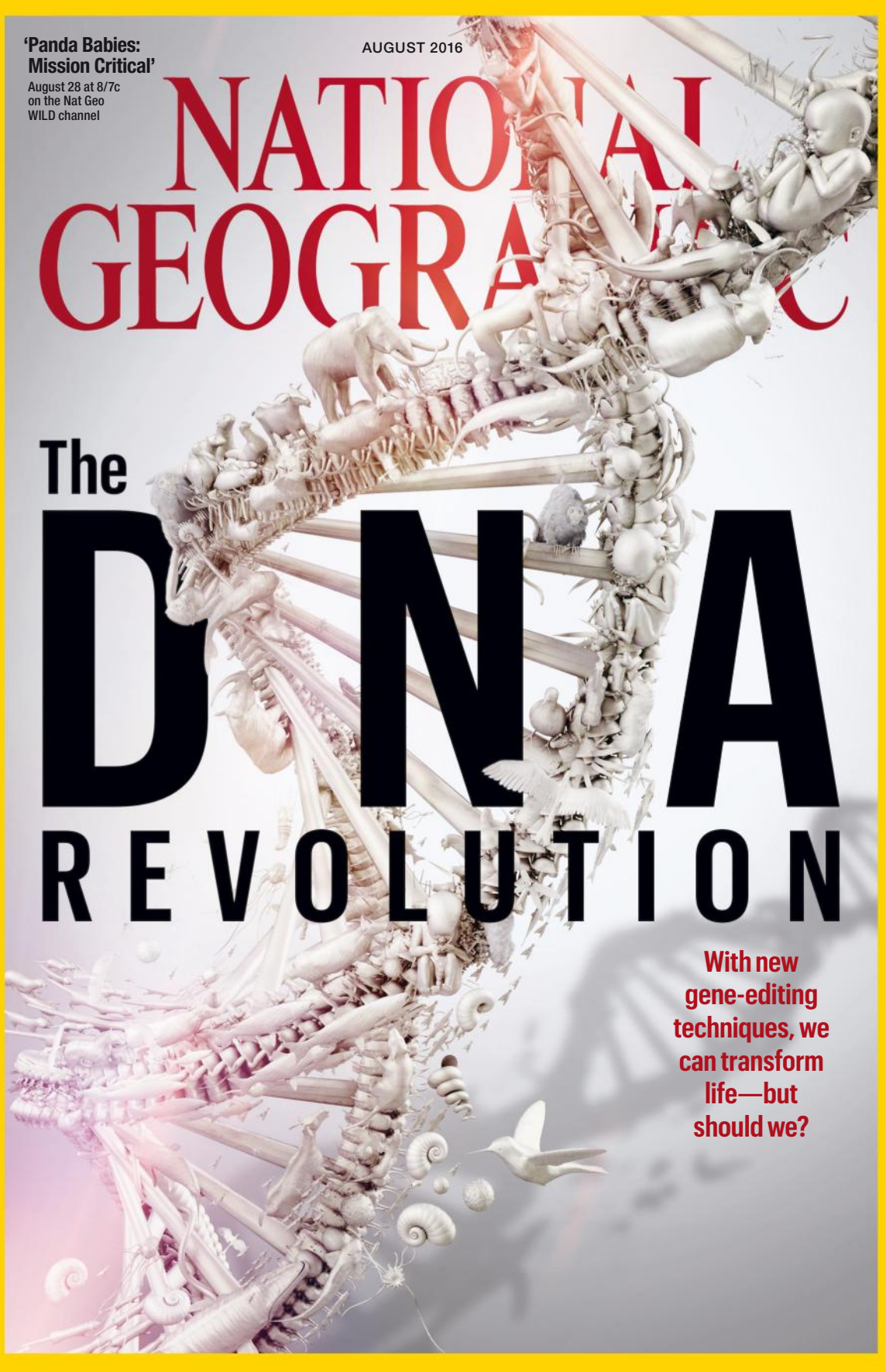
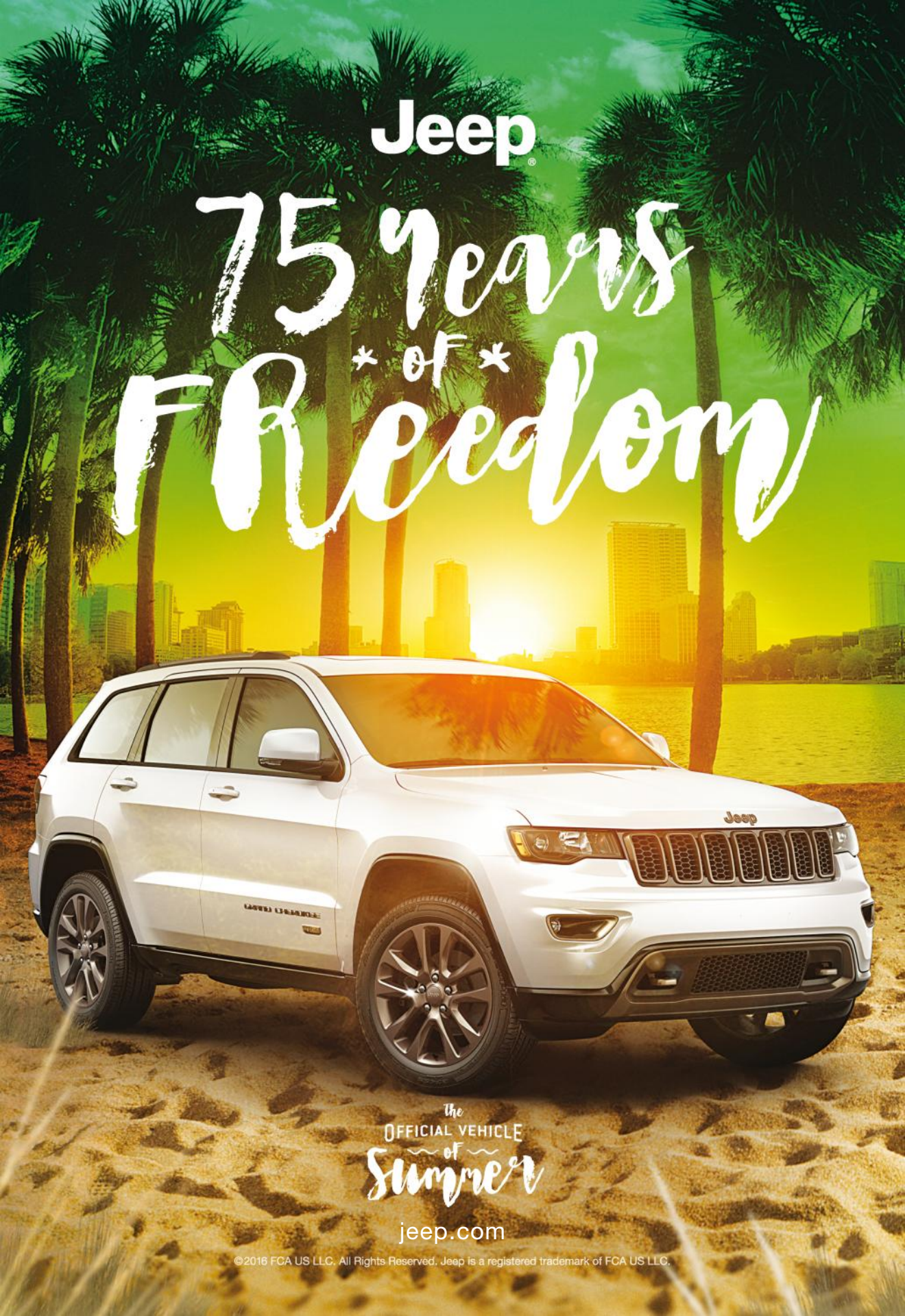
AUGUST 2016

NATIONAL GEOGRAPHIC



The DNA REVOLUTION

With new gene-editing techniques, we can transform life—but should we?



NATIONAL GEOGRAPHIC

AUGUST 2016 • VOL. 230 • NO. 2

Oceanic whitetips slice through the water near the Bahamas' Cat Island, believed to be one of the last havens for large numbers of the sharks.

On the Cover DNA is in every living thing, and scientists have learned to edit it. "We now have a power over species of all kinds that we never thought possible," says law professor Hank Greely. *Art by Bose Collins*

Corrections and Clarifications Go to *ngm.com/corrections*.

OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY

A New War on Mosquitoes

None of humankind's battles has proved more enduring—or less successful—than the war on mosquitoes.

Around the world each year, millions of people die of diseases spread by the insect. It's a familiar list of stubborn plagues—malaria, West Nile, dengue, yellow fever, forms of encephalitis—with some chilling recent additions. The mosquito-borne chikungunya virus has spread to parts of Africa, Europe, Asia, and as of 2013, the Americas. Its effects, while painful, pale in comparison with those of the Zika virus, which is careering through the Western Hemisphere and leaving tragically damaged babies in its wake.

During World War II the U.S. military used cartoons to tell troops how to protect themselves from malaria.

We have drained cesspools, warned of the dangers of standing water, and sprayed a river of pesticides. We have put up bed nets and window screens; we have educated and exhorted. And yet, by any fair measure, we're losing this fight. The mosquito remains the most dangerous nonhuman animal on Earth—and many scientists fear it may become even more prevalent and virulent with the rise in global temperatures and international travel.

Our next weapon of choice is DNA. Scientists are working to neutralize the mosquito on its swampy home turf by altering its genetics. New gene-editing techniques, described in this month's cover story, make it possible to tweak the mosquito's genome so it can't spread the malaria parasite. Another approach would genetically modify mosquitoes so that they bear sterile offspring. And yet another would alter mosquitoes' genes to prevent the birth of females—the ones that bite—so the diseases will stop spreading and, in time, the insect will die out.

Some may see these techniques as a revolutionary advance against infectious disease; others, as an unnerving case of scientists playing God. Like many breakthroughs, this one raises profound ethical questions. No matter how noxious a wild species is, can we afford to risk the consequences of altering its genetic code? Or can we afford *not* to, as malaria alone kills, on average, one child every two minutes in Africa? We invite you to read our cover story with these questions in mind.

Susan Goldberg, *Editor in Chief*

PHOTO: FRANK MACK, FOR THE U.S. ARMY; COURTESY NATIONAL LIBRARY OF MEDICINE

Humphead Wrasse *(Cheilinus undulatus)*
Size: Body length, up to 2.3 m (7.5 ft) **Weight:** Up to approx. 190 kg (419 lb) **Habitat:** Coral reefs and inshore habitats throughout the tropical Indo-Pacific **Surviving number:** Unknown

Photographed by Keith Ellenbogen

WILDLIFE AS CANON SEES IT

Hero of the reef. As one of the few predators of toxic reef animals such as sea hares and crown-of-thorns starfish, the humphead wrasse performs a valuable service in keeping its home range healthy. A sequential hermaphrodite, every individual spends its first 15 years as a female; some then turn into males, often doubling in size. But the perils this remarkable fish must overcome are enormous, including habitat loss, the live reef food fish trade and destructive fishing practices. Will the hero win in the end?

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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Why I Joke About the Ivory Trade

"I was raised wild," says India-born artist and conservationist **Asher Jay.** The National Geographic emerging explorer, 31, also dabbles in fashion design (such as the outfit here) and stand-up comedy. Her wildlife campaigns have appeared in Times Square and Tanzania and gone viral in China. The irony? She's "allergic to every animal."

When did you discover a passion for wildlife?
When I was younger, my mom allowed me to bring home any animal that fell out of a tree. She told me, "If you see something [broken], it's your responsibility to fix it." Eventually it was like living in a menagerie. I went through a phase where my parents had to tell me, "You are human." Even now when I go out on safari and see an animal, I feel it come alive in me—I don't see a separation. We tend to lose that over time as we begin to view things in a human context. That's why I do what I do—to get back into that space of being wild and unbound.

Are there any rules your art abides by?
Because I talk a lot about ivory, people think I could use it in my art. But if I used it, I'd be creating a gray area—it would seem like this material could be used by some because it has educational benefit, but not by others because it perpetuates death. I keep it very black and white, because life and death is black and white. Art for art's sake is a luxury we cannot afford.

What's the strangest way you've spread the word?
I started doing stand-up comedy just to see if I could get wildlife jokes out there. In my act I talk about how blood ivory has come to affect my dating life. Now every time I go on a date, I think of the fact that we're losing an elephant every 15 minutes. So by the time we get to dessert, I'm like, "Is this chap worth six elephants?"

PHOTO: BENEDICT EVANS

PROJET GOMBESSA

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VISIONS

France
With the mating season under way, two common toads get intimately acquainted in a shallow section of the Lez River. Their reproductive embrace—in which the smaller male clasps the female beneath her forelegs—is called axillary amplexus.

PHOTO: MATHIEU FOULQUIÉ, BIOSPHOTO

Spain
On a frigid winter day in Andalusia's Sierra de Grazalema Natural Park, a rain-fed pond ripples with color and life. Geranium leaves, frozen oxygen bubbles, and nutrient-rich algae share space beneath a thin sheet of ice scored with thaw lines.

PHOTO: ANDRÉS MIGUEL DOMÍNGUEZ

United Kingdom
A harvest mouse—Europe's smallest rodent—grooms itself on a hogweed flower head in a meadow near Moulton, England. This adult was raised in captivity, microchipped, and released as part of a study on how the elusive species survives.

PHOTO: NICK UPTON, NATURE PICTURE LIBRARY

Primary Colors

Assignment Red, yellow, and blue are traditional colors in their rawest form. We asked you to show them.

EDITOR'S NOTE

'There's a pureness that comes with boiling something to its core elements. Every complex color we see can be broken down and simplified.'

Marie McGrory, *Your Shot photo editor*

Heather Levingstone
Gorey, Ireland

It was a red balloon and news of a friend's death that made Levingstone imagine a photo tribute to people who risk their lives in dangerous jobs. She glued a figurine to the balloon and had it hold a pin to show its peril.

Zay Yar Lin
Yangon, Myanmar

Zay Yar Lin was working on a chemical tanker in the Gulf of Mexico. He peered over the bridge one day to watch a man painting a rail. The sun, low on the horizon around 4 p.m., threw the man's shadow onto the ship's deck.


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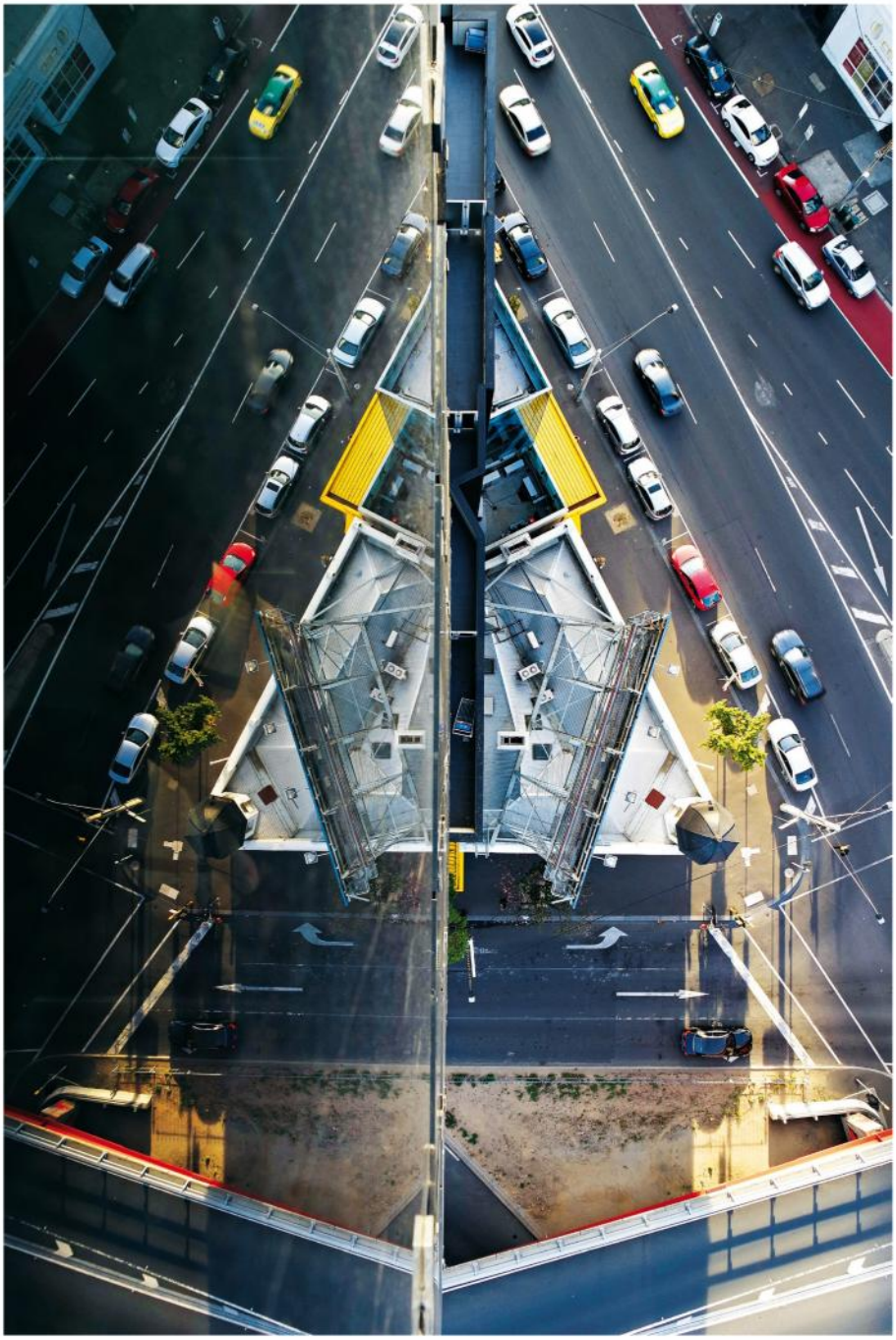
Reflection

Assignment Reflection is a powerful thing and a layered concept. We asked you to reflect on your reflections.



