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NATURAL HISTORY

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FEATURES



COVER STORY

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A series of deep freezes descended across the Earth 750 million years ago, each lasting millions of years. The spring that finally took hold may have triggered the present bloom of multicellular life.

BY GABRIELLE WALKER



58 ARCTIC COVENANT

Springtime in the Arctic National Wildlife Refuge

PHOTOGRAPHS BY SUBHANKAR BANERJEE

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For a thousand years before people settled in New Zealand, a small alien predator may have been undermining the islands' seabird populations.

BY LAURA SESSIONS



COVER

Lynn Davis, Iceberg 31,
Disko Bay, Greenland, 2000

STORY BEGINS
ON PAGE 44



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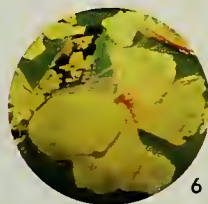
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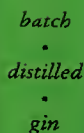
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THE NATURAL MOMENT

So Fleeting a Spring

Photograph by Christian Ziegler





◀ See preceding pages



Every year in Panama, just after the first downpour of the rainy season, the flowers of the guayacán tree (*Tabebuia guayacana*) burst open. The explosion of blossoms, whose timing coincides with the northern temperate spring, announces the end of the four- to five-month-long dry season. The downpour, and a temperature change, are thought to trigger the trees' ready buds to swell and bloom. Water plays such a critical role that, depending on rain patterns, a blossom-filled tree may be just a short distance away from a dry, unadorned one.

Native bees are drawn to the sensory delights of the guayacán, but the trees' golden-petal lucre is something of a cheat: the blossoms are not receptive to pollinators for more than a day, and they remain on the trees for only a few days before descending—like migrating butterflies—to the forest floor. Photographer Christian Ziegler found the guayacán tapestry pictured here not quite a mile from the Smithsonian Research Station on Barro Colorado Island in March. Detecting a "light, sweet smell" in the air, Ziegler said he spotted leaf-cutter ants carting away clippings of guayacán flowers—an easily digestible meal for the insects' symbiotic fungi.

Hours after dropping from the branches, Ziegler noted, the trees' saffron blossoms—even the ant's radiating trails—had darkened to yellow-brown. By the end of the day the flowers had lost all their brilliance, blending in with the leaf litter of the forest floor.

—Erin Espelie

UP FRONT

Life on Ice

I know, the picture on our cover this month makes it look as if we're all about to collide with an iceberg. And, truth be told, there seems plenty to be anxious about. A few weeks ago, those of us who live or work in Manhattan (the editorial staff of this magazine, for instance) thought that we had gone from yellow alert to orange, along with the rest of the country. Then the mayor reminded us that we'd been there, done that—New York City had been stuck in orange ever since the code went into effect.

Maybe it's small consolation—but things could be worse, much worse. Compared with what the Earth has undergone in its geological past, even the many human insults to our planet seem puny and fundamentally insubstantial. A few weeks ago Gabrielle Walker stopped by our offices to show us her latest report about what's hot on the geological front. A grand idea, first conceived many years ago but rejected soon afterward, has now returned with such compelling vitality—and is so well supported by the evidence of rocks all over the world—that it is stimulating new work and new thinking across an entire scientific community. Walker's story, with apologies to Laura Ingalls Wilder, is called "The Longest Winter" (page 44).

Walker isn't kidding. The "winter" in question lasted as long as 10 million years. The average annual temperature at the surface of the Earth hovered around 40 degrees below zero. Conditions were antarctic.

Most ice ages—certainly the ones people are most familiar with—are self-limiting: the ice advances, then retreats once again. The retreats may be the result of global warming by atmospheric greenhouse gases, among them carbon dioxide (CO₂). Exposed rock continually draws CO₂ out of the atmosphere and chemically locks up the carbon. During an ice age, however, the more the Earth's landmasses get covered by ice, the less rock is exposed to CO₂, and so the more CO₂ remains in the atmosphere. The atmospheric CO₂ eventually warms the Earth and reverses the march of ice.

But about 750 million years ago the continental tectonic plates haphazardly arranged themselves around the equator. That seems to have turned an "ordinary" ice age into a runaway catastrophe. Even after the polar ice began advancing, continental rock remained exposed, and it continued sucking carbon out of the atmosphere. The warming effect of atmospheric CO₂ steadily diminished. By the time the ice reached the tropics, it was too late. Ice quickly covered what was left of the Earth. Only the slow release of CO₂ by volcanoes eventually restored the greenhouse warming and enabled life to get a fresh start.

There's clearly a hopeful message in that fresh start. April, at least in the temperate zone of the Northern Hemisphere, brings mud, blossoms, new life—in short, the promise of spring. So, lest winter seem too prominent a topic for an April issue of *Natural History*, two photographers bring us their contrasting visions of renewal. Subhankar Banerjee portrays the robust glory of the vernal Arctic, which must gather all its life forces in the short months between breakup and freeze up (see "Arctic Covenant," page 58). Christian Ziegler, at the beginning of the Panamanian rainy season, documents the fragile beauty of falling blossoms that retain their color for just a few hours (see "So Fleeting a Spring," page 6).

And there it is, the simplest, most bracing antidote nature has for all our anxieties: Spring will come again. Count on it.

—PETER BROWN



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LETTERS

Foresight and Hindsight

After reading T.V. Rajan's article on lymphatic filariasis ["The Worm and the Parasite," 2/03], I thought your readers might like to know of ongoing efforts to apply recent medical discoveries to the treatment and possible elimination of both filariasis and the related parasitic disease onchocerciasis.

Onchocerciasis (river blindness), characterized by incessant, debilitating itching and eyesight damage, is spread through the bite of a small black fly that breeds in rapidly flowing rivers and streams.



Larva of the parasitic worm *Wuchereria bancrofti*, which causes filariasis

Eighteen million people are infected with the disease worldwide. Adult victims can neither farm nor care for their children. Fertile bottomlands are abandoned for fear of contracting the disease, and people move to less fertile grounds, disrupting farm economies. A global effort to fight this disease includes the Carter Center, the Lions Clubs International Foundation, the World Bank, and the World Health Organization (WHO). We at the Carter Center work both

in Africa and in all endemic areas in the Americas, which include Brazil, Colombia, Ecuador, Guatemala, Mexico, and Venezuela.

One oral dose a year of ivermectin (trade name, Mectizan) kills the microscopic infant worms. Merck & Co., Inc., has donated the drug to the world for as long as there

is a need, and our center has enabled the delivery of more than 40 million treatments—about nine million annually. Two years ago our center's task force for disease eradication concluded that it is feasible to kill the adult worms and eliminate river blindness in the Americas if at least 85 percent of the people living in endemic areas are treated with Mectizan twice a year. A more effective treatment of adult worms will be needed to accomplish the same goal in Africa.

Fortunately, the transmission of lymphatic filariasis can also be halted by treating infected individuals just once a year. The treatment must continue for four to six years with a single-dose combination of oral medicines, most commonly albendazole and ivermectin. Bed nets also help control the transmission of the infection by mosquitoes. In patients

with elephantiasis, it helps to bind the affected limbs with compressive bandages. That and, of course, the practice of proper hygiene helps reduce swelling and discomfort.

WHO ranks lymphatic filariasis as the second leading cause of permanent and long-term disability. But WHO also considers the disease eradicable—one of

bacteria, what their relationship with the nematodes was, and whether they might provide a new drug target.

Since that meeting the research community has been galvanized into action. Groups in Germany headed by Achim Hoerauf and Dietrich Büttner have tested standard antibacterial drugs in animals and

"Our hope is that filariasis can be eradicated [from Nigeria] in the next fifteen years." —Jimmy Carter

only six infectious diseases in that category. The Carter Center is now working in Nigeria, which has the greatest number of infected people in Africa, with the government, health authorities, and villagers. Our hope is that filariasis can be eradicated there in the next fifteen years.

*Jimmy Carter
The Carter Center
Atlanta, Georgia*

The Edna McConnell Clark Foundation for many years sponsored research on onchocerciasis (the spectrum of infections including river blindness), including meetings that brought workers together from many countries and fields. The 1998 meeting highlighted a series of findings suggesting that *Wolbachia* were present in human filarial nematodes. Many of us left the meeting determined to find out whether the "bacteria-like bodies" seen under the microscope were in fact

started a long-term trial of tetracycline for onchocerciasis in Africa. Their initial results report a prolonged and significant improvement in clinical status. (Note that it could have been otherwise: If the bacterium were just a hitchhiker, a parasite of the parasite, treatment with drugs might cure the parasite of its disease, and give rise to more human disease.)

Those promising findings have prompted a search through records to identify earlier experiments in which animals, treated with tetracycline for other reasons, were cured of filarial nematodes. Mr. Rajan suggests that such experiments were ignored because the results did not fit into a "reigning biological dogma." We would beg to differ: they were ignored because the experiments were not designed to measure the effects of drug treatment. Filarial life cycles are difficult to maintain,

and failures are common: one particular crash in the cycle of infection would not be especially noteworthy. With hindsight one can now identify the cause of the failure, but it was not evident in the original experiments.

Mark Blaxter and Katelyn Fenn
University of Edinburgh
Edinburgh, Scotland

Mr. Rajan is correct that certain preconceptions (or misconceptions) on the part of “Western” physicians may lead to the rejection of clear evidence for the efficacy of nontraditional or “nonsensical” disease treatments.

My colleagues and I were the first to identify the filarial bacteria as *Wolbachia*. Together with Norbert W. Brattig and his coworkers in Hamburg, Germany, we are now studying the effect of *Wolbachia*-derived molecules on human and canine immune cells. Results show that *Wolbachia* proteins are in part responsible for producing such mediators of immune responses as cytokines. As Mr. Rajan rightly states, these cytokines cause many of the symptoms of acute filariasis (fever, headaches, chills, and so on).

Two additional points: First, the caption to the illustration on page 32 states that the person depicted is a victim of filariasis. But the worm being removed by the patient is likely *Dracunculus medinensis*, which belongs to another superfamily. Second, *Wolbachia*, and “rickettsiae” in gen-

eral, do not lack cell walls, as Mr. Rajan states.

Claudio Bandi
University of Milan
Milan, Italy

Family Ties

It is not at all clear, as Carl Zimmer writes in “Searching for Your



Inner Chimp” [“The Evolutionary Front,” 12/02–1/03], that human beings and chimpanzees are so “astonishingly similar” genetically.

DNA sequences are one-dimensional, inviting decontextualized comparisons, but bodies are three-dimensional. So if human

percentage of similarity between the two species’ DNA sequences underestimates how similar people and chimps really are in the panoply of nature.

At the other end of the scale, two DNA sequences that share no common ancestry, and are thus as evolutionarily different as they can be, still probably match at a fourth of their nucleotides by chance alone. (The DNA alphabet offers only four “letters” to choose from.) By that logic, human DNA is at least one-quarter identical to carrot DNA, in spite of the fact that we are manifestly not one-quarter carrot.

Thus, for distant relatives, DNA similarities overestimate biological similarities.
Jonathan Marks
University of North Carolina
at Charlotte

In the first half of the twentieth century there was little agreement about

same number Mr. Zimmer cites as today’s consensus.

Although Morris Goodman was an early pioneer in molecular primate relationships, it was Vincent M. Sarich and Allan C. Wilson who, in 1967, applied the concept of a molecular clock, which set the stage for the current views of human evolution. Sarich and Wilson estimated that humans and chimpanzees diverged about five million years ago, an estimate now supported by much additional molecular data. *Ramapithecus*, dated at 14 million years old and declared a hominid solely on the basis of its jaws and teeth, was the first putative ancestor to be deposed by the new molecular approaches. But the lessons of history are soon forgotten. Mr. Zimmer, like many others, readily accepts the new skull from Chad, dated from between six and

If human and chimp DNA differ by 1.58 percent, just what does that say about the difference between the two species?

and chimp DNA sequences are 1.58 percent different, is that more or less than the difference between a human femur and a chimp femur? If we put a person and a chimp next to a sea urchin, we can readily see that the two primates match up almost perfectly bone for bone, muscle for muscle, organ for organ—and that in every case the sea urchin is the odd man out. If anything, the per-

centage of similarity between the two species’ DNA sequences underestimates how similar people and chimps really are in the panoply of nature. At the other end of the scale, two DNA sequences that share no common ancestry, and are thus as evolutionarily different as they can be, still probably match at a fourth of their nucleotides by chance alone. (The DNA alphabet offers only four “letters” to choose from.) By that logic, human DNA is at least one-quarter identical to carrot DNA, in spite of the fact that we are manifestly not one-quarter carrot. Thus, for distant relatives, DNA similarities overestimate biological similarities.

which animal is the closest living human relative. Various advocates promoted every known ape. The case for the chimpanzee was not fully made until the work by Charles G. Sibley and Jon E. Ahlquist on DNA hybridization in 1984. They measured similarities between entire genomes, and determined that people and chimpanzees are 98.6 percent identical, virtually the

seven million years ago, as the earliest hominid, even though the clock for hominid evolution did not begin ticking until at least a million years later.

Adrienne Zihlman

University of California,

Santa Cruz

CARL ZIMMER REPLIES: Molecular clocks are informative but not as precise as Adrienne Zihlman implies. One recent estimate for

the common ancestor of humans and chimps puts the date between 4.6 million and 6.2 million years ago; another puts it between 3.3 million and 8.3 million years ago. The age of the *Sahelanthropus* site in Chad is not certain either, because it is estimated from the dating of similar sites. That's why the discoverers of the fossil maintain only that it can be tentatively dated to between six million and seven million years ago. Given the overlap and fuzziness of these estimates, *Sahelanthropus* is not ruled out as a hominid.

Misting in Action

In "Grain Gain," ["Samplings," 2/03], Stéphan Reeb states: "Methane is the second

most damaging greenhouse gas in the atmosphere." Indeed, methane is the second most damaging greenhouse gas governed by the Kyoto Protocol, but the major greenhouse gases in the atmosphere are, in order of their warming effect, water vapor, carbon dioxide, and then methane. Like carbon dioxide and methane, water vapor has many anthropogenic sources, from the burning of hydrocarbons to the excess evaporation from reservoirs, lakes created by dams, and rice paddies.

WD. Benton
Albuquerque, New Mexico

Reading the Tree Leaves

Egbert Giles Leigh Jr. and Christian Ziegler
["Biosphere III," 2/03]

make the important observation that the interplay between plant and animal species is central to shaping the diversity of tropical forests. Their study of the



fragmentation of a Panamanian forest shows that the elimination of some animal species can dramatically alter the survival of certain plants and the composition of species.

Unfortunately, similar "experiments" are taking place throughout the

Tropics: more than 60,000 square miles of forest are lost each year, creating a patchwork of unconnected fragments. Studies such as Messrs. Leigh and Ziegler's underscore the value of preserving large tracts of land, and of considering such a web of interactions in making decisions about forest management and conservation. Now is the time to make these critical land-use decisions before too much of what they aptly call a magic web is lost.

Phyllis D. Coley and Thomas A. Kursar

University of Utah
Salt Lake City, Utah

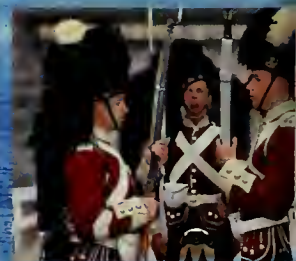
Messrs. Leigh and Ziegler offer an intriguing discussion of the unintended

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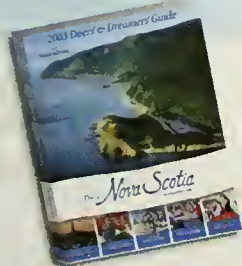
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consequences of the building of the Panama Canal. That an "upscale" rainforest could be reduced in ninety years to a Jurassic-like, low-rent district in terms of biodiversity is instructive. Public works

cies of mollusk blur the natural order, creating a biological cacophony where once a desert symphony played. But there's a bright side: electric power galore. Now we can catch the nature channels in Phoenix

were no mutualistic associations between plants and animals analogous to the ones observed today. In late Pennsylvanian deposits (beginning about 298 million years ago), in which plant tissues are

that were evidently pierced by a large piercing-and-sucking insect. Furthermore, fecal pellets in the same deposit contain the same or similar prepollen. Do such findings simply point to pollen eating, or was the insect providing a mutualistic benefit to the plant as well?

Conrad C. Labandeira
Smithsonian Institution
Washington, D.C.

Fish may swim around Anasazi ruins flooded by dams, but at least the dams enable us to catch nature channels.

projects in the United States offer similarly dramatic examples of these inadvertent experiments in ecology. Lake Powell and Lake Mead comprise 500 square miles of lake where once "a river ran through." Now fish swim around in Anasazi ruins, and exotic vegetation and invader spe-

and see the lights of Las Vegas from space.
Daniel J. Lenihan
National Park Service
Submerged Resources Center
Santa Fe, New Mexico

I am not so sure, as Messrs. Leigh and Ziegler maintain, that more than 150 million years ago there

preserved in considerable anatomical detail, there is evidence for intricate associations. One example, from the Calhoun Flora of Illinois, is a seed fern that bears prepollen (a kind of microspore) far bigger than any known wind-dispersed pollen. The prepollen was produced in large organs

ERRATUM: The caterpillar pictured on page 55 of "Biosphere III" (February 2003) should have been identified as belonging to the family Saturniidae, not Limacodidae.

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

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CONTRIBUTORS



An acclaimed photographer as well as a tropical ecologist, **CHRISTIAN ZIEGLER** ("The Natural Moment," page 6) spends part of the year based on Panama's Barro Colorado Island, where he recently collaborated with Egbert Giles Leigh Jr. on *A Magic Web*, a book about the biodiversity of the island's rainforest. More of Ziegler's work can be seen at www.naturephoto.de.

GABRIELLE WALKER ("The Day the Earth Froze Over," page 44) has traveled to all seven continents in search of stories about science. She has been to the South Pole, climbed trees in the Amazon rainforest, and pulled fresh lava from a volcano in Hawaii with a rock hammer. Walker, who earned her doctorate in natural sciences from the University of Cambridge, has been an editor at *Nature* and the features editor at *New Scientist*, for which she now acts as a consultant. Last fall she was a visiting professor in the geosciences department at Princeton University. *Snowball Earth*, from which her article has been adapted, is her first book.



A transplanted Virginian, **LAURA SESSIONS** ("Date with Extinction," page 52) has lived in New Zealand since 1996. After earning her master's degree in botany at the University of Canterbury in Christchurch, she began working on a doctorate in science communication, which she expects to complete this year. Sessions lectures on ecology and coordinates and leads tours for groups of American ecology students. "I was first introduced to New Zealand through one of these programs," she says, "so it is a great pleasure to introduce other students to such a beautiful place." Her article in this issue is her third contribution to *Natural History*.

"You may be wondering how a young man from Calcutta ended up taking photographs during Arctic blizzards," says freelance photographer **SUBHANKAR BANERJEE** ("Arctic Covenant," page 58), now based in Bellevue, Washington. "In my life, there are no straight lines. In the American Southwest, where I went to pursue graduate studies in science, I was drawn to the wide-open spaces. I began capturing nature on film. I was lured north by a passion to witness polar bears in an untrammelled landscape." Banerjee's work in the Arctic will culminate May 2 with the opening of a solo exhibition at the Smithsonian's National Museum of Natural History in Washington, D.C., and in the publication of the accompanying book, *Arctic National Wildlife Refuge: Seasons of Life and Land* (The Mountaineers Books). The exhibition is scheduled to travel to New York City's American Museum of Natural History in November.



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INCREDIBLE JOURNEY II Here's one for the record books: longest documented travel in the wild by a wild mouse. The new world-record holder is a three-quarter-ounce female white-footed mouse that took just a month to travel at least 9.2 miles across a stretch of New England forestland.

