FOOD THE TRUTH ABOUT GMOs

OCTOBER 2014

NATIONAL GEOGRAPHIC

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MAPPING CALIFORNIA'S WATER

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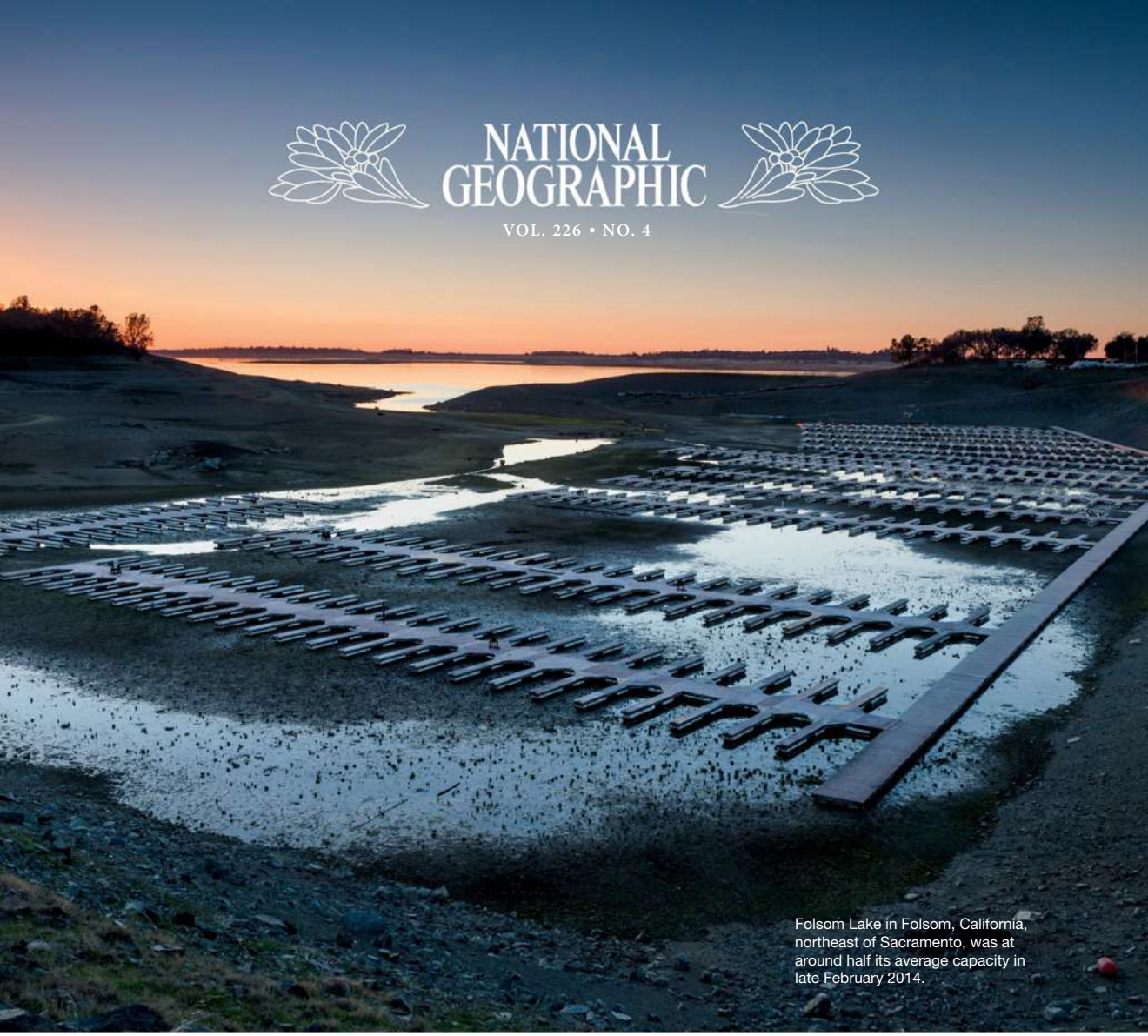
*Tested against upright market, dust loaded, using ASTM F608, ASTM F2607, IEC 60312-1 5.2, 5.9. Using competitor NPD sales volume data, MAT April 2014.

NATIONAL GEOGRAPHIC
VOL. 226 • NO. 4



Folsom Lake in Folsom, California, northeast of Sacramento, was at around half its average capacity in late February 2014.

October 2014

Departments

On the Cover With sharp, splayed teeth and a six-foot sail along its back, the *Spinosaurus* ruled the mid-Cretaceous in what is now northern Africa.

Photo by Mike Hettwer, assisted by Mark Thiessen, NGM Staff

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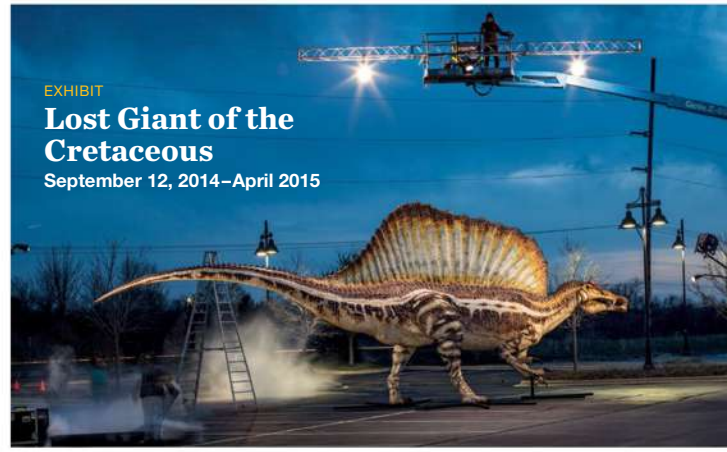

EXHIBIT

Lost Giant of the Cretaceous

September 12, 2014–April 2015

The 50-foot-long *Spinosaurus* (above) photographed for the cover will menace visitors to National Geographic's courtyard in Washington, D.C. (but a full-size skeleton of the dinosaur will stay inside the museum).

WORLD FOOD DAY

The Food and Agriculture Organization of the United Nations declared October 16 World Food Day to draw attention to hunger, malnutrition, food security, and agricultural development. Visit National Geographic's food blog, The Plate, at *theplate.nationalgeographic.com* for updates on this year's events.

NG BOOKS FOODS FOR HEALTH *Barton Seaver and P. K. Newby*

Discover the foods that have a high nutritional—and low environmental—impact in this science-based guide that will have you and your family shopping, cooking, and eating more sustainably. Find it wherever books are sold ($22.95).

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PHOTO: MIKE HETTWER. ART: ÁLVARO VALIÑO

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A Sign of the Dry Times

If you've ever heard of Modesto, California, a dusty agricultural town as unprepossessing as its Spanish name, it's likely because it is the place depicted by George Lucas in his 1973 blockbuster, *American Graffiti*.

Today Modesto's 200,000 residents are the stars of a different story: the unrelenting drought gripping the West. Modesto, like other parts of the Central Valley, is an agricultural paradise—when you water it—a vast, flat expanse, Michelle Nijhuis writes in this issue, where crops from grapes and tomatoes to almonds and oranges grow better than anywhere else in the country.

Modesto's arch was completed in 1912. The low-hanging Welcome sign was removed by 1913.

When you water it.

Which brings me to my second-favorite activity in Modesto—seeing the Modesto Arch. Standing 25 feet high, crossing the 75-foot expanse of I Street downtown, it was built in 1912 by the Modesto Business Men's Association and emblazoned with this slogan: "Water, Wealth, Contentment, Health." (This beat out the town's first choice, "Nobody's Got Modesto's Goat.")

There is no mistaking the order of the words. Water is the wellspring of the blessings that follow. Without water, there is nothing.

"You begin with water because water is synonymous with the creation of California," says Kevin Starr, University of Southern California professor and author of an eight-volume history of the state. The words on the arch, he says, are the "DNA code of the California dream."

Water, wealth, contentment, health.

Which brings me to my favorite activity in Modesto—visiting Aimee Peepgrass. She's a lively, funny 17-year-old who has struggled with cerebral palsy since the day she was born. Every September my husband and I attend a fund-raiser in a historic barn just outside Modesto—amid acres of the bounty for which the area is famous—to help defray Aimee's medical costs and pay for therapy that will allow her more independence.

Every year we visit Aimee. Every year we visit the arch. For Modesto I wish for water. For Aimee I wish for health.

Susan Goldberg, *Editor in Chief*

POSTCARD COURTESY McHENRY MUSEUM

Southern Pig-tailed Macaque *(Macaca nemestrina)*
Size: Head and body length, females average 45.3 cm (17.8 inches) and males 52.6 cm (20.7 inches) ; tail, females average 17.5 cm (6.9 inches) and males 21.3 cm (8.4 inches) **Weight:** Females average 5.4 kg (11.9 lbs) and males 8.8 kg (19.4 lbs) **Habitat:** Occurs at highest densities in lowland and hill dipterocarp rainforests **Surviving number:** Unknown

Photographed by Fiona Rogers

WILDLIFE AS CANON SEES IT

Worlds collide. As their habitat is lost to human encroachment, southern pig-tailed macaques are increasingly coming into conflict over crops. They view rainstorms as opportunities to raid crops, knowing farmers will likely be inside. Troops designate one individual to stand guard and give the alarm if people do appear. Their home ranges are large, and the macaques seldom stay in one place for long; as they move through the trees they keep in touch with low vocalizations. But the world as they know it is in grave danger due to habitat loss, hunting and capture.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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NATIONAL GEOGRAPHIC

Inspiring people to care about the planet

The National Geographic Society is chartered in Washington, D.C., as a nonprofit scientific and educational organization "for the increase and diffusion of geographic knowledge."

“A shower of light . . .”

“A connection to everything and everyone . . .”

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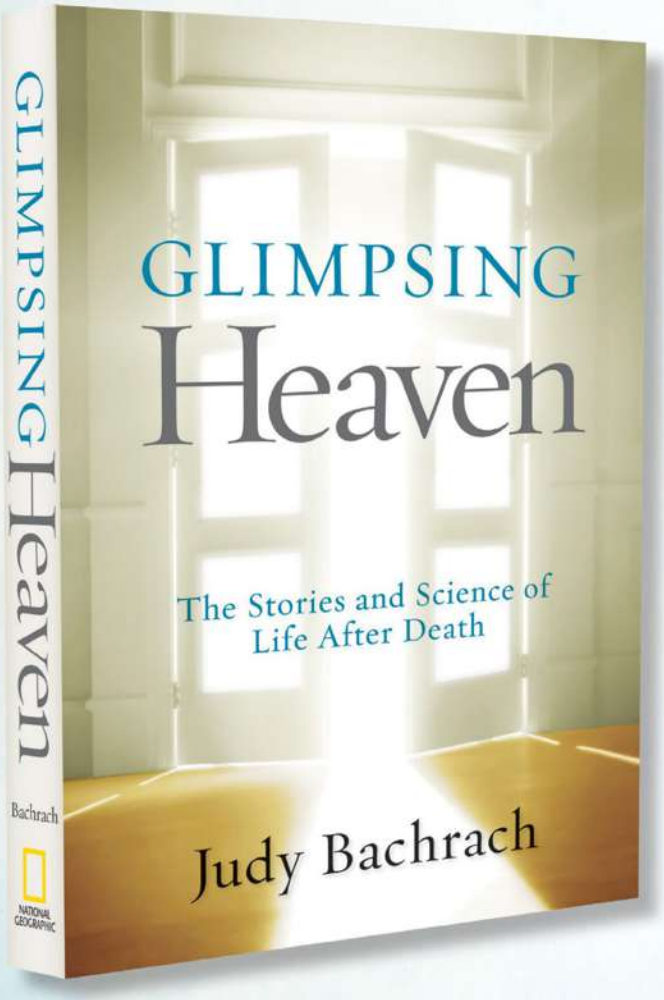

If you caught a glimpse of heaven, would you choose to come back to life? Many people alive today have experienced clinical death—a heart that has stopped beating, brain activity that has flat lined—and returned to life with lucid, vivid memories of what occurred while they were dead. Judy Bachrach, investigative journalist and contributing editor at *Vanity Fair,* presents their astonishing stories here, giving us a rare glimpse of life after death. She consulted the world's leading scientific and medical experts on death experience to explore whether the science supports the stories—and now, in *Glimpsing Heaven,* her surprising discovery puts death in a whole new light.

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Why I Bought the Magna Carta

David Rubenstein, 65, the Baltimore-born co-founder of the private-equity firm the Carlyle Group, practices what he calls patriotic philanthropy. Among his efforts: buying an original 1297 Magna Carta, an Emancipation Proclamation, and a Declaration of Independence for public display. He also gave $7.5 million to fix the earthquake-damaged Washington Monument.

WHAT IS THE MOTIVATION FOR YOUR GIVING?
"Philanthropy" comes from an ancient Greek word that means "loving humanity." It doesn't have to mean writing checks. I have more money than I really need, so I am giving it away to places that were good to me, or to good causes. Most of my money actually goes to education or medical research. I like to say that if you have a last name like mine and your father was a postal worker, you might not rise up in every country. Well, I got very lucky, and now I'm trying to give back.

WHAT IS PATRIOTIC PHILANTHROPY?
The word "patriotic" has been hijacked a bit lately. My idea of patriotism is to buy these documents of freedom, help restore them, then ultimately give them to the American people. They can go to the National Archives now to see the Magna Carta and feel comfortable that it's always going to be there. Then I realized I could also restore places related to our heritage.

WHY DOESN'T THE GOVERNMENT HANDLE THESE THINGS?
Not many people think about giving money back to something connected to the federal government, because the government is always thought to have money to fix the Washington Monument or the Kennedy Center. But in fact it doesn't have as much money as it used to. I would like to inspire others—not just the wealthy—to help the country. I'd like younger people to say, "I don't have a lot of money, but I'll give energy or time."

PHOTO: REBECCA HALE, NGM STAFF

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150 years

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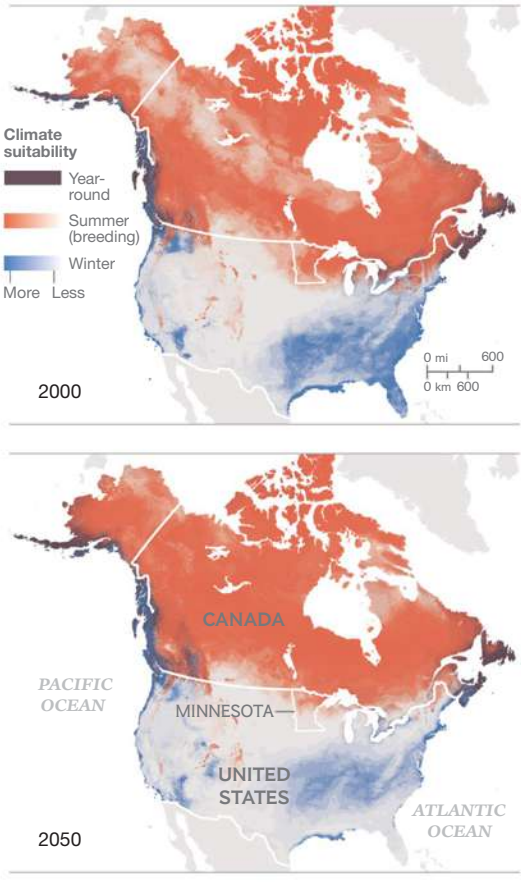
Wild Things

THE COMMON LOON is the state bird of Minnesota, but the Land of 10,000 Lakes may echo with fewer of its distinctive calls. Instead, Canada's climate could be more suitable. The loon's summer range could expand north, but only if it can find the habitat—especially lakes—that it needs to flourish.



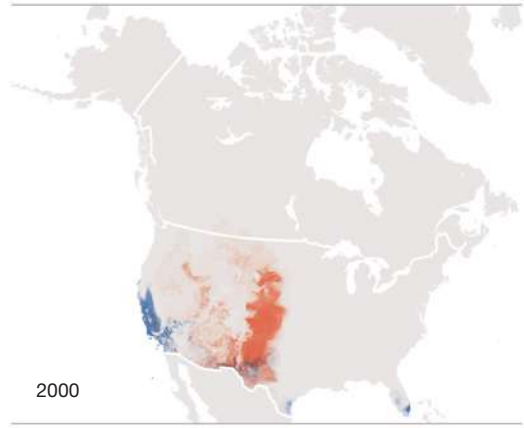
Caged by Climate

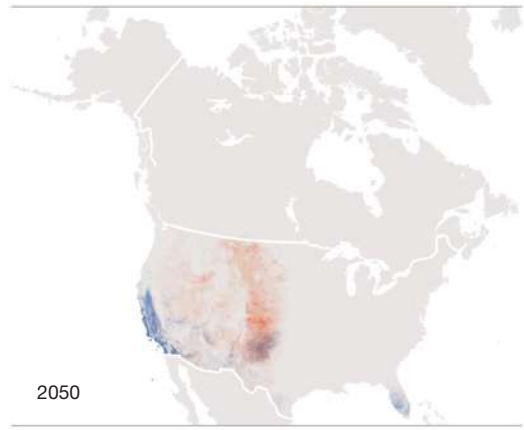
Climate change will force 314 bird species out of most of their current ranges by the end of the century, according to a new study from the National Audubon Society, which focused on birds in the continental United States and Canada. Nearly 200 of the threatened species may find hospitable climatic conditions elsewhere—with the right temperatures, precipitation, and seasonal fluctuations—but for 126 species there will be nowhere else to go. "Half of the birds of North America are at risk of extinction," says Gary Langham, Audubon's chief scientist.

Despite this grim prognosis, which doesn't factor in how physical habitats might change as the continent warms, Langham insists there's reason to be hopeful. The study generated maps of climatic suitability down to 38.6 square miles. Mapping each species' climatic range and assigning it a threat level "helps us conserve birds," he says. "It's not too late to do something." *—Rachel Hartigan Shea*

THE BAIRD'S SPARROW seeks the tall grass that grows on the high prairie. The Audubon study projects that the climate on 96 percent of its summer range and 97 percent of its winter range will become inhospitable to the little brown bird by 2050. Those numbers reach 100 percent by 2080.

THE BURROWING OWL is a familiar sight in the grasslands and deserts of the American West. Already endangered by the farming practice of destroying the prairie dog burrows where it nests, the owl may lose 68 percent of its breeding range and 60 percent of its winter range.





ART: KARL MÅRTENS. MAPS: JEROME N. COOKSON, NGM STAFF. SOURCE: NATIONAL AUDUBON SOCIETY

For people with a higher risk of stroke due to
Atrial Fibrillation (AFib) not caused by a heart valve problem

ELIQUIS® (apixaban) is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation, a type of irregular heartbeat, not caused by a heart valve problem.

IMPORTANT SAFETY INFORMATION:

- **Do not stop taking ELIQUIS for atrial fibrillation without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke.** ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.
- **ELIQUIS can cause bleeding, which can be serious,** and rarely may lead to death.
- **You may have a higher risk of bleeding if you take ELIQUIS and** take other medicines that increase your risk of bleeding, such as aspirin, NSAIDs, warfarin (COUMADIN®), heparin, SSRIs or SNRIs, and other blood thinners. **Tell your doctor about all medicines, vitamins and supplements you take.** While taking ELIQUIS, you may bruise more easily and it may take longer than usual for any bleeding to stop.
- Get medical help right away if you have any of these signs or symptoms of bleeding:
  - unexpected bleeding, or bleeding that lasts a long time, such as unusual bleeding from the gums; nosebleeds that happen often, or menstrual or vaginal bleeding that is heavier than normal
  - bleeding that is severe or you cannot control
  - red, pink, or brown urine; red or black stools (looks like tar)
  - coughing up or vomiting blood or vomit that looks like coffee grounds
  - unexpected pain, swelling, or joint pain; headaches, feeling dizzy or weak
- **ELIQUIS is not for patients with artificial heart valves.**
- **Spinal or epidural blood clots or bleeding (hematoma).** People who take ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis).

I focused on finding something better than warfarin.

NOW I TAKE ELIQUIS® (apixaban) FOR 3 GOOD REASONS:

1. ELIQUIS reduced the risk of stroke better than warfarin.
2. ELIQUIS had less major bleeding than warfarin.
3. Unlike warfarin, there's no routine blood testing.

ELIQUIS and other blood thinners increase the risk of bleeding which can be serious, and rarely may lead to death.

Ask your doctor if ELIQUIS is right for you.

This risk is higher if, an epidural catheter is placed in your back to give you certain medicine, you take NSAIDs or blood thinners, you have a history of difficult or repeated epidural or spinal punctures. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

- **Before you take ELIQUIS,** tell your doctor if you have: kidney or liver problems, any other medical condition, or ever had bleeding problems. Tell your doctor if you are pregnant or breastfeeding, or plan to become pregnant or breastfeed.
- **Do not take ELIQUIS if you** currently have certain types of abnormal bleeding or have had a serious allergic reaction to ELIQUIS. A reaction to ELIQUIS can cause hives, rash, itching, and possibly trouble breathing. Get medical help right away if you have sudden chest pain or chest tightness, have sudden swelling of your face or tongue, have trouble breathing, wheezing, or feeling dizzy or faint.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch, or call 1-800-FDA-1088.

Please see additional Important Product Information on the adjacent page.

Individual results may vary.

Visit ELIQUIS.COM or call 1-855-ELIQUIS

Eliquis®
(apixaban) tablets 5mg 2.5mg

IMPORTANT FACTS about ELIQUIS® (apixaban) tablets

℞ ONLY

The information below does not take the place of talking with your healthcare professional. Only your healthcare professional knows the specifics of your condition and how ELIQUIS may fit into your overall therapy. Talk to your healthcare professional if you have any questions about ELIQUIS (pronounced ELL eh kwiss).

What is the most important information I should know about ELIQUIS (apixaban)?

For people taking ELIQUIS for atrial fibrillation: Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke. ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.

ELIQUIS can cause bleeding which can be serious, and rarely may lead to death. This is because ELIQUIS is a blood thinner medicine that reduces blood clotting.

You may have a higher risk of bleeding if you take ELIQUIS and take other medicines that increase your risk of bleeding, such as aspirin, nonsteroidal anti-inflammatory drugs (called NSAIDs), warfarin (COUMADIN®), heparin, selective serotonin reuptake inhibitors (SSRIs) or serotonin norepinephrine reuptake inhibitors (SNRIs), and other medicines to help prevent or treat blood clots.

Tell your doctor if you take any of these medicines. Ask your doctor or pharmacist if you are not sure if your medicine is one listed above.

While taking ELIQUIS:

- you may bruise more easily
- it may take longer than usual for any bleeding to stop

Call your doctor or get medical help right away if you have any of these signs or symptoms of bleeding when taking ELIQUIS:

- unexpected bleeding, or bleeding that lasts a long time, such as:
  - unusual bleeding from the gums
  - nosebleeds that happen often
  - menstrual bleeding or vaginal bleeding that is heavier than normal
- bleeding that is severe or you cannot control
- red, pink, or brown urine
- red or black stools (looks like tar)
- cough up blood or blood clots
- vomit blood or your vomit looks like coffee grounds
- unexpected pain, swelling, or joint pain
- headaches, feeling dizzy or weak

ELIQUIS (apixaban) is not for patients with artificial heart valves.

Spinal or epidural blood clots or bleeding (hematoma). People who take a blood thinner medicine (anticoagulant) like ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis). Your risk of developing a spinal or epidural blood clot is higher if:

- a thin tube called an epidural catheter is placed in your back to give you certain medicine
- you take NSAIDs or a medicine to prevent blood from clotting
- you have a history of difficult or repeated epidural or spinal punctures
- you have a history of problems with your spine or have had surgery on your spine

If you take ELIQUIS and receive spinal anesthesia or have a spinal puncture, your doctor should watch you closely for symptoms of spinal or epidural blood clots or bleeding. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

What is ELIQUIS?

ELIQUIS is a prescription medicine used to:

- reduce the risk of stroke and blood clots in people who have atrial fibrillation.

(Continued)

IMPORTANT FACTS about ELIQUIS® (apixaban) tablets *(Continued)*

- reduce the risk of forming a blood clot in the legs and lungs of people who have just had hip or knee replacement surgery.

It is not known if ELIQUIS is safe and effective in children.

Who should not take ELIQUIS (apixaban)?

Do not take ELIQUIS if you:

- currently have certain types of abnormal bleeding
- have had a serious allergic reaction to ELIQUIS. Ask your doctor if you are not sure

What should I tell my doctor before taking ELIQUIS?

Before you take ELIQUIS, tell your doctor if you:

- have kidney or liver problems
- have any other medical condition
- have ever had bleeding problems
- are pregnant or plan to become pregnant. It is not known if ELIQUIS will harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if ELIQUIS passes into your breast milk. You and your doctor should decide if you will take ELIQUIS or breastfeed. You should not do both

Tell all of your doctors and dentists that you are taking ELIQUIS. They should talk to the doctor who prescribed ELIQUIS for you, before you have **any** surgery, medical or dental procedure. **Tell your doctor about all the medicines you take, including** prescription and over-the-counter medicines, vitamins, and herbal supplements. Some of your other medicines may affect the way ELIQUIS works. Certain medicines may increase your risk of bleeding or stroke when taken with ELIQUIS.

How should I take ELIQUIS?

Take ELIQUIS exactly as prescribed by your doctor. Take ELIQUIS twice every day with or without food, and do not change your dose or stop taking it unless your doctor tells you to. If you miss a dose of ELIQUIS, take it as soon as you remember, and do not take more than one dose at the same time. **Do not run out of ELIQUIS.**

Refill your prescription before you run out. When leaving the hospital following hip or knee replacement, be sure that you will have ELIQUIS (apixaban) available to avoid missing any doses. **If you are taking ELIQUIS for atrial fibrillation, stopping ELIQUIS may increase your risk of having a stroke.**

What are the possible side effects of ELIQUIS?

- See **"What is the most important information I should know about ELIQUIS?"**
- ELIQUIS can cause a skin rash or severe allergic reaction. Call your doctor or get medical help right away if you have any of the following symptoms:
  - chest pain or tightness
  - swelling of your face or tongue
  - trouble breathing or wheezing
  - feeling dizzy or faint

Tell your doctor if you have any side effect that bothers you or that does not go away.

These are not all of the possible side effects of ELIQUIS. For more information, ask your doctor or pharmacist.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

This is a brief summary of the most important information about ELIQUIS. For more information, talk with your doctor or pharmacist, call 1-855-ELIQUIS (1-855-354-7847), or go to www.ELIQUIS.com.

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Bristol-Myers Squibb Company
Princeton, New Jersey 08543 USA

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March 2014

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Silk Screws

The worms that crawl in David Kaplan's biomedical lab at Tufts University aren't pests. They're a key to helping broken bones heal faster. The protein fiber that silkworms spin into cocoons is being turned into screws and plates that can hold bones together.

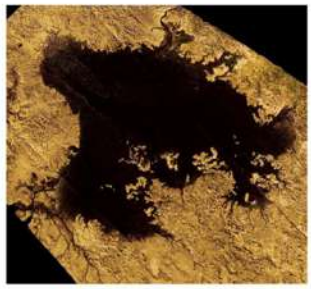
The silk screw (left) was designed by researchers at Tufts and Beth Israel Deaconess Medical Center as an alternative to traditional steel screws and alloy plates, which, while strong, often place stress on bone and tissues, interfere with x-rays, and require second surgeries to remove.

Silk, by comparison, degrades in the body, eliminating the need for follow-up incisions. "It has just the right mix of properties," says Kaplan, a biomedical engineer. It's both strong and malleable. Advanced engineering can create silk screws that last as little as a few hours or as long as several years.