Sophia Anca *Melbourne, Australia*

After a stressful workweek, Anca, a travel specialist, went up to a friend's balcony to relax by taking shots of Melbourne's skyline. "I wasn't getting what I wanted, so I decided to look down," she says. She found the symmetry of the building's reflection unexpectedly therapeutic.

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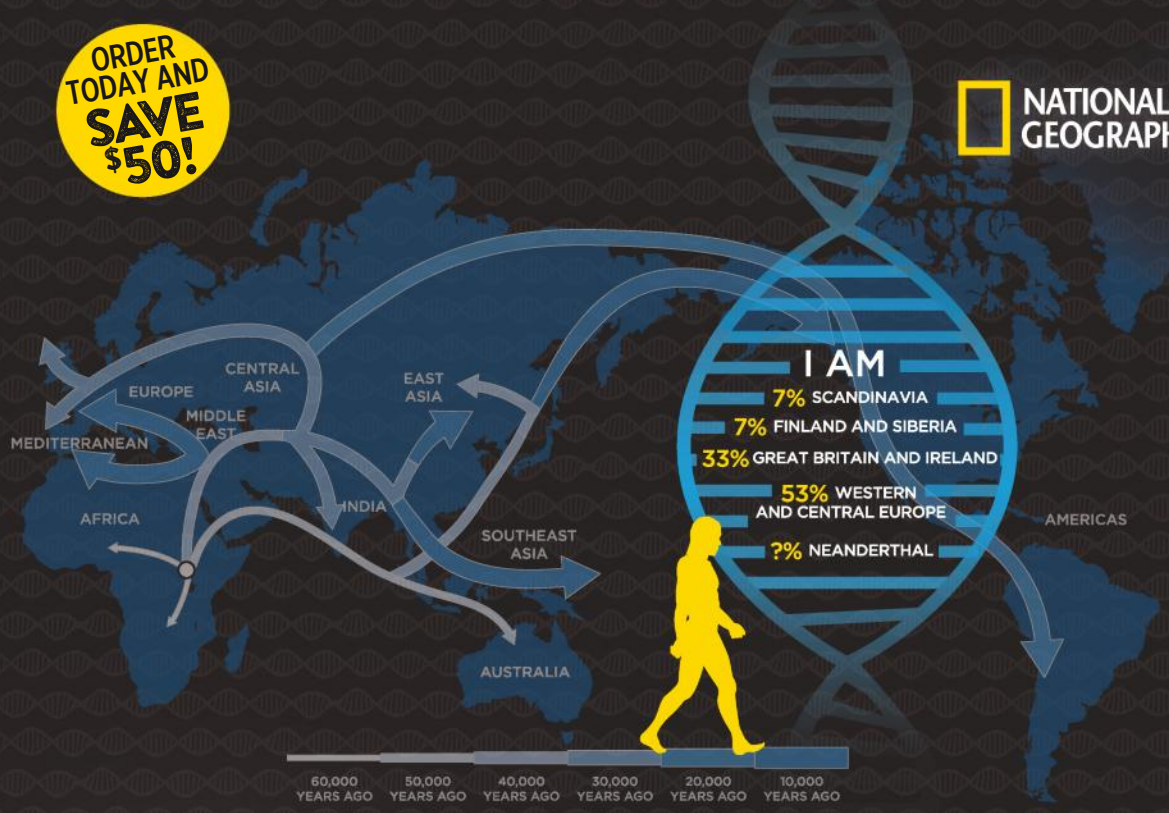

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EXPLORE

Wild Things

Average size at maturity

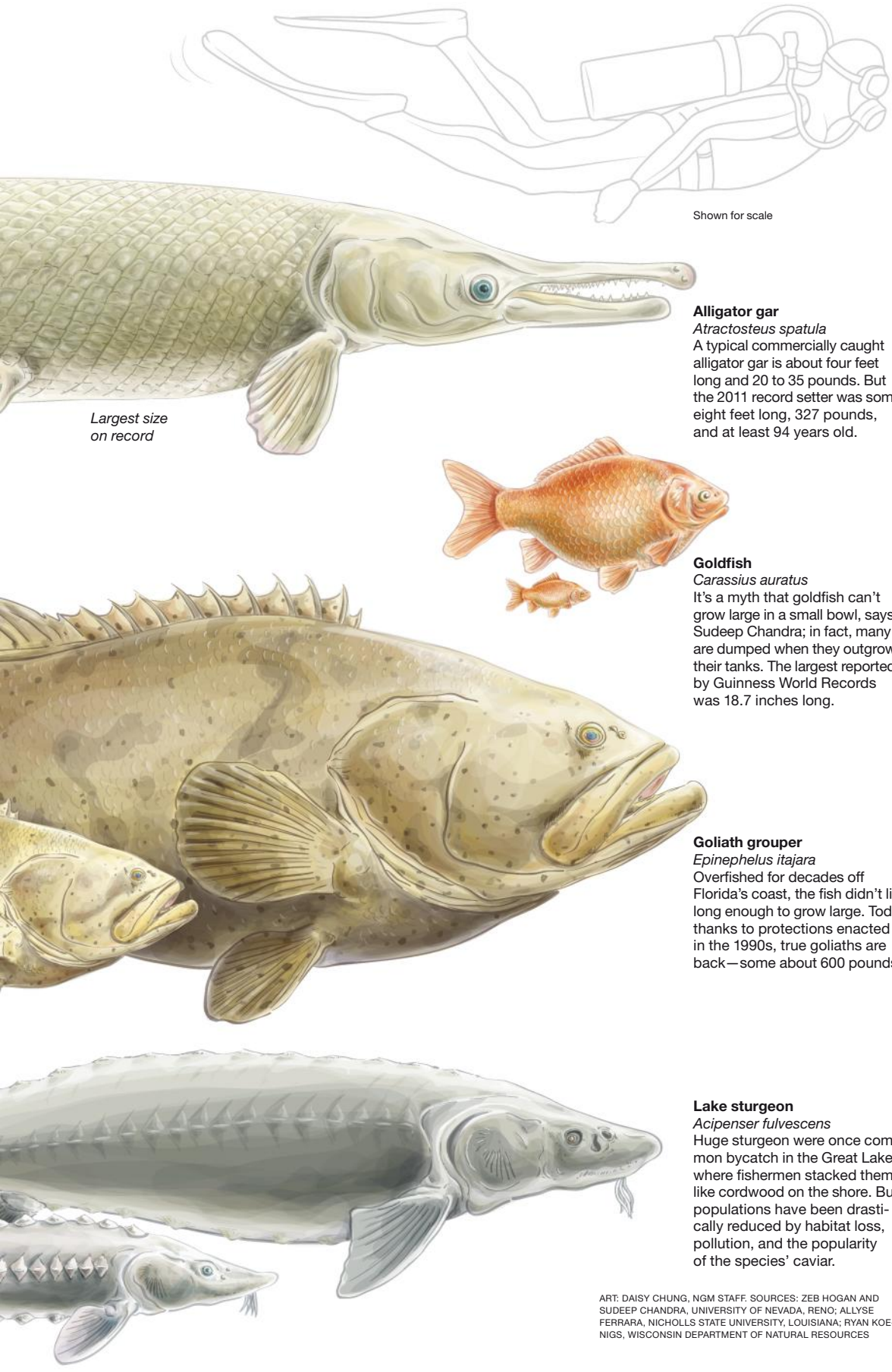
The Ones That Got Away Get Huge

Biologists were stunned, in 2013, to pull a goldfish more than 15 inches long from Lake Tahoe. And it had company; aquarium fish dumped by their owners have been multiplying in the lake—and growing enormous. Since the goldfish have plenty of food and little competition, "it may be possible to see larger goldfish in the future in Tahoe," says Sudeep Chandra, an aquatic ecosystems researcher at the University of Nevada, Reno.

The secret to growing these monster-size fish is time. Unlike people, who normally stop growing after puberty, many fish keep growing as long as they live. A lake sturgeon, for example, can live to be over a hundred and grow up to nine feet long. In much of the world, however, overfishing prevents fish from living long lives. As a result, "the world is losing its big fish," says fish biologist Zeb Hogan.

Yet in some places where fishing is restricted, new size records are being set. "What seemed like 'fish stories' in the past now seem believable," says Hogan, host of the *Monster Fish* television show on Nat Geo WILD. The return of true behemoths could take 30 or 40 years, he says: "You stop fishing one year, you don't see giant fish the next."

As the goldfish keep growing in Lake Tahoe, Chandra aims to document how they're changing the ecosystem. On the drawing board: a miniature robot fish that could stealthily observe the giants. *—Erika Engelhaupt*



Alligator gar
Atractosteus spatula
A typical commercially caught alligator gar is about four feet long and 20 to 35 pounds. But the 2011 record setter was some eight feet long, 327 pounds, and at least 94 years old.

Goldfish
Carassius auratus
It's a myth that goldfish can't grow large in a small bowl, says Sudeep Chandra; in fact, many are dumped when they outgrow their tanks. The largest reported by Guinness World Records was 18.7 inches long.

Goliath grouper
Epinephelus itajara
Overfished for decades off Florida's coast, the fish didn't live long enough to grow large. Today, thanks to protections enacted in the 1990s, true goliaths are back—some about 600 pounds.

Lake sturgeon
Acipenser fulvescens
Huge sturgeon were once common bycatch in the Great Lakes, where fishermen stacked them like cordwood on the shore. But populations have been drastically reduced by habitat loss, pollution, and the popularity of the species' caviar.

ART: DAISY CHUNG, NGM STAFF. SOURCES: ZEB HOGAN AND SUDEEP CHANDRA, UNIVERSITY OF NEVADA, RENO; ALLYSE FERRARA, NICHOLLS STATE UNIVERSITY, LOUISIANA; RYAN KOENIGS, WISCONSIN DEPARTMENT OF NATURAL RESOURCES

In Flight, Off Taste

The plane has reached cruising altitude, and flight attendants are moving down the aisle, taking drink orders. Suddenly tomato juice—or maybe even a Bloody Mary—sounds delicious.

Just a random craving? Not necessarily, says Robin Dando, Cornell University assistant professor of food science. The high decibel level in the cabin interferes with how people perceive taste. The palate registers sweets such as soft drinks less intensely, while the taste known as umami is heightened. Thirsty passengers may find they yearn specifically for something rich and savory, and they frequently choose tomato juice. In fact, the German airline Lufthansa estimates people consume about as much tomato juice as beer aboard its flights.

Oxford University psychologist Charles Spence, who studies how senses interact, says the phenomenon isn't unique to aircraft. Other loud environments can also alter taste perception, he says—which may explain why dinner at a noisy restaurant doesn't always hit the spot. *—Catherine Zuckerman*

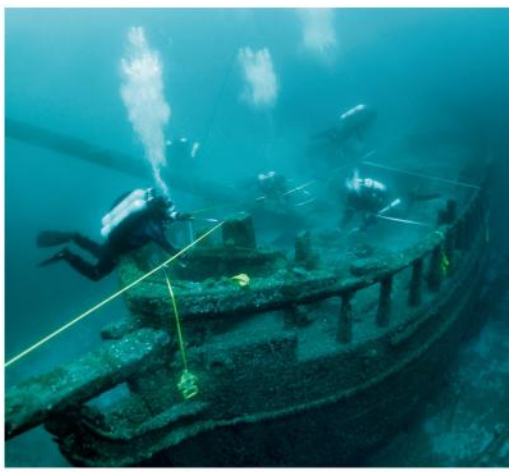
NOMINATE A NEW MARINE PRESERVE

For the first time, you can suggest areas in U.S. waters for consideration as new marine sanctuaries. In the past, government entities nominated sites such as California's Channel Islands and the Florida Keys. Now the Obama Administration has opened the process to the public.

Proposed areas must have significant biological or historical value, says Matt Brookhart, acting deputy director for National Marine Sanctuaries at NOAA, the agency that oversees the process. Two of the most recent active sanctuary proposals would protect historic shipwrecks, in Lake Michigan off southeastern Wisconsin (right) and in the Potomac River in Maryland.

The input from the public "has been great," says Brookhart. "We are doing this for future generations." *—Brian Clark Howard*

To nominate a site, visit www.nominate.noaa.gov.



PHOTOS: EGGLESTON ARTISTIC TRUST/CHEIM & READ (TOP); TAMARA THOMSEN, MARITIME PRESERVATION AND ARCHAEOLOGY PROGRAM, WISCONSIN HISTORICAL SOCIETY

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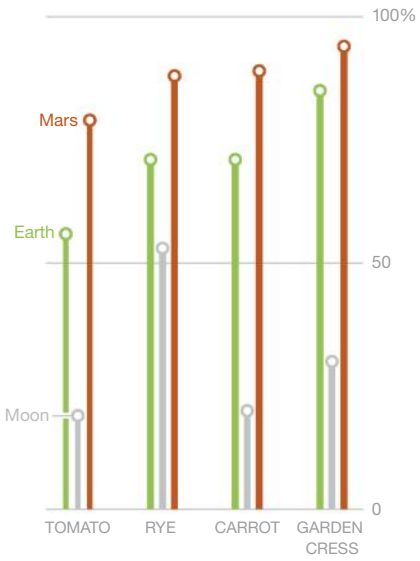
The Dirt on Mars

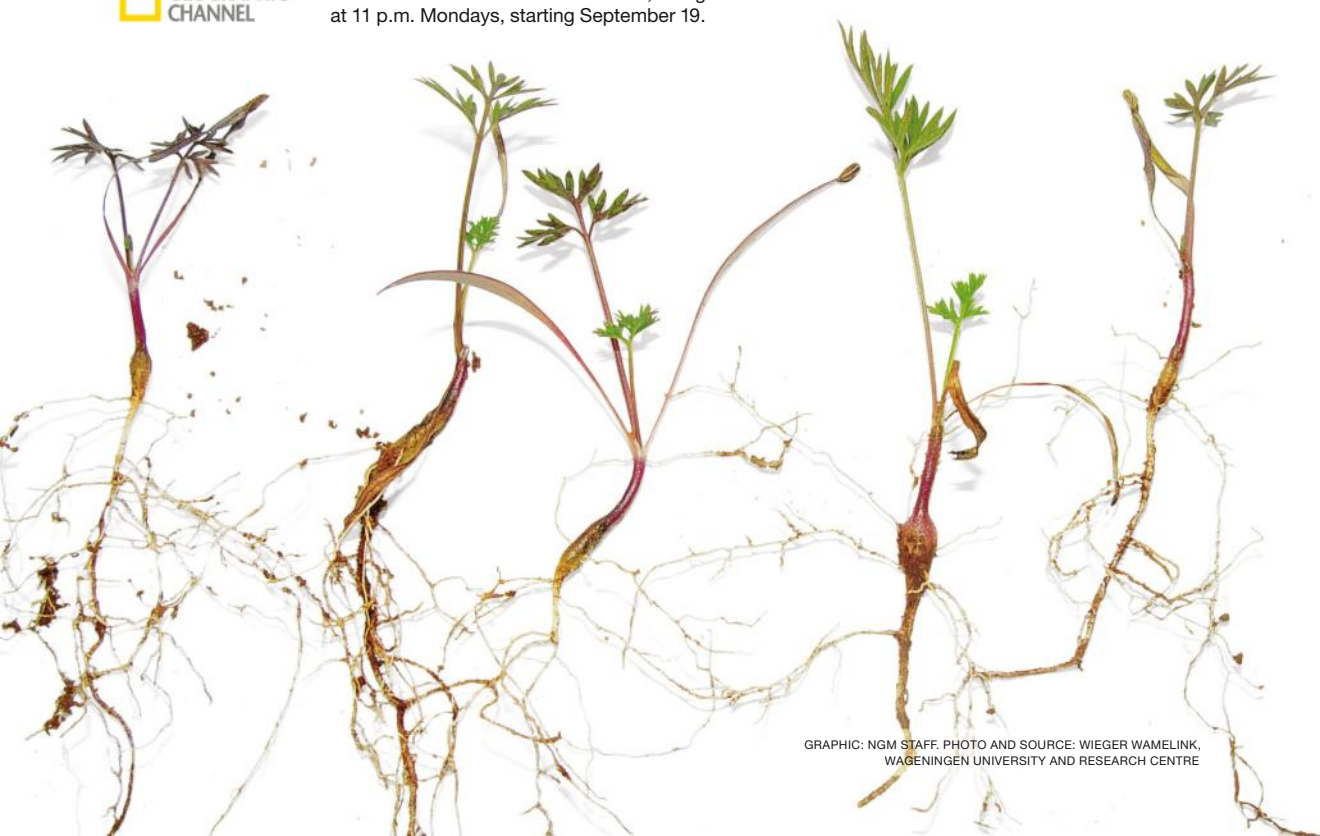
We know there's frozen water on Mars. We also know that the red planet used to have an atmosphere. One of the next questions for humans' eventual voyage is a matter of agriculture: Can earthly plants grow there?

Yes—sort of. Ecologists in the Netherlands tested 14 plants in soil simulated to chemically match that on the surface of Mars. The soil contained all essential nutrients for plants to grow, including phosphorus, nitrogen, and potassium, as well as magnesium, calcium, and iron. (And that's without the astronaut-excrement fertilizer demonstrated in the book/film *The Martian.*) Over several months many of the plants, such as the carrots below, survived. What Martian soil lacks, however, is water-carrying capacity; its sun-blasted grains are too fine to hold moisture.