Chronicling the achievement was Thomas J. Maier of the USDA Forest Service's research station in Amherst, Massachusetts, who trapped, tagged, and recaptured the peripatetic rodent. Most often it's the males that travel long distances, generally to avoid other males and to seek a mate, but Maier's mouse, too, had good reasons for her trek: the local mouse population had burgeoned, autumn food supplies were low (acorns were in particularly short supply), and the females in nearby areas, suffering equally scarce resources, were in no mood to be welcoming.



A vagabond's search rewarded

A potential competing claim: another white-footed mouse once ran the equivalent of twenty-three miles in twenty-four hours, but that was inside a well-oiled running wheel in a laboratory. Maier's adventurer ran mostly through forest, but she also had to cross at least

six forest roads, three small streams, a two-lane primary highway, and a power line right-of-way. ("Long-distance movements by female white-footed mice, *Peromyscus leucopus*, in extensive mixed-wood forest," *Canadian Field-Naturalist* 116:108–11, 2002)

YOUR PLACE OR MINE? Think of the word "household," and the associations that usually come to mind are positive: warmth, safety, sharing, interconnectedness. But conservationists are beginning to understand the word in a negative way. The problem is that in many "hotspots" of biodiversity—Brazil, south-central China, Florida's Indian River County—where native species are both abundant and threatened by human activities, the number of households is growing faster than the human population itself. That's because today's average household includes fewer people than yesterday's: halve the number of people living as a unit,

after all, and you double the number of households, even if the overall population remains constant.

For the most part, that's progress. Households get smaller when standards of living rise, when single people become more affluent, when women become more educated (which not only gives them greater access to paid work but also leads to fewer children), and when fewer generations live together under the same roof. But there is a downside. As Jianguo Liu of Michigan State University in East Lansing and his colleagues at Stanford University have recently pointed out, more housing units consume more land and more construction materials. And smaller households reduce sharing: each individual uses up more resources. The consequent urban sprawl and energy consumption strain ecosystems and erode biodiversity.

Analyzing United Nations data, Liu and his team note that in sixty-five non-hotspot countries, households and populations grew at similar rates between 1985 and 2000—about 1.7 percent annually. During the same period, though, seventy-six hotspots grew, on average, at the annual rate of 1.8 percent in population but 3.1 percent in number of households. The reduction in household size alone (from 4.7 to 4.0 people per household, on average) resulted in 155 million additional residences established in those hotspots in the final fifteen years of the twentieth century—bad news for the flora and fauna. ("Effects of household dynamics on resource consumption and biodiversity," *Nature* 421:530–33, January 30, 2003)



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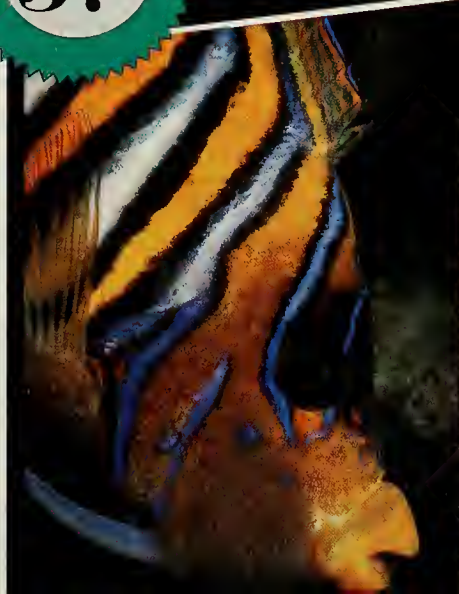
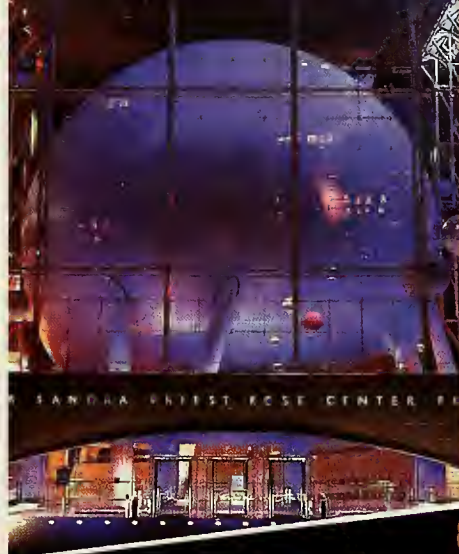
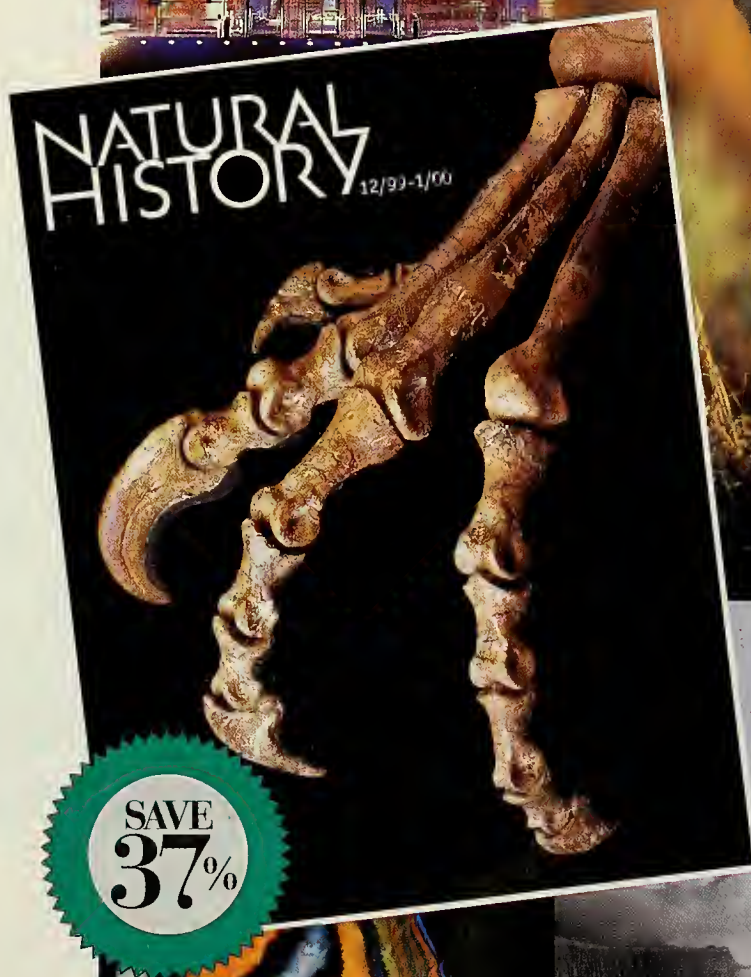
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SAMPLINGS

MULTITASKING If you're lucky enough to have a backyard vegetable garden this summer, pull up a bean plant (or any other legume) and take a look at its roots. The little swellings you'll see are nodules formed by the plant and inhabited by bacteria. But don't be alarmed: there's no disease. The plant needs nitrogen to make proteins, but the nitrogen in the plant's environment takes a "raw" form the plant cannot use. That's where the bacteria come in: they "fix" the nitrogen in a molecular form that makes it available to the plant. In exchange, the plant supplies the bacteria with sugars and other compounds.

The nitrogen-fixing partnership has long been the subject of intense scientific study—if only because so many of the world's protein-rich crops are legumes: alfalfa, soybeans, and peas, to name a few. Now Rieko Nishimura, a molecular biologist at the University of California, Berkeley, and several of her colleagues at Japanese universities have provided investigators with a new tool: a mutant form of the legume *Lotus japonicus*, a "model" organism well known to plant geneticists around the world. The mutant form is called astray because it grows long horizontal roots that, with respect to gravity, have "gone astray."

More to the point, the astray form generates many more nodules than the plant's nonmutant form, and it makes them early in its life. Astray has aboveground abnormalities as well. For example, its stem is elongated and its color a washed-out green—typical features of plants that lack access to light. Thus the astray gene is involved both in the plant's responses to light, an attribute of the aboveground world, and in the formation of roots and nodules underground. And the gene's multiple talents offer a window into the evolution of nodulation in legumes: certain proteins that were operating in the light of day were co-opted for work within the darkness of the soil. ("A *Lotus* basic leucine zipper protein with a RING-finger motif negatively regulates the developmental program of nodulation," *Proceedings of the National Academy of Sciences* 99:15206–10, November 12, 2002)

EAU DE DANGER Do animals smell fear? Mostly the answer is no. Sight, not smell, is what reveals a frightened creature's (or person's) emotional state. But for animals in a watery environment, the smell of fear does indeed act as a strong signal—albeit more as a warning to potential victims than as a giveaway to predators.

It is known that frightened crayfish, crabs, fish, and tadpoles spurt ammonia in their urine and through their gills. For neighboring animals—even unrelated species—the fluids serve as a kind of universal "disturbance cue," causing them to seek cover or become more

few ounces of water from the pike tanks. One of the new groups (the experimental group) also received a few ounces of the water from the tank that had been disturbed by the fake heron head. The second new group (the control group) received the same amount of water from a tank containing charr that hadn't been disturbed.

When the charr in the experimental group then encountered a pike in a test tank, they gave the unfamiliar predator a wider berth and avoided capture for a longer time than did the charr in the control group. Mirza and Chivers conclude that when charr detect disturb-



Brook charr can tune in to the smell of fear.

circumspect, even though they may not be able to sense the predator directly.

Now two biologists at the University of Saskatchewan in Saskatoon have shown that disturbance cues can even lead some fish to identify previously unknown predators. Reehan S. Mirza and Douglas P. Chivers scared young brook charr (also known as brook trout) by striking the water surface of the charr's tank with a fake heron head. Then they collected a sample of the water. They also collected water from tanks containing predatory northern pike. Then they subjected two new groups of charr to a

ance cues, they pay attention to other odors in the vicinity and thereafter treat those odors as suspicious, and so they are more alert to potential predators and can survive longer. ("Behavioural responses to conspecific disturbance chemicals enhance survival of juvenile brook charr, *Salvelinus fontinalis*, during encounters with predators," *Behaviour* 139:1099–1109, 2002)

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



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Reaching for the Stars

Instead of counting smart bombs, perhaps we should count smart scientists.

By Neil deGrasse Tyson

In the months since the space shuttle *Columbia's* fatal reentry through Earth's atmosphere, it seems that everyone has become a NASA critic. After the initial shock and mourning, no end of journalists, politicians, scientists, engineers, policy analysts, and ordinary taxpayers began to debate the past, present, and future of America's presence in space. Although I have always been interested in this subject, my recent tour of duty with the President's Commission on the Future of the U.S. Aerospace Industry has further sharpened my senses and sensitivities.

Amid the occasional new arguments on the op-ed pages and TV talk shows were questions that get rolled out with every new woe in the space program: Why send people into space instead of robots? Why spend money in space when we need it here on Earth? How can we get people excited about the space program again?

Yes, excitement levels are low. But lack of enthusiasm is not apathy. In this case, the business-as-usual attitude shows that space exploration has passed seamlessly into everyday culture, so most Americans no longer even notice it. We pay attention only when something goes wrong.

In the 1960s, by contrast, space was an exotic frontier—traversed by the few, the brave, and the lucky. Every gesture NASA made toward the heavens caused a splash in the media—the surest evidence that space was still unfamiliar territory.

For many, particularly for NASA aficionados and all of the people engaged in the aerospace industry, the 1960s was the golden era of American space exploration. A series of space

missions, each more ambitious than the one before, led to six lunar landings. We walked on the Moon, just as we said we would. Surely Mars was next. Those adventures sparked an unprecedented level of public interest in science and engineering, pumping eager, inspired students through the entire U.S. educational pipeline. What followed was a domestic boom in technology that would shape our lives for the rest of the century.

A beautiful story. But let's not fool ourselves into thinking we went to the Moon because we're pioneers or explorers or selfless discoverers. We

Let's not fool ourselves. NASA went to the Moon because of Cold War politics.

went to the Moon because Cold War politics made it the militarily expedient thing to do.

In 1961, just weeks after the Soviet cosmonaut Yuri Gagarin became the first person to orbit Earth, President John F. Kennedy told Congress:

I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.

But most people have forgotten the rest of his speech. Kennedy never suggested the Moon landing be accomplished for its own sake. He was issuing a powerful appeal to vanquish Communism:

If we are to win the battle that is now going on around the world between freedom and tyranny, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did the Sputnik in 1957, the impact of this adventure on the minds of men everywhere, who are attempting to make a determination of which road they should take.

Clearly the president knew that although bravery may win battles, science and technology can win wars. And Kennedy was hardly the first leader to call for an expensive military program.

But what about discovery for its own sake? Are the scientific returns on a manned mission to Mars inherently important enough to justify its costs? After all, any foreseeable mission to Mars will be long and immensely expensive. But the United States is a wealthy nation. It has the money. And the technology is imaginable. Those aren't the issues.

Expensive projects are vulnerable because they take a long time and must be sustained across changeovers in political leadership as well as through downturns in the economy. Photographs of homeless children and unemployed factory workers juxtaposed with images of astronauts frolicking on Mars make a powerful case against the continued funding of space missions.

A review of history's most ambitious projects—the ones that have garnered an uncommonly large fraction of a nation's gross domestic product—demonstrates that only three goals have won such support: defense (the Great Wall of China); the promise of eco-

nomic return (the voyages of Columbus and Magellan); and the praise of power (the pyramids of Egypt). And for expensive projects that fulfill more than one of these functions, money flows like beer from a freshly tapped keg. The 44,000 miles of U.S. interstate expressways make a crisp example. Conceived in the Eisenhower era to move matériel and personnel for the defense of the nation, that network is also heavily used by commercial vehicles. That's why there is always money for roads.

In the current space program the empirical risk of death remains high. With two lost shuttles out of 113 launches, an astronaut's chances of not coming home are about 2 percent. If your chances of death were 2 percent every time you drove to the Piggly Wiggly, you would never drive your car. To the *Columbia* crew, however, the return was worth that risk.

I'm proud to be part of a species whose members occasionally and willingly put their lives at risk to extend the boundaries of their existence. Such people were the first to leave the cave and see what was on the other side of the cliff face. They were the first to climb the mountain. They were the first to sail the ocean. They were the first to touch the sky. And they will be the first to land on Mars.

But somebody has to write the check. We've made it out of the cave and up the mountain. Now exploration costs real money. When nobody writes the check, we stall on the last breached frontier.

Actually, there *may* be a way to keep going places. But it involves a slight shift in what the government usually calls national defense. If science and technology can win wars, as the history of military conflict suggests, then instead of counting our smart

bombs, perhaps we should be counting our smart scientists and engineers. And there is no shortage of seductive projects for them to work on:

- We should search Mars for fossils and find out why liquid water no longer runs on its surface.
- We should visit an asteroid or two, and learn how to deflect them. If one is discovered heading our way, how embarrassing it would be for us big-brained, opposable-thumbed humans to meet the same fate as the proverbially pea-brained dinosaurs.
- We should drill through the kilometers of ice on Jupiter's moon Europa and explore the liquid ocean below for living organisms.



Rufino Tamayo, *El hombre*, 1953

- We should explore Pluto and its newly discovered family of icy bodies in the outer solar system, because they hold clues to our planetary origins.
- We should probe Venus's thick atmosphere to understand why its greenhouse effect has gone awry, giving rise to a surface temperature of 900 degrees Fahrenheit.

No part of the solar system should be beyond our reach; we should deploy both robots and people to get there (robots make poor field geologists). And no part of the universe should hide from our telescopes; we should launch them into orbit and give them the grandest vistas for looking back at the Earth and at the rest of the solar system.

With missions and projects such as those, the U.S. can guarantee itself an academic pipeline bursting with the best and the brightest astrophysicists, biologists, chemists, engineers, geologists, and physicists. And they will collectively form a new kind of "missile silo"—filled with intellectual capital—ready to come forward whenever they are called, just as the nation's best and brightest have always come forward in times of need.

For the U.S. space program to die along with the crew of the space shuttle *Columbia*—because nobody is willing to write the check to keep it going—would be to move backward just by standing still.

Astrophysicist Neil deGrasse Tyson is the director of the Hayden Planetarium in New York City. He was a presidential appointee to the twelve-member Commission on the Future of the U.S. Aerospace Industry (www.aerospace.com/mission.gov), whose final report was submitted to the White House in November 2002.



Leftovers from an ursine banquet: nutrients from the parts that were eaten will also fertilize the plants . . . indirectly.

How Bears Feed Salmon to the Forest

Trees get the table scraps from a fish dinner.

Story and Photographs by Robert S. Semeniuk

Wearing night-vision goggles, Thomas E. Reimchen maneuvers our inflatable boat around rocks, deadfalls, and barnacles as we pick our way in the dark up an estuary in Canada's Pacific Northwest. In our wake we leave brilliant bursts of bioluminescence, as schools of fleeing salmon agitate unicellular algae called dinoflagellates. Why the "dinos" emit light is open to interpretation. One explanation, Reimchen tells me, is that the light attracts fish that eat zooplankton such as copepods, which are predators of the dinoflagellates.

A biologist at the University of Victoria in British Columbia, Reimchen specializes in predator-prey interactions. We are here to observe black bears catching spawning salmon

(the bears get most of their catch in the dark). The field study is part of an investigation born more than a decade ago at Bag Harbour in the Queen Charlotte Islands. One day in 1992, as Reimchen was sitting under giant Sitka spruce trees and looking at half-eaten salmon carcasses strewn about on the forest floor, he realized that the abundance of carcasses and the abundance of giant trees adjacent to the river was probably no coincidence. Ever since that moment, he has collected evidence that the autumn return of salmon from the Pacific Ocean to the streams of their birth is much more than just the annual migration of fish. The run of salmon constitutes a major flow of marine nutrients into estuaries and coastal watersheds.

Reimchen estimates that before the expansion of commercial fishing and industrial logging in the twentieth century, when salmon were more abundant throughout coastal streams, each of the 30,000 black bears living in the salmon watershed may have caught on average 500 fish a year. If half of each carcass was left uneaten on the forest floor (a reasonable estimate), he figures the nutrient transfer into the rainforest amounted to more than 25,000 tons a year, of which 3.4 percent was nitrogen.

And salmon carcasses are by no means the only way bears spread salmon-derived nitrogen to the terrestrial ecosystem. Other field biologists, such as Grant V. Hilderbrand, formerly of the Alaska Department of Fish and Game, and his colleagues, have documented two other major means: urine and feces. Hilderbrand, who studied brown bears in Alaska, maintains that urine is particularly important. Bears consume salmon in the late summer and fall to accumulate the fat reserves they will need to hibernate—and that females will need to birth and provide milk for their cubs. Although some of the nitrogen from the salmon goes into building muscle tissue and meeting other physiological demands, the bears' fat tissue is virtually nitrogen-free. Consequently, much of the nitrogen in the salmon protein is excreted. "The bottom line," Hilderbrand says, "is that if the bears leave half of each carcass in the forest, the other, eaten half also is ultimately deposited in the forest as well."

Reimchen's boat carries us out of the salty estuary and up the Klekane River into the conifer rainforest of the coastal mainland of British Columbia. After the boat has been safely tied up at the bank, Reimchen leads me and two of his coworkers, Deanna D. Mathewson, also of the University of Victoria, and Daniel R. Klinka, a graduate student of Reimchen's, along a creek into the pitch-black woods. To avoid surprising any bears, Reimchen trudges steadily for-

ward, uttering low guttural sounds. Then, at the edge of the creek we stop and wait quietly; I scan the forest on the opposite bank.

"There is a bear downstream walk-

appears into the forest with a big chum salmon in its mouth.

Black bears favor the bigger chum salmon to the smaller pink salmon; they are more apt to eat pink salmon

Some bears have a taste for salmon brains; others eat everything but the fish's testicles.

ing towards us," someone whispers softly. The splash of the footsteps sounds closer than the animal appears through my night-vision goggles. The bear lunges forward, crashes through the water, but misses a fish. The bear moves upstream slowly, to within perhaps fifty feet of us, and takes another lunge. Again, no catch. On its fourth try, the bear succeeds. I hear the crunch of fish skull, and the bear dis-

in the stream, and usually carry chum salmon into the forest. At Bag Harbour Reimchen had predicted that bears would take larger and thus more valuable catch farther into the forest, where other bears and scavengers would be less likely to interfere. That led him deeper into the forest in search of carcasses. Occasionally he found them as far as 200 yards away from the streams.

