the wild are obviously thirsty, and therefore in negative water balance. Presumably that would not occur if the snakes could indeed get sufficient water from saltwater or from prey, using their salt glands.

To determine definitively whether sea snakes require freshwater to remain in water balance, I spent three field seasons, in 2005 through 2007, studying the question in three species of sea kraits that are common at Lanyu, a.k.a. Orchid Island, Taiwan. The three sea krait species represent a spectrum of habits: the yellow-lipped sea krait is semiterrestrial, the banded sea krait (*L. semifasciata*) is almost fully marine, and the blue-banded sea krait (*L. laticaudata*) is intermediate to the other two in its allocation of time between land and sea [*see photographs on pages 22, 26, and 24*].

I collaborated with Ming-Chung Tu, a biologist at the National Taiwan Normal University in Taipei, and several students assisted us. To begin, we dehydrated sea snakes by keeping them in mesh bags exposed to laboratory air. After two weeks, they were moderately dehydrated—having lost between 10 and 16 percent of their body mass—and therefore thirsty. We then placed each snake individually into an aquarium with seawater and watched to see whether it would drink. We weighed each animal before and after to measure any water it might have ingested. After one hour, none of the snakes had drunk any seawater. Next, we left the snakes in seawater for about twenty hours, overnight. Again we weighed them; none had gained any significant mass. We then placed each snake into a container filled with freshwater and repeated the process. All the snakes drank the freshwater, opening their mouths and sucking it in, and many of them drank copiously within minutes of sensing it.

We also investigated whether the sea snakes would dehydrate when kept in seawater without a source of freshwater for drinking. The snakes lost body mass at a constant rate for more than a month, yet did not drink seawater. Other individuals were offered freshwater every third day; they drank variable amounts to rehydrate throughout their time in the seawater. We didn't feed the snakes during either of the dehydration periods, which simplified the mass measurements. Snakes are intermittent feeders with relatively low metabolic rates, and they can go for several months and possibly longer in the wild without eating.

At the conclusion of the experiments, we tested the animals that had no access to freshwater to see what level of brackish water they might drink. We discovered that sea kraits will drink freshwater or very dilute seawater, but not brackish water more concentrated than 30 percent seawater. Our experiments showed conclusively that at least three sea snake species dehydrate in air and in seawater. Moreover, they voluntarily correct for body-water deficits by drinking fresh or dilute brackish water, but refuse seawater.

What was true in the laboratory also seems to be true in the wild. We collected sea kraits at Orchid Island that appeared very thin, and they drank large amounts of freshwater in the laboratory. And in the 1970s and 1980s, in Papua New Guinea and in Fiji, I encountered numerous sea kraits with peculiarly dimpled scales [*see photograph on preceding page*]. My team and I recently observed that the dimpling is a symptom of dehydration—though I didn't realize it back then. A quick check of historical weather records for Papua New Guinea and Fiji confirmed my suspicion: I had observed the dimpled sea snakes during seasonal droughts. French scientists working in New Caledonia have witnessed numerous yellow-lipped sea kraits emerging from seclusion beneath rocks or vegetation in dramatic synchrony when rain fell after a period of drought. The snakes drank rainwater that dripped or pooled onto rocks. Thus, it seems certain that sea snakes can become severely dehydrated in the wild.

What about exclusively marine species? Snakes living in coastal waters might have access to an underwater freshwater spring or to brackish or fresh water in estuaries. If not, their only source of drinking water appears to be rainfall. Because freshwater is less dense than seawater, it tends to remain on the ocean surface until currents and waves mix it in. In most cases, such freshwater "lenses" are thin and short-lived, but they can occasionally extend to depths of sixty feet and persist several days. Behavior I observed in the laboratory hints that saltwater-dwelling snakes are familiar with the phenomenon. Sprinkling freshwater over the surface of their tanks brought secretive little file snakes out of their PVC-pipe burrows. They rose quickly to the surface to drink the "rain."

One might expect that a freshwater lens would persist longer after a rainfall in a sheltered location, such as a bay or a lagoon, than on the open ocean. Interestingly, that's exactly where some notably large sea snake populations have been found. The distribution of sea snakes is characteristically patchy, and we are accumulating evidence that the patchiness might be explained, in part, by the distribution of rainfall both in time and in space.

During our field investigations at Orchid Island, we noticed that sea kraits were particularly abundant near a freshwater spring we had discovered while snorkeling near the coastline. Subsequently, we selected eight different coastal sites around the perimeter of the island, and sampled the abundance of the three *Laticauda* species there, searching at night, when the snakes are most active. Four of the sites have a known source of freshwater nearby. The other four have no apparent source other than rainfall. We confirmed the distinction by testing the salinity of water samples taken at each site. Our sampling showed that the freshwater sites sheltered several to seventy times more sea snakes than did the strictly marine sites, where we often encountered no snakes whatsoever.

In 2007, we sampled the two freshwater sites where the snakes had been most plentiful during the past two years. Our visit coincided with a period of local drought,

Banded sea kraits hunt among fish on a coral reef, where sea snakes are important top predators. The species, L. semifasciata, which requires freshwater, is almost entirely aquatic, leaving the sea mainly to lay eggs.

PETER SCOONES/NAPL

and we noted that they were less abundant than in the previous, wetter years. The drought was so bad that some streambeds were totally dry, including the source of the underwater spring we'd discovered while snorkeling. Some of the villages on the island even ran out of drinking water. When I totaled the local numbers of snakes that we'd counted each visit during three different years, and plotted them against the total precipitation that fell during the six months preceding each visit, there was a positive correlation: more rain meant more sea snakes. On a local geographic scale at Orchid Island, then, the abundance of sea snakes related positively to the availability of freshwater, both spatially and temporally.

I set out to investigate whether the correlation would hold up at a much broader geographic scale. Sure enough, data in the scientific literature indicate that the distribution of sea kraits generally coincides with areas having low-salinity surface waters in the tropical Indian and western Pacific oceans. Indeed, using data from South Asia for the known distributions of all sea snake species combined, I discovered that in general, more sea snake species live in areas of greater precipitation.

The distribution of *Laticauda* species among small islands is also quite patchy, so one might hypothesize a dynamic model in which populations persist in certain areas that receive adequate precipitation and either die out or emigrate from others during droughts. Dispersing individuals might later repopulate the abandoned sites when the climate turned favorable once more. There are, of course, other factors that determine sea snake distributions—temperature and prey abundance, for example. But to the extent that evolving populations have a physiological requirement for freshwater, they are more likely to survive in regions of high compared with low precipitation. Moreover, the changing availability of freshwater potentially influences the dynamics of coral reef communities, because sea snakes can be important top predators there.

The irregularity and unpredictability of rainfall patterns is likely to limit the distribution of at least some marine snake populations. It might even explain, in whole or in part, certain declines and local extinctions that have recently been documented. Precipitation has generally decreased over the tropics since the 1970s, and climate models predict it will decrease further in tropical regions with seasonal drought. Because at least some sea snakes are dependent on freshwater, we may expect to see corresponding changes in their populations.

But little file snakes and the two sea snake subfamilies of the Elapidae (the Hydrophiinae and the Laticaudinae) are not the only snakes that live in saltwater. A few members of two other snake lineages, both in the family Colubridae, inhabit the brackish waters of salt marshes and estuaries. William Dunson has shown that those species probably also depend on freshwater. Thus,

Rangers release yellow-lipped sea kraits and yellow sea kraits (L. saintgironsi, orange stripes) after gathering them for a population study in New Caledonia.

species representing four out of five distinct lineages of snakes that inhabit saltwater are now known to require freshwater to maintain normal water balance. The fifth, the Hydrophiinae, has not yet been thoroughly studied in that context. Although hydrophiines are the snakes most completely adapted to life in the sea, it does seem likely that they, too, need the sweet stuff: Dunson has observed that some hydrophiine sea snakes undergo a net loss of body water in seawater, and the pelagic species *P. platurus* not only will drink freshwater in the lab, but also reportedly dehydrates when fasting in seawater. My team and I are planning studies of representative hydrophiine sea snakes to settle the matter.

Understanding the water requirements of all sea snakes could prove to be crucial to their conservation. Some researchers have suggested that they may turn out to be indicator species for the health of coral reefs, which are in deep ecological crisis. Sea snakes' thirst also raises the question of whether other marine reptiles, such as sea turtles, might turn out to be more dependent on freshwater than we've presumed.

Harvey B. Lillywhite is a professor of biology at the University of Florida in Gainesville. He is also director of the university's Seahorse Key Marine Laboratory, located within the Cedar Keys National Wildlife Refuge. Lillywhite has studied the biology of snakes for more than thirty years. His latest research on sea kraits was supported by the National Geographic Society. Lillywhite's *Dictionary of Herpetology* (Krieger Publishing Company, 2008) was named as an outstanding title by *Choice: Current Reviews for Academic Libraries*. He is a past contributor to *Natural History*.

Web links related to this article can be found at
www.naturalhistorymag.com

The Secret Lives of Starlings

An unpredictable habitat sets the stage for cooperation and conflict in African starlings—and influences who cheats on whom.

BY DUSTIN R. RUBENSTEIN

When love is in the air, beautifully turned-out males trail their equally dazzling mates everywhere to ensure their fidelity. And still some of those females, albeit a minority, manage to elude their bodyguards and cheat on their partners. Some females do it for better genes, while others trade sex for extra food for their young. And when a female does cheat, it can be with a mysterious stranger—or with a close relative of her partner: his brother, cousin, or even nephew! What sounds like a sordid soap opera is conventional life for a group of African birds. Their social structure just happens to be one of the most complex in the avian world.

The superb starling (*Lamprotornis superbus*), which dwells in eastern Africa from Sudan to Tanzania, is one of 110 or so species of starlings, forty-five of which are found only in Africa. The superb starlings live in large communal groups and cooperate with one another to raise offspring, but not without some conflict, competition, and varying amounts of cheating, from rare to rampant. Their groups consist of breeding pairs as well as helpers that don't breed themselves, but aid multiple nests simultaneously. Although males do most of this helping, both sexes help.

Nearly 40 percent of African starling species are so-called "cooperative breeders," meaning that additional individuals help raise one breeding pair's young, but superb starlings are "plural cooperative breeders," with several breeding pairs sharing a large pool of helpers. Their family groups, which include parents, stepparents, siblings, aunts, uncles,

With its glossy blue back and neck, jet black head, rusty underbelly, and characteristic white breast band, the superb starling (*Lamprotornis superbus*) is hard to miss. It lives in savannas in eastern Africa, where it is one of the most common birds.

BUCKWINKEL/AURORA PHOTOS

Superb starlings live in cooperative family groups of as many as thirty individuals; their social structure is one of the most complicated in the avian realm.