The idea of future settlers farming the Martian terrain is "scientifically interesting, but is it practical? No," says soil ecologist Wieger Wamelink. Mars's air is too thin, its climate too cold, and the planet lacks an electromagnetic field (like Earth's) to shield botanical life from high levels of radiation. Mars colonists will need to grow food in domes or reinforced tents, says Wamelink. But at least they'll be able to make some use of the soil that's already there. *—Daniel Stone*

Crops grown in soil simulants
Percentage alive after 50 days





GRAPHIC: NGM STAFF. PHOTO AND SOURCE: WIEGER WAMELINK, WAGENINGEN UNIVERSITY AND RESEARCH CENTRE

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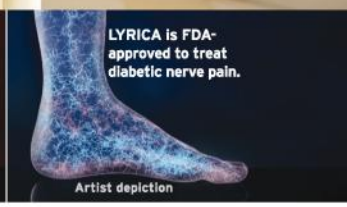

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- Have any trouble breathing
- Rash, hives (raised bumps) or blisters

Like other antiepileptic drugs, LYRICA may cause suicidal thoughts or actions in a very small number of people, about 1 in 500.
Call your doctor right away if you have any symptoms, especially if they are new, worse or worry you, including:
- suicidal thoughts or actions
- new or worse depression
- new or worse anxiety
- feeling agitated or restless
- panic attacks
- trouble sleeping
- new or worse irritability
- acting aggressive, being angry, or violent
- acting on dangerous impulses
- an extreme increase in activity and talking
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If you have suicidal thoughts or actions, do not stop LYRICA without first talking to your doctor.

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This swelling can be a serious problem with people with heart problems.

LYRICA may cause dizziness or sleepiness.
Do not drive a car, work with machines, or do other dangerous things until you know how LYRICA affects you. Ask your doctor when it is okay to do these things.

ABOUT LYRICA

LYRICA is a prescription medicine used in adults 18 years and older to treat:
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BEFORE STARTING LYRICA

Tell your doctor about all your medical conditions, including if you:
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- Have heart problems, including heart failure
- Have a bleeding problem or a low blood platelet count
- Have abused prescription medicines, street drugs or alcohol in the past
- Have ever had swelling of your face, mouth, tongue, lips, gums, neck, or throat (angioedema)
- Plan to father a child. It is not known if problems seen in animal studies can happen in humans.
- Are pregnant, plan to become pregnant. It is not known if LYRICA will harm your unborn baby. You and your doctor will decide whether you should take LYRICA.
- Are breastfeeding or plan to breastfeed. LYRICA passes into your breast milk. It is not known if LYRICA can harm your baby. Breastfeeding is not recommended while taking LYRICA.

Tell your doctor about all your medicines. Include over-the-counter medicines, vitamins, and herbal supplements. LYRICA and other medicines may affect each other causing side effects. Especially tell your doctor if you take:

BEFORE STARTING LYRICA, continued

- Angiotensin converting enzyme (ACE) inhibitors. You may have a higher chance for swelling and hives.
- Avandia® (rosiglitazone)*, Avandamet® (rosiglitazone and metformin)* or Actos® (pioglitazone)** for diabetes. You may have a higher chance of weight gain or swelling of your hands or feet.
- Narcotic pain medicines (such as oxycodone), tranquilizers or medicines for anxiety (such as lorazepam). You may have a higher chance for dizziness and sleepiness.
- Any medicines that make you sleepy.

POSSIBLE SIDE EFFECTS OF LYRICA

LYRICA may cause serious side effects, including:
- See "Important Safety Information About LYRICA."
- Muscle problems, pain, soreness or weakness along with feeling sick and fever
- Eyesight problems including blurry vision
- Weight gain. Weight gain may affect control of diabetes and can be serious for people with heart problems.
- Feeling "high"

If you have any of these symptoms, tell your doctor right away.
The most common side effects of LYRICA are:
- Dizziness
- Blurry vision
- Weight gain
- Sleepiness
- Trouble concentrating
- Swelling of hands and feet
- Dry mouth

If you have diabetes, you should pay extra attention to your skin while taking LYRICA.

HOW TO TAKE LYRICA

Do:
- Take LYRICA exactly as your doctor tells you. Your doctor will tell you how much to take and when to take it. Take LYRICA at the same times each day.
- Take LYRICA with or without food.

Don't:
- Drive a car or use machines if you feel dizzy or sleepy while taking LYRICA.
- Drink alcohol or use other medicines that make you sleepy while taking LYRICA.
- Change the dose or stop LYRICA suddenly. If you stop taking LYRICA suddenly you may have headaches, nausea, diarrhea, trouble sleeping, increased sweating, or you may feel anxious. If you have epilepsy, you may have seizures more often.
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Pandamania: A Brief History

Though today giant pandas are known and loved worldwide, it wasn't always so.

Ancient Chinese texts rarely mention the native animals. Westerners first learned of them in 1869 when French missionary Armand David, while in China, laid eyes on a distinctive black-and-white pelt and then bought a complete, dead specimen from local hunters. A zoologist in Paris wrote up the official description of *Ailuropoda melanoleuca* (literally, "cat foot, black and white").

In 1929 Chicago's Field Museum put two mounted pandas on display courtesy of the Roosevelt brothers, Theodore Jr. and Kermit. The two were sons of the 26th U.S. president, whose love of sport hunting ultimately propelled major conservation reforms. With the help of Sichuan Province locals, they brought home the first panda shot by white men for the museum's new Asian Hall. Their feat prompted copycat expeditions funded by other museums.

As dead bears lost some allure, plans shifted to getting a live panda out of China. In December 1936 a wild cub named Su-Lin left Shanghai by ship in a wicker basket carried by Ruth Harkness, with an export permit reading "One dog, $20.00." Harkness, a San Francisco socialite who had fallen in love as she bottle-fed Su-Lin on a visit to China, soon sold the animal to Chicago's Brookfield Zoo. There, pandamania was instantaneous: More than 53,000 visitors showed up for the exhibit's opening day.

That mania persists. Currently at least 20 zoos outside China boast giant panda displays. (For a time China gifted pandas to foreign countries; now the government rents out pairs for a million dollars a year and retains ownership of cubs born abroad.) Panda births and deaths make international news; web videos quickly go viral. The panda cam trained on a new cub at the Smithsonian's National Zoo in Washington, D.C., had nearly 14 million views by the animal's six-month birthday. During the 2013 government shutdown, fans had complained loudly when the camera went dark.

This tremendous devotion to pandas has roots in science. When humans see pandas, we are subconsciously affected by what developmental biologists call neoteny, the retention into adulthood of certain infant characteristics. That cute baby face and toddler-like behavior boost our body's production of oxytocin, a hormone that makes us feel loving and protective. *—Jennifer S. Holland*








PHOTOS: AMI VITALE; ROBIN COX (TOP ROW, MIDDLE)

LEGAL NOTICE

If you purchased and paid for Adderall XR® any time from January 1, 2007 to April 11, 2016, you could get benefits from a class action settlement.

A settlement has been reached with Shire U.S., Inc. and Shire LLC ("Shire") in a class action lawsuit alleging that it acted unlawfully to delay and limit the availability of generic versions of Adderall XR®. Shire denies the claims in the lawsuit and maintains that it did not act unlawfully. The Court has not decided who is right. Instead, the parties have agreed to settle this case and three related cases.

WHO IS INCLUDED? The settlement includes all persons who purchased and paid for some or all of the purchase price Adderall XR® (brand name only, for personal or household use) from January 1, 2007 to April 11, 2016 in Alabama, Arizona, California, Delaware, the District of Columbia, Florida, Georgia, Idaho, Illinois, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Utah, Vermont, West Virginia, and Wisconsin ("Settlement Class Members"). Third-party payors, purchases made directly from Shire, purchases made for resale purposes, "Flat co-pay" and "Cadillac Plan" purchases (fixed dollar-amount co-payments that did not vary between brand name and generic equivalents), and flat-rate co-pay provision purchases are not included in the settlement.

WHAT DOES THE SETTLEMENT PROVIDE? Shire will pay $14,750,000 into a Settlement Fund. After deducting Court-approved attorneys' fees, costs and expenses, service awards for the Class Representatives and related Plaintiffs, taxes, and the costs of settlement notice and administration (the "Net Settlement Fund"), the balance will be distributed to Settlement Class Members who submit a valid Claim Form. 74% of the Net Settlement Fund will be made available to Settlement Class Members who made purchases from January 1, 2007 through March 31, 2009 (the "pre-generic period") and 26% will be made for purchases made from April 1, 2009 through April 11, 2016 (the "post entry period"). Settlement Class Members can receive up to $16 for each eligible purchase (for example, if you have 5 eligible purchases, you may receive $80 (5 x $16)).

HOW DO YOU ASK FOR BENEFITS? You must complete and submit a claim form by **October 7, 2016**. Claim forms may be submitted online, via email to info@AdderallXRSettlement.com, or downloaded for printing and submission via U.S. Mail at www.AdderallXRSettlement.com. Claim forms are also available by calling 1-877-369-4085 or by writing to the Settlement Administrator at the address listed below.

YOUR OTHER OPTIONS. If you do nothing, your rights will be affected but you will not get a settlement payment. If you do not want to be legally bound by the settlement, you must exclude yourself from it by mailing or emailing a written exclusion to the Settlement Administrator. The deadline to exclude yourself is **October 7, 2016**. Unless you exclude yourself, you will not be able to sue or continue to sue Shire for any claim resolved by this settlement or released by the Settlement Agreement. If you exclude yourself, you cannot get a payment from the settlement but are free to pursue any claims that you may have against Shire in a different lawsuit. If you stay in the settlement (that is, don't exclude yourself), you may object to it by **October 7, 2016**. More information about how to exclude yourself or object can be found in the detailed notice and Settlement Agreement, which are available at www.AdderallXRSettlement.com.

THE COURT'S FAIRNESS HEARING. The U.S. District Court for the Southern District of Florida, located at 400 North Miami Avenue, Miami, Florida 33128, will hold a hearing in this case (*Barba v. Shire U.S., Inc*., Case No. 1:13-cv-21158) on November 9, 2016, at 2:30 p.m.. At the Fairness Hearing, the Court will decide whether to grant final approval of the settlement; a request for service awards to each of the Class Representatives and related Plaintiffs; and up to 35% of the Settlement Fund in attorneys' fees plus reimbursement of costs to Class Counsel. If approved, these fees, expenses and awards, as well as the costs to administer the settlement, will be deducted from the Settlement Fund before making payments to Settlement Class Members. You may appear at the hearing, but you do not have to. You may also hire your own attorney, at your own expense, to appear or speak for you at the hearing.

WANT MORE INFORMATION? Visit www.AdderallXRSettlement.com, email info@AdderallXRSettlement.com, call 1-877-369-4085, or write to *Barba v. Shire U.S., Inc*. Settlement Administrator, P.O. Box 40007, College Station, TX, 77842-4007.

Ice Cap Cannibalism

Tourists find a surprisingly grim scene at the western edge of the cap of ice and snow that covers about 80 percent of Greenland (above). The surface, far from being blindingly white, is sullied by atmospheric soot and dust. Also, the ice beneath is melting rapidly—a trend that will probably continue into the foreseeable future. Why? According to a study of satellite data from 1981 to 2012, Greenland began absorbing more solar radiation around 1996, when temperatures there began to increase. This has intensified the normal summer melt.

Blame the grime, at least in part. The impurities cause more solar energy to be absorbed and less to be reflected, as illustrated below. That produces more heat and thus accelerates the melting. The loss of ice concentrates the dirt, creating an even darker surface, which in turn leads to even faster melting. "I call it melting cannibalism," says lead investigator Marco Tedesco. "You have melting feeding on itself." Understanding this vicious circle will allow experts to better assess Greenland's contribution to rising sea levels. *—A. R. Williams*

Sunlight reflected by Arctic surfaces

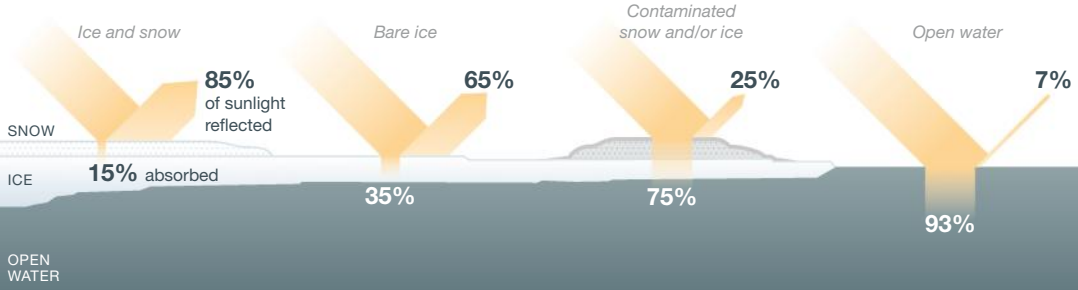

PHOTO: OLAF OTTO BECKER
GRAPHIC: JASON TREAT, NGM STAFF. SOURCE: MARCO TEDESCO, COLUMBIA UNIVERSITY

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United States

Preserving the odd charm of U.S. roadside attractions

MARISSA GAWEL *Nat Geo grantee*

In Indiana, Marissa Gawel was given a slice of the world's largest ball of paint. She stashed it in her backpack, where it joined other keepsakes from America's strangest displays: an ornately decorated plastic-foam cup, nestled salt and pepper shakers, a handful of miniature hands.

During summer 2015, the now 25-year-old Detroit-based photographer traveled from Michigan to Louisiana on a National Geographic Young Explorers Grant. For three weeks she documented roadside America, visiting homemade attractions like a fiberglass replica of Stonehenge and a residence covered in 4,000 birdhouses. "It's easy to see roadside attractions as this zany, oddball thing, but I'm trying to show that they're a really incredible part of the landscape," Gawel says.

She sought out handcrafted manifestations of an individual's eccentricity. In Tennessee, Gawel was awed by a 13-story metal structure called the Mindfield; its 60-year-old creator climbs to the top without a harness. Photographing the sites and their founders, she became convinced that there's an urgent need to preserve the country's offbeat folk art.

The same traits that make each spot unique can also make preservation difficult. The once brilliant pink, red, and yellow cinder block towers of Margaret's Grocery in Mississippi have faded and crumbled since its elderly proprietors died a few years ago. "A lot of these places are so tied to their creator that in the past when that person died, the place died as well," Gawel says. One organization, the Kohler Foundation, currently maintains some of these orphaned attractions.

The byways of the United States are rich in folk displays, like this collection at Louisiana's Abita Mystery House. But many attractions fall into disrepair when their creators are no longer able to care for them.

Gawel hopes her documentation will provide a record for posterityand a map for road trippers. "Many of these may not be here in 20 years," she says. "But if they get a few more visitors, they could stick around." *—Nina Strochlic*

Mexico

Indiana Jones meets drone technology

DOMINIQUE MEYER *Nat Geo grantee*

The day before classes started at the University of California, San Diego last September, senior Dominique Meyer returned from mapping Maya ruins in Mexico.

PHOTO: MARISSA GAWEL. NGM MAPS

99 Tips to Make Your Retirement More Comfortable

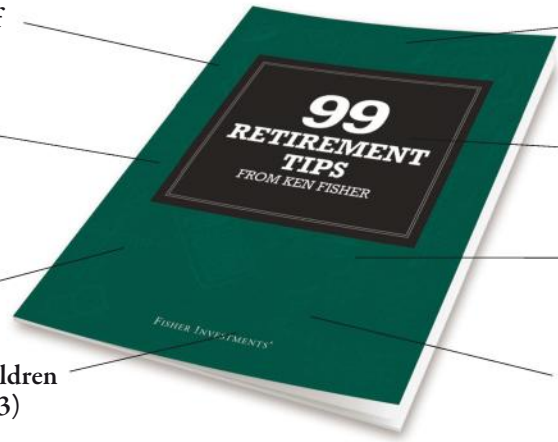
While it's easy to imagine retirement as a time of relaxation, enjoyment and fun, the fact of the matter is that a successful retirement doesn't just happen. It takes thought, planning and action. To help *National Geographic* readers get ready for retirement or make your retirement even better, Fisher Investments has assembled 99 retirement tips.

How not to run out of money. (Tip #10)

Longevity realities. (Tip #12)

The fallacy of most asset-allocation advice. (Tip #13)

Talking with adult children about money. (Tip #23)



How to select a financial benchmark. (Tip #19)

Savvy mortgage advice. (Tip #26)

Taxes and retirement. (Tip #40)

Retirement and marriage strain. (Tip #87)

And many more financial, lifestyle and health suggestions!

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It wasn't his first trip: The then 19-year-old Swiss astrophysics major had flown camera-equipped drones over the coastal Yucatán state of Quintana Roo. The images were used to create a 3-D map of the area and were analyzed with data from satellites and a technique called lidar, which can detect terrain levels through the tree canopy. Clues from this analysis hinted at possible architectural structures, so Meyer and three others, including archaeologist Dominique Rissolo, returned on a National Geographic grant in search of the ruins.

"Some of our technology has really revolutionized archaeology and excavations," Meyer says. "In the past, surveying a site would take multiple months, but we're able to go there and accurately do it in a couple hours."

The team strung up hammocks and spent 10 days hiking around three settlements, including two pyramids, all previously undocumented and—surprisingly—unlooted. Meyer stresses this wasn't their discovery: "The locals know pretty much every square meter of the rain forest." But he hopes the mapping will mean the structures are protected and studied for clues to how the mysterious Maya lived.