Rats were the first test subjects. Human trials may come next. One early application may be in facial reconstruction in children, whose growing bones can benefit from screws that disappear. *—Daniel Stone*

LAKES OF METHANE

There's no place quite like Earth, but Saturn's moon Titan, with an atmosphere, seasons, and a rocky surface, may be its closest relative nearby. The latest evidence: Titan has liquid on its surface. NASA's Cassini spacecraft, which has studied Saturn since 2004, captured high-resolution images of three seas, collectively about twice as large as North America's Great Lakes. The seas are not water but methane and ethane at minus 300°F, and they're believed to contain compounds that were precursors to life on Earth. Says astrogeologist Randolph Kirk, "What's cool about Titan is that the physics are the same as on Earth, but the chemistry is completely different." *—DS*



PHOTOS: FRITZ HOFFMANN (TOP); NASA/JPL/ASI/CORNELL

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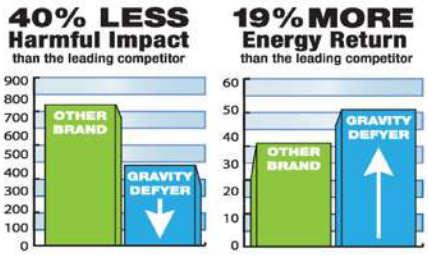
"I decided to fulfill a life's dream and go to China… without my Gravity Defyer® [shoes] this would have been impossible." – Eleanor W

"After ordering and wearing your Gravity Defyer® [shoes], I have renewed faith that I will be able to continue my passion for senior softball. Thank you." – Ron B

"I work in a restaurant. Finally found the shoes that don't kill my legs and feet…Gravity Defyer® shoes are awesome!" – Diana B



SHOCK ABSORPTION STUDY HPW Biomechanics, 2012

Shock absorption: Measurement of maximum pressure (KPI).
Energy return: Measurement of energy returned (Joules).

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Rescuing Alaska Artifacts

Four hundred miles west of Anchorage, archaeologists are racing to save the remains of a coastal village occupied by Yupik Eskimos between about 1300 and 1650. Known today as Nunalleq, the once frozen site is thawing and being swept away by the rising Bering Sea as the result of global climate change.

An emergency excavation, launched in 2009, has recovered some 20,000 artifacts previously locked in permafrost. Examples shown here include a life-size ceremonial wooden mask, dolls carved from driftwood, harpoon points of caribou antler, arrowheads of slate, and two linked rings of walrus ivory.

"Since we've been here, the site has eroded back about 30 feet," says lead archaeologist Rick Knecht. "We're barely ahead of it." He estimates five more years of work—unless a big winter storm carries off what's left. *—A. R. Williams*

PHOTO: KIERAN DODDS, WITH PERMISSION OF THE VILLAGE OF QUINHAGAK, ALASKA, AND THE UNIVERSITY OF ABERDEEN, SCOTLAND

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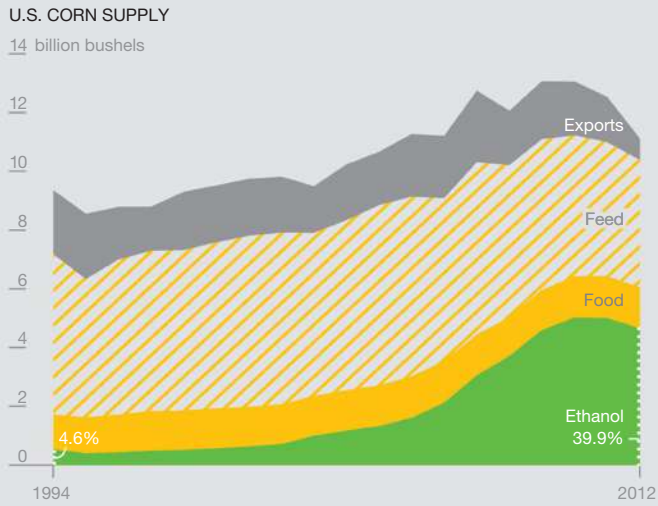
When Food Is Fuel

Biofuel production is booming, up fivefold in a decade. Investment in biofuel technologies creates more renewable fuels and jobs, but critics argue that industry-friendly policies have artificially inflated demand. Producing green fuels like corn-based ethanol diverts land and water resources from food crops.

Biofuels can also drive up the cost of corn that is used for food, especially in developing countries that rely on imports of the grain. According to Timothy A. Wise of Tufts University, "The higher your import dependence, the higher your vulnerability to global price spikes." —*Kelsey Nowakowski*

MEXICO'S CORN DILEMMA

Mexico produces most of its corn but still imports a third of its supply under a 1994 trade agreement with the U.S. Since 2005 growth in U.S. biofuel production has driven up corn prices in Mexico. Today 40 percent of U.S. corn goes to make ethanol.



MEXICO'S IMPORTS OF U.S. CORN AS A PORTION OF TOTAL CONSUMPTION

Eased trade restrictions allowed the U.S. to flood the Mexican market with corn, leading to a rise in Mexico's import dependency. Corn imports were cheap before the U.S. ethanol boom.

1994 **8%**

2012 **34%**

4%

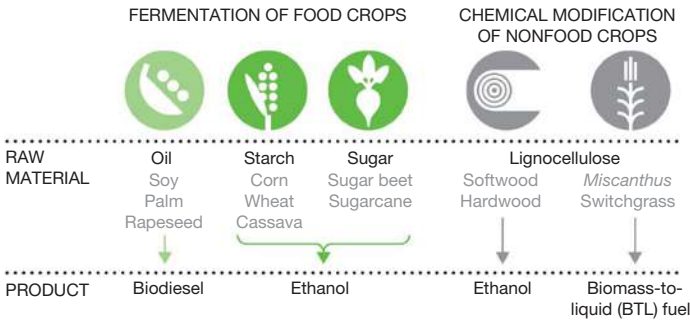
OF THE WORLD'S TRANSPORTATION FUEL IS BIOFUEL.

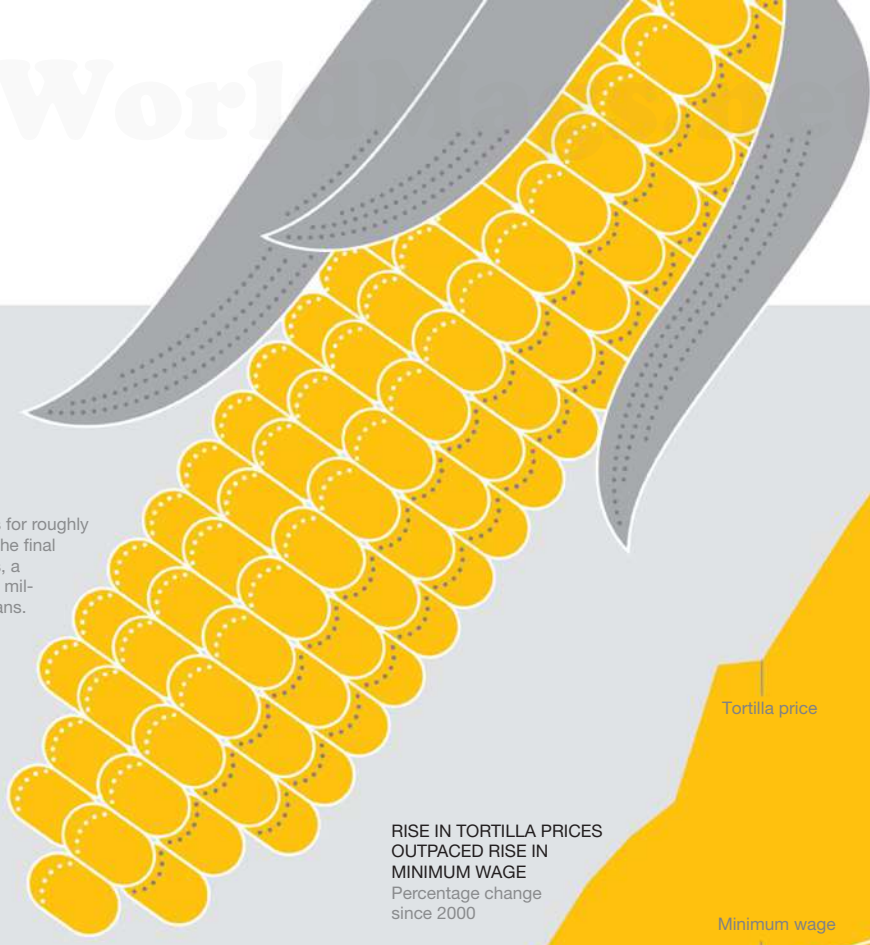
Biofuels account for 23% of all road transport fuel in Brazil but only 5% in the U.S. and 4% in the European Union.

SOURCES

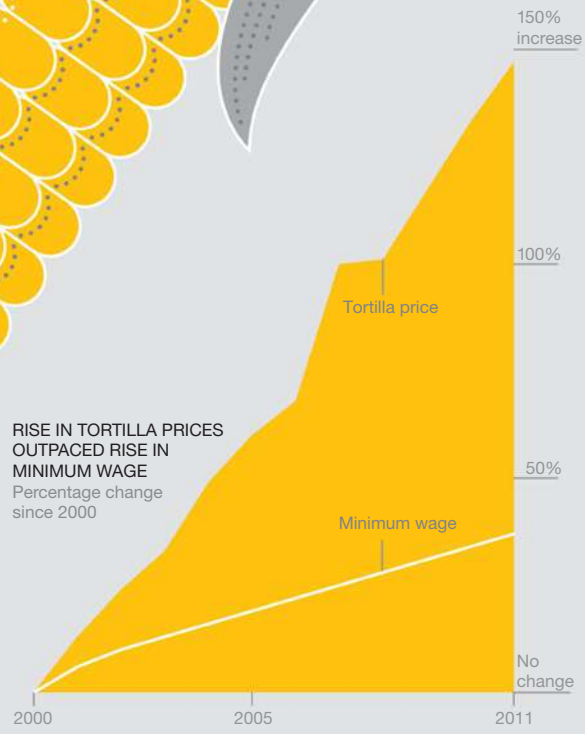
99%

OF BIOFUELS PRODUCED AND CONSUMED WORLDWIDE IN 2011 WERE MADE FROM FOOD CROPS.





Corn accounts for roughly 60 percent of the final cost of tortillas, a staple food for millions of Mexicans.



RISE IN TORTILLA PRICES OUTPACED RISE IN MINIMUM WAGE
Percentage change since 2000

Mexicans spend three times more of their income on food than Americans do. Mexico's urban poor spend an even higher share.

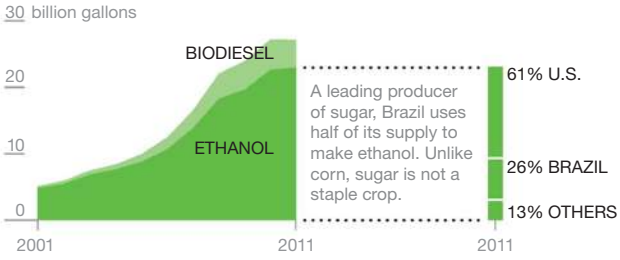
PORTION OF INCOME SPENT ON FOOD IN 2011

U.S. 7%

MEXICO 25%

From 2005 to 2011 the price of tortillas in Mexico rose nearly 70 percent, fueling the 2007 riots that led to government price controls. Experts estimate that increased U.S. ethanol production accounted for over 30 percent of the price spike.

WORLD BIOFUEL PRODUCTION



95%

OF U.S.-PRODUCED ETHANOL IS CONSUMED IN THE U.S.

GRAPHIC: ÁLVARO VALIÑO. SOURCES: TIMOTHY A. WISE, TUFTS UNIVERSITY; FAO; USDA ECONOMIC RESEARCH SERVICE; INTERNATIONAL ENERGY AGENCY

Hungry for information? Make a selection from our menu of food facts—and taste more at *natgeofood.com.*

DANGEROUS LEAVES
Rhubarb leaves contain a toxic substance and are poisonous, even though the stalks are fine to eat.

RICE TO THE PEOPLE
Rice is the staple food for more than half the world's population.

CHOCOWEEN
A 2013 survey found that 72 percent of people prefer chocolate at Halloween.

LIFE SAVERS
Life Savers candies were invented by a chocolate maker who wanted to sell sweets that wouldn't melt in the summer.

35 million lbs

CORNY HALLOWEEN
More than 35 million pounds of candy corn (original name: chicken feed) are produced annually.

TEA COORDINATES
What Westerners know as black tea (such as English breakfast) is called red tea in China.

PHOTO: REBECCA HALE, NGM STAFF. ART: ÁLVARO VALIÑO

How a Chicago Doctor Shook Up the Hearing Aid Industry with his Newest Invention

New nearly invisible digital hearing aid breaks price barrier in affordability

Superb Performance From Affordable Digital Hearing Aid

Board-certified physician Dr. Cherukuri has done it once again with his newest invention of a medical grade ALL DIGITAL affordable hearing aid.

Dr. Cherukuri knew that untreated hearing loss could lead to depression, social isolation, anxiety, and symptoms consistent with Dementia and Alzheimer's disease. In his practice he knew that many of his patients would benefit from new digital hearing aids, but many couldn't afford the expense, which is not generally covered by Medicare and most private health insurance.

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He evaluated all the high priced digital hearing aids on the market and then created his own affordable version — called **MD**HearingAid® ***AIR*** for its virtually invisible, lightweight appearance. This sleek doctor-designed digital hearing aid delivers crisp, clear sound all day long and the soft flexible ear domes are so comfortable you won't realize you are wearing them.

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"I would definitely recommend them to my patients with hearing loss" —Amy S., Audiologist, Indiana

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BBB RATING A

A breach torn through New York's Fire Island by Hurricane Sandy is bringing new life to a long-polluted ecosystem.

Sandy's Silver Lining

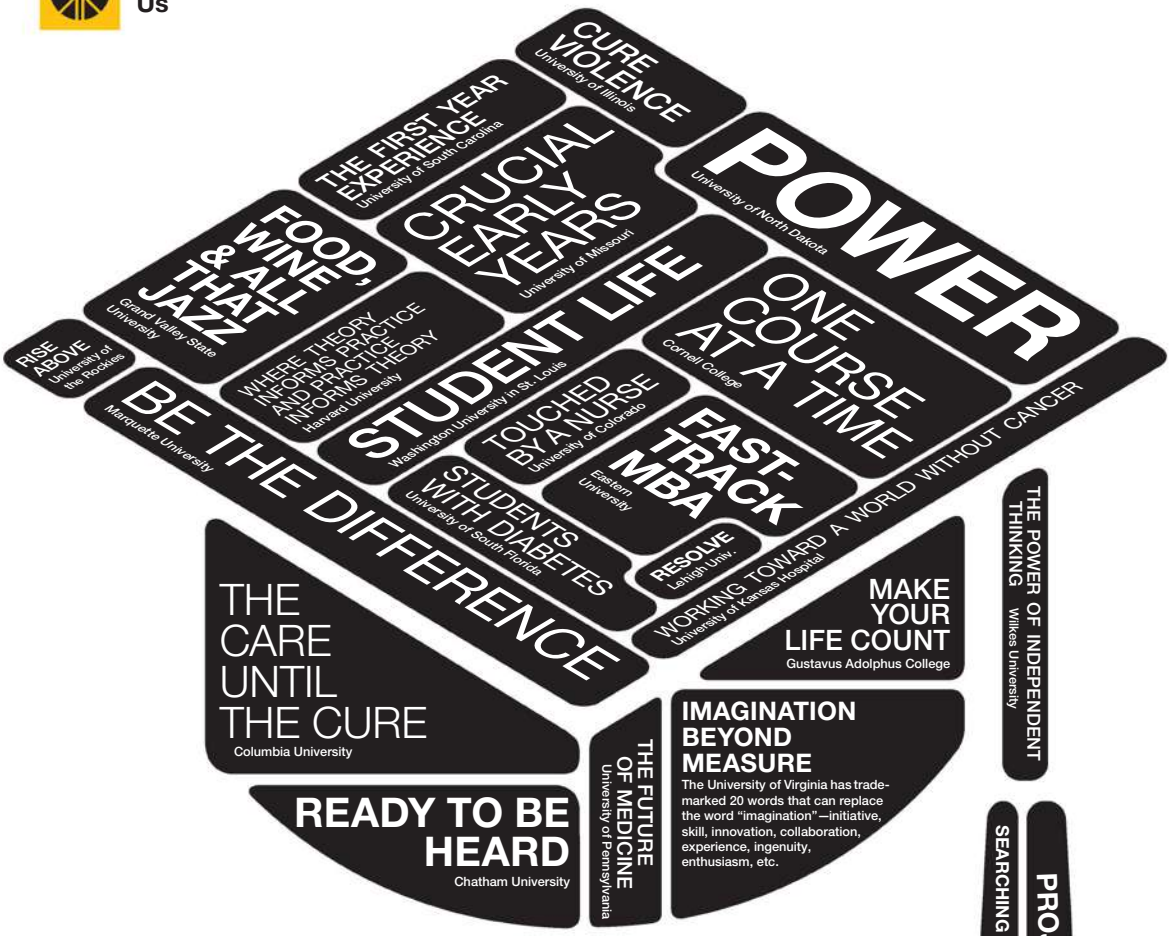
Two years ago Hurricane Sandy ripped three holes through the barrier islands off Long Island's southern coast. The Army Corps of Engineers quickly filled two. But the third, on Fire Island opposite Bellport on the Great South Bay, was in a federal wilderness area, requiring a waiting period before bulldozers could move in.

Though some flood-fearful homeowners demanded that the inlet be immediately closed, others noticed something miraculous occurring. Flushed twice a day into the ocean, the polluted waters of the bay were turning clear. The following summer clammers—the bay once supplied most of the clams for the U.S. market—noticed wide new growth rings on their quarry. Sightings of gray seals were not unusual. Before the inlet, one might as well have looked for mermaids.

"It's a totally different system now," says Chris Gobler, a Stony Brook University ecologist. And last winter's flooding on Long Island was no different than that of other places on the East Coast, letting the Bellport inlet off the hook.

The ultimate fate of the inlet awaits the results of an environmental impact study; an outdated state law still in effect calls for barrier island breaches opened by storms to be closed—no ifs, ands, or buts. Even if the inlet is allowed to remain open, or even deliberately stabilized—two options under consideration—it cannot stem the tide of nitrogen pollution from sewage runoff on its own. Still, says Bellport business owner Thomas Schultz, "it's a reminder of what the bay once was and what it could be again." *—Jamie Shreeve*

PHOTO: GEORGE STEINMETZ. NGM MAPS



School Slogans

College campuses used to produce radicals. Today they also produce revenues. U.S. universities netted $4.6 billion in 2011 licensing their names and logos for merchandise. In recent years they've also trademarked 10,265 slogans, like those on this page. That's led to puzzling litigation such as Eastern Carolina University suing Cisco Systems over the stock phrase "Tomorrow Begins Here."

Jacob Rooksby, a Duquesne University law professor, tracks the trend via the U.S. Patent and Trademark Office's database. He says excessive trademarking "blurs the lines of higher education and industry and encroaches on free speech in the public sphere. We need to say, Let's cool it a little bit." *—Jeremy Berlin*

OK, IT'S YOUR BIRTHDAY

It started as a joke—and ended up among the most commonly used words in the world. This year marks the 175th anniversary of "OK," first printed in a Boston newspaper in March 1839. Caught up in a fad for whimsical misspellings and abbreviations, editors indicated that a statement was all correct by using the first two letters in "oll korrect." By 1840 "OK" had gone national, used even by Martin Van Buren's presidential campaign. His nickname? Old Kinderhook. *—Margaret G. Zackowitz*

ART: HANNAH TAK, NGM STAFF. SOURCE: JACOB ROOKSBY, DUQUESNE UNIVERSITY. ART (BOTTOM): OLIVER MUNDAY

COPD making you huff and puff?

SYMBICORT could help you breathe better, starting within 5 minutes.*
SYMBICORT does not replace a rescue inhaler for sudden symptoms.

COPD can make it hard to get air out, which can make it hard to get air in. SYMBICORT is a twice-daily maintenance medication for adults with COPD, including chronic bronchitis and emphysema, that could help make a significant difference in your breathing.* ***Ask your doctor about SYMBICORT.***

*Results may vary.

IMPORTANT INFORMATION ABOUT SYMBICORT

Important Safety Information About SYMBICORT

SYMBICORT contains formoterol, a long-acting beta$_2$-adrenergic agonist (LABA). LABA medicines such as formoterol increase the risk of death from asthma problems. It is not known whether budesonide, the other medicine in SYMBICORT, reduces the risk of death from asthma problems seen with formoterol.

- **Call your health care provider if breathing problems worsen over time while using SYMBICORT. You may need different treatment**
- **Get emergency medical care if:**
  - Breathing problems worsen quickly, and
  - You use your rescue inhaler medicine, but it does not relieve your breathing problems

SYMBICORT does not replace rescue inhalers for sudden symptoms.

Be sure to tell your health care provider about all your health conditions, including heart conditions or high blood pressure, and all medicines you may be taking. Some patients taking SYMBICORT may experience increased blood pressure, heart rate, or change in heart rhythm.

Do not use SYMBICORT more often than prescribed. While taking SYMBICORT, never use another medicine containing a LABA for any reason. Ask your health care provider or pharmacist if any of your other medicines are LABA medicines.

SYMBICORT can cause serious side effects, including:

- **Pneumonia and other lower respiratory tract infections.** People with COPD may have a higher chance of pneumonia. Call your doctor if you notice any of the following symptoms: change in amount or color of mucus, fever, chills, increased cough, or increased breathing problems
- **Serious allergic reactions** including rash, hives, swelling of the face, mouth and tongue, and breathing problems
- **Immune system effect and a higher chance of infection.** Tell your health care provider if you think you are exposed to infections such as chicken pox or measles, or if you have any signs of infection such as fever, pain, body aches, chills, feeling tired, nausea, or vomiting
- **Adrenal insufficiency.** This can happen when you stop taking oral corticosteroid medicines and start inhaled corticosteroid medicine
- **Using too much of a LABA medicine** may cause chest pain, increase in blood pressure, fast and irregular heartbeat, headache, tremor, or nervousness
- **Increased wheezing** right after taking SYMBICORT. Always have a rescue inhaler with you to treat sudden wheezing
- **Eye problems including glaucoma and cataracts.** You should have regular eye exams while using SYMBICORT
- **Lower bone mineral density** can happen in people who have a high chance for low bone mineral density (osteoporosis)
- **Swelling of blood vessels** (signs include a feeling of pins and needles or numbness of arms or legs, flu like symptoms, rash, pain or swelling of the sinuses), decrease in blood potassium and increase in blood sugar levels

Common side effects in **patients with COPD** include inflammation of the nasal passages and throat, thrush in the mouth and throat, bronchitis, sinusitis, and upper respiratory tract infection.

Approved Uses for SYMBICORT

SYMBICORT 160/4.5 is for adults with COPD, including chronic bronchitis and emphysema. You should only take 2 inhalations of SYMBICORT twice a day. Higher doses will not provide additional benefits.

Please see full Prescribing Information and Medication Guide and discuss with your doctor.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch or call 1-800-FDA-1088.

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Inhalation Aerosol

AstraZeneca

IMPORTANT INFORMATION ABOUT SYMBICORT

Please read this summary carefully and then ask your doctor about SYMBICORT.

No advertisement can provide all the information needed to determine if a drug is right for you or take the place of careful discussions with your health care provider. Only your health care provider has the training to weigh the risks and benefits of a prescription drug.

WHAT IS THE MOST IMPORTANT INFORMATION I SHOULD KNOW ABOUT SYMBICORT?

People with asthma who take long-acting beta$_2$-agonist (LABA) medicines, such as formoterol (one of the medicines in SYMBICORT), have an increased risk of death from asthma problems. It is not known whether budesonide, the other medicine in SYMBICORT, reduces the risk of death from asthma problems seen with formoterol.

SYMBICORT should be used only if your health care provider decides that your asthma is not well controlled with a long-term asthma control medicine, such as an inhaled corticosteroid, or that your asthma is severe enough to begin treatment with SYMBICORT. Talk with your health care provider about this risk and the benefits of treating your asthma with SYMBICORT.

If you are taking SYMBICORT, see your health care provider if your asthma does not improve or gets worse. It is important that your health care provider assess your asthma control on a regular basis. Your doctor will decide if it is possible for you to stop taking SYMBICORT and start taking a long-term asthma control medicine without loss of asthma control.

Get emergency medical care if:

- breathing problems worsen quickly, and
- you use your rescue inhaler medicine, but it does not relieve your breathing problems.

Children and adolescents who take LABA medicines may be at increased risk of being hospitalized for asthma problems.

WHAT IS SYMBICORT?

SYMBICORT is an inhaled prescription medicine used for asthma and chronic obstructive pulmonary disease (COPD). It contains two medicines:

- Budesonide (the same medicine found in Pulmicort Flexhaler™, an inhaled corticosteroid). Inhaled corticosteroids help to decrease inflammation in the lungs. Inflammation in the lungs can lead to asthma symptoms
- Formoterol (the same medicine found in Foradil® Aerolizer®). LABA medicines are used in patients with COPD and asthma to help the muscles in the airways of your lungs stay relaxed to prevent asthma symptoms, such as wheezing and shortness of breath. These symptoms can happen when the muscles in the airways tighten. This makes it hard to breathe, which, in severe cases, can cause breathing to stop completely if not treated right away

SYMBICORT is used for asthma and chronic obstructive pulmonary disease as follows:

Asthma

SYMBICORT is used to control symptoms of asthma and prevent symptoms such as wheezing in adults and children ages 12 and older.

Chronic Obstructive Pulmonary Disease

COPD is a chronic lung disease that includes chronic bronchitis, emphysema, or both. SYMBICORT 160/4.5 mcg is used long term, two times each day, to help improve lung function for better breathing in adults with COPD.

WHO SHOULD NOT USE SYMBICORT?

Do not use SYMBICORT to treat sudden severe symptoms of asthma or COPD or if you are allergic to any of the ingredients in SYMBICORT.

WHAT SHOULD I TELL MY HEALTH CARE PROVIDER BEFORE USING SYMBICORT?

Tell your health care provider about all of your health conditions, including if you:

- **have heart problems**
- **have high blood pressure**
- **have seizures**
- **have thyroid problems**
- **have diabetes**
- **have liver problems**
- **have osteoporosis**
- **have an immune system problem**
- **have eye problems such as increased pressure in the eye, glaucoma, or cataracts**
- **are allergic to any medicines**
- **are exposed to chicken pox or measles**
- **are pregnant or planning to become pregnant.** It is not known if SYMBICORT may harm your unborn baby
- **are breast-feeding.** Budesonide, one of the active ingredients in SYMBICORT, passes into breast milk. You and your health care provider should decide if you will take SYMBICORT while breast-feeding

Tell your health care provider about all the medicines you take including prescription and nonprescription medicines, vitamins, and herbal supplements. SYMBICORT and certain other medicines may interact with each other and can cause serious side effects. Know all the medicines you take. Keep a list and show it to your health care provider and pharmacist each time you get a new medicine.

HOW DO I USE SYMBICORT?

Do not use SYMBICORT unless your health care provider has taught you and you understand everything. Ask your health care provider or pharmacist if you have any questions.

Use SYMBICORT exactly as prescribed. **Do not use SYMBICORT more often than prescribed.** SYMBICORT comes in two strengths for asthma: 80/4.5 mcg and 160/4.5 mcg. Your health care provider will prescribe the strength that is best for you. SYMBICORT 160/4.5 mcg is the approved dosage for COPD.

- SYMBICORT should be taken every day as 2 puffs in the morning and 2 puffs in the evening.
- Rinse your mouth with water and spit the water out after each dose (2 puffs) of SYMBICORT. This will help lessen the chance of getting a fungus infection (thrush) in the mouth and throat.
- Do not spray SYMBICORT in your eyes. If you accidentally get SYMBICORT in your eyes, rinse your eyes with water. If redness or irritation persists, call your health care provider.
- Do not change or stop any medicines used to control or treat your breathing problems. Your health care provider will change your medicines as needed
- **While you are using SYMBICORT 2 times each day, do not use other medicines that contain a long-acting beta$_2$-agonist (LABA) for any reason. Ask your health care provider or pharmacist if any of your other medicines are LABA medicines.**
- SYMBICORT does not relieve sudden symptoms. Always have a rescue inhaler medicine with you to treat sudden symptoms. If you do not have a rescue inhaler, call your health care provider to have one prescribed for you.