DUSTIN R. RUBENSTEIN

nieces, and nephews, can swell to upwards of thirty individuals, more than almost any other group-living avian species. Within those groups, up to six breeding pairs build individual nests inside thorn-encased acacia trees, on a large territory that the whole group then defends year-round. The males of the group are often related, because, as with most family-living birds, female superb starlings are more apt to disperse from the group than are males, creating a patrilineal society.

Within that complex web of cooperative familial relationships, mating conflict lurks. While superb starlings form mating pairs for as long as five years and are often strictly monogamous, promiscuity rates can be as high as 32 percent in some family groups. What drives some to cheat and others to stay faithful? And what environmental factors incline particular individuals to breed themselves or to help raise others' offspring? The answers are only just emerging—and they shed new light on the evolution of mating and social behavior.

Evolutionary biologists have long recognized that nurturing close relatives has enough of a genetic payoff to explain why some individuals forgo or delay reproduction and instead remain in their group as helpers. Beginning with studies of ants and other social insects, the importance of kin in the evolution of cooperation was recognized by William D. Hamilton in the 1960s [*for more about Hamilton, see "Life Zone" on page 16*]. The insight was soon extended to cooperatively breeding birds and mammals. Simply put, cooperating with kin and living with family is behavior that can pass the acid test of natural selection, since it perpetuates one's own genes.

By the 1980s, as studies of family living in birds began to accumulate, it also became clear to Cornell University behavioral ecologist Stephen T. Emlen and others that environmental factors might influence the decision to be a breeder or a helper. A shortage of suitable nesting sites might, for instance, constrain birds from leaving their natal territory in search of opportunities to breed, and might thus favor taking on the role of helper. Today, we recognize that both ecological constraints and kin relationships likely figure into cooperative-breeding decisions. Individuals must balance the costs and benefits of trying to disperse from their natal territory to breed independently against those of staying home to help raise relatives, a calculation that will vary depending on the availability of food, turf, mates, and more.

Ever since the naturalist Alexander F. Skutch made the first observations of cooperative-breeding behavior

in birds, nearly seventy-five years ago in the forests of Costa Rica, scientists have wondered why some species cooperate and others do not, particularly when cooperative and noncooperative species are closely related. It has long been suspected that some trait shared among cooperatively breeding species explains why they live in family groups, but the evidence for any one trait is weak at best. Take life span, for instance: cooperative breeders tend to be long-lived—but there are also plenty of long-lived species that do not cooperate.

If no single intrinsic trait promotes cooperation, perhaps some extrinsic one related to the environment plays a role? African starlings offer an excellent opportunity to examine that question, because their many species not only exhibit a range of family lifestyles, but also live in a variety of habitats. Africa is an ecologically diverse continent with harsh and forbidding deserts, lush rain forests, and wildlife-rich savannas. It is no less common to see a starling darting through a forest canopy than it is to see one riding atop a Cape buffalo in a savanna [*see photograph on page 33*]. However, the cooperative species live only in savannas, whereas the noncooperative species live primarily in forests.

A similar observation has been made in Australia, where an unusually high 13 percent or more of bird species are cooperative breeders: the cooperative species tend to reside in savanna–woodlands habitat. If savannas on two of the more arid continents in the world harbor so many cooperative species, what is it about these semiarid habitats that promotes family living? The answer hinges on how semiarid savannas differ from other ecosystems.

"African savanna" may conjure up images of the Serengeti and its open plains, covered with herds of migrating wildebeests and zebras, stalked by ferocious predators such as lions, hyenas, and cheetahs. Most African savannas, however, are actually savanna–woodlands, characterized by a mixture of trees and grass. Large animals are common, but the mosaic of trees and grass also supports an abundance of smaller animals, including numerous species of birds. Rain—the lifeblood for all savanna plants and animals—is seasonal, and for many months each year the savanna is dry and barren. That seasonality in rainfall explains the great wildebeest migrations, but it cannot explain why cooperative breeders are common in savannas. After all, seasonality is also characteristic of temperate and tropical forests, and even of arctic tundras.

But there is a crucial difference in savannas: the *unpredictability* of rainfall. Although there are pronounced annual dry and wet seasons, the start and duration of the

Elephants head to a watering hole on the Serengeti Plain. Along with lions, hyenas, and wild dogs, elephants are among the well-known savanna mammals that raise their young cooperatively. Superb starlings also rely on cooperative breeding to successfully raise young during the harsh times when the rains are meager or late.

ADRIAN BAILEY/AURORA PHOTOS

rains vary from year to year, making these semiarid ecosystems some of the most environmentally unpredictable places on Earth. The absence, or even delay, of the annual rains can mean the difference between success and failure for most savanna inhabitants, including starlings.

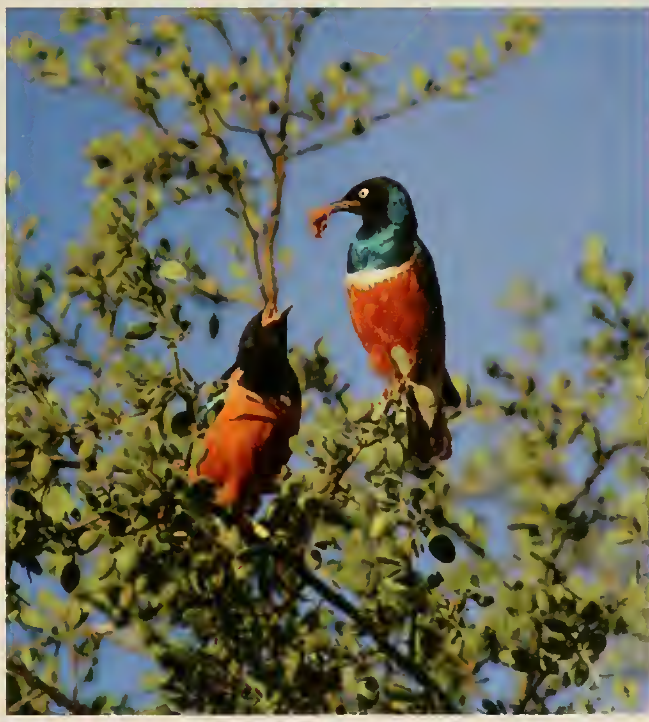
Cornell ornithologist Irby J. Lovette and I have constructed an evolutionary tree based on the DNA of all forty-five species of African starlings—primarily collected during trips we took across the savannas, forests, and deserts of Kenya. Using this tree, we have shown that the cooperative breeders are indeed found in the more seasonally unpredictable parts of Africa. When the rains fail to come or when they are scant, it may be impossible for many of the noncooperatively breeding starlings to successfully raise their young. But for the cooperative species, with helpers to share the burden of feeding their offspring, life is easier during the bad times. In fact, superb starling pairs with more helpers successfully raise more young. It is thus no coincidence that cooperative breeding is common in numerous other groups of birds that live in savannas, as well as in a variety of well-known savanna-dwelling mammals such as lions, hyenas, wild dogs, and elephants, and perhaps even early human ancestors [*see "Meet the Alloparents," April 2009*].

Cooperation in superb starlings may offer security in the face of unpredictable conditions, but conflict naturally arises, too. For one thing, same-sex individuals commonly fight over breeding opportunities. On average, only about four pairs per group breed, even though plenty of other birds are capable of reproducing. Since neither the availability of nest sites nor that of breeding partners seems to be a limiting factor, why do only a subset of the capable breeders in each group breed? Reproductive decisions seem to be related to rank: the more dominant individuals tend to breed, whereas the more subordinate individuals tend to help. However, it is not yet clear how dominance or social rank is determined in superb starlings.

Perhaps not surprisingly, reproductive conflict is influenced in part by the environment. Most fighting occurs during the dry season that comes immediately before the breeding period. That three-month period is when reproductive roles are determined, and it also happens to be the most unpredictable period in an already unpredictable environment, with the greatest variation in rainfall.

In drier years, the number of aggressive interactions between dominant and subordinate birds is higher. Those conditions are associated with higher levels of stress hormones in subordinates, more of which then adopt helping roles. Additionally, helpers do a greater proportion of the nestling feeding in drier years than they do in wetter ones. In contrast, during wetter years, conflict decreases; stress hormone levels in subordinates match those of dominant birds; and younger, inexperienced birds attempt to breed for the first time. Although stress hormones are not likely to determine breeding roles in this species directly, they are indicative of the level of social stress with which an individual must cope. Subordinate individuals must be adaptable in their reproductive strategies, gauging the conditions in a given year.

Attaining breeding status does not always mean that life is better, especially for male superb starlings. Preventing one's mate from straying and copulating with another individual is nearly as important as finding a mate in the first place. After all, failure to father the offspring of your mate would not only mean a wasted breeding attempt, but would also entail the costs of raising someone else's young. For decades ornithologists have known that 90 percent of bird species are socially monogamous, forming pair bonds to raise young. Now we also know that nearly 90 percent of bird species are promiscuous on the



Superb starlings form monogamous pairs for up to five years, but some females are promiscuous. Securing a male helper to bring food to the nest is one reason for the cheating.

side. Indeed, molecular studies (bird paternity tests) have confirmed that the outwardly devoted, altruistic appearance of superb starlings is deceptive.

So which males do females choose to cheat with? Like everything else in the secret lives of starlings, the answer is not simple. Two distinct mating strategies are pursued by promiscuous females: half copulate with males from inside the group, and the other half with males from outside the group. A given female's choice of cheating partner depends upon her needs. Promiscuous females that choose mates from inside the group tend to have few surviving offspring from previous years, and thus few potential helpers. Those females target subordinate, nonbreeding males from inside the group that can, and eventually do, help at their nests. In other words, females without potential helpers are trading sex for child care to improve the odds of successfully raising offspring. On the other hand, promiscuous females that consort with males from outside the group gain some genetic diversity for their young. In comparison with females that do not cheat, they are more genetically similar to their mates, possibly as a result of inbreeding. Males from neighboring groups enable such females to provide any resultant offspring with a measure of genetic variation that the original mate lacks.

PHILIP MARAZZI/PAPILIOPHOTOS.COM

Superb starlings vigorously compete for food with other species, such as these gray-headed sparrows in Kenya's Samburu National Park. Despite living in cooperative groups, starlings can also experience intense conflict with each other: dominant and subordinate individuals tend to fight over breeding opportunities during especially dry seasons, when food is scarce.

Given the two types of potential reproductive benefits of cheating in superb starlings—help feeding offspring and an increase in offspring's genetic diversity—one would think cheating would be the norm, as it is in many other cooperative breeders. But promiscuous matings are actually fairly rare in superb starlings, accounting for, on average, only 14 percent of offspring produced. A closer examination of the mating system reveals that promiscuous matings are extremely rare in some groups, but relatively common in others: promiscuity rates range from 4 percent to 32 percent among family groups.