"Archaeologists always say that you learn by sitting in environments," Meyer says. Seeing the sites by drone, "you lose a little. But now anyone is able to look at data. Archaeologists don't need to hike to Mexico; they can just sit in their offices." *—Nina Strochlic*

By studying the drone imagery that Dominique Meyer collected, archaeologists were able to identify potential excavation sites remotely.

PHOTOS: VERA SMIRNOVA, CISA3-CHEI, UCSD (ABOVE); BRIAN SKERRY

The Oceans

Prehistoric beasts deserve 'a makeover'

BRIAN SKERRY *Nat Geo photographer*

Skerry reports: When I started diving in the late 1970s, the movie *Jaws* had just come out. It was a big joke that no diver wanted to see a shark underwater. Today it's just the opposite. We know sharks are vital to the health of the oceans and are also incredible creatures that have been swimming since before dinosaurs emerged. Yet the world is killing 100 million sharks a year, largely just to put their fins in a soup. I think when an animal is villainized, it's an easy stretch to kill them. We need to give them a makeover.

I've spent the last two years traveling from New Zealand to Cape Cod to create intimate pictures of sharks. My task as a photographer is to portray them as what they really are: miracles of evolution. As much as they're the biggest, baddest guys in the ocean, life can still be hard: They're affected by climate change, by overfishing, by pollution. You can get into the water in the Bahamas with 14-foot tiger sharks that could easily tear you up, but they don't. If you went to the Serengeti and put a toe out of the Land Rover, those lions would be all over you—God forbid you put a steak on the ground and got out with your camera. Tiger sharks are certainly predators, but you can dive near them without a problem. It's a testament that these animals are not really out to get us.

Skerry's photos appear in the series "The Summer of Sharks" in the Geographic*'s June and July 2016 editions and starting on page 112 of this issue.*

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Why (Claw) Size Matters

All around her, guys wave seductively, beckoning her to their beach homes. How will the female fiddler crab pick a mate? By the quality of his lodging, the allure of his wave—and, especially, the size of his claw.

The female fiddler crab has two small, symmetrical claws; the male has one small and one oversize. "The large claw is all about the initial attraction," says marine biologist Zachary Darnell of Louisiana's Nicholls State University. After checking out several males and the love-nest burrows they've dug, a female "will find a male whose claw she really likes," he says. "Maybe a crab with a large claw relative to his body size, and a bit higher wave than others"—because if he can tote and swing a claw that's up to half his body weight, he's probably a physically fit sire.

After the pair has sex in the beach burrow, the female stays there while her eggs develop; the male goes back to waving, and often brings home other females. On the hot sand, his claw is more than just a chick magnet, Darnell's research has found. It's a thermoregulator, as air passing over it seems to dissipate heat and lower body temperature.

A big claw is also the male crab's best weapon: He uses it to fight rivals and keep intruders away from his burrow. After a few weeks, the pregnant females will emerge from that love lair and head for the waterline, where they'll release the larvae. *—Patricia Edmonds*

HABITAT/RANGE
Intertidal shorelines in tropical and temperate climates

CONSERVATION STATUS
Not listed

OTHER FACTS
The *Uca* genus's roughly 100 species include the sand fiddler crabs seen here.

NATIONAL GEOGRAPHIC
PHOTO ARK
JOEL SARTORE

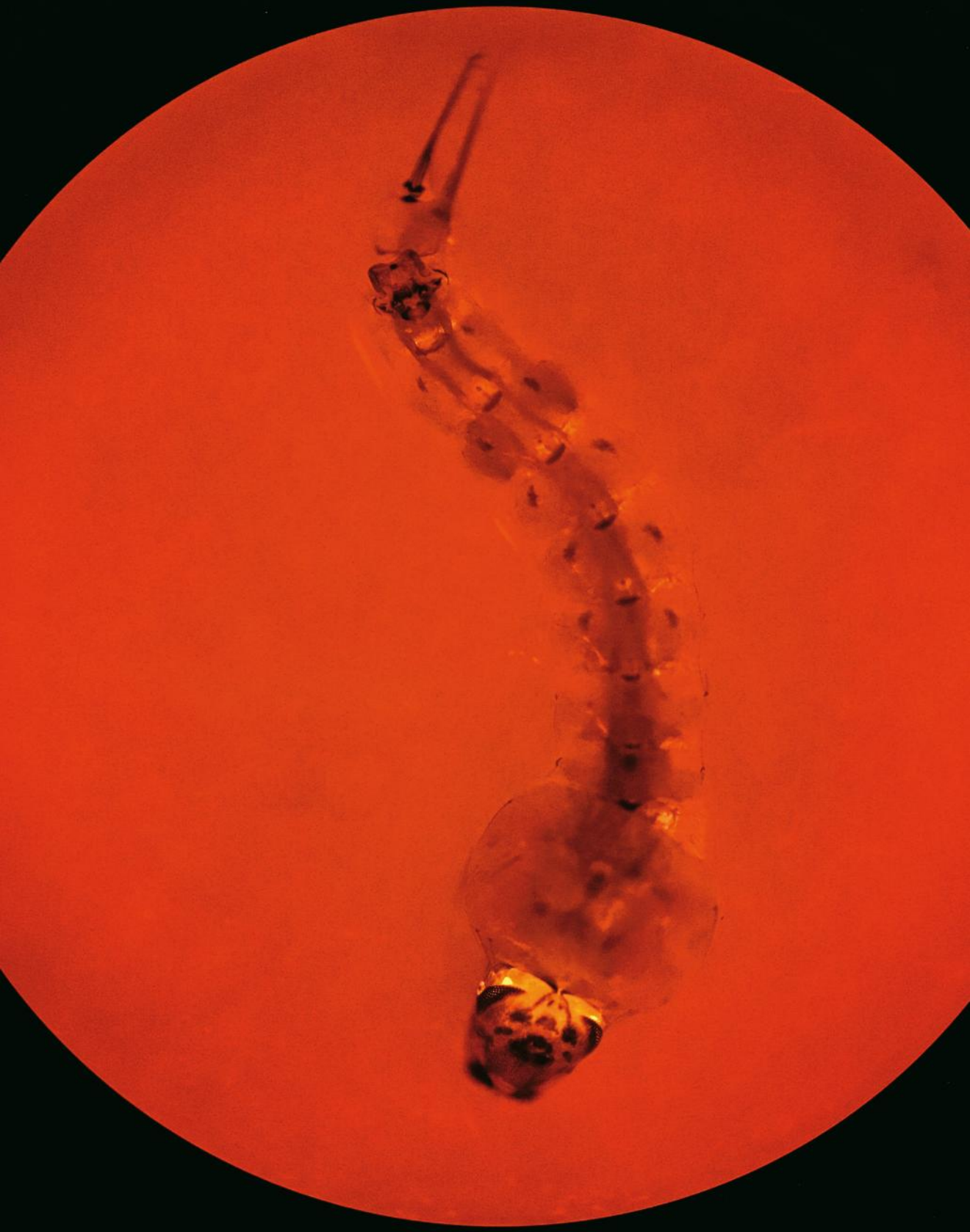
These sand fiddler crabs were photographed at Gulf Specimen Marine Lab and Aquarium in Panacea, Florida.

The ability to quickly alter the code of life has given us unprecedented power over the natural world. The question is: Should we use it?

DNA REVOLUTION

Calla Vanderberg enters the world at Inova Women's Hospital in Falls Church, Virginia. As with all newborns here, seven of her genes involved in drug metabolism will be analyzed. Physicians in the future will be able to tailor medicines to her unique genetic profile.

Mosquito larvae in the laboratory of Anthony James at the University of California, Irvine pay witness to how a dreaded disease might be stopped. Both are *Anopheles stephensi,* a major carrier of the malaria parasite in urban Asia. Using a technique called CRISPR, James has edited a gene in the larva on the right so that the



insect cannot transmit the parasite. A fluorescent protein signals that the experiment has worked. Released in the wild, mosquitoes engineered with CRISPR and a tool called gene drive could eventually replace the wild mosquitoes that carry the disease. But too much uncertainty still exists to put such science into practice.

DAVID LIITTSCHWAGER (BOTH)

Zhou Yin of the Yunnan Key Laboratory of Primate Biomedical Research in Kunming, China, shows off a young long-tailed macaque raised from a CRISPR-modified embryo. Dozens of other organisms—including chickens and cattle, mushrooms and wheat, catfish and koi—have been engineered with CRISPR to carry specific genetic traits. Many more will follow.

By Michael Specter
Photographs by Greg Girard

If you took a glance around Anthony James's office, it wouldn't be hard to guess what he does for a living. The walls are covered with drawings of mosquitoes. Mosquito books line the shelves.

Hanging next to his desk is a banner with renderings of one particular species—*Aedes aegypti*—in every stage of development, from egg to pupa to fully grown, enlarged to sizes that would even make fans of *Jurassic Park* blanch. His license plates have a single word on them: AEDES.

"I have been obsessed with mosquitoes for 30 years," says James, a molecular geneticist at the University of California, Irvine.

There are approximately 3,500 species of mosquito, but James pays attention to just a few, each of which ranks among the deadliest creatures on Earth. They include *Anopheles gambiae,* which transmits the malaria parasite that kills hundreds of thousands of people each year. For much of his career, however, James has focused on *Aedes.* Historians believe the mosquito arrived in the New World on slave ships from Africa in the 17th century, bringing with it yellow fever, which has killed millions of people. Today the mosquito also carries dengue fever, which infects as many as 400 million people a year, as well as such increasingly threatening pathogens as chikungunya, West Nile virus, and Zika.

In a widening outbreak that began last year in Brazil, Zika appears to have caused a variety of neurological disorders, including a rare defect called microcephaly, where babies are born with abnormally small heads and underdeveloped brains.

The goal of James's lab, and of his career, has been to find a way to manipulate mosquito genes so that the insects can no longer spread such diseases. Until recently, it has been a long, lonely, and largely theoretical road. But by combining a revolutionary new technology called CRISPR-Cas9 with a natural system known as a gene drive, theory is rapidly becoming reality.

CRISPR places an entirely new kind of power into human hands. For the first time, scientists can quickly and precisely alter, delete, and rearrange the DNA of nearly any living organism, including us. In the past three years, the technology has transformed biology. Working with animal models, researchers in laboratories around the world have already used CRISPR to

Cow blood engorges an exposed mosquito's gut in Anthony James's lab. Versions of the species carrying Zika and dengue fever can be manipulated with CRISPR so that they give birth to sterile offspring.

DAVID LIITTSCHWAGER

Scientists used conventional genetic engineering to add genetic material from two other fish species to create the AquAdvantage Atlantic salmon (top), which can reach market size twice as fast as its natural counterpart. The fish consumes less feed and can be raised in isolation close to cities, reducing transportation

costs and emissions, and eliminating any chance of escape into the wild. While the FDA has approved the fish as entirely safe for consumption, doubts over the safety of transgenic foods persist. In the future, CRISPR-engineered foods, which do not combine genes from different organisms, might find quicker acceptance.

No discovery of the past century holds more promise—or raises more troubling ethical questions.

correct major genetic flaws, including the mutations responsible for muscular dystrophy, cystic fibrosis, and one form of hepatitis. Recently several teams have deployed CRISPR in an attempt to eliminate HIV from the DNA of human cells. The results have been only partially successful, but many scientists remain convinced that the technology may contribute to a cure for AIDS.

In experiments, scientists have also used CRISPR to rid pigs of the viruses that prevent their organs from being transplanted into humans. Ecologists are exploring ways for the technology to help protect endangered species. Moreover, plant biologists, working with a wide variety of crops, have embarked on efforts to delete genes that attract pests. That way, by relying on biology rather than on chemicals, CRISPR could help reduce our dependence on toxic pesticides.

No scientific discovery of the past century holds more promise—or raises more troubling ethical questions. Most provocatively, if CRISPR were used to edit a human embryo's germ line—cells that contain genetic material that can be inherited by the next generation—either to correct a genetic flaw or to enhance a desired trait, the change would then pass to that person's children, and their children, in perpetuity. The full implications of changes that profound are difficult, if not impossible, to foresee.

"This is a remarkable technology, with many great uses. But if you are going to do anything as fateful as rewriting the germ line, you'd better be able to tell me there is a strong reason to do it," said Eric Lander, who is director of the Broad Institute of Harvard and MIT and who served as leader of the Human Genome Project. "And you'd better be able to say that society made a choice to do this—that unless there's broad agreement, it is not going to happen."

"Scientists do not have standing to answer these questions," Lander told me. "And I am not sure who does."

CRISPR-CAS9 HAS two components. The first is an enzyme—Cas9—that functions as a cellular scalpel to cut DNA. (In nature, bacteria use it to sever and disarm the genetic code of invading viruses.) The other consists of an RNA guide that leads the scalpel to the precise nucleotides—the chemical letters of DNA—it has been sent to cut. (Researchers rarely include the term "Cas9" in conversation, or the inelegant terminology that CRISPR stands for: "clustered regularly interspaced short palindromic repeats.")

The guide's accuracy is uncanny; scientists can dispatch a synthetic replacement part to any location in a genome made of billions of nucleotides. When it reaches its destination, the Cas9 enzyme snips out the unwanted DNA sequence. To patch the break, the cell inserts the chain of nucleotides that has been delivered in the CRISPR package.

By the time the Zika outbreak in Puerto Rico comes to an end, the U.S. Centers for Disease Control and Prevention estimates that, based on patterns of other mosquito-borne illnesses, at least a quarter of the 3.5 million people in Puerto Rico may contract Zika. That means thousands of pregnant women are likely to become infected.

Currently the only truly effective response to Zika would involve bathing the island in insecticide. James and others say that editing mosquitoes with CRISPR—and using a gene drive to make those changes permanent—offers a far better approach.

Gene drives have the power to override the traditional rules of inheritance. Ordinarily the progeny of any sexually reproductive animal receives one copy of a gene from each parent. Some genes, however, are "selfish": Evolution has bestowed on them a better than 50 percent chance of being inherited. Theoretically, scientists could combine CRISPR with a gene drive to alter the genetic code of a species by attaching a

desired DNA sequence onto such a favored gene before releasing the animals to mate naturally. Together the tools could force almost any genetic trait through a population.

Last year, in a study published in the *Proceedings of the National Academy of Sciences,* James used CRISPR to engineer a version of *Anopheles* mosquitoes that makes them incapable of spreading the malaria parasite. "We added a small package of genes that allows the mosquitoes to function as they always have," he explained. "Except for one slight change." That change prevents the deadly parasite from being transmitted by the mosquitoes.

"I'd been laboring in obscurity for decades. Not anymore, though—the phone hasn't stopped ringing for weeks," James said, nodding at a sheaf of messages on his desk.

Combating the *Ae. aegypti* mosquito, which carries so many different pathogens, would require a slightly different approach. "What you would need to do," he told me, "is engineer a gene drive that makes the insects sterile. It doesn't make sense to build a mosquito resistant to Zika if it could still transmit dengue and other diseases."

To fight off dengue, James and his colleagues have designed CRISPR packages that could simply delete a natural gene from the wild parent and replace it with a version that would confer sterility in the offspring. If enough of those mosquitoes were released to mate, in a few generations (which typically last just two or three weeks each) entire species would carry the engineered version.

James is acutely aware that releasing a mutation designed to spread quickly through a wild population could have unanticipated consequences that might not be easy to reverse. "There are certainly risks associated with releasing insects that you have edited in a lab," he said. "But I believe the dangers of not doing it are far greater."

IT HAS BEEN MORE THAN 40 years since scientists discovered how to cut nucleotides from the genes of one organism and paste them into the genes of another to introduce desired traits. Molecular biologists were thrilled by the possibilities this practice, referred to as recombinant DNA, opened for their research. From the start, however, scientists also realized that if they could transfer DNA between species, they might inadvertently shift viruses and other pathogens too. That could cause unanticipated diseases, for which there would be no natural protection, treatment, or cure.

This possibility frightened no one more than the scientists themselves. In 1975, molecular biologists from around the world gathered at the Asilomar Conference Grounds, along California's central coast, to discuss the challenges presented by this new technology. The group emerged from the meeting having agreed to a series of safeguards, including levels of laboratory security that escalated along with the potential risks posed by the experiments.

It soon became clear that the protections seemed to work and that the possible benefits were enormous. Genetic engineering began to improve the lives of millions. Diabetics, for example, could count on steady supplies of genetically engineered insulin, made in the lab by placing human insulin genes into bacteria and then growing it in giant vats. Genetically engineered crops, yielding more and resisting herbicides and insects, began to transform much of the world's agricultural landscape.

Yet while genetically engineered medicine has been widely accepted, crops produced in a similar fashion have not, despite scores of studies showing that such products are no more dangerous to eat than any other food. As the furor over the labeling of GMOs (genetically modified organisms) demonstrates, it doesn't matter whether a product is safe if people refuse to eat it.

CRISPR may provide a way out of this scientific and cultural quagmire. From the beginning of the recombinant era, the definitions of the word "transgenic" and the term "GMO" have been based on the practice of combining in a laboratory the DNA of species that could never

A worker waits to enter a clean room at China Regenerative Medicine International in Shenzhen, where pig corneas are modified for transplant into humans. Chinese scientists have twice conducted experiments to alter nonviable human embryos with CRISPR. Much work remains before the technique could be applied to viable human embryos that would pass on genetic changes.

Without regulation, the tremendous potential of this revolution could be overshadowed by fear.

mate in nature. But scientists hope that using CRISPR to alter DNA could appease the opposition. It gives researchers the ability to redesign specific genes without having to introduce DNA from another species.