Call your health care provider or get medical care right away if:

- your breathing problems worsen with SYMBICORT
- you need to use your rescue inhaler medicine more often than usual
- your rescue inhaler does not work as well for you at relieving symptoms
- you need to use 4 or more inhalations of your rescue inhaler medicine for 2 or more days in a row
- you use one whole canister of your rescue inhaler medicine in 8 weeks' time
- your peak flow meter results decrease. Your health care provider will tell you the numbers that are right for you
- your symptoms do not improve after using SYMBICORT regularly for 1 week

WHAT MEDICATIONS SHOULD I NOT TAKE WHEN USING SYMBICORT?

While you are using SYMBICORT, do not use other medicines that contain a long-acting beta$_2$-agonist (LABA) for any reason, such as:

- Serevent® Diskus® (salmeterol xinafoate inhalation powder)
- Advair Diskus® or Advair® HFA (fluticasone propionate and salmeterol)
- Formoterol-containing products such as Foradil Aerolizer, Brovana®, or Perforomist®

WHAT ARE THE POSSIBLE SIDE EFFECTS WITH SYMBICORT?

SYMBICORT can cause serious side effects.

- Increased risk of pneumonia and other lower respiratory tract infections if you have COPD. Call your health care provider if you notice any of these symptoms: increase in mucus production, change in mucus color, fever, chills, increased cough, increased breathing problems
- Serious allergic reactions including rash; hives; swelling of the face, mouth and tongue; and breathing problems. Call your health care provider or get emergency care if you get any of these symptoms
- Immune system effects and a higher chance for infections
- Adrenal insufficiency–a condition in which the adrenal glands do not make enough steroid hormones
- Cardiovascular and central nervous system effects of LABAs, such as chest pain, increased blood pressure, fast or irregular heartbeat, tremor, or nervousness
- Increased wheezing right after taking SYMBICORT
- Eye problems, including glaucoma and cataracts. You should have regular eye exams while using SYMBICORT
- Osteoporosis. People at risk for increased bone loss may have a greater risk with SYMBICORT
- Slowed growth in children. As a result, growth should be carefully monitored
- Swelling of your blood vessels. This can happen in people with asthma
- Decreases in blood potassium levels and increases in blood sugar levels

WHAT ARE COMMON SIDE EFFECTS OF SYMBICORT?

Patients with Asthma

Sore throat, headache, upper respiratory tract infection, thrush in the mouth and throat

Patients with COPD

Thrush in the mouth and throat

These are not all the side effects with SYMBICORT. Ask your health care provider or pharmacist for more information.

NOTE: This summary provides important information about SYMBICORT. For more information, please ask your doctor or health care provider.

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Percentage of fuel saved by hybrids compared with conventional cars

54 China

33 United States

44 India

Hybrids Beat the Traffic

Hybrids work better in countries where traffic is worse. In China and India traffic is so bad—slower than in the United States, with much more stop and go—that hybrids use up to 54 percent less fuel compared with conventional cars, according to a pair of studies from the Lawrence Berkeley National Laboratory. "In these highly congested conditions," says researcher Samveg Saxena, "your [conventional] engine is operating at close to its worst efficiency." Not so the hybrid: Braking recharges the battery, and idling shuts off the engine.

Carbon dioxide emitted by vehicles is projected to double by 2050, much of the growth coming from burgeoning car markets in countries such as India and China (that's the southern city of Shenzhen above). "If we can get cleaner vehicles deployed early on in the rapid growth process," says Saxena, "that will translate into a lot of avoided emissions." *—Rachel Hartigan Shea*

WHAT'S IN A NAME? THE LITERARY MOONS OF URANUS

Most planets and moons have names from Greek or Roman mythology—but the 27 moons of Uranus reflect characters in works of Shakespeare and Alexander Pope. The naming began as a nod to British astronomer William Herschel, who found Uranus (a Greek sky deity) and two of its moons in the 1780s. The tradition endured as more moons came to light, the last five in 2003. *—Jane Vessels*

Oberon	Bianca	Stephano
Titania	Cressida	Prospero
Ariel	Desdemona	Setebos
Umbriel	Juliet	Trinculo
Miranda	Portia	Cupid
Puck	Rosalind	Mab
Belinda	Perdita	Francisco
Cordelia	Caliban	Margaret
Ophelia	Sycorax	Ferdinand

● SHAKESPEARE ● ALEXANDER POPE

Moons listed in order of discovery

PHOTO: RI XI SZ, IMAGINECHINA/AP IMAGES. ART: MIKEL JASO


"After nine years, four Priuses, and over 300,000 miles, we wouldn't drive anything else."*
The Huangs, Prius owners
Prius
Let's lead the way.
toyota.com/prius
TOYOTA
Let's Go Places
Options shown. *Vehicle life is dependent on a variety of factors. Toyota basic warranty covers 3 years or 36,000 miles, whichever occurs first. Actual Prius owner made previously aware their likeness and statement may be used for advertising. ©2014 Toyota Motor Sales, U.S.A., Inc.

VISIONS

Canada
On a gravel beach along the Bay of Fundy, two semipalmated sandpipers take off as hundreds more flock together. These six-inch-long shorebirds migrate thousands of miles a year from Arctic breeding grounds to South American coasts.

PHOTO: YVA MOMATIUK AND JOHN EASTCOTT

Canada
Two miles off the western coast of the Hudson Bay and just south of the Arctic Circle, a polar bear comes in for a close-up. As the winter pack ice melts in summer months, the world's largest bears—a vulnerable species—must swim for shore.

PHOTO: PAUL SOUDERS, CORBIS

Order prints of select *National Geographic* photos online at **NationalGeographicArt.com.**

Bahrain
In the village of Sanabis, a suburb of the capital, Manama, two Shiite girls take part in an Ashura ceremony. The annual holiday commemorates the seventh-century martyrdom of Husayn, a grandson of the Prophet Muhammad, founder of Islam.

PHOTO: MOHAMMED AL-SHAIKH, AFP/GETTY IMAGES

Editor's Choice

Daily Dozen Editors pick 12 photos submitted online each day. Here are our favorites this month.

EDITOR'S NOTE

"Khalid [photo above] sent us photos of airplanes before, but this one had more depth. You can tell he waited for a rare moment. The plane, the flag, the woman—the elements all work together."

—*Jeanne Modderman,* National Geographic *photo editor*

Khalid Rayhan Shawon *Dhaka, Bangladesh*
For more than a year Shawon has photographed people living around Bangladesh's Hazrat Shahjalal International Airport. In a roofless building, he waited several days to capture his country's flag and a flying plane in the same frame.

Vedran Jankovic *Zagreb, Croatia*
A college project asked Jankovic to show "the illusion of space," so he and two friends decided to reimagine a zebra. One of them painted a hand with intricate stripes while Jankovic found a location and composed the shot.

Karl Ander Adami *Tallinn, Estonia*
As a rule, Adami's grandmother curls her hair before going into town. "She wants to show off her best look in case she runs into her girlfriends," he says. Adami grabbed his camera and asked her to stand still.

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Home

Assignment It's both a place and a feeling. Our members showed us inside their intimate worlds.

EDITOR'S NOTE

"When we asked to see versions of homes, we were surprised with the array of places people find comfort and identity. Homes vary widely and aren't always places to live."

—*Susan Welchman,* National Geographic *photo editor*

Hemant Deswal *New Delhi, India*
While visiting northern India, Deswal and his friends had to stop amid heavy rain at a hotel in Pulga. In a common room they met a young girl. Timid at first, she later started a pillow fight with one of Deswal's friends.

Larry Deemer *Breezy Point, New York*
During a trip to Nova Scotia, Deemer hiked with friends on Cheticamp Island. They stopped to rest in a patch of grass. "It was such a beautiful backdrop," Deemer says, "so I started taking pictures to record our time together."

If You Bought Sylvania Automotive Lighting

You Could Get Money from a $30 Million Settlement

A proposed Settlement has been reached with Osram Sylvania Inc. ("Sylvania"). The Settlement resolves claims that Sylvania misrepresented that certain replacement automotive lighting is brighter, provides a wider beam, and allows drivers to see farther down the road than standard halogen lighting. It also claims that Sylvania omitted material information regarding the reduced life of the replacement lighting. Sylvania denies that it did anything wrong.

Who is included in the Settlement?

The Settlement includes any person or entity who:

- Bought one or more of the following, other than for resale or distribution to another person or entity: SilverStar ULTRA®, SilverStar®, XtraVision®, or Cool Blue® replacement headlight capsules; SilverStar®, XtraVision®, or Cool Blue® sealed beam headlights; and SilverStar® fog or auxiliary lights.
- In the United States (or any territory or possession) from September 22, 2005 to July 11, 2014.

What does the Settlement provide?

A $30 million Settlement Fund will be established to make payments to eligible Class Members. Eligible individuals are expected to get a minimum $10 payment and perhaps more. All claims are limited to a single purchase only. The Settlement Fund will also be used to pay Court-approved attorneys' fees and expenses, costs of notice and Settlement administration, and incentive awards to the Class Representatives.

How can I get a payment?

If you did not receive a postcard notice in the mail, you may file a claim online or by mail by **November 14, 2014**. The Claim Form only takes 3-5 minutes for most individuals to complete.

What are my rights?

Even if you do nothing you will be bound by the Court's decisions. If you want to keep your right to sue Sylvania yourself, you must exclude yourself from the Settlement Class by **November 14, 2014**. If you stay in the Settlement Class, you may object to the Settlement by **February 9, 2015**.

The Court will hold a hearing on **March 20, 2015** to consider whether to approve the Settlement and award attorneys' fees, costs, and expenses up to one-third of the Settlement Fund, and total incentive awards up to $25,000 to the Class Representatives. You or your lawyer may appear and speak at the hearing at your own expense.

For more Settlement information or for a Claim Form:

1-866-430-8976 www.AutoLightClaims.com

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Call and Response

A megaphone-brandishing census taker hails occupants of the Deer Island lighthouse in Boston, Massachusetts. Was anyone listening? Yes, it turns out—under archivist Bill Bonner's magnifying loupe, a man in a jaunty cap is visible at the rail with a megaphone of his own.

This photo was likely acquired for (but never published in) our November 1959 story on the U.S. census. "An army 160,000 strong prepares to count noses across the land," wrote authors Albert W. Atwood and Lonnelle Aikman. "To satisfy the Nation's curiosity about itself, roving interviewers will trudge country roads, brave dark alleys, ride mules, row small boats, and bounce in jeeps and snowmobiles." Megaphones were optional. *—Margaret G. Zackowitz*

Meet Bill Bonner, National Geographic's archivist of vintage photographs: **proof.nationalgeographic.com/2014/01/27/the-archivist.**

PHOTO: UPI/NATIONAL GEOGRAPHIC CREATIVE

The Future of FOOD natgeofood.com

By 2050 we'll need to feed two billion more people. This special eight-month series explores how we can do that—without overwhelming the planet.

Science prevented the last food crisis. Can it save us again?

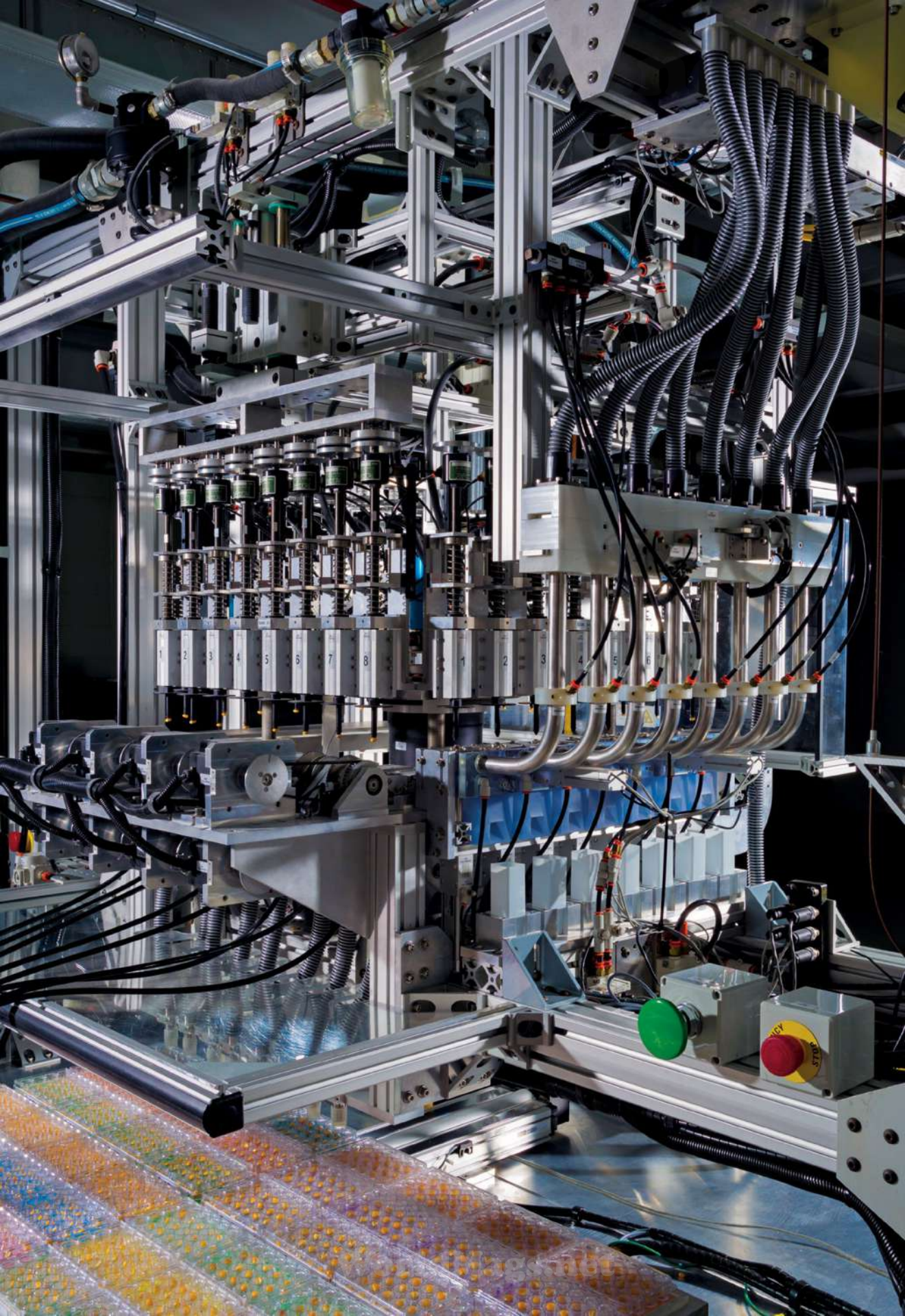
Modern supercrops will be a big help. But agriculture can't be fixed by biotech alone.

The Next Green Revolution

By *Tim Folger*

Photographs by *Craig Cutler*

In a wheat seed bank at Kansas State, plant pathologist Bikram Gill holds a “genetic treasure”: goat grass. About 8,000 years ago the Middle Eastern weed (enlarged above) naturally pollinated another wheat ancestor, creating a grain that went global. Gill is mimicking nature, tapping goat grass for genes to help modern wheat resist pests, heat, and cold.



Automating the search for valuable genes, Monsanto's seed chipper cuts tiny samples from thousands of corn kernels a day—without harming the embryonic plant within. Other machines extract and analyze the DNA from each sample. Breeders then plant only the few kernels in a million with the desired trait, such as resistance to pests or drought.


WorldMags.net

Red-eyed Asian citrus psyllids, an eighth of an inch long, feast on an orange stem. The insects spread citrus greening, a bacterial scourge sweeping through Florida's citrus groves. Infected trees produce deformed, green, bitter fruit. At left, seedlings genetically altered to make defensive antibiotics may help protect a nine-billion-dollar industry.

USGS BEE INVENTORY AND MONITORING LABORATORY (RIGHT)

FOOD

Something is killing Ramadhani Juma's cassava crop. "Maybe it's too much water," he says, fingering clusters of withered yellow leaves on a six-foot-high plant. "Or too much sun." Juma works a small plot, barely more than an acre, near the town of Bagamoyo, on the Indian Ocean about 40 miles north of Dar es Salaam, Tanzania. On a rainy March morning, trailed by two of his four young sons,

he's talking with a technician from the big city, 28-year-old Deogratius Mark of the Mikocheni Agricultural Research Institute. Mark tells Juma his problem is neither sun nor rain. The real cassava killers, far too small to see, are viruses.

Mark breaks off some wet leaves; a few whiteflies dart away. The pinhead-size flies, he explains, transmit two viruses. One ravages cassava leaves, and a second, called brown streak virus, destroys the starchy, edible root—a catastrophe that usually isn't discovered until harvest time. Juma is typical of the farmers Mark meets—most have never heard of the viral diseases. "Can you imagine how he'll feel if I tell him he has to uproot all these plants?" Mark says quietly.

Juma is wearing torn blue shorts and a faded green T-shirt with "Would you like to buy a vowel?" printed on the front. He listens carefully to Mark's diagnosis. Then he unshoulders his heavy hoe and starts digging. His oldest son, who is ten, nibbles a cassava leaf. Uncovering a cassava root, Juma splits it open with one swing of his hoe. He sighs—the creamy white flesh is streaked with brown, rotting starch.

To save enough of the crop to sell and to feed his family, Juma will have to harvest a month early. I ask how important cassava is to him.

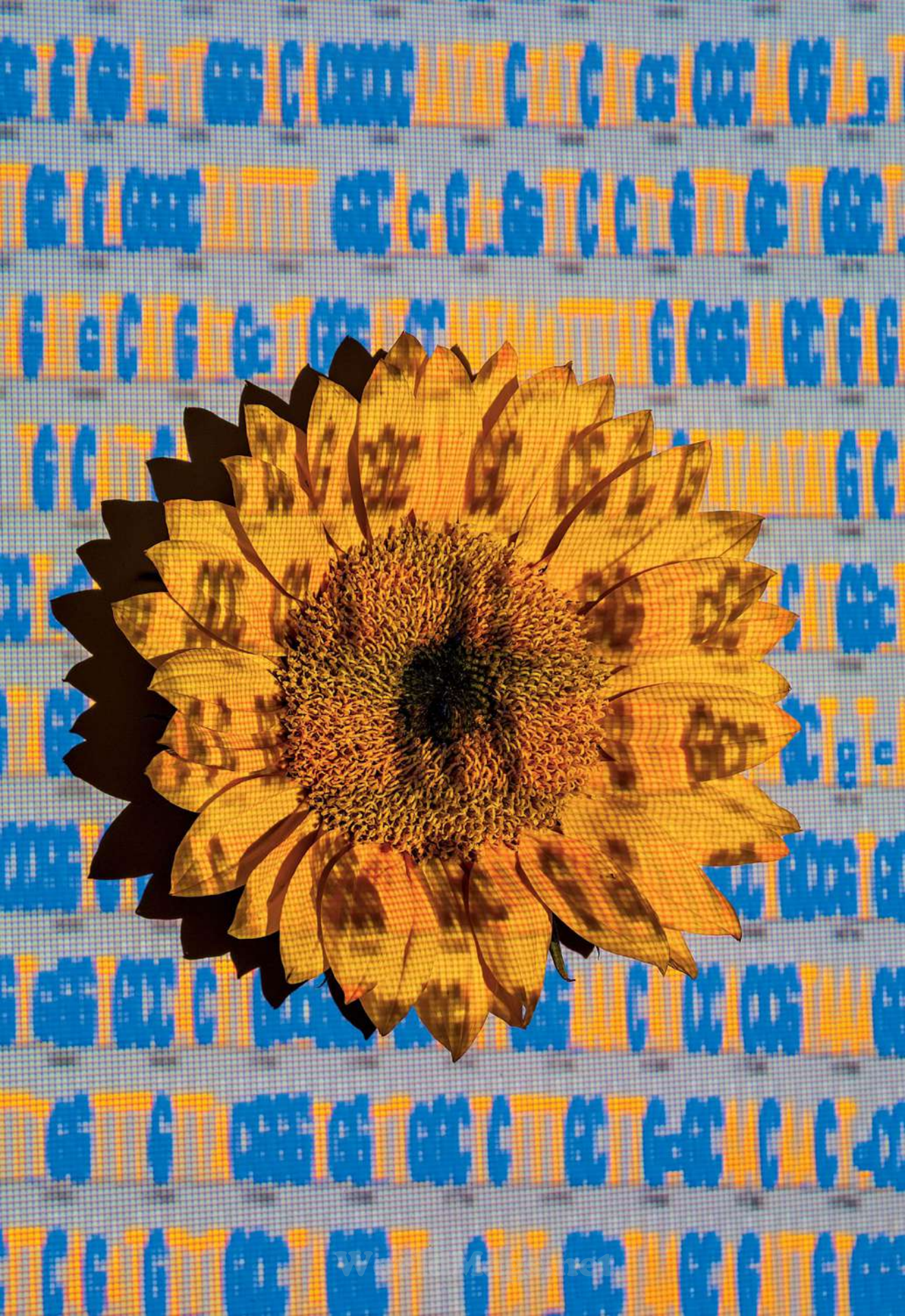
"*Mihogo ni kila kitu,*" he replies in Swahili. "Cassava is everything."

Most Tanzanians are subsistence farmers. In Africa small family farms grow more than 90 percent of all crops, and cassava is a staple for more than 250 million people. It grows even in marginal soils, and it tolerates heat waves and droughts. It would be the perfect crop for 21st-century Africa—were it not for the whitefly, whose range is expanding as the climate warms. The same viruses that have invaded Juma's field have already spread throughout East Africa.

Before leaving Bagamoyo, we meet one of Juma's neighbors, Shija Kagembe. His cassava fields have fared no better. He listens silently as Mark tells him what the viruses have done. "How can you help us?" he asks.

ANSWERING THAT QUESTION will be one of the greatest challenges of this century. Climate change and population growth will make life increasingly precarious for Juma, Kagembe, and other small farmers in the developing world—and for the people they feed. For most of the 20th century humanity managed to stay ahead in the Malthusian race between population growth and food supply. Will we be able to

The genes of all living things on Earth—including the sunflower, a valuable oil crop—consist of varying sequences of four chemical compounds: adenine, thymine, cytosine, and guanine, abbreviated as A, T, C, and G. By identifying genes and manipulating them, scientists hope to create new crops that will help us face the challenges of global warming and population growth.



maintain that lead in the 21st century, or will a global catastrophe beset us?

The United Nations forecasts that by 2050 the world's population will grow by more than two billion people. Half will be born in sub-Saharan Africa, and another 30 percent in South and Southeast Asia. Those regions are also where the effects of climate change—drought, heat waves, extreme weather generally—are expected to hit hardest. Last March the Intergovernmental Panel on Climate Change warned that the world's food supply is already jeopardized. "In the last 20 years, particularly for rice, wheat, and corn, there has been a slowdown in the growth rate of crop yields," says Michael Oppenheimer, a climate scientist at Princeton and one of the authors of the IPCC report. "In some areas yields have stopped growing entirely. My personal view is that the breakdown of food systems is the biggest threat of climate change."

Half a century ago disaster loomed just as ominously. Speaking about global hunger at a meeting of the Ford Foundation in 1959, one economist said, "At best the world outlook for the decades ahead is grave; at worst it is frightening." Nine years later Paul Ehrlich's best seller, *The Population Bomb,* predicted that famines, especially in India, would kill hundreds of millions in the 1970s and 1980s.

Before those grim visions could come to pass, the green revolution transformed global agriculture, especially wheat and rice. Through selective breeding, Norman Borlaug, an American biologist, created a dwarf variety of wheat that put most of its energy into edible kernels rather than long, inedible stems. The result: more grain per acre. Similar work at the International Rice Research Institute (IRRI) in the Philippines dramatically improved the productivity of the grain that feeds nearly half the world.

From the 1960s through the 1990s, yields of rice and wheat in Asia doubled. Even as the continent's population increased by 60 percent, grain prices fell, the average Asian consumed nearly a third more calories, and the poverty rate was cut in half. When Borlaug won the Nobel Peace Prize in 1970, the citation read, "More than any other person of this age, he helped provide bread for a hungry world."

To keep doing that between now and 2050, we'll need another green revolution. There are two competing visions of how it will happen. One is high-tech, with a heavy emphasis on continuing Borlaug's work of breeding better crops, but with modern genetic techniques. "The next green revolution will supercharge the tools of the old one," says Robert Fraley, chief technology officer at Monsanto and a winner of the prestigious World Food Prize in 2013. Scientists, he argues, can now identify and manipulate a huge variety of plant genes, for traits like disease resistance and drought tolerance. That's going to make farming more productive and resilient.

The signature technology of this approach—and the one that has brought both success and controversy to Monsanto—is genetically modified, or GM, crops. First released in the 1990s, they've been adopted by 28 countries and planted on 11 percent of the world's arable land, including half the cropland in the U.S. About 90 percent of the corn, cotton, and soybeans grown in the U.S. are genetically modified. Americans have been eating GM products for nearly two decades. But in Europe and much of Africa, debates over the safety and environmental effects of GM crops have largely blocked their use.

Proponents like Fraley say such crops have prevented billions of dollars in losses in the U.S. alone and have actually benefited the environment. A recent study by the U.S. Department of Agriculture found that pesticide use on corn crops has dropped 90 percent since the introduction of Bt corn, which contains genes from the bacterium *Bacillus thuringiensis* that help it ward off corn borers and other pests. Reports from China indicate that harmful aphids have decreased—and ladybugs and other beneficial insects have increased—in provinces where GM cotton has been planted.

The particular GM crops Fraley pioneered at

Tim Folger's last feature was the September 2013 cover story on sea-level rise. This is photographer Craig Cutler's first article for the magazine.

The cassava plants in this petri dish have been genetically engineered to resist brown streak virus, a disease that's spreading across sub-Saharan Africa, where cassava is a staple for 250 million people. Field tests began last spring in Uganda. Only four African countries allow the planting of genetically modified crops.

Monsanto have been profitable for the company and many farmers, but have not helped sell the cause of high-tech agriculture to the public. Monsanto's Roundup Ready crops are genetically modified to be immune to the herbicide Roundup, which Monsanto also manufactures. That means farmers can spray the herbicide freely to eliminate weeds without damaging their GM corn, cotton, or soybeans. Their contract with Monsanto does not allow them to save seeds for planting; they must purchase its patented seeds each year.

Though there's no clear evidence that Roundup or Roundup Ready crops are unsafe, proponents of an alternative vision of agriculture see those expensive GM seeds as a costly input to a broken system. Modern agriculture, they say, already relies too heavily on synthetic fertilizers and pesticides. Not only are they unaffordable for a small farmer like Juma; they pollute land, water, and air. Synthetic fertilizers are manufactured using fossil fuels, and they themselves emit potent greenhouse gases when they're applied to fields.

"The choice is clear," says Hans Herren, another World Food Prize laureate and the director of Biovision, a Swiss nonprofit. "We need a farming system that is much more mindful of the landscape and ecological resources. We need to change the paradigm of the green revolution. Heavy-input agriculture has no future—we need something different." There are ways to deter pests and increase yields, he thinks, that are more suitable for the Jumas of this world.

MONSANTO IS NOT THE ONLY organization that believes modern plant genetics can help feed the world. Late on a warm February afternoon

Breeding Better Crops

Genetic modification gets the public attention—and the controversy—but plant breeders today have numerous tools for creating crops with new traits. The goal: continually increasing yields in an increasingly challenging climate.