The bear returns in about fifteen minutes and starts fishing again, by swatting and grabbing. Bears exercise various techniques. Some patiently wait in the shallows and then just flop into the water on their bellies. Reimchen says that by day at Bag Harbour, black bears would just wade in and snorkel, or search overhangs and logs, and catch fish without any great motion. Salmon are more quiescent at night, he adds, and can readily be approached in the water. "At night I can pick up big chum salmon; as long as I don't take them out of the water, or squeeze them too hard, they allow me to hold them."

Reimchen notes that black bears catch more male fish than females. "Males are always darting around," he notes, "fending off other males and chasing females," whereas females are



A grizzly catches pink salmon in Knight Inlet of the mainland coast, near Vancouver Island

more likely to hide in the shadows, say, under a log. The distinguishing hump on the male's back may also make it easier to see or catch [see "Fin Tuning," below].

Some bears eat only parts of the fish—they bite out the brain, or strip out just the eggs. Other bears leave nothing except a pair of intact testicles

draped over a rock or a mossy log. The sperm are made up mainly of nucleic acids (DNA), and they are metabolically hard to digest because they may yield high levels of nitrogenous toxins. In contrast, eggs are mainly yolk—in other words, oils. Often bears delicately skin and eat only the fattest parts of the fish, leaving the rest

to be scavenged successively by eagles, martens, ravens, crows, gulls, beetles, and fly larvae. Even deer and squirrels feed on salmon carcasses.

Reimchen and his colleagues examine, weigh, and take a broad range of data about each carcass: lower jaw length; body length; sex; weight of testes, or the number of eggs in the

Fin Tuning

By Scott M. Gende and Thomas P. Quinn

Bears that live near salmon streams and spawning grounds tend to grow larger, have more cubs per litter, and belong to denser populations than do bears without access to salmon. No big surprises there. But what difference do the bears make to the salmon? Does being the prey of bears measurably affect salmon ecology, behavior, or evolution? Three criteria must hold for the answers to be yes. First, bears have to kill a "high enough" proportion of a salmon population. Second, predation can't be random; some fish must be favored, or ignored, according to some morphological or behavioral trait. Third, and most important, predation must influence salmon fitness, or in other words success at reproduction. Because salmon returning to freshwater streams will soon die anyway, whether killed by bears or not, the answers are far from obvious.

Having observed the interactions of bears and salmon for many years, we have concluded that the three criteria can be met only at small streams. First, in small streams, bears can kill a high proportion of the salmon; the fishing requires less effort there than it does in wider and deeper streams.

Second, perhaps because of the greater visibility or "catchability" of large fish in shallow water (or because of the simple preferences by the bears) large salmon (at least in small streams) are more likely to be killed than smaller ones. By targeting the large fish, bears may be maximizing the energy they gain from food, compared with the energy they spend in catching the fish.

Third, in small streams bears preferentially kill salmon that have not yet spawned. The reason is that salmon do not eat once they enter freshwater; instead, they draw on their own stores of fat, or lipid, as well as protein, for the energy to migrate upstream and reproduce. Consequently, the longer a salmon has been in a stream, the lower its energy content. Salmon just entering streams carry as much as 90 percent more lipid and 50 percent more protein than do salmon that have spent some time on the spawning grounds and are near

death. Thus the energy reward for the bears is much greater if they kill a salmon that has just entered a stream—particularly a female salmon, whose lipid-rich eggs are the bears' choicest meal. Bears may be able to distinguish energy-rich fish by their appearance because the loss in lipid and protein also leads to a loss of skin color and an increase in body fungus. By contrast, in larger or more structurally complex streams, bears do not or cannot selectively target the larger fish or the most recent arrivals.

The results of bear predation are evident in the salmon themselves. Compared with the salmon in large streams, the ones in small streams where predation is high tend to be smaller and to spawn their eggs sooner after entering the stream.



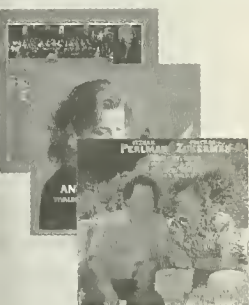
Pink salmon in Knight Inlet

Another effect of the bears is reflected in the dorsal humps of male sockeye and pink salmon: they are smaller than the humps of salmon not exposed to bears. Usually—even accounting for differences in body length—males with relatively large humps win out in the competition for females. The hump may serve the practical purpose of making the fish's profile too fat

for another male to bite, but it is also used in display. To some extent, too, females may prefer a larger hump in their mate. Other things being equal, a larger hump would seem to be the way to go.

The back-to-belly thickness of a male sockeye salmon may range from four to ten inches. Yet some of the streams they spawn in can be as shallow as three and a half inches deep. In those streams, the larger the hump, the more it will stick out of the water. Such a hump may be more readily visible to bears, and it may make maneuvering harder for the fish (in small streams, stranding is a more severe problem for large-humped males than for small-humped ones). Either way, the large-humped males are the ones more easily captured. Here, too, bear predation becomes a powerful source of natural selection, countering the selective pressures that otherwise would maintain a large hump.

Scott M. Gende is an ecologist at the Pacific Northwest Research Station in Juneau, Alaska. Thomas P. Quinn is a professor in the School of Aquatic and Fishery Sciences, University of Washington in Seattle.



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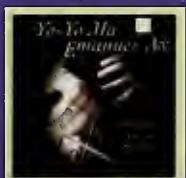


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body cavity and on the ground; position of the carcass and its distance from the stream; body condition and intactness; presence or absence of the brain. In addition, the biologists collect tree cores and plant-tissue samples in as many watersheds as possible.

During his initial investigations in Bag Harbour, Reimchen had reckoned he could gauge historical trends and fluctuations in the flow of salmon by examining the yearly growth rings of trees. The number of salmon entering Bag Harbour has varied enormously during the past half-century, ranging from 500 to 35,000 a year. Presumably, Reimchen reasoned, trees grew faster, and their growth rings became thicker, in the years in which salmon were more abundant. But he didn't know how he could rule out some independent external factor: after all, tree growth might be largely determined by rainfall.

Then a colleague, Joseph Rasmus-

sen, a biologist at McGill University in Montreal, suggested that Reimchen measure the relative proportions of nitrogen isotopes in the tissue of forest plants. Specifically, Rasmussen noted,

with its concentration in the air. That makes it fairly straightforward to measure the relative contribution marine nutrient sources such as salmon make to trees and other plants.

Nitrogen isotopes in tree rings record changes in the annual run of salmon.

Reimchen should measure the proportion of nitrogen that is made up of the isotope nitrogen 15. (By far the most common form of atmospheric or oceanic nitrogen is made up of the isotope nitrogen 14, so called because each atomic nucleus of nitrogen 14 contains a total of fourteen protons and neutrons.) Nitrogen 15, which has an extra neutron, becomes more concentrated in marine life-forms at progressively higher levels of the food chain. Hence in salmon, a fourth-level consumer, the concentration of nitrogen 15 is relatively high, compared

Although other investigators were already measuring nitrogen 15 to estimate the contribution of salmon-derived nitrogen to aquatic habitats, Reimchen was one of the first to apply the procedure in terrestrial plants. For example, to isolate the contribution of salmon to the forest nutrient mix, he has compared the nitrogen-15 proportions in vegetation growing above and below waterfalls that are barriers to migrating salmon. Similarly, he has looked at the proportion of nitrogen 15 to see if it falls off as one moves inland from the salmon-charged



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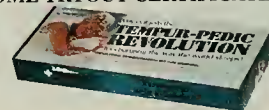


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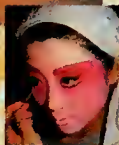
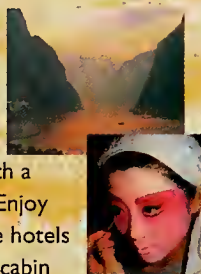
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streams. The results have confirmed that trees closest to the salmon streams draw the largest share of marine nutrients. In fact, fully half of the nitrogen in some old-growth trees near salmon streams comes from salmon.

But Reimchen's goal has remained the ambitious one he started with: to chronicle the annual ups and downs of marine-derived nitrogen. To do that, he had to measure the proportions of the nitrogen isotopes in each growth ring. Together with the age of the ring, he reasoned, that difficult measurement would give him the data he sought.

Reimchen and his colleagues set out to drill and extract half-inch cylindrical cores from old-growth cedar, spruce, and hemlock trees. At first, however, no mass spectrometer could measure the trace quantities of nitrogen 15 present in the minute wood samples cored from a single growth ring. After four years of false starts, though, Reimchen found a laboratory in Davis, California, that has been systematically able to resolve differences in nitrogen-15 levels in samples as small as one—or at most just a few—tree rings. As one might expect, the greatest annual swings in concentration occur in the trees closest to the streams. Independent historical data of salmon abundance correlates well with nitrogen-15 signatures in rings during the past fifty years. Because it takes a year or so for nitrogen to be incorporated into a tree, however, the nitrogen-15 fluctuations lag the fluctuations in salmon by one to three years. Reimchen's team has also found high total nitrogen levels in the rings of trees nourished by salmon, suggesting that such trees grow relatively fast and large. The investigators are currently examining watersheds where the salmon populations have dropped off sharply, and expect to document the general chronology of those changes.

The records of early European settlers—even the memories of Native American elders—recall rivers that ran with thousands of salmon, rivers

where the salmon have now become rare or have even vanished. Many such stories are largely rejected by fishery biologists as exaggerations. After all, how could anyone say whether salmon existed in some now-quiet stream, sometime in the past? "Now, for the first time, we have a method of answering that question," says Reimchen—and perhaps of determining the abundance of such salmon in the past.

Reimchen's work is not the only window into that past. Hilderbrand and his colleagues analyzed hair specimens from grizzly bears that existed in Oregon's Columbia River Valley until 1931. The investigators have shown that an average of 58 percent of the grizzlies' diet came from salmon. Even grizzly bears as far as 800 miles from the ocean consumed salmon. Reimchen's research could add a new dimension to those findings. Mapping trees enriched with salmon nutrients would reveal vital arteries that link marine and terrestrial habitats; in principle, that could be done with remote sensing by satellite.

As we come to the end of our nighttime observations, Reimchen speaks about how his work feeds into the formulation of conservation policies. "People act as if they harvest the surplus, and are the only harvesters. They think that all the dead fish in the stream are wasted." But the work of Reimchen and other investigators shows that not only do salmon replenish the forest; they also revitalize streams and estuaries with carbon, nitrogen, phosphorous, and other minerals. Among salmon themselves, the circle of life is particularly intimate: nearly half of the nutrients consumed by juvenile salmon comes from their dead parents. "In ecosystems there is no surplus," says Reimchen. "Everything is used."

Robert S. Semeniuk is a freelance writer and photojournalist based in Bowen Island, British Columbia. For further information about the work of Reimchen and his colleagues, see web.uvic.ca/reimlab/.

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ROCKS IN THE BAY OF FUNDY; BOTTOM: DANCERS
AT KINGS LANDING HISTORICAL SETTLEMENT



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TOP: PONTOON BOAT EXCURSION THROUGH GRAND FALLS GORGE; ABOVE: SUCCULENT LOBSTER FEAST; BELOW: CART RIDE AT THE VILLAGE HISTORIQUE ACADIEN



Photos: New Brunswick Tourism and Parks

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
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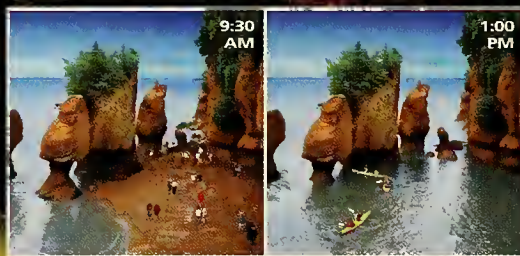
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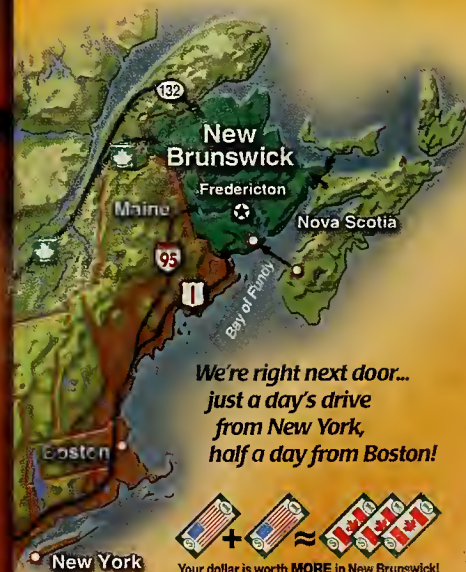
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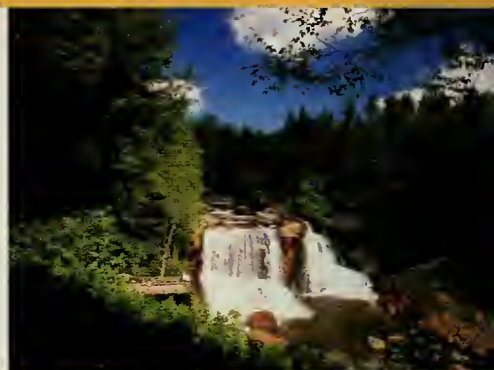


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NORWAY



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Photo: Mattias Persson / Norwegian Tourist Board



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CAYMAN ISLANDS



Photos: Top left, Patricia Bradley; Above, Yves-Jacques Rey-Millet

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Each island has an interpretative center, a museum, walking and hiking trails, wetland boardwalks, and viewing platforms. Beautiful ceramic signs

THE CAYMAN ISLANDS ARE HOME TO OVER 200 BIRD SPECIES SUCH AS THE BROWN RED-FOOTED BOOBY (TOP LEFT) AND THE VITELLINE WARBLER (ABOVE).

explain the biodiversity of birds, forests and wetlands, and butterflies and reptiles. And the islands are peaceful and crime-free.

Cayman Brac, whose bluff plateau is about 70 percent tropical forest, has the most resident land birds. Endemic subspecies include Caribbean elaenia, bananaquit, loggerhead kingbird, thick-billed vireo, and vitelline warbler (confined to the Cayman and Swan Islands). Found only on the Brac are red-legged

thrush and a subspecies of the rare, threatened Brac parrot, *Amazona leucocephala hesternia* (a second subspecies, *caymanensis*, occurs on Grand Cayman). Counts estimate 400 parrots, with only about 60 breeding pairs. A must for birders is a visit to the National Trust’s protected parrot reserve. And don’t miss the Brac’s colonies of brown boobies and white-tailed tropic birds.

Just five miles west of Cayman Brac lies Little

Cayman, with a population under 100. Deserted sandy beaches and mangrove-fringed lagoons make for outstanding wetland birding, with over 70 migrants. There are also resident pied-billed grebe; colonies of tricolored, snowy, and yellow-crowned night-heron and black-necked stilt; and one endemic land bird, the Greater Antillean grackle. The Booby Pond Nature Reserve has the largest red-footed booby colony in the Caribbean—more than 20,000 birds—and a magnificent frigatebird colony. Stop by the viewing platform at Grape Tree Pond, a favored breeding site for a growing population of threatened West Indian whistling-duck. The only West Indian endemic duck, the “whistler” is normally shy, but a robust conservation effort at Great Pond has made it unconcerned with visitors.

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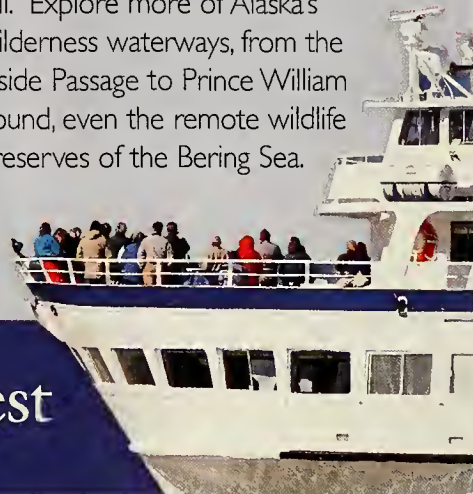
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Throwing Yourself into It

Were the weights held by Greek long jumpers a help or a hindrance?

By Adam Summers ~ Illustration by Patricia J. Wynne



Jumper holding weights, Greek red-figure cup, Evergides Painter, fifth century B.C.

At the Summer Olympics of 1968, in the dry, thin air of Mexico City, Bob Beamon redefined the limits of human performance. The altitude of the venue had led many sportswriters to speculate that records would fall, and the long-jump record was certainly in jeopardy. Jesse Owens's mark of 26 feet 8.5 inches had finally been surpassed in 1960 after having stood for twenty-five years; in the ensuing eight years it had been pushed eight inches. But no one was expecting what was to come. In the Mexico City long-jump finals, in a transcendent display of physical coordination, Beamon jumped twenty-two inches farther than anyone ever had. At 29 feet 2.5 inches it remains the Olympic record, the oldest one still standing; even now, thirty-five years later, the long-jump world record is just two inches greater.

Given Beamon's achievement, it seems ludicrous to say he could have done even better. But a new study of Olympic long jumping suggests that if he had been carrying a gallon jug of milk in each hand, he might still have the world record today.

Alberto Minetti, a biomechanist at Manchester Metropolitan University

in Alsager, England, is fascinated with human locomotion. He has explained why small children like to skip but adults don't, how toddlers toddle, and what a strolling gait would look like on another planet. Now, with his colleague Luca Ardigó, he has turned his attention to the role of ancient Greek sporting equipment. In the process he has unraveled a minor archaeological puzzle.

Records of the eighteenth Greek Olympiad, held on the plain of Olympia in the city-state of Elis in 708 B.C., are preserved as detailed paintings on the sides of vases. Documented in some of the sporting scenes are athletes holding peculiar stone or lead implements called halteres. The function of these implements had never been entirely clear. From the paintings on the vases, archaeologists had gathered that in the standing long jump (not to be confused with the running long jump, for which Beamon is celebrated), the athlete would hold one halter in each hand. During takeoff, he (the ancient Olympics were not co-ed affairs) would swing them both forward; then, while landing, he would swing



them back behind his body. But were the halteres carried to encumber, and thus handicap, the best athletes? Or were they, somehow, performance enhancers? Minetti and Ardigó, working with mathematical models and measures of jumping performance, have found that the latter is the case.

The distance covered in any jump depends on three factors: the angle and the velocity of the takeoff and the starting point of the jumper's center of mass. Although handheld weights don't increase the jumper's velocity (indeed, intuitively one would think they had the opposite effect) or change the launch angle, they do affect the center of mass.

Consider our depiction of an ancient jumper moving his arms [see illustration above]. As the athlete swung his arms forward, his center of mass would move forward and upward be-

fore his feet had even left the ground. In effect, the jumper gained the advantage of leaping from a slightly higher position, set a little past the takeoff line. As the jumper then came in for a landing, he would swing his arms backward. That motion did nothing to change the trajectory of his center of mass, which traced a parabola as the jumper moved through the air. But it did enable the athlete to push his feet farther out in front of his center of mass than he could without the halteres. As long as the extra weight hadn't slowed his takeoff, that push

added force of the muscle would actually generate more power, leading to an increase in jump distance.

Using a computer model of a jumper, the two investigators determined that adding between eight and fifteen pounds of weight did increase takeoff velocity. Heavier weights than those offset the increase in muscle force, leading to takeoff velocities either equal to or slower than those of an unburdened jumper. The model predicts improvements in jumpers' launch velocities of about 2 percent—an enormous gain in performance at elite levels of competition.

may not seem like much, but even for the untrained jumpers of the experiment, it would add seven inches or so to a ten-foot standing long jump. The last time the standing jump was an Olympic event, at the 1912 games in Stockholm, the three medal-winning jumps were separated by less than four inches; the winner leapt just over eleven feet. Assuming a modern long jumper could master the awkward matter of swinging both hands together during a running start, a similar gain would add about a foot to the distance. Perhaps Mike Powell, the current



would have enabled him to go farther, much as if he had swung over a fence and, at just the right moment, pushed off the top rail.