Golden rice, for example, is a GMO engineered to contain genes necessary to produce vitamin A in the edible part of the grain—something that doesn't happen naturally in rice plants. Each year up to half a million children in the developing world go blind for lack of vitamin A—but anti-GMO activists have interfered with research and prevented any commercial production of the rice. With CRISPR, scientists could almost certainly achieve the same result simply by altering genes that are already active in rice plants.

Scientists in Japan have used CRISPR to extend the life of tomatoes by turning off genes that control ripening. By deleting all three copies of one wheat gene, Caixia Gao and her team at the Chinese Academy of Sciences in Beijing have created a strain that is resistant to powdery mildew.

Farmers have been adjusting genes in single species—by crossbreeding them—for thousands of years. CRISPR simply offers a more precise way to do the same thing. In some countries, including Germany, Sweden, and Argentina, regulators have made a distinction between GMOs and editing with tools such as CRISPR. There have been signs that the U.S. Food and Drug Administration might follow suit, which could make CRISPR-created products more readily available and easily regulated than any other form of genetically modified food or drug. Whether the public will take advantage of them remains to be seen.

THE POTENTIAL FOR CRISPR research to improve human medicine would be hard to overstate. The technology has already transformed cancer research by making it easier to engineer tumor cells in the laboratory, then test various drugs to see which can stop them from growing. Soon doctors may be able to use CRISPR to treat some diseases directly.

Stem cells taken from people with hemophilia, for example, could be edited outside of the body to correct the genetic flaw that causes the disease, and then the normal cells could be inserted to repopulate a patient's bloodstream.

In the next two years we may see an even more dramatic medical advance. There are 120,000 Americans on waiting lists to receive organ transplants, and there will never be enough for all of them. Thousands of people die every year before reaching the top of the list. Hundreds of thousands never even meet the criteria to be placed on the list.

For years, scientists have searched for a way to use animal organs to ease the donor shortage. Pigs have long been considered the mammal of choice, in part because their organs are similar in size to ours. But a pig's genome is riddled with viruses called PERVs (porcine endogenous retroviruses), which are similar to the virus that causes AIDS and have been shown to be capable of infecting human cells. No regulatory agency would permit transplants with infected organs. And until recently, nobody has been able to rid the pig of its retroviruses.

Now, by using CRISPR to edit the genome in pig organs, researchers seem well on their way to solving that problem. A group led by George Church, a professor at Harvard Medical School and MIT, used the tool to remove all 62 occurrences of PERV genes from a pig's kidney cell. It was the first time that so many cellular changes had been orchestrated into a genome at once.

When the scientists mixed those edited cells with human cells in a laboratory, none of the human cells became infected. The team also modified, in another set of pig cells, 20 genes that are known to cause reactions in the human immune system. That too would be a critical

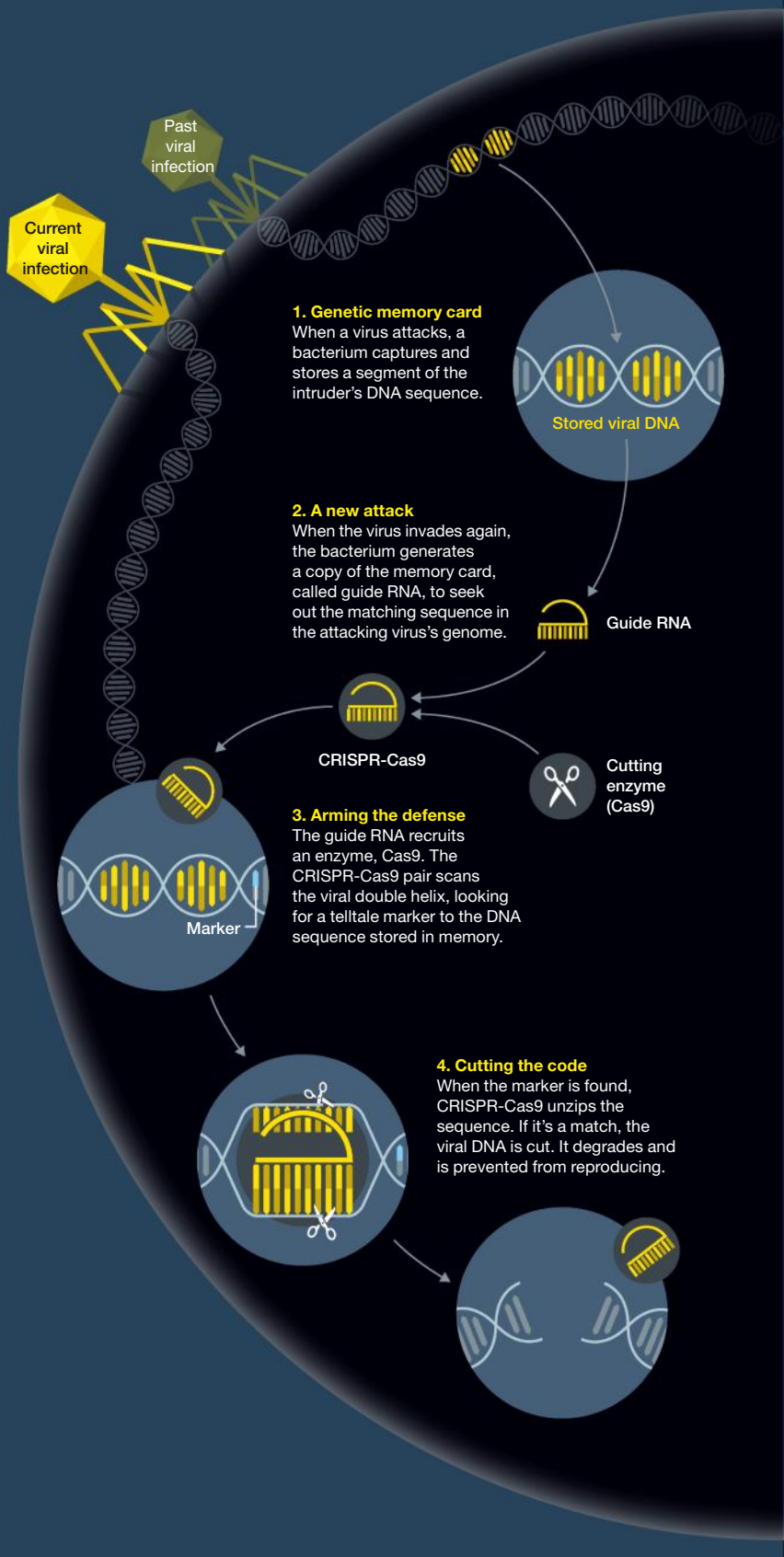
At Guangzhou General Pharmaceutical Research Institute in China, vet Long Haibin pets Taingou, one of two beagles grown from embryos edited to double muscle mass. Such experiments could eventually improve understanding of muscular dystrophy and other human diseases.

How to Hack DNA

Some bacteria have evolved a powerful system, called CRISPR, to fight viral infections. When a virus strikes, a bacterium captures and stores a short, identifying sequence of the virus's DNA—a sort of genetic "memory card." If the same virus attacks future generations of the bacteria, they use the memory card to guide a killer enzyme to the identical sequence in the new invader and cut it away. Scientists have co-opted this natural molecular machinery not only to turn off the action of a gene but also to insert new genetic code into living organisms, including humans. CRISPR has sparked an explosion of research—and a heated ethical debate.

HOW IT WORKS IN NATURE

Researchers studying how viruses infect bacteria discovered a natural immune system that cuts the invader's DNA.

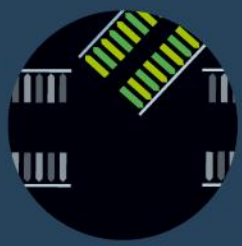


JASON TREAT AND RYAN WILLIAMS, NGM STAFF. ART: THOMAS POROSTOCKY. SOURCE: JENNIFER DOUDNA, UNIVERSITY OF CALIFORNIA, BERKELEY

HOW IT'S HARNESSED IN THE LAB

Scientists realized they could adapt this mechanism to disable genes or insert DNA into any organism.

Hacking the system
Scientists can begin to understand gene function by turning a gene on and off. To do this, they program CRISPR-Cas9 structures in a lab to snip DNA and disable genes that affect health and crops.



Customized genomes
Synthetic DNA sequences can also be engineered in the lab and spliced in at the site of the cut, introducing desired traits into an organism, such as resistance to a parasite.

Unlimited possibilities
With CRISPR, scientists can alter and edit any genome that has been sequenced—quickly, cheaply, and efficiently.

APPLICATIONS FOR CRISPR TECHNOLOGY

Treating Disease
Genome-editing technology is revealing which DNA sequences are involved in diseases such as AIDS.

Altering Ecology
The spread of vector-borne illnesses like malaria could be reduced by introducing disease-resistant genes into wild insect populations.

Transforming Food
CRISPR could be used to develop drought-resistant or otherwise hardier crops. CRISPR mushrooms that don't brown have already been approved in the U.S.

Editing Humans?
Experiments with nonviable embryos show that much work will have to be done—and many questions answered—before CRISPR can be used to edit humans.

American chestnut trees blanketed much of the eastern U.S. until an invasive fungus all but wiped them out in the early 20th century—a tragedy visible in a Virginia forest (above). William Powell of the State University of New York College of Environmental Science and Forestry and colleagues (including Kristen Stewart, right, tending a transgenic plant) have used a wheat gene to develop a blight-resistant chestnut. It may one day repopulate the eastern forest.

LIBRARY OF CONGRESS (ABOVE)

part of making this kind of transplant work.

Church has now cloned those cells and begun growing them in pig embryos. He expects to start primate trials within a year or two. If the organs function properly and are not rejected by the animals' immune systems, the next step would be human trials. Church told me he thinks this could happen in as few as 18 months, adding that for many people the alternative to the risk of the trial would surely be death.

Church has always wanted to find a way to provide transplants for people who aren't considered healthy enough to receive them. "The closest thing we have to death panels in this country are the decisions made about who gets transplants," he said. "A lot of these decisions are being made based on what else is wrong with you. Many people are rejected because they have infectious diseases or problems with substance abuse—a whole host of reasons. And the conceit is that these people would not benefit from a transplant. But of course they would benefit. And if you had an abundance of organs, you could do it for everyone."

THE BLACK-FOOTED FERRET is one of the most endangered mammals in North America. Twice in the past 50 years, wildlife ecologists assumed that the animals, which were once plentiful throughout the Great Plains, had gone extinct. They came close; every black-footed ferret alive today descends from one of seven

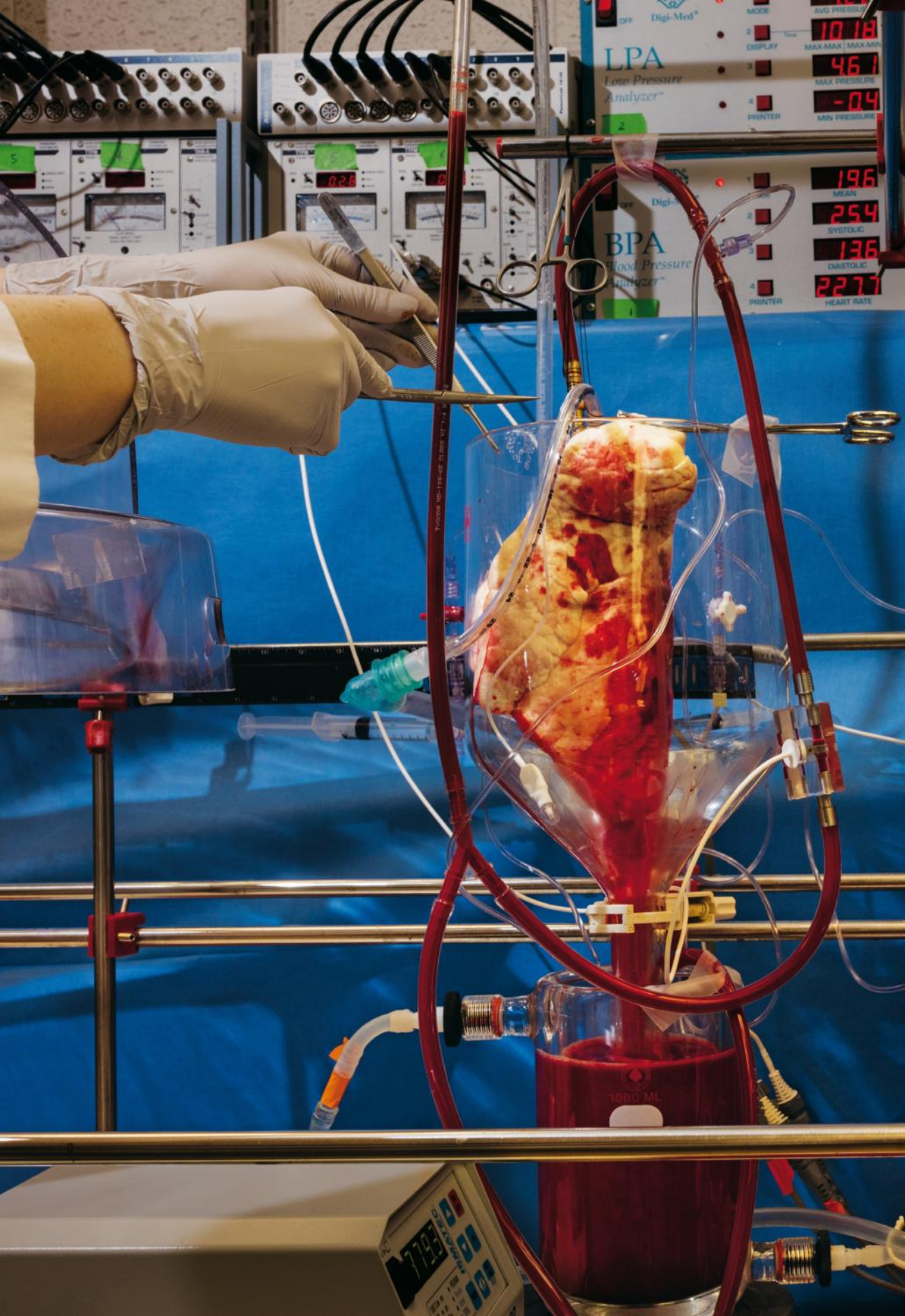
ancestors discovered in 1981 on a cattle ranch near Meeteetse, Wyoming.

But the ferrets, inbred for generations, lack genetic diversity, which makes it harder for any species to survive.

"The ferrets are a classic example of an entire species that could be saved by genomic technology," said Ryan Phelan of the group Revive & Restore, which is coordinating efforts to apply genomics to conservation. Working with Oliver Ryder at the San Diego Frozen Zoo, Phelan and her colleagues are attempting to increase the diversity of the ferrets by introducing more variable DNA into their genomes from two specimens preserved 30 years ago.

Phelan's work can address two immediate and interlocking threats. The first is lack of food: Prairie dogs, the ferrets' main prey, have been decimated by sylvatic plague, which is caused by the same bacterium that gives rise to bubonic plague in humans. And the plague is also fatal to the ferrets themselves, which become infected by eating prairie dogs that have died of the disease. A vaccine against human plague developed in the 1990s appears to provide lifelong immunity in ferrets. Teams from the Fish and Wildlife Service have captured, vaccinated, and released as many of the ferrets (a few hundred exist in the wild) as they can. But such a ferret-by-ferret approach cannot protect the species.

A more sophisticated solution has been proposed by Kevin Esvelt, an assistant professor


LPA
Low Pressure
Analyzer
BPA
Blood Pressure
Analyzer
Digi-Med
MODE
DISPLAY
PRINTER
MAX PRESSURE
MIN PRESSURE
MEAN
SYSTOLIC
DIASTOLIC
HEART RATE
1000 ML

Human blood filters through pig lungs in the lab of Lars Burdorf at the University of Maryland School of Medicine. Thousands of people die every year for lack of transplantable human organs. Scientists are experimenting with CRISPR to rid pig organs of viruses that harm humans. Pig organs have already been successfully transplanted into primates.

Both of Jack's parents are carriers of a defective gene that imparts a 25 percent chance that their children will develop cystic fibrosis. Jack, 16 months old, is also a carrier but will never suffer from the illness. Embryos (like the five-day-old blastocyst above) were screened to select ones free of the disease before they were implanted in his mother's uterus, a process called preimplantation genetic diagnosis (PGD). Ilan Tur-Kaspa, who performed the treatment at the Institute for Human Reproduction/Reproductive Genetics Institute in Chicago, has calculated that PGD could save $2.2 billion annually in cystic fibrosis treatment costs.

DAVID LIITTSCHWAGER (ABOVE)

at the MIT Media Lab, who developed some of the CRISPR and gene drive technology with Church. Esvelt describes his work as sculpting evolution. "All you need to do is provide resistance," he explained—by encoding antibodies generated by vaccination and then editing them into the ferrets' DNA.

Esvelt believes a similar approach could not only help the ferrets resist plague but could also help eradicate Lyme disease, which is caused by a bacterium transmitted by ticks that commonly feed on white-footed mice.

If resistance to Lyme could be edited into the mice's DNA with CRISPR and spread through the wild population, the disease might be reduced or eliminated with little visible ecological impact. Esvelt and Church, however, both feel strongly that no such experiment should be attempted without public participation and unless the scientists who carry it out have developed a reversal system, a kind of antidote. Should the original edits have unforeseen ecological consequences, they could drive the antidote through a population to cancel them out.

