

NATURAL HISTORY

6/04



AN EYE
ON FROGS



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NATURAL HISTORY

JUNE 2004

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FEATURES

26 AGE AND BEAUTY

Like to both irises and onions, orchids have a long history and a large repertoire of enticing tricks.

KENNETH M. CAMERON



34 A TRANSIT OF VENUS

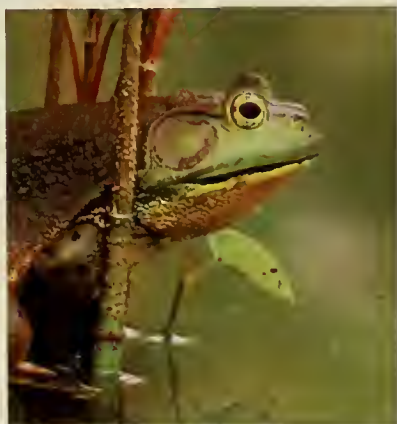
Early on the morning of June 8, the silhouette of Venus will slip across the Sun.

ELI MAOR

40 GOLDEN MOLDIES

Treasured by aficionados, fungi remain mostly anonymous subjects of distant kingdoms, underappreciated for their role as recyclers.

GEORGE W. HUDLER



COVER STORY

44 WHERE HAVE ALL THE FROGS GONE?

Biologists have examined a rogues' gallery of possible culprits. A leading suspect is an infective fungus.

JAMES P. COLLINS

ON THE COVER: Bug-eyed stare of the red-eyed treefrog (*Agalychnis callidryas*) might serve to scare off predators.





DEPARTMENTS

4 THE NATURAL MOMENT

Calm Before the Song

Photograph by Leon G. Higley

8 UP FRONT

Editor's Notebook

10 CONTRIBUTORS

12 LETTERS

15 SAMPLINGS

News from Nature

18 NATURALISTS AT LARGE

Dirty Little Secrets

Bruce Lyon and Robert Montgomerie

24 BIOMECHANICS

As the Whale Turns

Adam Summers

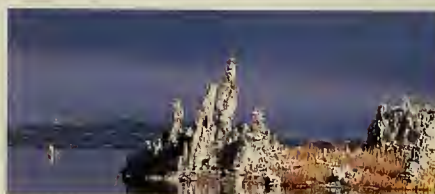
50 THIS LAND

Mono Mania

Robert H. Mohlenbrock



18



50



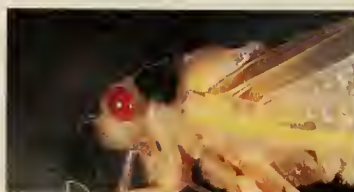
58



52



15



4

52 REVIEW

The Fate of the Soul

William H. Calvin

58 BOOKSHELF

Laurence A. Marshall

63 nature.net

Animals By Ear

Robert Anderson

64 OUT THERE

A Desert No More

Charles Liu

66 THE SKY IN JUNE

Joe Rao

68 AT THE MUSEUM

72 ENDPAPER

Patricia J. Wynne

CREDITS: Page 6

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Calm Before the Song

Photograph by Leon G. Higley





Kevin Karlson

THE NATURAL MOMENT

◀ See preceding pages

An insect's age is typically measured in days or weeks, not years. Yet the periodical cicada ("locust" is a common misnomer), like the one poised here atop its recently shed "skin," lives alone in the soil for many years. Underground in their flightless nymph form, the cicadas slurp tree sap, biding their time. Then, after thirteen or seventeen years (depending on the species), the nymphs crawl to the surface and metamorphose into red-eyed adults. Incredibly, all the cicadas in the same brood—a population connected geographically—emerge in synchrony. Billions of them take over many forests across eastern North America for a few raucous weeks of mating before they die.



Higley and his family had to shout to be heard above the 120-decibel calls. Females cause significant tree damage when they

rake back the bark of twigs to lay their fertilized eggs. A few weeks after all the adults have died, new nymphs drop to the ground and burrow down under their parents' corpses for a long wait.

Such a long development period, followed by such a brief window for mating puts all periodical cicadas at risk. Yet they are far from vulnerable. The insects Higley photographed were so dense near the Platte River, northeast of Lincoln, that predators could gorge themselves without making a dent in the ability of the brood to reproduce. Another evolutionary hypothesis is that the thirteen- and seventeen-year cycles help the cicadas avoid predators with shorter, multiyear life cycles. Both 13 and 17 are prime numbers, divisible only by themselves and 1. A predator in sync with the cicadas one year could not benefit from them again soon enough to become a threat.

This June the largest known brood of seventeen-year periodical cicadas, dubbed Brood X, will emerge across fifteen states in the midwestern and eastern United States. Their next hurrah won't be until 2021. Don't miss out!

—Erin Espelie

Leon G. Higley, an entomologist and photographer from the University of Nebraska–Lincoln, observed the 1998 emergence of a seventeen-year cicada brood. The insects were so thick, he recalls, that "you crunched them underfoot and were pelted by them from above." So perfect is the cast of the cicada's shed skin in Higley's photograph that a mold of the insect's respiratory vessels, or tracheoles, is visible (see the white stringy-looking strand of chitin at the left of the image).

Males announce the mating frenzy with deafening noise; the loudest choristers attract mates.

CALL OF THE WILD

How to take great wildlife photos

Photographing wildlife is a unique challenge. In addition to finding the right animal at precisely the right time with the right light and a clean background, there's the difficulty of shooting a moving subject.

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WARNING: May cause film lovers to drool, have bouts of ecstasy and go completely gaga.



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Unwelcome Distraction

And the locusts sang off in the distance,
Yeah, the locusts sang such a sweet melody.

—Bob Dylan, "Day of the Locusts"

Two generations of "locusts" (actually, seventeen-year periodical cicadas—see "The Natural Moment," page 4) have passed since Bob Dylan wrote those lines. In June 1970 Dylan spent a sweltering morning in cap and gown, receiving an honorary degree from Princeton; then, as he says in the song, he headed for the hills. But what should have been simply a joyous graduation was overshadowed by the sickness of war, a pestilence next to which even the deafening chorus of "locusts" was a welcome distraction.

Many of us who lived through those times of national trauma have hoped, and even believed, that wars fought by a nation deeply divided might be a thing of the past. But with the passage of two generations of seventeen-year cicadas, the only lesson that seems to have been learned from the mistakes of that era is, "Support the troops." Meanwhile, many traditional American values—tolerance of difference, openness to debate, respect for truth—not to mention some of the hard-won American reputation for competence, decency, fairness, and transparency, have become casualties of war. In particular, this page is sickened and ashamed for our country by the breakdown of discipline that has led to the torture of prisoners in American custody.

What, you may ask, do such issues have to do with *Natural History*? The American character and habits of mind have been fertile soil for science. Scientific inquiry, after all, is based on honesty, openness, unfettered access to evidence, and candid, vigorous public debate about individual views and theories. Yet as *The New York Times* reported recently, the United States has lost some of its world leadership in science in the past decade. In part, that slippage has come about from the welcome spread of science to other countries. But we must be especially vigilant that American science itself is not threatened by the debasement of the habits of mind on which scientific inquiry is founded.

Furthermore, we all have an interest in the freedoms that make it possible to discover the genealogy of orchids (see "Age and Beauty," by Kenneth M. Cameron, page 26); or investigate the stresses on amphibians (see "Where Have All the Frogs Gone?" by James P. Collins, page 44); or ponder how the workings of the solar system give rise to a rare planetary alignment (see "A Transit of Venus," by Eli Maor, page 34). Nature, the science of nature, and the interest in those topics by people young and old, get pushed aside—even, more darkly, put at risk—by the most unwelcome distraction of war.

• • •

Collins's cover story on frogs is the perfect complement to a visit to a brand-new exhibition at the American Museum of Natural History, "Frogs: A Chorus of Colors," which opened May 29 and runs through October 3.

A final note: Neil deGrasse Tyson is enjoying a well-deserved break this month; his column, "Universe," will return in our next (July/August) issue.

—PETER BROWN

NATURAL HISTORY

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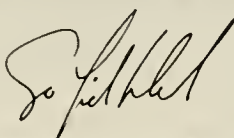
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Experience Matters. And so does commitment. I first visited Galápagos with my father in 1967, when he opened up the possibility of exploring the islands by ship. I still remember that voyage moment by moment. I was struck above all with the wildlife's total lack of fear as my daughter (below) discovered too in her first encounter with marine iguanas. Galápagos is a very special place and I believe that if you, the traveler, have a great experience there, your passion will play a big role in securing the future well-being of these islands. In so many ways, large and small, our longstanding commitment will ensure that you have a great experience. And, together, we will strive to make sure that the next generation may experience the joy and wonder of Galápagos.


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A professor of entomology with a penchant for photography, **LEON G. HIGLEY** ("The Natural Moment," page 4) made his close-up photograph of an emerging seventeen-year cicada near the Platte River, northeast of his home in Lincoln, Nebraska. In addition to conducting research on, among other topics, forensic entomology, Higley hopes soon to initiate a course on macrophotography at the University of Nebraska-Lincoln, where he teaches.

For his tenth birthday, **KENNETH M. CAMERON** ("Age and Beauty," page 26) begged his parents for a lady's slipper orchid. That was the birth of his passion for and scientific curiosity about these remarkable plants. A specialist in the evolution of *Vanilla* and related orchids, he is an associate curator in the Lewis B. and Dorothy Cullman Program for Molecular Systematics Studies at the New York Botanical Garden in the Bronx. Cameron makes heavy use of DNA sequencing to reconstruct evolutionary patterns among orchids and other flowering plants. His work has been featured in *The New York Times* and on the PBS television series *NOVA*.

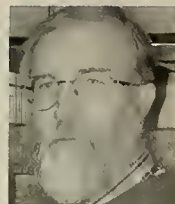


Mathematician **ELI MAOR** ("A Transit of Venus," page 34) has published widely, both in professional mathematics journals and in such magazines as *Orion*, *Sky & Telescope*, and *The Sciences*. His essay on the history of trigonometry appears in the *Encyclopaedia Britannica*. He is also the author of *To Infinity and Beyond; e: the Story of a Number*; *Trigonometric Delights*; and *Venus in Transit* (all published by Princeton University Press). Maor received his Ph.D. from the Technion (Israel Institute of Technology) in Haifa, and teaches at Loyola University Chicago.

The most popular course **GEORGE W. HUDLER** ("Golden Moldies," page 40) offers at Cornell University in Ithaca, New York, where he has been teaching since 1976, is *Magical Mushrooms, Mischievous Molds* (his book by that title was published in 1998 by Princeton University Press). In addition to his courses on mycology and plant pathology, for which he has won numerous teaching awards, Hudler—known around the Cornell campus as "the mushroom man"—edits *Branching Out*, a newsletter about tree and shrub pests and pest control (on the Web at branchingout.cornell.edu/BranchingOutHome.html).



Biologist **JAMES P. COLLINS** ("Where Have All the Frogs Gone?," page 44) devotes much of his professional life to protecting amphibian diversity. A professor at Arizona State University in Tempe, he has spent the past thirty-five years studying the ecology and evolution of frogs and salamanders. Collins directs a team of international scientists in a project investigating emerging diseases that threaten amphibians, and also acts as chair of the Declining Amphibian Populations Task Force, a specialist group within the World Conservation Union (IUCN). For those interested in learning more about the threats to frogs, as well as their evolution, biology, and importance to ecosystems, be sure to visit the newest exhibition at the American Museum of Natural History in New York City: "Frogs: A Chorus of Colors," which opened May 29 and runs through October 3, 2004.





AMERICA.

CHAPTER I.

* * *

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The Heat Is On

Robert Ehrlich ("Heat Exchange," 4/04) criticizes the global warming projections based on assumptions built into the computer models. But his view, that there is no present need to take action to slow global warming, seems based on his own questionable assumptions.

He says it is "fairly improbable" that developing nations will be as wasteful of energy as Americans are today. Is there evidence to support such an assumption? He states, with apparent approval, that "some economists" estimate that a warming of up to five degrees Celsius (nine degrees Fahrenheit) "could be economically positive for the United States." Since climate scientists are still debating how warmer temperatures might affect such things as the conditions for growing crops, the circulation of the Gulf Stream, and the spread of tropical diseases, how can any economists predict that global warming will be a good thing?

If global warming poses as serious a crisis as many climate scientists fear, we will be in real trouble if we do not try to alleviate it.
James J. Foley
Hingham, Massachusetts

In all the articles from all sources I have read over the years about global warming and climate change, Robert Ehrlich's is the most thoughtful and least

biased I have yet come across. We learn that discrepancies among projections of future warming appear to be driven more by different assumptions about growth in economies and energy use, than by differences in views about inputs to climate-change models.

At the same time, the science behind these models is itself not yet settled. For example, as James Hansen of NASA's Goddard Institute for Space Studies points out in



a recent article ("Defusing the Global Warming Time Bomb," *Scientific American*, March 2004), the Greenland ice cap could melt at lower temperatures than previously foreseen, causing substantial damage by raising the sea level.

Elsewhere, Hansen and his colleague Larissa Nazarenko have noted that though earlier studies took into account the warming that occurs when black carbon aloft absorbs heat and thus warms the atmosphere, when black carbon lands on Arctic sea ice and on glaciers, it reduces reflectivity and increases warming on these surfaces, resulting in

earlier melting. When Arctic sea ice melts, it reveals dark water, which absorbs far more heat from sunlight than ice.

Mr. Ehrlich alludes to "the end of cheap oil." Consider that from the end of the Second World War until the 1973 oil embargo, carbon dioxide (CO₂) emissions grew at the rapid rate of 4.7 percent annually, whereas from 1973 until 2002, market forces and governmental actions slowed the annual CO₂ increase to just 1.4 percent. If world oil prices increase substantially, as they will when the world oil supply stops growing, it won't be surprising to see CO₂ emission growth stop or even go negative.

Tom Grahame
Washington, DC

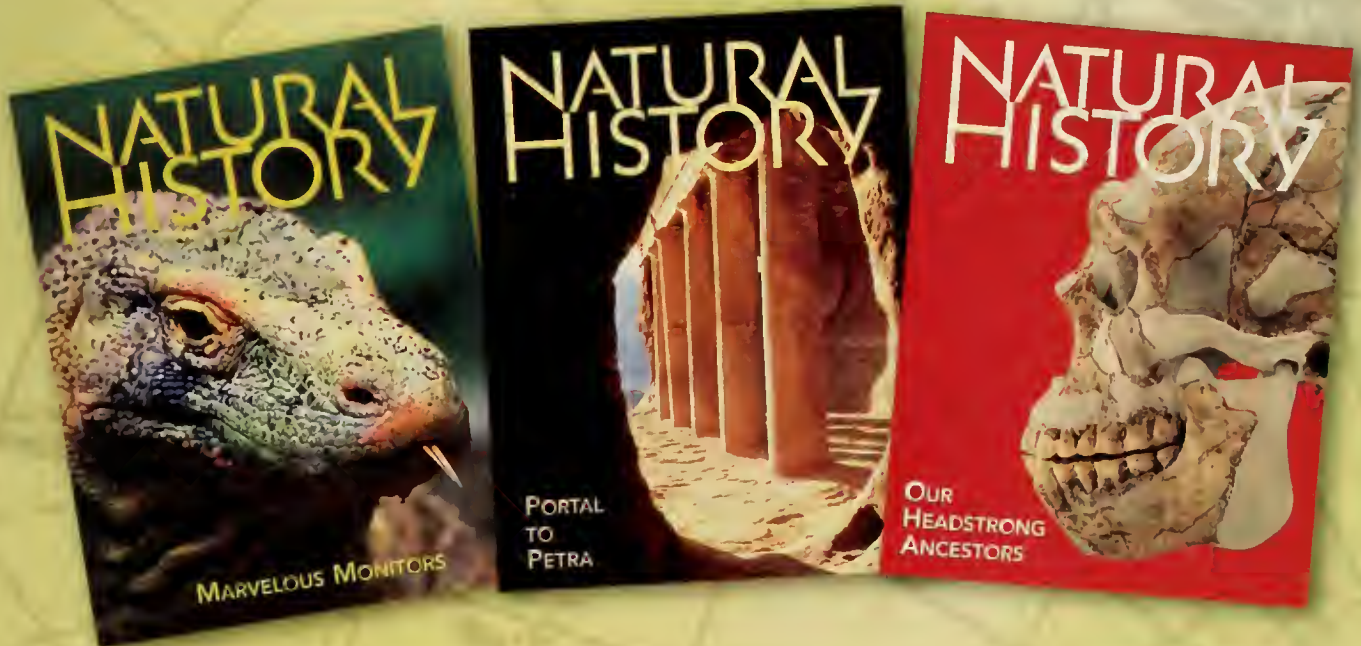
ROBERT EHRLICH REPLIES: James J. Foley questions my assumptions, distorts my position, and disparages the work of unnamed economists mentioned in my review. I never claimed that there is no need to take actions to slow global warming; instead, I suggested that until the uncertainties are reduced, it would be desirable to limit such actions to those in the "no regrets" category, such as energy conservation, which are useful and economical in their own right. Mr. Foley wonders how I can say without evidence that it is "fairly improbable" that developing nations will be just as wasteful as

Americans are today. He leaves off the more important first half of my formulation, namely that I consider it fairly improbable that the developing world will soon catch up with the West economically. My main point was to call attention to the tie-in between the high estimates for the extent of global warming and highly questionable assumptions of economic growth.

Different economists have come to different conclusions over whether global warming will be beneficial or harmful. Generally, those who say that on balance it will be beneficial allow realistically for adaptation by farmers, and they consider potentially positive effects on agriculture and timber resources, such as fewer killing frosts, less day-night temperature variation, and higher CO₂ levels. These economic analyses have mostly been limited to the developed world and may leave out some unpredictable effects, such as possible changes to the Gulf Stream, but they cannot be dismissed out of hand. Furthermore, as Tom Grahame notes, market forces could even lead to dropping CO₂ emissions in the future, rather than drastically rising ones.

One clear implication is that the global warming problem (to the extent that it is a problem) may well take care of itself because of market forces—so why impose potentially costly actions now (such as those mandated by the Kyoto

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NATURAL HISTORY

THE WONDERS OF NATURE AT YOUR FINGERTIPS

protocol) that will have only negligible benefits?

Losing Nemo?

Melanie L. J. Stiassny ("Saving Nemo," 3/04) is basically optimistic about the marine ornamental trade in clownfish, because market forces should encourage local fishers to maintain and protect the reefs and their associated fish. That makes sense, but logic does not always hold sway. Overfishing has often put fishers out of business because short-term profits outweigh long-term sustainability of the enterprise.

When I was in Thailand in January, an editorial appeared in the *Bangkok Post* titled, "Losing Nemo" through Greed." The editorial speaks about an "assault on our already largely-ruined coastline" to meet the large demand for exotic reef fish. Despite some regulations, inspectors in airports have found many thousands of illegally caught fish in styrofoam boxes. The authors refer to reefs in the Philippines and Indonesia as "being swept clean."

Obviously, the editorial writers in Thailand are not as optimistic as Ms. Stiassny.
Judith S. Weis
Rutgers University
Newark New Jersey

I wish I had a dime for every parent I've seen in the past year or so desperately trying to explain to a child that, "Nemo is a saltwater fish . . . I don't know how to keep saltwater fish." Even worse are the unscrupulous local fish stores trying to convince these parents that "keeping

a saltwater tank is easy."

Another step lower are the same local fish stores that sell fish injected with dyes to an unknowing public. Dyed fish may be attractive, but their colors will fade—if they live long enough.

The lowest step of all are the sellers of baby fish four to six inches long, that become four-foot-long adults.

Amanda Parker
Sharon, Massachusetts

MELANIE L. J. STIASSNY REPLIES: Judith S. Weis is right in stating that populations of marine ornamental fishes may be seriously threatened by poorly regu-

lated trade. But the market value to the fishermen of each individual ornamental fish is likely to be much higher than the market value of an individual specimen of many species of commercial "food fishes." Hence, at least in theory, local fishermen do have a strong economic incentive for sustainable trade in ornamental fishes. Steps must be taken to help inform fishermen, so that they can manage their resources better.

Amanda Parker notes that retailers have a duty to provide accurate information and reliable advice about the fish they sell. However, it is just as important for us, the consumers, to research what we are buying. The Internet offers a wealth of relevant information. If

enough of us set criteria for what we want, the market will respond.

Hobby Horses

In his "Biomechanics" column "Meddling with Pedaling" (3/04), Adam Summers writes, "The first bicycle . . . debuted in 1817 as a toy, rather than as transport." But the bicycle historian Hans-Erhard Lessing would surely object to this. He points out that in 1815 the Indonesian volcano Mount Tambora launched so much dust into the atmosphere that 1816 was "the year without a summer": crops failed, there was little food for horses or men,

with the usual kind of handlebar. People whose legs cannot bear the full body weight, or can do so only for short times, but can move in a walking motion, could be held in a manner that would put them more at eye level with walking people.

Joan Lehmkuhl, R.N.
Nampa, Idaho

ADAM SUMMERS REPLIES: I am not surprised that, as David Gordon Wilson reports, bicycle historians might have more to say about the vehicle's origins. As for the figure of 350 watts, it refers to the metabolic input, not the output

To the fisherman the market value of each ornamental fish is likely to be much higher than that of a "food fish."

and horses were slaughtered. Baron von Drais therefore invented the Hobby Horse bicycle at a time when it was needed for transport.