In spite of all the swinging and weight-shifting, the extra weight might still seem an obstacle for a jumper. After all, the kinetic energy of any object—a jumper included—is equal to half its mass multiplied by the square of its velocity. It might seem that adding mass would reduce takeoff velocity, and, that because of the squared velocity, such a trade-off would be far less efficient for the jumper. Yet there is good reason to suppose that takeoff power might actually increase with increasing weight—at least within limits. The more slowly muscles contract, the more force they are able to deliver, which is why heavy weights can only be lifted slowly. Perhaps with some small increase in weight, Minetti and Ardigó reasoned, the

The predictions of computer models are often more compelling than the empirical results with living, breathing (and misbehaving) human beings. But in this case quite the opposite is true. People untrained in long jumping were asked to select a set of randomly weighted halteres, and then to jump while swinging their arms from a platform that measured takeoff forces. Jumpers carrying weights ranging from two to about twenty pounds managed to increase their takeoff power by more than 5 percent. Minetti and Ardigó attributed the improvement over the computer model to the energy-storing effect of the body's elastic tissues: tendons, ligaments, and muscles. Such tissues stretch like rubber bands when loaded. When the jumper takes off, they spring back and return the energy to the jumper.

Such a small increase in power

world-record holder, would be interested in coming out of retirement to try out a well-used set of stone hand weights.

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



Jumping youth holding weights, Greek red-figure cup, fifth century B.C.

The Longest Winter

A series of deep freezes descended across the Earth 750 million years ago, each lasting millions of years. The spring that finally took hold may have triggered the present bloom of multicellular life.

By Gabrielle Walker

Look around, take in the intricacies of life on Earth, and then consider this: complex life is a very recent innovation. For billions of years the only earthlings were made of goo. Huddling together in the primordial sludge, they coated the seafloor and inched their way up the shore with the tide; they clustered around steaming hot springs and soaked up rays from the faint young Sun. Dull green or brown, excreting a gloopy glue that bound them into mats, these creatures were little more than bags of soup. Each was just a single cell. Each had mastered the rudiments of how to eat, grow, and reproduce, no more. Each was its own cottage industry in a society that had no interest in collaboration or specialization. The Earth was Slimeworld, just about as simple as life gets.

Then, suddenly, roughly 590 million years ago, something shook the Earth out of its complacency. That event—whatever it was—gave rise to the beginnings of eyes, teeth, legs, wings, feathers, hair, and brains. For life, it was the Industrial Revolution. Forget the old cottage industries where each single cell had to perform all the tasks of living. Now factories with specialized departments could thrive. From that moment, simple slime yielded its preeminence to the complex creations that heaved their way out of the sludge and started life's long march toward modernity. Whatever triggered that chain of events was ultimately responsible for the existence of you and everyone you've ever known.

Paul F. Hoffman, a geologist at Harvard University, thinks the culprit was something truly extra-

ordinary—the biggest climate catastrophe the Earth has ever known. That idea has been lurking in the scientific shadows for nearly sixty years, but Hoffman has now brought it firmly into the limelight. Marshaling evidence in rocks from Australia and Namibia to Russia and Newfoundland, Hoffman contends that life's richness, diversity, and sheer overwhelming complexity arose from a prodigious disaster known as “snowball Earth.”

Some 750 million years ago, says Hoffman, ice began to creep southward and northward from its strongholds at the North and South Poles. Individual crystals of ice first appeared in the sea like tiny floating snowflakes. They were smashed together by wind and waves, their fragile arms broken and their debris turning the water slick. The surface thickened and froze. In some places, the ice congealed into large pancakes, with raised edges like those of giant lily pads where they bumped and crashed against one another.

For perhaps a few thousand years, the ice stole unheeded toward the equator, while most of the Earth's life-forms bathed in the warmth of the shallow, equatorial seas. Geysers blew. The Sun shone. Rain fell. There was no hint of the devastation to come.

But when the ice reached the Tropics, its slow creep became a sprint. In a matter of decades, ice engulfed the tropical oceans. It spread out from shallow bays and grew a skin, then a carapace, over the oceans. It clung to the beaches and scraped against the microbial mats coating the

For a few thousand years, ice crept from its strongholds at the Poles. But when the ice reached the Tropics, its slow creep became a sprint.



Andy Goldsworthy, *Thin ice*, made over two days, welded with water from dripping ice, hollow inside, Scaur Water, Dumfriesshire, 10–11 January 1987

seafloor. In some places the shell of ice stayed thin enough to crack and seal again. In others it was thousands of feet thick.

At first the land itself remained bare. Then ice began to accumulate there, too, condensing out of the thin air of mountain ranges, creating great frozen rivers that flowed down to fill the surrounding valleys. In the end, the whiteout was complete. Earth's surface looked like the frigid wasteland of Mars, or one of Jupiter's ice-covered moons. Instead of adding its warmth, sunlight bounced off the bright surface and was dazzled back into space. The average temperature plummeted to -40 degrees Fahrenheit. Clouds by and large disappeared, except perhaps for minute ice crystals high in the atmosphere, which scattered sunsets into blue and green rimmed with vibrant pink. No rain fell, and little snow. Every day brought silent, unrelenting cold.

Hoffman's snowball wasn't just another brief cold blip in an otherwise fairly comfortable world, like the ice ages of the more recent geological past. Instead, it was the coldest, most dramatic, most severe shock the planet has ever undergone. The entire world was coated with a layer of ice nearly a mile thick, and for perhaps 100,000 successive centuries the Earth was a frozen white ball, desolate and all but lifeless.

There may have been as many as four snowball episodes until 590 million years ago, when the last one melted. Some microorganisms survived the deep freeze, of course—if they hadn't, they wouldn't still be around today. Maybe they huddled around undersea volcanoes or near hot springs, or found fissures and cracks in the sea ice where the Sun's rays could slip through. But for many, perhaps most of them, the snowball was disastrous.

Evidence for the snowball is written in the only surviving record from the late Precambrian: rocks. All over the world, on every single continent, rock outcrops contain mad jumbles of pebbles and stones of every shape, size, color, and provenance. They are scratched and scarred from having been bulldozed out of their home territory and dragged hundreds of miles across the landscape. And lodged in siltstone outcrops that used to form the Precam-

brian seafloor are occasional giant boulders, dropped by icebergs that were once passing overhead. Only one agent could have transported so many kinds of rock such long distances: glacial ice.

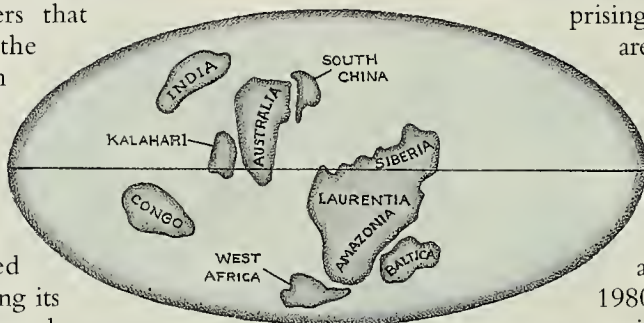
Hoffman was far from the first person to imagine an ice-encased world—which isn't surprising, since the "ice rocks"

are ubiquitous. Half a century earlier an English geologist named Walter Brian Harland had begun to develop the outlines of a "great infra-Cambrian ice age." And in the late 1980s, by examining magnetic iron particles in Australian ice rocks, Joseph L. Kirschvink, a geologist at Caltech, had shown that ice had reached the equator in Precambrian times. Even so, few geologists believed the

entire Earth could have frozen over. Snow and ice reflect sunlight much more effectively than rocks. A shiny white icebound Earth ought to send the Sun's rays bouncing back into space, and if the planet ever got into such a state—so the reasoning went—it should never be able to get out of it.

But in 1992 Kirschvink presented a brilliant solution to that conundrum. The snowball, he suggested, was melted by volcanoes. Then as now, volcanoes studded the Earth, periodically spilling out heat, gas, and molten rock. Whether beneath the sea or on land, they were perfectly happy to erupt under ice—as they do today in Iceland [see *"The Ice Above, the Fire Below,"* by Robert S. White, with photographs by Ragnar Th. Sigurdsson, June 2002]. And one of the main gases to come from the heart of a volcano is carbon dioxide, CO_2 , the gas that threatens us all with global warming. Carbon dioxide lets sunlight in but prevents the Earth's body heat from escaping, and so provides an effective way of warming up a planet. Each volcanic eruption, Kirschvink realized, would pour a little more CO_2 into the sky, eventually turning the air into a thick blanket. And after millions of years of frigid stasis, the ice would finally succumb, melting within perhaps just a few centuries.

The aftermath of the melting would have been hell on Earth. Dante, says Kirschvink, would have been proud of it. To lock the CO_2 back up in the rocks and clear off the blanket would have taken tens of thousands of years. In the meantime, average annual temperatures soared to 100 degrees F



A proposed distribution of Earth's landmasses 750 million years ago (Laurentia would become part of North America, Baltica part of present-day Europe). Geologists now speculate that this continental arrangement may have created conditions that gave rise to "snowball Earth."

or higher. Intense hyperhurricanes brought floods of acid rain. The Earth had leapt from the freezer into the fire.

Although Kirschvink's inferno was a stirring idea, he didn't pursue it. Before moving on to other things, however, he not only invented the term "snowball Earth" but also mentioned his ideas to Paul Hoffman. A few years later the spark ignited.

In the mid-1990s Hoffman was working among Precambrian ice rocks in Namibia and becoming increasingly baffled by a mysterious layer of

the carbonates showed up wherever the ice rocks were deposited, on every single continent. And that is peculiar, because one of the first lessons every geologist learns is that the Earth is emphatically not one big layer cake. Individual regions end up layered with quite different kinds of rock. You simply aren't supposed to get single events that blanket the entire planet with the same kind of rock. Period. Except that on every continent, ice rocks are capped by carbonates.

So how could an icehouse turn into a hothouse? The answer came from Hoffman's colleague Daniel



Lynn Davis, *Iceberg 30, Disko Bay, Greenland, 2000*

carbonate rock immediately on top of them. This "cap" of carbonate bore no pebbly interlopers, no boulders, no signs of ice at all. And carbonate rocks form at the bottom of balmy seas, so finding carbonates right above signs of ice was bizarre—like seeing palm trees in Antarctica. What's more,

P. Schrag, a geochemist also at Harvard. Schrag reasoned that the cap carbonates were a direct consequence of the snowball and its aftermath. The way Schrag envisioned it, the acid that rained onto the ground in torrents after the snowball ended fell onto a thick layer of dust, left behind by millions of years

of grinding by the glaciers. In the post-snowball world, that combination of ground-up rock and acid rain was a chemical factory waiting to happen. (Think how much faster sugar dissolves when it's not bound up in a lump.)

Rock dust and acid met, mated, and were swept off into the sea. They set the waters fizzing and foaming, creating a Coca-Cola ocean. Oceans frothed and bubbled with dissolved CO_2 ; rocks dissolved like baking powder. All around the world, the post-snowball ocean turned milky with flakes of white. They poured down onto every inch of the ocean floor. From the chemistry of acid rain and rock dust had come a massive outpouring of carbonate, blanketing the entire planet. The flakes squeezed together, hardened, and turned back into rock. They became the cap carbonates.

Hoffman and Schrag put their ideas together with Kirschvink's and published the amalgam in the journal *Science* in August 1998. That fall Hoffman went from one institution to another, purveying the good news in impassioned lectures. He had never, he said repeatedly, been so convinced that something was right.

But some in his audience were disturbed by the sheer extremity of the snowball vision. To buy into the snowball, you had to think of our home planet acting like some eerily alien world. You had to imagine oceans freezing over completely, even at the equator; an ice age that spanned 150 million years; a planet that plunged from the coldest temperatures it had ever undergone into an intense hothouse within a few centuries; CO_2 levels hundreds of times higher than have ever been seen in the geological record; and rates of rock weathering like nothing on Earth today. How could anyone accept a theory that was so far out of the box?

In the past half decade, plenty of adversaries have attacked the snowball theory, and Hoffman has had to answer their objections. Yet so far, the theory has survived every challenge with its core intact. And Hoffman's proselytizing has brought about a sea change in scientific attitudes. Virtually everyone now agrees that the period from about 750 million until 590 million years ago was a time of extraordinary ice, cold, and catastrophe. Even critics who think the tropics had at least some remaining open water—a scenario appropriately called “slushball Earth”—admit that ice went almost all the way around.



While Hoffman continues to bolster his geological case, he has had to leave the biological implications of the snowball theory to the work of other specialists. How, for instance, did the earlier life-forms survive the deadly ice? And could the snowball have provided the creative spark for the new, complex life that followed?

To answer the first question, you need to think about heat. Any hot spring or volcano on a shallow enough ocean floor would have created at least a small hole in the ice above it. So there would have been at least a few puddles and cracks in which living things could have grabbed their chance to make and store food, as they do in Antarctica today. And according to Douglas H. Erwin, a conservation modeler and the interim head of the Smithsonian's National Museum of Natural History, all you would have needed to get virtually all the extant species through the snowball epoch was about a thousand



Norbert Wu, *Sea Ice Lead, McMurdo Sound, Antarctica*

havens of open water, with about a thousand individuals in each. What's more, because snowball-era creatures weren't exactly gargantuan, each haven could have been no wider than a dinner plate.

But the second question is trickier. Until recently, most biologists had assumed that complex, multicellular life-forms arose about 545 million years ago, during an event called the Cambrian explosion. But that event couldn't possibly have been triggered by Hoffman's snowballs. They ended around 590 million years ago, and 45 million years is far too long to sit around with a lighted fuse waiting for the bang. In fact, fame has come to Cambrian creatures mainly because they invented skeletons, scales, shells, spines—in short, all the various bodily supports that stick around long enough after death to turn into clear, unambiguous fossils. But they needn't have been the first complex animals, any more than papyrus or the

printing press marked the beginning of language. Complex, multicellular life-forms could easily have been around for millions of years before the Cambrian, and just not left such a clear record of themselves in the rocks.

If Hoffman is right, if the snowball truly triggered the invention of multicellular life, the world's first complex creations must have appeared shortly after the ice receded. The question is, did they?

One way to answer the question is to supplement fossil hunting with a more oblique approach: the molecular clock. The genetic material inside every living cell carries information about its ancestry. But DNA changes slightly with each generation, with each tick of the genetic clock. If you measure how much DNA has changed from one species to another, and if you know how fast the clock was ticking, you can track evolution backward even without the help of fossils.

Most molecular clocks have indicated that complex animals emerged long before the snowball, too long ago for it to have triggered their appearance. Different clocks, however, have also yielded radically different dates: some said biological

complexity began 800 million years ago; others said more than a billion. That inconsistency frustrated Kevin J. Peterson, a biologist at Dartmouth College in Hanover, New Hampshire. Determined to prove once and for all that the beginnings of complexity had nothing to do with the snowball, he decided to make the most accurate molecular clock he possibly could.

Peterson chose echinoderms, a family of creatures that includes urchins and sea stars. Working backward, checking each result against the substantial number of well-dated available fossils in that family (until he ran out of fossils), he finally had his answer. He was stunned. The last common ancestor of all complex animals lived sometime around 700 million years ago. In other words, the appearance of that ancestor coincided almost exactly with the end of the first icehouse episode of snowball Earth.

Recall that Hoffman thinks he is dealing with a

series of events, not just one. Perhaps complex animals were triggered by the first freeze-over and then survived the remaining episodes of ice. It's also possible that despite Peterson's care, his clock overestimates the age of complex animals; some biologists think that genetic changes happened more quickly in the past, and that all molecular clocks yield older times than they should.

If an icebound Earth really did trigger complexity, encouraging life to diversify and experiment, how could it have done so? New species often arise when a single population of creatures becomes isolated from its fellows for a long time, perhaps a million years or so. Or perhaps the ice opened up a niche for complexity by wiping large areas of the planet clean of life. Until the enveloping mats of slime were kept from hogging all the resources, there might have been no way to innovate.

The most popular idea about how to trigger complexity, however, is to shock the system with

the planet. Now Schrag has taken that idea a few steps further. When continents spread out to the far north and south, they act as a brake on the spread of the polar ice caps. White ice reflects sunlight, which causes cooling, and that breeds more ice. Rocks, by contrast, normally prevent the Earth from overheating: in the chemical reaction known as weathering, rock and water combine with atmospheric CO₂, thereby removing one of the major greenhouse gases that volcanoes pump out. But if polar ice starts to spread, the rocks of high-latitude continents no longer soak up CO₂. Instead the gas stays in the atmosphere to do its greenhouse thing, warming up the Earth and melting the excess ice. That's what happens in the reassuring continental arrangement we have today.

Now imagine what would happen if all the continents were arranged in a band around the equator. The polar ice caps could spread with impunity. By the time ice reached the equatorial continents, a

When the continents bunch together near the equator, an alternating icehouse-hothouse cycle may ensue—until the continents move on.

oxygen—the agent that “burns” food and enables animals to develop large and complicated bodies. For millions of snowball years, when life would have been restricted to a few small refuges, unused nutrients would have built up in the sea, making it into a tasty chemical soup. As soon as the period of ice was over, the white planet would have become green. Massive colonies of bacteria and algae would have soaked up sunlight, made food, and belched out oxygen as a waste product. That sudden pulse of oxygen may have been just what complex life was waiting for.

One question remains outstanding: Why did the snowball ever happen at all? The answer may lie in a peculiar alignment of the continents. As the world's tectonic plates drift over its surface, the continents sometimes scatter and sometimes bunch together. On rare occasions they arrange themselves in a band around the equator—and there's reasonably good data suggesting that might have been the case during Hoffman's snowball.

More than a decade ago Kirschvink suggested that if all the available landmasses were collected in the tropics, they would reflect more of the incoming sunlight than seawater does, and so help cool

snowball would be unstoppable. And as long as the continents stayed in the tropics, the alternating icehouse-hothouse cycle would continue—until eventually the continents moved on.

The good news is that another snowball is unlikely to be imminent. Reassembling the continents into a band around the equator will take at least a few hundred million years. But the bad news—at least if the threat is a snowball—is that the Earth has come a long way since the simple days of Slimeworld, and life is now a complex web of interdependent creatures. If another snowball should ever engulf the Earth, many—perhaps most—of those creatures would perish.

Perhaps our descendants will be so unimaginably advanced that they will be able to prevent a snowball. But the Earth is a powerful and stubborn force. It limits our resources, and its geological will is extremely hard to check.

If distant descendants of the human lineage cannot stop another snowball, could they weather it? That, too, is hard to imagine. Getting a few simple marine creatures through the ice is one thing, but the complex creatures that inhabit our planet today present a much bigger challenge. Antarctica is the



Lynn Davis, *Iceberg 34, Disko Bay, Greenland, 2000*

most hostile place on Earth. Unless you take your own life-support system of food, fuel, and shelter along with you, you die. And on a snowball planet, Antarctica takes over everywhere in the world. For any truly complex creatures, the result would surely be disastrous. Norse mythology has a word for it: after the catastrophe of *Fimbulwinter* comes *Ragnarok*, the end of the world.

But a new snowball would not be the end for all life on Earth, any more than the earlier ones were. Our planet is, after all, a master of invention.

Through geologic time, the Earth has constantly taken on remarkable new identities. One mountain range rises; another falls. Oceans open here and close there. Change doesn't alarm the Earth; it is a fundamental part of its nature. We human beings, and the other creatures that share our slice of geologic time, are the fragile ones. □

This article has been adapted from Snowball Earth: The Story of the Great Global Catastrophe That Spawned Life As We Know It, by Gabrielle Walker, which is being published this month by Crown.

Date with Extinction

For a thousand years before people settled in New Zealand, a small alien predator may have been undermining the islands' seabird populations.