Promiscuity rates do not vary from year to year, and are not related to variation in rainfall. Nor does rank or social structure seem to influence the patterns. Instead, promiscuity relates most closely to territory quality, which remains stable across years. Females living on high-quality territories, with plenty of food, are less promiscuous than those living on low-quality territories with little food. As New Yorkers might especially appreciate, it all comes down to real estate.

The highest-quality superb starling territories encompass large open grassy areas, or glades, where insects are readily available during the rainy season, and to a lesser extent during the dry season. Superb starlings are omnivorous throughout the year, but they need to feed their nestlings insects—primarily grasshoppers—during the breeding season. Securing that high-quality real estate seems to be the birds' prime reproductive strategy. Yet such glades are rare, and unevenly distributed across the landscape. The best real estate comes from abandoned livestock corrals, called *bomas* in East Africa, where an accumulation of dung and urine has enriched the soil—an effect that lasts at least forty to fifty years, and possibly as long as a hundred years or more.

Those nutrient-rich hot spots support large numbers of insects and attract a diversity of wildlife, ranging from large herds of antelopes to small creatures such as bat-eared foxes

DUSTIN R. RUBENSTEIN

A greater blue-eared glossy starling (Lamprotornis chalybaeus) rides atop a Cape buffalo in Kenya's Lake Nakuru National Park.

[*see "The Natural Moment," page 2*]. Superb starlings build their nests around the edges of glades and forage throughout the year in those food-rich patches. The abundance of insects is essential to producing offspring during the breeding period, and groups with more, or larger, abandoned boma sites on their territories have greater access to food throughout the year. It is not yet clear how or why those nutrient-rich patches affect promiscuity patterns, but clearly they are important to starlings. Thus, resource availability as it varies unpredictably in *time*—rainfall patterns from year to year—has a greater influence on the social system of superb starlings, in terms of cooperation and reproductive conflict over breeding roles, whereas resource availability as it varies in *space*—insect location and abundance—has a greater influence on the birds' mating system, with respect to mating conflict and patterns of promiscuity.

Rainstorms on the African savanna are life-giving and life-changing events. Within only a day or two of the first storms of the season, life bursts forth from the dry, barren land as green grass sprouts from soil, bringing with it a flush of new insects. A few minutes after a particularly intense storm, millions of winged termites erupt from the ground, causing a feeding frenzy among the birds. As we've seen, starlings are adapted to the unpredictable nature of these rainstorms and to the savanna environment in general.

But humans are modifying these semiarid environments. Whereas traditional livestock practices have had generally positive effects on superb starlings by creating nutrient-rich glades, not all human-directed changes in land use are beneficial. In the coming months, I will begin to explore how overgrazing by cattle, goats, and sheep influences starling social behavior. Numerous studies have shown that overgrazing in Africa can lead to declines in bird and mammal populations, as well as to land degradation. My research suggests that such degradation could also have more subtle consequences for avian reproductive behavior.

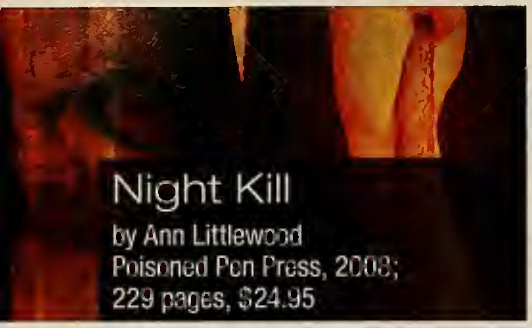
In addition, as the Earth continues to warm at alarming rates, unpredictable and extreme weather events such as droughts, floods, and tornadoes are becoming increasingly common everywhere. In sub-Saharan Africa in particular, droughts are becoming more intense and more frequent. At my study site at the Mpala Research Centre in central Kenya, superb starlings have largely failed to breed during the past two years during the primary rainy season, which barely materialized. I will now begin to examine the reproductive physiology and social behavior of superb starlings living in different Kenyan habitats to see how they and other bird species might respond to global warming and its associated increase in environmental unpredictability. The secret and complicated lives of starlings still have a lot to teach us about adapting to uncertainty. Although research about them will not reduce the volatility in New York real estate prices, it may help predict the future biotic consequences of climate change and habitat degradation.

Dustin R. Rubenstein is an assistant professor of ecology, evolution, and environmental biology at Columbia University. He earned his PhD at Cornell University and held a Miller Research Fellowship at the University of California, Berkeley. For nearly ten years, he has been studying the social behavior and reproductive physiology of African starlings in Kenya. He also studies the complicated family lifestyles of Caribbean sponge-dwelling snapping shrimp. Previously, he studied the breeding and migratory behavior of birds in North and Central America, and the mating system and reproductive physiology of marine iguanas in the Galápagos Islands. These studies convinced him that how animals cope with the unpredictable nature of the environment, particularly in the semiarid tropics, is central to our understanding of the evolution of social and mating behavior.

Web links related to this article can be found at www.naturalhistorymag.com

BOOKSHELF BY LAURENCE A. MARSCHALL

For a reviewer on deadline, summer comes early—so here I am in May sifting through a stack of warm-weather fiction with themes in natural history and the sciences. The stack is heavy, but the prose is light, perfect entertainment for a summer afternoon out-of-doors. Here are some of the best of the bunch:



Iris Oakley loves working with big cats at the Finley Memorial Zoo in Vancouver, Washington, but lately things have not been going her way. For starters, the lions seem to have killed her husband, Rick Douglas. An experienced zookeeper, he wouldn't have fallen in the moat at the lion enclosure that night if he hadn't been blind drunk. Alcohol, and plenty of it, had been the bane of their on-again, off-again marriage, and now, thanks to alcohol, the marriage was off—forever. Still, Iris is understandably shaken, and maybe that's why she almost got mauled herself: she must have forgotten to close the door on old Rajah the Bengal tiger before going out into the cat's exercise yard. As a result, the foreman, Mr. Wallace, is on her case and has transferred her to working with birds under the graying, taciturn Calvin Lorenz. Birds, of all things!

Still, something doesn't quite add up. Why would Rick get drunk on the very same night that he had promised Iris he'd stay on the wagon, only hours after the two had celebrated a new intimacy by getting back together? Could someone else have opened the door to the tiger's cage *after* Iris had closed it and gone into the yard?

If so, then who? *Night Kill* is a fine Agatha Christie-style whodunit, with a large cast of quirky suspects, a sense of gentle foreboding, and, as befits a zoo story, lots of red herrings. Iris's character is nuanced, sharp, and resourceful, like any good heroine, but believably vulnerable and insecure as well. The narrative—thanks to the author's own experience as a zookeeper—ably describes the daily lives of keepers, the operations of small zoos, and the behavior of captive animals. You turn the last page having learned about a part of the world you might never have encountered otherwise. If a mystery's a good read—and this is—you leave eager for a sequel; since this is Littlewood's first novel, we can only urge her not to make it her last.

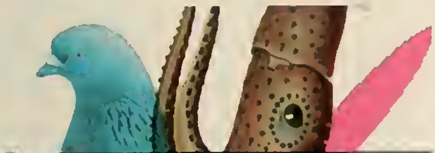
The pioneering Europeans who colonized New Zealand in the mid-1800s found themselves in strange and unfamiliar territory. Birds, many of them flightless, filled most of the ecological niches occupied by mammals in other parts of the world, and large mammals, in fact, were totally absent. So, in an attempt to recreate a bit of the old country in the new land they now dominated, settlers brought in sheep, cattle, and pigs for husbandry, and rabbits for sport. The bunnies were a big mistake. Within a few decades rabbits had overspread the islands and were chewing up the greenery at an alarming rate. The solution recommended by experts at the time was to bring in the mustelids: ferrets, stoats, and weasels—fierce hunters whose natural prey was thought to be rabbits.

Kiwi author Fiona Farrell uses the first ecoblunder to launch her graceful historical novel, though much of it is set in rural England. For starters, Walter Allbones, a lad of humble origins, supports his younger siblings by taking on odd jobs and by poaching rabbits from the estates of wealthy landowners. He's a born naturalist who knows ferrets firsthand, as he breeds them to flush rabbits from their burrows.

Returning from hunting one night, his pockets filled with game, Allbones comes upon a Mr. Pitford and his granddaughter Eugenia. Pitford owns a large estate nearby, and, like many well-to-do Victorians, he's an avid natural history buff. Pitford's specialty is exotic birds. Aware of the rabbit problem in New Zealand, he contracts with Allbones to provide several hundred ferrets for shipment to the colony, to be exchanged for avian species Pitford wants to add to his collection.

What follows is not altogether unpredictable—a growing love affair between the rough-cut Allbones and the delicate Eugenia, with occasional rough patches along the way. Allbones has conflicts with envious villagers, and run-ins with arrogant gentry. Eventually he embarks, with his ferrets, on a white-knuckle clipper-ship voyage halfway around the world, accompanied by Eugenia and Pitford.

You can almost breathe the atmosphere of nineteenth-century England. But there's a modern thread of irony woven into the plot line. With the hindsight of over a century, we can see the futility of Mr. Pitford's plan to, as he tells Allbones, "rescue the New Zealander from ruin." Ferrets and stoats do indeed love rabbits, but they also love a good egg with their meal. Mr. Pitford's prized birds, many of which (in the absence of predators) laid their eggs unprotected on the ground, found themselves on the brink of extinction soon after the importation of mustelids. New Zealanders today set poisoned traps for stoats throughout their forestlands, and would surely regard Mr. Allbones's ferrets as pests, not rescuers.



The Great Perhaps

by Joe Meno
W.W. Norton & Company, 2009;
415 pages, $24.95

Jonathan Casper, a professor of paleontology at the University of Chicago, dreams of "knowing the answers, of seeing the simplicity of the universe, of solving the big questions." But his own personal universe seems less and less simple the older he gets. His father is in a nursing home, wasting away. His wife is harried and distracted, and his two teenage daughters are rebelling against all family ties.

The narrative of *The Great Perhaps*, a series of alternating chapters revealing the inner lives of each of the five members of the Casper family, resembles one of those dark and quirky film comedies, like *Little Miss Sunshine*, in which unusual characters struggle to come to terms with the harsh banality of existence. Jonathan is obsessed with the hunt for a living fossil, a prehistoric giant squid that may have survived the millennia by hiding in the depths of the sea. Madeline, a behavioral psychologist, wants to understand society by studying pecking order in birds, but is baffled by what appear to be a series of rapes and murders committed by the pigeons in her laboratory. The elder daughter, Amelia, fancies herself a revolutionary Marxist, while her sister Thisbe prays incessantly in an attempt to puzzle out her relationship with God. Meanwhile Henry, the grandfather, is trying to simplify his life by speaking less and less and reducing his memory to a few slips of paper filed away in a drawer.