A second, unrelated point: there must have been an error in the quoting of 350 watts exerted by walkers and pedalers at the speeds indicated. The actual value should be around 150 watts.
David Gordon Wilson
MIT
Cambridge Massachusetts

It strikes me that the Hobby Horse version of the bicycle could be adapted to help people with ambulatory difficulties. I can see one made with four wheels for stability and the seat between them, with a hand bar along each side or

of mechanical power. In other words, a very efficient human "engine" needs 350 watts' worth of food fuel to obtain a mechanical power of about 150 watts.

I agree with Joan Lehmkuhl that new means of assisting the physically challenged with wheels could be explored. As Steven Vogel points out in his book *Cat's Paws and Catapults: Mechanical Worlds of Nature and People*, nature makes little use of wheels because the terrains normally encountered by animals are not suited to smooth rolling.

The Wrong Stuff

In his "Universe" column, my good friend Neil deGrasse Tyson argues that
(Continued on page 67)

In Hot Water

Seawater is always on the move, traveling across the planet as if a giant conveyor belt were pulling it along, and the colder, saltier, and denser the water is, the lower it sinks. Most of the water at the bottom of the North Pacific Ocean has not seen the Sun in at least 800 years. Some of it has been down there for two millennia. It's understandable, then, that oceanographers have assumed the temperature of the bottom layer is stable, impervious to atmospheric warming. New evidence, however, shows the lower depths there and elsewhere have warmed significantly in recent decades.

Masao Fukasawa of the Japan Marine Science and Technology Center in Yokosuka and his colleagues compared temperatures and salinities, measured across the full width of the deep North Pacific in 1985, with the same measurements, at the same latitude, made in 1999. Below 16,000 feet, the water temperature had risen, on average, by nearly a hundredth of a degree Fahrenheit. That increase may sound trivial, but it reflects, and may also eventually trigger, major changes in the dynamics of ocean circulation—a primary engine of the weather on planet Earth. ("Bottom water warming in the North Pacific Ocean," *Nature* 427:825–27, February 26, 2004) —Sarah L. Zielinski

HOW TO SPREAD DIVERSITY

Why do some plant families blossom forth with a wealth of species, whereas others have so few? What contributes to the emergence of new plant species? One factor, according to Risa D. Sargent, a zoologist at the University of British Columbia in Vancouver, is symmetry: it makes a difference whether the flowers are bilaterally symmetrical (the left half mirroring the right half, as in orchids) or radially symmetrical (the same pattern all around, as in lilies).

Sargent, who studies the interactions between pollinators and flowers, compared nineteen pairs of closely related plant families. One member of each pair had bilaterally symmetrical flowers, the other, radially symmetrical. In fifteen such pairs, the bilaterally symmetrical families were the more species-rich.

New species usually arise from mutations, but at first the mutated genes may have trouble getting a foothold in the genetic pool of the population. Evidently, though, if the pollen (the male agent) of a mutated plant reaches a plant belonging to the same species—instead of being wasted on another, incompatible species—those mutations will spread more easily. What makes that scenario more likely? Well, one good way for a plant to spread mutations is to rely exclusively on a specialized pollinator, usually an insect. Bilaterally symmetrical flowers are good at inducing such specialization, because they constrain pollinators to take exactly the right position on the flower to bring the pollen into contact with the stigma, gateway to the next generation. ("Floral symmetry affects speciation rates in angiosperms," *Proceedings of the Royal Society of London B* 271:603–608, March 22, 2004) —Stéphan Reeb



Invitation to a pollinator

PASS THE DINNER ROLLS

It's not likely to grace the table of your favorite restaurant anytime soon, but a greasy substance known as "bog butter" has long been found buried in some of the better peat bogs of the British Isles. Burying it seems to have been popular from about 2,400 years ago through the end of the seventeenth century.

Stashing fat belowground could have been done to preserve it or possibly modify it (into soap or wax, for instance, which is what bog butter most resembles now), or perhaps to refine its flavor. Most archaeologists have maintained that bog butter was literally buried butter, long forgotten in the "fridge." But some have also recognized its resemblance to a fatty wax called adipocere, which is known to form from body fats buried in wet, anaerobic environments. Whether bog butter was tallow or dairy fat has thus remained an open question.

Seeking to resolve it, Robert Berstan, an organic chemist at the University of Bristol in England, and his colleagues recently analyzed nine Scottish samples (most packed in wooden kegs or troughs, one wrapped in leather and placed in a cauldron, another stuffed inside an animal's intestine) to determine their origins. Because tallow and dairy fat are synthesized through different metabolic processes, they have different quantities of various fatty acids and, more tellingly, of carbon-13, an uncommon isotope of carbon. The results of the chemists' investigations showed three of the samples were originally tallow and the other six dairy fat. No word yet on bog butter's potential as a replacement for olestra. ("Characterisation of 'bog butter' using a combination of molecular and isotopic techniques," *The Analyst* 129:270–75, March 2004) —T.J. Kelleher



Barrel of bog butter

BEAR BEWARE

Between July and mid-November, polar bears lounge on the shores of Hudson Bay, living off their own fat while they wait for the sea to freeze up. Once the ice is thick enough to support their thousand-pound bulk, the bears can resume hunting for seals, their main source of food. Since the early 1980s, the huge loafing bears have become an autumn tourist bonanza, attracting bus-size tundra vehicles full of curious bear-watchers. The balloon-tired vehicles sometimes come within 130 feet of the bears and stay near them for as long as two hours. Markus G. Dyck and Richard K. Baydack, wildlife biologists at the

University of Manitoba in Winnipeg, recently confirmed that such tourism may be seriously disturbing the animals.

The two investigators observed that polar bears interrupt their relaxation and visually scan their environment more often when



See any tourists?

even one of the large vehicles is on the scene. The bears don't get their rest, because every ten minutes or so another vehicle arrives or leaves. In autumn, the investigators note, polar bears need to just chill out, and the increased vigilance could lead to elevated heart rates and increased output of stress hormones.

Intriguingly, only the males become more vigilant. Dyck and Baydack note that the main danger to a female and her cubs is the male of her own species. When males are preoccupied with tundra vehicles, the females can afford to relax.

("Vigilance behaviour of polar bears (*Ursus maritimus*) in the context of wildlife-viewing activities at Churchill, Manitoba, Canada," *Biological Conservation* 116:343-50, 2004)

—S.R.

WHITER AND BRIGHTER

When a Florida cottonmouth snake sinks its fangs into prey, an enzyme in the snake's venom dissolves the blood clots normally present in the prey's system and thus enables the venom to



For whiter cottons, try some cottonmouth venom.

spread throughout its body. So Devin Imoto, a chemist at Whittier College in California, and his students did what comes naturally: they tested the venom extract on a load of blood-stained white denim. Lovers of spiffy laundry, take note: the venom-treated denim, washed the next day with ordinary detergent, came out noticeably cleaner than usual.

—Caitlin E. Cox

Sumo Star

How big is too big? Nature puts size limits on stars, just as it does on animals, but what was once thought to be the stellar max has just been dramatically surpassed, according to Stephen S. Eikenberry, an astronomer at the University of Florida in Gainesville, and his collaborators. The team has been scrutinizing the infrared output of a star 45,000 light-years from Earth, designated LBV 1806-20. This star, it turns out, is at least 150 times as big as the Sun, and as much as 40 million times as bright. In fact, according to standard theories about the way stars form, Eikenberry's colossus is so big it shouldn't exist at all.

In theory, long before the star reached its current size, its own radiation should have blasted away all surrounding

gas and dust, depriving the star of the raw materials for further growth. In this case, though, says Eikenberry, a supernova may have exploded nearby while LBV 1806-20 was still quite young, sending out shock waves intense enough to push gas and dust toward the child star, and stuffing it to beyond obese.

Several of LBV 1806-20's neighbors, too, are freakishly large, and one is a much younger star. And that puts another supposed rule on the watch list: standard theory maintains that all the stars in a given cluster form at the same time. ("Infrared observations of the candidate LBV 1806-20 and nearby cluster stars," to be published in *The Astrophysical Journal* 611, August 20, 2004)

—Joomi Kim

INVASION OF THE GIANT BLOBS

This past February, the beaches of southern Chile looked like the aftermath of some interplanetary conflict, as hundreds of large, bizarre-looking bodies washed ashore. The only thing extraterrestrial about them, though, was that the European Space Agency satellite Envisat provided the explanation for their presence.

The bodies were jumbo flying squid—*Dosidicus gigas*—creatures whose length may reach thirteen feet. Deep-sea dwellers, they make their living by hunting for fish at the interface between cold and warm waters.



Jumbo flying squid

Prevailing westerly winds usually blow the warm surface waters of the austral summer out to sea, making room for deep, cold water to well up along the coast. This year, however, the cold upwelling ceased in late February, and a renegade pocket of cold water got trapped within masses of warmer water, according to Cristina Rodríguez-Benito, an oceanographer at the company Mariscope Chilena in Puerto Montt, Chile. Attracted to the interface between warm and cold, the squid must have come closer to shore than they usually do, possibly following the nutrient-rich waters where they habitually find their food. (www.esa.int/esaCP/SEMVNJYV1SD_index_0.html) —S.R.

PUBLIC INFORMATION

In the forests of West Africa, Diana monkeys make one kind of bark when they spot a crowned eagle, another when they see a leopard. Both animals prey on Dianas, and so the distinctive warnings provide crucial information to troopmates. Now Hugo J. Rainey and two other biologists at the University of Saint Andrews in Scotland show the Dianas' code can also be deciphered by eavesdropping birds.

Hornbills are large, canopy-dwelling birds that fear eagles but don't mind leopards—after all, the birds fly and the leopards don't. When the biologists played

back the Dianas' two different alarm calls for hornbills to hear, the birds reacted only to "EAGLE NEARBY!"

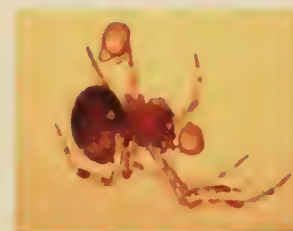
It was already known that various species of monkeys can distinguish between different alarm calls of birds, but this study is the first to show that the tables can be turned. It is still unclear, though, how any of the eavesdroppers learns another species' vocabulary. ("Hornbills can distinguish between primate alarm calls," *Proceedings of the Royal Society of London B* 271:755–59, April 7, 2004)

—S.R.

Need for Speed

Here's a consummately unequal partnership for you: male cobweb spiders (genus *Tidarren*) weigh in at only about 1 percent the weight of the females. Not surprisingly, that creates a few problems.

The male has two copulatory organs known as pedipalps, and either one can make him a dad. To do the job properly, each pedipalp has to be enormous, relative to the rest of his body. Sure enough, the two make up about 20 percent of his body weight—more, apparently, than he's willing to carry around. So, just before molting into his adult form, the male *Tidarren* half-emasculates himself. He spins a silk structure, ties it around one—just one—of his pedipalps, and then twists off the unwanted organ.



Weight reduction, spider style

Working in the laboratory of Duncan J. Irschick, an ecologist at Tulane University in New Orleans, undergraduate Margarita Ramos and a colleague quantified how much the pedipalps drag males down. By chasing spiders, the investigators found that males with a single pedipalp move 44 percent faster, have 63 percent more endurance, and travel 300 percent farther before pooping out than males with both pedipalps intact. Evolution didn't come up with a way to grow just one pedipalp so as to increase mobility, but it did find a behavioral work-around. ("Overcoming an evolutionary conflict: Removal of a reproductive organ greatly increases locomotor performance," *Proceedings of the National Academy of Sciences* 101:4883–87, April 6, 2004)

—S.R.

Cryptic Creatures



Only three of these pictures are close-ups of the same animal. Which one doesn't belong? (Answer on page 65)

Dirty Little Secrets

"Dress for success" is the key to the mating game among Arctic ptarmigan.

By Bruce Lyon and Robert Montgomerie

Most birds act as if cleanliness really is next to godliness. Watch any bird for a while, and you will see that it spends a lot of time preening its feathers and bathing in water or dust. Feathers are essential for flight, waterproofing, and insulation, so it is not surprising that maintaining them is a vital part of a bird's daily routine. How to explain, then, the bizarre sartorial metamorphosis we have observed in the male rock ptarmigan, a species of grouse? In just a couple of days in early summer, the male ptarmigan suddenly transforms himself from an immaculate, pugnacious white bird that stands tall on large boulders, to a filthy, bedraggled creature that skulks about on the tundra. Why do these birds get so dirty? Equally intriguing, why are their feathers so white and conspicuous to begin with?

Charles Darwin was one early naturalist who took an interest in such plumage changes. Probably referring to the willow ptarmigan, which winters in the boreal forest and flies north in the spring to breed in the Arctic, he argued that the species' superb camouflage—white in winter, brown in summer—supported his idea that natural selection shapes the traits that increase an animal's ability to survive. To buttress his case, he noted that the birds often suffer intense predation in the spring, when the snow melts and the once-camouflaged white plumage stands out dazzlingly against the brown tundra. Our own study of rock ptarmigan in the Canadian High Arctic, assisted by Karen R. Holder, currently a lecturer

in biosciences at Loyalist College in Belleville, Ontario, confirms that the bird's strategy as a camouflage artist follows a predictable pattern, at least in females. As it happens, though, the story for males is more complicated than Darwin realized.

For thirteen springs in the 1980s and 1990s, we headed for Sarcpa Lake, on the remote Melville Peninsula at the top end of Hudson Bay. To get there we had to hop and skip from place to place on commercial and

chartered airlines. Some years we could take a six-hour commercial flight from Montreal that would land more than 1,800 miles to the north, at Hall Beach (population about 625), in what is now the territory of Nunavut. From there we would charter a Twin Otter to fly us the final sixty-mile leg of our journey, transporting all the gear and food needed for a six- to eight-week stay. Our field station was a former Distant Early Warning Line radar site, abandoned in the 1960s when satellites became the method of



Male rock ptarmigan's bright plumage, which provides good camouflage in the High Arctic winter, stands out after the snow melts in the spring. In a matter of weeks he will lose his white feathers as brown ones grow in, but in the meantime he presents an easy target for sharp-eyed gyrfalcons.

choice for watching for Soviet invaders from over the pole.

We usually arrived at the end of May, when the treeless tundra was still covered with snow. At that time, flocks of migratory shorebirds and waterfowl are yet to arrive, but small coveys of rock ptarmigan are already roaming about, looking for exposed seed heads to eat. Dressed in white ever since the preceding September, they have spent the winter on the snowy tundra as far south as the tree line and are all but invisible against the snow.

Once settled on their territories, ptarmigan were spread thinly over our five-square-mile study area. A typical day of fieldwork involved walking for miles as we followed and watched the birds. Our first priority each year was to find out which banded birds had returned from the preceding year and which birds needed to be captured and banded for the first time. The ptarmigan at our site were ridiculously tame, making it easy to catch them with a noose at the end of a twenty-foot-long pole. We found it hard not to giggle while slipping a wobbly noose over a walking but oblivious target. Once birds were individually color-banded, we spent our days recording the color and condition of their plumage and documenting the birds' daily activities to see which males were successful at attracting females. The hard part was that the birds are active twenty-four hours a day, since the summer sun never sets in the High Arctic.

The Arctic spring is brief and intense—the transition from a snowy winterscape to the brown tundra of summertime seems to happen overnight. When the color of the landscape changes, females shed their white plumage as brown replacement feathers grow in. This transformation makes good sense, because the females are entirely responsible for incubating the eggs and tending the chicks. The low-growing vegetation on the treeless tundra provides nothing in the way of protective cover, and the Arctic has many predators that find ptarmigan

tasty. From overhead, nests and chicks are vulnerable to ravens and jaegers, and adults are exposed to gyrfalcons and peregrines. From the ground, Arctic foxes, ground squirrels, and people are a persistent threat. The mottled brown summer plumage of females helps conceal the nest and chicks from those unfriendly eyes.

The effectiveness of the female's spring camouflage is as uncanny as that of her white plumage in winter. We once found ourselves crawling on

breeding season, often changing their colors through a feather molt. Although the male ptarmigan also acquires special breeding colors, in this case the colors come free of charge, because it is the background that changes. Then, a few weeks later, well after the snow has melted, the male's color finally does change, but not just by molting. All the males in our study population changed color during a two-week period simply by getting dirty: literally bathing in dirt. Dirt-



Female ptarmigan, which acquires her mottled coloration at the very start of spring, has a good chance of escaping the notice of raptors, Arctic foxes, and other predators. The low-growing tundra vegetation otherwise offers little protective cover. Why the male lags about a month behind the female in changing his appearance is one mystery the authors set out to solve.

hands and knees in a small patch of tundra to rediscover a ptarmigan nest we had found only a few minutes earlier. Motionless and blending almost perfectly into the surrounding heather and lichen, the female was as close to undetectable as an animal can get. Her mate, though, nervously watching us from atop a nearby boulder, was anything but cryptic. His white plumage practically glowed against the dark tundra.

The males, in fact, delay their molting until about a month after the females molt. Their spring plumage has two unusual features. In most bird species the males sport conspicuous, even gaudy plumage during the

bathing precedes their molt into the brown summer plumage by a couple of weeks or more.

The presence of dirty males in summer seems to be universal in rock ptarmigan populations. In his award-winning book *Iceland Summer: Adventures of a Bird Painter*, the ornithologist George Miksch Sutton recalled observing the same phenomenon:

The male ptarmigan was largely in winter plumage, but so worn and soiled were its feathers that it was pale gray rather than white. Why the molt into dark summer feather should proceed so much more rapidly in the hen than in her mate puzzled us. How, we continued to ask ourselves,

could retention of a conspicuous white male plumage throughout the period of egg laying and incubation be advantageous to the ptarmigan in its struggle for survival?

Sutton was mystified by the male's delayed molt and conspicuousness, whereas our attention was first engaged by the male's dirtiness. We soon realized, however, that cleanliness and dirtiness are flip sides of the same coin.

It is well known (at least among ornithologists) that grouse and many other birds bathe in dust, a practice that discourages feather parasites and keeps the feathers in good condition. But dust-bathing does not necessarily lead to a color change, or to soiling. Studies of chickens have shown that dust-bathing cleans feathers by removing excess oils. And we have often seen male ptarmigan emerge from dust-bathing without soiling their plumage—though not during the two-week spring period before they molt.

Birds that get soiled seem to be exercising an option. Could this be their quick and—as it were—dirty method of camouflaging themselves without undergoing a feather molt? Certainly, dirty males evaded our detection until we were within twenty yards, whereas we could easily sight clean males from more than 150 yards away—or even from as much as a mile away when the air was clear.

Detecting prey from far away is an essential element in the unique hunting strategy of gyrfalcons. These predators typically spot potential prey from high above the tundra and then swoop down to within a few feet of the ground to launch a surprise attack. Gyrfalcons specialize in ptarmigan across much of the Arctic; in fact, they are the main cause of ptarmigan mortality. Because the gyrfalcon's vision is much more acute than human vision, gyrfalcons should be able to see a white male ptarmigan on the brown tundra from many miles away. For the ptarmigan, getting dirty could be a lifesaver.

Several studies confirm the high cost of conspicuousness. In the early sum-



Male ptarmigan, only beginning to assume his summer coloration, has stained himself light brown, a "quick and dirty" way of blending in. The stain, a temporary, transitional camouflage, is adopted when his mate begins to lay her eggs.

mer, when males are at their most conspicuous and females are cryptic, male ptarmigan often suffer much higher predation rates. Sometimes the casualty rates are extreme. During May and June, on the island of Hrísey in Iceland, Arnthor Gardarsson, an ornithologist at the University of Iceland in Reykjavík, found that a third of all breeding males are killed by gyrfalcons. If this predation rate continued year-round, a thousand males would be reduced to fewer than ninety within a year—strong natural selection indeed!

If predation is so high, why do males stay conspicuous while females molt to a safer brown? One possible reason, suggested by the Danish ornithologist Finn Salomonsen, is that males cannot molt because their blood carries extra-high levels of testosterone during breeding season. The hormone not only plays an important role in regulating male aggression and territoriality in early spring, but it also inhibits molting. In other words, delayed molting may be an unavoidable side effect of being a good contender in the mating game. Even if this

should prove to be true, however, it would not explain why males maintain their gleaming white plumage for so long. Our findings show they do not need to molt to become cryptic: getting dirty does the job just fine.

The biologist and writer Julian Huxley, grandson of Darwin's great friend and supporter Thomas Henry Huxley, thought that the white plumage of the male ptarmigan might distract a predator away from the female. But when we tested that idea, pretending to be predators ourselves, the ptarmigan males led us toward the females rather than away. Of course, even though people have been serious ptarmigan predators for centuries, we might not be the best stand-ins for natural predators.

Our close look at what was going on when individual males became dirty has, we think, shown why the transition to protective coloration is delayed. As do many other male birds, the male ptarmigan seems to gain mating advantages from conspicuous plumage. Perhaps females find such

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plumage more attractive, or perhaps it somehow helps a male prevail in competition with other males. Either way, more mating opportunities lead to greater reproductive success, or fitness. As a result, the trait of sporting bright plumage is passed on to the male offspring of bright-plumaged males.

Darwin distinguished this kind of natural selection by the term “sexual selection.” In general, and more commonly, natural selection favors traits that enhance the survival of the individual in its environment, enabling it to reproduce. In the more specific case of sexual selection, selected traits directly enhance mating success (the male peacock’s showy tail is a classic example). Such traits may actually reduce the individual’s chances of long-term survival. Indeed, the mortality data suggest that among male ptarmigan, conspicuous plumage can lead to untimely death, but bright white plumage might still confer greater fitness, in the sense that males sporting white plumage father more offspring than less conspicuous birds do.