By Laura Sessions



Hutton's shearwater, a species of petrel, is still abundant near the shores of New Zealand's South Island. Here the birds rest on the sea within sight of their nesting area, about 5,000 feet up in the Seaward Kaikoura Range.

Our yellow Zodiac bobbed across the choppy sea and made its way slowly through the clouds of seabirds that wheeled and soared around us. Albatross, cape pigeons, diving petrels, mollymawks, mottled petrels, and sooty shearwaters all took their turns skimming our bow wave for fish. In the distance my boat mates and I could see the final stop on our sub-Antarctic tour: the Snares Islands, about 130 miles south of New Zealand's South Island. The chorus of screeching birds drowned out our rumbling boat motor, and even from several miles away we could smell the acrid white guano that coats much of the Snares's rocky coasts. During the summer breeding season

the Snares, whose entire area totals not much more than one and a quarter square miles, are home to more than 6 million seabirds—as many as nest along the coasts of Great Britain and Ireland combined.

Today in the New Zealand archipelago, such dense seabird colonies persist only on small offshore islands, but at one time much of the coastline of the North and South Islands (by far New Zealand's two largest islands, commonly called the mainland) would have been equally pungent and raucous. New Zealand once supported one of the most diverse seabird faunas in the world; the country was particularly rich in species of petrels. Nowadays those populations have crashed, and many species have been extirpated on the mainland. One can only imagine what it must have been like for ancient Polynesian seafarers reaching the shores of uninhabited New Zealand. The archipelago, no doubt a welcome sight after months of arduous ocean sailing in a double-hulled canoe, would also have presented a far different scene from that of most of New Zealand today.

But did these colonizers encounter a truly pristine environment? It would be easy to “round up the usual suspects” and blame the loss of so many

species from the mainland on the encroachments of civilization. But in reality, the early Polynesian settlers were not responsible for the destruction of many of the seabird populations. Even before people settled this southern land, other visitors may have already irrevocably altered the New Zealand environment.

Those earlier arrivals on the New Zealand mainland were Pacific rats (*Rattus exulans*), or *kiore*, as they are called in the Maori language. It has been known for almost a decade that these small stowaways helped drive some of the native bird species from the mainland, or, in some cases, to outright extinction. According to the standard account of the invasion, the rats arrived in New Zealand between 800 and 1,000 years ago, in the canoes of the first Polynesian settlers. But in 1996, Richard Holdaway, an independent extinction biologist, presented evidence that the rodents first made landfall perhaps a thousand years earlier. That date has called into question the entire sequence of prehistoric events that shaped New Zealand—and, not surprisingly, has fueled much debate in New Zealand about the strength and validity of Holdaway's evidence.

But even more, Holdaway has hypothesized that a rat-generated crash in island bird populations could have led to “a cascade of damage” and even to a change in the nearshore oceanic food web: seabird colonies generate a prodigious quantity of guano, which can form a kind of organic bridge between sea and shore, enriching soil and promoting plant growth. If the seabird populations crashed, Holdaway argues, so did this bridge. The islands would have lost a major source of nutrients. If Holdaway is right, the rats had accidentally landed on a choke point of the ecosystem, causing a ripple effect that went far beyond the destruction of seabirds.

Thanks to their remoteness—New Zealand lies 1,200 miles east of its nearest neighbor, Australia—the North and South Islands faced the onslaught of invaders considerably later than did many other islands around the globe. But just as they have on Hawaii and Guam, alien species that were suddenly introduced onto the islands have had devastating effects. New Zealand birds were particularly at risk, because they had evolved for millennia in the absence of mammalian predators (indeed, the only land mammals of prehistoric New Zealand were three species of ground-feeding bats). Many of the native birds were flightless and seminocturnal, mak-



A Hutton's shearwater skims the ocean surface, a habit that gives shearwaters their name.



ing them easy prey for the rats and the eleven other introduced species of predatory mammals that eventually prospered in the archipelago. Even seabirds were vulnerable; though they can spend months of each year at sea, many of them nest in ground burrows and are helpless against terrestrial threats.

As an ecologist and environmental writer, one of my main interests is to understand the damage that relatively recent introductions—from stoats to wasps to possums—have wreaked on native plants and animals. Often enough, I have discovered, even one such invader can set in motion a spiral of

discovered at non-archaeological sites, that is, sites without evidence of human settlement, with accelerator mass spectrometry (AMS)—a relatively new and particularly sensitive method of radiocarbon dating. To his astonishment, the AMS readings showed that some of the bones were as old as 2,000 years. That may sound recent by the standards of North American or European archaeology, but it is ancient history for New Zealand, the last large habitable landmass to be settled by people. The early date suggested that rats had not only occupied New Zealand before any other introduced land mammal, but that they had appeared on the scene more than a millennium before any human settlers.



A pair of Pacific rats feed on fruit. But given the chance, these mouselike rats readily devour small adult birds, chicks, and eggs. Evidence suggests that Pacific rats were the first mammalian predators introduced to New Zealand.

ill effects [see “A Floral Twist of Fate,” September 2000, and “New Zealand Sweet Stakes,” May 2001]. It was through those interests that I first met Holdaway, and became acquainted with his work, in 2001. Holdaway not only shares my concerns about the current state of New Zealand’s ecosystems; he also adds perspective by looking to the past. He hopes to document the species of prehistoric New Zealand, how its ecosystems worked, and what they can say about the islands today.

From 1991 until 1995 Holdaway took part in a collaborative study to examine fossils for signs that early Polynesian settlement had led to changes in animal populations and the mix of animal species. When rat bones were discovered at some of the fossil sites, he decided to test the assumption that the rats had arrived in New Zealand with the people who settled in the islands about 800 years ago. (Archaeologists have established the dates of those settlements on independent grounds.)

Holdaway measured the ages of the fossil rat bones

How firm are Holdaway’s findings? How likely are they to stand up to further scientific scrutiny? The late astronomer Carl Sagan once remarked that “extraordinary claims require extraordinary evidence.” The implications of Holdaway’s theory of early rat arrival are far-reaching, both for ecology and for the protohistory of Polynesian migrations. And sure enough, his findings have been hotly contested by some archaeologists, who have questioned the accuracy of his radiocarbon dates.

Atholl Anderson, an archaeologist at the Australian National University in Canberra, argues vigorously that dates earlier than 800 years ago, as determined by AMS measurement, can be explained by contamination of bones in the deposits. Recently, however, Holdaway published the results of a compar-

ison between radiocarbon dating and a second technique, known as optical dating, carried out by geochronologist Bert Roberts of the University of Wollongong in Australia. Optical dating determines when the quartz grains in the sediments containing the fossilized bones were last exposed to sunlight. The technique made it possible to estimate how long the sediments and the rat bones had been buried. The results of those tests confirmed the radiocarbon chronology for the Pacific rat fossils.

Archaeologists also point to the lack of evidence for human colonization of New Zealand before about 800 years ago. Known for their intrepid voyages throughout the Pacific, the people who first permanently settled New Zealand were eastern Polynesians in language and culture, and they were to become the direct ancestors of the Maori people. Holdaway believes that any population of more than about fifty people occupying New Zealand for any length of time would have left clues to their presence, such as bones of large flight-

less birds killed for food, or the remains of cleared forests—as the first settlers did. Yet no evidence for settlements more than 800 years old has ever come to light.

So if the colonizers didn't bring the rats, how could the animals have come to New Zealand? Pacific rats originated in southeastern Asia. Could they have made the trip on their own? The answer is surely no. The animals are reluctant swimmers, unable to cross water barriers more than 200 yards wide, even in the tropics. And it is unlikely that they rafted on vegetation to New Zealand from some far-off South Pacific isle. In spite of their relatively long tenure in the North and South Islands, they did not reach some of the offshore islands of New Zealand until quite recently.

Holdaway agrees with that scientific consensus: people brought rats to New Zealand. In fact, the Polynesians are known to have sometimes transported Pacific rats—perhaps at times for food—throughout the vast Pacific triangle, from Hawaii to Easter Island to New Zealand. But Holdaway thinks the people who brought the rats to New Zealand were earlier seafarers known as Lapita, who were probably the ancestors of the Polynesians. The Lapita left no archaeological evidence of their presence in New Zealand, Holdaway argues, simply because their visits to such southern latitudes were so transient. They may have touched on New Zealand shores intermittently for centuries before they, or other early Polynesians, decided to stay. And for rats to have arrived, become feral, and established themselves in the new habitat, they need not have “jumped ship” or been purposefully introduced in great numbers. Pacific rats, after all, are rodents, and so they are prolific reproducers; arriving at the right time of year, one pregnant rat could eventually have populated an entire island.



Skeleton of the neck and head of a moa, a long-necked flightless bird that grew as tall as six and a half feet. Native to the islands of New Zealand, moas were rapidly hunted to extinction by the Maori. (Photograph by Rosamond Purcell)

The idea that intermittent visitors carried rats to the islands several times is borne out by a study of the mitochondrial DNA of Pacific rats by Lisa Matisoo-Smith, an anthropologist at Auckland University in Auckland, New Zealand. Matisoo-Smith compared genetic sequences in Pacific rats from New Zealand with the same sequences in rats of the same species from other Pacific islands. Random mutations in mitochondrial DNA accumulate at a slow but relatively constant rate.

Matisoo-Smith reasoned that the mutations could serve as a clock for determining the arrival dates of rats on various islands across the Pacific. Assuming the rats arrived with early Polynesians (or perhaps with the Lapita), the rodents' mitochondrial DNA could serve as an independent record of pre-

historic human migrations. Her data show that the rats living in New Zealand today carry genetic heritages from various lineages of *R. exulans*, suggesting that they were introduced to New Zealand more than once, from various geographic sources.

Ecologists have only recently come to recognize that the rodents could have fundamentally altered



Maori seafarers power a war canoe in inshore waters, as depicted in this engraving by Paulo Fumagalli and his assistants. The Maori, a Polynesian people, were the first group to establish permanent settlements in New Zealand. Their oceangoing vessels, unlike their war canoes, were double-hulled and had triangular sails.



A kakapo, New Zealand's ground parrot, uses its stubby wings for display but not for flight. Adults are too large for Pacific rats to threaten directly, but their eggs are a manageable mouthful.

New Zealand's ecosystems. Until a decade ago, most biologists thought that Pacific rats, unlike Norway rats (*R. norvegicus*) and black, or ship, rats (*R. rattus*), were vegetarians. Pacific rats do feed frequently on plants and insects, but they are also avid meat eaters when the opportunity arises. Moreover, because rats are nocturnal, few people had ac-

New Zealand. Indeed, Holdaway and his colleagues have found evidence that within a hundred years or so of their arrival, Polynesian settlers had hunted the giant flightless birds known as moas to extinction. But if Holdaway's work is on the mark, New Zealand was far from pristine when the Polynesians came to stay. Rats that arrived 1,000 years before any permanent human occupation would have had more than twice as long as people had to alter their adopted ecosystem.

Although Polynesians might occasionally have killed and eaten lizards and the small flightless wrens that were once widespread throughout the islands, they would hardly have hunted such smaller prey to extinction. The Pacific rat was the only small feral mammalian predator in New Zealand before the European era began with the arrival of Captain James Cook in 1769. (Archaeologists think that Polynesian dogs, also introduced by Polynesian settlers and kept for food, had little impact on native species.) The blame for those extinctions clearly rests with the rat.

When Pacific rats arrived in New Zealand, they found themselves in a land of plenty. Millions of seabirds nested in ground burrows. Other birds, such as the flightless wrens, emerged at dusk to forage, the rats' favorite time to hunt. The rats simply did what any hunter would do. Their victims were well-adapted to avoiding birds of prey, which had always occupied the islands. But predatory birds attack from above, relying on their excellent vision to sight prey during daylight. The

By indirectly disrupting the flow of nutrients from the sea, the small Pacific rat may have altered island wildlife throughout the Pacific.

usually seen them in the act of predation until infrared video captured them at their gruesome tasks.

But by now biologists have observed them attacking adult saddlebacks (a native songbird whose numbers are dwindling) and devouring eggs of the little shearwater (a native petrel). Petrel chicks are sometimes skinned alive and their eyes eaten out. And Pacific rats are voracious. In New Zealand they weigh in at less than half a pound but can devour any prey as large as they are and eat eggs two-and-a-half inches long. They can even threaten the eggs of such large birds as the kakapo, the heaviest parrot in the world and now one of the rarest.

The Polynesians themselves are usually blamed for irrevocably changing the landscape of a pristine

rats hunted by night, on the ground, with their keen sense of smell.

A series of inadvertent natural experiments, involving the mix of people, rats, and wildlife on some of New Zealand's offshore islands, suggests in even greater detail how rats may have affected native fauna over time. For example, on offshore islands such as Aorangi and Stephens—which became home to Polynesians but never to Pacific rats—petrels, other small birds, invertebrates, frogs, and lizards still abound. Those species have largely disappeared from islands inhabited for long periods by Pacific rats.

It is the petrels, though, that most dramatically illustrate the magnitude of the damage that rats prob-

ably inflicted in New Zealand. Thirteen species of petrel once bred on the South Island. Today only six still breed there, and only one, Hutton's shearwater, remains on the island in great numbers. The seven extirpated species certainly disappeared before the Europeans arrived and may have been gone even before the Polynesians settled in New Zealand.

The petrel species that became extinct were precisely the ones whose size and habitat made them most accessible to the Pacific rats. Petrel species that were too big a mouthful for rats persisted on the mainland, even in lowlands, where rats were common. In contrast, the smaller petrel species all disappeared, even where their breeding habitats remained intact. Scarlett's shearwater, for instance, disappeared from the west coast of the South Island, even though the area retains some of the largest tracts of relatively undisturbed forest in the country. The only small petrel species that survived were the ones that nested on rat-free offshore islands or in cold mountainous regions, inhospitable to subtropical rats. Many of those refuges were later invaded by other, even feistier rat species and by stoats introduced by Europeans.

If rats were responsible for killing off petrels and other native species, what additional effects might their depredations have had? By eliminating huge colonies of seabirds, for instance, Pacific rats could have generated ecological damage far beyond the extinction of particular species.

Holdaway has drawn particular attention to the amount of organic waste once generated by the seabird colonies—mainly guano, but also lost eggs, dead birds, spilled food, and molted feathers. That waste would have constituted a bonanza of nutrients that flowed continuously from the sea to the land. (Miners on other oceanic islets, such as Nauru and Christmas Island, have come across guano-derived phosphate rock deposits as thick as seventy-five feet.)

The massive wastes of the seabird colonies on the mainland would have added phosphorus, nitrogen, and carbon to relatively nutrient-poor soils, and lowered the pH of the soil. The birds would also have aerated the soil as they burrowed to shape their nests. The nutrients would have fostered the growth of plants that sustained inver-

tebrates, lizards, birds, bats, and other herbivores. Take the case of Hutton's shearwater. Holdaway estimates that a remnant colony of these birds on the South Island still supplies more than 1,000 pounds of guano per acre in each breeding season. Extrapolating from that estimate, he maintains that before the appearance of the rats, seabird colonies could have supplied two million tons of fertilizer a year.

The possible implications of the loss of such a nutrient flow are astonishing. Pacific rats have spread to hundreds of islands and have eliminated hundreds of seabird populations. If those changes have equally disrupted hundreds of food webs, it could be that these small rodents have altered island wildlife across the entire Pacific. Holdaway's next step is to collaborate with investigators from a variety of disciplines to examine the possible connections between petrel disappearances and changes in those food webs. The Pacific rat may be the only mammal in the world, besides our own species, that has fundamentally altered an ecosystem on a continental scale. □



The Westland petrel, big and mean enough to fend off even large Norway and black rats, is one of the few petrel species that still breeds on the New Zealand "mainland," and whose numbers are on the rise.



Capitata lousewort, temporarily shrouded by a summer snowfall

Photographs by Subhankar Banerjee

Here the summer sun lingers above the horizon from mid-May until mid-August. Here the sky of the long winter night dances with the luminous curtains of the aurora borealis. The setting is the Arctic National Wildlife Refuge, in the northeastern corner of Alaska. Its 30,000 square miles of wildlands straddle the

Continental Divide, including the four highest peaks and most of the glaciers in the Brooks Range. Waterways that flow northward cross the tundra of the coastal plain and empty into the Beaufort Sea; waters flowing southward pass through forests of spruce and birch to join the mighty Yukon River or the Porcupine River, one of the Yukon's tributaries.

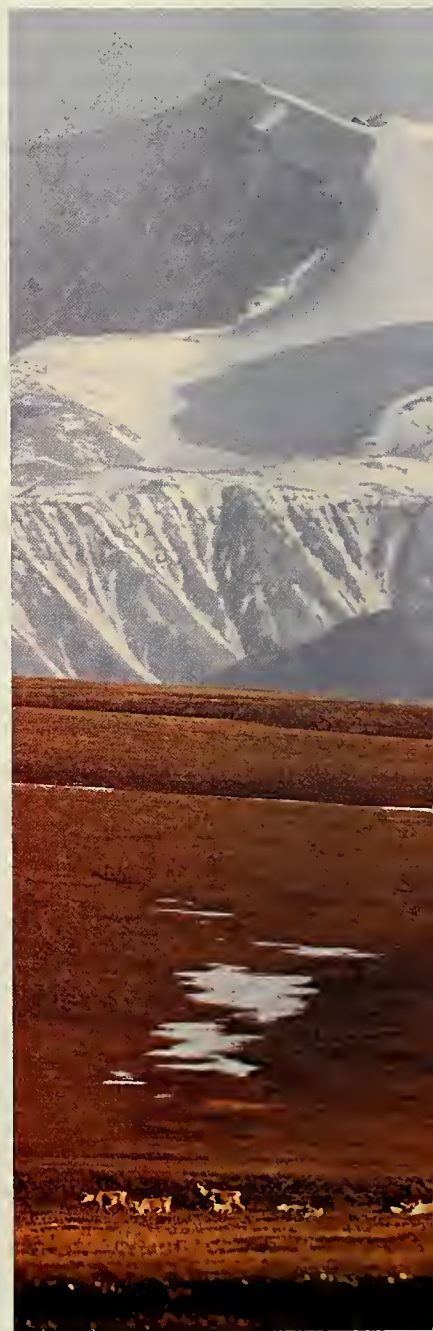
In May and early June the coastal plain serves as the principal calving ground for the Porcupine herd of caribou. Musk oxen give birth on the plain a bit earlier, from mid-April until mid-May. In the past few years, apparently as a result of global warming, the coastal plain has had more snow than usual and, as a consequence, a later spring thaw. Driven to the foothills to find forage, the musk oxen are more often giving birth there, even though that makes them and their young more vulnerable to grizzly bears. The net result is that their numbers are in decline.

Altogether the refuge is home to thirty-six species of land mammals and nine marine mammals that frequent its coast. About seventy species of birds nest on the coastal plain; another sixty-five make their annual pilgrimages from lands as distant as South America and Southeast Asia, just to feed on the clouds of early summer insects.

The refuge was created in 1980, enlarging a national wildlife range established in 1960. Nearly 14,000 square miles are designated as wilderness and are governed by the 1964 Wilderness Act. Mining and timber cutting are forbidden, and recreational equipment is circumscribed. But the coastal plain, despite its pivotal ecological role, is not classified as a wilderness area.

Owned by the citizens of the United States, the Arctic National Wildlife Refuge is now managed by the U.S. Fish and Wildlife Service (www.fws.gov/nwr/arctic/arctic.html). More than 300 archaeological sites, however, attest to the priority of an indigenous human presence. Exploiting the tundra and the sea are Inupiat Eskimos, traditional hunters of bowhead whales, while in the interior forests live the Gwich'in Athabascan Indians, whose fate and culture have long been joined with the herds of caribou. Inhabiting settlements on the periphery of the refuge, these people remain among its best-informed guides.

—VITTORIO MAESTRO



Arctic Covenant

In the springtime the Arctic National Wildlife Refuge of Alaska comes to life.