At first you read on because those people seem so extraordinary—Jonathan suffers a strange form of epilepsy triggered by clouds; his wife follows hallucinations around town in her white Volvo; Amelia is building a pipe bomb in a toy airplane; Thisbe struggles with sexual feelings for a classmate; and grandfather Henry keeps trying to escape his nursing home so he can fly to Japan. The satisfaction of a novel like this, however, is that the more we get to know those oddballs, the more ordinary they seem. Like the protagonists, we must eventually come to terms with the limited span of our days, and the limited power we have to comprehend what it all means.

Ultimately, then, *The Great Perhaps* is about the failure of certainty that we face at critical junctures in our lives: at coming-of-age, at middle age, and at the great summing-up at the end. Perhaps.

Pythagoras' Revenge:
A Mathematical Mystery
by Arturo Sangalli
Princeton University Press, 2009;
201 pages, $24.95

Secret societies are . . . well, secret. That makes them ideal players in the particular brand of fiction whose main thesis is that nothing is what it seems, and that the workings of the everyday world are guided by a hidden agenda known only to a select few. Though it was hardly the first of this genre, the enormous success of *The Da Vinci Code* has given encouragement to a swelling list of imitators, each seeking a unique conspiratorial slant. Enterprising authors have mined the literature for esoteric groups that might provide distinct frameworks for their plots—the Masons, the Illuminati, the Knights Templar.

Arturo Sangalli's "mathematical mystery" novel draws its inspiration from one of the oldest of those orders, the Pythagoreans, who flourished around the sixth century B.C. Pythagoras, founding father of the sect, was a shadowy figure, known only through secondhand accounts. But we do know that he taught that the soul was immortal, that humans could be reincarnated as animals, and that the eating of beans was strictly forbidden—possibly because they resembled human testicles. Above all, he taught that nothing is what it seems, and that the workings of the everyday world are guided by a hidden agenda—mathematics—known only to a select few who understood the workings of numbers.

The Pythagorean brotherhood was sworn to secrecy, which is why no contemporary documents survive. But suppose that Pythagoras, prior to his death, had written down some of his secrets and entrusted them to an acolyte. And suppose that this manuscript had been preserved by a few surviving members of the clandestine order. And suppose that a sect of neo-Pythagoreans reconstituted itself in the twenty-first century to welcome the second coming of their prophet, reincarnated as a human after more than two millennia inhabiting various other animate forms (which species, we can only imagine). And suppose that a young mathematician is recruited by the Order to aid in the search for the manuscript and any clues it might offer on the return of Pythagoras.

That's a lot of "supposes"—and there are many more in this novel—but Sangalli really isn't in the business of writing a blockbuster thriller. His plot line meanders, and his cast of characters seems to have been selected at random from a list of pulp-fiction stereotypes. Formulaic elements cannot save the tale: *Pythagoras' Revenge* is not likely to be optioned as a major Hollywood movie.

Yet it makes entertaining and instructive warm-weather reading. Sangalli is a science writer with a PhD in mathematics, and *his* hidden agenda is to pass on a little Pythagorean lore through digressions on Greek philosophy and the basics of number theory (with the preservation of ancient manuscripts thrown in as a bonus). Since we live in a technological world that relies on numbers for its day-to-day operation, we are all, in a sense, followers of Pythagoras. Except most of us can eat beans without feeling guilty.

ALSO OF NOTE

Whispers of the Dead
by Simon Beckett
Delacorte Press, 2009;
309 pages, $26.00

In last year's *Written in Bone*, by English thriller writer Simon Beckett, forensic anthropologist David Hunter solved a series of gory murders on a remote island off the coast of Scotland, narrowly escaping a similar fate. This year he's back, on a professional visit to the "Body Farm" in Tennessee, world famous for research in forensic science. Needless to say, the cadavers are not just of academic interest. There are serial killers on the loose, and Dr. Hunter once again finds himself among the hunted.

Arctic Drift
by Clive Cussler and Dirk Cussler
G. P. Putnam's Sons, 2008;
515 pages, $27.95

So what if Clive Cussler pushes credulity to the limit? You can count on him for a plot that moves along at a breathless pace and offers a few historical and scientific "what-ifs" to challenge the imagination. Cussler's latest offering is co-written with his son. In it, perennial hero Dirk Pitt of the National Underwater and Marine Agency (NUMA) saves the U.S. from all-out war as he investigates reports of a discovery that might save the world from global warming. There's plenty of hot action in the Arctic—an ideal refreshment for muggy summer days.

Laurence A. Marschall is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and coauthor, with Stephen P. Maran, of Galileo's New Universe: The Revolution in Our Understanding of the Cosmos, *published by BenBella Books.*

LIFE ZONE

Continued from page 20
But many more people, thousands of us, miss his ideas, his awe-inspiring, sometimes wrong, often right, narrative of the living world. At Hamilton's funeral, Luisa Bozzi, his partner of several years, offered over him: "You will live not only in a beetle, but in billions of spores of fungi and algae. Brought by the wind higher up into the troposphere, all of you will form the clouds, and wandering across the oceans, will fall down and fly up again and again."

Every time you catch a snowflake on your tongue you have some chance at finding, buried inside it, if not Bill Hamilton, then the life he predicted. However such life tastes to you, to Hamilton it could only have tasted sweet. He was, like those snowflakes, one of a kind.

ROBERT R. DUNN *is an ecologist in the Department of Biology at North Carolina State University in Raleigh. His first book,* Every Living Thing: Man's Obsessive Quest to Catalog Life, from Nanobacteria to New Monkeys, *was recently published by Smithsonian Books/HarperCollins.*

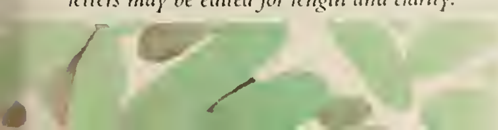
WORD EXCHANGE

Continued from page 6
ness in their family. One woman mentioned that her uncles were colorblind. That individual not only saw three emission lines, but a fourth line even farther toward the ultraviolet part of the spectrum.

Tetrachromats are obviously an overlooked population deserving study. One wonders if their capacity is recently evolved or a genetic remnant of an ancient adaptation.

Larry Wegmann
Ozarks Technical Community College
Springfield, Missouri

NATURAL HISTORY *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*



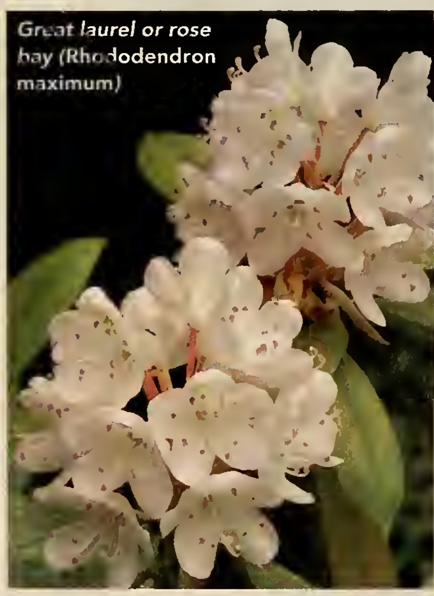
THIS LAND BY ROBERT H. MOHLENBROCK

The Name of the Rose Tree

A grove in New Hampshire features one species in the huge genus Rhododendron.

Great laurel and eastern hemlock

In April 1985, for a column on Roan Mountain, North Carolina, I paid tribute to the magnificent Catawba rhododendron, *Rhododendron catawbiense*. My column this time centers on *R. maximum*, most commonly known as great laurel or rose bay. The shrub, sometimes attaining the height of a small tree, usually lives in low woods along mountain streams. It occurs in the Canadian provinces of Quebec and Nova Scotia, and in the United States from Maine to Georgia and westward as far as Ohio, Kentucky, Tennessee, and Mississippi. It is especially common in the Great Smoky Mountains of North Carolina and Tennessee, but one of the finest stands anywhere lies in southern New Hampshire. Covering sixteen acres, the stand is the focal point of Rhododendron State Park and is designated a National Natural Landmark.



Great laurel or rose bay (Rhododendron maximum)

BEN KIMBALL FOR THE NH NATURAL HERITAGE BUREAU

In 1753 Linnaeus gave the genus names *Rhododendron* ("rose tree") and *Azalea* ("dry") to two groups of handsome flowering shrubs, distinguishing them, as was his custom, by apparent differences in the sexual parts of their flowers. A decade later he named a third, similar genus, *Rhodora*. The species of all three genera look a lot alike, however. Acknowledging the strong family resemblance, the German botanist Johann Georg Gmelin included *Rhodora* within *Rhododendron* in 1791, and five years later the British botanist Richard Anthony Salisbury folded *Azalea* into that grouping. In 1834 George Don, also British, formally organized the expanded genus *Rhododendron* into eight sections, or subgenera, a taxonomy that has lasted until now, although genetic studies have begun to refine and consolidate it further.

Several features still distinguish rhododendrons in the narrow sense. They have evergreen leaves, which are typically large and leathery, and bell-shaped flowers, each with five petals of equal size and usually ten pollen-producing stamens. Azaleas have either deciduous or "persistent" (semi-evergreen) leaves, which are smaller and not leathery, and funnel-shaped flowers, also with five petals of equal size but usually with five stamens. Rhodoras have deciduous leaves and ten stamens per flower, but the petals are arranged into two groups, three on one side and two on the other.

There are more than 850 wild species of *Rhododendron* in the world, including at least twenty-six native to the U.S.—fourteen azaleas, ten rhododendrons, and two rhodoras (not counting myriad hybrids). Great laurel, one of the rhododendrons, is distinguished by its large, leathery leaves, about eight inches long and two to three inches wide, combined with dense clusters of large, usually

HABITATS

Hemlock–beech-oak-pine forest American beech and eastern hemlock are common, but several other tree species are prominent in this transitional forest that falls between the boreal forest to the north and the eastern deciduous forest to the south, including eastern white pine, mountain maple, red maple, and yellow birch, along with lesser numbers of American elm and paper birch. Allegheny serviceberry, gray birch, northern red oak, and white oak occur in slightly elevated areas. Arrowwood, Canada yew, and maple-leaf viburnum help make up the shrub layer.

Wildflowers include the spring-blooming bloodroot, bluebead, Canada lily, Canada mayflower, downy rattlesnake plantain, false Solomon's seal, foamflower, Indian cucumber, jack-in-the-pulpit, pink lady's slipper, pipsissiwa, red baneberry, Solomon's seal, starflower, waxflower shinleaf, wild geranium, wild sarsaparilla, wood anemone, yellow dogtooth lily, and three kinds of trilliums.