Traditional breeding

Desired traits are identified in separate individuals of the same species, which are then bred to combine those traits in a new hybrid variety.

Interspecies crosses

Breeders can also cross different yet similar species. Modern wheat comes from such hybridizations, some of which happened naturally.

Glenn Gregorio, a plant geneticist at the International Rice Research Institute, shows me the rice that started the green revolution in Asia. We're in Los Baños, a town about 40 miles southeast of Manila, walking along the edge of some very special rice fields, of which there are many on the institute's 500 acres.

"This is the miracle rice—IR8," says Gregorio, as we stop beside an emerald patch of crowded, thigh-high rice plants. Roosters crow in the distance; egrets gleam white against so much green; silvery light glints off the flooded fields. IRRI, a nonprofit, was founded by the Ford and Rockefeller Foundations in 1960. Two years later a plant pathologist named Peter Jennings began a series of crossbreeding experiments. He had 10,000 varieties of rice seeds to work with. His eighth cross—between a dwarf strain from Taiwan and a taller variety from Indonesia—created the fast-growing, high-yielding strain later known as India Rice 8 for its role in preventing famine in that country. "It revolutionized rice production in Asia," says Gregorio. "Some parents in India named their sons IR8."

Walking along the paddies, we pass other landmark breeds, each designated with a neatly painted wooden sign. The institute releases dozens of new varieties every year; about a thousand have been planted around the world since the 1960s. Yields have typically improved by just under one percent a year. "We want to raise that to 2 percent," Gregorio says. The world's population growth rate, now 1.14 percent a year, is projected to slow to 0.5 percent by 2050.

For many decades IRRI focused on improving traditional varieties of rice, grown in fields that are flooded at planting time. Lately it has shifted its attention to climate change. It now offers drought-tolerant varieties, including one that can be planted in dry fields and subsist on rainfall, as corn and wheat do. There's a salt-tolerant rice for countries like Bangladesh, where rising seas are poisoning rice fields. "Farmers don't realize the salt water is coming into their fields," says Gregorio. "By the time the water is salty enough to taste, the plants are already dying."

Only a few of the rice varieties at IRRI are GM crops, in the sense that they contain a gene transferred from a different species, and none of those are publicly available yet. One is Golden Rice, which contains genes from corn that allow it to produce beta-carotene; its purpose is to combat the global scourge of vitamin A deficiency. Last summer an IRRI test plot of Golden Rice was trampled by anti-GM activists. IRRI creates GM varieties only as a last resort, says director Robert Zeigler, when it can't find the desired trait in rice itself.

Yet the institute's entire breeding operation has been accelerated by modern genetics. For decades IRRI breeders patiently followed the ancient recipe: Select plants with the desired trait, cross-pollinate, wait for the offspring to reach maturity, select the best performers, repeat.

Marker-assisted selection

When genes for a trait aren't precisely known, targeting a DNA marker near them can speed up breeding: It identifies plants with the trait even before they mature.

Genetic modification

Genes identified in one species can be transferred directly to an unrelated species, giving it an entirely new trait—resistance to a pest, say, or to a weed killer.

Mutation breeding

Seeds are irradiated to promote random mutations in their DNA. If a mutation happens to produce a desirable trait, the plant is selected for further breeding.

Now there's an alternative to that painstaking process. In 2004 an international consortium of researchers mapped the entire rice genome, which comprises some 40,000 individual genes. Since then, researchers around the world have been pinpointing genes that control valuable traits and can be selected directly.

In 2006, for example, plant pathologist Pamela Ronald of the University of California, Davis, isolated a gene called *Sub1* from an East Indian rice variety. Seldom grown now because of its low yields, the East Indian rice has one remarkable characteristic: It can survive for two weeks underwater. Most varieties die after three days.

Researchers at IRRI cross-pollinated *Sub1* rice with a high-yielding, flavorful variety called Swarna, which is popular in India and Bangladesh. Then they screened the DNA to determine which seedlings had actually inherited the *Sub1* gene. The technology, called marker-assisted breeding, is more accurate and saves time. The researchers didn't have to plant the seedlings, grow them, and then submerge them for two weeks to see which would survive.

The new flood-tolerant rice, called Swarna-Sub1, has been planted by nearly four million farmers in Asia, where every year floods destroy about 50 million acres of rice. One recent study found that farmers in 128 villages in the Indian state of Odisha, on the Bay of Bengal, increased their yields by more than 25 percent. The most marginal farmers reaped the most benefit.

"The lowest castes in India are given the worst land, and the worst lands in Odisha are prone to flooding," says Zeigler. "So here is a very sophisticated biotechnology—flood-tolerant rice—that preferentially benefits the poorest of the poor, the Untouchables. That's a helluva story, I think."

The institute's most ambitious project would transform rice fundamentally and perhaps increase yields dramatically. Rice, wheat, and many other plants use a type of photosynthesis known as C3, for the three-carbon compound they produce when sunlight is absorbed. Corn, sugarcane, and some other plants use C4 photosynthesis. Such crops require far less water and nitrogen than C3 crops do, "and typically have 50 percent higher yields," says William Paul Quick of IRRI. His plan is to convert rice into a C4 crop by manipulating its own genes.

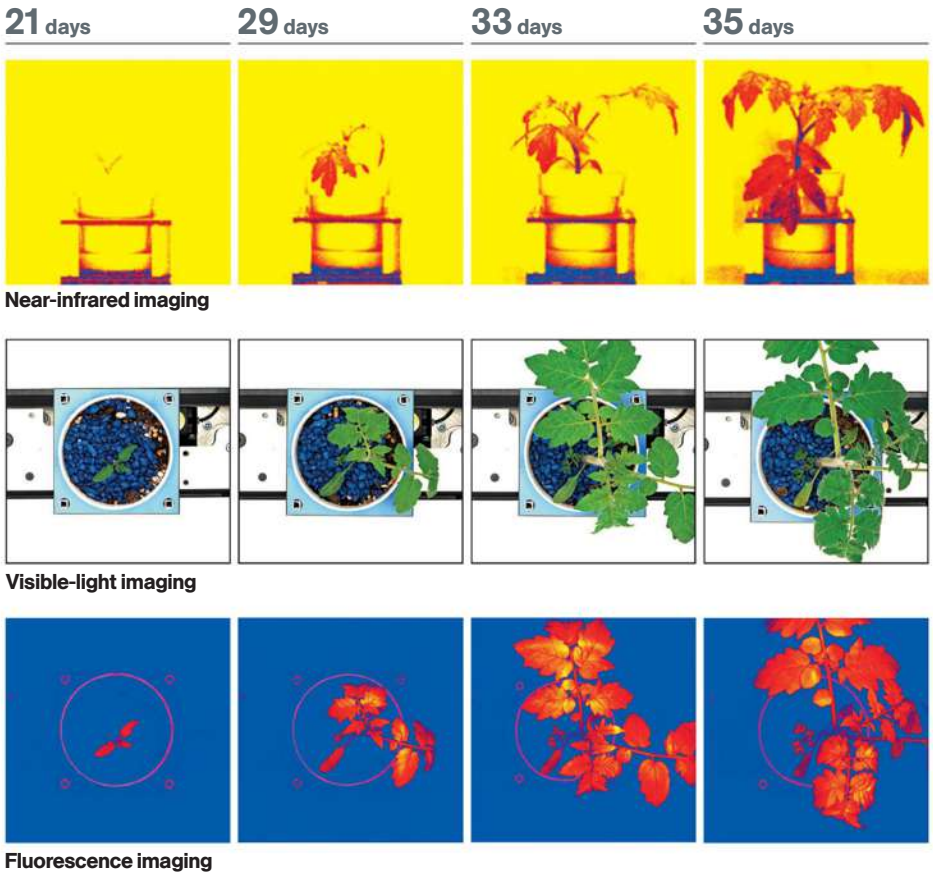
C4 photosynthesis, unlike the submergence tolerance of *Sub1* rice, is controlled by many genes, not just one, which makes it a challenging trait to introduce. On the other hand, says Quick, "it has evolved independently 62 times. That suggests it can't be that difficult to do." By "knocking out" genes one by one, he and his colleagues are systematically identifying all the genes responsible for photosynthesis in *Setaria viridis,* a small, fast-growing C4 grass. So far all the genes they've found are also present in C3 plants. They're just not used in the same way.

Quick and his colleagues hope to learn how to switch them on in rice. "We think it will take

ART: OLIVER MUNDAY. SOURCE: JANELLE JUNG, INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)

The Search for a Less Thirsty Tomato

To find out how tomato plants resist drought, Danforth Center researchers cut their water ration 18 days after planting, then monitor them using three kinds of imaging. Near-infrared images show the plant's water content. Fluorescence images show where photosynthesis is occurring.



DAN CHITWOOD, MALIA GEHAN, NOAH FAHLGREN, AND MINDY WILSON, DONALD DANFORTH PLANT SCIENCE CENTER (ABOVE)

Tomatoes are typically grown in hot, dry climates with a lot of irrigation water—more than 13 gallons per tomato on average. To create less thirsty varieties, Dan Chitwood's team at the Donald Danforth Plant Science Center in St. Louis are crossing tomato plants with a wild relative from Peru's Atacama Desert, one of the driest places on Earth.

"We do feel a bit betrayed by the environmental movement, I can tell you that." ***–Robert Zeigler***

a minimum of 15 years to do this," Quick says. "We're in year four." If they succeed, the same techniques might help enhance the productivity of potatoes, wheat, and other C3 plants. It would be an unprecedented boon to food security; in theory yields could jump by 50 percent.

Prospects like that have made Zeigler a passionate advocate of biotechnology. White-bearded and avuncular, a self-described old lefty, Zeigler believes the public debate over genetically modified crops has become horribly muddled. "When I was starting out in the '60s, a lot of us got into genetic engineering because we thought we could do a lot of good for the world," he says. "We thought, These tools are fantastic!

"We do feel a bit betrayed by the environmental movement, I can tell you that. If you want to have a conversation about what the role of large corporations should be in our food supply, we can have that conversation—it's really important. But it's not the same conversation about whether we should use these tools of genetics to improve our crops. They're both important, but let's not confound them."

Zeigler decided on his career after a stint as a science teacher in the Peace Corps in 1972. "When I was in the Democratic Republic of the Congo, I saw a cassava famine," he says. "That's what made me become a plant pathologist."

WHICH VISION OF AGRICULTURE is right for the farmers of sub-Saharan Africa? Today, says Nigel Taylor, a geneticist at the Donald Danforth Plant Science Center in St. Louis, Missouri, the brown streak virus has the potential to cause another cassava famine. "It has become an epidemic in the last five to ten years, and it's getting worse," he says. "With higher temperatures, the whitefly's range is expanding. The great concern is that brown streak is starting to move into central Africa, and if it hits the massive cassava-growing areas of West Africa, you've got a major food-security issue."

Taylor and other researchers are in the early stages of developing genetically modified cassava varieties that are immune to the brown streak virus. Taylor is collaborating with Ugandan researchers on a field trial, and another is under way in Kenya. But only four African countries—Egypt, Sudan, South Africa, and Burkina Faso—currently allow the commercial planting of GM crops.

In Africa, as elsewhere, people fear GM crops, even though there's little scientific evidence to justify the fear. There's a stronger argument that high-tech plant breeds are not a panacea and maybe not even what African farmers need most. Even in the United States some farmers are having problems with them.

A paper published last March, for instance, documented an unsettling trend: Corn rootworms are evolving resistance to the bacterial toxins in Bt corn. "I was surprised when I saw the data, because I knew what it meant—that this technology was starting to fail," says Aaron Gassmann, an entomologist at Iowa State University and co-author of the report. One problem, he says, is that some farmers don't follow the legal requirement to plant "refuge fields" with non-Bt corn, which slow the spread of resistant genes by supporting rootworms that remain vulnerable to the Bt toxins.

In Tanzania there are no GM crops yet. But some farmers are learning that a simple, low-tech solution—planting a diversity of crops—is one of the best ways to deter pests. Tanzania now has the fourth largest number of certified organic farmers in the world. Part of the credit belongs to a young woman named Janet Maro.

Maro grew up on a farm near Kilimanjaro, the fifth of eight children. In 2009, while still an undergraduate at the Sokoine University of Agriculture in Morogoro, she helped start a nonprofit called Sustainable Agriculture Tanzania (SAT). Since then she and her small staff have been training local farmers in organic practices. SAT now receives support from Biovision, the Swiss organization headed by Hans Herren.

Morogoro lies about a hundred miles west of Dar es Salaam, at the base of the Uluguru Mountains. A few days after my visit with Juma in Bagamoyo, Maro takes me into the mountains to

The magazine thanks The Rockefeller Foundation and members of the National Geographic Society for their generous support of this series of articles.

IR8, the rice in this test plot at the International Rice Research Institute (IRRI) in the Philippines, became known in Vietnam as Honda rice: Bumper crops paid for farmers' motorcycles. In 1966 it started the green revolution, which allowed farmers in Asia to double their yields—and rev up their incomes.

visit three of the first certified organic farms in Tanzania. "Agricultural agents don't come here," she says as we lurch up a steep, rutted dirt road in a pickup. Greened by rains drifting in from the Indian Ocean, the slopes remain heavily forested. But increasingly they've been cleared for farming by the Luguru people.

Every quarter mile or so we pass women walking alone or in small groups, balancing baskets of cassavas, papayas, or bananas on their heads. It's market day in Morogoro, 3,000 feet below us. Women here are more than porters. Among the Luguru, landownership in a family passes down the female line. "If a woman doesn't like a man, out he goes!" Maro says.

She stops at a one-room brick house with partially plastered walls and a corrugated metal roof. Habija Kibwana, a tall woman in a short-sleeved white blouse and wraparound skirt, invites us and two neighbors to sit on her porch.

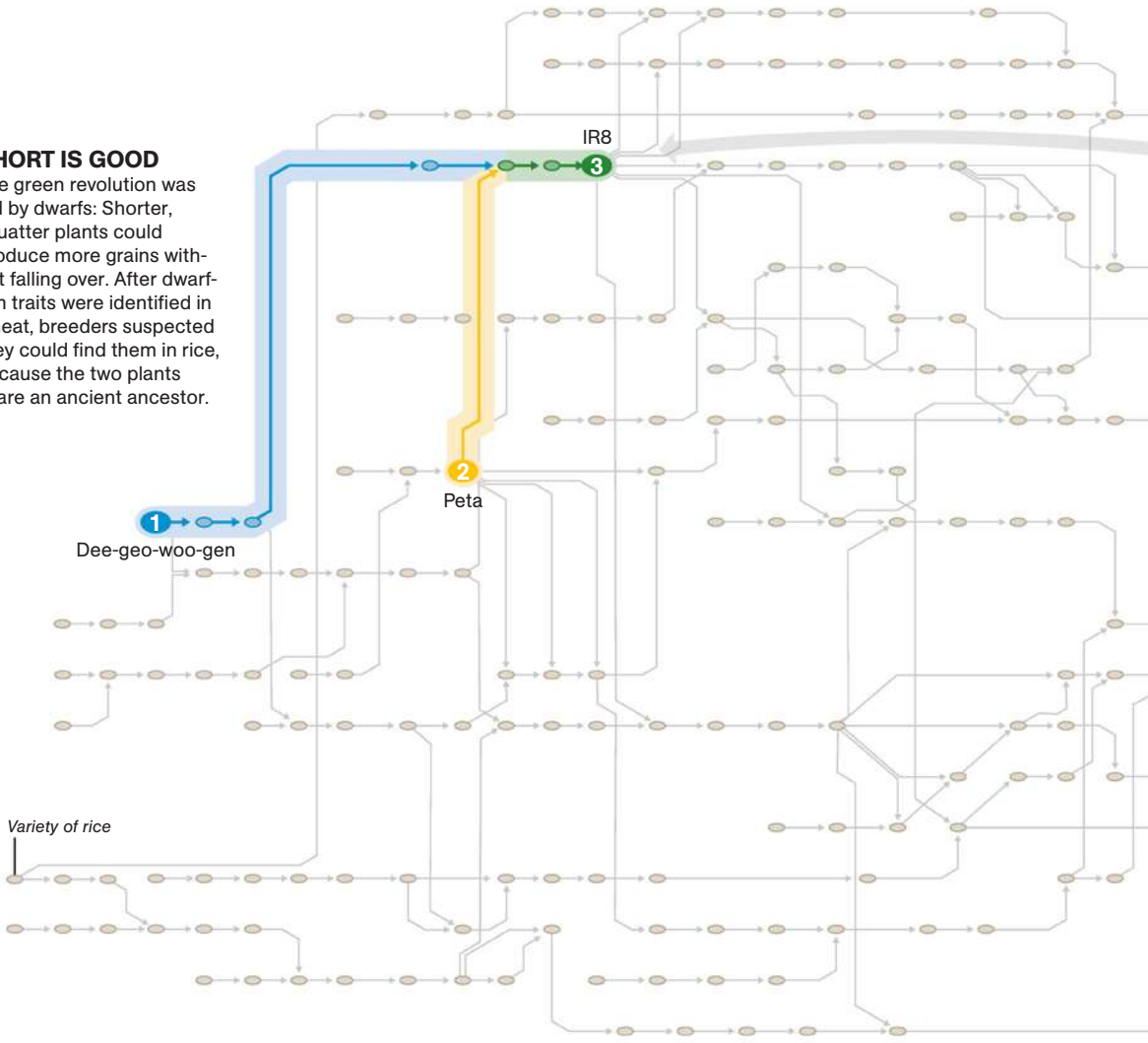
Unlike the farmers in Bagamoyo, Kibwana and her neighbors raise a variety of crops: Bananas, avocados, and passion fruit are in season now. Soon they'll be planting carrots, spinach, and other leafy vegetables, all for local consumption. The mix provides a backup in case one crop fails;

Global warming is raising sea levels and inundating coastal areas. A new strain of rice called IR64 Sub1, seen here in an aquarium at IRRI in the Philippines, can survive for two weeks underwater—a boon for poor farmers in low-lying regions of Asia, where floods destroy 50 million acres of rice every year.

The Path to Flood-Tolerant Rice

When the green revolution began in the 1960s, it was before the revolution in molecular genetics: IR8, the first miracle rice, was bred without knowledge of the genes that blessed it with high yields. Breeders today can zero in on genes, but they still use traditional techniques and ever more complex pedigrees. That's how they've created rice varieties adapted to rising sea levels—including Swarna-Sub1, popular in India, and IR64 Sub1, whose pedigree is shown here.

SHORT IS GOOD
The green revolution was led by dwarfs: Shorter, squatter plants could produce more grains without falling over. After dwarfism traits were identified in wheat, breeders suspected they could find them in rice, because the two plants share an ancient ancestor.



1 Dwarfism
The dwarfism traits were first identified in a Chinese rice variety called Dee-geo-woo-gen (DGWG).

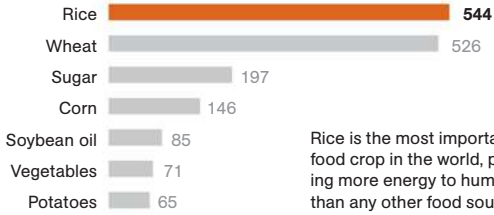
+

2 High Yields
A rice from Indonesia named Peta produced high yields, but it fell over under the weight of its own grains.

=

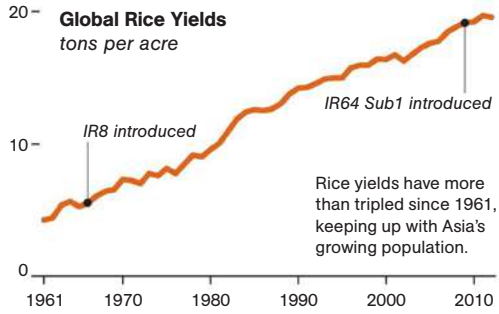
3 Green Revolution
Breeders combined the high yields of Peta with the dwarfism of DGWG to create IR8, a short, strong rice that could carry a heavy load of grain.

Global Food Supply
kilocalories per capita



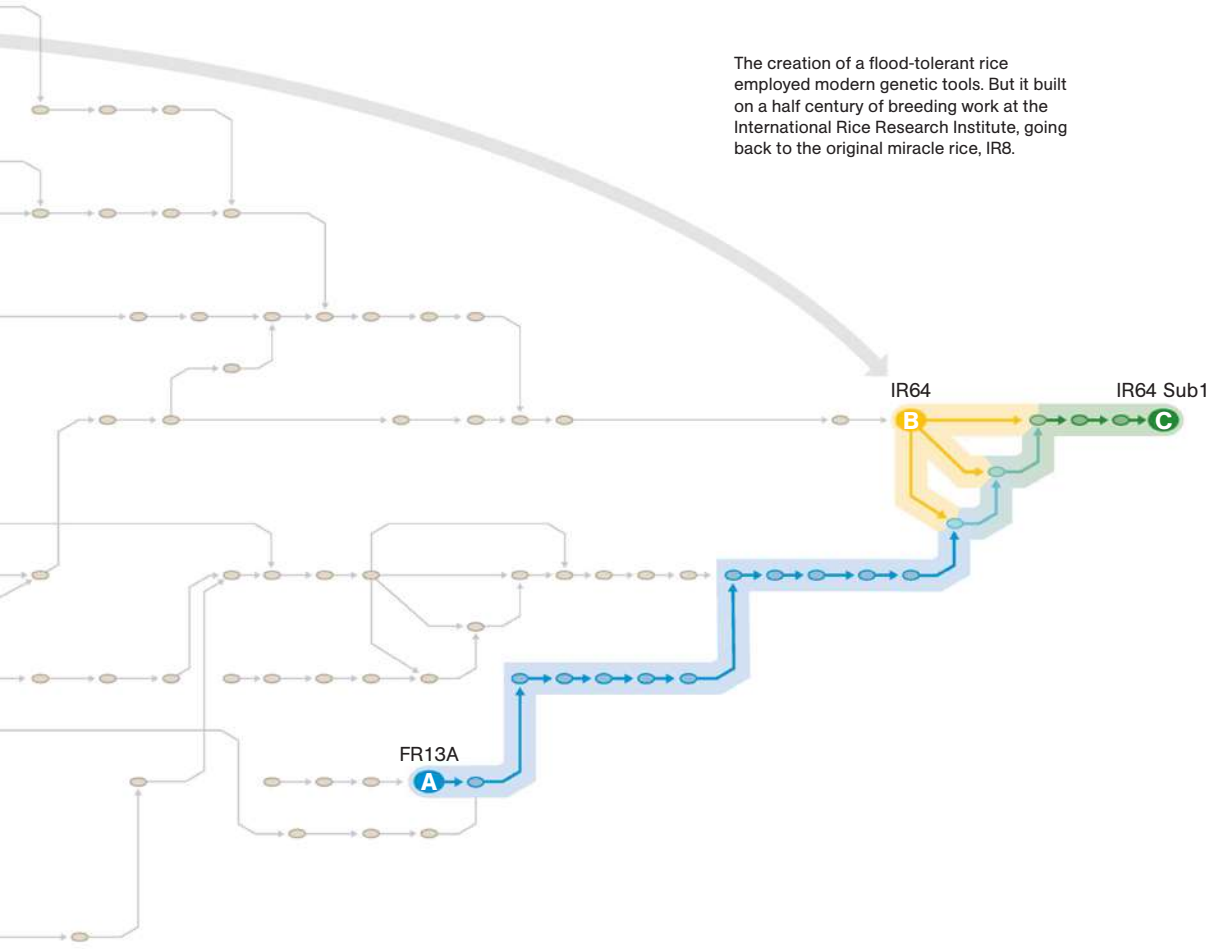
Rice is the most important food crop in the world, providing more energy to humanity than any other food source.

Global Rice Yields
tons per acre



Rice yields have more than tripled since 1961, keeping up with Asia's growing population.

The creation of a flood-tolerant rice employed modern genetic tools. But it built on a half century of breeding work at the International Rice Research Institute, going back to the original miracle rice, IR8.



A Flood Tolerance
A single gene for submergence tolerance, *Sub1*, was isolated in 2006 in a low-yielding indica variety called FR13A.

+

B High Yields
A descendant of IR8, IR64 is a high-yielding variety and widely used, but it doesn't tolerate flooding well.

=

C A Rice for Rising Seas
Advanced breeding techniques, including marker-assisted selection, were used to transfer the gene for submergence tolerance, creating IR64 Sub1.

JASON TREAT, NGM STAFF. SOURCES: JANELLE JUNG, IRRI; FAOSTAT

***The central problem** isn't choosing low-tech or high-tech. It's getting **knowledge that works** to people like Juma.*

it also helps cut down on pests. The farmers here are learning to plant strategically, setting out rows of *Tithonia diversifolia,* a wild sunflower that whiteflies prefer, to draw the pests away from the cassavas. The use of compost instead of synthetic fertilizers has improved the soil so much that one of the farmers, Pius Paulini, has doubled his spinach production. Runoff from his fields no longer contaminates streams that supply Morogoro's water.

Perhaps the most life-altering result of organic farming has been the liberation from debt. Even with government subsidies, it costs 500,000 Tanzanian shillings, more than $300, to buy enough fertilizer and pesticide to treat a single acre—a crippling expense in a country where the annual per capita income is less than $1,600. "Before, when we had to buy fertilizer, we had no money left over to send our children to school," says Kibwana. Her oldest daughter has now finished high school.

And the farms are more productive too. "Most of the food in our markets is from small farmers," says Maro. "They feed our nation."

When I ask Maro if genetically modified seeds might also help those farmers, she's skeptical. "It's not realistic," she says. How could they afford the seeds when they can't even afford fertilizer? How likely is it, she asks, in a country where few farmers ever see a government agricultural adviser, or are even aware of the diseases threatening their crops, that they'll get the support they need to grow GM crops properly? From Kibwana's porch we have sweeping views of richly cultivated terraced slopes—but also of slopes scarred by the brown, eroded fields of nonorganic farmers, most of whom don't build terraces to retain their precious soil. Kibwana and Paulini say their own success has attracted the attention of their neighbors. Organic farming is spreading here. But it's spreading slowly.

That's the central problem, I thought as I left Tanzania: getting knowledge that works from organizations like SAT or IRRI to people like Juma. It's not choosing one type of knowledge—low-tech versus high-tech, organic versus GM—once and for all. There's more than one way to increase yields or to stop a whitefly. "Organic farming can be the right approach in some areas," says Monsanto executive Mark Edge. "By no means do we think that GM crops are the solution for all the problems in Africa." Since the first green revolution, says Robert Zeigler, ecological science has advanced along with genetics. IRRI uses those advances too.

"You see the egrets flying out there?" he asks toward the end of our conversation. Outside his office a flock is descending on the green paddies; the mountains beyond glow with evening light. "In the early '90s you didn't see birds here. The pesticides we used killed the birds and snails and everything else. Then we invested a lot to understand the ecological structures of rice paddies. You have these complex webs, and if you disrupt them, you have pest outbreaks. We learned that in the vast majority of cases, you don't need pesticides. Rice is a tough plant. You can build resistance into it. We now have a rich ecology here, and our yields haven't dropped.