White plumage may be critical for attracting a mate, but even after pairing with a female during the breeding season, a male that keeps a clean profile may have an advantage. Adulterous matings appear to be common in ptarmigan, and so by remaining conspicuous the male may be able to better defend his territory against philandering neighbors and unmated males, or he may simply remain attractive to his mate when she is tempted by these intruders. So by staying white, a male could enhance his reproductive success. Once his mate’s eggs are fertilized, though, he would have little to gain by maintaining his sexually alluring appearance.

What evidence can we offer that this account is correct? Within a given breeding season, the tinning of transformation from clean to dirty often varies dramatically among males, but it

is tightly linked to the timing of his mate’s reproductive schedule: males get dirty when their mates are laying their eggs and will soon have no more eggs to fertilize. We have also observed a few males that obtained two mates in rapid succession. These polygamists got dirty later than monogamous males, remaining clean until their second female began laying.

We wondered what would happen if a female lost her eggs or nestlings to predators and began the nesting cycle anew. Would her now-dirty mate have a mating disadvantage? Although such



Establishing his spring territory, a male ptarmigan (right) has attracted a female, perhaps thanks to his immaculate feathers. Another theory maintains that the male’s conspicuous plumage serves to warn away rival males.

re-nesting is extremely rare at our site, simply because the breeding season is so short, two intriguing cases suggest the answer. Within a day after their mates lost their nests to predators, two males cleaned up their act and went from “medium dirty” to immaculate. The reason, presumably, was that their mates became sexually receptive again. Thus plumage soiling not only provides instant camouflage but, unlike molting, is easily reversible.

Although conspicuous plumage appears important for mating success, we do not yet know which of Darwin’s two main mechanisms of sexual selection are at work—female

choice of mate, or competition among males. If the females are calling the shots, their choice may merely ensure that their own male offspring will also be attractive to females and, therefore, have higher fitness. But it’s also possible that at the same time their offspring will be inheriting some strong survival skills. By “strutting his stuff” with clean, white plumage, a male could be advertising his ability to avoid predation despite being highly conspicuous. And such open risk-taking would be an honest signal, not a deception or a bluff, because staying alive while bearing such conspicuous plumage is proof of good survival skills.

The other possibility is that clean white plumage mainly helps keep male competitors at bay. Perhaps it functions as an aggressive signal between males, serving notice to would-be philanderers to keep away while the female is fertile. One way to distinguish between female choice and male-male competition would be to create dirty males experimentally, early in the season, and examine the consequences with respect to mate choice and interactions with other males. That experiment is much trickier than it sounds, however. On several occasions we actually tried to “dirty” some males with so-

called indelible marker pens, but we failed miserably: the males were just too good at keeping their feathers clean. Those experiments highlighted the importance of clean white plumage for these birds, but they have also taught us just how hard it can be to get at all of the rock ptarmigan’s dirty little secrets.

BRUCE LYON is an associate professor of biology at the University of California, Santa Cruz, where he studies the evolution of social signals and reproductive strategies in birds that breed in open, treeless habitats. **ROBERT MONTGOMERIE** is a professor of biology and Killam Research Fellow at Queen’s University in Kingston, Ontario, where he investigates sexual selection in a wide variety of animals, including humans.

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As the Whale Turns

The shape of the humpback's flippers might hold the secret to more maneuverable submarines.

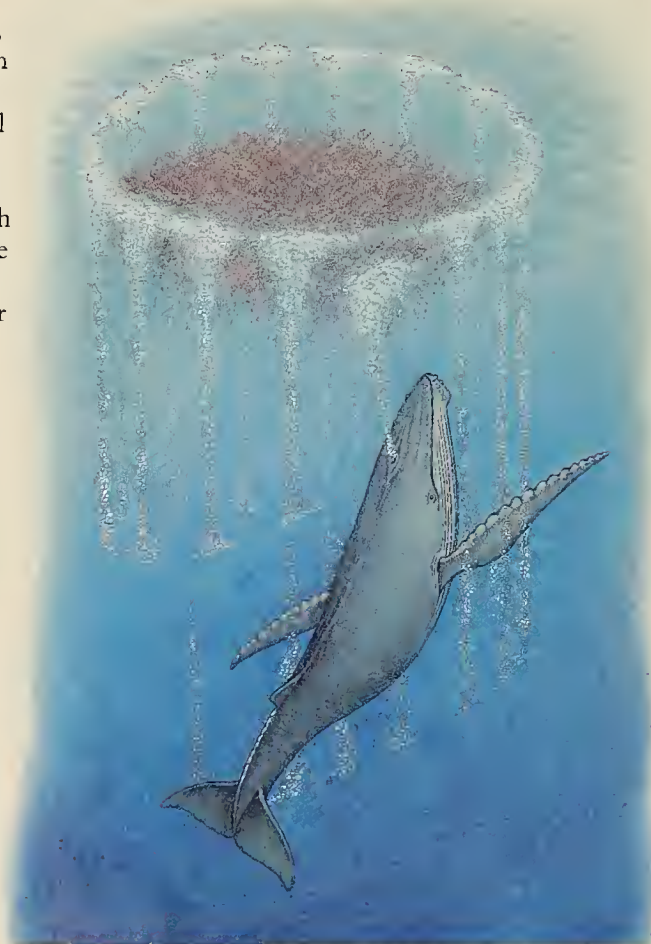
By Adam Summers ~ Illustrations by Patricia J. Wynne

The humpback whale, that mighty leviathan of the briny deep, hardly strikes one as a marvel of agility; on the contrary, it seems the very embodiment of stateliness and power. Each the size of a school bus, these awesome mammals cruise, mouths agape, so as to gather the tons of biomass they need to sate their appetites every day.

But the humpback gives the lie to the notion that things of great bulk move only by lumbering. After all, who hasn't seen, at least on film, the spectacle of a huge whale's great breach, its breathtaking leap from the water followed by a great returning splash? And underwater, the animals move with such astonishing agility that they've caught the attention of naval engineers, who hope that some of the principles learned from the study of the humpback's flippers can be applied to designing submersible vehicles of unprecedented maneuverability.

M*egaptera novaeangliae*, the humpback's scientific name, means "big-winged New Englander"—a nod to the pods of humpies living near the Stellwagen Banks of Massachusetts Bay, as well as

to their very long flippers. Humpbacks, like other baleen whales, eat large amounts of small prey. But instead of simply swimming through



Humpback whale attacks its prey by encircling them in a "bubble net"—a turbulent cylinder of bubbles the whale creates by expelling air through its blowhole as it spirals upward toward the ocean surface. The path of the whale has been traced for clarity by a series of columns of bubbles. The bubble net can be as small as five feet in diameter. Such tight turning is made possible by the hydrodynamic lift generated by the whale's long pectoral flippers.

aggregations of prey, as many of their cousins do, humpbacks often make "bubble nets"—narrow, cylindrical walls of bubbles—by exhaling while they swim in circles beneath their prey [see "Bubble Feast," by Erin Espelie, May 2003]. The bubble nets concentrate the prey, and so, when a whale then swims through the center of a bubble net, its payoff is a rich mouthful.

Bubble nets vary in size, depending on the kind of prey the whales are pursuing. When a humpback is coralling herring and other fishes, the net may be 150 feet wide. But when the humpbacks are rounding up krill—small, shrimpy crustaceans—the net may be as small as five feet across. That behavior raises an intriguing question: How can a thirty-five-foot-long animal swim in such tight circles?

The question has long fascinated the aptly named Frank E. Fish, a biomechanist at West Chester University of Pennsylvania. Fish thought the secret to the humpback's tight turning radius might be its flippers.

The humpback has the longest flippers of any whale, and they lie substantially forward of the whale's center of mass, well placed to exert turning forces on

the whale. In fact, the two flippers look quite a bit like wings: each is between nine and twelve feet long, about four times longer than its width, and each has a rounded leading edge and a thin trailing edge. Most intriguing, each flipper also has large bumps, called tubercles, that jut out from its leading edge, giving the flipper a serrated appearance.

Over the years, biologists have suggested a number of possible functions for the humpback's flippers. Some have seen them as large heat exchangers, or prey attractors, or devices for making sound when slapped against the water. Some have seen them as hydrofoils—water wings—that help the whale make its turns. Oddly, the tubercles have not led to the same level of speculation.

Working with three engineers—David S. Miklosovic and Mark M. Murray, both at the U.S. Naval Academy in Annapolis, Maryland, and Laurens E. Howle of Duke University in Durham, North Carolina—Fish set out to test his hypothesis that the tubercles help the flipper hydrodynamically. For their work, the four investigators relied on two scaled-down plastic replicas of a humpback flipper, twenty-two inches long. One replica featured prominent tubercles; the other had the same area and cross section, but a smooth leading edge. Both models were then tested in a wind tunnel.

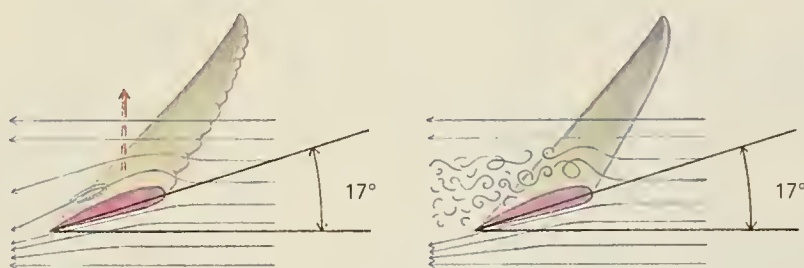
A wind tunnel might not seem to be the environment of choice for testing a flipper that functions in water. Fortunately, though, results obtained with airfoils in moving air can be “translated” into findings that pertain to flippers moving in water. The key to the translation is known as the Reynolds number, a kind of scaling factor that combines three sets of numbers to summarize how an object interacts with a surrounding fluid. In this case, the sets of numbers relevant to the Reynolds number are the length and width of the wing, the density and viscosity of the surround-

ing fluid, and the speed at which fluid and fin slide past each other.

As long as the Reynolds number is held constant, a one-hundredth scale model of an airplane wing will act just like its full-scale version—and a scale model of a flipper in a wind tunnel can become a stand-in for the real thing in the ocean. That remarkable property is a huge convenience for engineers and biomechanists, making it possible to study objects moving at practical speeds simply by varying the viscosity of the surrounding fluid. In this case, Miklosovic and Murray kept the Reynolds number for their scale models appropriate to conditions in nature by running the air past the models faster than the whales would move in seawater. Yet they were still

humpback turns, it can roll farther onto its side without losing its “grip” on the water, and so make a sharper turn, because of the tubercles.

But the tubercles would seem to solve one problem only to introduce another. Protruding into the flow as they do, they would appear to increase the drag of the flipper as the whale swings into a turn. Appearances can be deceiving, though—particularly where drag is concerned. When the scalloped flipper is held nearly horizontal in the flow, the drag is no different from that of a smooth flipper, and at high angles of attack the drag is actually lower. So, just when the whale is using its flipper to turn the tightest, the flipper slides through water more easily than it would if it had a smooth leading edge,



Fluid—whether liquid or gaseous—passing over a wing (blue arrows) creates lift (upward-pointing arrow). But what distinguishes the humpback's flipper from an ordinary wing is the presence of tubercles, or bumps, on the flipper's leading edge (above left). The tubercles enable the flipper to create lift at angles as steep as roughly seventeen degrees, because the water gets accelerated into an organized, rotating flow behind the troughs formed by the tubercles. A flipper with a smooth leading edge (above right) would stall, or cease to provide lift, at such an angle, because the water would be spun into a disorganized series of eddies.

able to get a good idea of the effect of having bumps on the leading edge.

The body of a whale is relatively stiff, and so the animal cannot curve sinuously into a turn the way a swimming seal can. To propel itself around a corner, a whale instead relies on the lift generated by its flippers. Fish and his colleagues found that the tubercles enable a flipper to continue generating lift at angles of attack 40 percent steeper than are possible with a smooth wing [see illustration above]. In other words, when a

even as it generates far more lift than a smooth flipper could.

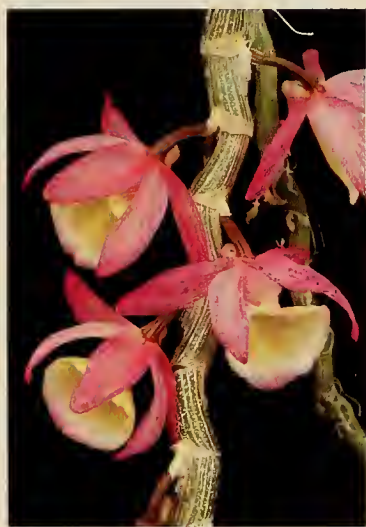
With their stiff bodies, whales are far better analogues for man-made submersibles than more sinuous aquatic animals are. Fish and his colleagues hope to design guidance fins for underwater vehicles that can give them some of the agility that enables a thirty-ton animal to turn on a dime—or at least a large doormat.

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Age and Beauty

Kin to both irises and onions, orchids have a long history and a large repertoire of enticing tricks.

By Kenneth M. Cameron



Ask a glamorous older woman her age and the secret to her beauty, and you're likely to get a Mona Lisa smile and a deft change of subject. Until recently, botanists have met with similar impenetrability when asking these questions about orchids, the glamour queens of the plant kingdom.

The orchid family—Orchidaceae—has a greater wealth of species than any other plant family on Earth: naturally occurring species number around 30,000, and artificially created hybrids in the tens of thousands. Most of them are epiphytes, growing with their roots not in soil but instead harmlessly clasping tree branches high in the forest canopy. A few are parasites; lacking chlorophyll, they extract the necessary nutrients from the organism on which they have made their home. One Australian genus spends its entire life underground. Orchids come in every color except black, and though few have any fragrance, the ones that do run the gamut from the scent of chocolate to that of carrion.

The astonishing diversity of these plants is matched only by the complexity and unconventionality of their lifestyles. Orchids are so unlike other flowering plants, in fact, that they seem to live in a kind of splendid isolation from the great hierarchy of other organisms. Darwin wrote a book on them—*On the various contrivances whereby British and foreign orchids are fertilised by insects, and on the good effects of intercrossing*. The book served as a kind of sequel to his *Origin of Species*, and was intended to clarify certain points crucial to the theory of natural selection. But only quite recently—and only

because of the advent of powerful molecular techniques such as genetic sequencing—have plant biologists been able to reconstruct the history of the family to which these alluring flowers belong.

Darwin argued that natural selection cannot take place unless organisms cross with other individuals. The reason he gave is that the survival of individuals best adapted to prevailing ecological conditions—often called “survival of the fittest”—depends on the existence of a broad spectrum of characteristics to meet whatever those conditions throw at the individuals of a species. Sexual reproduction, with its radical reshuffling of genes in each new generation, gives rise to that variety.

Most plants—particularly the angiosperms, or flowering plants—possess both male and female parts, and so they can, in principle, fertilize themselves. The fact that they do not—indeed, that they have evolved a wide range of strategies for preventing self-fertilization—seems to support Darwin's reasoning. In his book on orchids he documents the elaborate frills and furbelows, gimmicks and traps, that lure and exploit insect pollinators, thereby ensuring cross-fertilization. Darwin's classic volume thus also lays the foundation for the study of the coevolution of plants and animals: how changes in one alter the other, leading to the ongoing evolutionary adjustment of both.

The blossoms of the orchid plant are simplified in certain respects but quite complex in others. Consider the architecture of the stamen, the flower's male component, and the pistil, its female component. Orchids belong to the class Liliopsida (informally called monocots), along with grasses and lilies, which both produce stamens in multiples of three. But orchid flowers typically bear just one fertile stamen. Furthermore, that stamen is fused with the pistil, forming a bisexual structure



Orchids, the most species-rich plant family on Earth, come in an astounding array of shapes and colors. Above: *Encyclia fragrans*, the fragrant cockleshell orchid from Central America, is a member of the epidendroid subfamily. Opposite page: *Dendrobium primulinum*, an Indian epidendroid, has been overcollected because of its reputed medicinal value.

called the column [see illustration on bottom of opposite page].

Pollen is produced within the anther at the apex of the column. Typically, the pollen grains adhere to one another, forming one or two small masses attached to a sticky pad—a complex structure called the pollinarium. Atop the pollinarium is the anther cap, a kind of hood that prevents self-pollination and is easily dislodged by an insect's body or a hummingbird's bill. Any visitor that comes in contact with the pollinarium's sticky pad ends up conveying the entire structure, pollen and all, to its next stopover—which may or may not be another orchid of the same species.

Because the pollinarium attaches to any visitor that dislodges the anther cap, the anther is empty when the insect or bird flies away. In other words, the orchid has a one-shot chance of effectively attaching the pollinarium to a visiting pollinator, and thence to another flower. Increasing the odds of success is the flower's labelum, or lip—usually the largest, most colorful, most elaborate petal—which serves as a landing platform for insects, and positions the apex of the column immediately above the potential pollinator's body. Instead of relying primarily on fragrance or nectar to attract and reward pollinators, orchids generally use color, shape, mimicry, and overall floral morphology to lure (though usually not to reward) them. All this reducing, restructuring, and fusing of the male and female floral organs, coupled with a lack of reward for the pollinators and a single

chance of success, may seem a risky reproductive strategy—but evidently it works. Orchids, after all, are one of the most successful families of plants.

Once pollinated, the ovary of an orchid develops into a capsule filled with tens of thousands of microscopic seeds. Within each seed is an amorphous embryo made up of just a few cells; unlike the embryos of most seed plants, the orchid embryo is not provisioned with a food source. Furthermore, the orchid progeny are protected from the elements by nothing more than a paper-thin seed coat, leaving them vulnerable to damage and desiccation, and to attack by microorganisms. But the design has the great advantage of being economical, enabling the seeds to travel great distances.

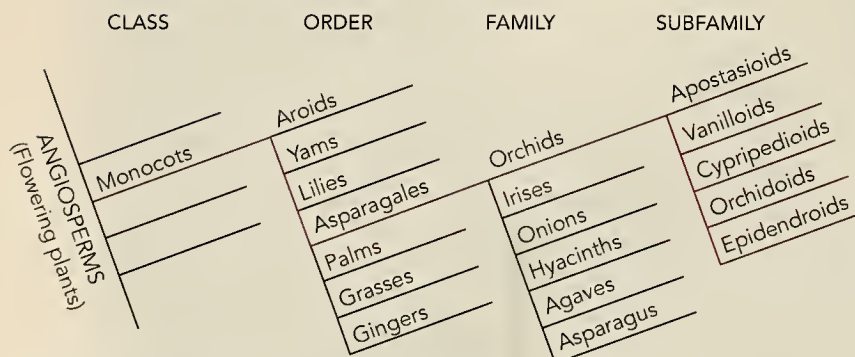
Actually, and counterintuitively, the seed's exposure to microbial attack is no bad thing. To germinate at all, the seed must first be invaded by a fungus. Once the orchid embryo makes a cellular connection with a fungus, the immature seedling begins to siphon off essential nutrients from its fungal host. In other words, the orchid seedling becomes a parasite on the fungus. The orchid may carry on with this living arrangement until it develops leaves capable of photosynthesis, making it able to manufacture food on its own. Alternatively, the orchid may continue to feed off its host for the rest of its life, without ever producing green chlorophyll. This strategy is called myco-heterotrophism, and orchids are its most common practitioners.



Neuwiedia veratrifolia, an aspostasioid orchid from Malaysia, has a number of primitive features in common with other plants in the Asparagales order.



Pogonia ophioglossoides, a North American vanilloid orchid, is a close relative of *Vanilla*, without which bakers and ice cream lovers would be bereft.



Simplified cladogram showing the evolutionary position of orchids in the branching family tree of flowering plants. Orchids were the first group to branch off from the order Asparagales. More than 85 percent of orchid species are epidendroids, but species from all five subfamilies are pictured in the photographs across the top of this page and the next.



Paphiopedilum fairrieanum, one of numerous orchids often called lady's slippers, is a cypripedioid that occurs in India and Bhutan.



Western prairie fringed orchid (*Platanthera praeclara*) is a terrestrial orchidoid that occurs in prairies in the United States and south-central Canada.



Liparis condylobulbon, an epidendroid from Southeast Asia, lives in trees, but some of its closest relatives returned to the ground—orchids' original dwelling

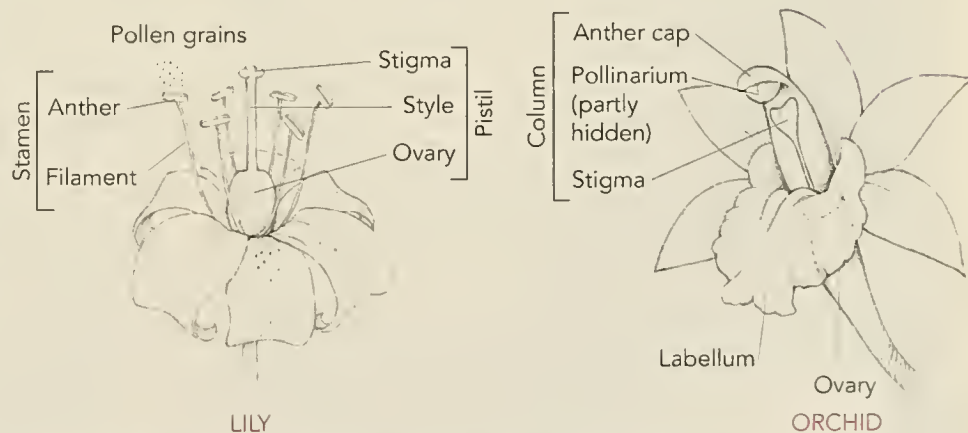
Clearly, orchids are an exceptional family of plants. Classifying them within the standard system of taxonomy, and thereby indicating their closest relatives, has been a matter of considerable controversy among botanists. Some have focused on the orchid seed as the basis for classification, placing Orchidaceae alongside other myco-heterotrophs. Others have focused on the flower, and considered the family closely related to the lilies. Still others have placed them in their own unique order, Orchidales, which just sweeps the controversy under the rug.