Summer and autumn bloomers include Canadian honewort, gaywings, mountain woodsorrel, northern heart-leaved aster, white avens, white rattlesnake-

BEN KIMBALL FOR THE NH NATURAL HERITAGE BUREAU

pink flowers borne on flower stalks with sticky hairs (probably a means of keeping insects that provide little help with pollination from crawling into the flowers). It lives in dense shade along streams and on moist, rocky, forested slopes, and like many rhododendrons and azaleas, tolerates acidic soils, such as those found in bogs.

Covering four and a quarter square miles, Rhododendron State Park embraces a hemlock-beech-oak-pine forest, a part of the Great North Woods that lies between the boreal forest to the north and the eastern deciduous forest to the south. Botanist Doug Ladd, who is director of conservation science for the Nature Conservancy in Missouri (and whose *North Woods Wildflowers* is a must for anyone exploring the region), locates the Great North Woods in all of Maine, New Hampshire, and Vermont, and most of Massachusetts and New York; across southern Quebec, southern Ontario, north-central Pennsylvania, and much of Michigan; and as far west as northeastern Minnesota and the northern half of Wisconsin. Because the habitat includes a mixture of cone-bearing trees and cold-tolerant hardwoods, Ladd characterizes it as "transition forest."

According to Ladd, the Great North Woods occupies lands that are relatively "new," having been covered by thick glacial ice during the late Pleistocene and then gradually released from its grip between about 18,000 and 10,000 years ago. Many glacial features such as moraines and potholes are found throughout the region, and because the mountainous bedrock is usually impermeable, many wetlands occur.

The sixteen acres of dense *Rhododendron maximum* shrubs would be an impenetrable thicket if it were not for the tunnel-like trail carved through it. Great laurel usually grows in rich organic soil, and its roots sometimes form thick mats, similar to those created by peat moss. At one place along the trail, where the soil becomes extremely mucky, a boardwalk permits the hiker to continue unimpeded. Beyond the boardwalk is a spruce-fir swamp. A short branch trail goes through a dense growth of mountain laurel, and a wildflower trail with plantings by the local garden club shows off native and other species.

Pink lady's slipper

BEN KIMBALL FOR THE NH NATURAL HERITAGE BUREAU

At the entrance to the park, history buffs can pause at the Old Patch Place, the home built by Captain Samuel Patch or his son around 1815. It has been listed on the National Register of Historic Places since 1980.

VISITOR INFORMATION
Rhododendron State Park
Route 119W,
Fitzwilliam, NH 03447
603-532-8862 (at Monadnock State Park)
http://nhstateparks.org/state-parks/alphabetical-order/rhododendron-state-park/

ROBERT H. MOHLENBROCK *is a distinguished professor emeritus of plant biology at Southern Illinois University Carbondale.*

root, white snakeroot, white wood aster, wild bergamot, wreath goldenrod, and zigzag goldenrod.

Among the spore-producing plants are Christmas fern, groundcedar, intermediate wood fern, interrupted fern, maidenhair fern, and shining clubmoss.

Spruce-fir swamp A scattering of trees include conifers—balsam fir and red spruce—and the deciduous red maple and black gum. Among the shrubs (in addition to abundant great laurel) are common winterberry, highbush blueberry, mountain holly, sheep laurel, and speckled alder. Nonwoody plants include bunchberry dogwood, cinnamon fern, creeping snowberry, partridgeberry, spotted wintergreen, Virginia iris, and several sedges.

Rhododendron stand Most of the great laurels in the grove are less than twenty feet tall, although the species can grow twice that high. The slender, leaning stems weave a thicket so crowded and shaded that no other plants grow beneath them. The plants bloom from late June to mid-July, producing large pink or white blossoms.

The next issue for Marketplace is SEPTEMBER.

ON SALE AUGUST 21,2009.

To advertise in *Marketplace* contact:
Media Options at 800 442-6441
or email at mediopt@aol.com
Charge your ad to
American Express/Mastercard/Visa

fyi READER SERVICE

For free information from the advertisers listed below, circle the corresponding numbers on the attached postage-paid card. Mail card, fax it to 856-380-4101, or visit us at www.naturalhistorymag.com. If the card is missing, mail your request to: P.O. Box 9000, Maple Shade, NJ 08052.

ADVENTURE TRAVEL/TOURS

1. ADVENTURESMITH EXPLORATIONS
Explore nature up close and in style aboard luxury yachts, small ships and wilderness lodges with adventure travel experts.

2. AMAZONIA EXPEDITIONS
Award-winning Jungle Lodge in the Tamshiyacu-Tahuayo Reserve, shown to have the greatest diversity of mammals in all of the Amazon.

3. BUSHTRACKS
Tailor-made adventures by private air to exotic destinations in Africa, India, and South America—including expert guides and educational experiences.

4. CHEESEMANS' ECOLOGY SAFARIS
In-depth wildlife tours to unique destinations: Antarctica, Africa, Bhutan, more! Maximum field time, small groups.

5. GALAPAGOS TRAVEL
Comprehensive, educational, professionally-led natural history tours of the Galapagos Islands. 11- or 15-day tours of all the significant outer islands.

6. MAYA RESEARCH PROGRAM
MRP offers opportunities to participate in archaeological excavations and study tours in Belize.

7. TARA TOURS
Tara Tours specialize in travel to Central and South America since 1980. Free brochures and quotes.

8. WILDSIDE NATURE TOURS
Small group photo workshops, birding tours and family adventures! Alaska and Galapagos cruises, African Safaris and much more!

CANADA

9. NEW BRUNSWICK
Walking on the ocean floor...just one of the Magnifique moments waiting in New Brunswick, Canada!

10. NEWFOUNDLAND & LABRADOR
It's a short trip to the very end of the Earth, where the dawn breaks first at the most easterly edge of the continent.

11. NOVA SCOTIA
You're invited to explore scenic beauty, rich heritage and vibrant culture of Nova Scotia on Canada's seacoast.

12. TOURISM PRINCE EDWARD ISLAND
Come experience our unique red cliffs and parabolic sand dunes and hike or bike the Confederation Trail across our island.

CRUISES

13. AMERICAN CANADIAN CARIBBEAN LINE
Cruise historic American waterways and Caribbean to places usually only accessible by private yacht. Spectacular itineraries, 100 guests.

14. CANODROS
Canodros offers up-scale services in Ecuador with the Galapagos Explorer II. Enriching experience of the culture and natural history.

15. VOYAGES OF DISCOVERY
Voyages of Discovery takes you to Asia, India, Africa, Northern Europe and the Mediterranean on *mv Discovery*.

INTERNATIONAL TRAVEL

16. BELIZE
Catch the Adventure! From rainforest resort to Barrier Reef. Belize is only 2 hours from the USA. Belize. Mother Nature's best kept secret.

MARYLAND

17. ALLEGANY COUNTY
300 Years of American history is alive in Allegany County. Discover the original Gateway to the West.

18. CAROLINE COUNTY
Small town charm, rich heritage and nature's adventures among majestic Chesapeake landscapes.

19. CECIL COUNTY
Beautiful countryside right on I-95! Rolling hillsides meet harbors and historic villages, Chesapeake Bay cuisine, horseback riding, antiques, and more!

20. DORCHESTER COUNTY
Home to Blackwater National Wildlife Refuge; explore the heart of Chesapeake Country.

21. FREDERICK COUNTY
Maryland's Crossroads of History. Antiques, battlefields, covered bridges, parks, wineries and more, close to Gettysburg and DC.

22. KENT COUNTY
A scenic peninsula on the Chesapeake Bay, offering fishing, boating, kayaking, small beaches, great shopping, and museums.

23. MARYLAND VACATIONS
Beaches, mountains, big cities, small towns. Maryland has so many things to do, so close together.

24. MONTGOMERY COUNTY
Experience transportation history along the C&O Canal and the National Capital Trolley Museum. So many things to do.

25. U.S. NAVAL ACADEMY
U.S. Naval Academy, Annapolis, MD. Learn about life and traditions of midshipmen on a tour of the four-year college of the U.S. Navy.

26. WORCESTER COUNTY
Maryland's only seaside. Discover Assateague Island National Seashore. Kayak, birdwatch, cycle, golf and explore our historic towns.

MISCELLANEOUS

27. ATHENA REVIEW
Athena Review, journal of archeology, history and exploration, invites you to send for more information on a free issue.

28. GORILLA GLUE
Gorilla Glue is the ideal solution for projects indoors and out. Bonds wood, stone, metal, ceramic, foam, glass and more!

29. HERITAGE AUCTION GALLERIES
Heritage Auction Galleries' auctions feature comprehensive private collections of mineral specimens and rare, historical items.

U.S. TRAVEL

30. ALABAMA'S GULF COAST
Necessities: Time together to enjoy the simple pleasure and beautiful treasures of Alabama's Gulf Coast.

31. ARIZONA MUSEUM OF NATURAL HISTORY
Plan your visit to AzMNH, it is the great place for dinosaurs and much more!

32. ARIZONA. THE GRAND CANYON STATE.
From vast ranchlands to historic mining towns, from Native American ruins to fossils 225 million years old, timeless discoveries await around every corner.

33. BATON ROUGE, LOUISIANA
Need a good reason to stick around? We don't have one, we've got 225. Dive into the colorful political history of Louisiana's capital city, Baton Rouge.

34. DELAWARE
Discover natural history from life-sized dinosaurs to tiny fossils. Explore cultural treasures, wildlife areas and birding hot-spots in Delaware!

35. HELENA, MONTANA
Helena offers so many amazing experiences for history buffs; you'll have a hard time choosing how to "punch your ticket." Free planner.

36. HOLBROOK, ARIZONA
Come explore Northeastern Arizona, Petrified Forest National Park, Old West History, Route 66, Native American Culture.

37. MESA, ARIZONA
Outdoor adventure is just minutes away. Go hiking, golfing, horseback riding or tubing down the Salt River, or just enjoy the best in Southwest Cuisine.

38. MONTANA'S MISSOURI RIVER COUNTRY
Explore unspoiled land offering fishing, wildlife, birding trails, history and dinosaur museums.

39. NAVAJO NATION TOURISM
Plan your unforgettable memories within the four sacred mountains on the Navajo Nation.

40. NEBRASKA
Experience frontier adventures, natural wonders, arts and culture. Order free travel guide today.

41. RUSSELL COUNTRY
Discover majestic beauty while enjoying Montana's legendary recreation and historic landmarks.

42. SIERRA VISTA VISITORS CENTER
Enjoy the natural beauty, the world-renowned birding experience, the thousands of years of history and the diverse cultural activities.