"At certain times of the day we get a hundred or so of those egrets. It's really uplifting to see. Things can get better." ▯

MORE ONLINE ngm.com/more

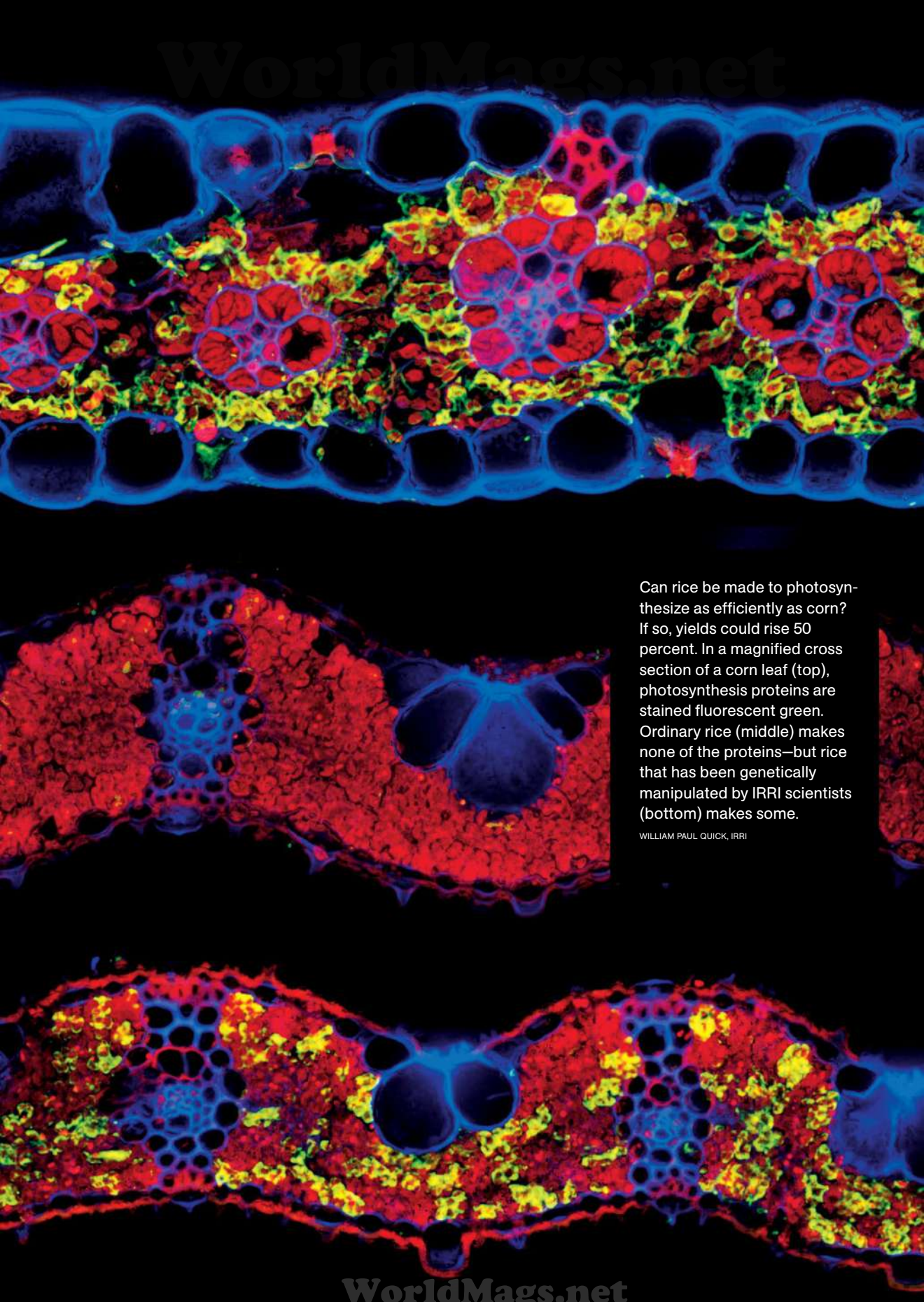
The End of the Florida Orange?

This year's Florida orange crop may be 20 percent smaller than last year's. The culprit is citrus greening, a fatal bacterial infection spread by invasive Asian psyllids to almost all of the state's groves. One way to combat the problem involves heating the trees in tents (right).

INTERVIEW

"Unless you have a concept behind the picture, you're not going to remember it."

—Photographer CRAIG CUTLER shows the detailed drawings he made before shooting this story.



Can rice be made to photosynthesize as efficiently as corn? If so, yields could rise 50 percent. In a magnified cross section of a corn leaf (top), photosynthesis proteins are stained fluorescent green. Ordinary rice (middle) makes none of the proteins—but rice that has been genetically manipulated by IRRI scientists (bottom) makes some.

WILLIAM PAUL QUICK, IRRI

The Future of FOOD natgeofood.com

Going to Pieces

In the chicken business the whole (bird) is worth less than the sum of its parts. About 90 percent of U.S.-raised broiler chickens—those destined for the plate rather than a life of egg laying—are cut up before they are sold. The American appetite for white meat means very few of these birds' breast quarters are exported; palates elsewhere tend to find the meat bland. But the rest of the chicken may go all over the world. Discovering international markets for parts few used to want has been crucial. Chicken-part exports (see maps) grew from 6 percent of production in 1990 to more than 20 percent today.

PHOTO: JOEL SARTORE. NGM MAPS
SOURCES: USA POULTRY & EGG EXPORT COUNCIL; USDA FOREIGN AGRICULTURAL SERVICE
CHINA DATA DO NOT INCLUDE HONG KONG, MACAU, OR TAIWAN.

Wings

Top importer: **China**
Total U.S. exports: 118,980 tons

Wing tips have long been favorites in Asia, but a bump in U.S. consumption is due almost entirely to the popularity of Buffalo chicken wings—a dish first served in an upstate New York bar in 1964.

Feathers

Top importer: **Indonesia**
Total U.S. exports: 210,822 tons

The U.S. poultry industry produces some 1.6 million tons of feathers every year. They are ground up into feather meal and used as animal feed or as plastic fortifiers.

Leg Quarters

Top importer: **Russia**
Total U.S. exports: 2,005,892 tons

In the early 1990s, during the breakup of the Soviet Union, the U.S. government donated chicken legs to help with food shortages; Russians called them *nozhki Busha,* or Bush's legs. Now the need for aid is over, but a taste for dark meat remains.

Viscera

Top importer: **South Africa**
Total U.S. exports: 48,477 tons

Intestines generally go to rendering plants to be ground and used as pet food or fertilizer.

Feet

Top importer: **China**
Total U.S. exports: 330,509 tons

Known as paws in the poultry business, chicken feet were considered worthless until Asian markets were tapped in the early 1990s.

LAKE OROVILLE, CA
Boats crowd a marina in this large reservoir north of Sacramento. The state water system delivers Sierra Nevada snowmelt to 25 million Californians.

When the Snows Fail

The American West faces persistent drought, whether or not relief comes this winter. When will the hard choices be made?

430,000 ACRES IN CALIFORNIA WILL

FARMLAND NEAR AVENAL, CA
This plot is usually planted with wheat, tomatoes, or melons. Last summer water shortages kept many Central Valley fields bare and dusty, worsening the area's already substandard air quality.

PANORAMA COMPOSED OF FIVE IMAGES

BE LEFT FALLOW THIS YEAR DUE TO DROUGHT.

By Michelle Nijhuis
Photographs by Peter Essick

For three generations the Diener family has farmed the same ten square miles of Central Valley dirt. In the 1920s they grew barley and alfalfa to feed the mules that powered the construction of Los Angeles. In the 1930s, as internal combustion replaced animal muscle, they grew cotton to bind rubber car tires.

Today, as California limps through its third year of drought, John Diener, his sons, and their land are getting into the cactus business.

Diener grows produce on as grand a scale as any in the Central Valley, cultivating hundreds of acres of tomatoes, almonds, organic broccoli, and other crops. But he thinks differently from most farmers here. Maybe it's that he's the youngest son of a youngest son, used to making the most of bad situations. Or maybe his years living outside the valley have given him a maverick's confidence.

Whatever the reason, he doesn't put much stock in more dams, fewer environmental restrictions, or any of the other measures his neighbors say will relieve the economic pain. Short-term fixes, he shrugs. "The real problem," he says as he navigates his pickup through the valley's grid of dusty roads, "is that there's just not enough water in the system."

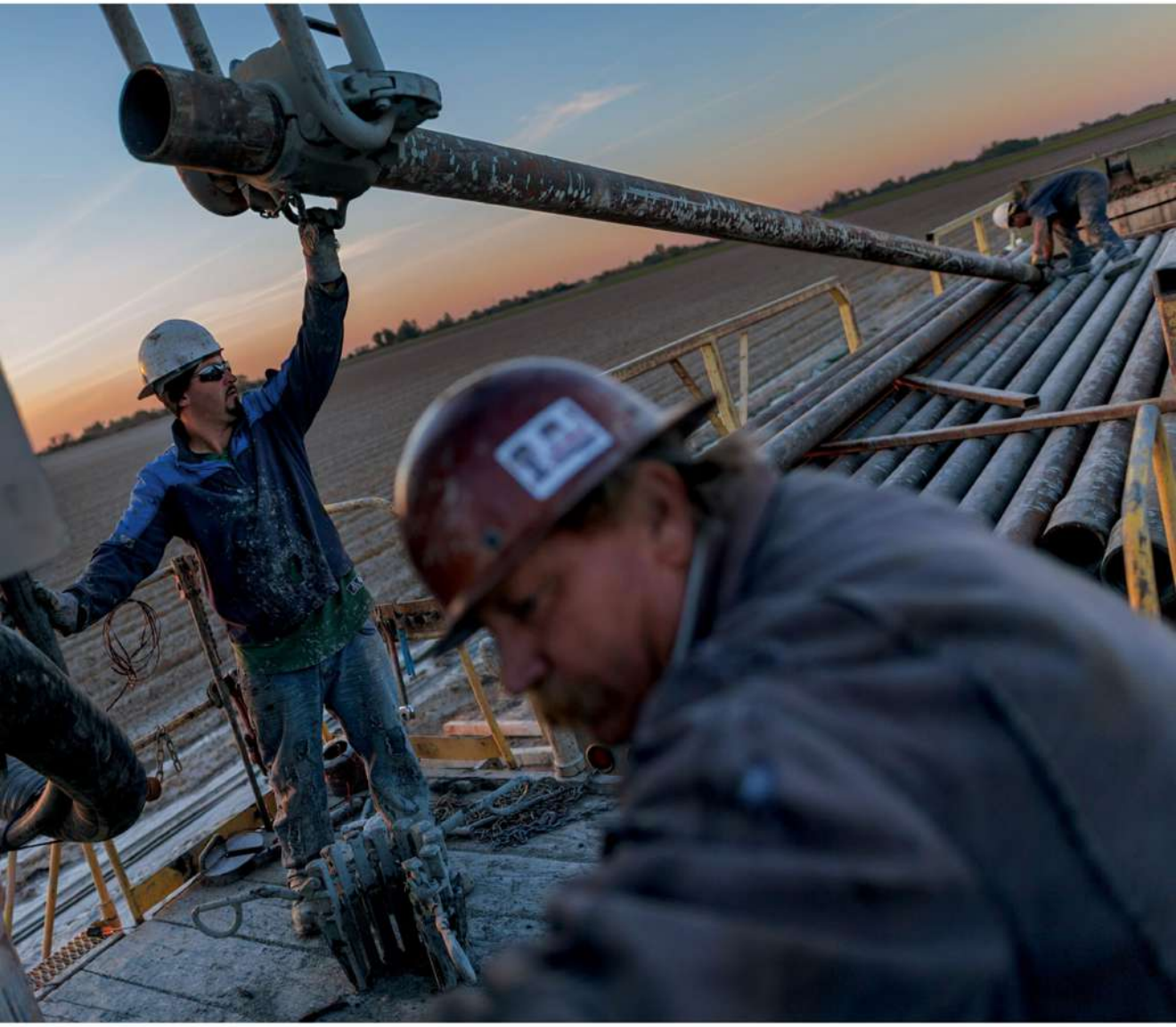
On the western edge of his property, below the snowless hills of California's coastal mountains, Diener stands on the dry dirt between rows of young cacti, inspecting the bright green new growth. In cooperation with researchers at the U.S. Department of Agriculture, Diener has planted about 20 acres of a patented variety of prickly pear cactus, a crop he hopes to sell both as food and as a mineral-rich nutritional supplement. Years of drought have concentrated naturally occurring salts in this field's soil, but the cacti appear to be doing just fine.

"If we need to, we'll plant more," he says. He laughs. "We're opportunists, after all."

WATER DRILLING NEAR HANFORD, CA
With water supplies slashed, farmers have been sinking hundreds of new wells into the region's dwindling groundwater reserves, leaving land vulnerable to subsidence.

Science writer Michelle Nijhuis has covered the West for 15 years. Photographer Peter Essick's work captures the fragile state of our environment.

THE STORY OF THE CENTRAL VALLEY of California is the story of much of the American West, and of other inhabited deserts around the world.



We have altered the driest parts of California, Nevada, and Arizona to fulfill our ambitions, and for years we have been able to ignore their natural limits. Now a growing population and a changing climate are exposing those limits as never before.

And yet the Central Valley is in many ways an agricultural paradise. The soil is rich—remarkably so. The weather is warm—reliably so. More than 300 different crops, from rice and asparagus to pomegranates and oranges, thrive on the valley's wide, flat floor, and at times grow better here than anywhere else in the country. Virtually all of the almonds, olives, and walnuts grown in the United States come from the Central Valley, as does most of the nation's domestic supply of canned tomatoes.

For all its riches the valley looks nothing like paradise, and in drought years like this one, its shortcomings are excruciatingly obvious. Dust

SHASTA DAM, CA
The dam is one of the tallest in the state, and some politicians are lobbying to build it taller still. The reservoir is fed mostly by rainfall, which was less than half of normal this year.

PANORAMA COMPOSED OF TEN IMAGES

SHASTA LAKE WATER LEVELS ARE 65

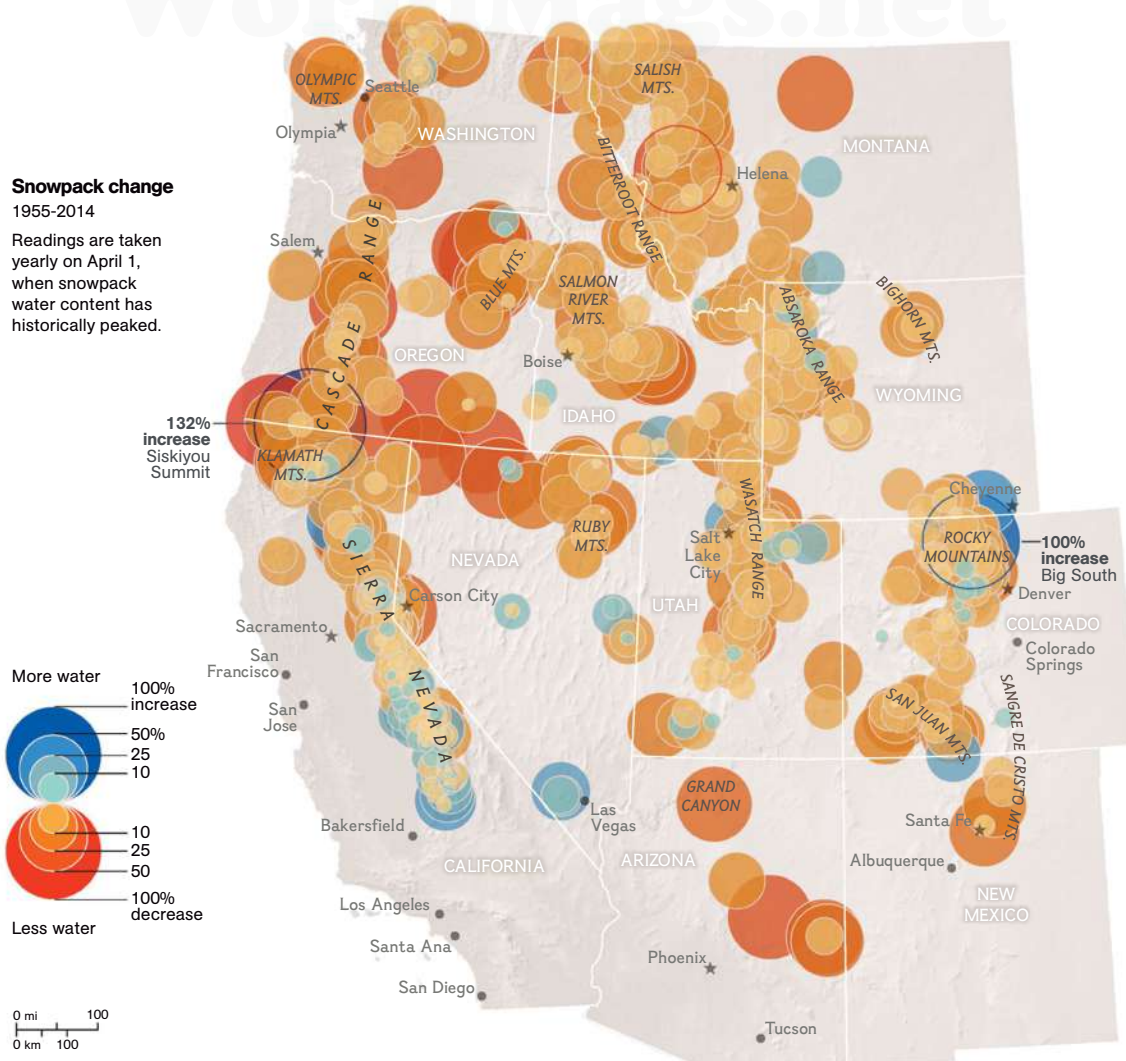
PERCENT BELOW THE HISTORIC AVERAGE.

THE POPULATION OF THE PHOENIX AREA GREW

SUN CITY, AZ
The Central Arizona Project, a 336-mile-long system of canals and pipelines, carries Colorado River water through the desert to the Phoenix metro area.

PANORAMA COMPOSED OF 12 IMAGES


4 TIMES LARGER BETWEEN 1970 AND 2010.



THE IMPACT OF SNOWPACK

Mountain snowpacks are frozen reservoirs, their spring melt supplying as much as 75 percent of the West's water. Decades of measurements, taken by hand or automatic sensors, show dramatic decline.

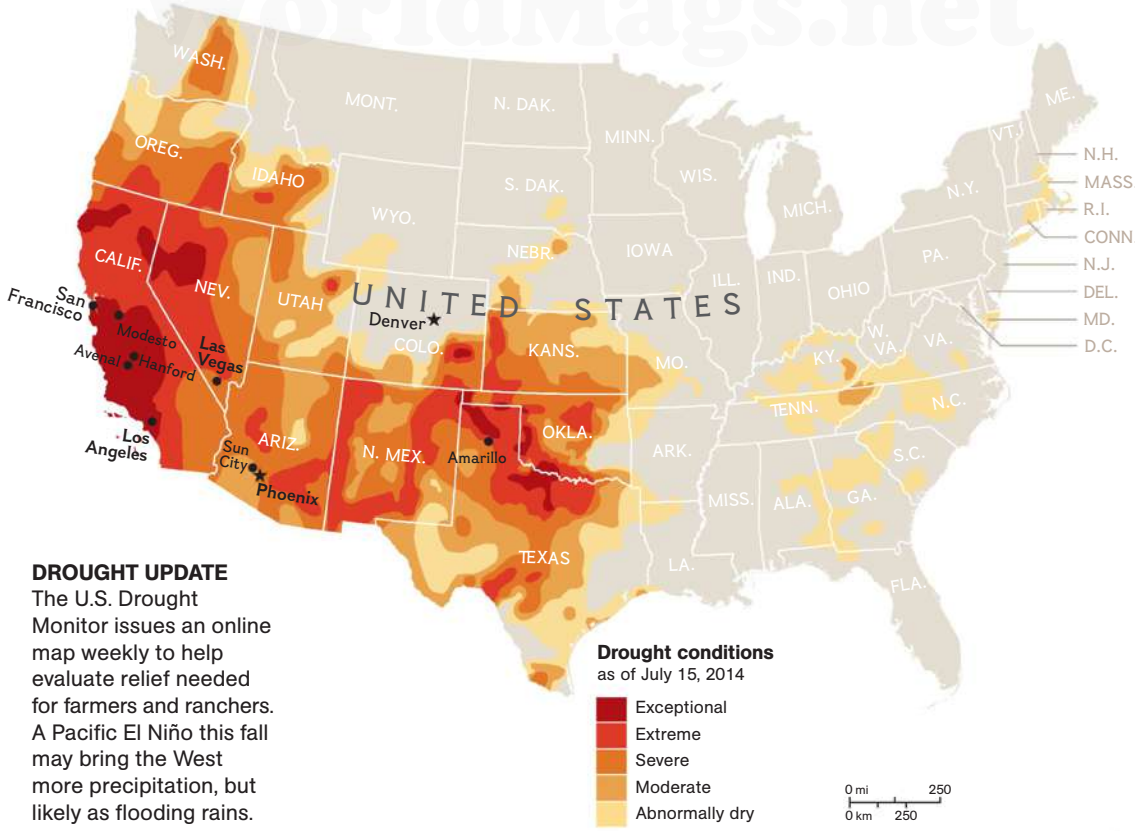
rises from fallowed fields, often thickly enough to obscure the snowcapped Sierra Nevada in the distance. The whole place seems to stagger under a heavy blanket of grit and heat.

Here, where rain is just a lucky break, farmers have long depended on two interconnected sources of water. Many use surface flows from the San Joaquin and Sacramento Rivers, divvied up according to water rights that date back to the 19th century and delivered to fields via a complex network of pipes and canals. Most supplement this plumbing with groundwater, and in the driest corners of the valley, aquifers are so overdrawn that fields have sunk by more than 30 feet. "The pattern of groundwater use in California practically defines the term unsustainable," says Jay Famiglietti, a hydrologist from the University of California, Irvine, who uses satellite data to study water supplies.

On this land farming takes money: money for the equipment to move water to fields, money to survive the driest years, and money to fight the constant legal and political battles over water in the state. Most farmers in the Central Valley win

VIRGINIA W. MASON AND KELSEY NOWAKOWSKI, NGM STAFF

SOURCES: NATURAL RESOURCES CONSERVATION SERVICE; CALIFORNIA DEPARTMENT OF WATER RESOURCES; DARRIN SHARP AND PHILIP MOTE, OREGON STATE UNIVERSITY



DROUGHT UPDATE
The U.S. Drought Monitor issues an online map weekly to help evaluate relief needed for farmers and ranchers. A Pacific El Niño this fall may bring the West more precipitation, but likely as flooding rains.

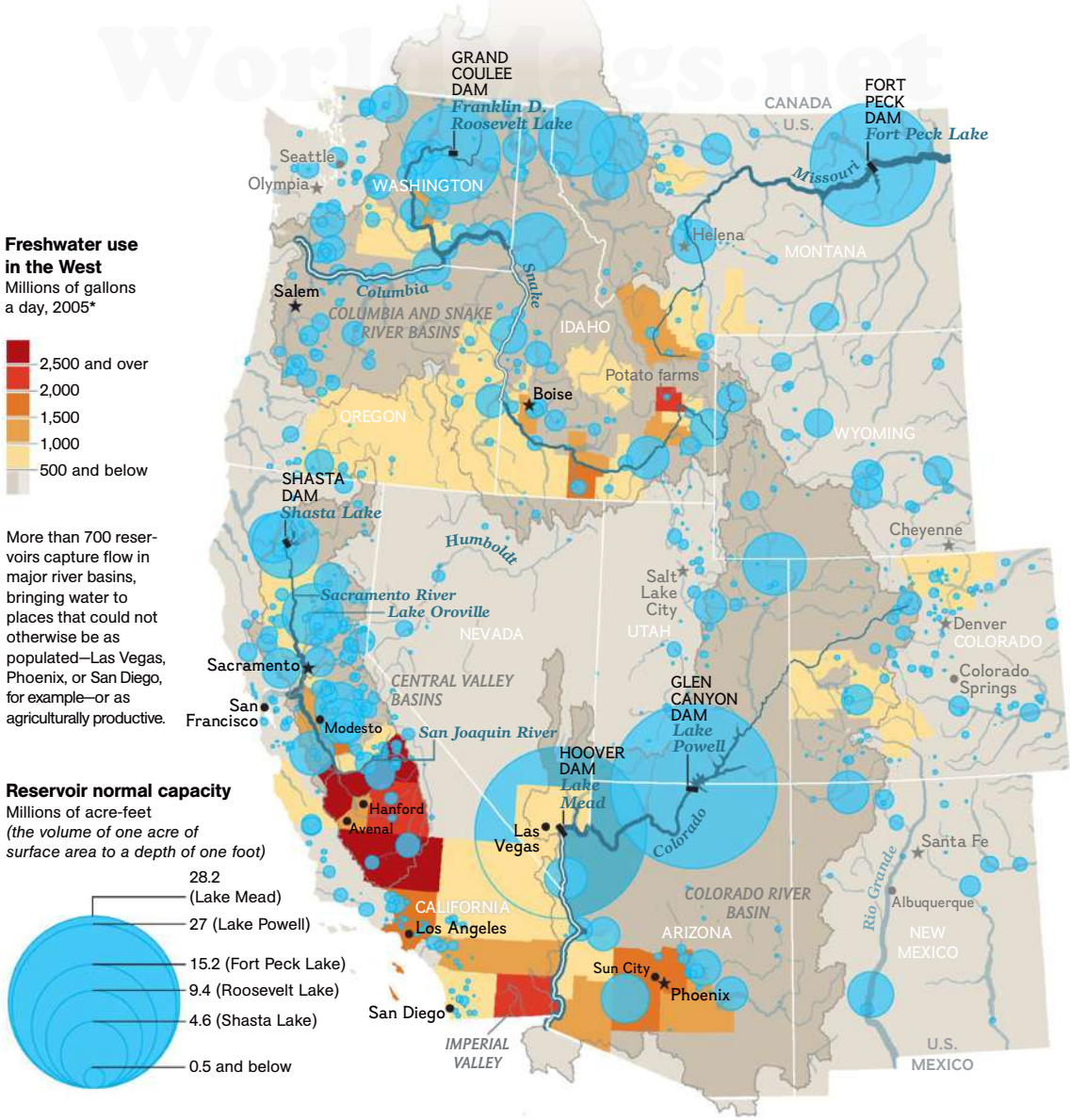
and lose on a grand scale, cultivating hundreds of acres of land and selling millions of dollars of crops every season. Many have invested in lucrative but thirsty crops such as almonds and pistachios, betting that they'll get enough water each year to keep the trees alive.

That gamble is getting riskier. In the western United States, most water arrives in winter storms, which swoop in from the Pacific and dump snow atop the region's mountain ranges. Mountain snowpack serves as the West's water tower, and over the past century Westerners have built hundreds of dams to catch and store snowmelt as it fills the region's rivers in spring. Today most major rivers in the West are saddled with a complex system of dams, canals, and aqueducts. Most years the Colorado River never reaches its mouth in the Gulf of California, and its once lush delta has become a vast mudflat. Salmon and other fish are struggling or gone altogether. Hetch Hetchy, a mountain valley said to have rivaled Yosemite in beauty, was flooded in 1923 to provide water to San Francisco.

Yet in their way these systems work. They built and sustain cities like Phoenix, Las Vegas, Los Angeles, and Denver. They make uninhabitable land habitable. And they make it possible to grow food in places like the Central Valley. The valley represents just under 2 percent of the country's cropland, but in dollar terms it produces nearly half of the nation's fruit and nuts. As the climate changes, scientists predict that the southwestern U.S. will get less precipitation, and the northwestern U.S. will get more. They're not so sure about the future of precipitation in the Central Valley, where it may decrease, increase, or simply fall at different times during the year than it used to.