Recently, however, cutting-edge techniques of molecular biology have offered an entirely new basis for classification. The most important of those techniques is DNA sequencing—the process of determining the exact order of the nucleic acids that collectively constitute the genes comprising the genome of the plant. Biologists have already sequenced the complete genomes of more than a dozen multicellular organisms, including mice, rice, and human beings. But the sequence of even a small portion of an organism's genome can help reveal fundamental aspects of its natural history—the path the organism took to get to where it is today.

The genetic approach, then, is amplifying the practice of classifi-

cation, rooting it in history. Systematics—the broad investigation into the discovery, naming, and cataloging of biodiversity—has become not just a collector's passion, but a fundamental pursuit in biology. For the plant systematist, DNA sequences yield crucial information about the ancestors and closest living relatives of orchids, when and where orchids evolved, and why they came to have such a complex lifestyle.

Genetic analysis shows that Orchidaceae is a member of the order Asparagales, to which the agave, asparagus, hyacinth, iris, and onion families



Schematic representation of the reproductive organs of a lily, a "typical" bisexual flower with separate male and female parts, and a "typical" orchid, with male and female parts fused in a structure called the column. Pollen, the source of the male gametes, must generally be transported by a pollinator, either as separate grains or as the entire pollinarium (containing small masses of pollen), to the stigma of another flower to achieve cross-fertilization. The stigma leads to the ovary, containing the female gametes; in the orchid, the fertilized ovary develops into a capsule filled with tens of thousands of microscopic seeds.



Chloraea gaudichaudii, an orchidoid found in southern Argentina, has close relatives in New Caledonia, an island in the southwestern Pacific, suggesting that the orchid family originated when the continents of the Old and New Worlds were still connected.

also belong. The orchid family, moreover, was the first of those groups to branch off on its own. But because orchids have left almost nothing in the fossil record, determining a date for their origin has not been straightforward.

Some biologists, therefore, have turned to an investigative tool known as a “molecular clock,” whose ticking is based on the assumption that DNA mutates at a fairly constant rate. The clock is usually calibrated by comparing its (admittedly speculative) readings with the independently agreed-upon dates of some widely recognized fossils from various plant or animal families. Molecular clocks are not without their critics, but one such clock has enabled botanists to calculate that Orchidaceae may have branched off prior to 100 million years ago, around the end of the Early Cretaceous epoch—much earlier than traditionally thought.

One reason that age estimate seems surprisingly ancient to many botanists is that most major orchid groups occur in either the Old World or the New World, but rarely in both. A plant group native to the continents in one of those regions, but absent from those in the other, might be expected to have established itself more recently than 100 million years ago—that is, after South America and Africa (which were once part of the supercontinent Gondwana) had fully separated, thereby preventing further exchanges of organisms between the two landmasses.

Two other reasons for thinking orchids are of relatively recent origin are that most are epiphytes (and thus presumably arose after the emergence of forests full of flowering plants), and most sustain complex relationships with certain insect groups (bees, for instance, didn’t become pollinators until the advent of flowering plants). And sure enough, most horticulturally popular orchids evolved not so very long ago. Yet DNA data from several small groups—particularly the one to which the genus *Vanilla* (source of the much-loved flavoring) belongs—support the idea that orchids in general are of ancient origin.

Vanilloid orchids, which encompass some fifteen genera that form the subfamily Vanilloideae, have always posed an enigma to orchidologists. They incorporate certain advanced features—some are climbing vines, some have winged seeds, most have highly elaborate flowers—as well as features that usually

occur in more primitive orchids: they are terrestrial, their pollen grains are not lumped together on a pollinarium, and the fusion of their stamens and pistil is less complete than in most other orchids. DNA sequencing, in fact, shows that *Vanilla* and its close relatives diverged from other orchid lineages early on.

Furthermore, vanilloid genera today are distributed across the tropical belt of the Southern Hemisphere: Africa, eastern Australia, the Pacific island of New Caledonia, South America, and Southeast Asia (especially Papua New Guinea, but also Indonesia and Malaysia), all of which were once part of Gondwana. Although significant rifting began in Gondwana about 165 million years ago, it was not until about 100 million years ago that Africa and South America became distinct continents; Antarctica, Australia, and New Caledonia, however, remained in contact until as recently as 85 to 90 million years ago. If the orchid family evolved on Gondwana prior to 100 million years ago, the ancestors of the vanilloid orchids would have had plenty of time to spread across the supercontinent before it broke apart, and their family tree should reflect that historical pattern of continental breakup. Indeed, that’s precisely what the DNA data show.

So orchids have been around for a long time. But the same holds true for many other families of flowering plants. What, then, has enabled orchids to become so diverse? Extreme specialization in tandem with specific insect pollinators—an elabo-

rate ballet of coevolution—is usually cited as the primary driving force. And that is almost certainly an important factor. But the DNA data suggest an alternative, though complementary, explanation.

Biologists often specify the evolutionary relationships among organisms via a treelike diagram called a cladogram. In essence, a cladogram is a map of history as well as kinship [see bottom illustration on page 28]. Genetic change takes place through time, and on the orchid's genetic tree, one of the most recent (sometimes represented as one of the shortest) branches includes more than 85 percent of all orchid species.

That kind of pattern is generally a sign that a single momentous event or a decisive biological innovation has taken place—say, a drought that led to desertification, or a petal transformed into a vessel for nectar. Such changes often lead to increased evolutionary activity and speciation: in effect, an evolutionary big bang.

The plant systematist seeking to explain such a pattern would logically look for the distinguishing features of the plethora of orchids populating that single branch of the cladogram. Could the branch-

ing mark a shift from one kind of pollinator to another? Does it signal some innovation in the structure of the orchid's flower, fruit, leaf, pollen, seed, or stem? All are logical possibilities.

But the DNA evidence—from five of the orchids' chloroplast genes—actually points elsewhere. It turns out that the branching records a divergence between species that dwell almost exclusively on the ground (terrestrials) and species that dwell almost exclusively in trees (epiphytes). Obviously that's a major shift, and, not surprisingly, it was accompanied by changes in orchid physiology. Stems became specialized for water storage. Roots developed to absorb water from the atmosphere, hold it like a sponge, and resist desiccation. Leaves learned to perform photosynthesis in sunny, windy, drying conditions. And so quite possibly this change in both habit and habitat—even more than coevolution with pollinators—drove the evolution of the biological innovations and the new orchid lineages.

One mustn't rush to conclusions, though. A transition from a terrestrial to an epiphytic lifestyle might have led to an explosion of diversity in orchid



Encyclia megalantha, an epiphytic epidendroid that occurs in Brazil (compare this flower with another species of *Encyclia*, pictured on page 27)

species, but that doesn't imply the shift is always strictly a one-way trip, or that pollinators haven't played a major role in the evolution of orchids. Quite the contrary. Several otherwise epiphytic orchid groups appear to have descended from the trees back to the ground ("back" because orchids originally started out on the ground). Once again, DNA evidence has helped resolve the question.

Consider the evolutionarily advanced group of orchids known as Malaxideae, which traditionally includes at least three genera: *Oberonia*, *Malaxis*, and *Liparis*. All *Oberonia* species are epiphytes, whereas all *Malaxis* species are terrestrials. *Liparis*, however, includes nearly equal numbers of epiphytes and terrestrials. The traditional classification of malaxids is based on the assumption that epiphytism was its ancestral condition, and that members of two genera independently adopted a terrestrial lifestyle. But now DNA sequences from both the nucleus and the chloroplasts of more than fifty malaxid species show that all the epiphytic species are derived from a single common ancestor, and all the terrestrial species are derived from another. In other words only one evolutionary event brought these orchids down from the trees again.

Such new hypotheses about the relations among species challenge the traditional basis for classification: the architecture of the flowers. For centuries, botanical taxonomists have focused on reproductive structures, such as flower parts, fruits, pollen, and seeds. Their underlying assumption was that the visible forms of vegetative structures, such as leaves, roots, and stems, are subject to considerable change because of the plant's need to adapt to particular environments, and thus those forms are unreliable indicators of kinship. That process, called "convergent evolution," is exemplified in the remarkable similarities among the thorny, leafless stems of var-



Grammatophyllum speciosum, the tiger orchid of Malaysia, is an epidendroid that can grow several yards tall. It is the most massive orchid plant on Earth.

ious unrelated desert plant families, such as cacti, milkweeds, and spurges.

Yet the DNA data seem to indicate that orchids—whose flowers readily change color, form, shape, and size as a result of the selective pressure of specific pollinators—disobey that "rule." Flowers can be misleading. The mode of growth—whether terrestrial or epiphytic—and the structure of the leaves and stems turn out to be the better indicators of malaxids' (as well as some other orchids') evolutionary history.

Biologists generally maintain that hierarchical classification systems should be "natural"—that is, based on evolutionary relations

rather than on some shared attribute such as flower color, leaf shape, or geography. To some extent, a plant's name and its placement in the hierarchy should enable one to infer part of its evolutionary history. And as hypotheses about evolutionary relationships change, so must the names.

Darwin and countless other biologists of the past made huge strides in understanding the natural history and evolution of orchids. Some of their hypotheses, however, were based on educated speculation and have quite recently been shown to be in error. New genomic data and high-speed computers have helped contemporary investigators propose more objective and testable hypotheses than those put forward by their predecessors.

Most of the DNA data support traditional classifications, but some—the data on the malaxids, for instance—do not. From where I stand, the present century is an exciting time to be in the business of botanical sleuthing. Soon botanists will know a lot more about the plant kingdom's most glamorous angiosperms—the flowers, as Darwin put it, "universally acknowledged to rank amongst the most singular and most modified forms in the vegetable kingdom." □



Myrmecophila brysiana, an epidendroid from Central America, has hollow stems that house colonies of ants, which defend the plant against other insects.

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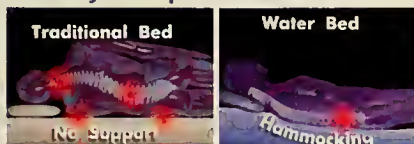
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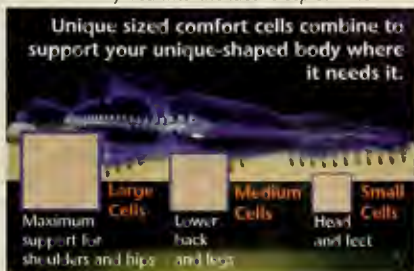
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A Transit of Venus

Early on the morning of June 8, the silhouette of Venus will slip across the Sun. The event, last seen in 1882, was once the key observation in determining the size of the solar system.

By Eli Maor

Catching sight of celestial spectacles requires more than patiently sitting at a telescope set up in your backyard. Birdwatchers can pursue their passion almost wherever and whenever they choose. Flower and plant aficionados have only to stroll through their favorite park to enjoy the sights and scents of nature. But to experience the wonders of the heavens, the skywatcher must be in the right place at the right time. Moreover, even predictable astronomical events are often notoriously rare. A total eclipse of the Sun, for example, takes place on average only once every eighteen months. But to see it you may have to travel halfway around the globe to station yourself in the path of the Moon's shadow. Even then, you're still at the mercy of the elements. Some spectacular events, such as a Leonid meteor shower as splendid as the one in 2001, may happen only once in a lifetime—if at all.

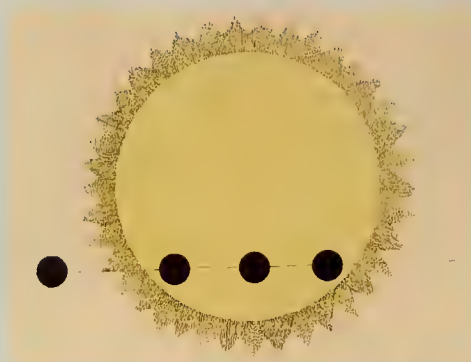
Few celestial phenomena can compete in rarity and in historical interest with the passage of the planet Venus in front of the Sun: a "transit" of Venus. Only five times in recorded history has this event been witnessed: in 1639, 1761, 1769, 1874, and 1882. How lucky we are, then, to be around for Venus's next visit to the Sun, scheduled to begin at 05:13 Universal Time (1:13 A.M. Eastern daylight time), also called Greenwich Mean Time, on Tuesday, June 8, 2004, and to end at 11:26 Universal Time (7:26 A.M. Eastern daylight time) the same day.

The story of the transits of Venus begins in 1627, just three years before the death of the German astronomer Johannes Kepler. In that year

Kepler finished his last major work, the *Rudolphine Tables*, a compilation of astronomical data on the positions of the Sun, Moon, and planets for every day of the year. On the basis of his tables, Kepler made a startling prediction, published separately: on November 7, 1631, the Sun, Earth, and the planet Mercury would be in perfect alignment, so that for a few hours Mercury's dark silhouette would be visible on the face of the Sun. That was not all: one month later, on December 6, the show would be repeated, with Venus in the place of Mercury.

Mindful of the rarity of each of these celestial alignments, let alone the near coincidence of two such events, Kepler issued an admonition to his fellow astronomers in 1629, urging them to watch the two events with the utmost care. Should each transit take place at the time he had predicted, it would verify the accuracy of his tables. Moreover, by observing Mercury and Venus starkly projected against the solar disk, astronomers would have a golden opportunity to measure each planet's apparent diameter—which until that time had been a matter of wild speculation.

As far as is known, only four astronomers heeded Kepler's call, and only one, the Frenchman Pierre Gassendi, left a written account. Through a small telescope in his apartment in Paris, Gassendi projected the Sun's image on a screen in a darkened room. Watching it intently, he could see sunspots, as usual, but there was also a small, perfectly round black dot that was slowly moving across the solar disk—the silhouette of Mercury! With two perpendicular scales Gas-



"Transit of Venus over the Sun's Disc" is rendered in this hand-colored drawing by the nineteenth-century English artist Charles F. Blunt, from his 1849 book *The Beauty of the Heavens*. In reality, to an Earthbound observer the diameter of Venus appears to be only about 3 percent the diameter of the Sun.



English astronomer Jeremiah Horrocks is portrayed observing the 1639 transit of Venus in this oil painting, *The Founder of English Astronomy*, by the English artist Eyre Crowe (1891).

sendi had drawn on his screen, he estimated Mercury's apparent diameter to be twenty arc seconds, about the angle a dime would subtend when viewed from a distance of 200 yards. That was much smaller than most astronomers had expected, and it stirred intense debate in scientific circles.

Flushed with success, Gassendi now prepared himself for the transit of Venus the following month. He set up his equipment as before and waited, but this time luck was not with him: the sky was cloudy and he saw nothing. Today it is known that for most of Europe the transit actually took place during the night between the sixth and seventh of December and was thus invisible.

Kepler's success in predicting the transit of 1631 precipitated one of the strangest episodes in the history of astronomy. His prediction that Venus would not transit the Sun again until June 6, 1761, attracted the attention of a

young, obscure English astronomer named Jeremiah Horrocks (or Horrox, according to some sources). Horrocks made a sensational discovery when he was just twenty-one years old; he reexamined Kepler's calculations and concluded that Venus would cross the Sun's disk on December 4, 1639—just eight years after the 1631 transit.

Of relatively modest background, Horrocks had shown an early passion for mathematics and astronomy. He attended the University of Cambridge for a time but did not graduate, and so was mostly self-educated. He made his meager living as a schoolteacher in the hamlet of Hoole (now called Much Hoole), some thirty miles northwest of Manchester. Barely a month before the transit was to take place,

To observe the upcoming transit of Venus, see "The Sky in June," by Joe Rao, page 66. Do not look directly at the Sun.

Horrocks hurriedly wrote to some of his friends, urging them to be on the lookout for this rare event. He himself began his vigil the day before, in case his calculations for the transit were a bit off.

December 4, the predicted day, was a cloudy Sunday. Horrocks was at his telescope as soon as the Sun was up, but around one in the afternoon he had



Changing position of Venus against the Sun is shown for the transit of June 3, 1769, as the Sun sets. The illustration was first published in 1769.

to interrupt his watch, perhaps to perform some clerical duties at his church. When, by his own account, he returned to his telescope, at 3:15 P.M.,

The clouds, as if by Divine interposition, were entirely dispersed, and I was once more invited to the grateful task of repeating my observations. I then beheld a most agreeable spectacle, the object of my sanguine wishes, a spot of unusual magnitude and of a perfectly circular shape, which had already fully entered upon the sun's disc on the left, so that the limbs of the sun and Venus precisely coincided, forming an angle of contact. Not doubting that this was really the shadow of the planet, I immediately applied myself sedulously to observe it.

But December days in England are short. Horrocks followed Venus for barely thirty minutes before the Sun set. Nevertheless, he was justly proud that the transit took place at the exact time he had predicted. Alas, because of his church duties, Horrocks missed what would become the most important moment of the transit for determining the distance between the Earth and the Sun—the instant when Venus completely entered the solar disk.

One other person saw the historic 1639 transit: Horrocks's friend William Crabtree, a draper by trade. Following Horrocks's alert, Crabtree pre-

pared to observe the transit from his home near Manchester. When the moment finally came, though, he was so overcome by the sight of Venus on the Sun that he momentarily lost his composure, regaining it just long enough to make a few hurried sketches before the Sun set.

Horrocks and Crabtree resolved to meet and compare their observations, but it was not to be. The day before their scheduled meeting Horrocks suddenly died at twenty-three years of age. Crabtree, who mourned him deeply, survived him by only three years.

As far as is known, only Horrocks and Crabtree recorded their observations of this historic transit. It would be more than 121 years before Venus would appear once again on the Sun's face. When that day finally arrived, on June 6, 1761, hundreds of astronomers around the globe were ready, eager to greet the wandering planet at their telescopes.

Transits of Venus follow a strange schedule. They cluster in pairs, eight years apart, after which no transit takes place for 105 years. Then comes another eight-year pair of transits, followed by 121 transitless years, before the entire cycle starts over again. For the present, and for the next few millennia, transits of Venus take place only in early June and early December.

That schedule is a result of the slight tilt in the orbit of Venus around the Sun, relative to Earth's orbit. The Earth's tilt keeps Venus clear of the Sun (as seen from Earth) during most of its passages between the Sun and the Earth. Those passages, which take place every 584 days, or about every nineteen months, are known to astronomers as inferior conjunctions. Only when Earth and Venus reach inferior conjunction along the line where their orbital planes intersect in space do terrestrial observers see a transit of Venus.

The next transit after 2004 will take place on June 6, 2012, followed by two December transits in 2117 and 2125. So we should consider ourselves doubly lucky to live in a "double transit" period, giving many of us the chance to witness two transits in a lifetime. Meanwhile, you might want to mark some future events on your calendar. For example, on December 25, 3818, Venus will pass almost directly across the center of the Sun, making this transit one of the longest ones possible—eight hours and eight minutes—nearly as long as the theoretically maximum duration.

The next major figure in the history of transits of Venus was Edmond Halley, of comet fame. On November 7, 1677, the twenty-year-old future Astronomer Royal observed a transit of Mercury from

the island of St. Helena, in the South Atlantic off the coast of Angola. Halley's observation of the transit of Mercury gave him an idea for answering one of the most pressing astronomical questions of his day: How far away is the Sun? The mean distance, called the astronomical unit, or AU—is known today to the nearest mile (NASA puts it at 92,955,807 miles). But in the seventeenth and eighteenth centuries its value was a matter of wild speculation. Most astronomers, in fact, greatly underestimated it.

Kepler's laws of planetary motion make it possible to calculate the *relative* distance between each planet and the Sun, compared with the distance between Earth and the Sun—in other words, to calculate planetary distances in terms of the AU. But finding the *actual* distances is another matter. It is as if you had a map without a scale marked on it: you could tell that town A is twice as far away as town B, but you wouldn't know how many miles it is to either town. Determining the value of the AU was thus the key to measuring the dimensions of the solar system.

Halley's idea was a straightforward application of geometry: If two observers, positioned far apart on the Earth, could each record the duration and path of Venus as it crossed the solar disk, the times they measured and the paths they plotted would differ slightly because of parallax. To understand parallax, hold your arm straight out in front of you and raise your thumb. Now watch your thumb against a nearby background, first only with your right eye, then only with your left. Your thumb's apparent position with respect to the background will shift slightly, depending on which eye is open. That shift is known as parallax. Surveyors employ the same effect to find the distance to a remote landmark: choose a baseline of known length, and from each of its two endpoints measure the angles between the baseline and the landmark. With simple trigonometry, the surveyor can then calculate the distance from either endpoint to the landmark.

According to Halley, the image of Venus would be starkly outlined against the solar background. He figured that if the moments of entrance and exit of the planet from the Sun's disk (known as *ingress* and *egress*, respectively) could be timed by each of his two observers to the nearest second, the AU could be determined to an accuracy of one part in 500. Of course, the distance between the two observers—the length of the baseline—would also

have to be determined with great accuracy, a task that was by no means easy in Halley's time. He recommended the use of the rare transits of Venus for the task, because Mercury is too close to the Sun to ensure accurate results.