Black-footed ferrets are hardly the only endangered animals that could be saved through a CRISPR gene drive. The avian population of Hawaii is rapidly disappearing, largely because of a type of malaria that infects birds. Before whalers brought mosquitoes in the early 19th century, birds in the Hawaiian Islands had no exposure to the diseases that mosquitoes carry,

and therefore no immunity. Now only 42 of more than a hundred species of birds endemic to Hawaii remain, and three-quarters of those are listed as endangered. The American Bird Conservancy has referred to Hawaii as "the bird extinction capital of the world." Avian malaria is not the only threat to what remains of Hawaii's native birds, but if it cannot be stopped—and gene editing seems to be the best way to do that—they will likely all disappear.

Jack Newman is a former chief science officer at Amyris, which pioneered development of a synthetic form of artemisinin, the only genuinely effective drug available to treat malaria in humans. Now he focuses much of his attention on eliminating mosquito-borne disease in birds. The only current method of protecting birds from malaria is to kill the mosquitoes by spreading powerful chemicals over an enormous region. Even that is only partially successful.

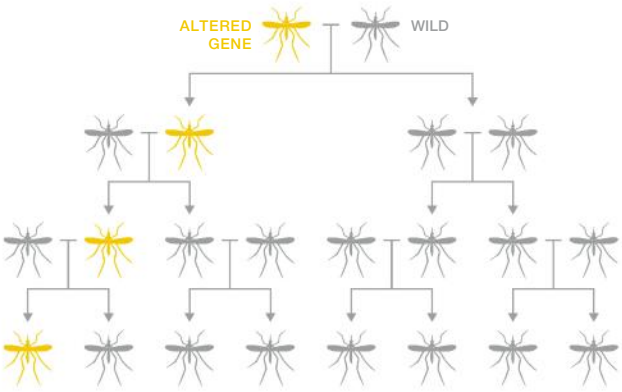
"In order to kill a mosquito," Newman says, "the insecticide actually has to touch it." Many of these insects live and breed deep in the hollows of trees or in the recessed crags of rock faces. To reach them with insecticides almost certainly would require poisoning much of the natural life in Hawaii's rain forests. But gene editing, which would result in sterile mosquitoes, could help save the birds without destroying their surroundings. "Using genetics to save these species is just an incredibly targeted way to address a variety of environmental ills," Newman

Spreading the Cure

Most genes in a species have a one-in-two chance of being inherited by each offspring. But with the advent of CRISPR and a controversial technique called engineered gene drive, scientists are beating those odds in the lab. An alteration that makes a mosquito resistant to malaria, for example, can be engineered to be inherited by all its offspring.

Natural process

A gene is typically inherited by its offspring about 50 percent of the time.



says. "Avian malaria is destroying the wildlife of Hawaii, and there is a way to stop it. Are we really willing to just sit there and watch?"

IN FEBRUARY OF THIS YEAR, U.S. Director of National Intelligence James Clapper warned in his annual report to the Senate that technologies like CRISPR ought to be regarded as possible weapons of mass destruction. Many scientists considered the comments unfounded, or at least a bit extreme. There are easier ways for terrorists to attack people than to conjure up new crop plagues or deadly viruses.

Nevertheless, it would be shortsighted to pretend that the possibility for harm (including, and perhaps especially, accidental harm) does not exist with these new molecular tools. The scientists most responsible for advances like CRISPR agree that when we begin to tinker with the genetic heritage of other species, not to mention our own, it may not be easy, or even possible, to turn back.

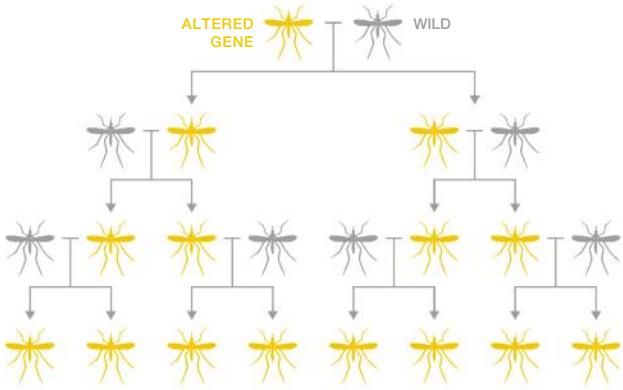
"What are the unintended consequences of genome editing?" asked Jennifer Doudna, as we spoke in her office at the University of California, Berkeley, where she is professor of chemistry and molecular biology. In 2012, Doudna and her French colleague Emmanuelle Charpentier were the first to demonstrate that scientists could use CRISPR to edit purified DNA in lab dishes. "I don't know that we know enough about the human genome, or maybe any other genome, to fully answer that question. But people will use the technology whether we know enough about it or not."

The more rapidly science propels humanity forward, the more frightening it seems. This has always been true. Do-it-yourself biology is already a reality; soon it will almost certainly be possible to experiment with a CRISPR kit in the same way that previous generations of garage-based tinkerers played with ham radios or rudimentary computers. It makes sense to be apprehensive about the prospect of amateurs using tools that can alter the fundamental genetics of plants and animals.

But the benefits of these tools are also real, and so are the risks of ignoring them. Mosquitoes cause immense agony throughout the world every year, and eradicating malaria or another

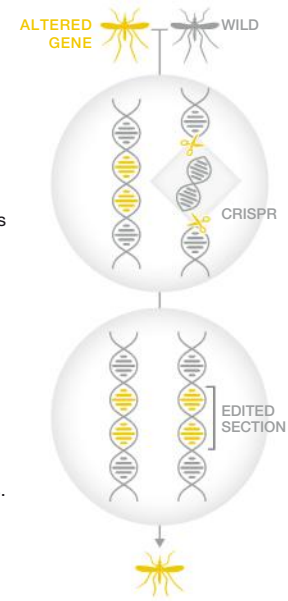
Engineered process

CRISPR-Cas9 can introduce an altered gene into a population and ensure nearly 100 percent inheritance.



With gene drive, CRISPR can cut out a targeted gene in an offspring's germ-line cell, which holds gene sequences from both its CRISPR-edited parent and its wild parent.

The altered gene provides a template to repair the cut, allowing the wild gene to accept the changed sequence. The altered gene can now be passed on through the generations.



JASON TREAT AND RYAN WILLIAMS, NGM STAFF. ART: THOMAS POROSTOCKY.
SOURCE: OMAR S. AKBARI, UNIVERSITY OF CALIFORNIA, RIVERSIDE

disease they carry would rank among medicine's greatest achievements. Although it is clearly too soon to contemplate using CRISPR in viable human embryos, there are other ways of editing the human germ line that could cure diseases without changing the genetic lineage of our species.

Children born with Tay-Sachs disease, for instance, lack a critical enzyme necessary for the body to metabolize a fatty waste substance found in the brain. The disease is very rare and occurs only when both parents transmit their defective version of the gene to a child. With CRISPR it would be easy to treat one parent's contribution—say, the father's sperm—to ensure that the child did not receive two copies of the faulty gene. Such an intervention would clearly save lives and reduce the chance of recurrence of the disease. A similar outcome can be achieved already through in vitro fertilization: Implanting an embryo free of the defective gene ensures that the child won't pass the disorder on to a future generation.

When faced with risks that are hard to evaluate, we have a strong tendency to choose inaction. But with millions of lives at stake, inaction presents its own kind of danger. Last December scientists from around the world met in Washington to discuss the difficult ethics of these choices. More discussions are planned. There will never be simple answers, but without any regulatory guidance—and there is none yet for editing human DNA—the tremendous potential of this revolution could be overshadowed by fear.

"With gene drives and CRISPR we now have a power over species of all kinds that we never thought possible," says Hank Greely, director of Stanford's Center for Law and the Biosciences. "The potential good we can do is immense. But we need to acknowledge that we are dealing with a fundamentally new kind of power, and figure out a way to make sure we use it wisely. We are not currently equipped to do that, and we have no time to lose." □

What do you think about editing the DNA of living organisms? Scientists have the tools—but how should they use them, and who should decide? **Pro-con essays** probe the issues at *ngm.com/Aug2016.*

BY CYNTHIA GORNEY

Science vs. Mosquitoes

We squash mosquitoes with our enormous hands. We poison-bomb them from spray trucks and airplanes. We irradiate them, drain their habitats, breed them experimentally in laboratories to confound their DNA. We've known for more than a century that a mosquito's bite can pass on brutal disease: Zika is the virus receiving the most attention now, but malaria alone kills more than 400,000 people a year, and scores of thousands die from mosquito-borne yellow fever and dengue. **To this day, insects smaller than a child's thumbnail remain the most dangerous nonhuman animals on the planet.**

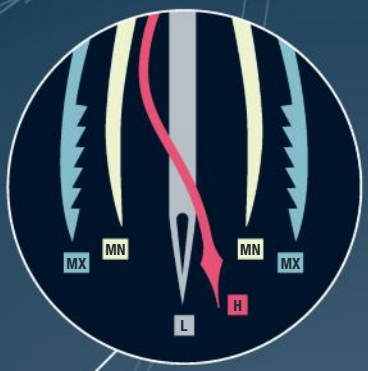
And we are still trying to figure out how to vanquish them. There's a line one hears frequently from entomologists and other mosquito experts, especially amid the Zika alarms: "We have no silver bullet." What they really mean is no stake through the heart; silver bullets are for werewolves. Mosquitoes—some of them, anyway—are vampires. Of the 3,500 species that researchers have identified so far, only a few hundred feed on human blood, including the Zika-carrying *Aedes aegypti* and *Aedes albopictus*. Some, notably *Ae. aegypti,* turn out to be assailants of astonishing formidability.

Start with their physical equipment, especially in the mosquitoes that are the most anthropophagous, which is an elegant way of saying they prefer human blood. A mosquito homes in on you by sensing the proximity of blood from your sweat, your breath, your warmth. Her feeding apparatus, that elaborate proboscis, is a multipart marvel with a skin-piercing fascicle of tiny stylets that can suck your blood while injecting mosquito saliva laced with an anticoagulant. A mosquito can slip that fascicle into your skin so gently that you have no idea what's happening until the blood meal is already under way. She can sip your blood until she's more than twice her weight and has to lumber off someplace to rest, jettisoning the liquid and retaining the nutrients, before she can fly properly again.

Yes, your vampire is always a female. In

The Feeding Tube

The mosquito's proboscis consists of six tightly bound stylets called the fascicle, surrounded by a sheath known as the labium—which doesn't penetrate the skin.



Multipronged Strike

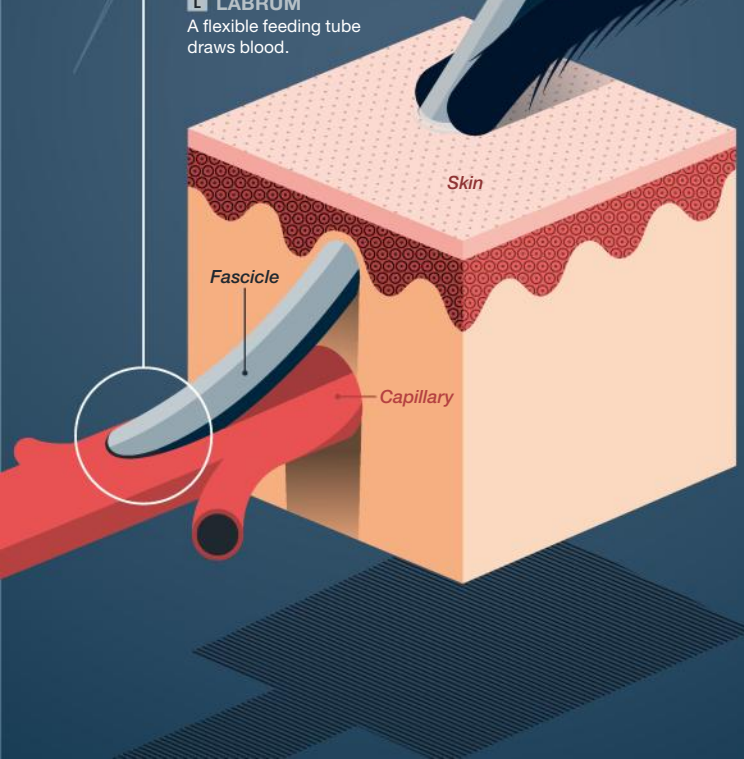
The fascicle pierces the skin. Each of the stylets has a different role in extracting blood.

MX MAXILLA
Blades like saws pierce tissue.

MN MANDIBLE
Pointed spears advance the fascicle.

H HYPOPHARYNX
A ribbonlike tube injects the saliva.

L LABRUM
A flexible feeding tube draws blood.

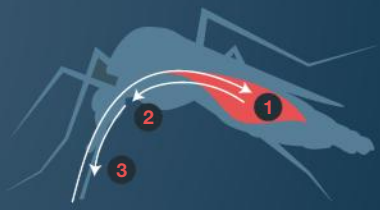


Stealth Attack

Mosquito saliva acts as an anesthetic to numb a victim's skin, making the pain of penetration less noticeable, and as an anticoagulant to keep the blood flowing.

A Vicious Cycle

Viruses and parasites pass through the mosquito and into a new host in three general stages, usually over several days.



1. An infectious agent enters the mosquito in consumed blood, making its way to the gut.
2. It then moves through the mosquito's body, accumulating in the salivary glands.
3. Once in the saliva, the agent infects a host when the mosquito sucks blood.

JASON TREAT AND RYAN WILLIAMS, NGM STAFF
ART: THOMAS POROSTOCKY
SOURCE: ALEXANDRA WESTRICH, FIELD MUSEUM

Mosquito Maladies

Pathogens have adapted to thrive in different species of mosquitoes with characteristics that make them good hosts.

ZIKA VIRUS DISEASE
This rapidly spreading virus can cause defects in the unborn babies of infected pregnant women.

CHIKUNGUNYA
Named after a Kimakonde word meaning "to be contorted," the virus, discovered in Tanzania, causes severe joint pain.

YELLOW FEVER
Nearly 60,000 deaths a year are attributed to this skin-yellowing disease, which can be prevented with a vaccine.

DENGUE FEVER
Spreading since the 1970s, the potentially fatal virus now threatens 50 percent of the world's population.

MALARIA
The parasitic disease killed more than 400,000 people in 2015. Most of the fatalities were in sub-Saharan Africa.

LYMPHATIC FILARIASIS
This tropical disease alters the lymphatic system and causes devastating disfigurement and enlargement of body parts.

WEST NILE FEVER
In 1999, the appearance of this virus in the U.S. highlighted the threat of vector-borne diseases outside native ranges.

Aedes aegypti
Found in cities, this insect feeds almost exclusively on human blood.

Aedes albopictus
The aggressive, adaptable species can easily colonize the habitats of other mosquitoes.

Haemagogus*
These forest vectors of yellow fever can be identified by their metallic sheen.

Anopheles*
The only genus that transmits malaria, it is known for its long front feelers.

Culex quinquefasciatus
These night feeders, common around the world, prefer to lay eggs in dirty water.

* Many species within the genus can transmit the disease.

the mosquito world, males live off plants. The female is the biter, the worker, the source of human peril; she lives off plants too, but all those blood nutrients are for her eggs, the nourishing and laying of which are the great project of her short, purposeful, and somewhat solitary life. A single mating may be all an *Ae. aegypti* needs; she stores sperm inside her body, fertilizing separate batches of eggs as needed, up to several hundred at a time. Five or six occasions of egg laying are common for an *Ae. aegypti* that escapes extermination by swat or insecticide and reaches her expected month-long life span. The multiplication possibilities are staggering.

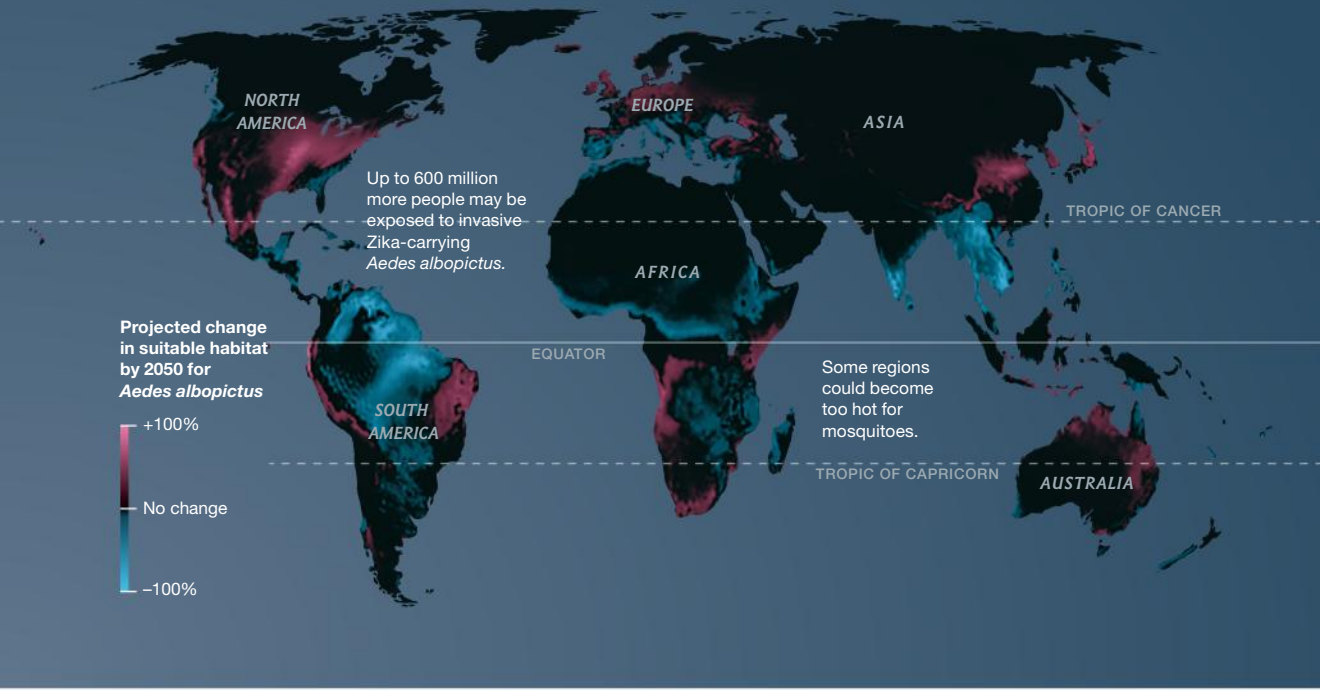
Ask biologists what natural advantage different mosquito species might have gained by spreading disease—why *Aedes* became the primary carrier of the Zika virus, for example, and *Anopheles* the carrier of malaria parasites—and they're likely to tell you that you're thinking about the question backward. It's the pathogens, those disease-causing organisms driven to multiply in mammalian bodies, that over millennia "learned," evolutionarily speaking, what excellent transport and delivery services some mosquitoes happen to provide. It's not an easy ride for the pathogens: They have to survive being sucked into a mosquito's gut, exposed to digestive enzymes, and then pushed through membranes into a mosquito salivary gland before being injected into the next warm-blooded host. The injectors, on the other hand, are simply perpetuating their family line. "It's such a rare confluence of evolution that has allowed this to happen," says Karl Malamud-Roam, a mosquito research scientist who helps direct a pest management program based at Rutgers University. "It's *hard* to be a successful germ or mosquito."