As in most of the rest of the American West, fortunes depend less on how much precipitation falls from the sky than how much of it falls as snow and how long that snow stays in the mountains. Despite the occasional severe winters, western snowpacks have declined in recent decades, and key researchers expect the trend to accelerate. "Warmer winters are reducing the amount of snow stored in the mountains, and they're causing snowpacks to melt earlier in the spring," says Philip Mote, director of the Oregon Climate Change Research Institute at

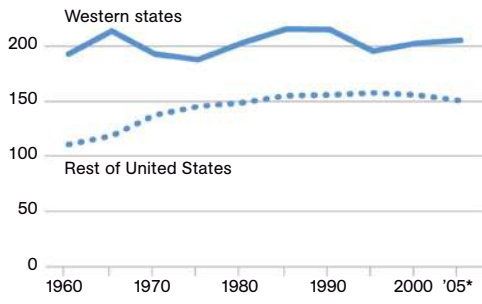
KELSEY NOWAKOWSKI, NGM STAFF; JAMIE HAWK. SOURCE: NATIONAL DROUGHT MITIGATION CENTER



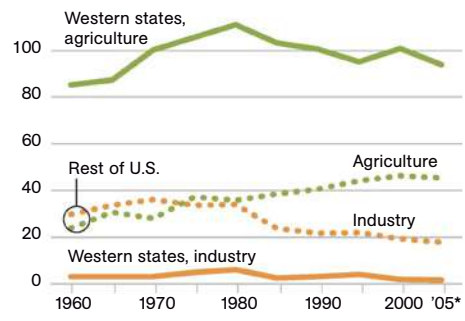
TAPPING THE WEST

U.S. domestic and municipal water use is highest per capita in the West. Naturally dry, the region relies on irrigation to keep landscaping green. California's agricultural dominance accounts for much of the farm-water usage.

Public and domestic water use
Gallons a day per capita



Agriculture and industry water use
Billions of gallons a day



*Most recent data; does not include thermo- and hydroelectric power

VIRGINIA W. MASON AND KELSEY NOWAKOWSKI, NGM STAFF
SOURCE: NANCY BARBER, USGS

SHASTA LAKE, CA
Before the 602-foot-high Shasta Dam was completed in 1945, the pine and fir forests were logged. As the reservoir contracted this spring, tree stumps—some of which were preserved underwater for 60 years—were exposed.

Oregon State University. Shrinking snowpacks and earlier snowmelts mean—in practical terms—that the region faces a persistent and worsening drought.

Early this year, as the East Coast shivered, California baked. January wildfires burned suburban homes, a sinking reservoir exposed the long-drowned ruins of a gold rush town, and in the spring, Yosemite Falls shrank to a trickle. As the drought crept toward historic levels, the political conversation settled into familiar ruts.

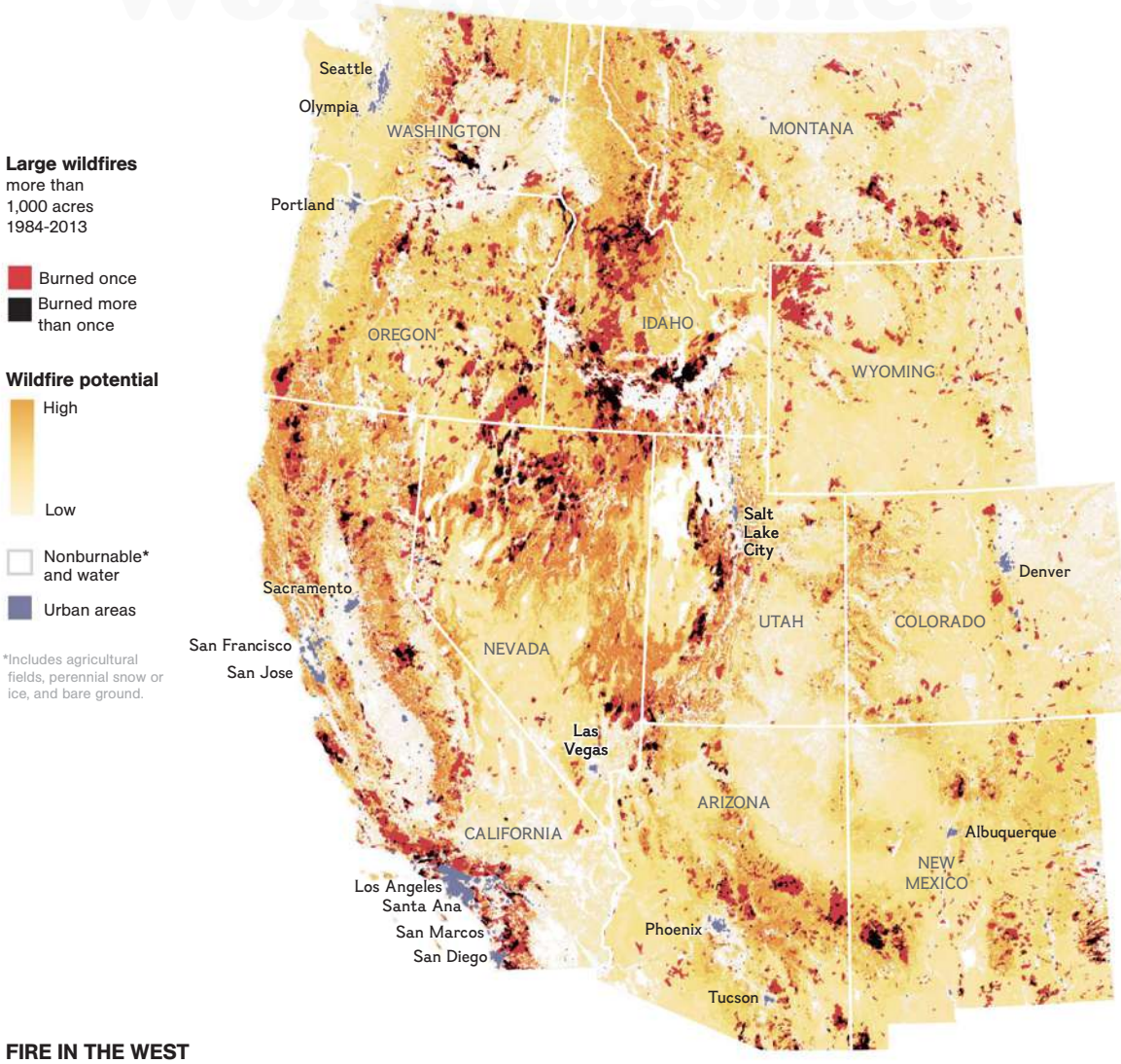
Farmers called on Congress to lift protections for endangered fish species. Urbanites pointed out that an average of 41 percent of California's water is used for agriculture, while less than 11 percent goes to cities (nearly 49 percent stays in the rivers). Sound bites prevailed, and any sign of rain silenced the conversation entirely.

"And it never failed that during the dry years the people forgot about the rich years," John Steinbeck wrote in his 1952 epic, *East of Eden,* a family tragedy set in the Salinas Valley of the early 20th century, "and during the wet years they lost all memory of the dry years."

Such forgetfulness is almost a western birthright. But it doesn't have to be. For proof, look to Australia, a place with deep parallels to California and the West.

Both California and Australia have desert cores and a temperate, urbanized edge. Both depend on complex plumbing to move their water: In fact, the pair of Canadian brothers who built some of California's first irrigation systems in the late 1800s also helped engineer the water-delivery systems of Australia's arid Murray-Darling Basin.

Australia's Big Dry, a decade-long drought that began around the start of this century, led at first to the same kind of political bickering heard recently in California. But after years of environmental destruction, urban water stress, and great suffering by many dryland farmers, Australian politicians—and farmers—took some serious risks. "At the peak of the drought, it became very apparent that the environment doesn't lie," says Mike Young, a professor at the University of Adelaide who was active in the country's drought response. Australia reduced urban water use by investing billions in conservation, education, and efficiency improvements.



FIRE IN THE WEST
Vegetation such as chaparral and ponderosa pine flourishes with occasional wildfires. But a drier West has seen more frequent and intense burns. Protecting a rising population has hiked firefighting costs.

Most important, it began to reform the old water allocation system, which, like California's, had promised specific amounts of water to rights holders. The country instituted a system that guaranteed a minimum supply of water for the environment, then divided the remainder into shares that could be quickly sold and traded—or stored for the next season. Farmers fought the changes, but with a financial incentive to use less water, they soon got more creative and more efficient. Water use dropped, and though consumption has risen since the drought eased in 2010, it remains below pre-drought levels in towns and cities.

California's water system—with annual expenditures exceeding $30 billion—is a long way from following Australia's "shining example," says University of California, Berkeley, economist Michael Hanemann. "California and most of the West haven't done a damn thing to put ourselves in a good position to handle drought," he says. "We have been unwilling to make the sort of changes ahead of time that we absolutely need [to make] to face a drier future."

VIRGINIA W. MASON, KELSEY NOWAKOWSKI, AND LAUREN E. JAMES, NGM STAFF
SOURCES: U.S. FOREST SERVICE; USGS; MONITORING TRENDS IN BURN SEVERITY PROJECT; PHILIP E. DENNISON, UNIVERSITY OF UTAH

WILDFIRE NEAR SAN MARCOS, CA
Hills and canyons burn in the Cocos fire, which ravaged San Diego County in mid-May. Because of drought and rising temperatures, the western wildfire season now lasts at least two months longer than just a few decades ago.

Yet after decades of unregulated, unsustainable pumping of groundwater in California, some regional authorities have instituted rules to protect groundwater supplies. Los Angeles and other large cities have dramatically improved water efficiency. "There's a lot of slack in the system that we've tolerated for a long time, just because we could get away with it," says Peter Gleick, president of the Pacific Institute. "Now we have to learn to live within the limits of what nature provides."

The story of water in the American West hasn't changed: It's still a tale of ambition and optimism, both in dangerous amounts. But the California drought, and the droughts to come, could force the start of a new chapter.

John Diener plans to be part of it. Unlike many Central Valley farmers, he hasn't moved into Fresno, to farm at a distance. He still attends church in nearby Riverdale, and when pressed for time, he goes to the Spanish-language Mass at the mission church his aunt and uncle established in the 1940s. But although he's attached to the place, and to the land his family claimed nearly a century ago, he's a pragmatist to the core.

This year Diener didn't receive any river water, so he fallowed half his acreage. He planted tomatoes and broccoli, watering them with the high-efficiency underground drip systems he's purchased in recent years. He is working with a local public-private partnership to turn his sugar beets into ethanol. And of course, he's tending his 20 acres of cactus. He's not making money off his plants yet, but he's optimistic that they will find a market: Prickly pear pads, or nopals, are a wildly popular vegetable in Mexico and elsewhere in Latin America, and they have value as selenium-rich supplements. It's hardly the future his uncle and father expected. But if the elder Dieners were here today, they'd probably approve. Adaptation helped them survive too. ▯

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INTERACTIVE

Motion graphics show the crucial role of snowmelt in irrigating California's Central Valley.

SEAN M. HAFFEY, SAN DIEGO UNION-TRIBUNE/ZUMA (WILDFIRE)

IN THE CENTRAL VALLEY, WATER IN WILDLIFE

REFUGES IS DOWN BY AROUND 30 PERCENT.

GEESE NEAR MODESTO, CA
On their journey north, migratory geese congregate on the Faith Ranch near the San Joaquin River National Wildlife Refuge, one of the Central Valley's few scraps of native wildlife habitat.


IN EARLY 2014 NO WATER

RYE PATCH DAM ON THE HUMBOLDT RIVER, NV
Mark Twain called the Humboldt River a “sickly rivulet,” but farmers in the fertile yet arid Lovelock Valley depend on it to fill the near-empty reservoir with water for their alfalfa and corn.

REACHED THIS NEVADA DAM.

Svans in the collection of villages that make up Ushguli—a World Heritage site—hold on to deep traditions. Horses still provide reliable transport throughout the largely roadless Svaneti.

Medieval Mountain Hideaway

In Svaneti, high in Georgia's Caucasus Mountains, centuries-old defensive towers loom over remote villages.

Student Nana Merlani rehearses with the Lagusheda Folk Ensemble in the town of Mestia. Learning traditional dances and songs in the Svan language, the troupe is part of a mainly youth-led cultural revival.

Illuminated by birch torches, villagers in Mulakhi pour alcohol on the graves of relatives in a midwinter commemoration called Lamproba. Predating the arrival of Christianity, it is now timed to Christmas and Easter.

By Brook Larmer
Photographs by Aaron Huey

THE MEN GATHER AT DAWN near the stone tower, cradling knives in callused hands. After a night of snowfall—the first of the season in Svaneti, a region high in Georgia's Caucasus Mountains—the day has broken with icy clarity. Suddenly visible above the village of Cholashi, beyond the 70-foot-high towers that form its ancient skyline, is the ring of 15,000-foot peaks that for centuries has kept one of the last living medieval cultures barricaded from the outside world.

Silence falls as Zviad Jachvliani, a burly former boxer with a salt-and-pepper beard, leads the men—and one recalcitrant bull—into a yard overlooking the snow-dusted valley. No words are needed. Today is a Svan feast day, *ormotsi,* marking the 40th day after the death of a loved one, in this case Jachvliani's grandmother. The men know what to do, for Svan traditions—animal sacrifices, ritual beard cutting, blood feuds—have been carried out in this wild corner of Georgia for more than a thousand years. "Things are changing in Svaneti," Jachvliani, a 31-year-old father of three, says. "But our traditions will continue. They're part of our DNA."

In the yard he maneuvers the bull to face east, where the sun has crept above the jagged crown of Mount Tetnuldi, near the Russian border. Long before the arrival of Christianity in the first millennium, Svans worshipped the sun, and this spiritual force—along with its derivative, fire—still figures in local rituals. As the men with knives gather in front of him, Jachvliani pours a shot of moonshine on the ground, an offering to his grandmother. His elderly uncle chants a blessing. And then his cousin, cupping a candle against the wind, lights the hair on the bull's forehead, lower back, and shoulders. It is the sign of the cross, rendered in fire.

After the blessing, the men lasso one of the bull's legs with a rope and, heaving in unison,

The twin peaks of Svaneti's 15,453-foot Mount Ushba—called the Matterhorn of the Caucasus but more than 750 feet taller—rise from the palette of Misha Mchedliani. Long winters give him time to paint in the Mestia home where he was born and raised.

In times of danger, lowland Georgians sent icons, jewels,

truss the bellowing beast over the branch of an apple tree. Jachvliani grabs its horns, while another villager, unsheathing a sharpened dagger, kneels down next to the bull and, almost tenderly, feels for the artery in its neck.

OVER THE COURSE OF HISTORY many powerful empires—Arab, Mongol, Persian, Ottoman—sent armies rampaging through Georgia, the frontier between Europe and Asia. But the home of the Svans, a sliver of land hidden among the gorges of the Caucasus, remained unconquered until the Russians exerted control in the mid-19th century. Svaneti's isolation has shaped its identity—and its historical value. In times of danger, lowland Georgians sent icons, jewels, and manuscripts to the mountain churches and towers for safekeeping, turning Svaneti into a repository of early Georgian culture. The Svans took their protective role seriously; an icon thief could be banished from a village or, worse, cursed by a deity.

In their mountain fastness the people of Svaneti have managed to preserve an even older culture: their own. By the first century B.C. the Svans, thought by some to be descendants of Sumerian slaves, had a reputation as fierce warriors, documented in the writings of the Greek geographer Strabo. (Noting that the Svans used sheepskins to sift for gold in the rivers, Strabo also fueled speculation that Svaneti might have been the source of the golden fleece sought by Jason and the Argonauts.) By the time Christianity arrived, around the sixth century, Svan culture ran deep—with its own language, its own densely textured music, and complex codes of chivalry, revenge, and communal justice.

If the only remnants of this ancient society were the couple of hundred stone towers that rise over Svan villages, that would be impressive enough. But these fortresses, built mostly from the 9th century into the 13th, are not emblems of a lost civilization; they're the most visible signs of a culture that has endured almost miraculously through the ages. The Svans who still live in Upper Svaneti—home to some of the highest and most isolated villages in the Caucasus—hold fast to their traditions of singing, mourning, celebrating, and fiercely defending family honor. "Svaneti is a living ethnographic museum," says Richard Bærug, a Norwegian academic and lodge owner who's trying to help save Svan, a largely unwritten language many scholars believe predates Georgian, its more widely spoken cousin. "Nowhere else can you find a place that carries on the customs and rituals of the European Middle Ages."

What happens, though, when the Middle Ages meet the modern world? Since the last years of Soviet rule a quarter century ago, thousands of Svans have migrated to lowland Georgia, fleeing poverty, conflict, natural disasters—and criminal gangs. In 1996, when UNESCO bestowed World Heritage status on the highest cluster of Svan villages, Ushguli, the lone road that snakes into Svaneti was so terrorized by bandits that few dared to visit. Security forces busted the gangs in 2004. And now the government is implementing a plan to turn this medieval mountain zone into a tourist magnet.

Svaneti arguably has seen more change in the past few years than in the past thousand. It's not just the vans full of foreign backpackers discovering the region's pristine trekking routes. In 2012 the government installed power lines to light up even the remotest villages. The road that links most villages of Upper Svaneti will soon be paved all the way to Ushguli. Frenzied construction has transformed the sleepy regional hub of Mestia into a faux Swiss resort town lined with clapboard chalets and bookended by hypermodern government buildings and an airport terminal out of *The Jetsons.* Meanwhile on the flanks of Mount Tetnuldi, directly across the river from Jachvliani's home in Cholashi, one of Georgia's largest ski resorts is beginning to take shape.

Perhaps it makes some kind of karmic sense that the mountains and stone towers that kept outsiders at bay for all these centuries should now be enlisted to lure them in. But will all this change save the isolated region—or doom it?

Beijing-based Brook Larmer is a frequent contributor. Aaron Huey began making photographs in Svaneti in 1999, while he was still in college.

and manuscripts to the mountain churches for safekeeping.

MOUNTAIN FORTRESS
Georgia is geographically in Asia but sees itself as part of Europe. Upper Svaneti, where this story is set, was never conquered by outsiders. Its population, now perhaps 12,000, more than that of Lower Svaneti, has fallen as people have left for better jobs. Yet more tourists are coming, mainly trekkers, climbers, and skiers who are spreading the word about its wild terrain.

Bavchi Kaldani, the old family patriarch in Adishi, speaks in a hoarse whisper, but his words—in the abrupt cadences of Svan—land with force: "If I stop, I'll die." Even at age 86, with gnarled hands and a stooped back, Kaldani insists on carrying on the hard labor of Svan village life: chopping wood with a heavy ax, scything grass for his animals' winter rations, and repairing his family's stone tower.

It's a measure of the precariousness of mountain life that Kaldani too was once tempted to leave Svaneti. Raised in a *machubi*—a traditional stone dwelling for extended families, livestock included—he remembers when Adishi bustled with 60 families, seven churches, and dozens of sacred artifacts. Clan leaders from across Svaneti rode days on horseback to pray before the village's leatherbound Adishi Gospels, dating from 897. Disaster always loomed, however, and Kaldani struggled to stockpile enough for the bitter winters, which even today cut off Adishi from the rest of Svaneti. Yet nothing prepared him for the deadly avalanches of 1987. He kept his family safe in the base of their stone tower, but dozens of others died across Svaneti that winter—and the exodus began.

As more Svan families emigrated to lowland Georgia, Adishi became a ghost town. At one point only four families remained—Kaldani and his wife, the village librarian, among them. Kaldani's sons, who had also abandoned Adishi, persuaded their parents to join them one winter

Family and friends gather at a *supra,* or feast table, where men and women sit separately, to celebrate the first birthday of a family's first child. Eloquent toasts, both to guests and their ancestors, can go on for hours.

During a holy festival in Kala, men compete to ring a bell weighing more than 260 pounds. People come from across Georgia to a nearby church to honor the Orthodox St. Kvirike and a pre-Christian fertility god, Kviria.

Forty days after a death an *ormotsi* ceremony in Ipari marks the release of the soul. A sheet of cheese is stretched like a tablecloth over bread for a feast.

Kaldani is one of the last village mediators, called upon

on the arid plains. They lasted four months before rushing back to Adishi. "My family has lived here for more than 1,200 years," he says. "How could I let my village disappear?"

Going about his chores in his traditional woolen cap, Kaldani embodies the persistence of Svan culture—and the peril it faces. He is one of the few remaining fully fluent speakers of Svan. He is also one of the last village mediators, who have long been called upon to adjudicate disputes ranging from petty theft to long-running blood feuds. The obligation to defend family honor, though slightly tempered today, led to so many vendettas in early Svan society that scholars believe the stone towers were built to protect families not just from invaders and avalanches but also from one another.

In the chaos after the fall of the Soviet Union, blood feuds returned with a vengeance. "I never rested," Kaldani says. In some cases, after negotiating a blood price (usually 20 cows for a murder), he brought feuding families to a church and made them swear oaths on icons and baptize one another. The ritual, he says, ensures that the families "will not feud for 12 generations."

Blood feuds have virtually disappeared in Svaneti over the past decade, but the ancient justice codes, carried out by mediators like Kaldani, persist. Other village traditions endure too. Every August one local family hosts Adishi's annual feast day, Lichaanishoba, drawing former villagers from the lowlands and couples praying for a son or giving thanks for the birth of one. Each couple brings a sheep as an offering, along with a jug of home-brewed spirits. In the summer of 2013, 500 people showed up. On a knoll next to

Oleg Samsiani lingers over breakfast with his three sons in the village of Ieli. He left Svaneti for work when he was younger but came back to raise a family.

to adjudicate disputes ranging from theft to blood feuds.

the tiny 12th-century Church of St. George, 32 sheep were blessed and sacrificed.

From atop the Kaldanis' 50-foot stone tower, Adishi looks beautiful and forsaken. Rusted shutters swing in the breeze. Pine trees sprout from half-collapsed towers. The river below has washed out the dirt road leading to the village, making it accessible only on foot or horseback. Yet Adishi is coming back to life, thanks to Kaldani's stubbornness and to the village's location along a popular trekking route. In the past two years seven families have moved back to rebuild their homes and open small guesthouses, bringing the full-time population up to nearly 30. As two of Kaldani's neighbors sharpen their scythes for the final days of grass cutting before winter, Adishi no longer feels abandoned. It feels reborn.

THE SONG OF LOVE and vengeance begins softly, with a lone voice tracing the line of an ancient melody. Other voices in the unheated room off Mestia's main square soon join in, building a dense progression of harmonies and countermelodies that grows in urgency until it resolves in a single note of resounding clarity.

This is some of the world's oldest polyphonic music, a complex form that features two or more simultaneous lines of melody. It predates the arrival of Christianity in Svaneti by centuries. Yet none of the musicians in the room this autumn afternoon is over 25. When the session ends, the young men and women spill out into the square, chatting and laughing and air kissing—and thumbing their mobile phones. "We're all on Facebook," says Mariam Arghvliani, a 14-year-old girl who plays three ancient stringed

Some 200 towers, like these in Ushguli—built mainly from the 9th into the 13th centuries for shelter during wars, raids, and blood feuds—remain in Svaneti. Now they're used to store hay and grain for farm animals, including pigs.

Candles on its horns, a bull is blessed at a tenth-century church near Mestia before being sacrificed for a February feast dating from pre-Christian times.

The severed head of the other bull, sacrificed in honor of

instruments (including an L-shaped Svan wooden harp) for her youth folk ensemble, Lagusheda. "But that doesn't mean we forget our heritage."

It's one of Svaneti's bittersweet ironies that even as its language dies out, its traditional music is experiencing a revival. The resurgence is driven not by elders in the villages, the longtime keepers of Svan culture, but by young people in Mestia, a town whose modern aspirations are reflected in the undulating, futuristic police station that faces the stone towers on the slopes above.

Like most in her generation, Arghvliani speaks only a smattering of Svan—"mostly just the lyrics to our songs," she says. But her musical immersion began almost from birth; by age four she was singing in her aunt's choir. Still, her talent might have withered, along with Svan musical tradition, were it not for a youth program launched 13 years ago by Svaneti's charismatic cultural crusader, Father Giorgi Chartolani.

Sitting in his church's graveyard, Chartolani recalls the post-Soviet tumult that endangered a culture already weakened by nearly seven decades of Communist suppression. "Life was brutal then," he says, stroking his long beard. The priest nods at the tombstones, some etched with the images of young men killed in feuds. "Villages were emptying out, our culture was disappearing," he says, noting that 80 out of 120 known Svan songs have disappeared in the past two generations. "Something had to be done." His program, which has taught traditional music and dance to hundreds of students like Arghvliani, was, he says, "a light in the darkness."

Now it illuminates an alternative future. That evening the young musicians return to Mestia's

Village children spend much of the winter skiing. Now, spurred by an expanded airport in Mestia, developers are building modern ski resorts to boost tourism.

Jachvliani's dead grandmother, sits on a wooden table.

square in full festival regalia: boys in burgundy cassocks, silver daggers hanging from their belts; girls in long black peasant dresses. Their audience consists of 50 foreign tourists in colorful parkas, paying six dollars each for the show. The revival of Svan music was under way before tourists began arriving in Svaneti, but it wasn't until 2012 that the all-male ensemble, Kviria, first performed for visitors. The outside world's growing interest in the intricate musical form has had a rebound effect: More Svan children are flocking to Chartolani's classes.

Arghvliani doesn't know yet if she'll pursue a career in traditional music—she loves Beyoncé and dubstep too—or even if she'll stay in Svaneti. She sees her culture moving in two directions: "The Svan language will disappear with my generation," she says. "But the music will live on."

IN SVANETI even old feuds can have lasting repercussions. A century ago in Cholashi, Jachvliani's great-grandfather killed a neighbor to avenge the slaughtering of his prize bull. The feud ended when the Jachvlianis paid the neighbors two and a half acres of farmland and 20 head of cattle, a blood price whose effects can still be felt.

The family now has just one bull. The severed head of the other, sacrificed in honor of Jachvliani's dead grandmother, sits on a wooden table, eyes still open, thick gray tongue lolling sideways. Under the beast's implacable gaze, Jachvliani and the other men of Cholashi devour the ormotsi's ceremonial first dish: a spicy heart-and-liver stew. Later in the day, before the raucous evening feast, Jachvliani and several men who haven't shaved in the 40 days since his grandmother's death gather outside her room.

A prayer, a toast. Then snippets of their scraggly beards are clipped off and placed on an offering table next to her wooden cane.

The dead, like history itself, are kept close in Svaneti. Every month for a year the Jachvlianis will hold smaller feasts in the grandmother's honor. Then, 70 days before Easter, the family will gather for Lamproba, a ceremony for "mentioning souls" that mixes pre-Christian and Christian elements. Jachvliani and his male relatives will carry flaming birch branches through the snow and lay them next to her grave. Toasts and prayers will be shared until the torches burn out.

How long will the embers of tradition keep smoldering in Svaneti? On the morning after the ormotsi, a clean-shaven Jachvliani heads across the valley to his new job—on a construction crew paving the dirt road to the top of the pass. The road will eventually go all the way to Ushguli, but work on this section is enabling heavy machinery to access the emerging ski resort on Mount Tetnuldi. Next to the river below Cholashi, a chain-link fence encircles evidence of what's to come: row after row of chairlifts and gondolas.

The looming changes in this valley, along with a proposed hydroelectric dam farther south, unsettle many Svans. What will happen to their villages, their land, their traditions? Jachvliani tries to be optimistic. The ski resort, he says, could inject badly needed resources into their isolated region—and bring back some of the 20 families that left the village. "We need more jobs, more opportunities," he says.

Sitting with his widowed mother near the kitchen hearth, Jachvliani peers out at the mountains silhouetted against the sky. He stayed in Svaneti when his sisters left for lowland Georgia because he was the only son, the last man in the family. Now, at 31, he can't imagine leaving. "Come back in ten years," he says, laughing as his two young daughters climb on his back, "and see if our village has survived." His confidence comes from Svaneti's long history of survival, yes, but also from the simple fact that he is now one of the keepers of the flame. □

A boy and his horse return home to Ushguli, more than 7,000 feet above sea level. Although modern travel, technology, and tourism are bringing the outside world into Svaneti, for now Svans are keeping their family ties and culture strong.