43. THE GREAT STATE OF TEXAS
Create your perfect vacation with your FREE Texas State Travel Guide.

44. TUCSON
Entertainment options are as wide open as the landscape—first-rate golf, esteemed spas and fine outdoor dining.

45. YUMA
Historic Colorado River location amid desert and mountains. Watchable wildlife, birding, hiking, boating, golfing, casinos, museums.

MARKET CLASSIFIED

ALASKA WILDLAND ADVENTURES
907-783-2928 • www.kenaifjordsglacierlodge.com

HOLIDAY GROUP
800-597-5783 • www.holidaygroup.com/nh

MATH TUTOR DVD. COM
877-MATH-DVD • www.mathtutordvd.com

SAN FRANCISCO HERB & NATURAL FOOD CO.
800-227-2830 • www.herbspicetea.com

SKYLOG BY JOE RAO

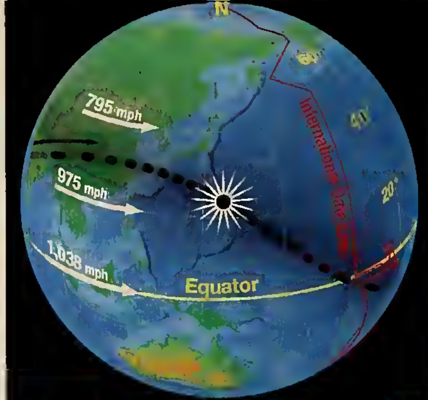
The astronomical event of the summer occurs on July 22: a total eclipse of the Sun. The Moon's dark umbral shadow will touch down in the Arabian Sea off the west coast of India at 6:23 A.M. local time, then sweep across Asia and over the Pacific Ocean. About 200 miles east-southeast of Iwo Jima, the eclipse hits the "sweet spot," where viewers stationed at sea should enjoy six minutes and thirty-nine seconds of totality, beginning at 11:32 A.M. local time, when the Sun is almost directly overhead. Thereafter, the umbra will move southeast, finally lifting off a little beyond the international date line. (Ecliptomaniacs east of the line should mark their calendars for July 21!)

Under absolutely optimal conditions, a solar eclipse could provide as much as seven minutes thirty-one seconds of totality to a stationary observer, but most eclipses average about two to three minutes. Several factors contribute to making this one especially long, and they go into figuring out the best observation post.

A solar eclipse occurs when the Moon is lined up between the Sun and Earth, and therefore when the Moon is new. However, not every new Moon results in an eclipse. That is because the Moon's orbit is slightly tilted with respect to the ecliptic, the plane of Earth's orbit around the Sun. During each orbit around Earth, the Moon passes once down and once up through the ecliptic. Those intersections are known as the descending and ascending nodes. On July 22, the Moon will be close to the descending node when it is new, and thus well lined up between the Sun and Earth.

Second, Earth will be near aphelion, the most distant point in its orbit around the Sun, so the Sun will appear a bit smaller in the sky than at other times of year. And, coincidentally, the Moon will be near perigee, when it is closest to Earth in its own orbit, so its disk will appear slightly enlarged.

As viewed from above the North Pole, the Moon orbits Earth counterclockwise, so its shadow travels west to east. The shadow's shape and size change as it moves across Earth's spherical surface; the shadow also changes speed as the Sun angles higher in the sky—it is slowest wherever it is landing most perpendicularly to the ground. For example, for this eclipse, if you stood on the Moon and looked at the umbra when it is most nearly centered on Earth's disk, you would see an almost perfect circle of shadow 161 miles across, traveling at the same speed as the Moon in its orbit—about 2,400 miles per hour at perigee. Based on that information, you might expect a viewer stationed at the center of the umbra's path to witness a total eclipse lasting roughly four minutes (that's how long it takes to cover 161 miles at 2,400 miles per hour).



The duration of totality for the July 22 solar eclipse is longest where the passing shadow slows down (highlight, center). Earth's rotation boosts the viewing time.

JOSEPH SHARKEY AFTER XAVIER M. JUBIER/TERRAMETRICS & FRED ESPENAK

But there is another factor that must be taken into account: Earth's rotation. For example, anyone standing at the equator is being passively carried west to east at about 1,038 miles per hour. For this eclipse, Earth's North Pole will be tilted toward the Sun, making it summertime in the Northern Hemisphere, so the rotational benefit will be more limited, but still enough to extend the duration of totality for more than an additional two and a half minutes.

JOE RAO is a broadcast meteorologist and an associate and lecturer at the Hayden Planetarium in New York City (www.haydenplanetarium.org).

JULY NIGHTS OUT

7 The Moon is full at 5:21 A.M. EDT.

9 Jupiter and Neptune engage in the second of three conjunctions this year [*see "Skylog," May 2009*]. Jupiter rises before 10:30 P.M. in the east-southeast and is high in the sky several hours later. With good binoculars or a small telescope, focus first on Jupiter; Neptune is the tiny bluish "star" appearing about 0.56 degrees to Jupiter's north.

10 As the Moon rises late this evening, Jupiter shines about 5 degrees to the Moon's right.

15 The Moon wanes to last quarter at 5:53 A.M. EDT.

18 A couple of hours before sunrise, in the east-northeast, Mars sits about 4 degrees below and to the right of the Moon.

21 The Moon arrives at perigee, the part of its orbit closest to Earth, at 4 P.M. EDT. It becomes new at 10:35 P.M. EDT, and crosses the descending node of its orbit an hour and a quarter later. Those events contribute to shaping a long total solar eclipse on July 21–22 (see story above).

28 The Moon waxes to first quarter at 6:00 P.M. EDT.

AUGUST NIGHTS OUT

5 The Moon is full at 8:55 P.M. EDT.

6 Soon after sunset, the Moon rises in the east-southeast with Jupiter, which is about 4 degrees to the Moon's right.

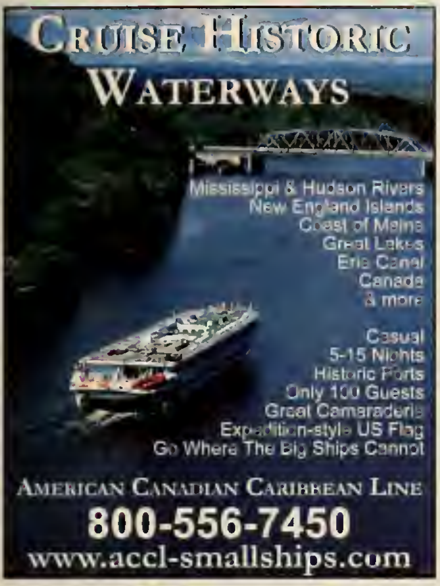
12 and 13 The Perseid meteor shower peaks during the predawn hours for U.S. time zones. The meteors appear to emanate from the constellation Perseus. Unfortunately, the Moon, which wanes to last quarter on the 13th at 2:55 P.M. EDT, brightens the sky during the prime meteor-watching hours.

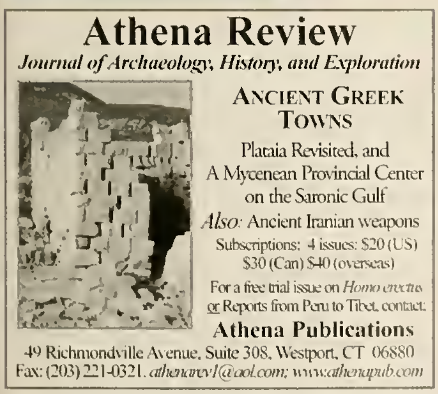
16 Low in the east-northeast at around 2 A.M. local daylight time, Mars sits about 3 degrees to the right of a crescent Moon.

20 The Moon is new at 6:02 A.M. EDT

27 The Moon waxes to first quarter at 7:42 A.M. EDT.

EXPLORER GUIDE





Around the Country

Gold artifacts from Latin American cultures are a highlight of the new "Visible Vault" exhibition at the Natural History Museum of Los Angeles County.

ARIZONA

Mesa

ARIZONA MUSEUM OF NATURAL HISTORY

Ongoing: "Mars!" The red planet is revealed in this new exhibition that shares some of the latest scientific research gathered through satellite imaging and rovers on the surface. Visitors can see a rover vehicle, a meteorite from Mars, and spectacular photographs highlighting geologic features, including polar regions, tectonic fractures, and the 2,500-mile-long Valles Marineris canyon. Interactive exhibits demonstrate how "dust devils" form, dunes are created, and rifts develop in the planet's crust, and the exhibition also presents some technologies and processes scientists are using to investigate the possibility of past or present life on Mars.

53 North Macdonald
480-644-2230
www.azmnh.org

Phoenix

ARIZONA SCIENCE CENTER

Ongoing: "Forces of Nature." Explore—and even experience—some of the raw power generated by a dynamic Earth, including phenomena such as earthquakes, hurricanes, tornadoes, volcanic eruptions, and wildfires. An "Immersion Theater" puts you in the center of the action, and hands-on exhibits help explain the underlying causal phenomena of plate tectonics, ocean currents, wind patterns, and more.

600 East Washington Street
602-716-2000
www.azscience.org

CALIFORNIA

Los Angeles

NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY

Ongoing: "Visible Vault: Archaeological Treasures from Ancient Latin America." Rendered as a museum storeroom, this new exhibition brings more than 700 objects from ancient cultures of Mexico, Central America, and South America into public view, including an Aztec stone skull, Maya glyphs, pre-Inca gold drinking vessels, and more. Step inside the vault and you'll find artifacts arranged by region—covering cultures as diverse as the Chupicuaro, Hohokam, Jalisco, Olmec, Veracruz, and Zapotec—and nearby multimedia stations that provide handy tools for in-depth research, including maps and information about each object on display.

Exposition Park
900 Exposition Boulevard
213-763-DINO
www.nhm.org

San Diego

SAN DIEGO NATURAL HISTORY MUSEUM

Through October 10: **"Body Worlds & The Brain—Our Three Pound Gem: The Original Exhibition of Real Human Bodies."** Visitors can learn about anatomy, physiology, and health by examining real human bodies that have been preserved through a process called plastination. The exhibition includes more than 200 authentic human specimens—including entire bodies illustrating neurological, circulatory, and other systems. The show also features new research findings on the brain's development and function, diseases and disorders, and performance and improvement.

Balboa Park
1788 El Prado
619-232-3821
www.sdnhm.org

COLORADO

Denver

DENVER MUSEUM OF NATURE AND SCIENCE

Ongoing: "Space Odyssey." One of the Museum's newest permanent exhibition halls features 21st-century, interactive learning technology that immerses visitors in the planets, stars, nebulae, and galaxies of our universe. Experiment with infrared technology scientists use to see distant objects, try docking a space shuttle at the International Space Station, explore the 15,000-foot cliffs of Mars, and much more. The adjacent planetarium boasts digital technology that may be "light-years" beyond the usual planetarium experience.