It took Halley nearly forty years to shape a detailed plan of action. In 1716, the now sixty-year-old astronomer submitted his plan to the Royal Society in London. He knew he would not live to witness the next transit, due in 1761, but he urged his younger colleagues to seize this golden opportunity. It would be up to them to determine the length of the AU.

The time now shifts forward to 1761. As the transit approached, expeditions from several European countries journeyed to remote corners of the Earth, equipped with clocks and telescopes. All shared the single goal of recording the exact moments of ingress and egress. One team went to Siberia, another to the South Pacific, a third to the



Device for training astronomers to time the precise moments that Venus entered and then left the solar disk was invented by Sir George Biddell Airy, England's seventh Astronomer Royal. Some observers practiced for six months on the setup before traveling to faraway sites around the globe where they would observe the 1874 transit.

Arctic Circle; others went to Africa and India. Their stories could fill volumes of high adventure: some were successful, others were beset by war, cloudy skies, and gusty winds.

The most moving tale of all belongs to a Frenchman by the impossibly long name Guillaume-Joseph-Hyacinthe-Jean-Baptiste Gentil de la Galaisière, commonly known as Le Gentil. He left for the Indian Ocean in March 1760, more than a year before the transit. En route he stopped

at the island of Mauritius, where he learned that his destination, the town of Pondicherry on the southeastern coast of India, was under siege by the British—it was the height of the Seven Years' War between England and France.

After surviving a hurricane and a bout of dysentery, Le Gentil set sail aboard a French troop ship bound for Pondicherry in March 1761, less than three months before the transit. Time was now running out. The British captured Pondicherry before the ship could dock, so it turned back to Mauritius, plunging Le Gentil into despair. On the crucial day he was still at sea. He recorded the times of ingress

It was not to be. To quote Richard A. Proctor, from his book *The Transits of Venus*:

On June 3, 1769, at the moment when this indefatigable observer was preparing to observe the transit, a vexatious cloud covered the Sun, and caused the unhappy Le Gentil to lose the fruit of his patience and of his efforts.

To add insult to injury, Le Gentil later learned that in Manila, his original destination, the sky had been perfectly clear! It took him two weeks before he could muster the courage to report his failure in a letter to Paris. When he finally returned home, he learned that he had been presumed dead, and his heirs were already dividing his property. He spent the rest of his life regaining his legal status and writing a two-volume account of his exploration of the Indian Ocean.



Point Venus, Tahiti, was the site of the observatory from which Captain James Cook and several members of his British expedition viewed the 1769 transit of Venus. The skies were favorably cloudless that day, and, as Cook wrote, "The little black dot [of Venus] could be clearly discerned moving across the face of the sun until it touched the far side."

and egress, but his observations, made from the deck of a rolling ship, were practically useless.

But Le Gentil was not one to give up. He resolved to stay right where he was, on the island of Mauritius, waiting out the eight years until the next transit. During that time he explored the history and geography of the Indian Ocean, crisscrossing it from Madagascar to Manila. The approaching transit, however, was never far from his thoughts. He decided to watch it from Manila, but then got a letter from the Academy of Sciences in Paris, the sponsors of his trip, instructing him to head for his old destination of Pondicherry, even though only the egress would be visible from there.

He reached the town in March 1768, still more than a year before the event, and started at once to make all the necessary preparations. Transit Day approached. The night before, the skies were crystal clear, and Le Gentil had high hopes for the morrow.

The elaborate efforts to observe the 1761 and 1769 transits marked the first large-scale international scientific cooperations in history. As a result, the AU was determined to be about 95,370,000 miles, a measure that became, in the words of the nineteenth-century American astronomer Simon Newcomb, "a classic number adopted by astronomers everywhere." But the "classic number" would not last for long: the results of the next two transits, in 1874 and 1882, proved that it was too high; the new value was put at 92,500,000 miles. Even that value had an unacceptably large margin of error: about half a million miles. To the chagrin of astronomers, the atmospheres of Earth and Venus conspired to make the exact timing of ingress and egress nearly impossible, often leaving an uncertainty of nearly half a minute. Fortunately, other methods for determining the AU had by then become available, and those gradually replaced the transit method.

After a wait of more than 121 years, Venus will return to the Sun on the morning of June 8, 2004. None of the astronomers who witnessed the past five transits of Venus are alive today, but they surely reflected on the rarity of what they saw—a reminder of the brevity of human life. Newcomb watched the 1882 transit of Venus from the town of Wellington in South Africa, and mused:

On our departure we left two iron pillars, on which our apparatus for photographing the Sun was mounted, firmly imbedded in the ground, as we had used them. Whether they will remain there until the transit of 2004, I do not know, but cannot help entertaining a sentimental wish that, when the time of that transit arrives, the phenomenon will be observed from the same station, and the pillars be found in such condition that they can again be used. □

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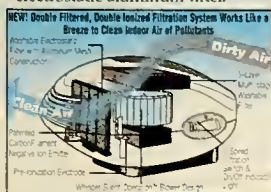
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This ghostly white specimen is *Clavaria fragilis*, a coral fungus—so named for its resemblance to the skeletons of undersea creatures. Its single-stalked fruit body is much like the surface of a mushroom gill, rich with spores. Long-term survival of a *C. fragilis* colony requires that the germinating spores soon find new roots of a compatible plant—often a tree or shrub. Together the fungus and plant form structures known as mycorrhizae (from the Greek words *mykēs*, or “fungus,” and *rhiza*, or “root”), which are essential for the survival of both partners.

Golden Moldies

Treasured by aficionados, fungi remain mostly anonymous subjects of distant kingdoms, underappreciated for their role as recyclers.

By George W. Hudler

Fungi tend to be inconspicuous, growing under a log, on a peach skin, inside a building wall. The gallery of photographs on display here highlights a few strikingly beautiful species, as visual reminders that there are entire kingdoms of organisms, often neglected, that are not to be overlooked. For one thing, fungi are extremely sensitive to the environment. Whenever people get alarmed about the stability of the Earth’s ecosystems, from deforestation to global warming, the threats to plants and animals are what invariably spring to mind. But behind the scenes are the untold millions of fungus species whose fate is bound up with the health of their sometimes more charismatic hosts—and vice versa. Fungi play a vital role in the web of life by taking apart the complex but specialized molecules assembled by plants and animals and recovering the basic molecular building blocks in a form that future generations can use. Fungi are some of our best recyclers.

Fungi were once united as a taxonomic kingdom by such common features as nucleated cells, the absence of chlorophyll, and reproduction by spores. Until the late 1980s, for instance, students burrowed into mycology textbooks that described “old” fungi (like your traditional mushroom) right next to chapters on such groups as slime molds that usually don’t even have cell walls.

Recent rapid advances in molecular systematics have shaken the fundamental bases of fungus classification. Now, under the overarching heading of the Fungi kingdom, or true fungi, are grouped the phyla Chytridiomycota (one-tailed spores), Zygomycota (pin molds and their diverse relatives), Ascomycota (sac fungi), and Basidiomycota (club fungi). Similarities in critical nucleic acid sequences and morphological features unite them all. The Oomycota (two-tailed spores), in contrast, are more closely related to algae than to fungi. The Myxomycota, or slime molds, will probably be assigned to their own separate kingdom. Fortunately, many reputable scientists still speak about “fungi” colloquially. Thus, just as

You might forget you are on land as you stoop for a closer look at *Calocera viscosa*. It looks for all the world as if it should be among the 125 species of coral fungi because its reproductive bodies appear so similar to marine coral. But don’t be fooled; the so-called yellow tuning fork is actually a jelly fungus coated with microscopic spore-bearing cells, a feature that distinguishes the jelly fungi from all other fungi in their kingdom. Yellow tuning forks occur on the forest floor, where they digest decaying pine and spruce trees.





Stinkhorns such as this *Anthurus archeri* (also known as *Clathrus archeri*) come in all shapes and sizes, but they all give off the odor of rotting flesh. The source of the odor—enough to send even the most ardent picnickers packing—is the slimy, greenish brown matrix (seen here on the arms of the stinkhorn), which houses the spores. Some members of this group are colored bright pink to red, including *A. archeri*, and send out particularly strong signals: flies accustomed to dining on animal carcasses descend on the spore bodies with gusto. After they eat their fill, the insects do their part by carrying spores away on their legs or in their gut to other locations.

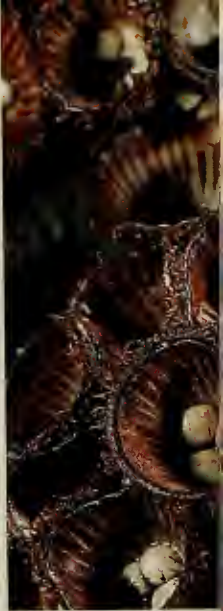
botanists and nutrition experts unabashedly refer to fruits such as cucumbers and peas as vegetables, so it is acceptable to blame the mid-nineteenth-century Irish potato famine—caused by one of the Oomycota, *Phytophthora infestans*—on a fungus.

What hasn't changed is that many people are still fascinated by fungi, drawn by their mystery, their taste, or their fantastical shapes. For some fungi, reproduction proceeds by way of mushrooms, which bear spores on their gills, or by way of puffballs—the relatively large structures that produce millions of spores in dry, powdery masses, to be whisked away by a breeze. For others, spores come in slimy masses, often with characteristic odors or tastes that attract insects. And still other fungi have evolved to take advantage of the energy released by splashing rain or falling sticks to improve their chances for continued survival of their species.

To one who has made a career of introducing young minds to the world of the fungi, I am constantly reminded that appearance is what causes newcomers to stop and look and learn and then learn some more. It seems unlikely that someone can just walk away, after seeing these specimens, without some curiosity about their structure or their role in the environment—fungi, after all, are remarkably adept at using their spectacular forms to spread around and set up for an extended stay.



So-called earthstar puffballs (genus *Geastrum*) have adapted their shapes to literally "puff" their spores out from a single hole. The earthstar first keeps its spore packet enclosed in a tough shell of fungus tissue, then splits open at maturity to form a star-shaped platform. As it dries, the round puffball rises up slightly and then spits out its spores.



Novice mushroom hunters, beware! From the top, this could be *Macrolepiota rachodes*, the shaggy parasol, edible and choice. But it could also be *Chlorophyllum molybdites*—the green-spored parasol, a mushroom responsible for more mushroom poisonings than any other species collected from the wild. *M. rachodes* has white spores and white gills on specimens of all ages, and the stem stains orange to red when cut near the junction with the cap. A mature specimen of *C. molybdites*, in contrast, has light green spores, gills that turn light green to gray with age, and a stem that does not stain darkly when cut.



Spinellus fusiger is a hairy-looking fungus that evolved to feed on its close relatives instead of on plants or animals. Here *S. fusiger* is devouring a mushroom in the genus *Laccaria*. Although such parasitic molds are little more than curiosities in fields and forests, some species annually destroy commercial mushroom crops worth millions of dollars. Contaminating molds have caused some growing facilities to be abandoned.



Wood decay fungi, such as *Cyathus striatus*, produce packets of spores in the shape of small eggs, giving them the common name bird's nest fungi. The characteristic cup-shaped fruit bodies are usually about eight millimeters wide at the top and as much as fifteen millimeters deep. When a raindrop scores a direct hit on the cups, the packets are forced up and out, dispersing the spores. Subsequent weathering degrades the shell, until eventually the spores blow free.

Rubbery fruit bodies of *Bulgaria inquinans* fungi are commonly found in autumn on the bark of dead oak trees. The shiny, blue-black layer that is so conspicuous on each fruit body in the photograph is comprised of thousands of balloon-like cells, each pointing up and each containing eight spores. When the cells break open, the spores are shot a centimeter or more into the air, where they can be picked up by the wind.



Stemonitis splendens is one of those fungi that isn't. It's actually a slime mold, and differs from true fungi most conspicuously in the way it feeds. True fungi digest food outside their bodies by excreting enzymes; the products of digestion are then absorbed into the fungus body. Slime molds flow over food such as bacteria, algae, and small animals, engulfing their meals whole. When resources dwindle, the slime mold is reprogrammed to produce spore-bearing fruit bodies. On *S. splendens*, these bodies look like thick brown hairs, and in this form, the mold is commonly called chocolate tube slime.





Where Have All the Frogs Gone?

*Biologists have examined a rogues' gallery of possible culprits.
A leading suspect is an infective fungus.*

By James P. Collins

Think of an outdoor place where you like to walk. Take a moment and picture what you expect to see: familiar trees and flowers, perhaps singing robins or squawking jays. Think of your favorites, the plants and animals you look for, the pleasure and even reassurance that seeing them brings. What if, the next time you went for that walk, you found that half of your favorites were missing; that still fewer were around the next time; and that, by the third trip, everything you treasured most had disappeared? It would be painfully sad, of course, but wouldn't it seem odd, as well? If all the squirrels, say, or house sparrows in the eastern United States were to suddenly disappear, the first questions on everyone's lips would be: What happened? Why are they gone?

Unfortunately, for biologists studying the Earth's biodiversity, discovering that a familiar organism is suddenly gone is an all-too-familiar experience. Sometimes the explanation is easy. The unmistakable marks of a chain saw on tree stumps provide obvious clues. But more often the answer is not so clear-cut.

By profession I am a herpetologist, a biologist specializing in reptiles and amphibians. In the late 1980s, my colleagues and I began reporting that in familiar amphibian haunts the numbers of frogs and salamanders were declining. By the mid-1990s we were hearing reports that species were going extinct in only a few years; the search for the answer to our question—why are they gone?—was becoming paramount.

Actually, our search became a quest for answers (plural!): the reality in the science, as in any good mystery, turned out to be complicated. In fact, the full story of the decline and extinction of amphibian species remains unknown. But the dimensions of the problem are easier to appreciate if the leading explanations are split into two major categories, the historical and the recent.

Historical explanations point to such causes as competition with exotic, introduced species, or predation by the same; to the harvesting of wild animals for food or pets; and to changes in patterns of land use. Those processes account for most of the damage to amphibian populations for much of the twentieth century, and even today. Although the details of how one of these pressures caused a species to disappear may elude biologists, historical stresses often leave clues—some as obvious as the mark of a chainsaw—from which an investigation can begin.

Of course, none of these historical pressures is unique to amphibians. And, in any event, the declines and extinctions in the 1980s and 1990s left few, if any, clues. Perhaps our biggest shocks were

the disappearances of species from national parks and nature reserves, where the obvious historical causes did not apply; somehow, habitat protection, perhaps the best way to ensure a species' survival, was failing to protect some amphibians.

When the standard historical explanations could not solve the mystery, we began to consider the possible role of recent change. Three leading suspects have emerged: global change, particularly global warming and increased ultraviolet radiation; toxic chemicals in the environment; and emerging—in some sense, new—infectious diseases. Each suspect has its champions (or, perhaps, each has its accusers), and most likely none is acting alone. What's more, some suspected causes probably have accomplices that we don't yet even know about. To crack the mystery of the disappearing frogs, the herpetologists' "detective squad" must look at all possibilities.

To appreciate what kinds of stresses must be considered, take the case of the California red-legged frog (*Rana aurora draytonii*), as documented by Mark R. Jennings, a herpetologist at the National Biological Service in San Simeon, California, and Marc P. Hayes, a herpetologist at the Washington Department of Fish and Wildlife in Olympia. During the great California gold rush of 1849, thousands of forty-niners made fortunes mining gold. Food, though, was so scarce that even a rich man could have a hard time finding something to eat; a chicken egg could sell for fifty cents. So people turned to California's native species for food.

The red-legged frog was among the animals col-



Monteverde Cloud Forest Reserve (above), in Costa Rica, used to host the harlequin frog (opposite page), which is now extinct. A variety of stresses likely related to rapid climate change is to blame. Global warming causes the clouds that define the forest habitat to form at higher altitudes than they have in the past, essentially robbing the amphibians of their home.



California red-legged frog fell prey to the voracious appetites of nineteenth-century Californians, who hunted the species until it collapsed. Still craving frogs' legs, Californians imported bullfrogs to raise for food. The farmed bullfrogs became feral, competing with, and often eating, the native amphibians.

lected, but populations could not sustain the hunting indefinitely. By the end of the nineteenth century commercial frog harvesting had crashed: after a peak harvest of twenty-five tons (about 120,000 frogs) in 1895, by 1907 California produced quantities too small to bother reporting.

Even as populations of the red-legged frog collapsed, consumer demand for frogs remained high. Between 1900 and 1935 entrepreneurs created "frog farms" in California's Central Valley. But because native frog populations were largely gone, the producers imported bullfrogs (*Rana catesbeiana*) from the eastern U.S. Although the commercial enterprises eventually failed, the bullfrogs thrived, and the animals left over from the abandoned commercial operations established feral populations. Large, invasive, and voracious as adults, bullfrogs often out-compete—and often eat—native amphibians. Since the 1930s they have replaced red-legged frogs in many habitats. What's more, even as the Central Valley became a major source of edible frogs, Californians were converting wetlands to farmland on a massive scale. The triple blow of uncontrolled harvesting, an aggressive exotic species, and the loss of habitat nearly created a knock-out punch for red-legged frogs.

The case history of the red-legged frog is likely quite common. In 2001 the U.N. Food and Agriculture Organization (FAO) issued a report titled "The World Market for Frog Legs," based on data collected from 1987 to 1998. According to that re-

port, wild stocks supply almost 95 percent of worldwide demand for frog legs and frog products. Worldwide, the FAO estimates, at least 5,200 tons of frogs—more than 200 times the peak harvest of red-legged frogs—were collected annually worldwide from 1987 until 1997. Given the history of the red-legged frog, those harvests are so large that at least some local populations are almost undoubtedly being depleted. Many countries on the FAO list of heavy producers are also rapidly developing countries (just as California was in the nineteenth century), which entails rapid changes in land-use patterns. Species such as the North American bullfrog are being introduced in new regions, such as South America. Clearly, the causes of historical amphibian declines have not disappeared.

In spite of the worldwide scope of the problem epitomized by the red-legged frog, those threats still do not explain the rapid disappearance of species from undisturbed and protected areas. Biologists have been forced instead to focus on the ways amphibians might be particularly harmed by recent environmental changes. Many amphibian species, for instance, have both terrestrial and aquatic stages, making them susceptible to stresses on land as well as in the water. Permeable skin and eggs without a shell also increase their susceptibility. The most likely new threats, to which natural selection in amphibian populations has had little time to react, include: changes in global climate at an unprecedented rate, the introduction of novel toxic chemicals, and emerging infectious diseases to which the amphibians have never before been exposed.

In the tropical cloud forests of Costa Rica and



Tissue of an Australian frog infected by the fungus *Batrachochytrium dendrobatidis*, an emerging pathogen, is magnified some 400 diameters in the photomicrograph. The fungus infects amphibians around the globe. Of the three banded layers in the sample, the upper one is infected; off-white vessels called sporangia (S) contain black spores. One sporangium (D) is releasing its spores as a hole opens in its side; many other sporangia, already empty, are visible, too.

Panama, at altitudes between about 5,000 to 9,000 feet, global warming poses a clear threat to the local ecosystem. Changing climate alters the patterns of temperature, mist, and rainfall, causing cloudbanks to form at increasing elevations, and compressing the possible range for cloud forests. Such a clear causal relation makes the cloud forests excellent natural laboratories for studying the effects of global warming on amphibians. The amphibians living there are often supported by the water in the clouds. And sure enough, frog populations in cloud forests have significantly declined, and a number of species have become extinct.

Nevertheless, rising temperatures per se don't seem to be killing the amphibians. What is happening instead, according to investigators such as Allen Pounds of the Tropical Science Center in San José, Costa Rica, and his colleagues, is that by narrowing the range of cloud forests, global warming could be forcing populations of amphibians to live together so densely that they become more susceptible to stresses such as disease-causing pathogens. Global warming is also making the cloud-forest habitat so attractive to species from lower elevations that they are invading and could threaten the amphibian communities.

Of course, global temperatures have fluctuated throughout the evolutionary history of amphibians, but that fact does not address the unprecedented speed with which temperatures and moisture patterns are predicted to change, and the possibility that amphibians won't be able to keep up with the shifting locations of their cloud-forest habitat. Even if the present amphibian declines are not caused by global warming, the magnitude of the predicted changes will likely threaten all amphibians.

What about the role of ultraviolet radiation? Studies by Andrew R. Blaustein at Oregon State University in Corvallis and his students have demonstrated how increased UV radiation has diminished the hatching success of amphibians in the Pacific Northwest. Blaustein has noted the effect was particularly strong when other stressors were present, such as global warming or changes in precipitation patterns. So far investigators have not been able to show that places where amphibians are declining are exposed to increased UV radiation, but UV exposure could still be part of a complex set of interacting stresses that are causing declines.

As for the other environmental stresses, laboratory research has long demonstrated that pollutants such as pesticides and herbicides can kill or debilitate amphibian larvae and adults. For example, Tyrone B. Hayes of the University of California,

Berkeley, and his students have shown that minute levels of atrazine, a widely used herbicide, cause individual leopard frogs (*Rana pipiens*) to develop both ovaries and testes. These accidental hermaphrodites cannot reproduce. Although no one knows how such deformed frogs affect a population, there is no reason to expect the effect to be positive.