A modicum of respect seems in order, then, for this remarkable confluence and the very resourcefulness of the flying vampires. Consider the reproductive strategies of *Aedes aegypti,* which because of Zika has been the subject of international symposia and plans of attack. An *Ae. aegypti* will lay her eggs in the

JASON TREAT, RYAN WILLIAMS, AND CHARLES PREPPERNAU, NGM STAFF
SOURCES: WORLD HEALTH ORGANIZATION; CENTERS FOR DISEASE CONTROL AND PREVENTION (GRAPHIC); YIANNIS PROESTOS, CYPRUS INSTITUTE (MAP)

Skeeter Scatter

Mosquitoes thrive in a tropical climate. Scientists expect this zone to widen toward the poles as the planet warms.



random bodies of water that humans tend to create just by living day to day: A pet dish will do, or an upturned jar top, a discarded tire, a cistern with a cracked lid. She will spread each egg batch around, making it much harder for natural or man-made interventions to wipe out a whole brood at once. She can find egg-laying spots that aren't wet yet but will be, when the weather changes; she's that ingenious. She bites all day long; bed nets (which have helped reduce worldwide malaria deaths because the malaria-carrying *Anopheles* tends to bite at night) aren't as effective against Zika and other *Aedes*-carried diseases.

And when you reach down to slap a biting *Ae. aegypti,* she's likely to dart lightly away, escaping the descending palm of death, and then come back to bite you again. "So she makes sure you get a multiple dose," says University of Kentucky entomologist Grayson Brown, who in March went to Brazil, where Zika has hit hard, to help lead an *Aedes aegypti* summit.

"Crisis in the Americas" was the summit's billing, and Brown says the discussion included more crises than the potentially explosive spread of Zika. Yellow fever remains a terrible worry, as do dengue, chikungunya, and Mayaro, a mosquito-spread monkey virus infecting people in northwestern Brazil. Defensive strategies under consideration range from simple to scientifically ambitious: campaigns to clean out breeding spots, experimental trap designs, larva-killing acoustic signals, plans to prevent mosquitoes from reproducing successfully by infecting them with bacteria or altering their genetic makeup. One presentation described an "autocide" technique that takes lethal advantage of the way *Ae. aegypti* spread each brood to multiple sites: lace the first with larva poison that the mosquito takes in when she lands. Then at her next site, she poisons her own offspring.

No silver bullets, though. "There is not going to *be* a silver bullet," Brown says. "It's going to be hard work. But it has to be done, on a year-to-year basis—for forever." □

Ye Ye, a 16-year-old giant panda, lounges in a wild enclosure at a conservation center in Wolong Nature Reserve. Her name, whose characters represent Japan and China, celebrates the friendship between the two nations. Ye Ye's cub Hua Yan (Pretty Girl) is being trained for release into the wild.

Pandas gone wild

The Chinese know how to breed giant pandas. Now they're releasing them into the wild, where both the animals and their habitat face risks.

Zhang Hemin—"Papa Panda" to his staff—poses with cubs born in 2015 at Bifengxia Panda Base. "Some local people say giant pandas have magic powers," says Zhang, who directs many of China's panda conservation efforts. "To me, they simply represent beauty and peace."

By Jennifer S. Holland
Photographs by Ami Vitale

I crouch down low in the grass to get a closer look at the animal lurching toward me. She's about four months old, the size of a soccer ball, slightly bug-eyed, and no doubt soft and fragrant as a puppy. The urge to scoop her up and squeeze her is overwhelming.

That adorability is one reason the giant panda is an international sensation as well as a cultural icon, an economic gold mine, and a source of national pride in China—the only country in which these Asian bears still survive. Now the whole world is watching China's dogged attempt to keep pandas on the map—which in some ways has been an unprecedented success.

Like many endangered species, giant pandas have declined as a growing human population has grabbed wild lands for human uses. That problem hasn't gone away since the species was labeled endangered in 1990. But the Chinese have spent the past quarter century perfecting breeding methods and building a captive population hundreds strong—and leveraging it to bring in millions of tourist dollars.

It's one thing to raise animals in captivity before adoring crowds and another to ensure a species' survival in nature. Whatever comes next in this bear's conservation may decide whether the giant panda becomes a relic behind bars or roams free in the wild.

GIANT PANDAS ARE MASTERS of adaptation. "We humans are used to changing the environment to suit our needs," says Zhang Hemin, director of the China Conservation and Research Center for the Giant Panda, which oversees three panda bases: Bifengxia, Dujiangyan, and Wolong. "The difference is that pandas changed themselves to suit the environment."

Time and necessity have fine-tuned pandas to thrive in a very specific habitat. Still built like their carnivorous kin, these bears—and they are true bears, according to their DNA—have the canine teeth to tear flesh and the enzymes to digest meat. Because of gaps in the fossil

Is a panda cub fooled by a panda suit? That's the hope at Wolong's Hetaoping center, where captive-bred bears training for life in the wild are kept relatively sheltered from human contact, even during a rare hands-on checkup.

record, exactly when they diverged from other bears isn't clear. A jaw from Spain puts an early panda relative at 11.6 million years old, while DNA evidence suggests 18 million. And bones from a cave in China indicate giant pandas as we know them are at least two million years old.

The exact timing and reason for pandas going vegetarian is debated, but those eons of adaptations leave modern pandas with some unique tools, including flat molars for crushing and a thumblike appendage, an extension of the wrist bone, helpful for handling bamboo. Interestingly, they lack any special gut microbes to break down the bamboo that has become 99 percent of their food—one reason they are relatively low-energy animals. To derive enough nutrients, pandas eat 20 to 40 pounds of plant material a day.

To satisfy their love for particular flora that grows best beneath big, old trees with hideyholes for stashing cubs, pandas can't live just anywhere. But that specialization is now working against them. The species used to range across southern and eastern China and northern Myanmar and Vietnam. Now they're found in patchy mountain habitat only in China, in perhaps one percent of their historic range.

How many wild pandas are out there? Researchers have been trying to count them since the 1970s, when it is thought there were roughly 2,500 animals. That dropped dramatically in the 1980s, in part because of a periodic natural die-off of bamboo. (Normally pandas can survive such natural ecological events by shifting to more fruitful habitat, but if there's nowhere to move, they'll starve.)

The Chinese government's most recent survey, from 2014, reported 1,864 in the wild, 17 percent more than in 2003. But Marc Brody, a National Geographic grantee who founded the conservation nonprofit Panda Mountain, warns that it's tough to trust any specific figures. "We may just be getting better at counting pandas," he says. Also, it's difficult to compare numbers across the decades because ranges and survey methods have varied; today they include DNA analysis of panda poo.

In the meantime, the Chinese are furiously breeding their iconic bear in captivity. The early years (until the late 1990s) saw a lot of failed attempts, both at breeding and at keeping cubs alive. And genetic diversity—which supports helpful adaptations and can protect a population from extinction—was a low priority.

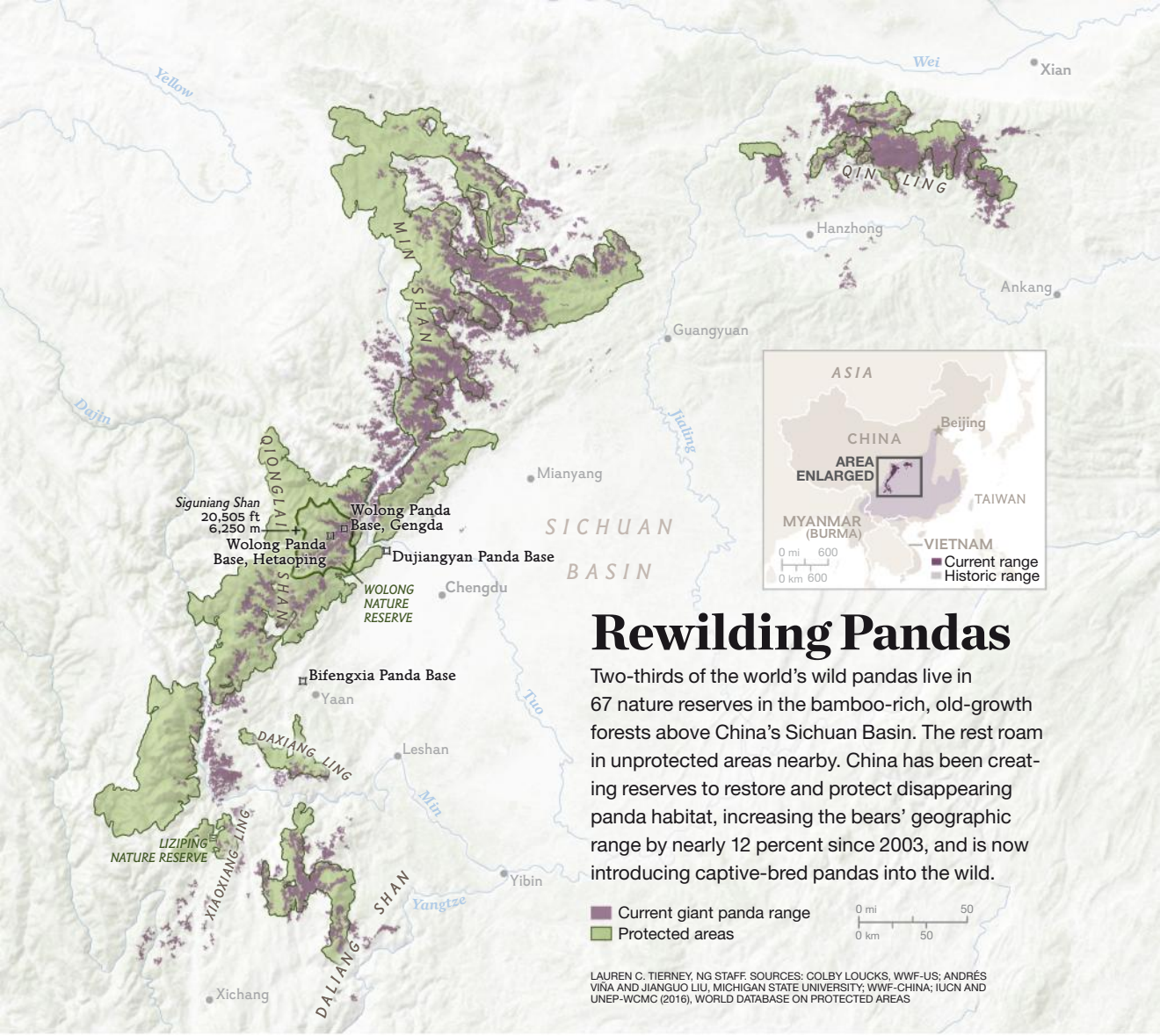
With assistance from abroad, the Chinese turned things around. David Wildt, of the Smithsonian's Conservation Biology Institute, was part of the international team that first worked with Chinese scientists on panda biology and husbandry. "Pretty soon they had piles of baby pandas," he says. "In a sense we trained ourselves right out of a job." Now "pandas are one of the most genetically diverse animals in captivity," says Wildt's colleague, geneticist Jonathan Ballou, who developed the algorithm that the Chinese now apply to breeding decisions.

Much of the action happens at Bifengxia Panda Base, or BFX, where I had my close-up with cubs. Visitors here can see adult bears in outdoor yards—hunched over broad bellies, chomping messily on long bamboo stalks from enormous piles delivered several times a day.

Up a hill from these exhibits lies the staff-only building where bears in the breeding program reside. Enclosures are concrete with iron-barred doors; each opens to an outdoor pen. Typically there is a female panda in each, eating or sleeping, sometimes with a cub in her arms.

"Even after many years, whenever a panda is pregnant or gives birth here, everyone is so joyful and excited," Zhang Xin, a rather bearlike veteran keeper, told me. "We look every day at the adults, the babies, how much they are eating, what their poo looks like, if their spirit is good. We just want them to be healthy."

In this setting, little about panda production is natural. Dropping a male in with a female can even lead to aggression instead of mating. To set the mood, breeders in China have tried "panda porn"—videos of pandas mating—mostly for the



Rewilding Pandas

Two-thirds of the world's wild pandas live in 67 nature reserves in the bamboo-rich, old-growth forests above China's Sichuan Basin. The rest roam in unprotected areas nearby. China has been creating reserves to restore and protect disappearing panda habitat, increasing the bears' geographic range by nearly 12 percent since 2003, and is now introducing captive-bred pandas into the wild.

Current giant panda range
Protected areas

0 mi 50
0 km 50

LAUREN C. TIERNEY, NG STAFF. SOURCES: COLBY LOUCKS, WWF-US; ANDRÉS VIÑA AND JIANGUO LIU, MICHIGAN STATE UNIVERSITY; WWF-CHINA; IUCN AND UNEP-WCMC (2016), WORLD DATABASE ON PROTECTED AREAS

encouraging sounds; apples on sticks to tempt males into mounting position; Chinese herbs; and even Viagra and sex toys. Director Zhang Hemin, also known as Papa Panda, recalls an awkward shopping trip to an "adult toy store" in Chengdu. "We told the clerk we needed a female-genital stimulator that had to warm up," he told me. "Then I had to ask for a receipt to submit to the government for reimbursement."

Now protocol includes artificial insemination, sometimes with sperm from two males. Part of the challenge is that female pandas are in estrus just once a year for only 24 to 72 hours. Endocrinologists monitor hormones in the urine that can predict ovulation and may inseminate several times within a day or two to boost the chances of implantation.

Then, for months, females keep the keepers guessing. "It's hard to even know if a panda is pregnant," says BFX's director, Zhang Guiquan. "The fetus is so tiny that it's easy to miss on an ultrasound." Pandas can have delayed implantation, extremely varied gestation times, random hormone fluctuations, and quiet miscarriages.

This massive captive-breeding effort might suggest that pandas are simply sexually inept. Not so. For millions of years wild bears have done the deed without human intervention, based on natural cycles, scent marking, mating calls, and complex social relationships that are mostly missing in captivity.

The artificialness of this and other aspects of their lives worries Sarah Bexell of the University of Denver, who *(Continued on page 74)*

At Bifengxia, bears mate under keepers' watch—a far cry from the privacy they have in the wild. The panda base's operators are finding ways to allow for natural reproductive behaviors such as scent marking, mate choice, and male competition.

Blind, nearly hairless, squeaky, and 1/900 the size of its mother, a newborn panda is as needy as it gets. But it won't be for long: The panda is among the fastest growing mammals, increasing from around four ounces to four pounds in its first month.

Three-month-old cubs nap in the panda nursery at Bifengxia. A panda mother that bears twins usually fails to give them equal attention. Keepers reduce the load by regularly swapping cubs in and out—making sure each gets both human and panda-mom care.

When not in the care of a mother or surrogate mother bear, panda cubs receive 24/7 human attention in a nursery. 'They always need something,' says a caretaker.

worked at another panda breeding center for years: "Bears are so stoic, especially pandas. You really have to freak them out to get a reaction that we'd perceive as stress." They learn to cope and may seem relaxed, she says, "but if we could sit down and interview them, we'd hear something very different." Smithsonian ecologist William McShea adds: "What we are asking them to do—basically have sex in a phone booth with a crowd of people watching—has little to do with real panda reproduction."

Still, the Chinese are getting big results. In 2015, 38 cubs were born in China. (BFX produced 18 of them—its highest number yet.) In the panda kindergarten building at the center of BFX is the immaculate incubator room, where the cubs, when not with mama or a surrogate mother bear, get 24/7 human care. Separating mothers and babies is controversial, but it boosts cub survival when staff can place a weaker or rejected infant with an attentive surrogate.

Visitors outside press their noses and cameras against the incubator room window, *oohing* and *aahing* over five fluff balls in baskets on the floor. Some of the cubs are napping; others are wide-eyed and wiggly, squeaking like dog toys.

Liu Juan, petite and shy behind square-rimmed glasses, is working a 24-hour shift, her second one that week. She has a toddler son who stays at home with family. "This job is more intense," she says of mothering the pandas, "but I love being with them."