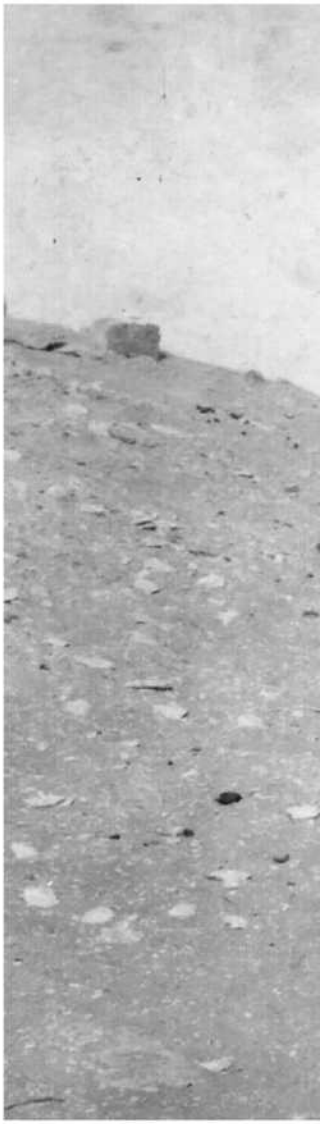
Mister Big

Move over, *T. rex:* The biggest, baddest carnivore to ever walk the Earth is *SPINOSAURUS*.

A model of the Cretaceous predator *Spinosaurus* gets rock star treatment at a photo shoot.

Workers grind the rough edges off an anatomically precise, life-size *Spinosaurus* skeleton created from digital data. Scientists assembled a computer model from CT scans of fossils, images of lost bones, and extrapolations from related creatures, then expressed it in polystyrene, resin, and steel.

By Tom Mueller
Photographs by Mike Hettwer



On the evening of March 3, 2013, a young paleontologist named Nizar Ibrahim was sitting in a street-front café in Erfoud, Morocco, watching the daylight fade and feeling his hopes fade with it. Along with two colleagues, Ibrahim had come to Erfoud three days earlier to track down a man who could solve a mystery that had obsessed Ibrahim since he was a child. The man Ibrahim was looking for was a *fouilleur*—a local fossil hunter who sells his wares to shops and dealers. Among the most valued of the finds are dinosaur bones from the Kem Kem beds, a 150-mile-long escarpment harboring deposits dating from the middle of the Cretaceous period, 100 to 94 million years ago. After searching for days among the excavation sites near the village of El Begaa, the three scientists had resorted to wandering the streets of the town in hopes of running into the man. Finally, weary and depressed, they had retired to a café to drink mint tea and commiserate. "Everything I'd dreamed of seemed to be draining away," Ibrahim remembers.

Ibrahim's dreams were inextricably entangled with those of another paleontologist who had ventured into the desert a century earlier. Between 1910 and 1914 Ernst Freiherr Stromer von Reichenbach, a Bavarian aristocrat, and his team made several lengthy expeditions into the Egyptian Sahara, at the eastern edge of the ancient riverine system of which the Kem Kem forms the western boundary. Despite illness, desert hardships, and the gathering upheaval of World War I, Stromer found some 45 different

PALEONTOLOGY PIONEER Ernst Stromer tirelessly explored the eastern Sahara on the eve of World War I. His finds, including *Spinosaurus,* illuminated the Cretaceous in Africa, a crucial moment in Earth's history marked by the breakup of the supercontinent Gondwana.

taxa of dinosaurs, crocodiles, turtles, and fish. Among his finds were two partial skeletons of a remarkable new dinosaur, a gigantic predator with yard-long jaws bristling with interlocking conical teeth. Its most extraordinary feature, however, was the six-foot sail-like structure that it sported on its back, supported by distinctive struts, or spines. Stromer named the animal *Spinosaurus aegyptiacus*.

Stromer's discoveries, prominently displayed in the Bavarian State Collection for Paleontology and Geology in central Munich, made him famous. During World War II he tried desperately to have his collection removed from Munich,

STROMER FAMILY TRUST

Among Stromer's finds was a gigantic predator with yard-long jaws bristling with conical teeth. Its most extraordinary feature was the six-foot sail on its back.

out of range of Allied bombers. But the museum director, an ardent Nazi who disliked Stromer for his outspoken criticism of the Nazi regime, refused. In April 1944 the museum and nearly all of Stromer's fossils were destroyed in an Allied air raid. All that was left of *Spinosaurus* were field notes, drawings, and sepia-toned photographs. Stromer's name gradually faded from the academic literature.

Ibrahim, who grew up in Berlin, first encountered Stromer's bizarre colossus in a German children's book on dinosaurs. From that day on, dinosaurs haunted him. He made three-toed theropod tracks at the beach, and his favorite cookies were shaped like *Triceratops* and *Tyrannosaurus rex*. He visited paleontological collections around Germany and built an impressive collection of models and fossil casts.

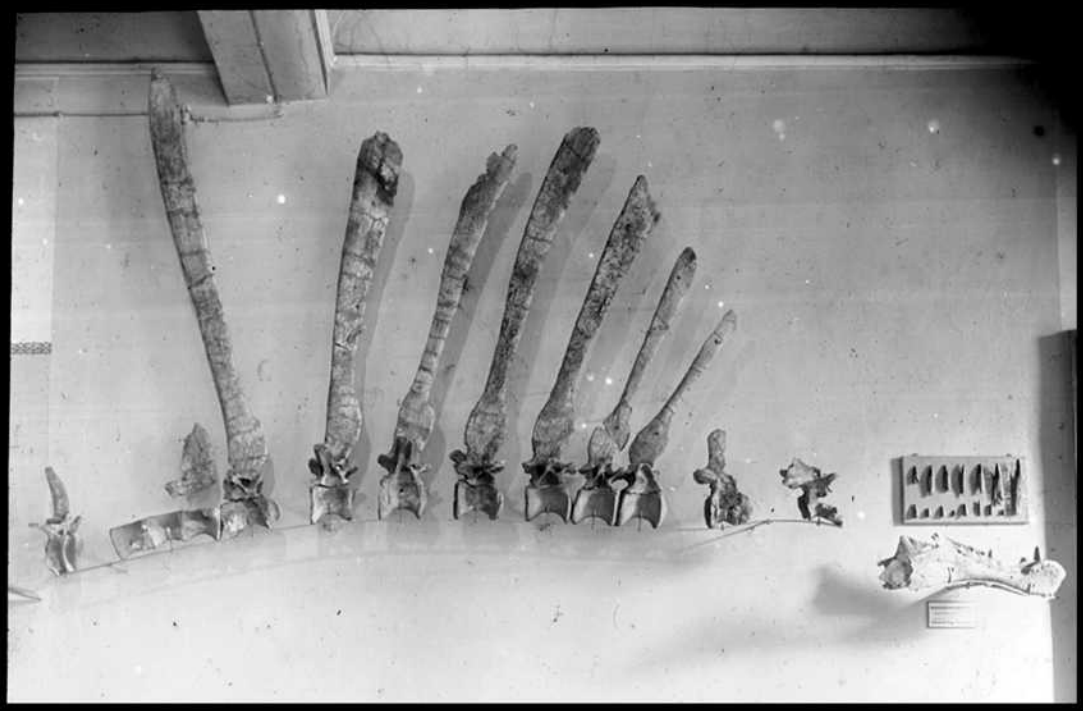
He encountered Stromer's work again while studying paleontology at the University of Bristol. "The breadth and the depth of his work was incredible and inspired me to be ambitious in my own research," Ibrahim says. While most doctoral students explore a tightly circumscribed topic, Ibrahim's 836-page dissertation at University College Dublin described the entire fossil record of the Kem Kem.

Fieldwork for his Ph.D. brought him to Erfoud several times. On a visit in 2008, when Ibrahim was 26, a Bedouin showed him a cardboard box containing four blocks of distinctive purplish stone streaked with yellow sediment. Protruding from the rock were what looked like a dinosaur hand bone and a flat blade of bone with an unusual milk-white cross section. Like all fossils heedlessly torn from their surrounding geology, the bones' scientific value was dubious. Ibrahim offered to buy them anyway, thinking they might be of some use for the University of Casablanca's fledgling paleontology collection.

Ibrahim would come to understand their potentially enormous significance during a visit the next year to the Natural History Museum in Milan, Italy. Researchers Cristiano Dal Sasso and Simone Maganuco showed him a partial skeleton of a large dinosaur they had recently received from a fossil dealer. The specimen was laid out on tables in the basement: leg bones, ribs, numerous vertebrae, and several tall, distinctive dorsal spines. Ibrahim was astounded. It was clearly a *Spinosaurus,* substantially more complete than Ernst Stromer's lost specimens. Dal Sasso and Maganuco told him that the dealer thought it had been excavated at a site called Aferdou N'Chaft, near El Begaa. The bones were still encrusted with the rock they'd been buried in, a purplish sandstone with yellow streaks. Lifting a chunk of spine, Ibrahim saw a familiar white cross section.

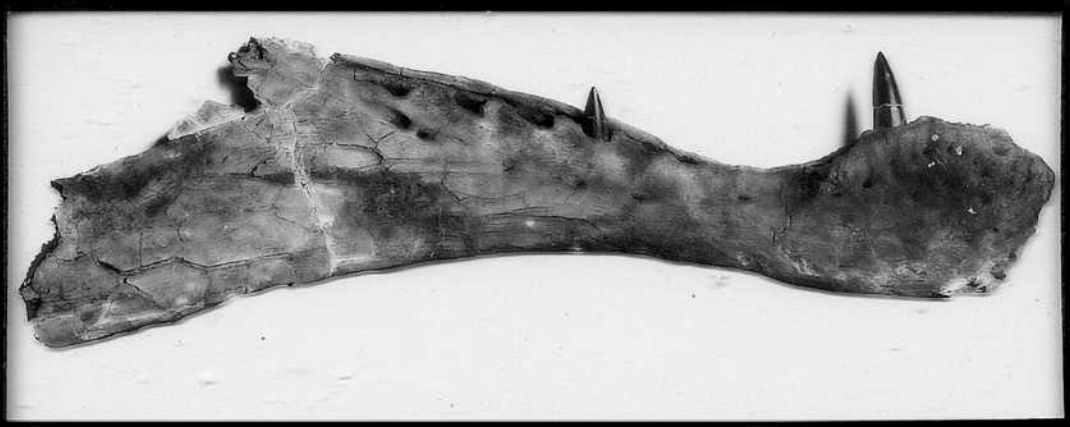
"I realized the bones I'd bought in Erfoud must be *Spinosaurus*—that odd flat bone was a piece of spine," Ibrahim remembers. It then occurred to him that the scrappy fossils from Erfoud and the magnificent specimen in Milan might belong to the same individual. If so, and if he could pinpoint the exact spot where the fossils had been buried, *(Continued on page 118)*

Italy-based writer Tom Mueller wrote on Florence's Duomo in the February 2014 issue. Mike Hettwer shot the May 2014 story on ship-breakers.



LOST AND FOUND
Stromer's type specimen of *Spinosaurus,* found in Egypt in 1912, was incinerated during an Allied bombing of Munich in World War II. Paleontologists have used these rare photos to digitally reconstruct the lost bones. Combining them with more recent discoveries produced a skeleton 50 feet long, the largest of all predatory dinosaurs.

NIZAR IBRAHIM, UNIVERSITY OF CHICAGO; ORIGINAL PHOTOGRAPHS AT BAVARIAN STATE COLLECTION FOR PALEONTOLOGY AND GEOLOGY, MUNICH

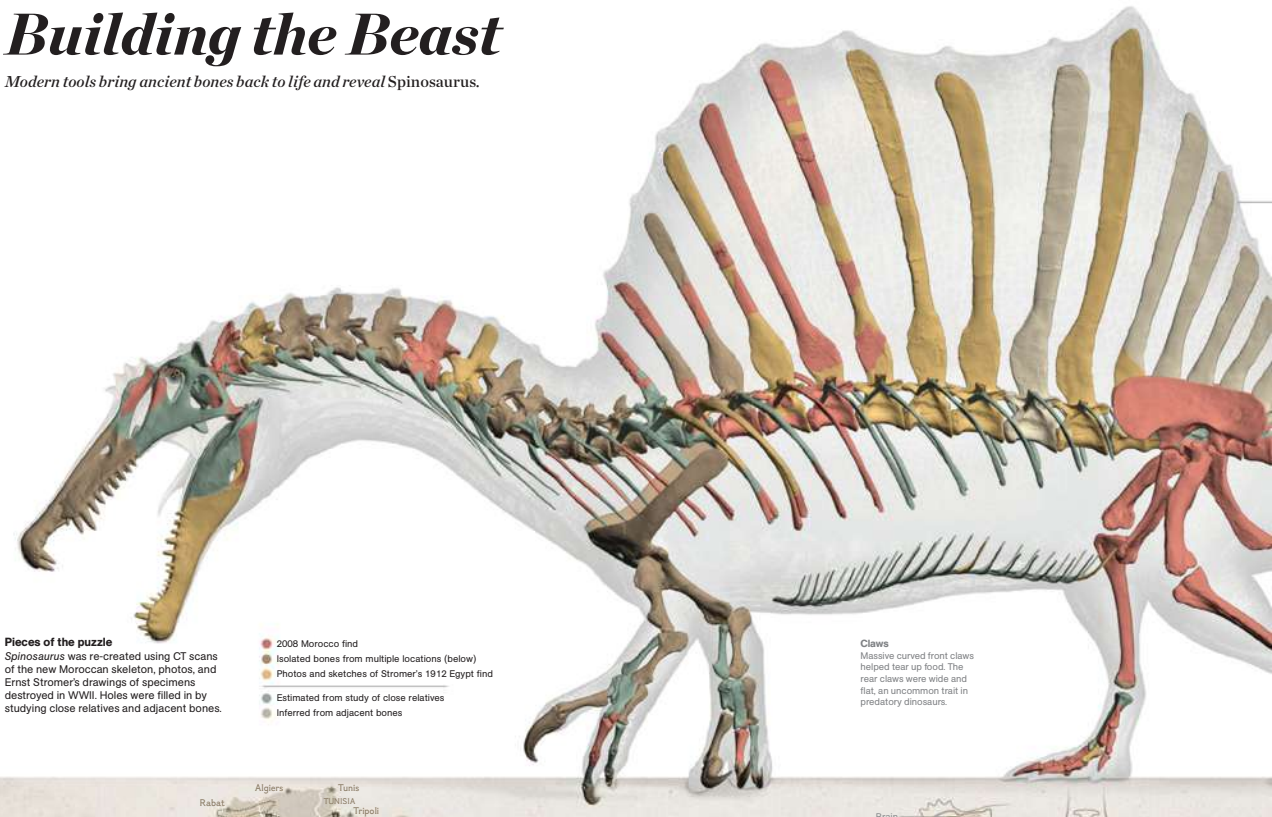


CRETACEOUS LEVIATHAN
The only known dinosaur adapted to life in water, *Spinosaurus* swam the rivers of North Africa a hundred million years ago. The massive predator lived in a region mostly devoid of large, terrestrial plant-eaters, subsisting mainly on huge fish.

ART: DAVIDE BONADONNA
SOURCES: NIZAR IBRAHIM, UNIVERSITY OF CHICAGO; CRISTIANO DAL SASSO AND SIMONE MAGANUCO, NATURAL HISTORY MUSEUM OF MILAN

Building the Beast

Modern tools bring ancient bones back to life and reveal Spinosaurus.



Pieces of the puzzle
Spinosaurus was re-created using CT scans of the new Moroccan skeleton, photos, and Ernst Stromer's drawings of specimens destroyed in WWII. Holes were filled in by studying close relatives and adjacent bones.

- 2008 Morocco find
- Isolated bones from multiple locations (below)
- Photos and sketches of Stromer's 1912 Egypt find
- Estimated from study of close relatives
- Inferred from adjacent bones

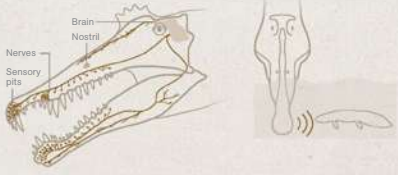
Claws
Massive curved front claws helped tear up food. The rear claws were wide and flat, an uncommon trait in predatory dinosaurs.

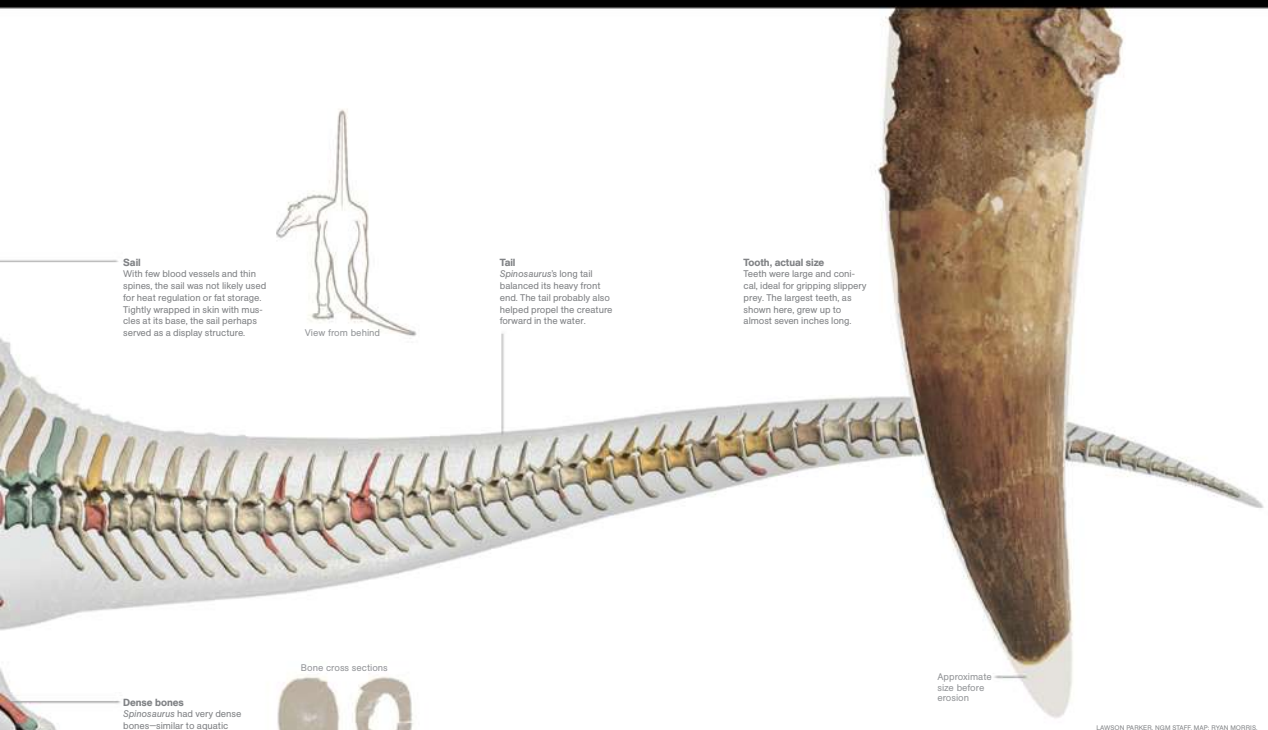
Africa, then and now
Northern Africa 95 million years ago had rich river systems. The bones of *Spinosaurus* and other species were preserved in their sediments.

Spinosaurus fossil discovery site

0 mi 600
0 km 600

Nose of a hunter
While swimming, *Spinosaurus* sensed prey using pressure-sensitive receptors lining pits on its snout. Nostrils high on the snout allowed the dinosaur to breathe when on the hunt.





Sail
With few blood vessels and thin spines, the sail was not likely used for heat regulation or fat storage. Tightly wrapped in skin with muscles at its base, the sail perhaps served as a display structure.

View from behind

Tail
Spinosaurus's long tail balanced its heavy front end. The tail probably also helped propel the creature forward in the water.

Tooth, actual size
Teeth were large and conical, ideal for gripping slippery prey. The largest teeth, as shown here, grew up to almost seven inches long.

Approximate size before erosion

Dense bones
Spinosaurus had very dense bones—similar to aquatic and semiaquatic animals alive today—easing diving and other water maneuvers.

Bone cross sections

Spinosaurus *T. rex*

Getting around
Spinosaurus was so front heavy that it likely walked on four limbs. Forearm and hand joints were fairly rigid, so its fingers likely rested on the ground. Hands may have also pointed outward.

Possible positions

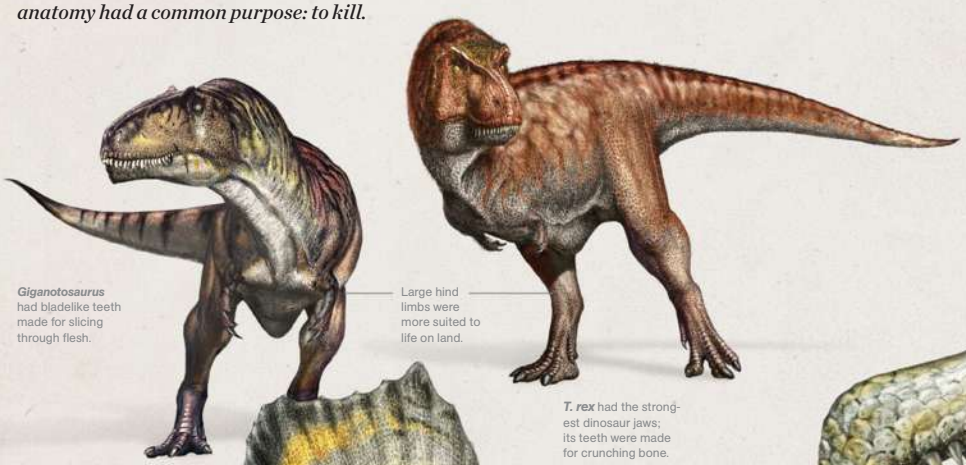
Aquatic life
Estimated to spend most of its time in water, *Spinosaurus* probably had webbed feet. Its sail would have been the only thing visible when it swam, perhaps serving as a territorial warning sign.

Webbed feet

LAWSON PARKER, NGM STAFF; MAP: RYAN MORRIS, NGM STAFF; ART: DAVIDE BONADONNA
3-D SKELETON: TYLER KELLOR AND LAUREN CONROY, UNIVERSITY OF CHICAGO
SOURCES: NIZAR IBRAHIM, UNIVERSITY OF CHICAGO; CRISTIANO DAL SASSO AND SIMONE MAGANUCO, NATURAL HISTORY MUSEUM OF MILAN; RON BLAKEY, COLORADO PLATEAU GEOSYSTEMS (MAP); MATTEO FABBRI, UNIVERSITY OF BRISTOL (BONE SCANS)
PHOTO: NIZAR IBRAHIM AT CANADIAN MUSEUM OF NATURE (TOOTH)

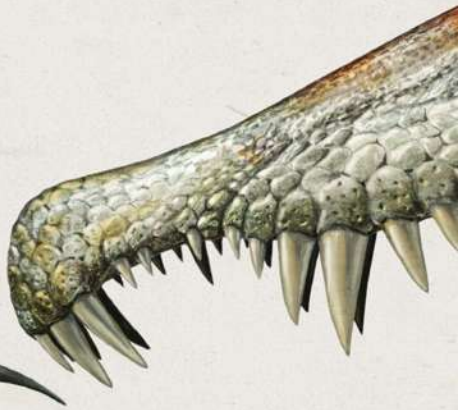
Big, Bigger, Biggest

The largest predatory dinosaurs didn't cross paths; they lived in different times and places. But their anatomy had a common purpose: to kill.



Giganotosaurus had bladelike teeth made for slicing through flesh.

Large hind limbs were more suited to life on land.



T. rex had the strongest dinosaur jaws; its teeth were made for crunching bone.

A long, narrow skull and smooth, conical teeth allowed ***Spinosaurus*** to prey on aquatic life.

LAWSON PARKER, NGM STAFF; SAMANTHA WELKER. ART: DAVIDE BONADONNA
SOURCES: NIZAR IBRAHIM, UNIVERSITY OF CHICAGO; CRISTIANO DAL SASSO AND SIMONE MAGANUCO, NATURAL HISTORY MUSEUM OF MILAN

Though over a yard long and bristling with fearsomely splayed teeth, *Spinosaurus*'s jaws were far less robust than those of predatory dinosaurs of comparable size—less suited to crushing bone than to snagging fish in the rivers where it thrived.

In 1944 nearly all of Stromer's fossils were destroyed in an Allied air raid. All that was left of* Spinosaurus *were field notes, drawings, and photographs.

they could become a Rosetta Stone for understanding *Spinosaurus* and its world.

To find the spot, however, he would first have to do something tougher than finding a needle in a haystack: find a Bedouin in the desert.

"I didn't know his name, and all I could remember was that he had a mustache and was wearing white," Ibrahim says. "Which in Morocco didn't narrow things down much."

Four years would pass before Ibrahim could return to Erfoud and attempt to track down his man. Along with Samir Zouhri from the Université Hassan II, Casablanca, and David Martill from the University of Portsmouth in the U.K., Ibrahim visited several excavation sites, starting with Aferdou N'Chaft. Nobody seemed to recognize Ibrahim's photos of the *Spinosaurus* fossils or to know the Bedouin from Ibrahim's vague description. After searching the streets of Erfoud on their last day, they had finally given up and slumped down in a café.

AS THEY SAT STARING BLANKLY at the people passing on the street, a man with a mustache wearing white walked by. Ibrahim and Zouhri exchanged glances, then hopped up and gave chase. It was the same man. He confirmed that he'd chipped the bones out of a rock face over two months of hard work, first uncovering the bones he had sold to Ibrahim, then finding more farther into the hillside, which he had eventually sold to a fossil dealer in Italy for $14,000. When they asked if he would show them the findspot, however, the man at first refused. Ibrahim, who speaks Arabic, explained how essential it was to know where the bones had been found and why that knowledge would someday allow the dinosaur to return to Morocco, as part of a new museum collection in Casablanca. The Bedouin, who had listened in silence, nodded.

"I will show you," he said.

After driving their battered Land Rover through the palm plantation north of Erfoud, the man led them on foot along a dry wadi and up a steep bluff. Strata in the surrounding cliffs showed that great meandering rivers had flowed there a hundred million years ago.

Finally they reached a gaping hole in a hillside, which had once been a riverbank.

"There," said the Bedouin.

Ibrahim climbed in, noting the walls of purplish sandstone with yellow streaks.

FOR ERNST STROMER, *Spinosaurus* was a lifelong enigma. He struggled for decades to understand the strange creature from the pieces of two skeletons that his team had found. He first speculated that its long neural spines might have supported a shoulder hump like a bison's, then later surmised that they were part of a dorsal sail, like those sported by some modern lizards and chameleons. He noted that *Spinosaurus*'s narrow jaws were unique among predatory dinosaurs. So were its teeth—most carnivorous theropods had bladelike, serrated teeth, but these were smooth and conical and resembled those of a crocodile.

Society Grant The reconstruction of *Spinosaurus* was funded in part by the Expeditions Council and your National Geographic Society membership.

BONE SLEUTH
National Geographic Emerging Explorer Nizar Ibrahim (below) traced a *Spinosaurus* skeleton to the precise spot in southeastern Morocco where it had been found by an amateur fossil hunter years before. In 2013 his Italian colleagues Cristiano Dal Sasso and Marco Auditore (above) prospected for more pieces of the skeleton.

The peculiarities of the creature began to make sense only when it was viewed from an entirely different perspective: as a dinosaur that spent most of its time in the water.

Stromer concluded, with evident perplexity and perhaps a bit of frustration, that the animal was "highly specialized," without saying what it was specialized for.

Spinosaurus was part of a larger mystery, sometimes called Stromer's Riddle, that he'd first observed in North African fossils. In nearly all ancient and modern ecosystems, plant-eaters greatly outnumber meat-eaters. Yet along the northern edge of the African continent, from Stromer's Egyptian excavations in the east to the Kem Kem beds of Morocco in the west, the fossil record suggests the opposite. Indeed, this region was inhabited by three enormous meat-eaters, each of which would have been an apex predator elsewhere: swift, 40-foot-long *Bahariasaurus;* 40-foot *Carcharodontosaurus,* like an African *T. rex;* and *Spinosaurus,* perhaps biggest and certainly oddest of all. Stromer speculated that large herbivores had probably been present—what else had the carnivores eaten?—but not many of their bones had turned up yet. Other scientists have suggested the paradox is merely sampling error, caused by geological processes that mix fossils of different ages together—or by fossil hunters who preferentially select large, spectacular carnivores because they sell better.