There is one threat, however, that might connect a number of recent losses of amphibians: emerging infectious diseases. Several features distinguish an emerging disease from an established one:



Leopard frog is the poster child for the effect of pollutants on amphibian populations. The male leopard frog undergoes feminization when exposed to the common herbicide atrazine, which spurs the development of both testes and ovaries and leaves the animal unable to reproduce. Levels of atrazine high enough to cause this unhappy change have been identified in tap water in the American Midwest.

it may be newly recognized by biologists; it may be a known disease that has recently appeared in a new population; or it may be an established disease that is rapidly increasing in incidence, virulence, or geographic range. AIDS, SARS, and hepatitis C are all diseases that have emerged in human populations in the past fifty years or so. Amphibians, of course, don't suffer from those diseases, but they do suffer from others. The two major suspected emerging pathogens of amphibians are a fungus.

Batrachochytridium dendrobatidis, and a class of viruses known as iridoviruses.

The decline and extinction of frogs and toads in Australia, Central America, and North America are associated with *B. dendrobatidis*. Analysis shows that thirty-two globally distributed strains of the fungus are closely related, which suggests it emerged only recently. Of the infected amphibian populations, the most susceptible species occur at relatively high elevations in the tropics. They also have large bodies and breed in streams, which is consistent with what is known about the biology of the fungus.

Out of forty-six affected Australian frog species analyzed to date, mainly from eastern Australia, but especially from the northeast, thirteen species appear to have declined, and three are extinct. Of the frog species surveyed in Costa Rica and Panama, many of which spend at least part of their lives in streams at high elevation, three-quarters have declined, and *B. dendrobatidis* is associated in almost every instance.

The precipitous declines of the Wyoming toad (*Bufo baxteri*) and the boreal toad (*B. boreas*) in the U.S. likewise are associated with infection by the fungus. Both species live above 7,500 feet.



American, or eastern, bullfrog, originally from the eastern United States, has become an invasive species around the globe, carrying diseases, out-competing native amphibians, and—somewhat ironically—posing a general risk to the continued existence of amphibian biodiversity.

Iridoviruses, the second kind of pathogen, make up a large group of viruses that occur around the world. A research group of students and postdoctoral associates at Arizona State University in Tempe, led by Elizabeth Davidson, Bertram Jacobs, and me, collected virus samples from tiger salamanders (*Ambystoma tigrinum*) in six western states and two Canadian provinces. We found only slight genetic diversity in our samples, suggesting that, like the fungus strains, the viruses in at least some populations only recently emerged as infectious in the salamanders.

People are probably partly to blame for the quick spread of the virus. Tiger salamanders are commonly used as bait in the western U.S., and so they are shipped by the millions from ponds, marshes, and stocktanks in the Great Plains. Those bodies of water can serve as excellent incubators and reservoirs for the virus. Fortunately, though, the virus has not proved to be as harmful to salamanders as *B. dendrobatidis* has been to frogs and toads.

Ironically, even as some amphibian species are declining or going extinct, others are increasing in numbers and range. In fact, the latter species probably play a major role in the overall pattern of decline. For example, marine, or cane, toads (*Bufo marinus*) were introduced into Queensland, Australia, from South America in 1935, to eat beetles feeding on sugar cane. As it turned out, they rarely ate the beetles, but they dispersed rapidly, by as much as twenty-five miles a year, and by now they have reached the Northern Territories.

Likewise, American bullfrogs, endemic to the eastern U.S., have become established not only in the western continental U.S., but also in Hawai'i, South America, Mexico, various Caribbean islands, Europe, and Asia. And bullfrogs are just one of a number of amphibian species people have moved, either by accident or for some intended benefit. But the exotic newcomers not only displace native species through competition and predation; they can also carry pathogens such as *B. dendrobatidis*.

The global decline and extinction of amphibians is not a simple problem. Whatever the causes, the extinctions can be understood in a couple of ways. On the one hand, the history of life is a story of extinction: 99 percent of the species that ever existed are now extinct. On the other hand, extinction, as it is happening now in amphibians, also occurs on a much smaller scale, as one, two, tens, or even dozens of species die out in various locales.

Time affects how we understand extinction, too. One can only stand in awe before the fact that 99 percent of species have disappeared over thousands



Congregation of male golden toads competing for mates is likely a thing of the past. Once endemic to Costa Rica's Monteverde Cloud Forest Reserve, the frogs have disappeared. Their legacy, however, may be to spur the preservation of other frogs.

or millions of years: the span of time alone is impossible to grasp. But the disappearance of amphibians and other species in perhaps less than a human lifetime is far more shocking and worrying. These extinctions become a problem to solve rather than the natural course of things.

The final irony of the recent amphibian extinctions is that, as the twentieth century gives way to the twenty-first, species are disappearing just when herpetologists are poised to make great progress in describing and understanding them. Throughout the twentieth century the number of amphibian species described by scientists increased each decade. Molecular methods and more research combined to increase greatly the rate of discovery since the 1970s.

The harlequin frogs of the genus *Atelopus*, which disappeared in the 1990s from the cloud forests of Monteverde, Costa Rica, afford a particularly poignant case. Specimens collected in that region decades earlier and stored in the Museum of Vertebrate Zoology at the University of California,

Berkeley, were studied recently by Roberto Ibáñez and César Jaramillo of the Smithsonian Tropical Research Institute in Panama as part of an effort to describe the number of species in the genus. The results suggest that the Monteverde form is an unknown species that had gone extinct in the wild before it was even described.

That frog, of course, was not the first such case. Some 360 million years ago, the forebears of today's amphibians, creatures that could grow to more than six feet long, walked in great marshes that also harbored ferns the size of oak trees. The amphibians of today are smaller and less numerous. Yet the present generation has its charms—in the sounds of spring and summer evenings in marshes, meadows, forests, and deserts, and in the nearly continuous sounds and stunning colors and shapes of the inhabitants of tropical forests. Some of those songs are coming to an end. Even as we look for signs of life elsewhere in the solar system, we are watching species disappear on our own planet every day. □

Mono Mania

You can't drink the water, but brine shrimp and alkali flies prosper in a mineral-rich California lake.

By Robert H. Mohlenbrock

As my wife Beverly and I drove down U.S. Highway 395, heading south toward Lee Vining, California, we crossed over the crest of a pass and found a large, silvery lake spread before us. Covering sixty-six square miles, the waters of Mono Lake fill a deep depression in the center of a basin-shaped landscape. Beyond the lake we saw gray-topped mountains. Known as the Mono Craters, these mountains are volcanic in origin, and the gray we were seeing was not snow, but ash and pumice from eruptions that took place as recently as 600 years ago.

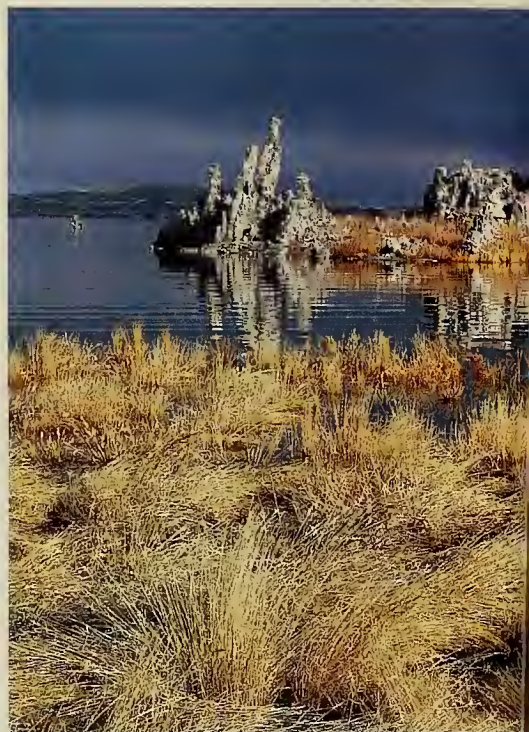
Approaching the lakeshore, we could see that the water was bordered by grotesque gray formations; others pierced the lake surface from below. All were so-called tufa towers, formations of calcium carbonate deposited by the mineral-rich lake water, which is two and a half times saltier than seawater and eighty times more alkaline.

The federal government has designated the lake and its surroundings the Mono Basin National Scenic Area, and the natural attractions are under the care and management of the Inyo National Forest and the Mono Lake Tufa State Reserve. A modern visitor center overlooks the west side of the lake.

The Mono Basin was formed 3 million or 4 million years ago, as the Sierra Nevada was uplifted to the west. Water runoff from the mountains created Mono Lake, because the surrounding basin has no natural outlet. When the last

ice age ended, about 12,000 years ago, water from the melting glaciers enlarged the lake until it was 900 feet deep and covered 358 square miles. Since then, however, Mono Lake has been evaporating and shrinking. And as that process continues, the salts and minerals washed into it by the mountain streams become increasingly concentrated.

On average, the region gets only ten inches of precipitation a year, mostly as snow: far too little to counter the drying trend. In addition, in 1941 the city of Los Angeles began to divert the water from four of the five major streams that enter Mono Lake. Within four decades the lake dropped forty feet and its surface area shrank from eighty-six to sixty square miles. Then, after much debate between officials from Los Angeles and people concerned about the future of Mono Lake, the State Water Resources Control Board issued a decision in 1994 that protects the lake and the streams that feed it.



The peculiar tufa towers owe their existence to calcium in freshwater springs entering beneath the lake and mixing with the lake water. The result is the formation of solid structures of a porous calcium carbonate rock also known as travertine. The tufa towers originally formed below the surface around the mouths of springs, but some of them have become partly exposed by the falling water level, and others are now totally stranded on the shore. The ones in the readily accessible South Tufa Area are between 200 and 900 years old.

On the north shore of Mono Lake lies Black Point, a 576-foot hill originally created underwater by volcanic eruptions. As its top cooled and contracted, it developed narrow crevices more than fifty feet deep. Today you

For visitor information, contact:
Mono Basin Scenic Area Visitor Center
P. O. Box 429
Lee Vining, CA 93541
760-873-2408
www.r5.fs.fed.us/inyo/



Formations of calcium carbonate, built up on the lakebed where calcium-rich spring water flowed into alkaline Mono Lake, are now exposed because the lake level has fallen.

can walk inside the crevices and view tufa towers thought to be about 10,000 years old.

Although sometimes referred to as a dead sea, Mono Lake supports ample life. Quite recently, in fact, Richard B. Hoover and Elena V. Pikuta, both microbiologists at NASA's National Space Science and Technology Center in Huntsville, Alabama, discovered some previously unknown bacterial species that live in the lake's salty, alkaline, oxygenless mud. (These investigators are on the prowl for the kinds of organisms that might survive in extreme extraterrestrial environments.) More conspicuous species are green algae, brine shrimp, and alkali flies.

In winter, when the single-celled algae reproduce unhindered, the lake turns a pea-soup green. At other times of the year, the algae become food for the brine shrimp and the larval and adult flies. The shrimp, which grow to about half an inch long, are active from April to October, laying eggs that overwinter on the lake bottom. Alkali flies can

walk into the lake in an air bubble and lay their eggs on tufa. After hatching, the larvae grow for three or four weeks and then pupate. (The Paiute Indians who lived in the area used the pupae for food.) The adult flies begin to emerge and mate in the late spring. Most live for just a few weeks, but some adults, as well as some eggs, survive the winter to begin the cycle anew.

The shrimp and flies are major food sources for eighty species of migrating birds. An estimated 1.5 million eared grebes, 50,000 Wilson's phalaropes, 50,000 California gulls, and 200 snowy plovers visit Mono Lake each spring and summer. Red-necked phalaropes stop off on their way to their winter home in South America.

HABITATS

Alkaline flat Trees are absent in the salty flats that surround the lake, but two shrubs, greasewood and rabbit-brush, are common. Saltgrass forms mats, above which protrude prickly

Russian thistle, smotherweed (also called bassia), sweetscent (better called stinkweed!), and western tansy mustard. The attractive alkali buttercup also grows here.

Sagebrush scrub In some areas, such as around Panum Crater on the south shore of Mono Lake, plants grow in pumice and volcanic ash, using long taproots to reach freshwater far underground. The shrubs, often widely spaced, include big sagebrush, bitterbrush, desert peach, hollyleaf burr ragweed, and spiny hopsage.

Freshwater marsh A few wetlands around the lake are the freshwater homes of a variety of rushes and sedges as well as cattails. Growing among the tufa formations in the marshes are dock, giant red Indian paintbrush, groundsel, horsetail, Rocky Mountain iris, an aquatic speedwell, stinging nettle (which often surrounds each tower), and willow herb. The marshes are excellent areas to see red-winged blackbirds, swallows, Virginia rails, and yellow-headed blackbirds.

Streamside A good variety of woody species grow along the streams that feed the lake. Among the trees are Fremont cottonwood, lodgepole pine, narrowleaf willow, and quaking aspen. The shrub layer includes mugwort, red osier, silver buffaloberry, and Woods' rose. The night-blooming Hooker's evening primrose is a common wildflower.

Mountain slope Surrounding the lake are open woods with relatively low-growing trees and a scattering of shrubs. The most prevalent trees are juniper, Utah juniper, and single-leaf pinyon. Commonly associated with them are curl-leaf mountain mahogany, desert ceanothus, Mormon tea, and serviceberry.

ROBERT H. MOHLENBROCK is professor emeritus of plant biology at Southern Illinois University in Carbondale.

The Fate of the Soul

Centuries of “experimental philosophy” and cognitive neuroscience have led to a revolutionary understanding of how the brain makes the mind.

By William H. Calvin

If any organ could claim to be the seat of feeling and intellect, surely it was the heart. Until three centuries ago, that seemed a fact too obvious to contest. Unlike other organs, you can feel your heart pounding away inside you. If you start thinking exciting thoughts, it beats even faster. If it stops beating, you are animated no more. And so the heart seemed to be the seat of the soul.

“Soul” was the name for what animated something, what gave it goals and the ability to make things happen. Just as people now distinguish hardware from software, anatomy from physiology, brain from mind, nouns from verbs, and form from function, it was once commonplace to distinguish body from soul. Besides The Soul, philosophers also believed in various “little souls,” which made the bodily organs into something more than meat. The stomach’s soul, for instance, was said to attract food down from the mouth. Once seventeenth-century science began to realize the heart is just a humble pump, it was as if the soul had suddenly fled the chest like a restless ghost to lodge itself in the head.

Today we physiologists would point out that the “little soul” animating an organ is simply its function, which arises from the emergent properties of a “committee” of cells. And we would suggest that the big, catchall Soul is one of the brain’s higher functions.

Only forty years ago, it also seemed obvious that the world was divided into animated stuff and nonanimated stuff. But now, instead of a sharp

boundary between the living and the inert, there is a gray zone at the level of molecular biology. The still-useful distinction is expressed by the special word we employ for the formerly animated: “dead.”

What really counts, physiologists now know, is “brain dead.” Even though some ancient philosophers knew the brain plays a role in paraly-

***Soul Made Flesh:
The Discovery of the Brain—
and How It Changed the World***
by Carl Zimmer
Free Press, 2004, \$26.00

***The Birth of the Mind:
How a Tiny Number of Genes
Creates the Complexities
of Human Thought***
by Gary Marcus
Basic Books, 2004; \$26.00

sis, seizures, and behavioral derangement, that knowledge was regularly overlooked for the following 2,000 years. The Delphic oracle’s reputed advice to “know thyself” has had a rocky road. No one understood what was inside the brain. No one was able to imagine how all that fatty stuff could animate us, enabling us to think complex thoughts and communicate them to others. Soul, mind, and brain all overlap—but how much? Can we do without one category entirely?

Two new books now provide important perspectives on that question for the general reader. Carl Zimmer’s

Soul Made Flesh traces the rise in England of experimental philosophy through the lives of the so-called virtuosi—anatomists, physicians, and philosophers—in the dozen years before they banded together to form the Royal Society in London in 1660. It was the virtuosi who began to replace Aristotle’s theory of the soul with knowledge about the body and the brain gleaned for the first time through the scientific method. In *The Birth of the Mind*, Gary Marcus writes from the twenty-first-century perspective of how the brain makes mind (“soul” has now been dropped from the scientific vocabulary). He describes the biological basis for higher mental processes, and explains how the gene-controlled process of wiring up the brain leads to behavioral differences between individuals—the in-born source of the unique individuality of every mind.

Like most brain scientists, I am inconsistent in using the term “mind” (and I haven’t heard a serious discussion about the soul’s interface with the brain for thirty years). Some say “Mind is what brains do,” but most of what the brain does is routine and no different from what all other animal brains do: controlling the search for food and mates, analyzing the sensory inputs, and deciding what to do next. What are so obviously mindlike are the higher intellectual functions involving structured thought. And despite the accomplishments of centuries of science, which are celebrated in

these two books, scientific knowledge of how and why our remote ancestors first developed these higher capacities is still anything but complete.

Some 50,000 years ago a burst of technological and artistic activity erupted in Africa and soon became a great profusion of art, trading, body decoration, and new tools.

The material evidence of that creative explosion is taken as an indicator of the mind's "big bang": the time after which *Homo sapiens* did things from which we infer that, for the first time, people could think long, complicated thoughts, much as we do today.

What triggered that "modernity"? Was it an enhanced ability to imitate? Planning ability? The use of symbolism, even words? Many suspect that the spark 50,000 years ago may have come from the development of structured language.

A protolanguage made of nothing more complex than short sentences, similar to the ones uttered by two-year-olds, could have been around for a long time, slowly building vocabulary without lengthening sentences. Without longer sentences, though, our ancestors probably lacked long and complex thoughts. That most likely restricted them to a mental life in the here-and-now. They would have been unable to see themselves as the narrators of a life story, always (as we are today) at a crossroads between alternative interpretations of the past and various paths projected into possible futures. (They might not have worried much, either. Although they saw death every day, without the ability to speculate about the future they could not conceive of their own mortality.)

Yet there is a major barrier to creating longer sentences. As the number of words increases, there are so many ways they could relate to one another that you drown in ambiguity. Short sentences—at least in context—are seldom ambiguous, so structuring is optional. But long sentences—the

about, just from the clues in the short string of sounds I utter. You thus recreate my model of events in your mind. This everyday exercise in structured speech, even if its only use was to gossip about who did what to whom, likely facilitated logic, narrative, and contingent planning—perhaps even structured music.

Nevertheless, you may ask, weren't our ancestors gradually getting smarter, as the brain enlarged threefold in the past several million years? Bigger is smarter, is better—why, it seems obvious.

That common assumption, however, is challenged by what archaeologists have been finding in the past few decades. There were two early periods of human history, each lasting a million years, without obvious signs of toolmaking progress, despite all of the brain enlargement going on at the same time. The increases in brain size must have been driven by something that has not been preserved for the archaeologists to find—perhaps protolanguage, imitation, expanding cooperation, or more accurate throwing. Perhaps cleverness was a by-product? But if



Jeremy Comins, *Introspection*, 2001

the brain-size increase resulted in gradually increasing cleverness (again, the common assumption), note that it didn't gradually improve their toolmaking. Oops. Even more to the point, by the time of the mind's "big bang," people who looked like us, big brain and all, had been running around Africa for more than 100,000 years without showing signs of modern behaviors like fine toolmaking. Oops again. The big brain may (or may not) turn out to be necessary for

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our kind of intelligence, but it sure isn't sufficient for modernity.

Once writing was invented, around 3200 B.C., knowledge could not be lost as easily as before; you could actually learn from dead people, and even reanimate their ideas. Indeed, as Zimmer's historical account makes clear, the ideas about the soul expounded first by Aristotle and then by Galen, the Greek philosopher-physician of second-century Rome, kept popping up—and preventing progress—for two millennia. Beginning in the sixteenth century, as standards improved for what constituted an adequate explanation, many traditional concepts about human bodily and mental animation began to seem simplistic, or even erroneous. In the seventeenth century, as Zimmer recounts, the English physician William Harvey figured out that the “soul” of the heart seemed to be all about pumping endlessly. The organ just didn't seem to have the right stuff for all those other functions ascribed to it.

The search for a better seat of personhood soon began to focus on the brain. Christopher Wren, remembered today mainly for his grand architecture and for rebuilding London after the great fire of 1666, was partic-

the practice of science as they went along, but also to navigate the treacherous waters of well-established doctrine regarding the soul.

Willis and the rest of the virtuosi who emerged from the English Civil War pondered how they should go about gathering knowledge through experiments and observations, but only in an ad hoc way. It was [John] Locke who [subsequently] transformed this kind of thinking into a full-blown philosophy, one that would become the heart of the scientific method.

The new science of human nature conflicted with some vested interests concerning the soul. Selling indulgences, for instance, to ensure preferred treatment for your soul in the afterlife, had become a big business, aided by the invention of the printing press. The tortures imposed on dissenters by the inquisitions of the Roman Catholic Church attested to the dangers of thinking differently, and many an early scientist-philosopher was wary and guarded for good reason. The natural philosophers who populate *Soul Made Flesh* were no exception. “In 1666,” Zimmer writes, “bishops blamed [London's] fire and plague on [Thomas Hobbes's] atheism.” Although Hobbes was never formally charged as a heretic, he was

aristocratic patients to surrender the bodies of their dead for autopsies.

Because the brains belonged to England's ruling class, it became hard for his readers to dismiss his observations. The respectability of his success allowed Willis to expand his mechanical, chemical explanations of the brain to include the soul itself without being accused of heresy.

That tactic of Willis's for gaining scientific acceptance, as Zimmer points out, was a clever bit of social jujitsu.