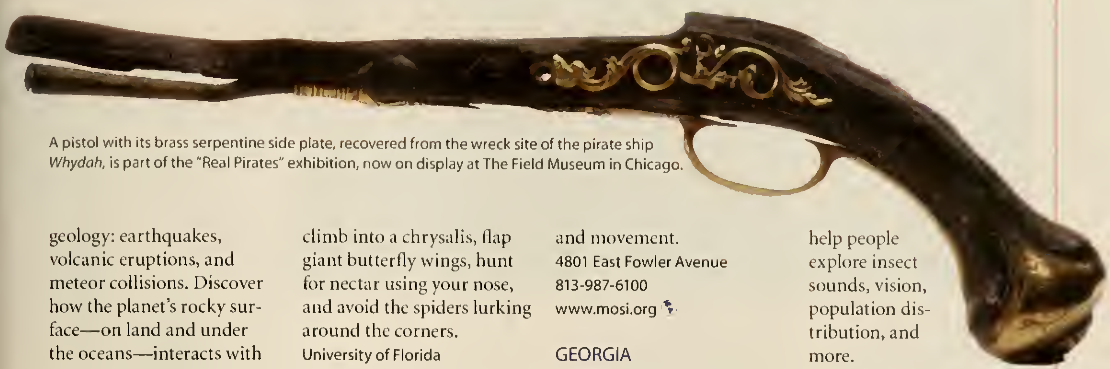
2001 Colorado Boulevard
800-925-2250
www.dmns.org

CONNECTICUT

New Haven

PEABODY MUSEUM OF NATURAL HISTORY

Ongoing: "Hall of Minerals, Earth, and Space." This geological exhibition explores the birth of the solar system and the forces that shaped the Earth's early



A pistol with its brass serpentine side plate, recovered from the wreck site of the pirate ship *Whydah*, is part of the "Real Pirates" exhibition, now on display at The Field Museum in Chicago.

geology: earthquakes, volcanic eruptions, and meteor collisions. Discover how the planet's rocky surface—on land and under the oceans—interacts with the atmosphere and waters to create Earth's livable climate. From the museum's vast collections, see rare gems as well as minerals with unusual properties such as fluorescence, magnetism, and radioactivity.
Yale University
170 Whitney Avenue
203-432-5050
www.peabody.yale.edu

FLORIDA
Gainesville
FLORIDA MUSEUM OF NATURAL HISTORY
Through September 7: "Amazing Butterflies." Discover the life cycle of these remarkable insects in a new exhibit laid out as a giant maze filled with larger-than-life leaves, grass, and trees that shrink you to the size of a caterpillar. On your journey, slip on some caterpillar legs to inch along, climb into a chrysalis, flap giant butterfly wings, hunt for nectar using your nose, and avoid the spiders lurking around the corners.
University of Florida
Cultural Plaza
SW 34th Street and Hull Road
352-846-2000
www.flmnh.ufl.edu

Tampa
MUSEUM OF SCIENCE AND INDUSTRY (MOSI) *Ongoing:* "Kids in Charge!" Colorful, interactive exhibits encourage creativity and science skills in this special facility just for children 12 and under. Test differently shaped wings in a wind tunnel, lie down on a "bed of nails," figure out how to crack a safe with a mathematical code, discover facts about an animal's history from a single tooth, play checkers on a 20-foot-square board, and much more. A separate area for preschoolers features specially designed activities that focus on gross and fine motor skills, balance, coordination, and movement.
4801 East Fowler Avenue
813-987-6100
www.mosi.org

GEORGIA
Atlanta
FERNBANK MUSEUM OF NATURAL HISTORY
Through August 16: "Dinosaurs: Ancient Fossils, New Discoveries." Presenting an up-to-date look at what scientists currently think about dinosaur physiology and behavior, this exhibition builds on cutting-edge science and explores the latest research about why dinosaurs became extinct. It includes an impressive, detailed walk-through of a Mesozoic-era environment.
767 Clifton Road NE
404-929-6300
www.fernbankmuseum.org

HAWAII
Honolulu
BISHOP MUSEUM
Through September 7: "Backyard Monsters." Giant animatronic insects flap their wings, wiggle their legs, and engage in combat in this exhibit that explores the world of insects. Visitors feel tiny compared to the 10-foot bugs, which include Atlas beetles, a monarch butterfly, a tomato caterpillar, a paper wasp, and a dragonfly. Actual specimens are on display in adjacent cases, and hands-on exhibits help people explore insect sounds, vision, population distribution, and more.
1525 Bernice Street
808-847-3511
www.bishopmuseum.org

ILLINOIS
Chicago
THE FIELD MUSEUM
Through October 25: "Real Pirates: The Untold Story of the *Whydah* from Slave Ship to Pirate Ship." Starting out as a slave ship in 1715, the *Whydah* was captured by pirates, who used it to attack more than 50 other ships before it sank during a storm. Now the *Whydah* reveals her secrets in this exhibition, which features real stories of the pirates' lives; gold and silver coins from all over the globe; pirates' buckles, buttons, and cuff links; clay smoking pipes; pewter tableware; and cannons, muskets, and swords. Since the *Whydah* pirates plundered so many different ships, the recovered treasure now provides archaeologists—and visitors—with a fascinating window on the intersections of the slave trade, pirates, commercial activity, and everyday life in 18th-century America.
1400 South Lake Shore Drive
312-922-9410
www.fieldmuseum.org

MEMBERSHIP HAS ITS REWARDS

Institutions marked with participate in the Passport program run by the Association of Science-Technology Centers (ASTC). If you're a member of a participating museum or science center, you may receive free admission at more than 300 other institutions around the world.

See www.astc.org/passport for more information.

FROM LEFT: NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY; NATIONAL GEOGRAPHIC/KENNETH GARRETT

MASSACHUSETTS
Cambridge
HARVARD MUSEUM OF NATURAL HISTORY *Through September 6:* "Language of Color." Find out what bold zebra stripes, bright butterfly wings, and iridescent beetle wings are saying in this dazzling new exhibition of real animal specimens and interactive exhibits. Discover how different animals' bodies produce the rainbow of hues found in nature, the varied ways their eyes perceive color, and how color is used to conceal or communicate in this interactive show that lets you experience colors as other animals do, including parts of the spectrum that are normally imperceptible to humans.
26 Oxford Street
617-495-3045
www.hmnh.harvard.edu

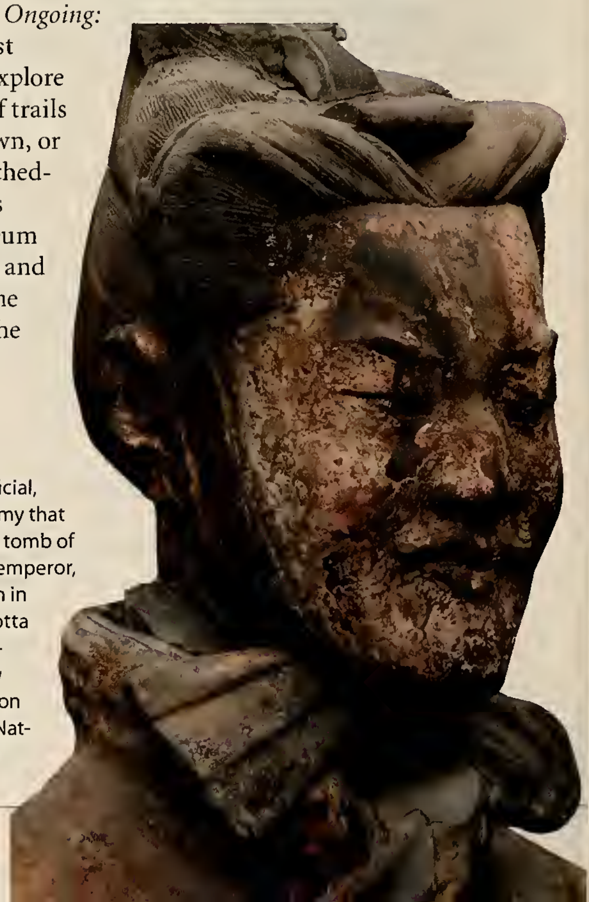
MISSOURI
Saint Louis
SAINT LOUIS SCIENCE CENTER
Through September 7:
"Ends of the Earth: From Polar Bears to Penguins." Discover the animal adaptations, human adaptations, and science that are unique to Earth's polar regions. Compare bear skulls and find out what scientists are discovering about the status of polar bears. Discover the stories of polar explorers who braved the cold. Examine real specimens to learn which Arctic whale has a tusk and which Arctic animal has the most hair. If you're feeling adventurous, don a penguin suit and try walking and sliding like a penguin.
5050 Oakland Avenue
800-456-SLSC
www.slsc.org

NEW MEXICO
Albuquerque
NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE *Ongoing:*
"STARTUP: Albuquerque and the Personal Computer Revolution." Historical artifacts, interactive exhibits, and videos in this new permanent exhibition explain how microcomputers developed—and how they transformed society. From early electronic computer toys such as Hasbro's Think-A-Tron, through an early personal computer (the Altair 8800) and the marketing of the Macintosh, to today's advanced hardware and software, the show traces the PC industry's Albuquerque roots and subsequent growth. An additional gallery invites visitors to speculate about the future of personal computers.
1801 Mountain Road NW
505-841-2800
www.nmnaturalhistory.org

NEW YORK
New York
AMERICAN MUSEUM OF NATURAL HISTORY
Through August 16:
"Climate Change: The Threat to Life and A New Energy Future." Step into this new exhibition and explore the science, history, and impact of climate change—and discover how you can reduce your carbon footprint. Interactive exhibits and dramatic displays help explain the science behind changes in polar ice, oceans, and land and suggest concrete actions people, communities, and countries can take to reduce CO_2 emissions. Experiment with a scale model of lower Manhattan to see the effect rising sea levels would have on the island, ponder your coal usage next to a giant model of a ton of coal, investigate alternative energy sources, and more.
Central Park West at 79th Street
212-769-5100
www.amnh.org

Tupper Lake
THE WILD CENTER, NATURAL HISTORY MUSEUM OF THE ADIRONDACKS
Opening July 4:
"Mother of Invention: How the Genius of Nature Can Help Us Live Smarter." In this new exhibition, find out how scientists and engineers are tapping into the secrets of the natural world—copying moth eyes to make solar panels more efficient, developing surgical instruments inspired by wasp mouths, making low-energy cell phone screens based on butterfly wings, and more. *Ongoing:* **"Naturalist Walks."** Explore six acres of trails on your own, or on daily scheduled walks with museum educators, and discover the banks of the Racquette River, step into a hidden bird blind to watch migrating birds at rest and play, and much more.
45 Museum Drive
518-359-7800
www.wildcenter.org

NORTH CAROLINA
Durham
MUSEUM OF LIFE AND SCIENCE
Ongoing: "Catch the Wind." This new, four-acre outdoor exhibition focuses on how wind influences our environment. Maneuver radio-controlled sailboats by harnessing the wind, ride a Leonardo da Vinci-inspired ornithopter—complete with flapping wings modeling bird flight—ten feet up into the air, launch giant "seeds" from a 30-foot tower to explore the aerodynamics of seed dispersion, and much more.
433 West Murray Avenue
919-220-5429
www.ncmls.org



A civilian official, part of an army that guarded the tomb of China's first emperor, stands watch in the "Terra Cotta Warriors" exhibition now at the Houston Museum of Natural Science.