Mount Michelson looms over caribou on the coastal plain. As many as 120,000 animals belong to the Porcupine herd, named for the Porcupine River, which flows across the southeastern corner of Alaska's Arctic National Wildlife Refuge. Each spring the animals travel northward and congregate on the coastal plain in the refuge and in adjacent Canadian territory.

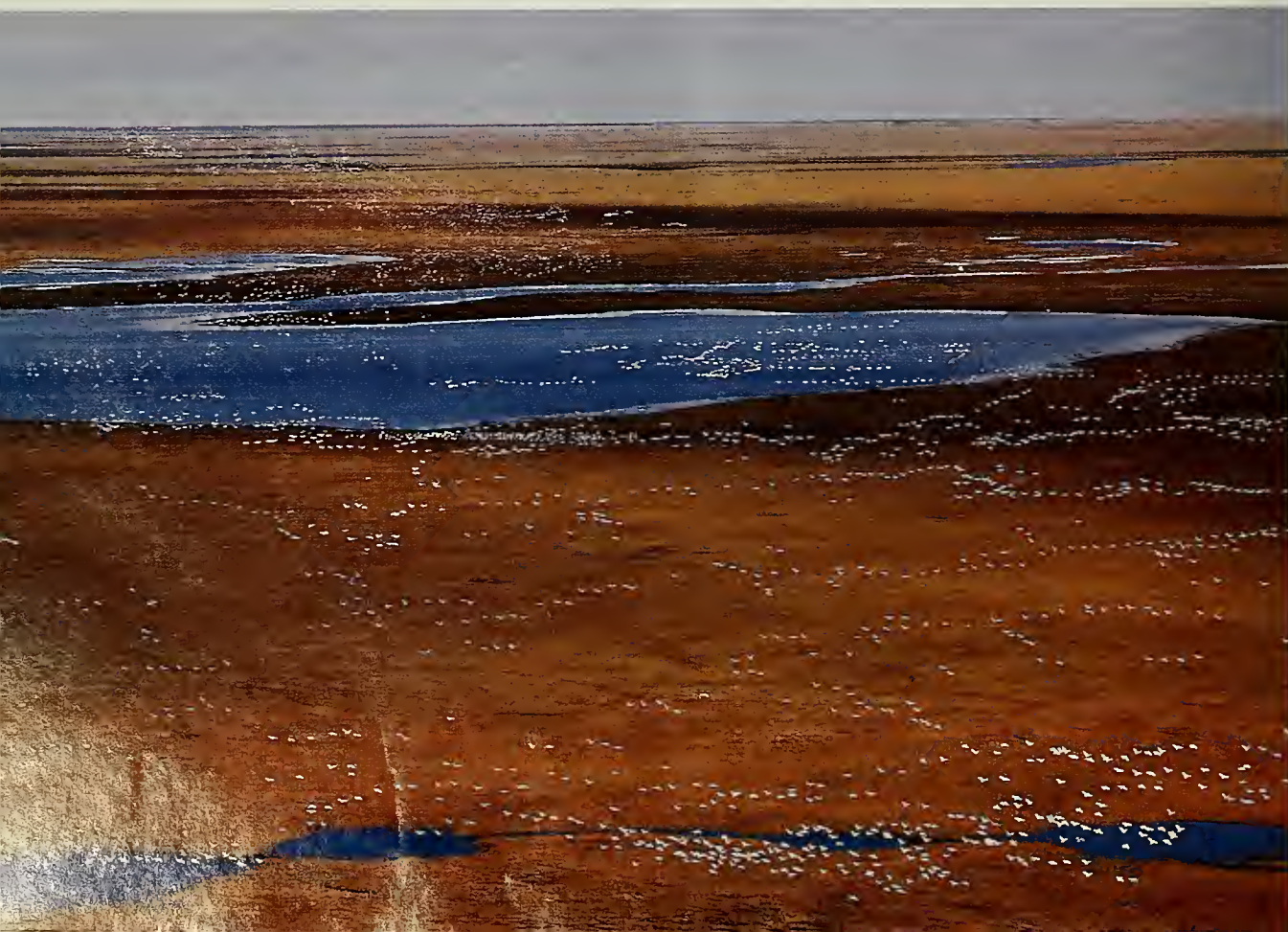


Arctic fox in its summer coat



Marsh fleabane grows in the valley of the East Fork of the Chandalar River, which flows south of the refuge to join the Yukon River. In the distance, Nichenthray Mountain and spruce trees are reflected in an unnamed lake.

In the fall 300,000 snow geese stop in the coastal plain of the refuge to bulk up on the root stalks of tall cotton grass before heading south to their wintering grounds.



Standing among sharp-edged peaks, at the convergence of mountain and sky, I am alone at a place without roads or people, not even trails except those trodden by wild sheep and caribou; there is nothing to violate the peace, with the mountains still unaffected by humankind. Here one can recapture the rhythm of life and the feeling of belonging to the natural world.

—GEORGE B. SCHALLER



A male buff-breasted sandpiper makes his courtship display. The world population of the species is only about 15,000. The birds migrate each year from Argentina to the coastal plain of northeastern Alaska and adjacent Canada.



Rock lichens in the valley of the Hulahula River, which flows northward across the coastal plain and empties into the Beaufort Sea.

Big predator species such as the polar bear and wolf signify the biological health of the Arctic ecosystem. But to me, in such a harsh environment, the smaller life-forms such as the American dipper, a songbird I saw feeding on the open waters of the Hulahula River in November, signify its spiritual health.

—SUBHANKAR BANERJEE

These photographs by Subhankar Banerjee will soon be published in Arctic National Wildlife Refuge: Seasons of Life and Land (Seattle: The Mountaineers Books, 2003).

Happy Birthday, DNA!

Return with us now to those thrilling days of discovery, fifty years ago this month.

By Everett I. Mendelsohn

James D. Watson opened his irreverent and at times malicious popular book, *The Double Helix*, with the comment: "I have never seen Francis Crick in a modest mood." Watson was referring of course to his partner in the discovery of the structure of DNA. The narrative is clear: immodesty led to success. It is that singular success that is now being celebrated, the fiftieth anniversary of the three papers on DNA (one by Watson and Crick, one by Maurice Wilkins and two coauthors, and the third by Rosalind Franklin and a coauthor) originally published in the journal *Nature* on April 25, 1953.

The tone of the papers, obviously constrained by the editorial policies of what was at the time indisputably the premier journal of science, was subdued if not comically understated:

We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

Watson and Crick knew, however, that if their structure was correct, they were on to something very big, and in one of the last paragraphs of their "Letter" to *Nature* they stated their claim:

It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

One could almost say, "The rest is history." The details sketched by Watson and Crick relatively rapidly stimulated enormous amounts of experimentation and further theorizing. Yes,

**Watson and DNA:
Making a Scientific Revolution**

by Victor K. McElheny
Perseus Publishing, 2003; \$27.50

**Rosalind Franklin:
The Dark Lady of DNA**

by Brenda Maddox
HarperCollins, 2002; \$29.95

their discovery does mark a critical milestone in the coming age of molecular biology. The combined effort is as important as any discovery in twentieth-century science. The detailing of the double helical structure of DNA in



James Watson and Francis Crick's 1953 molecular model of DNA, made up of metal plates and rods, arranged helically around a retort stand. Each plate represented one of the four bases whose complementary arrangement "suggest[ed] a possible copying mechanism for the genetic material."

1953 and its implications for how genetic information is replicated marked the opening of a major shift in how genetics would be practiced. Prior to 1953 the replication process was "black boxed." In contrast, following the work of Watson, Crick, Wilkins, and Franklin, genes were understood as molecules, and the search for how the molecules functioned and how they influenced the development of the structures and processes of living organisms became the focus of the new, very active, and very large field of molecular biology. Numerous Nobel Prizes were awarded for the scientific discoveries that resulted, and numerous patents were granted for the application of the new science to medicine, agriculture, and commerce.

Victor McElheny's book *Watson and DNA: Making a Scientific Revolution* is the first full biography of Watson (Crick has yet to be the subject of a full biographical account). In McElheny's account, Watson's is a long and eventful life in science: the DNA discoveries; the appointment at Harvard; the years as director of the Cold Spring Harbor Laboratory on Long Island, New York, during which Watson oversaw its reconstruction as a leading center for biological research; and the vigorous efforts he made as the first director of the Human Genome Project.

In their initial paper Watson and Crick conceded that they had not done experimental work on DNA, nor had they collected X-ray data; rather, they relied on previously published data. In their final paragraph they note:

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We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M.H.F. Wilkins, Dr. R.E. Franklin and their coworkers at King's College, London.

Maurice Wilkins, who did important work on the X-ray crystallographic analysis of DNA, went on to share the Nobel Prize with Watson and Crick in 1962. Rosalind Franklin, a colleague of Wilkins's at King's who had produced some of the clearest X-ray pictures of DNA, died young, of ovarian cancer, on April 16, 1958. Franklin had been a focus of parody in Watson's *Double Helix*, but her pictures had been shared with Watson and Crick, and they proved to be crucial in confirming their structural analysis of DNA. Unable to defend herself from the grave, she became a feminist icon and the subject of two biographies; Brenda Maddox's *Rosalind Franklin: The Dark Lady of DNA* is the more recent.



Watson (right) and Crick in 1953, shortly after working out the structure of the DNA molecule

It is fitting that these two biographies are part of the public record of the fiftieth-anniversary celebrations. And there is little doubt that Watson and Crick will get the lion's share of attention—after all, they are both still alive and active, and both have enjoyed long and quite successful careers since their youthful discovery.

Yet I'm not sure either of them is entirely comfortable sharing the lime-light with Franklin. The irony is that Franklin looms as large as she does today in part because of the way Watson portrayed her in *The Double Helix*.

Maddox recounts Watson's first encounter with Franklin, which took place at a lecture she gave as part of a colloquium at King's College. Watson, in recalling the lecture for his book, betrays something of his attitude toward women: "Momentarily I wondered how she would look if she took off her glasses and did something novel with her hair." But he says little or nothing about the stunning X-ray pictures she had made and which he hoped would give him the evidence he and Crick needed to support their developing theory of a helical structure for DNA.

Instead, Watson went on to belittle Franklin's dress and her lack of "lipstick to contrast with her straight black hair." Maddox concludes that "Watson could not have given the world his 'Rosy' if Rosalind had been alive." A number of scientific colleagues, as well as friends and family of Franklin's who were sent copies of the draft manuscript, protested Watson's account of Franklin, as well as his references to others. In response to his critics Watson added what Maddox calls "a pious epilogue," which was published with the first edition of the book in 1968. From that historical vantage, Watson writes, virtually everyone mentioned in the book was still alive, with "one unfortunate exception. . . ."

Rosalind Franklin died at the early age of thirty-seven. Since my initial impressions of her . . . (as recorded in the early pages of this book), were often wrong, I want to say something here about her achievements.

The rest of the paragraph and the concluding one that followed tried to make amends, but the text in the body of the book remained unchanged.

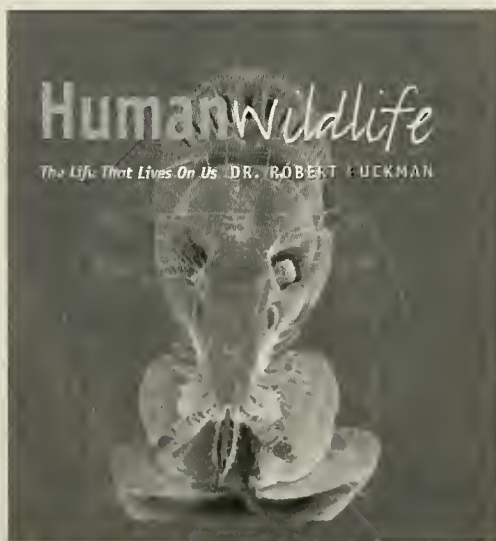
But if Watson had been so clearly nasty and catty about Franklin that he now sought to apologize, he seemed unmoved by the anger both Wilkins

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and Crick expressed at the book's tone and content. In a vivid section of his biography, McElheny chronicles their reactions. Wilkins thought *The Double Helix* should not be published. It was "extremely badly written, juvenile, and in bad taste." Crick, McElheny notes, was even more savage: "It shows such a naïve and egotistical view of the subject as to be scarcely credible." And perhaps most tellingly, it "grossly invades my privacy. . . . [It was] a violation of friendship." Several years later, in an article in *Molecular Biology* celebrating the twenty-first anniversary of the 1953 paper, Crick confessed that he too had contemplated writing a book. He had gotten as far as a title, *The Loose Screw*, and the opening line: "Jim was always clumsy with his hands. One had only to see him peel an orange. . . ."

If the text of *The Double Helix* is what brings these two biographies together at one moment in time, there is no question that both of them go far beyond that text. Both are filled with detail, much of it previously unknown or only hinted at. Each one provides valuable historical appraisals of both Watson and Franklin by members of the founding generation of DNA studies, as well as by subsequent generations of practitioners. The interviews noted by each biographer are prodigious and in many cases add context and color.

But the two books are also quite different. McElheny's is one of heroism mixed with quirkiness; Maddox's one of tragedy and attempted reconstruction. Both directly and implicitly offer accounts of how science operates, how its practitioners behave, how its institutions function (or malfunction), and how myths are made and destroyed. McElheny's focus is a man who is at once both immodest and ill at ease. Although McElheny is at pains to avoid discussion of Watson's private life and family, his subject's personal immaturity and curious attitude toward women cannot be overlooked. (Watson's most recent

volume of "autobiography," titled *Genes, Girls, and Gamow*, is further illustration of the type.)

McElheny has known Watson for more than four decades, covering him first as a science reporter for *The Boston Globe* during Watson's years at Harvard. He also spent four years working for Watson at Cold Spring Harbor. Although he thanks Watson for years of friendship, he is also at pains to point out that "Watson did not participate in this project." That may be literally true, yet Watson clearly gave his blessing to this biography. He steered



X-ray diffraction photograph of DNA. This image of the B form of DNA was obtained by Rosalind Franklin in 1953, and was a crucial piece of evidence supporting the structure proposed by Watson and Crick.

McElheny to many colleagues who gave extensive interviews and who helped review the manuscript. He still directs the archives at Cold Spring Harbor, and made sure McElheny could make good use of them through unencumbered access. Accordingly, though *Watson and DNA* is not an "authorized" biography, it is one composed from deep within the molecular-biology community.

McElheny wants to insist that there is much more to Watson than his reputation as "biology's bad boy," and the book is bracketed with tales of honor and scientific recognition. McElheny opens with an ac-

count of the lecture Watson was invited to give at Harvard in George Wald's introductory course on biology, on the day after Watson's Nobel Prize was announced in October 1962. The book closes as Watson is made an honorary Knight of the Order of the British Empire, in January of last year. In between, McElheny does a thorough job of pulling together an account of the 1953 discovery of the structure of DNA, integrating into it the views of many others, both contemporary and later. Taken together with the "formal" histories of that discovery (by Robert C. Olby of the University of Pittsburgh and by Horace Freeland Judson of George Washington University), McElheny's book adds valuable elements to the story of how that important work was accomplished.

But to his credit, McElheny also gives full rein to the many manifestations of "brat/genius" behavior (his words) and the criticisms of it. According to McElheny, Watson's "bad boy" image is richly deserved, and in part self-inflicted (perhaps self-crafted is more accurate) in Watson's two autobiographical volumes. McElheny is also well aware of the controversy arising out of Watson's (and Crick's) failure to appropriately recognize the work of Franklin, as well as the contingent nature of the discovery itself. He notes Watson's own retrospective judgment: "We were lucky. I don't think it was any great intellectual insight." And elsewhere, Watson said: "The DNA structure was ready to be solved. I can't imagine two years going by [after 1953] without someone else making the discovery."

Brenda Maddox moves directly into the territory that McElheny eschewed in his volume. She explores the life, work, and personality of Franklin. A strong-minded, complex, and highly intelligent woman, Franklin was born into a prominent, well-to-do and well assimilated Anglo-Jewish family. Her biographer locates her in time, in place, and in culture.

Her father's family had come to England from Breslau, in Silesia (now part of southwestern Poland), in 1763 and prospered through the generations in banking and publishing. One of her relatives was the first high commissioner of Palestine. Her mother's family included the first Jewish professor at an English university and the first Jewish lord mayor of London. There were suffragists and socialists, a trade union organizer, and a London city councillor in her heritage.

Maddox looks at length at Franklin's early career and provides a detailed and sympathetic account of her unhappy (albeit, coincidentally, highly productive) years from 1951 until 1953. She spent those years at King's College working with Wilkins, and most of her encounters with Watson and Crick took place there. They were stiff and unfriendly meetings, and led Crick to refer to Franklin as "that dark lady"—the phrase Maddox adopts as a subtitle. Franklin's move in 1953 to Birkbeck College, London, and to the laboratory of the crystallographer J.D. Bernal, provided a much friendlier and more supportive environment, where her talented research continued.

But by then Franklin's work with DNA had ceased. Instead, she began to carry out quite successful studies of the structure of tobacco mosaic virus (she located the infective element of the virus in its ribose nucleic acid). Part of what is known about Franklin's work of that period comes from two obituaries Bernal wrote at the time of Franklin's death, one for *The Times* of London and the other for *Nature*. In both he recounted her scientific work, and dealt delicately but fairly with how credit had been assigned for the discovery of the helical structure of DNA. As Bernal summed up her contributions:

As a scientist Miss Franklin was distinguished by extreme clarity and perfection in everything she undertook. Her photographs are among the most beautiful X-ray photographs of any substance ever taken.



Rosalind Franklin in an undated portrait

Franklin is well served by Maddox's intelligently written and eminently fair biography.

Many commentators have asked whether Franklin would have shared the Nobel Prize with Wilkins, Watson, and Crick had she been alive in 1962 (the Nobel Prize is never awarded to a deceased scholar). Still others have contested whether she would have deserved it. Counterfactual history seldom yields adequate answers, and I see little point to indulging in it here. But the wisdom of fifty years of hindsight does allow several incontrovertible observations.

The very fact that the Nobel Prize for physiology or medicine was split three ways and the chemistry prize in the same year was shared by the biochemists Max Perutz and John Kendrew for their work on the structure of proteins, illustrates how much scientific activity was focused on cracking the structures of important biological molecules. The chemist Linus Pauling, already a Nobel laureate for work that led to the elucidation of the helical structure of proteins, was also racing to find the structure of DNA.

Although the high drama in the story of Watson, Crick, Wilkins, and Franklin arises, in part, from the remarkably different styles and tem-

peraments of the personalities involved, the science on which they were working was yielding answers to each one of them. The history of the discovery is certainly linked to individuals, but, in this case particularly, it also transcends them. One indication of how far along the research was on several fronts was the simple fact that a single step taken by the original group (Watson and Crick) was able to meet with such complete success. As the biochemist John Edsall remarked in 1962: "No fundamental revision of the picture has been required since the early formulation of Watson and Crick." That assessment remains largely true to the present day.

Of course, even after fifty years key elements of the molecular processes of reproduction and development are still being sought. Efforts to modify organisms through molecular manipulation—genetic engineering—are being widely practiced in agriculture, and more circumspectly experimented with in medicine. Virtually all these developments have been controversial. Genetically manipulated foods have been greeted with stiff resistance in Europe, even while they have been much more readily accepted in the United States. Genetic manipulation in humans—gene therapy—has met with only mixed success, as well as with some highly visible failures. It has also brought into sharp focus the ethical issues raised by seeking to treat genetically linked diseases via the genetic engineering of human beings. Not yet tried, but even more controversial, would be any scheme to engineer the future by genetically manipulating the reproductive cells. The genetic revolution begun in 1953 is unlikely to have run its course, either scientifically or culturally, by the time our grandchildren celebrate its one-hundredth anniversary, in 2053.