One might think, in the enlightened present, that holding nonconformist views about the comings and goings of the soul would not be criminalized—but that's what is happening. The fallacy of “the little person inside” (about which, more in a minute) has long confused matters even for modern psychology students, who expect “a viewer” to be at some location inside the brain. Centuries ago, a little person was imagined to lie within a sperm. (Now the little person is imagined inside the fertilized egg. This is not progress.) The little person or soul causes endless confusion in otherwise responsible reasoning about regulating abortion.

“When life begins” is a phrase that already carries with it the idea that the soul pops out of a starting gate at the moment the sperm enters the egg. Next we see the dubious line of reasoning that concludes that a single cell has achieved legal personhood. It's only another small leap to claiming that interference with such a one-cell stage of a fertilized human egg is manslaughter or murder.

Few people, however, seem to realize that nature seems rather careless with early embryos; many beginnings are not finished. At least one in four embryos is spontaneously aborted in the first several months. In women who smoke too much (or drink from the wrong water supply), three out of four may be lost. (The usual figures of between 10 and 15 percent for “pregnancy loss” refer to what happens even later, once pregnancy becomes obvi-

Ascribing thought to a person inside the head is like asking, “What makes a car move?” and answering, “Another car inside” instead of “An engine.”

ularly skillful at illustrating dissected brains. (He also invented intravenous injection—pretty good for an Oxford professor of astronomy.) Wren's countryman Thomas Willis, an anatomist and physician who plays a central role in Zimmer's history, “did for the brain and nerves what William Harvey had done for the heart and blood: made them a subject of modern scientific study.” As Zimmer makes clear, however, Wren, Willis, and the other virtuosi were forced not only to invent

“forbidden to write ever again about human nature.”

Even medical men such as Willis had to tread warily through both the religious and the social conventions. Zimmer notes that for most of his working life, Willis was allowed to dissect only the bodies and brains of condemned criminals—his results could thus be ignored because they pertained only to the brains of the “abnormal.” Willis, however, was good at persuading relatives of his

ous.) Those numbers are, of course, far greater than those of elective abortions.

So when conflicts arise in the early stages of pregnancy, many people have concluded that the beginnings need not be finished—that other considerations (time, place, health, resources, the father, other responsibilities) can reasonably be taken into account by the prospective mother. Many biologists—and some modern theologians, too—would add that, just as a pile of construction materials and some assembly instructions does not constitute a house, neither does a fertilized egg and its genome constitute a person, absent a lot of “value added” over many, many months.

Whatever one thinks about the soul and its connection with the contemporary abortion conflict, the terms in which that issue is argued make it abundantly clear that big ideas still matter. And the soul is one of the big ideas of all time.

Zimmer gives us a history of early concepts of soul and mind, in *Soul Made Flesh*, and Marcus gives us an overview of contemporary notions of mind, in *The Birth of the Mind*. In a nutshell, the two books tell the story of how centuries of scientific inquiry have led to new and revolutionary explanations for what animates us.

Many of us, as I mentioned earlier, imagine a little person inside the head watching sensory inputs, then telling the muscles what to do. It took a long time for scientists to realize that ascribing thought to a little person inside the head is the equivalent of asking, “What makes a car move?” and answering, “Another little car inside” rather than “An engine.” But to explain thinking, it is all too easy to argue in a circle. And that classic beginner’s mistake is not always innocuous; it sets you up to view a fertilized egg as

also containing a little person inside.

With what, however, does science replace the little person inside? How does the brain make mind? To begin to address those questions—to do justice to the complexity of human imagination, foresight, and capacity for reflection—you have to come to

must be possible for structured mental activity to become qualitatively improved. How do you manage to do something structured that you’ve never done before—say, utter a long sentence about a friend’s hopes and fears? Somehow you start with an incoherent jumble of concepts, then you improve its



René Magritte, *Le Double Secret*, 1927

grips with three basic conceptual features of human mentality.

First, mental life and functionality develop gradually. They occupy no single spot in the brain. And they form a push-and-pull web of influences rather than a falling-domino chain of causation.

Second, human mental life depends, crucially, on structuring to keep concepts from blending together like a summer drink. Structuring makes complex sentences possible, such as “I think I saw him leave to go home,” in which three sentences nest inside a fourth, like Russian dolls. Structuring enables people to test out chains of logic, enjoy complex music, play games with rules, make contingent plans for the weekend.

Third, and probably most difficult, it

quality, editing them into a more coherent sentence in a second or two, before you finally decide to go with it.

How did the human animal ever acquire such features of mind? The only relevant process known in nature is Darwin’s variation and selection. Of course, one can see the Darwinian process at work on a grand time scale, in the evolution of new species. But one also sees its results after any flu shot, in the response of the body’s immune system to the challenge of the vaccine, creating better and better antibodies. The Darwinian process is the foundation of biology, without which nothing makes much sense (yet many parents do not wish their children to hear about it). Biologists are just beginning to explore how the brain could apply natural selection to

the memories it stores in order to improve the quality of, say, a verbal performance—and do it all in the few instants between an incoherent thought and a structured utterance.

Soul Made Flesh provides an account of the first big steps toward an understanding of how the brain makes mind. Zimmer, a science writer and the author of *Evolution: The Triumph of an Idea*, the companion volume to the eight-hour PBS television series of the same name, has written a fine intellectual history of early neuroscience. It is full of drama, and it brings to life the struggles for insight that begin in William Harvey's time with the flowering of physiology.

Most of us regularly fail to distinguish how from why, a process from an object, distributed from pointlike, structured from simple, gradual ramp-ups from sudden beginnings. Scientists, in the course of centuries of investigation, have made all those mistakes; but they also, eventually, corrected them. We still eagerly compete to discover our present misconceptions, one of the things that makes doing science so different from other endeavors.

One long-since-corrected but persistent misconception, at least among nonscientists, is that "science says" genes determine behavior and destiny. If you share that misconception, you probably need to read *The Birth of the Mind*.

The real story, as Marcus is at pains to emphasize, is about the flexible interactions between genes and the ways the brain is wired up, then subsequently between experiences and how genes are expressed in the brain. What emerges from those interactions are behavioral propensities that allow for an ever-widening set of choices, not "fate." "A brain built by pure blueprint," Marcus writes, "would be at a loss if the slightest thing went wrong; a brain that is built by individual cells following self-regulating recipes has the freedom to adapt."

Marcus, a psychology professor at New York University and the author

of *The Algebraic Mind: Integrating Connectionism and Cognitive Science*, neatly explains why genes are less like blueprints and more like recipes. A blueprint has point-to-point correspondences between plan and construct. A recipe often shows no such correspondence: indeed, what comes out of the oven is often impossible to reconcile with its list of ingredients. Similarly, Marcus explains, there is seldom a sin-

*The little person
or soul causes endless
confusion in reasoning
about abortion.*

gle gene for the variable aspects of the body, such as eye color. Instead a gene is usually part of a committee of genes in which some push while others pull to help control a process.

Marcus also explains how genetic variations change the receptors sticking out from the surface of a so-called pathfinder cell. During embryonic development those variations can give rise to alternative "wiring diagrams" of brain tissue, which, in turn, promote some behaviors more than others. Finally, in considering the prospects for genetically modified humans, Marcus squarely faces the problem of unintended consequences. Soon, he notes, geneticists will be able to synthesize "whatever genes we like." But, he warns:

For many years it will be difficult, if not impossible, to gauge the potential side effects of a given [gene] manipulation in advance. I can live with a buggy beta-test version of a new software package, but I don't want to have to restart my child.

The fate of the soul, I suspect, is to be reinvented again and again. That's because one nonessential aspect of it—that little person inside—is a beginner's error. Even today, when higher education provides a much better explanation for the

emergence of persons and their roles and responsibilities toward one another in a society, the old version survives, because it is so easily reinvented by each succeeding generation.

The problem is serious because relying on the "little person" concept may force us to devalue things people might want to retain. Some optional add-ons to the soul (which vary around the world) include: comforting the bereaved or downtrodden, intimidating a misbehaving child, proselytizing, reaching for the greater meaning of self and life. Many are invaluable appeals to kindness or long-term individual responsibility that could readily stand on their own. The ghostly prop (the "little person," the soul) carries a danger with it: when a historic or scientific analysis casts doubt on "the little person within," some will throw out the baby with the bathwater and turn away from the valuable teachings.

Yet a stripped-down concept of soul might continue to stand for the uniqueness that different genes, in conjunction with different formative experiences and different personal decisions, confer on each individual. While the term "individual" might suffice, the term "soul" might better connote human foresight, ethics, and sense of responsibility, the personal track record and outlook on life that should matter to each of us. All those ideas are well worth emphasizing, no matter what one's religious tradition or beliefs about an afterlife.

Once on the right track, science is pretty good at turning the crank. The coming decades will likely see a revolution in our thinking about how one cell slowly becomes a real person, gradually able to comprehend life's great journey.

WILLIAM H. CALVIN is the author of A Brief History of the Mind: From Apes to Intellect and Beyond (Oxford University Press, 2004). He won the Phi Beta Kappa book prize for his previous book, A Brain for All Seasons. He is a neurobiologist and an affiliate professor of psychiatry and behavioral sciences at the University of Washington in Seattle.

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***Against the Grain:
How Agriculture
Has Hijacked Civilization***

by Richard Manning
North Point Press, 2004; \$24.00

Don't get him wrong. Richard Manning, who lives on seventy acres of unspoiled land in western Montana, is not suggesting that mid-western farmers, not to mention the residents of New York City and Tok-



Thomas Hart Benton, *Wheat*, 1967

yo, abandon their homes and take to the woods, as he has. After all, his own grandfather was a successful farmer in northern Michigan.

What he wants to make clear, however, in this amiably grouchy and carefully crafted polemic, is just how much we have sacrificed with our reliance on agriculture. The abundance of food that accompanied the domestication of plants and animals thousands of years ago also led to a concentration of power unthinkable in nomadic societies. Slavery, poverty, and political oppression took root wherever there was fertile farmland; social inequity came, as it were, with the territory. Pharaohs and Aztec high priests feasted, while commoners, who suffered the ravages of war and despotism, were tied to the furrow and the farmyard or labored to build public monuments.

Social ills, however, were not the only price to be paid for human settlement. As Manning sees it, the transformation also represented a general lowering of the overall standard of living. Periodic famines punctuated times of plenty, and farmers could not pack up their tents in search of better harvests. Even when harvests were plentiful, domesticated grains, higher in energy than their wild counterparts and easier to consume when ground into soft gruel, made it possible to wean children earlier, and so populations grew explosively. Communicable diseases spread more quickly under crowded conditions, and, because farmers' diets depended too much on monoculture, deficiency diseases ran rampant. Pressed by population pressure, settlements spread to marginal lands, where conditions left people even more susceptible to illness. Virtually every malady, from malaria to tooth decay, could thrive in the new agricultural societies.

Manning makes a fundamental distinction between farming—growing food in small plots for local consumption—and large-scale agriculture, whose ultimate goal (whether in ancient Mesopotamia or in the modern global economy) is the accumulation of wealth. “I have come to think of agriculture not as farming, but as a dangerous and consuming beast of a social system,” he writes. In its most recent incarnation—as a mechanized, chemical-driven system of industrial-scale commodity growing—it has taken on a particularly demonic form, for it requires an energy-intensive and heavily subsidized infrastructure to sustain it.

Having run out of arable land, farming in effect began to claim oil fields, steel mines, phosphate mines, and the network of gravel, steel, and asphalt needed to connect them. Once farming ran out of arable land to devour, it started in on the rest.

Insatiable and immensely powerful global agribusinesses such as Cargill, Inc., and Archer Daniels Midland Company now exercise enormous leverage on what we eat (processed grains), what we drink (high-fructose corn syrup), and what we use to fuel our cars (farm states are heavily promoting the use of gasohol).

Although he's a forceful advocate of small, organically run farms, Manning is no romantic utopian, and he doesn't see a practical cure-all for the predicament he defines so incisively. Take time off to hunt, he suggests—whether that means using a rifle to fill your freezer with deer meat or searching local farmers' markets for the best-tasting fresh tomatoes and free-range chickens. Agriculture, after ten millennia, is here to stay, but maybe we can find a way to live the good life in spite of it.

***A Pirate of Exquisite Mind—
Explorer, Naturalist, and Buccaneer:
The Life of William Dampier***

by Diana and Michael Preston
Walker & Company, 2004; \$27.00

Piracy—both buccaneering and privateering—was a viable career choice in seventeenth-century England for young men such as William Dampier. With mercantile expansionism at its peak, the ships and colonies of Spain and France could be judged not as honest business enterprises but as legitimate targets in an economic war. To those with adventurous souls but little tolerance for military discipline, shipping out with a crew of marauders was an attractive option. Many crews even practiced a form of participatory democracy, electing their captains and apportioning their sometimes considerable booty by common consent. True, the life of a pirate might be a trifle risky and a bit unsavory, but it appealed to the same sort of entrepreneurial character who, two hundred years later, might have felt at home in the boiler room of a

powerhouse brokerage, or the office of a start-up dot-com.

Even so, Dampier was hardly your run-of-the-mill cutthroat, dreaming only of Spanish gold. In two decades of cruising the Caribbean and the Pacific—even during shipwrecks and in the midst of fierce exchanges of cannon fire—he was never without his pen and his journals. Steamy jungles and mangrove swamps, sources of misery to his shipmates, to him were wonderlands of exotic plants and animals. While ashore, he savored unusual foods with the locals and carefully described their methods of building, hunting, and dress. While at sea, he sketched the coastlines, reckoned distances between landmarks, and carefully observed the winds and the tides. He had, if not the training, the mind and the soul of a great naturalist.

Had Dampier remained an errant adventurer all his life, no one might have known of his brilliant powers of observation. But when he returned to England, in 1691, he set to work preparing an account of his exploits. The resulting book, *A New Voyage Round the World*, handsomely illustrated with maps and drawings, was published in London in 1697, and a sequel appeared two years later.

Written as engaging narratives, Dampier's books were immediate best sellers, combining eloquent descriptions with colorful impressions. "The armadillo," he wrote,

is enclosed in a thick shell, which guards all its back. . . . The head is small with a nose like a pig, a pretty long neck, and [the animal] can put out its head before its body when it walks; but on any danger she puts it under the shell, and drawing in her feet she lies stock-still like a land-turtle. And though you toss her about she will not move herself.

For the record, he added, "the flesh is very sweet and tastes much like a land-turtle."

Dampier's books, and his later accounts of his travels as a bona fide

explorer (he made two more trips around the world after the publication of his first two books), were as scientifically substantial as they were entertaining. He was the first Englishman to explore Australia, and he had the finest knowledge of ocean currents and wind patterns of anyone of his day.

The *Oxford English Dictionary* cites Dampier as the source of more than a thousand English words, many of them related to food: *avocado*, *barbecue*, and *cashew* begin the Dampier ABCs. Captain James Cook read Dampier during his travels in the late 1700s, as did Alexander von Humboldt and Charles Darwin in the 1800s. Dampier's "exquisite mind," the epithet Samuel Taylor Coleridge recorded in his book of essays *The Table Talk and*



William Dampier, on a voyage in the western Pacific, March, 1700 (from an illustration by Alec Ball, 1912)

Omniiana, provided the title for Diana and Michael Preston's new biography.

These days Cook, Darwin, and Humboldt are all well-known figures, but Dampier's fame, for some reason, seems to have faded. The Prestons, accordingly, have interwoven accounts of contemporary travelers into Dampier's story, to provide the modern reader with a fuller account of his career.

Yet Dampier's driving spirit remains a mystery. He spent so much of his life away from home that virtually all we know of him as a person is what we read in his books. Even though Diana and Michael Preston have not unearthed any remarkable new insights about Dampier the man, their appreciative biography may revive an interest in Dampier the writer. Perhaps then, another generation will read his travel books with renewed amazement and admiration.

*The Secret Life of Lobsters:
How Fishermen and Scientists
Are Unraveling the Mysteries
of Our Favorite Crustacean*

by Trevor Corson
HarperCollins, 2004; \$24.95

It takes about eight seconds for a pair of lobsters to copulate; it takes a lot longer to get them into the mood.

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It's a bit of a gamble; the male is usually a little testy from all the unsolicited attention, and a careless claw stroke to a shell-less midriff can be fatal. At this point, a little perfume is always a turn-on, so the female secretes a powerful pheromone to set the mood, and, presto! the male becomes a crustacean Cary Grant, caressing the soft body of the female with his long antennae.

If all goes well, the male lobster soon embraces his mate firmly, assumes a posture suggestive of the missionary position, and deposits his sperm inside an egg receptacle near her tail. Finally, because it is customary to have a little

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postcoital snack, the male and female discreetly nibble a few bites of her discarded shell. It's the "lobster equivalent," science journalist Trevor Corson quips, "of edible underwear."

Corson spent two years as a hand on a lobster boat, and he has now constructed a book that cuts almost cinematically between intimate scenes of lobsters doing their stuff and scenes of people in lobster boats and research vessels. His protagonists include the tight-knit population of Little Cranberry Island in Maine, where families carry on a fishing tradition that goes back a hundred years. Although the classic lobster traps haven't changed much over the generations, the boats now carry a GPS plotter, computerized depth sounder, and high-tech radar.

Often laboring alongside the fishermen—sometimes as allies and sometimes as antagonists—are marine scientists, many of them headquartered in Woods Hole, on Cape Cod. Their tools, no less high-tech than the lobstermen's, range from remote-controlled minisubs to infrared video-recorders operated from onshore labs.

Corson's account describes how, in the past thirty years, fishermen and marine scientists have arrived at a firmer knowledge of where and when lobsters mate, how they move from place to place, and what environmental variables affect their reproductive and survival rates. Along the way he gives an authentic feel for the lives of fishing families in Maine.

Fishermen and marine scientists share a common interest in the sex life of lobsters because maintaining a healthy breeding population is essential to maintaining a healthy lobster fishery. And that is important, of course, not only to the small population of New England lobstermen, but also to

the millions of people worldwide who view lobster meat as a gift of the sea.

Even so, a book like this could be a pretty dull litany of facts were it not for Corson's gift for delivering insights through moving, human narrative. The courting, fighting, and survival behavior of lobsters is so smoothly intertwined with episodes of courting, fighting, and survival behavior among the fishermen and scientists that it is almost impossible to stop reading his book until one runs out of pages.

Admirers of Verlyn Klinkenborg or John McPhee will recognize Corson's voice as that of a skillful practitioner of a style one might call "occupational



Lobsterman with traps (Evelyn Carlson, *Fingers Weary and Worn*, 1983)

documentary"—science writing in which the interaction between nature and people is the central theme. I hope that the fishermen and scientists who are profiled this way feel well served, because, speaking only as a lobster eater, I can highly recommend the book as one of the best things you can enjoy without melted butter. Spend a day at the beach with it and then feast on its chief protagonist, *Homarus americanus*; a great recipe is provided at the end of the last chapter.

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.

Animals By Ear

By Robert Anderson

An avid birder recently invited me to join him on a spring walk. His ability to rattle off the names of the species flitting through the scrub was uncanny. "Because my vision is so poor," he told me, "I can barely see them, so I've trained myself instead to recognize them primarily by song." I was so impressed that when I got home, I turned to the Internet to learn more.

A quick search turned up a site dedicated to birdsong ID (virtualbirder.com/bbestu), compiled by Dick Walton, a naturalist and author of a birder's field guide. I found one of the most comprehensive collections of birdsong recordings at the Web site of the Cornell Lab of Ornithology (www.birds.cornell.edu/programs/AllAboutBirds/BirdGuide). You can choose from a long list of species, from Acadian flycatchers to yellow-throated vireos. Song recordings are available for each bird, along with information about how to identify the bird in the wild.

Tony Phillips, a mathematician at Stony Brook University in New York, maintains a site highlighting the calls and songs of birds from New York State (math.sunysb.edu/~tony/birds). Click on the map of the world in the center of the page, enclosed by the hypertext "Links to other bird-song sites," to connect to sites with recordings of birds from around the globe.

Among the other features on Phillips's fascinating site is "Bird songs in musical notation." A link brings you to an informative introduction, followed by a list of six birds whose sounds are represented as sonograms and in musical notation; you can hear the notes played and the actual bird-song as well. For more about the topic, read about the New England naturalist E. Schuyler Mathews, who set down musical notation for the songs of birds

in eastern North America in 1904 (www.npr.org/features/feature.php?wfId=1783346.html).

Listening to recorded birdsong is only one of many ways on the Internet to tune in to real animal voices. If you miss this year's live performance of the seventeen-year cicada [see "The Natural Moment," by Erin Espelie, page 6], you can find a recorded version at the University of Michigan Museum of Zoology's Periodical Cicada Page (insects.ummz.lsa.umich.edu/fauna/michigan_cicadas/Periodical/Index.html).

As the weather heats up this summer, frog song may be as easy to hear as bird warbling. One useful site provides a long list of amphibian audio clips, plus an amusing inventory of some onomatopoeic names from around the world for the characteristic amphibian sound (allaboutfrogs.org/weird/general/songs.html). (In Sweden, for instance, a frog goes "kvack.")

And for recordings from a veritable Noah's Ark of animals—from the American alligator to the zebra scaly cricket—you can scroll through a remarkably long list of links, compiled by an apparently anonymous nature lover (members.tripod.com/Thryomanes/AnimalSounds.html).

Additional insect sounds can be found at an Iowa State University site (www.ent.iastate.edu/list/insect_sounds.html). Of particular interest there is a link to "Bug Bytes," where Richard W. Mankin, an entomologist with the U.S. Department of Agriculture, demonstrates how he and his colleagues are using sound to monitor insect pests (select "Digitized Sounds of Insect Movement, Feeding, and Communication," or go directly to cmave.usda.ufl.edu/~rmankin/soundlibrary.html).