With a new *Spinosaurus* in hand and knowledge of the precise location where it had been found, Nizar Ibrahim was in a position to find a more satisfying answer to Stromer's Riddle. At first glance, however, the new bones made the animal all the more puzzling. For starters, the surface of the dorsal spines was smooth, which meant they were unlikely to have supported a lot of soft tissue like a hump. The spines had few channels for blood vessels, so it seemed unlikely that they were used to regulate body temperature, as other researchers had conjectured. The ribs were equally dense and tightly curved, creating an unusual barrel-shaped torso. The neck was long, the skull enormous. But the jaws were surprisingly slender and elongated, with a peculiar arched snout tip speckled with tiny pits. The forelimbs and thoracic girdle were bulky, while the hind limbs were disproportionately short and slender.

"*Spinosaurus* is incredibly front heavy," says paleontologist Paul Sereno, Ibrahim's postdoctoral adviser at the University of Chicago and the discoverer of several notable North African dinosaurs, including *Suchomimus,* a relative of *Spinosaurus* with long, crocodile-like jaws. "It's like a cross between an alligator and a sloth."

Ibrahim had a life-size image of the animal's skull on the wall in his office that he often stared at, unfocusing his eyes and struggling to imagine the enormous body stretching out behind. "I tried to see all the bones, the muscles, the connective tissue, everything. Sometimes it was there for an instant, then it vanished, like a mirage. My brain couldn't quite compute all that complexity."

But a computer might. Together with Simone Maganuco at the Milan museum and Tyler Keillor, a fossil preparator and paleoartist at the University of Chicago, Ibrahim set about digitally reconstructing the dinosaur. They CT-scanned each bone of their specimen at the University of Chicago Medical Center and Maggiore Hospital in Milan, then added other body parts by

scanning photos from museum specimens in Milan, Paris, and elsewhere, as well as digital images of Stromer's photographs and sketches, scaling up the remains of younger individuals to adult size in some cases. Keillor, an expert in the digital modeling program ZBrush, sculpted missing bones in ZBrush's "digital clay," mapping his work with scans of the same anatomy in related spinosaurid dinosaurs like *Suchomimus* and *Baryonyx*. By painstakingly shaping and spacing the 83 vertebrae in their model, they determined that an adult *Spinosaurus* measured 50 feet from nose to tail. There had been claims that *Spinosaurus* was the largest carnivore to ever walk the Earth. This confirmed it. (The largest *T. rex* is 40.5 feet head to tail.)

Next they wrapped the skeleton in digital skin to create a dynamic model, which allowed them to estimate the animal's center of gravity and body mass, the better to understand how it moved. Their analysis led to a remarkable conclusion: Unlike all other predatory dinosaurs, which walked on their hind legs, *Spinosaurus* may have been a functional quadruped, also enlisting its heavily clawed forelimbs to walk.

The peculiarities of the creature began to make real sense, however, only when Ibrahim and his colleagues viewed *Spinosaurus* from an entirely different perspective: as a dinosaur that spent most of its time in the water. The nostrils are set high on the skull toward the eyes, allowing the animal to breathe with much of its head submerged. The barrel-shaped torso recalls dolphins and whales, and the density of its ribs and long bones is similar to that of another aquatic mammal, the sea cow. The hind legs, so oddly proportioned for walking, would have been perfect for paddling, particularly if the flat claws in its broad hind feet had been connected with webbing like a duck's, as the researchers suspect. Its long, slender jaws and smooth, conical, croc-like teeth would have been devastatingly effective at snaring fish, and the pits in its snout, also present in crocs and alligators, probably housed pressure sensors to detect prey in murky water. Ibrahim imagines *Spinosaurus* hunting a bit like a heron, leaning forward and snapping up fish with its long muzzle.

This new vision of *Spinosaurus* as an aquatic dinosaur suggests a possible solution to Stromer's Riddle. The river along which this animal died was one of many large waterways in a vast fluvial system that occupied much of North Africa in the Cretaceous. If the carnivores here were big, so too was the aquatic life, whose remains are common in the Kem Kem deposits: 8-foot lungfish, 13-foot coelacanths, 25-foot sawfish, and similarly outsize turtles. These animals would have made healthy meals for even the largest predator, obviating the need for abundant large herbivores to balance the food web.

All this came home to Ibrahim with full force when he saw the culminating phase of the digital dinosaur project: a life-size *Spinosaurus* skeleton in high-density polystyrene foam, created from the computer model in part by a 3-D printer. The skeleton is mounted in a swimming posture, which Ibrahim thinks it may have employed as much as 80 percent of the time. "I wish Ernst Stromer could see this model, which shows just how much of a specialized swimmer *Spinosaurus* had become. It would have made him smile." ▯

MORE ONLINE ngm.com/more

VIDEO

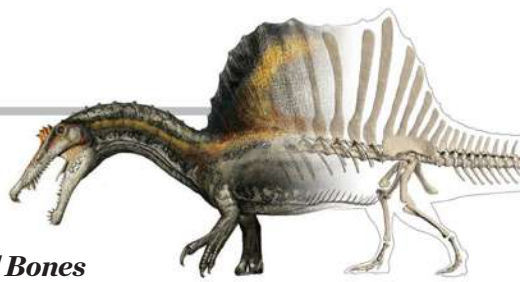
"Wow, this thing could... pull me into three pieces!"

—Paleontologist NIZAR IBRAHIM

TELEVISION

Bigger Than *T. rex*

A paleontologist turns detective to find the source of mysterious bones. Watch this Nat Geo/NOVA special on November 5 at 9 p.m.

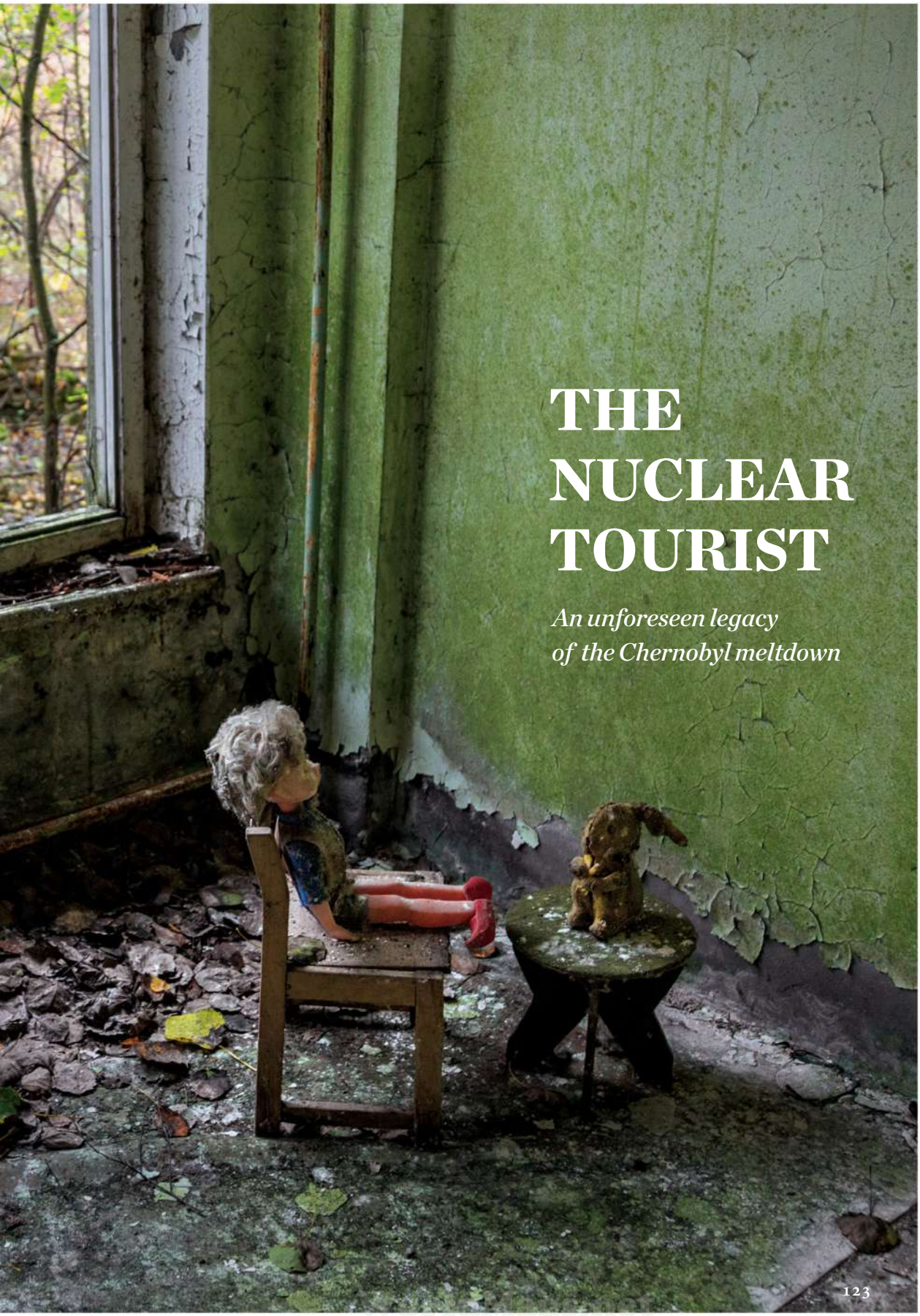


INTERACTIVE GRAPHIC

Flesh and Bones

Teeth, neck, sail, tail: See how researchers pieced together the *Spinosaurus*. Then take your own tour through the dinosaur's anatomy.

After a nuclear accident in 1986, nearby Pripyat, Ukraine, was abandoned. The desolate city is now open to tourists. Among the sights: dolls posed by visitors in unsettling scenes.



THE NUCLEAR TOURIST

An unforeseen legacy of the Chernobyl meltdown

An amusement park scheduled to open on May Day—five days after the explosion—has become a new kind of attraction.

By George Johnson
Photographs by Gerd Ludwig

They say that five sieverts of radiation is enough to kill you, so I was curious to see the reading on my Russian-made dosimeter as our tour van passed into the exclusion zone—

the vast, quarantined wilderness that surrounds Chernobyl. Thick stands of pines and birches crowded the roadside as our guide reminded us of the ground rules: Don't pick the mushrooms, which concentrate radionuclides, or risk letting the contaminants into your body by eating or smoking outdoors. A few minutes later we passed the first of the abandoned villages and pulled over to admire a small band of wild Przewalski's horses.

Twenty-eight years after the explosion of a nuclear reactor at Chernobyl, the zone, all but devoid of people, has been seized and occupied by wildlife. There are bison, boars, moose, wolves, beavers, falcons. In the ghost city of Pripyat, eagles roost atop deserted Soviet-era apartment blocks. The horses—a rare, endangered breed—were let loose here a decade after the accident, when the radiation was considered tolerable, giving them more than a thousand square miles to roam.

I glanced at my meter: 0.19 microsieverts per hour—a fraction of a millionth of a single sievert, a measure of radiation exposure. Nothing to worry about yet. The highest levels I had seen so far on my trip to Ukraine were on the transatlantic flight from Chicago—spikes of 3.5 microsieverts per hour as we flew 40,000 feet over Greenland, cosmic rays penetrating the plane and passengers. Scientists studying Chernobyl remain divided over the long-term effects of the radiation on the flora and fauna. So far they have been surprisingly subtle. More threatening to the animals are the poachers, who sneak into the zone with guns.

A few minutes later we reached Zalesye, an old farming village, and wandered among empty houses. Broken windows, peeling paint, crumbling plaster. On the floor of one home a discarded picture of Lenin—pointy beard, jutting chin—stared sternly at nothing, and hanging by a cord on a bedroom wall was a child's doll. It had been suspended by the neck as if with an executioner's noose. Outside, another doll sat next to the remains of a broken stroller. These were the first of the macabre tributes we saw during our two days in the zone. Dolls sprawling half dressed in cribs, gas masks hanging from trees—tableaux placed by visitors, here legally or otherwise, signifying a lost, quiet horror.

Farther down the road we were surprised by an inhabitant. Dressed in a scarf, a red sweater, and a winter vest, Rosalia is one of what officials call the "returnees"—stubborn old people, women mostly, who insist on living out their lives in the

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George Johnson's most recent book is The Cancer Chronicles: Unlocking Medicine's Deepest Mystery. *Gerd Ludwig's new book,* The Long Shadow of Chernobyl, *showcases his photography over 20 years.*

place they call home. She seemed happy for the company. Prompted by our guide, she told us of worse hardships. The lands around Chernobyl (or Chornobyl, as it is known in Ukraine) are part of the Pripyat Marshes on the eastern front, where the bloodiest battles of World War II were fought. She remembers the German soldiers and the hardships under Stalin.

"You can't see radiation," she said in Ukrainian. Anyway, she added, she is not planning to have children. She lives with five cats. Before we departed, she showed us her vegetable garden and said her biggest problem now is Colorado potato bugs.

THERE IS SOMETHING DEEPLY rooted in the human soul that draws us to sites of unimaginable disaster. Pompeii, Antietam, Auschwitz, and Treblinka—all eerily quiet now. But in the 21st century we hold a special awe for the aftermath of nuclear destruction. The splitting of the atom almost a hundred years ago promised to be the most important human advance since the discovery of fire. Unleashing the forces bound inside atomic nuclei would bring the world nearly limitless energy. Inevitably it was first used in warfare, but after Hiroshima and Nagasaki a grand effort began to provide electricity "too cheap to meter," freeing the world from its dependence on fossil fuels.

More than half a century later the swirling symbol of the atom, once the emblem of progress and the triumph of technology, has become a bewitching death's-head, associated in people's minds with destruction and Cold War fear. Every spring visitors head for Stallion Gate in southern New Mexico for an open house at Trinity Site, where the first atomic bomb was detonated—a preview of what was to come when the bombers reached Japan. Monthly tours to the Nevada Test Site in the Mojave Desert, where more than a thousand nuclear weapons were exploded during the Cold War, are booked solid through 2014.

Then there is the specter of nuclear meltdown. In 2011, Chernobyl, site of the world's worst catastrophe at a nuclear power plant, was officially declared a tourist attraction.

Nuclear tourism. Coming around the time of the Fukushima disaster, the idea seems absurd. And that is what drew me, along with the wonder of seeing towns and a whole city—almost 50,000 people lived in Pripyat—that had been abandoned in a rush, left to the devices of nature.

Sixty miles away in Kiev, Ukraine's capital city, weeks of bloody demonstrations had led in February to the expulsion of the president and the installation of a new government. In response to the upheaval Russia had occupied Crimea, the peninsula that juts from southern Ukraine

NGM MAPS. SOURCE: STATE AGENCY OF UKRAINE ON EXCLUSION ZONE MANAGEMENT

into the Black Sea. Russian troops were massing on Ukraine's eastern border. In a crazy way, Chernobyl felt like the safest place to be.

The other diehards in the van had come for their own reasons. John, a young man from London, was into "extreme tourism." For his next adventure he had booked a tour of North Korea and was looking into options for bungee jumping from a helicopter. Gavin from Australia and Georg from Vienna were working together on a performance piece about the phenomenon of quarantine. We are used to thinking of sick people quarantined from the general population. Here it was the land itself that was contagious.

Of all my fellow travelers, the most striking was Anna, a quiet young woman from Moscow. She was dressed all in black with fur-lined boots, her long dark hair streaked with a flash of magenta. It reminded me of radioactivity. This was her third time at Chernobyl, and she had just signed up for another five-day tour later in the year.

"I'm drawn to abandoned places that have fallen apart and decayed," she said. Mostly she loved the silence and the wildlife—this accidental wilderness. On her T-shirt was a picture of a wolf.

"'Radioactive Wolves'?" I asked. It was the name of a documentary I'd seen on PBS's *Nature* about Chernobyl. "It's my favorite film," she said.

Mounted over the door was an educational poster illustrating the spectrum of electromagnetic radiation.

IN THE EARLY HOURS OF APRIL 26, 1986, during a scheduled shutdown for routine maintenance, the night shift at Chernobyl's reactor number four was left to carry out an important test of the safety systems—one delayed from the day before, when a full, more experienced staff had been on hand.

Within 40 seconds a power surge severely overheated the reactor, rupturing some of the fuel assemblies and quickly setting off two explosions. The asphalt roof of the plant began burning, and, much more threatening, so did the graphite blocks that made up the reactor's core. A plume of smoke and radioactive debris rose high into the atmosphere and began bearing north toward Belarus and Scandinavia. Within days the fallout had spread across most of Europe.

Throughout the night firefighters and rescue crews confronted the immediate dangers—flames, smoke, burning chunks of graphite. What they couldn't see or feel—until hours or days later when the sickness set in—were the invisible poisons. Isotopes of cesium, iodine, strontium, plutonium. The exposures they received totaled as much as 16 sieverts—not micro or milli but whole sieverts, vastly more radiation than a body can bear. From the high-rises of Pripyat, less than two miles away, Chernobyl workers and their families stood on balconies and watched the glow.

In the morning—it was the weekend before May Day—they went about their routines of shopping, Saturday morning classes, picnics in the park. It was not until 36 hours after the accident that the evacuation began. The residents were told to bring enough supplies for three to five days and to leave their pets behind. The implication was that after a quick cleanup they would return home. That didn't happen. Crews of liquidators quickly moved in and began bulldozing buildings and burying topsoil. Packs of dogs were shot on sight. Nearly 200 villages were evacuated.

The immediate death toll was surprisingly small. Three workers died during the explosion, and 28 within a year from radiation poisoning.

Tourists, some of whom lived near the Fukushima nuclear plant, prop Geiger counters on a memorial to show how it blocks radiation from the reactor, which will be shielded by a new 32,000-ton arch.

But most of the effects were slow in unfolding. So far, some 6,000 people who were exposed as children to irradiated milk and other food have had thyroid cancer. Based on data from Hiroshima and Nagasaki, the overall mortality rate from cancer may rise by a few percent among the 600,000 workers and residents who received the highest doses, possibly resulting in thousands of premature deaths.

After the accident a concrete and steel structure—the sarcophagus—was hastily erected to contain the damaged reactor. As the sarcophagus crumbled and leaked, work began on what has been optimistically named the New Safe Confinement, a 32,000-ton arch, built on tracks so it can be slid into place when fully assembled. Latest estimate: 2017. Meanwhile the cleanup continues. According to plans by the Ukrainian government, the reactors will be dismantled and the site cleared by 2065. Everything about this place seems like science fiction. Will there even be a Ukraine?

WHAT I REMEMBER MOST about the hours we spent in Pripyat is the sound and feel of walking on broken glass. Through the dilapidated hospital wards with the empty beds and cribs and the junk-strewn operating rooms. Through the school hallways, treading across mounds of broken-back books. Mounted over the door of an old science class was an educational poster illustrating the spectrum of electromagnetic radiation. Heat to visible light to x-rays and gamma rays—the kind that break molecular bonds and mutate DNA. How abstract that must have seemed to the schoolkids before the evacuation began.

In another room gas masks hung from the ceiling and were piled in heaps on the floor. They were probably left there, our guides told us, by "stalkers"—surreptitious visitors

Gas masks, common in Soviet schools, were scattered on the floor, creating a popular sightseeing spot. One tourist brought a mask to put on for photos.

Scavengers and salvagers took what was useful; nature is reclaiming the rest. A doll, placed near a playground slide, is an eerie reminder of the vanished community.

Visitors stealthily and often subtly alter the landscape. A battered doll keeps company with Vladimir Lenin, while children's toys appear frozen in flight on a moss-covered school patio.

who sneak into the zone. At first they came to scavenge, later for the thrill. They drink from the Pripyat River and swim in Pripyat bay, daring the radiation and the guards to get them. A stalker I met later in Kiev said he'd been to Chernobyl a hundred times. "I imagined the zone to be a vast, burnt-out place—empty, horrible," he told me. Instead he found forests and rivers, all this contaminated beauty.

Our tour group walked along the edge of a bone-dry public swimming pool, its high dive and racing clock still intact, and across the rotting floor of a gymnasium. Building after building, all decomposing. We visited the ruins of the Palace of Culture, imagining it alive with music and laughter, and the small amusement park with its big yellow Ferris wheel. Walking up 16 flights of steps—more glass crunching underfoot—we reached the top of one of the highest apartment buildings. The metal handrails had been stripped away for salvage. Jimmied doors opened onto gaping elevator shafts. I kept thinking how unlikely a tour like this would be in the United States. It was refreshing really. We were not even wearing hard hats.

From the rooftop we looked out at what had once been grand, landscaped avenues and parks—all overgrown now. Pripyat, once hailed as a model Soviet city, a worker's paradise, is slowly being reabsorbed by the earth.

WE SPENT THE NIGHT in the town of Chernobyl. Eight centuries older than Pripyat, it now has the look of a Cold War military base, the center for the endless containment operation. My hotel room with its stark accommodations was like a set piece in a museum of life in Soviet times. One of the guides later told me that the vintage furnishings were salvaged from Pripyat. I wasn't able to confirm that officially. The radiation levels in my room were no greater than what I've measured back home.

In a postapocalyptic video game called "S.T.A.L.K.E.R.: Shadow of Chernobyl," virtual visitors to the radioactive wonderland can identify the hot spots by their blue-white glow. As you travel around the exclusion zone, the radiation counter for your avatar steadily increases. You can reduce your accumulation and avoid getting radiation sickness by drinking virtual Russian vodka.

If only it were so easy. By the next morning we were becoming almost cavalier about the exposure risk. Standing beneath the remains of a cooling tower, our guide, hurrying us along, exclaimed, "Oh, over here is a high-radiation spot! Let's go see!" as casually as if she were pointing us toward a new exhibit in a wax museum. She pulled up a board covering the hot spot, and we stooped down holding our meters—they were frantically beeping—in a friendly competition to see who could detect the highest amount. My device read 112 microsieverts per hour—30 times as high as I had measured on the flight. We stayed for only a minute.

All overgrown now, Pripyat, once hailed as a worker's paradise, is slowly being reabsorbed by the earth.

The hottest spot we measured that day was on the blade of a rusting earthmover that had been used to plow under the radioactive topsoil: 186 microsieverts per hour—too high to linger but nothing compared with what those poor firemen and liquidators got.

On the drive back to Kiev our guide tallied up our accumulated count—ten microsieverts during the entire weekend visit.

I'd probably receive more than that on the flight back home. □

Once a model Soviet city with almost 50,000 people, Pripyat is slowly decaying, as are about 200 villages in the exclusion zone.

Students from Finland, wearing foil-covered helmets to amuse themselves and repel rain, pose in bumper cars in the verdant amusement park.

Ready When She Is

Consider the male giant panda, the ultimate long-suffering suitor.

The object of his desire, the female *Ailuropoda melanoleuca,* goes into heat once a year—for just 24 to 72 hours. Small wonder that pandas are endangered and their procreation in captivity is monitored as obsessively as the begetting of British royals.

With such a fleeting chance to make that love connection, what's a panda lad to do? Be anatomically equipped and on sexual standby.

Female pandas' fertility spell can occur at any time from February through May. To be forearmed for that moment, males go into hormonal overdrive starting in autumn. During the females' four "maybe" months, the males' testes may balloon to two or three times their normal size.

When scientists in Chengdu, China, studied anesthetized panda males, they found the animals' sperm was more abundant and motile during females' peak season than at other times of the year. In short, the would-be panda daddy gives it his all—making those months a prime time to collect sperm for use in captive-breeding programs.

A swain can stay so ready for only so long, after all. Come June or July, the giant pandas' gonads will go out of production until the next breeding season. *—Patricia Edmonds*

HABITAT
China

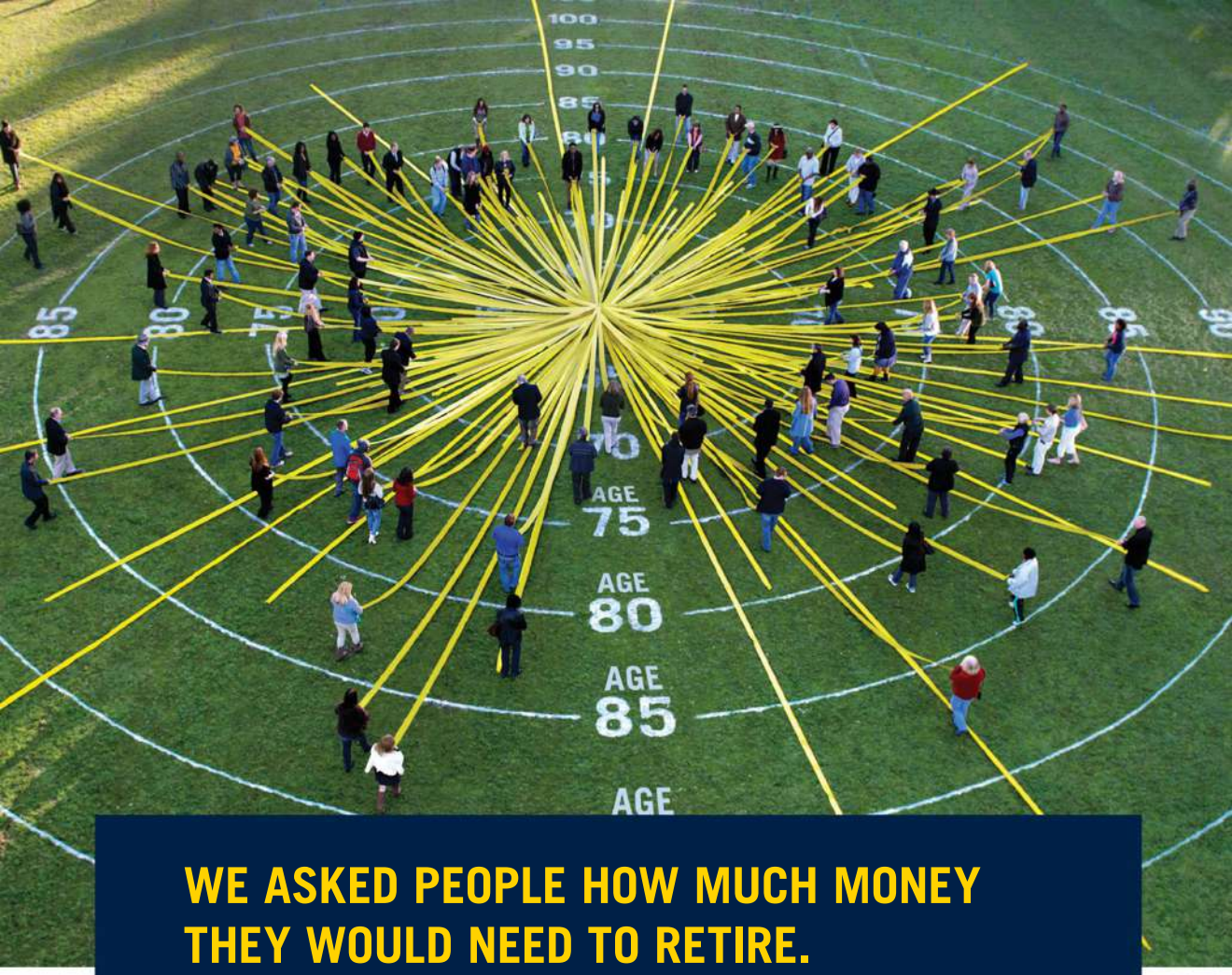
STATUS
Endangered

FASCINATING FACTS
Ravenous for bamboo, the average panda eats more than 60 pounds of it a day.

Given their breeding habits, small wonder that pandas are endangered.

This giant panda was photographed at Zoo Atlanta in Georgia.

PHOTO: JOEL SARTORE



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