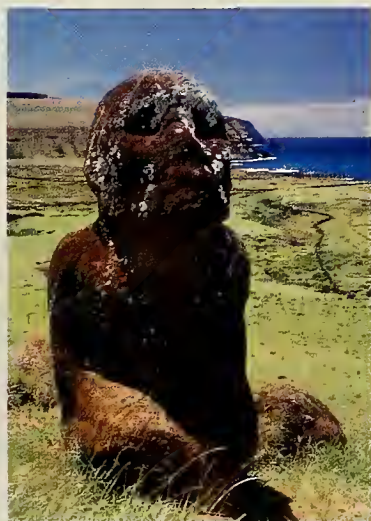
Everett I. Mendelsohn is a professor of the history of science at Harvard University. He has worked extensively on aspects of the social and sociological history of science and the relations between science and modern societies.

***Among Stone Giants:
The Life of Katherine Routledge
and Her Remarkable Expedition
to Easter Island***

by Jo Anne Van Tilburg
Scribner, 2003; \$26.00

Almost a century has passed since Katherine Routledge and her husband Scoresby raised the anchor of their custom-built ninety-foot schooner *Mana* and set sail for adventure. Few Europeans had ever visited Rapa Nui, as the local residents called Easter Island, but all Victorians with an ounce of romance in their soul knew of the island's alluring riddle. Katherine hoped to solve it.

Although Rapa Nui had no trees, it had a forest: hundreds of huge stone statues were scattered across its barren landscape. Who had carved these otherworldly monuments? And what purpose—religious, ceremonial, commemorative—could justify such a large investment of labor and re-



Oldest Easter Island statue, on the slope of the volcano Rano Raraku

sources? The Routledges, possessed of Katherine's inherited fortune as well as the Victorian mania for collecting, were determined to find out. Their expedition made landfall on Rapa Nui, after an eventful year at sea, on March 29, 1914.

From the start it was Katherine's show. Although she had little formal training in archaeology, she knew what to look for and how to listen. In her party's seventeen months on the island she made drawings and watercolors of each landmark. She sat daily with village elders, compiling notebooks of their replies to her questions about the old ways, the ancient gods, how the island and its people came to be. While Katherine sketched and scribbled, Scoresby collected artifacts from caves and burial sites, and members of the *Mana's* crew photographed and mapped with military precision. It was the first true attempt to conduct an archaeological survey of the island.

Van Tilburg has dug deeply into Katherine's family records and the notebooks of the *Mana* expedition to present a convincing picture of science as it was practiced in an era when natural history was a popular sport of the moneyed class. Because government funding was rare, wealthy amateurs, rather than professional associations and peer reviewers, set research agendas. Today's field-workers may employ far more culturally sensitive and environmentally sound techniques than did the Routledges, who looted gravesites with abandon and spaded like gardeners through delicate layers of artifact-bearing earth. But a well-managed expedition today would be hard-pressed to provide as colorful a cast of characters, or grist for such a lively story.

Scoresby was arrogant and tactless; the crew of the *Mana* was mutinous (usually in response to Scoresby's outrageous behavior); Katherine was often sidelined by bouts of hallucinations and depression. The islanders staged an armed revolt during Katherine's stay. By the time the couple's seventeen months came to an end, war-torn Europe must have seemed like a haven.

Later archaeological surveys did better work than the *Mana* expedition, and the history of Rapa Nui has

since been convincingly linked to Polynesian cultures to the west, making Easter Island seem a bit less mysterious and remote. But Katherine Routledge's work stands the test of time. In a letter to her mother, written as she was packing to leave the island, Katherine wrote: "If people ask you if we have 'solved the riddle,' you can say that we do not claim to have done that, but we have found much that is new & interesting." That is an apt description both of Routledge's work and of Van Tilburg's elegant and compelling biography.

***Tycho & Kepler:
The Unlikely Partnership
That Forever Changed
Our Understanding
of the Heavens***

by Kitty Ferguson
Walker & Company, 2003; \$28.00

When Copernicus first proposed a universe with the Sun at its center in 1543, most of his sixteenth-century contemporaries regarded the idea as interesting but hardly revolutionary. Geometrically, it made little difference whether the Sun or the Earth stood still, and the crude observations of the time offered precious little evidence for telling one case from the other. Even those partial to a sun-centered scheme hedged their bets by harrumphing, at least in public, that, yes, this Copernicus was a clever fellow, but whatever the merits of his model, it was, after all, only a model. God could have chosen to make the Earth revolve around the Sun—but simply didn't.

In private, though, some of his contemporaries believed He did. Tycho Brahe, a Danish nobleman and amateur astronomer, thought Copernicus might be on to something. Tycho had seen a new star appear in the heavens in 1572, and he determined that it lay far beyond the Moon, in a region of the firmament where, according to the conventional

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astronomy of his day, nothing ever changed. Convinced that the old picture of the Earth-centered universe needed repair, Tycho proposed a hybrid system in which the Sun carried the orbiting planets around a stationary Earth. But Tycho knew that his proposal would be just another clever model without the support of careful astronomical measurements—measurements Tycho, with the right resources, would be happy to make.

King Frederick II of Denmark provided the money Tycho needed for his purposes, and granted him the little island of Ven (formerly Hven), at the mouth of the Baltic Sea, within view of Hamlet's fabled castle, Elsi-

continue his father's royal indulgence of Tycho's expensive hobby.

So Tycho packed up and wandered through Europe, eventually stopping in Prague. There he found a patron in Rudolph II, the Holy Roman Emperor—and, just as important, a new assistant named Johannes Kepler. Twenty-five years Tycho's junior, Kepler was an impoverished German mathematician on a quest to prove his own pet theory about the motions of the planets.

Science writer Kitty Ferguson begins her book with this meeting of Kepler and Tycho, and continues in flashbacks of the lives of the two great figures viewed against the unsettled backdrop of post-Reformation Europe. Taken separately, as many earlier biographers have done, the stories of the two astronomers seem merely eccentric: Tycho's artificial nose and Kepler's mother's trial for witchcraft are the only details my students usually remember. But Ferguson's approach, enlivened with the dramatic pacing of a mystery novel, shows beautifully how the obsessions of the pragmatic, imperious Brahe meshed perfectly with the obsessions of the idealistic, pensive Kepler.

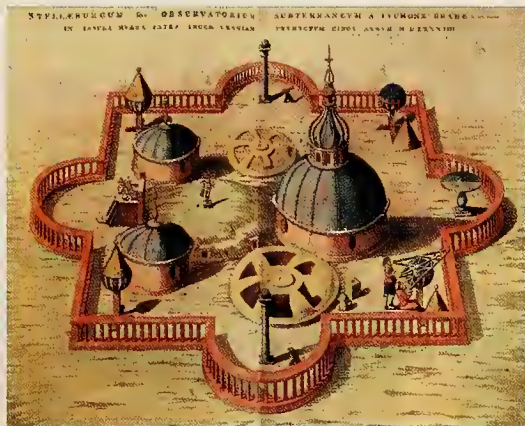
They were an odd couple, indeed, and Tycho, weary and wary of the world by the time they met, resisted full collaboration with the young Kepler to the very end. As it was, he died scarcely a year after their meeting, and Kepler became heir to the finest observations of the planets ever made. From those, he showed conclusively that the Earth and the planets orbited the Sun—though in elliptical orbits, not the circular ones Copernicus preferred. Kepler's laws led, in turn, to Newton's laws of motion, which laid the groundwork for modern physics and cosmology. If the story of Tycho and Kepler was, as Kitty Ferguson's subtitle states, an "unlikely partnership," it was nonetheless a marriage made in heaven.

Smokechasing
by Stephen J. Pyne
The University of Arizona Press,
2003; \$37.50

When the harmattan blows south from the Sahara, nighttime satellite images of Ghana and Nigeria light up like fireflies on a summer's evening: West Africa is burning. The harmattan is a dry wind in a dry season. Later, when the rains return, fires can still be sparked by lightning, but most of the harmattan fires are set by rural agriculturists, who recognize and welcome their help in clearing and fertilizing their fields. The fires complete a cycle as old as respiration itself, for both the carbon-rich detritus and the oxygen that burns it ultimately come from plants, making wildfire a closing step in the process of respiration. From a global perspective, fire is an integral element of the biosphere, an essential cog in the marvelous engine that gives life on Earth its dynamic stability.

For those of us who live in cities, that truth is far from obvious. In an urban setting fire is a disaster, but in the wilderness, fire takes on quite a different function. It is best regarded as a tool of control, not an evil to be eliminated. One of the paradoxes of rural fires is that, by trying to eliminate them, we make them worse when they do occur: in the year 2000 wildfires in the United States burned at least seven million acres, called out 30,000 firefighters, and cost the nation more than \$2.5 billion. Many were kindled in areas where dry undergrowth had accumulated for decades, the result of aggressive fire control. Smokey Bear should have been sued for negligence.

If informed opinion is more sensitive to such issues nowadays, the credit is due in large part to Stephen Pyne, our most eloquent narrator of the natural history of fire (a branch of literature he almost single-handedly created). His style is recognizable by its heavy load of metaphor and by its



Observatory of Tycho Brahe, 1546–1601

nore. There Tycho erected a battery of precise sighting devices (the telescope had not yet been invented); for almost thirty years, he and a staff of assistants compiled nightly observations of the positions of the planets.

As the data accumulated, however, Tycho found he lacked the mathematical skills, not to mention the time away from his aristocratic lifestyle, to make the calculations he needed to prove his point. By the last decade of the sixteenth century, the fifty-year-old astronomer was facing a midlife crisis, afraid that immortality was slipping from his grasp. Nicolaus Reimers Bär, a former assistant, had written a scurrilous book claiming Tycho's system as his own. Worse, Denmark had a new king, who was not inclined to



William Buckleysque use of recondite, albeit evocative, language. (As I read the book, my notepad quickly filled up with unfamiliar words and phrases: “swiddeners,” “impauperate,” and “lithic horizon,” to mention a few.)

Readers of Pyne’s earlier books will hear echoes of many familiar themes in *Smokechasing*, a collection of miscellaneous essays from recent journals and magazines. Some show how the approaches of developing countries must differ from those in the industrialized world, both in learning to manage fire and in reconciling the priorities of public forest preserves with the concerns of private industries that depend on forest products. Other essays deal with the growing problem of “inter-



Forest fire in Spain

mix” fires that burn in places such as the canyons of California, where urban sprawl has turned forested areas into residential compounds. And a few of the essays are just rousing good stories of fires and of firefighters.

Yet Pyne remains on message, always returning to his point that good public fire policy must strike a balance between total suppression and uncontrolled burning, and urging that such a policy be set locally, to meet local needs. Whether or not you’ve heard all this before, it’s rewarding to hear it again, if only for the pleasure of a prose style that slices through tangled thickets like a bulldozer clearing a fire line, and lights up the darkness like a blazing forest.

Laurence A. Marschall, author of The Supernova Story, is the W.K.T. Sahn professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.

nature.net

Oil to Burn?

By Robert Anderson

Daniel Yergin, writing at the end of the 1990–91 Gulf War, concluded his monumental history of oil, *The Prize: The Epic Quest for Oil, Money, and Power*, with this prediction: “The fierce and sometimes violent quest for oil—and for the riches and power it conveys—will surely continue so long as oil holds a central place.” How long that would be, he made no bets. As I write, a second war with Iraq is contemplated. According to some expert prognostication on the Web, the king of natural resources may, once again, be consumed and wasted in spectacular wildfires.

At its height, the Kuwaiti inferno burned oil at a rate equivalent to 10 percent of total world demand. Jonathan Lash, president of the World Resources Institute (www.wri.org), foresees the possibility of a similar catastrophe if war comes again, as he writes in his article “The Environment: Another Casualty of War?” (click on “About WRI,” at left, then click on “From the President”).

Forbes magazine’s Paul Klebnikov (forbes.com/global/2002/1028/024_print.html) sketches the mammoth size of the Iraqi reserves, which may ultimately exceed those of Saudi Arabia. He also notes that the fields currently producing in Iraq have the world’s lowest “lifting costs”:

the expense of extracting a barrel of low-sulfur crude from rock formations. Iraq’s reservoir is so shallow that the lifting cost is under a buck. Compare that with \$2.50 in Saudi Arabia and between three and four dollars in the Gulf of Mexico and the North Sea. The ease with which Iraqi oil shoots to the surface doesn’t bode well for the environmental devastation that will take place if these fields are set ablaze.

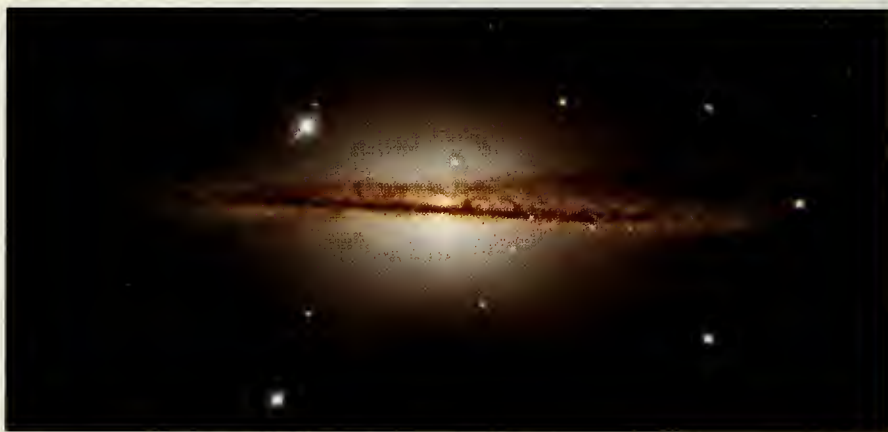
Regardless of its scale, such a disaster wouldn’t make much difference to global petroleum stocks, which took hundreds of millions of years to accumulate. By most reasonable estimates, peak world oil production is just a few years away. For detailed background on oil as a finite resource, go to hubbertpeak.com, named for the petroleum geologist who correctly predicted the 1970 peak in U.S. production. The information on the site makes it disturbingly clear that oil will follow the pattern typical of other finite resources: its extraction rate will reach a high and then dwindle to nothing. Similar dire predictions (but more attractively displayed) are outlined by James J. MacKenzie in “Oil as a Finite Resource: When Is Global Production Likely to Peak?” (www.wri.org/wri/climate/jm_oil_001.html), another page on the WRI site. Don’t miss the links on the right for the text and slide show of MacKenzie’s project “Thinking Long Term.” Humanity will soon be on the downward slope of the oil age. How we all cope with that will be the story of the century.

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

Warp Factor

A spinning dwarf may have twisted our galaxy's disk.

By Charles Liu



An edge-on view of the spiral galaxy ESO 510-G13, in the constellation Hydra (visible from the Southern Hemisphere), shows the warp in its disk, much like the warp in our own Milky Way. The warp suggests that ESO 510-G13 may have swallowed another, smaller galaxy in its past.

Astronomers sometimes describe the shape of our home galaxy, the Milky Way, as a thin-crust pizza with a plum stuck in the middle. The plum is the slightly oblong central bulge, protruding about 3,000 light-years above and below the galactic plane, comprised mostly of older stars; it makes up the core of the Milky Way, and includes a black hole two and a half million times the mass of the Sun. The crust of the pizza is the galactic disk—the source of most of our galaxy's light. Thin and flat, the disk is 100,000 light-years across, about 1,000 light-years thick, on average, and includes more than 80 percent of the galaxy's hundred billion or so stars.

The plum-and-pizza picture works well enough, but like most simple metaphors, it breaks down if you push it. For one thing, the galactic disk isn't a rigid body, but a loose agglomeration

of matter streaming around a common center of gravity. (The swirling pattern of a hurricane far better resembles our spinning galaxy than a flying Frisbee does.) For another thing, our galaxy's disk isn't flat; it's warped, like an old-fashioned phonograph record left out in the hot sun. Picture that sun-baked record spinning on a turntable—or a disk of pizza dough spun into the air by a skilled chef: our galaxy goes through the same kind of floppy, wobbly gyrations, though at a rate best measured in revolutions per hundreds of millions of years.

Why does the Milky Way have such an odd-looking warp? We astronomers have been puzzling over that question for decades, but no definitive answer has emerged. One thing we do know: when it comes to warps, our galaxy is hardly unique. About half of all spiral galaxies are warped to some degree. Theoretical and computational models

have shown that a number of physical processes can warp a galaxy, so it's a matter of figuring out which scenario applies. Now an innovative new analysis of the problem by Jeremy Bailin, an astronomy graduate student at the University of Arizona in Tucson, has implicated a small satellite galaxy, currently being ripped to shreds by the gravity of the Milky Way.

The Sagittarius Dwarf Spheroidal Galaxy, so named because of its shape, size, and location in the sky, was discovered in 1994. It appears to be in a roughly polar orbit around the Milky Way—that is, above and below the galactic disk—about 50,000 light-years from the galactic center. That orbit brings the dwarf galaxy far too close to the huge gravitational tidal forces of the Milky Way for the dwarf to remain intact. As a result, the Sagittarius Dwarf now looks something like strands of spaghetti spilling from the front of a pasta-making machine, the galaxy's matter being drawn out over hundreds of millions of years by intergalactic tides.

Gravitational collisions between small satellite galaxies and big spiral galaxies have long been regarded as possible culprits in the warping of a larger galaxy's disk. The best known satellite galaxies orbiting the Milky Way—the Large and Small Magellanic Clouds—are too far away, and have the wrong orbital characteristics, to have warped our galactic home. The Sagittarius Dwarf seems a much more likely candidate, simply because it is only a third as far from the center of the Milky Way as the Magellanic Clouds. But in astronomy—unlike in real estate—location isn't everything; to show a direct connection between warp and dwarf, the orbital motion of the Sagittarius Dwarf must be linked to the rotation of the Milky Way's disk.

Bailin's study is the first to find such a link. His analysis of the galactic warp is based on angular momentum—a measure of how much a system is spinning or rotating. Just as objects moving

in a straight line have momentum, objects spinning or orbiting around an axis have angular momentum; and just as the momentum of two objects combine when they collide, so too does their angular momentum. Imagine two figure skaters coming together for a combination spin. When they make physical contact, their individual spiraling motions combine to produce a single, unified whirl.

Starting with the latest measurements of the structure and spin of the Milky Way, Bailin deduced the angular momentum of the warped portion of the Milky Way's disk. He then compared that measure with the angular momentum of the Sagittarius Dwarf—and found for the first time, within the margins of measurement error, that the two angular momenta are identical in both quantity and direction. Such a coupling of the angular momentum of two bodies almost never happens by chance; usually, it takes place only when two spinning systems, like the skaters, come into contact. The coupling isn't enough to prove cause and effect by itself, but it's solid circumstantial evidence that the interaction of the Sagittarius Dwarf with the Milky Way disk created the warp in our galaxy.

With enough spinning, warps in disks eventually disappear. That's why a pizza chef spins pizza dough, tossing it into the air again and again: in time, the thick lumps get spun out, leaving the disk smooth, even, and thin. Some day, that will probably happen to the Milky Way, too. Sooner or later—the latest calculations range from a few hundred million years to a few billion years from now—our galaxy will work out the kink in its disk. That is, unless another dwarf galaxy like Sagittarius appears, coming along with just the right orbit, giving the Milky Way disk just the kick it needs to start warping all over again.

Charles Liu is an astrophysicist at the Hayden Planetarium and a research scientist at Barnard College in New York City.



Mercury climbs progressively higher above the western horizon every evening at dusk in the first half of the month, but the improving view is offset by the planet's fading brilliance. On the 1st the planet shines at magnitude -1.4 ; about thirty minutes after sunset, it is very low above the west-northwestern horizon. On the following evening the Moon—visible as an exceedingly thin sliver—hovers about 4 degrees below and to the left of Mercury. On the 16th the planet reaches its greatest elongation (20 degrees east of the Sun) and appears noticeably higher in the sky, but shines more dimly, at magnitude $+0.2$. For the rest of the month Mercury sinks back down to the horizon while fading rapidly, and is out of sight well before the end of April.

Venus rises like clockwork about an hour before the Sun all month. The planet lingers low in the eastern predawn sky.