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

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A Desert No More

Astronomers have finally learned how to see the hidden galaxies in a murky epoch of ancient cosmic history.

By Charles Liu

If a galaxy glows, but no astronomer notices, does it give off light? This celestial version of the classic tree-falling-in-the-forest conundrum comes to mind whenever I think about the “redshift desert.” As its name implies, the desert is a zone of the cosmos where, after decades of

Here’s how redshift works—schematically, anyway. As Edwin Hubble demonstrated more than seventy years ago, the universe has been expanding since the beginning of time. Now imagine a beam of light traveling from one spot in the universe to another. As the light beam travels through an ever-

One of the grandest challenges in observational cosmology today is to catch the superfaint light from distant sources and decipher the early history of the universe.

searching, astronomers had found almost no galaxies—even though it seemed that there should have been lots of them. Now, thanks to the work of a research team led by Charles C. Steidel at the California Institute of Technology in Pasadena, there’s proof that the zone isn’t a desert at all: the galaxies have been there all along, but no one could identify them. Before I get too far ahead of myself, though, here’s a brief—okay, very brief—history of cosmic time, and how astronomers measure it.

Geological sampling puts the age of Earth at 4.56 billion years. Stellar data indicate our Sun is slightly older—about 4.7 billion years old. But what about the universe? It is more than 13 billion years old, so it was already fully mature when the Sun and Earth were born. How were astronomers able to determine its age? The answer is, we measured it with the cosmically appropriate timekeeper—redshift.

expanding space, it gets “stretched” along with space. The farther it travels, the more the beam is stretched, and so the longer its wavelength becomes. An increase in wavelength is equivalent, at least for visible radiation, to a change in color, according to the familiar order of the rainbow: violet has the shortest visible wavelength, followed by indigo, blue, green, yellow, orange, and, finally, the longest visible wavelength, red. So light emitted from a very distant source—it needs to be millions of light-years away for the effect to be noticeable—gets shifted in color toward the red end of the spectrum. Hence the name: redshift.

In spite of its name, however, “redshift” also happens to electromagnetic radiation that is outside the visible part of the electromagnetic spectrum. Ultraviolet light, for instance, which has shorter wavelengths than visible light, can be redshifted into the visible window; visible light, in turn, can be red-

shifted into the infrared part of the spectrum, which people feel as radiant heat. By measuring the amount of redshift in the light from a distant source (usually a galaxy or a quasar), astronomers can deduce how long that light has been traveling—and thus, how old the source is, compared to the time elapsed since the big bang.

Astronomers quantify redshift with a number, commonly denoted by the letter z . For light that’s not redshifted at all, z is zero. Light for which z is one began its journey to Earth when the expanding universe was just half its current size; light for which z is two left its source when the universe was a third its current size; for z equal to three, the universe was a quarter its current size; and so on. For reference, z is infinite for light from the big bang,

if we could see it at all. The cosmic microwave background [see “Sharper Focus,” by Charles Liu, May 2003] appeared early enough for its value of z to be about 1,100; the light of the first stars departed sometime

corresponding to z values between twenty and ten.

Not surprisingly, then, one of the grandest challenges in observational cosmology today is to search for light from those ancient sources, superfaint and super-redshifted, and to decipher the early history of the universe from such cosmological fossils.

Nearer at hand, though, there’s another problem. To measure redshift you need markers in the spectrum of a distant light source to calibrate the “starting point” for the redshifted light—its color when it was first emitted. Those markers are recognizable patterns of bright and dark spectral features. The most prominent of those features, which serve as benchmarks, occur only at a few specific unredshifted, or “rest,” wavelengths.

Here on Earth, a number of effects—primarily atmospheric obscuration and technological limitations—have historically made those strong

spectral lines all but undetectable for values of z between about 1.4 and 2.0. At those redshifts, the strong lines with rest wavelengths in the visible part of the spectrum shift so far redward that they become infrared light, and get blocked by Earth's atmosphere; meanwhile, the strong lines with ultraviolet rest wavelengths aren't shifted far enough toward the visible-light portion of the electromagnetic spectrum, so they're still not detectable with the electronic cameras that astronomers use.

Since the 1980s astronomers have pushed their instruments—and the design of their experiments—to the limits to study the void in the cosmic historical record, with some success but without major breakthroughs. In their multiyear bid to break into that void, Steidel and his collaborators employed new instrumentation on the ten-meter Keck I telescope on Mauna Kea, Hawai'i, to measure the light of hundreds of faint galaxies in the near-ultraviolet. In addition, they compared their observations with the output of detailed computer models of the spectral-line patterns they expected galaxies in the redshift desert to emit. Their painstaking work reveals what many astronomers suspected but, until now, could never prove: the redshift desert is a mirage. Not only is it empty, it's just as dense with galaxies as any other era in the history of the universe.

Alas, as cosmologically pure and beautiful as it may be to keep time in

units of redshift alone, we astronomers must still (grudgingly!) convert redshift into Earth years, if cosmic history is to be relevant to our Earthbound existence. It's a complicated and inexact conversion, but it's accurate enough to say that z values between 1.4 and 2.0 correspond to cosmic history between about 9 billion and 11 billion years ago. In short, that epoch is, at last, now officially open for study. And that's good news indeed: the Milky Way galaxy formed during the period, and so now we know that,

when our galactic home was born, it wasn't an infant alone in a desert, but a baby surrounded by a thriving community of galaxies.

It's not that these galaxies were once lost, but now are found. Rather we astronomers were once blind to them—but now, thanks to creative scientists and improved techniques, we see.

CHARLES LIU is a professor of astrophysics at the City University of New York and an associate at the American Museum of Natural History.

Answer to "Cryptic Creatures" puzzle (page 17): d



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Mercury is obscured throughout June by the glare of the Sun. Superior conjunction, the configuration in which Mercury is behind the Sun from the perspective of Earth, takes place on the 18th.

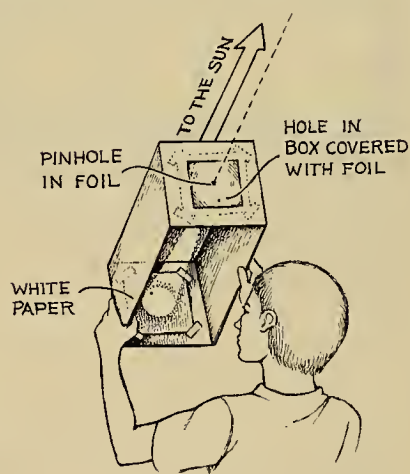
Venus is close to the western horizon at sunset at the beginning of June, and the planet may become more difficult to see with each passing evening. In a telescope or through good binoculars, Venus appears as a large but very thin crescent, before it sinks into the fires of sunset. On June 8 Venus reaches inferior conjunction and crosses, or transits, directly between the Earth and the Sun, appearing in silhouette on the solar disc [see "*A Transit of Venus*," by Eli Maor, page 34]. During the eighteenth and nineteenth centuries, a transit of Venus was a key observation for astronomers seeking to determine the distance of the Earth from the Sun. Transits of Venus, moreover, are rare events: the last one took place on December 6, 1882.

The beginning of the transit will be visible from parts of northern and western Alaska, all of Asia, Indonesia and Australia, the eastern half of Africa, and northern and eastern Europe, as well as from the northernmost parts of Greenland. The end will be visible over central and western Asia and all of Africa, Europe, and Greenland, as well as from the northernmost and eastern areas of North America and parts of northern and eastern South America.

In the contiguous United States viewing opportunities are limited. To the east of a line running roughly from Havre, Montana, to Galveston, Texas, Venus is already on the Sun's disk at sunrise on the 8th; in fact, for all but the most easterly locations, the transit is nearly over by sunup. To the west of that line the transit ends

before sunrise. The disc of Venus begins to move off that of the Sun within a minute of 7:05 A.M. Eastern daylight time (EDT). The last bit of the disc of Venus leaves the Sun at 7:26 A.M. EDT.

Transits of Venus are visible with the unaided eye; the planet appears as a distinct, albeit small, black spot with a diameter one-thirty-second that of the Sun. But anyone planning to watch the transit must be



A pinhole camera obscura makes a safe tool with which to view the transit of Venus. See text below for instructions for this and other viewing methods. Never look directly at the Sun.

aware of the risk of permanent damage to the eyes, and take the same special precautions needed to view a solar eclipse.

It is **not safe** to view the transit through sunglasses or smoked glass. Instead, use at least a number 13 welder's glass to look at the Sun—available for just a few dollars at most hardware stores and welders' supply shops. The safest method of all is to project the Sun's image through a small pinhole poked through one end of a shoe box, then view the image that is projected onto the in-

side surface of the end of the shoe box opposite the pinhole [see diagram on this page]. A dark dot—the image of Venus—will be clearly visible against a bright circle—the image of the solar disk.

During the second half of June, Venus begins to reappear low in the eastern sky at dawn. It will climb higher each morning and will leap into brilliant prominence as a morning "star" during July.

Early in June **Mars** sets in the west-northwest about half an hour after darkness falls. But by the 30th, the planet, shining at magnitude 1.8 all month, is setting half an hour before evening twilight fades to dark, making it difficult to see.

In the first week of June **Jupiter** replaces Venus as the evening "star" in the west at dusk. Jupiter is in the constellation Leo, the lion, between 10 and 13 degrees to the east of the star Regulus, which is roughly one-twenty-third as bright.

The best views of **Saturn** can be had in the first week of June. On the 1st it sets slightly more than two hours after the Sun; look for it close to the west-northwestern horizon as darkness falls. By the 15th, though, it has all but disappeared into the sunset glow, as it heads toward conjunction with the Sun in July.

The **Moon** waxes full on the 3rd at 12:20 A.M. EDT. It wanes to last quarter on the 9th at 4:02 P.M. EDT and becomes new on the 17th at 4:27 P.M. EDT. It waxes to first quarter on the 25th at 3:08 P.M. EDT.

The solstice takes place on June 20 at 8:57 P.M. EDT. Summer begins in the Northern Hemisphere, winter in the Southern.

astronauts are needed to explore the solar system because preprogrammed robots cannot react to the unexpected ("Launching the Right Stuff," 4/04). But this argument overlooks the intimate synergy between remote robots and their human controllers on Earth. A robot on Mars, say, typically sends an image back to a large interdisciplinary team of scientists, and the people then tell the robot what to do next. With months or years to work interactively in this way, the delay of a few minutes between messages is no problem. And the controllers can reprogram the robot to meet changing conditions.

The idea that people have to explore the solar

system is a quaint holdover from the nineteenth-century world of Jules Verne, when no one could imagine any other way to do it. We've now wasted thirty years and stupendous sums so astronauts could orbit the Earth a hundred thousand times. For a small fraction of that cost, we could have sent more and better robots to return samples and IMAX-quality images from the surfaces of every planet and large moon in the solar system.

If robot explorers ever discover compelling reasons for us to send people to other planets, then we can do it.

Steven Soter
American Museum of Natural History
New York, New York

Tanks But No Tanks

The caption to a picture in Zainab Bahrani's excellent article ("Lawless in Mesopotamia," 3/04) identifies the vehicle standing guard at an entrance to the Iraq Museum as a "U.S. tank." The vehicle is in fact an M-109A6 155mm self-propelled howitzer.

In military parlance, a tank is a heavily armored vehicle for attacking enemy tanks, other enemy vehicles, and enemy personnel. The maximum effective range of the main tank gun is less than two miles. The gunner virtually always sees the target directly through the gunsight or other sighting devices.

A howitzer is a field artillery piece, used primarily to attack enemy personnel,

fortifications, and artillery emplacements. Howitzers can be self-propelled or towed by a truck; the self-propelled howitzer is lightly armored. Normally the gunner does not see the target directly; the howitzer is aimed for direction and distance using data provided by a fire direction center. The maximum effective range is approximately eleven miles.

Clay Smith
Lieutenant Colonel
U.S. Army (Retired)
Alexandria, Virginia

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At the Museum

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Amphibian Alert!

Frogs live almost everywhere—from tropical forests to frozen tundra to scorching deserts. This summer, hundreds of them will be taking up temporary residence at the American Museum of Natural History. Opening May 29, *Frogs: A Chorus of Colors* will showcase approximately 25 spectacular, vividly colored frog species from around the world in re-created habitats complete with rock ledges, live plants, and waterfalls. The exhibition explores the biology of these popular amphibians, their importance to ecosystems, and the threats they face in the world's changing environments.

Frogs have filled the night with croaks, yaps, grunts, chirps, trills, and warbles since the Age of Dinosaurs; some can be heard from a mile away. Frogs also sport an amazing range of colors, shapes, and sizes: many are more vibrantly tinted than the most dazzling birds, and the largest can grow to the size of a human infant.

Among the fantastic frogs you might see in this exhibition are the dinner plate-sized African bullfrog; the dumpy tree frog that can climb trees and hang from a branch by one toe; the fire-bellied toad that throws its legs into the air to show a bright red underside when it is disturbed; the dart poison

frogs, some of which are among the most toxic animals on Earth, containing enough poison to kill ten people (or 20,000 mice); the African clawed frog that looks as though it was flattened in a traffic accident; the Chinese gliding frog whose webbed

an inch.) How many eggs does a frog lay? (From as few as one to as many as thirty thousand, for those that lay eggs—some frogs give live birth.) Do some frogs eat birds? (Yes indeed.)

Some frogs' skin is covered with a cocktail of protective

phine—and non-addictive. Chemists are working to perfect a less toxic version of the drug.

Frogs are perhaps the world's most adaptable denizens. There are more than 4,000 species of them, and they live on every continent except Antarctica. But over the past 50 years, scientists have recorded precipitous declines in frog populations, with some species vanishing completely. Frogs are delicate creatures, and are often the first casualties when pollution or human activity affects a habitat, making them important barometers of environmental change and giving an early warning for endangered ecosystems. Many frogs are also useful in other fields of scientific study: their transparent eggs offer embryologists a chance to watch single cells grow into wriggling tadpoles, and scientists have also used frogs to study muscle function, perform pregnancy tests, and experiment with cloning—the first frog was cloned 30 years before Dolly the sheep.

Frogs: A Chorus of Colors is presented with appreciation to Clyde Peeling's Reptiland.

Left column top to bottom: Dyeing poison frog; golden poison frog; fire-bellied toad; golden mantella frog; smooth-sided toad. Right column: (top) blue dart poison frog; (bottom) ornate horned frog



Vietnamese mossy frog

toes act like a parachute; and the smoky jungle frog that squawks like a chicken. Also see fishlike tadpoles that will later metamorphose into American bullfrogs, sprouting legs and losing their tails.

The exhibition is rich in froggy facts. How do frogs drink? (Through the skin of their bellies.) What is the world's smallest frog? (The Cuban robber frog, which grows to a length of only half

an inch.) How many eggs does a frog lay? (From as few as one to as many as thirty thousand, for those that lay eggs—some frogs give live birth.) Do some frogs eat birds? (Yes indeed.) Some frogs' skin is covered with a cocktail of protective

toxins as a defense against predators, and many of these toxins are remarkably potent in the human body. Scientists study frog toxins for use in human medicine to treat such ailments as

Frogs: A Chorus of Colors

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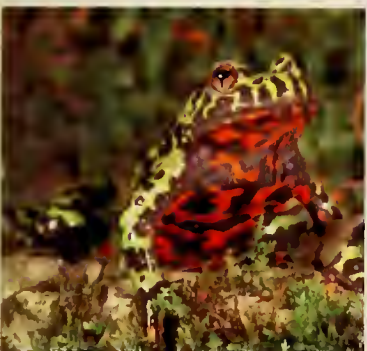
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PIOTR NASRECKI

Giant green sea anemone, *Anthopleura xanthogrammica*

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Exploratorium/AMNH is funded in part by a grant from the Small Business Administration. For information on accessibility, call 212-769-5100.

Petra: Lost City of Stone

Through July 6

This exhibition tells the story of a thriving metropolis

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In New York, *Petra: Lost City of Stone* is made possible by Banc of America Securities and Con Edison. The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Fiyal and of The Andrew W. Mellon Foundation. This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.

The Bedouin of Petra

Through July 6

Photojournalist Vivian Ronay's evocative color photographs document the Bedouin group of Bedouin tribes living near the archaeological site of Petra in Jordan.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

Seasons of Life and Land:

Arctic National Wildlife Refuge Through September 6

Stunning large-format color photographs by conservationist Subhankar Banerjee focus on the interdependence of land, water, wildlife, and humanity in Alaska's Arctic Refuge.

Art for Heart

Through September 26

Paintings by children who lost loved ones in the attacks on New York City's World Trade Center on February 26, 1993, and September 11, 2001, create a powerful and poignant memorial.

Project sponsored by the Lower Manhattan Development Corporation. Exhibition made possible through the generous support of White & Case LLP and Toys'R'Us.



Petra: Lost City of Stone

SUMMER SOLSTICE

The Science of the Sun

Sunday, 6/20

11:00 a.m.—1:30 p.m.

Sun-related activities for children of all ages.

Quillas

Sunday, 6/20, 2:00–3:00

or 4:30–5:30 p.m.

Ecuadorian troupe Quillas performs pieces from the traditional Quechua Festival of the Sun.

An Introduction to the Middle of the World

Sunday, 6/20, 3:15–4:15 p.m.

Gabriel Roldós Prösser of the Solar Culture Museum in Ecuador reveals surprising links between ancient and colonial sites at the “middle of the world.”

LECTURES

Why We Do It

Tuesday, 6/1, 7:00 p.m.

Niles Eldredge, Curator in the Museum's Division of Paleontology, challenges the almighty status of genes in evolution and human behavior. A book signing follows.

Frog Songs

Thursday, 6/10, 7:00 p.m.

Martha Tobias, Columbia University, discusses frog vocal behaviors and the evolution of song.

Digital People

Tuesday, 6/15, 7:00 p.m.

Sidney Perkowitz, Emory University, explores the role of artificial beings in science fiction and fantasy. A book signing follows.

An Alchemy of Mind
 Thursday, 6/17, 7:00 p.m.
 Diane Ackerman examines what it is about our brain that makes us quintessentially human. A book signing follows.

The Bounty:
The True Story of the Mutiny on the Bounty
 Thursday, 6/24, 7:00 p.m.
 Caroline Alexander shatters the centuries-old myths surrounding the story of William Bligh and Fletcher Christian. A book signing follows.

Extreme Frogs
 Tuesday, 6/29, 7:00 p.m.
 Join Michael Klemens, Metropolitan Conservation Alliance, to learn about frog evolution and current conservation efforts.

FAMILY AND CHILDREN'S PROGRAMS

Talking with Your Hands, Listening with Your Eyes
 Saturday, 6/12, 1:00 p.m.
 Children and adults will be introduced to American Sign Language.

Dr. Nebula's Laboratory: Light and Optics



Sunday, 6/13, 1:00–2:00 or 3:00–4:00 p.m. (Ages 4 and up, each child with one adult)
 Dr. Nebula's apprentice Scooter "illuminates" the mysteries of light and optics.

Earthly Adventures
 Saturday, 6/12, 12:30–2:00 p.m. (Ages 4–5, each child with one adult) or 3:00–4:30 p.m. (Ages 6–7)
 Explore earthquakes, tornadoes, and other forces of nature.

Frog Wire Sculptures
 Sunday, 6/13
 10:30–11:30 a.m. (Ages 5–7) or 12:30–1:30 p.m. (Ages 8–10)
 Create take-home crafts that capture the essence of frogs.

Tadpole to Frog Workshop
 Sunday, 6/20, 10:30 a.m.–12:00 noon (Ages 8–10)

Sunday, 6/27, 10:30 a.m.–12:00 noon (Ages 5–7, each child with one adult)
 Children learn about the metamorphosis of frogs.

HAYDEN PLANETARIUM PROGRAMS
TUESDAYS IN THE DOME
Virtual Universe:
The Grand Tour
 Tuesday, 6/1, 6:30–7:30 p.m.

This Just In . . .
June's Hot Topics
 Tuesday, 6/15, 6:30–7:30 p.m.

Celestial Highlights:
The Summer Sky
 Tuesday, 6/29, 6:30–7:30 p.m.

PLANETARIUM SHOWS
SonicVision
 Fridays and Saturdays, 7:30, 8:30, and 9:30 p.m.
 Hypnotic visuals and rhythms take viewers on an unforgettable ride through fantastical dreamscape.
 SonicVision is made possible by generous sponsorship and technology support from Sun Microsystems, Inc.

Passport to the Universe
 Narrated by Tom Hanks

The Search for Life: Are We Alone?
 Narrated by Harrison Ford
 Made possible through the generous support of Swiss Re.

LARGE-FORMAT FILMS
 LeFrak Theater
Volcanoes of the Deep Sea
 Explore Earth's most hostile environments and its strangest creatures, and consider the implications for our search for life.

Bugs!
 This live-action rain forest adventure follows the dramatic lives of a praying mantis and a graceful butterfly and ends with their inevitable encounter.

INFORMATION
 Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION
 Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org. A service charge may apply.

All programs are subject to change.

STARRY NIGHTS *Live Jazz*

Friday, 6/4
 5:30 and 7:00 p.m.
 Rose Center for Earth and Space

Harold Mabern Trio

Tune in to the 5:30 set live on WBGO Jazz 88, hosted by *Morning Jazz's* Gary Walker.

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsors CenterCare Health Plan, Constellation NewEnergy, and WNBC-TV.



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By Patricia J. Wynne



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