Visitors guide scarab beetles pushing dung balls in a video game that is part of the "Animal Grossology" exhibition, now at Pacific Science Center in Seattle.

Raleigh
North Carolina Museum of Natural Sciences
Through September 7: "Chocolate: The Exhibition." Discover how a small seed from the rainforest changed the world. This exploration of one of nature's greatest delights includes the natural history of the cacao tree, an explanation of how chocolate is made, and illustrations of its many uses over time and around the world.
11 West Jones Street
877-4NATSCI
www.naturalsciences.org

PENNSYLVANIA
Philadelphia
The Academy of Natural Sciences
Through September 7: "Geckos—Tails to Toepads." Explore the world of these likable lizards, which have adapted to environments as diverse as ocean beaches, dry deserts, and freezing mountaintops. Fifteen of more than 1,250 living species are on display in naturalistic habitats, where you can see their size and color variations and hear their barks, chirps, growls, and squawks. Hands-on exhibits demonstrate the animals' night vision, hunting skills, sticky toepads, and disposable tails.
1900 Benjamin Franklin Parkway
215-299-1000
www.ansp.org

TEXAS
Fort Worth
Fort Worth Museum of Science and History
Through August 8: "Dinosaurs Alive!" Join real-life paleontologists on the hunt for dinosaur remains, and new information about their behaviors and evolution, in this large-format film. Realistic and scientifically accurate computer-generated imagery portrays dinosaurs fighting, nesting, and facing catastrophic forces of nature; and 1920s documentary footage shows how paleontology has both changed and remained the same in the past 80 years.
1501 Montgomery Street
817-255-9300
www.fwmuseum.org

Houston
Houston Museum of Natural Science
Through October 18: "Terra Cotta Warriors: Guardians of China's First Emperor." Qin Shi Huang was the first person to rule a unified China, and he had thousands of lifelike, life-size army figures crafted from clay to protect his tomb after his death in 210 B.C. They lay hidden until 1974, but now some of these silent guardians are traveling abroad in this monumental exhibition, where you'll see generals, officers, infantrymen, servants—and even a cavalry horse—along with other funerary artifacts, including armor, jewelry, and ritual objects.
One Hermann Circle Drive
713-639-4629
www.hmns.org

VIRGINIA
Martinsville
Virginia Museum of Natural History
Ongoing: "Uncovering Virginia." This new, permanent gallery tells the story of Virginia's natural history over the course of the past 300 million years. Six exhibits focus on different geologic epochs being studied by scientists in various locations around the commonwealth. Each exhibit describes the animals and plants that lived there in the past and features a laboratory-like environment where visitors can use the same tools scientists do to interpret fossils and archaeological items. See a tropical swamp from a time when Virginia was south of the equator, visit a site occupied by Native Americans both before and after Europeans arrived, and much more.
21 Starling Avenue
276-634-4141
www.vmnh.net

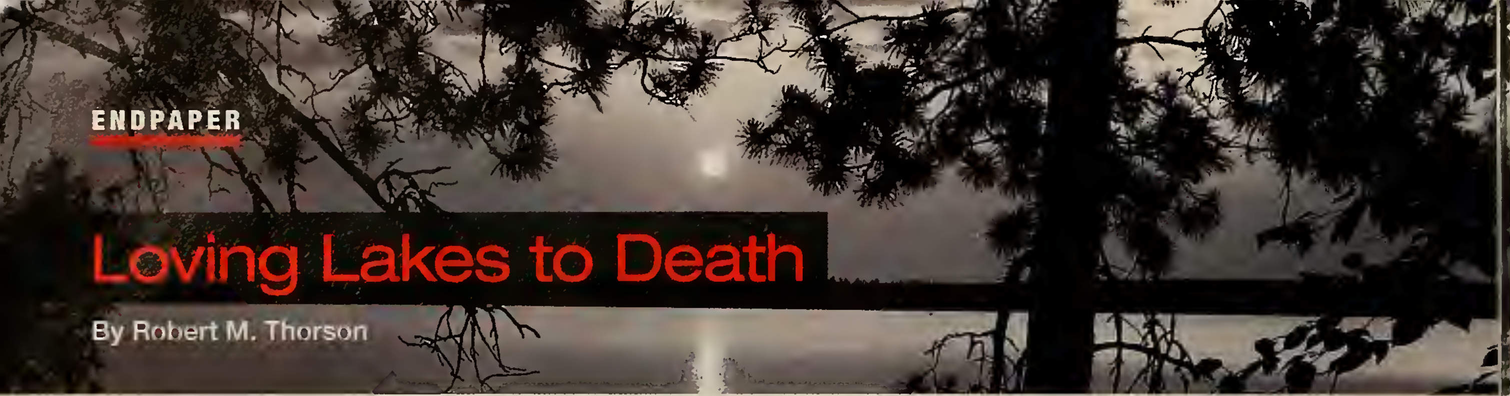
WASHINGTON
Seattle
Pacific Science Center
Through September 7: "Animal Grossology." Based on a popular children's book, this exhibition's interactive stations and informative, humorous graphic panels allow visitors to discover the scientific reasons why cats cough hairballs, skunks stink, and birds regurgitate into their babies' mouths, among other fascinating biological adaptations.
200 Second Avenue North
206-443-2001
www.pacsci.org

WISCONSIN
Milwaukee
Milwaukee Public Museum
Ongoing: "Puelicher Butterfly Wing." Stroll through an indoor tropical garden while native and exotic species of butterflies flutter around you; see young insects emerge from their chrysalides; discover how artistic expression in other cultures and in other times has been inspired by the beauty and movement of butterflies.
800 West Wells Street
414-278-2702
www.mpm.edu

FROM LEFT: SHAANXI PROVINCIAL ARCHAEOLOGICAL INSTITUTE, XI'AN/WANG DA-GANG; PACIFIC SCIENCE CENTER

Loving Lakes to Death

By Robert M. Thorson



Lake Plantagenet, Minnesota—a kettle lake

As a child during the 1950s and 1960s, I summered on the shore of Union Lake, Minnesota. As the summers rolled by, my chore of raking weeds near the beach grew more demanding, the water seemed ever murkier, and the sandy shallows felt squishier between my toes. Invisible to me were the burgeoning fecal bacteria and the increasing levels of heavy metals, such as lead. Only years later did I make the connection between the changes in the water and the rising number of cottages sprouting around the 104-acre lake.

Known as a kettle lake, Union Lake is a remnant of the last ice age, created when a block of ice stranded in sediments melted, leaving behind a bowl-shaped depression. Kept filled by groundwater, kettle lakes lack significant inlet and outlet streams. In consequence, one of their thorniest problems is being overfed with nutrients, such as carbon, nitrogen, and phosphorus, from both natural and human sources. Phosphorus is the most common culprit—whether from manufactured field and lawn fertilizers, laundry detergent, or human and animal waste.

Nutrients are essential to lake life, yet beyond a certain threshold they can turn into choking pollutants. Rural lakes develop the greenish-gray, sludgy look of an urban duck pond; coves become miniature Sargasso Seas smothered with floating rafts of reeds; and lake flies fall so thickly after expiring that their remains have to be shoveled off streets.

An overfed lake lacks the oxygen needed to decompose the excess growth. A decline in oxygen forces fish adapted to cool conditions, such as trout, into warmer surface waters, where they languish. Bacteria that depend on oxygen for respiration are elbowed out by bacteria species that thrive on fermentation or produce methane. That, in turn, can lead to botulism or salmonella outbreaks. Methane bubbling upward through the water column gobbles up whatever dissolved oxygen is left. If methane escapes the water, it will spontaneously oxidize or even catch fire, producing a ghostly nighttime effect known as "will-o'-the-wisp."

Once a lake reaches the tipping point, there are only two reasonable management alternatives: put the lake on a strict diet, restricting nutrient intake from all external sources, or remove some of the pollutant. Phosphorus-enriched water just above the muck can be pumped away; dissolved phosphorous can be precipitated to the bottom; bottom water can be oxygenated; muck can be vacuumed up and trucked away (think of it as lake liposuction).

In 2000, Congress asked the United States Environmental Protection Agency about the status of American lakes. The agency's answer was, in essence, "We don't know." That response led to the funding of a National Lakes Assessment, designed to produce a statistically robust snapshot by the year 2010. The sample covers the lower forty-eight states, plus a pilot project in Alaska; more than a thousand randomly selected lakes are being surveyed.

In the meantime, I decided to carry out my own assessment of kettle lakes across the glaciated fringe of the northern U.S. One problem with such an exercise is that defining lake quality is a value judgment. A fisherman who prefers bass to trout might argue that lake quality improves with additional nutrients. For a seventeenth-century *voyageur*, the quality of a lake was measured by the efficacy of travel. Are lakes now playgrounds for water sports? Natural areas? The criteria I used were nutrient pollution, invasive species, shoreline habitat destruction, disease-causing bacteria, acid rain, and chemical contamination by toxic metals and synthetic organic compounds, including pharmaceuticals. My general conclusion: approximately one-third of the kettle lakes are in good shape. The rest are either compromised or in deep trouble.

As for Union Lake—its shore once shaded by trees, its waters decorated with clutches of cattails and sheets of lily pads—it has changed. Gone are the dozens, if not hundreds, of frogs that used to jump out of my way every time I walked its perimeter, and the thousands of minnows that darted about in schools. Last summer a fellow I talked to, who was repairing a cottage porch, complained that he hadn't had a nibble in three nights of fishing. The biologically rich lake of my memories is still scenic and cool to the touch on hot days, but it is eerily quiet, devoid of all but boat noise and dog barks.

ROBERT M. THORSON is a professor of geology at the University of Connecticut. This story is adapted from his recent book *Beyond Walden: The Hidden History of America's Kettle Lakes and Ponds* (Walker & Company, 2009).


ROLEX
OYSTER PERPETUAL
DATE
28
SUPERLATIVE CHRONOMETER
OFFICIALLY CERTIFIED
SWISS
MADE