Mars—god of war—glares ever more fiercely at the Earth. The pumpkin-colored planet rises in the southeast about four hours before the Sun and nearly reaches culmination by sunrise. Mars is one magnitude, or roughly two-and-a-half times, brighter now than it was on January 1. If your daily routine this month rouses you while the sky is still fairly dark, look to the southeast to watch the planet brighten over April's course from magnitude $+0.5$ to magnitude 0. At midmonth it stands just 104 million miles from Earth. The planet leaves the constellation Sagittarius, the archer, for Capricorn, the sea goat, on the 21st.

Lordly **Jupiter**, high in the southern sky at dusk on the 1st, descends toward the west. It starts the month just to the east of the Beehive star cluster, near

the center of the faint zodiacal constellation Cancer, the crab. On the 3rd, Jupiter reverses its retrograde, or westward, motion among the stars and begins moving slowly east, away from the Beehive. The waxing gibbous Moon slowly approaches Jupiter from the west—falling for another of Jupiter's famed seductions—in the overnight hours between the 10th and the 11th.

Saturn rides the constellation Taurus, the bull, into April. The planet is readily visible, shining pale yellow at magnitude 0 in the west-northwestern sky during the first half of each night of the month. On April 7, the same night a fat crescent Moon glides well above Saturn, the Earth will finally attain its maximum Saturncentric latitude. Translation: Saturn's ring system will list at its greatest possible angle toward the Earth, 27 degrees—making for a stunning, brilliant display even through the lens of a small telescope. The last such event took place in September 1988, and the next one isn't due until October 2017. The rings appear to hide the north end of the planet, and stick out a bit behind the south end. Don't miss it!

The **Moon** is new on the 1st at 2:19 P.M., Eastern Standard Time. It reaches first quarter on the 9th at 7:40 P.M., waxes full on the 16th at 3:36 P.M., and wanes to last quarter on the 23rd at 8:18 A.M. Our satellite reaches perigee at 1:00 A.M. on the 17th, orbiting just 221,937 miles from Earth. Beachcombers, take note. Very high tides can be expected from the coincidence of perigee with the full Moon—a phenomenon known as an astronomical spring tide.

“Spring ahead” in much of Canada and the United States, as daylight saving time returns on Sunday, the 6th. Remember to set clocks ahead one hour.

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

AT THE MUSEUM

AMERICAN MUSEUM OF NATURAL HISTORY



AN INTERVIEW

WITH MELANIE STIASSNY

Milstein Family Hall of Ocean Life Reopens May 17

Melanie Stiassny is Axelrod Research Curator of Ichthyology in the Division of Vertebrate Zoology and a lead curator of the renovation of the Milstein Family Hall of Ocean Life. She spoke with us about the oceans, the new hall, and the blue whale.



Q: You've said that we know more about the dark side of the moon than we know about the ocean.

A: Which is sadly true. As terrestrial creatures, we tend to think of life on our planet as being essentially life on land. It couldn't be further from the truth.

A little over 70 percent of the Earth's surface is covered in water. We've seen the blue marble from outer space. It's blue because there's so much water on Earth. And 362 million square kilometers of that is marine—the world ocean. Yet perhaps as little as 1 percent of the ocean floor has actually been explored. The ocean as a whole is very much the “final frontier,” the last truly wild place on our planet.

It's a place that is not only extraordinary in its dimensions and all of the implications of its size but it's also the place that was the cradle of life on Earth. But instead of everything leaving the cradle, in fact, most things have stayed in the ocean. Most of the life on Earth is still living in the ocean.

Q: I think most people are surprised by the amount and diversity of life under the water.

A: It's phenomenal. Estimates vary and, believe it or not, we're not even

able to say how many species exist on the planet. But probably about 80 to 90 percent of all life on Earth is found in the ocean. And it's not just the quantity or “biomass”—the actual amount of living material—it's also the diversity, the number of different kinds of living things.

The people visiting the new Hall of Ocean Life are going to be exposed to kinds of organisms that they've never heard of, they've never even imagined. And yet these organisms all work together to create something incredibly diverse and fundamentally important for life on the entire planet.

Q: When people leave the hall, what do you want them to think?

A: Well, that's really difficult because there are so many different things. But I want people to walk away with an understanding of how remarkably superlative the oceans really are. Not just in terms of sheer size and beauty, but also in their ecological complexity and the tremendous biological wealth they contain. Perhaps above all, I want them to understand how absolutely critical ocean health is to the health of all life on Earth. The oceans are a series of interconnected ecosystems

that can unravel very, very, quickly.

So I also want visitors to the hall to be empowered in a sense, to have an idea of how their behavior as individuals can impact the oceans but how it can also help to save them.

Q: Can you tell us a little bit about the renovation?

A: I hope people are going to be very happy when they come back to the hall. This is one of the most beloved halls in the museum—for good reason. We want people to experience all the wonder they felt in the older version, but to be amazed by the new. We didn't want to change it beyond recognition, but we did want to tell a much richer story. By giving the oceans a proper introduction and a real explanation as to what they are, where they came from, how long they've been around, what's living there, and that it all functions as a complex whole, I think that's going to be an eye-opener for many visitors. It's also going to be tremendously beautiful.

I think we steer a very nice path between being absolutely state-of-the-art, but at the same time, keeping this kind of majesty and splendor of the old style of exhibit. I really hope people

appreciate how much thought actually went into that because we do know how dear much of the old hall was.

Q: What can you tell us about the centerpiece of the hall, the blue whale model?

A: As you know, the blue whale is a kind of "jewel in the crown" for this institution. An incredible animal, the largest that ever lived. Ours is a female (they are slightly larger than males). When she was installed in 1969, we knew so little about blue whales that we actually got some of the anatomical details wrong. She had been modeled from a specimen about to be butchered and decomposition had already begun to distort her frame. We've now corrected that, and we've metaphorically released her back into her habitat—the open ocean. Now, when you come into the hall and see this beautiful animal you'll not only learn about blue whales, and whales in general but also about work being done in whale conservation throughout the globe. And you're going to learn about the habitat that the whale lives in. In short, we have really tried to insert all of the organisms that live in the ocean into their ecological context. So that now the blue whale in a sense becomes the ambassador to the open ocean—the largest habitat on our planet.

The magnificent restoration and rejuvenation of the Museum's beloved Milstein Family Hall of Ocean Life is made possible by the generosity of Paul and Irma Milstein. The Museum gratefully acknowledges the critical role of the City of New York, the New York City Council, the Department of Cultural Affairs, and the Borough President of Manhattan in the realization of this project. The Museum deeply appreciates major support from Edwin Thorne and from Swiss Re. Significant support has also been provided by The Marc Haas Foundation, Ruth Unterberg, MetLife Foundation, and Mikimoto. Additional generous funding was provided by Jennifer Smith Huntley, Patricia S. Joseph, William H. Kearns Foundation, Denise R. Sobel and Norman K. Keller, Mrs. Frits Markus, Jane and James Moore, David Netto, Mrs. John Ungar, and the Bristol-Myers Squibb Foundation, Inc.

Starry Nights Hits the Airwaves



WBGO's Gary Walker introduces Antonio Hart and The Antonio Hart Quintet during the February 7 live broadcast of *Starry Nights*.

After three years of crowd-pleasing performances, *Starry Nights*, the American Museum of Natural History's jazz performance series, burst onto the airwaves this winter. The Museum and WBGO Jazz 88.3 FM have teamed up to broadcast select *Starry Nights* performances live from the spectacular Rose Center for Earth and Space where two sets—at 5:30 and 7:00 p.m.—take place on the first Friday of each month. Tune in at 5:30 p.m. on Friday, April 4, for this month's broadcast.

WBGO, the only full-time jazz station in the New York metropolitan area, will carry a total of six live broadcasts this year of *Starry Nights*. February 7 inaugurated the collaboration, and future broadcasts will take place on April 4, June 6, August 1, October 3, and December 5, from 5:30 to 6:30 p.m. Gary Walker, WBGO's *Morning Jazz* host for 13 years and winner of the 1996 *Gavin Report* Jazz Radio Personality of the Year award, will host the hour-long broadcasts.

Starry Nights was launched soon after the Museum opened its acclaimed Frederick Phineas & Sandra Priest Rose Center for Earth and Space in February 2000. The series kicked off with Ray Vega's Latin Jazz Sextet. Since then, over 35 celebrated jazz groups have appeared, including Bobby Sanabria and Quinteto Aché,

Jimmy Heath, The Jazz Passengers, Jerry Gonzalez and the Fort Apache Band, and Ray Barretto and New World Spirit. The first WBGO broadcast aired in February 2003 with the Grammy-nominated alto saxophonist Antonio Hart and The Antonio Hart Quintet.

Nearly 1,000 jazz enthusiasts attend *Starry Nights* each month, and have been treated to a wide spectrum of today's best jazz, ranging from Afro-Cuban fusion to Latin and blues rhythms. A selection of authentic tapas, sparkling water, sangria, wine, and beer combined with the sounds of hot jazz and the cool blue, "otherworldly" glow of one of New York's boldest architectural treasures, makes *Starry Nights* one of the city's most popular attractions.

WBGO 88.3 FM serves the New York/New Jersey metropolitan area with straight-ahead jazz, blues, and award-winning news and public affairs programming. Non-commercial WBGO is supported by over 14,000 members and has 400,000 weekly listeners. WBGO also streams its broadcast signal to audiences worldwide at www.wbgo.org. It was named Jazz Station of the Year for 2001 by the *Gavin Report* and also is the recipient of the Blues Foundation's Keeping the Blues Alive Award for Achievement in Non-Commercial Radio.

Media sponsorship for *Starry Nights* is provided by CenterCare Health Plan.

MUSEUM EVENTS

EXHIBITIONS

Vietnam:

Journeys of Body, Mind & Spirit

Through January 4, 2004

Gallery 77, first floor

This comprehensive exhibition presents Vietnamese culture in the early 21st century. The visitor is invited to "walk in Vietnamese shoes" and explore daily life among Vietnam's more than 50 ethnic groups.



Vietnamese clay toys depicting zodiac symbols

Organized by the American Museum of Natural History, New York, and the Vietnam Museum of Ethnology, Hanoi. This exhibition and related programs are made possible by the philanthropic leadership of the Freeman Foundation. Additional generous funding provided by the Ford Foundation for the collaboration between the American Museum of Natural History and the Vietnam Museum of Ethnology. Also supported by the Asian Cultural Council. Planning grant provided by the National Endowment for the Humanities.

Biodiversity of Vietnam

Through January 4, 2004

Akeley Gallery, second floor

This exhibition of photographs highlights Vietnam's remarkable diversity of plants and animals.

This exhibition is made possible by the Arthur Ross Foundation and by the National Science Foundation.

The First Europeans: Treasures from the Hills of Atapuerca

Through April 13

Gallery 3, third floor

The mysteries of ancient humans in western Europe are revealed through exquisitely preserved hominid and animal fossils found in the hills of Atapuerca in northern Spain.

Co-organized by the American Museum of Natural History and Junta de Castilla y León.

Einstein

Through August 10, 2003

Gallery 4, fourth floor

This exhibition profiles this extraordinary scientific genius, whose achievements were so substantial that his name is virtually synonymous with science in the public mind.

Organized by the American Museum of Natural History, New York; The Hebrew University of Jerusalem; and the Skirball Cultural Center, Los Angeles. Einstein is made possible through the generous support of Jack and Susan Rudin and the Skirball Foundation, and of the Corporate Tour Sponsor, TIAA-CREF.

The Butterfly Conservatory

Through May 26, 2003

More than 500 live butterflies fly freely in an enclosed tropical habitat.

The Butterfly Conservatory is made possible through the generous support of Bernard and Anne Spitzer and Con Edison.

Experience the sights and sounds of a bustling

Vietnamese Marketplace

at the Museum, throughout the run of the *Vietnam* exhibition.

Sample traditional foods and take home a one-of-a-kind handicraft.

77TH STREET LOBBY, FIRST FLOOR

FILMS

A Dream in Hanoi

(In Vietnamese and English with English subtitles)

Tuesday, 4/1, 7:00 p.m.

Two theater companies, one American and one Vietnamese, work together to stage the first performance in Vietnam of *A Midsummer Night's Dream*.

The Season of Guavas

(In Vietnamese with English subtitles)

Thursday, 4/10, 7:00 p.m.

Since falling from a guava tree as a youth, Hoa, now in his fifties, has been trapped in his childhood memories. His obsession with returning to his childhood home leads to a series of unforeseen events.

Chac

(In Vietnamese and English with English subtitles)

Saturday, 4/19, 2:00 p.m.

The director embarks on an emotional and physical journey to discover what caused her mother to flee Vietnam with an American man.

PERFORMANCES

Creativity in Moschen

Saturday, 4/5, 8:00 p.m.

Juggler Michael Moschen brings his innovative object manipulation to the Museum.

Spring Essence: Poetry and Preservation

Sunday, 4/13, 2:00 p.m.

Selected poems from the 18th-century *Spring Essence* sung in the original Vietnamese, and read in English.

When You're Old Enough

Saturday, 4/26, 4:00 p.m.

A dance-theater work in which a young Vietnamese American woman searches for an identity.

LECTURES

The Genomic Revolution: Unveiling the Unity of Life

Tuesday, 4/1, 7:00 p.m.

A discussion about the scientific, social, and ethical implications of the Human Genome Project.

Science and Society: Academic Freedom vs. National Security

Wednesday, 4/2, 7:00–8:30 p.m.

A panel discussion on the topic of intellectual freedoms versus national security concerns.

Krakatoa: The Day the World Exploded: August 27, 1883

Thursday, 4/10, 7:00 p.m.

Simon Winchester discusses his latest book.

World Monument Preservation in Hue, Vietnam

Wednesday, 4/23, 7:00 p.m.

With Minja Yang, Deputy Director of the World Heritage Centre, UNESCO.

Operation Babylift: The Adoptee Experience

Saturday, 4/26, 2:00 p.m.

Roundtable discussion with Vietnamese who were adopted by American families in 1975.

Land Mines: The Legacy of War

Wednesday, 4/30, 7:00 p.m.

Activists and advocates discuss international education and community assistance initiatives.

GUIDED WALKS

Spring Bird Walks in Central Park

Eight-week sessions begin 4/1, 2 & 3

KIDS AND FAMILY

Vietnamese Woodblock Prints

Sunday, 4/6, 11:00 a.m. or 3:00 p.m.

Printmaking a Hand-Book Necklace

Sunday, 4/6, 1:00 p.m.

Mummies

Sunday, 4/13, 10:30 a.m.–1:30 p.m.

Undersea Fossils

Sunday, 4/27, 10:30 a.m.–1:30 p.m.

Origami Birds

Sunday, 4/27, 10:30 a.m.–1:30 p.m.

The Magic of Science

Sunday, 4/27, 11:30 a.m.–12:30 p.m.

HAYDEN PLANETARIUM PROGRAMS

Strange Worlds: Radar Encounters with Earth-Approaching Asteroids

Monday, 4/7, 7:30 p.m.

With Steven J. Ostro, Jet Propulsion Laboratory, NASA.

City of Stars

Sunday, 4/13, 12:00–3:00 p.m.

References to the cosmos in New York City, with Neil deGrasse Tyson.



Einstein in Berlin

Monday, 4/14, 7:30 p.m.

Tom Levenson discusses his book on Einstein's years in Berlin.

2003 Isaac Asimov Memorial Panel Debate

The Big Bang

Tuesday, 4/22, 7:30 p.m.

The world's leading cosmologists debate how the universe was born.

Celestial Highlights

Tuesday, 4/29, 6:30–7:30 p.m.

A view of May's night sky.

SPACE SHOWS

The Search for Life: Are We Alone?

Narrated by Harrison Ford

Passport to the Universe

Narrated by Tom Hanks

Look Up!

Saturday and Sunday, 10:15 a.m.
(Recommended for children ages 6 and under)

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Ongoing

Pulse: a STOMP Odyssey

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Kilimanjaro: To the Roof of Africa

INFORMATION

Call 212-769-5100 or visit

www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 8:00 a.m.–5:00 p.m., and Saturday, 10:00 a.m.–5:00 p.m., or visit

www.amnh.org. A service charge may apply.

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Both a God and a Rogue

By Ravi Corea

I feel a sense of great loss at the sight of a dead elephant. Its colossal size, thick eyelashes, wrinkled skin, long prehensile trunk, and huge caloused footpads evince an animal of magnificent proportions. On a deeper level, what also come to mind are the things I've learned since my childhood in Sri Lanka—the myths, folklore, and all the fantasies of supernatural powers attributed to elephants. The stories form an integral part of the culture in my country.

I still remember the first time I saw an elephant. It was a huge male, with sweeping white tusks. I was about three years old. I thought the elephant never ended! He took over my entire visual world.

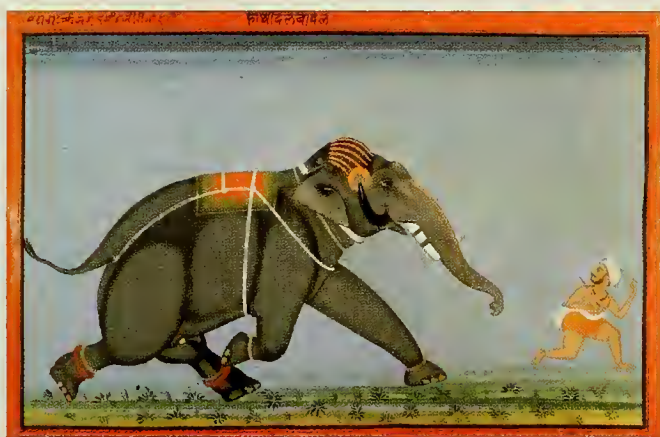
know him as Ganapathi and pray to him for wisdom; Hindus invoke the blessings of Ganesha at the beginning of all enterprises.

Today the elephant in Asia is at a crossroads. Fewer than 50,000 remain. (Within a far more restricted range, their African cousins number more than 600,000.) In Sri Lanka, as elsewhere, the elephant's mythical and worldly roles are in conflict. Every year for the past decade, between 100 and 150 elephants have been killed in their increasingly intense competition with people for land. Still revered as a god, the elephant has now become a rogue that steals crops, destroys property, and plunders villages in the dark of night, killing farmers and settlers.

Two years ago in a village in the island's North Central province, a young woman named Sudu Menika went to her temple to pray. There she made a special offering to Ganapathi on behalf of her oldest son. Later that night a call went out that an elephant was on the rampage. Sudu Menika was running for shelter, her second-born son in her arms, when the elephant appeared and rushed at her from the side, striking her with its trunk. The infant landed on a heap of straw, which probably saved his life. Sadly, though, his mother died a short time later. In one night she had both prayed to the elephant god and met her death from its earthly counterpart.

The conflict between people and elephants is most often measured by such physical loss, but there is also an emotional price to pay. The elephant's godly status is deeply ingrained in the local culture and religion, yet, to protect themselves, the Sri Lankans persecute the animal. That internal conflict takes its toll: whenever a marauding elephant is killed, the entire village gathers to pay its solemn respects. Most of the mourners are seeing a wild elephant in the light of day for the first time, an animal that lived and breathed, but that they also worship as a god. In our relentless push for development we have displaced this living symbol of the divine and turned it into a rogue.

Ravi Corea studies at Columbia University's Environmental Research Center, and is the president of the Sri Lanka Wildlife Conservation Society (www.SLWCS.org).



The royal elephant Dal Badal chasing his attendant, Mewar, Rajasthan, India, c. 1750

According to an ancient Sri Lankan belief, if you creep under an elephant's belly, you will be safe from *graha dosha* (bad planetary effects) and *deva dosha* (the evil eye), and you will drive away your fears. With a sense of wild adventure and intense excitement—and urged on by my nanny—I crouched down and crawled under its seemingly infinite mass. I will never forget how it felt: as though I were crawling forever. Only when you are underneath an elephant can you appreciate its size.

Elephas maximus has been domesticated in south Asia for more than 4,000 years, and from time immemorial the elephant-headed Lord Ganesha has occupied a place in the Hindu pantheon. Both Hindus and Buddhists revere the god: Buddhists

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