Incubating the newborns, bottle-feeding, rocking, burping, responding to their bleats for attention, rubbing bellies to stimulate the gut, weighing and measuring, and keeping toddlers from wandering—"the work is nonstop, a crazy amount," she says. Her puffy orange slippers *shush* across the floor as she chases an escapee. "My body never recovers. I've lost hair from being under so much stress." There is massive pressure, she says, to keep the cubs alive: "They are so important to China."

Most pandas at BFX will spend their lives in captivity, in China or in zoos abroad. But elsewhere in Sichuan Province, researchers have a much wilder future in mind for baby bears.

Hetaoping, the older panda base within Wolong Nature Reserve, is a series of stone and concrete buildings socked into a valley of the Qionglai Shan mountains. In the late 1970s the Chinese set up a field station on the forested slopes here and, since 1980, have been working with the WWF, the first Western organization

Caretaker Li Feng cradles her precious charge by the window of Bifengxia's panda nursery, the most popular stop for visitors touring the facilities. More than 400,000 people visit each year to glimpse and snap photos of China's most beloved baby animals.

to cooperate on pandas with the Chinese government. WWF sent renowned biologist George Schaller to conduct research that became the basis for what we know of pandas today.

Papa Panda—so nicknamed because bears in labor at the centers seem to hold off giving birth until Zhang arrives and because of his devotion to the animals—worked with Schaller in the field. "It was then that I learned to deeply love the panda," he told me, patting his heart. He had a favorite bear then, a curious female who mangled his teakettle and stole his food one snowy night before taking over his tent. "She wouldn't go away. She used it for months, coming back each night, leaving me gifts of feces in my bed."

These days, select cubs are trained for life in the wild at Hetaoping. Keepers wear full-body panda costumes scented with panda urine so that young bears don't get used to humans. A cub here remains with its mother, and over two years, while in her care, he or she is eased toward wildness. After a year or so, the pair is moved to a large, fenced-in habitat up the mountain where the mother can continue coaching her offspring until the youngster is released—if deemed fit for freedom. To qualify, Zhang explained, a young panda must be independent; wary of other animals, including

Triple the cuteness—and the work. One mom cares for all these cubs, only one of which she bore. Transferring a weak or rejected infant from its birth mother to a surrogate is helping boost cub survival at panda breeding centers.

Wolong Reserve keepers transport Hua Jiao (Delicate Beauty) for a health check before she finishes "wild training." The habitat also protects red pandas, pheasant, tufted deer, and other species that benefit from giant panda conservation.

humans; and capable of finding food and shelter unaided. Not all are.

Adequate habitat for the bears' release is also a concern. Since the 1970s the Chinese have gone from 12 panda reserves to 67, making the bears, on paper, the most protected animal on the planet. But many of these reserves are very small, populated by villagers, and cut up by roads, farms, and other human constructions. More than a third of wild pandas live or venture beyond reserves' invisible boundaries anyway, says the Smithsonian's McShea, where habitat may be marginal. Because of the emphasis on regional economic development, "officials may say yes to hydroelectric dams, highways, and mining operations" inside panda habitat with no thought of long-term effects, he says.

On a positive note, "poaching isn't a problem here: Nobody is touching pandas," McShea says. "They're the third rail for poachers." (Hunting pandas was legal in China until the 1960s; now killing one could mean 20 years in prison.)

Other troubles remain, such as livestock grazing in panda habitat. "Horses and pandas both like gentle slopes and bamboo forests; horses also eat bamboo. So the impact of horses on panda conservation is significant," says China West Normal University's Zhang

Since 2006 Chinese scientists have released five pandas, all wearing tracking collars, into the wild. Two have been found dead. The other three are still out there.

Jindong, who does research in Wolong. In 2012 the local government ordered horses removed from the forests and urged people "to raise yaks and other animals instead," he says. But those animals' presence also spurs pandas to move, he says—"and where can they go?"

A massive earthquake in 2008 killed tens of thousands of people and turned mountain homes to waste. The disaster, which destroyed part of Hetaoping, gave the government fodder to persuade villagers living in bear habitat to move. Officials built a series of lowland villages to house many of the displaced and declared a victory for panda conservation.

Some villagers have found work building a new highway that tunnels through mountains between Chengdu and Wolong. Others who gave up their fields and livestock remain jobless. Some refuse to let go of their old life. Li Shufang, a 75-year-old woman I visited in the simple home she shares with relatives, walks several hours a day, up and down the mountain, to tend to pigs and a garden where the family lived before the quake. When I asked how she felt about making way for pandas, she spat back in a local dialect, "Why didn't they move the pandas instead?"

Others I met seemed more content with the "easier" life in the village, though few are currently benefiting directly from pandamania. With a new panda breeding and education center called Gengda in Wolong, "perhaps when the road is complete and tourists start coming, we will make money and feel better about pandas being so important to the government," said a local man. "Right now, to me, a panda is just a bear, nothing special."

To turn the reclaimed land into bear habitat, locals are hired to plant seedlings where forests were diminished by logging or quake damage. The Chinese have focused on quick-growing tree species, whose roots inhibit erosion. But those species don't make good panda habitat: The most nutritious bamboos grow in the understory of old-growth forests, which take decades to mature. The mountainous terrain makes it hard to plant on a large scale—so the landscape remains fragmented, which means the panda populations do too.

Barney Long, director of species conservation at Global Wildlife Conservation, says that only nine of some 33 panda subpopulations "are really viable," with enough animals to persist long term. Climate change is bound to make this worse: Scientific models warn that in the next

Gao Xiaowen poses with the stuffed leopard that Wolong keepers use to train young pandas to fear their biggest wild foe. A cub's reactions to the "predator" and its recorded growls help determine if the bear is prepared to survive on its own.

In a large forested enclosure of the Wolong Reserve, panda keepers Ma Li and Liu Xiaoqiang listen for radio signals from a collared panda training to be released to the wild. Tracking can tell them how the cub is faring in the rougher terrain up the mountain.

Trained and ready for freedom, Zhang Xiang (The Thoughtful One) takes her first steps into the Liziping Nature Reserve in 2013. She was the first female released since reintroductions began—and judging from her tracking-collar signals, she's doing just fine.

70 years, warming could reduce the remaining giant panda habitat by nearly 60 percent. At least for now, rebuilding, connecting, and protecting habitat may be the best focus for panda conservation. More important than sheer numbers of cubs produced, says Marc Brody, is "the chance to give those young pandas a home."

Sending pandas "home" has had mixed results so far. Of the five animals released since 2006, all wearing tracking collars, three are still out there. Two were found dead, one probably the victim of aggression from wild male pandas. Those losses were "media disasters for China," Wildt says. But each led scientists to "try to think more like a panda, to understand what the bears truly need" and refine training and release protocols, Papa Panda says. At press time, as many as three pandas were being considered for release in July.

Like breeding, rewilding pandas "will take trial and error, time and money," McShea says. "But the Chinese will be successful."

Papa Panda is similarly confident: "The ultimate goal is to release, release, release," he told me. "I've had two important jobs in my life so far. To get pandas breeding, which is now no problem. Now we have to make sure there's good habitat and then put pandas in it."

And once they're running free and ready to

Once a captive-bred panda is released into the wild, 'we can't interfere,' says a Wolong Nature Reserve keeper. 'What comes next will be up to them.'

mate, like Tao Tao (Little Rascal), a male who has so far survived nearly four years in the wild? "We hope that they like each other, but we can't interfere," says Hetaoping keeper Yang Changjiang. "What comes next will be up to them."

IN A TRAINING ENCLOSURE in Wolong, Ye Ye—a female whose name honors the friendship between Japan and China—appears at the fence looking for a handout. Her cub Hua Yan (Pretty Girl) is nowhere to be seen, and that's a good sign. Independence is key to survival—and the three-year-old cub, her training nearly complete, will soon be released into the wild.

But first, it's another cub's turn. Over four days in mid-November, Hua Jiao (Delicate Beauty) is caught, given a final health check, fitted with a collar, crated, and driven 200 miles to the Liziping Nature Reserve. It has good bear habitat and a small panda population ripe for a new member.

It's a day that's been in the works since the start of this exceptional conservation experiment. Saving pandas is a bear-by-bear process, Hua Jiao's release a small but essential step on a long, rocky path. With five other cubs at Wolong up for release within a few years, panda conservation will doubtless be in the news. Whether for tragedy or triumph, no one can say.

On this November morning, under a bright blue sky, four men lift Hua Jiao's cage from the truck and position it facing the forest. Bamboo-draped barriers conceal spectators and point the way forward. Without fanfare, a keeper unlatches the door. At first the young panda stays put at the back of the crate, munching bamboo, her last captive meal. After today she'll fend for herself in every way. In a few years she may seek a mate and could add five or more cubs to the population over her lifetime. It's not a game-changing number, but for an endangered species with fewer than 2,000 animals in the wild, every individual counts.

Finally, with some coaxing from the keepers, Hua Jiao emerges, blinking into the light, her paws sinking into the soft soil. And then, without a glance back at her captors and the life she's known thus far, she lopes toward freedom. □

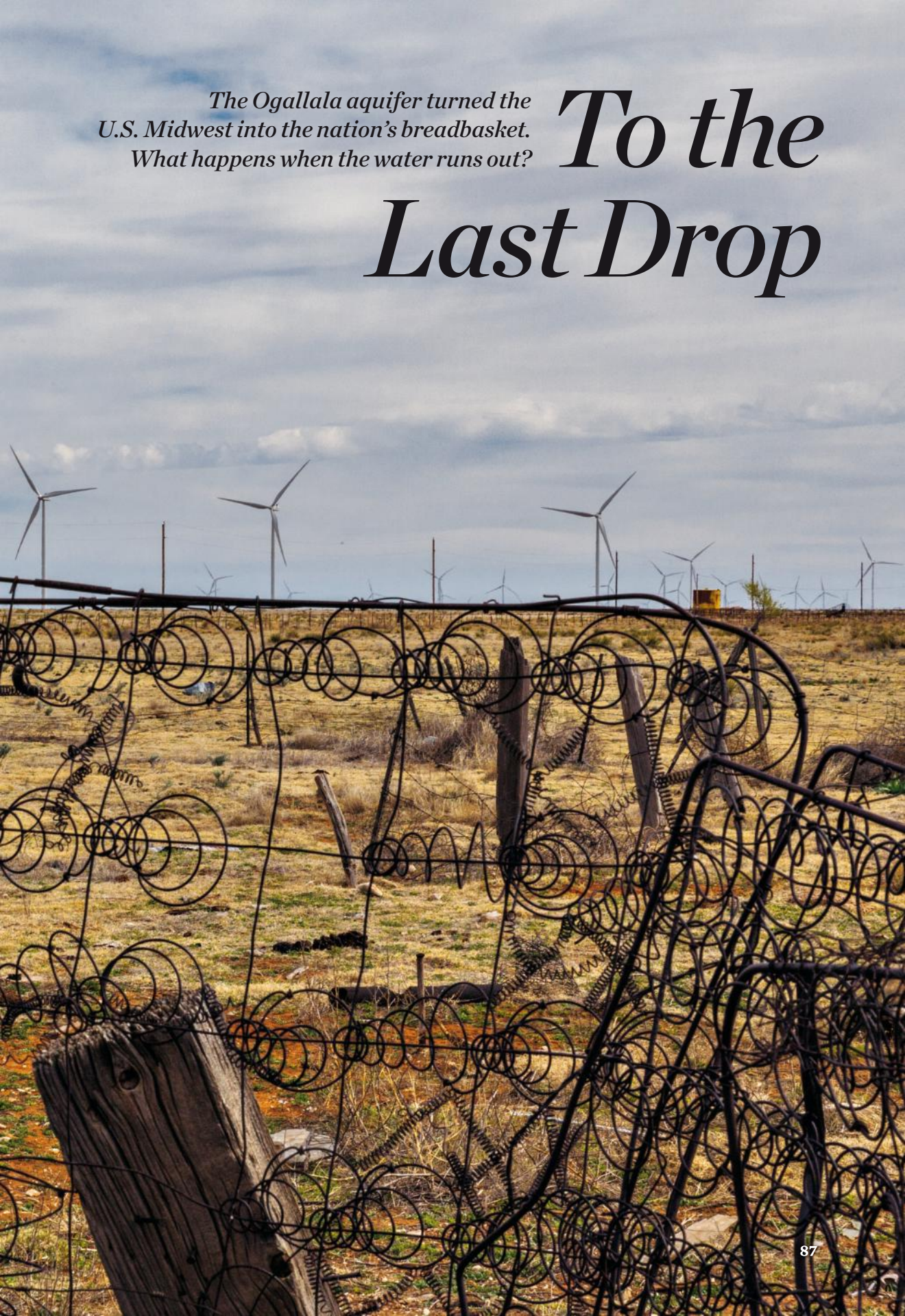
REBECCA HALE, NGM STAFF

At the Smithsonian's National Zoo in Washington, D.C., a cub named Bei Bei has been the focus of much attention since his birth last summer. Follow his growth in images and video at *ngm.com/Aug2016.*

Bedsprings once served as a corral near Elida, New Mexico, where turbines tap into the High Plains' unrelenting wind, generating new income for farmers who have lost earnings as their wells dry up.

The Ogallala aquifer turned the U.S. Midwest into the nation's breadbasket. What happens when the water runs out?

To the Last Drop



Tractors pack down a giant mound of corn at a feedlot near Imperial, Nebraska, before storm clouds roll in. Much of the region's corn, a thirsty, irrigated crop, is grown to fatten cattle. This mound eventually would stretch 300 feet long, contain five million bushels, and feed 50,000 cattle for a year.

A steer is coaxed into its pen at a feedlot near Garden City, Kansas. Sparse population, a semiarid climate, and abundant groundwater turned the southern High Plains into the world's feedlot capital. A single quarter-pound hamburger requires about 460 gallons of water to raise and process the beef.

By Laura Parker
Photographs by Randy Olson

'Whoa,' yells Brownie Wilson, as the steel measuring tape I am feeding down the throat of an irrigation well on the Kansas prairie gets away from me and unspools rapidly into the depths below.

The well, wide enough to fall into, taps into the Ogallala aquifer, the immense underground freshwater basin that makes modern life possible in the dry states of Middle America. We have come to assess the aquifer's health. The weighted tip hits the water at 195 feet, a foot lower than a year ago. Dropping at this pace, it is nearing the end of its life. "Already this well does not have enough water left to irrigate for an entire summer," Wilson says.

It is three days into January, and we are alone on an endlessly flat expanse surrounded by 360 degrees of pale blue horizon, not a cloud, not a tree in sight. We are 4,000 feet above sea level, the reason this is called the High Plains. The incessant wind that blew topsoil from the Dust Bowl east to the Atlantic Ocean and onto the decks of ships during the 1930s is unseasonably calm, although Wilson's SUV is packed to the roof with gear for every possible weather calamity. On the field behind us, the spindly steel skeleton of a center-pivot irrigation sprinkler stretches out over brown earth like a giant sci-fi insect, dormant until spring.

Wilson, who is 47 with a lean, athletic build, is the water-data manager for the Kansas Geological Survey and part of a team that travels to western Kansas every winter to document how rapidly this aquifer is disappearing. The water beneath our feet has been accumulating in porous rock for about 15,000 years, before the end of the last ice age. For the past 60 years, the Ogallala has been pumped out faster than raindrops and snowmelt can seep back into the ground to replenish it, thanks largely to irrigation machinery like the one sleeping nearby. As a result, in parts of western Kansas, the aquifer has declined by more than 60 percent during that period. In some parts, it is already

Two-year-old Annalea Garcia is bathed nightly by her mother, Crystal, in a bucket filled with water hauled from town. Their well and the wells of some 30 other families on the outskirts of Clovis, New Mexico, have run dry.

exhausted. The decline is steady now, dry years or wet. In 2015 rain was exceptionally heavy—50 to 100 percent above normal. Even so, water levels in the wells dropped again. Wilson's field report will put the best face on it, noting it was the slowest decline in five years.

Tagging along with Wilson, I am nearing the end of a 5,000-mile journey along the back roads of Ogallala territory, from South Dakota to Texas. My drive has taken me through some of the most productive farmland anywhere, home to at least a $20-billion-a-year industry that grows nearly one-fifth of the United States' wheat, corn, and beef cattle. It's also a place facing hard choices: Farmers can reduce consumption of water to further extend the life of the aquifer. Or they can continue on their path toward an end that is already in sight. Some don't like to frame the dilemma quite so starkly. But if they don't reduce pumping and the aquifer is drained, food markets will be profoundly affected around the world. In the coming decades this slow-speed

'The consequences will be huge. Is draining the Ogallala the smartest thing for food production in the U.S. and globally?'

Jay Famiglietti, NASA senior scientist

crisis will unfold just as the world needs to increase food production by 60 percent, according to the United Nations, to feed more than nine billion people by mid-century.

The draining of North America's largest aquifer is playing out in similar ways across the world, as large groundwater basins in Asia, Africa, and the Middle East decline rapidly. Many of these aquifers, including the southern Ogallala, have little ability to recharge. Once their water is gone, they could take thousands of years to refill.

"The consequences will be huge," says Jay Famiglietti, senior water scientist at NASA Jet Propulsion Laboratory and lead researcher on a study using satellites to record changes in the world's 37 largest aquifers. "We need to sustain groundwater to sustain food production, and we're not doing it. Is draining the Ogallala the smartest thing for food production in the U.S. and globally? This is the question we need to answer."

Wilson's route takes us 20 miles east of the Colorado border, where little towns are named for springs that long ago ran dry. People who live on the Ogallala, also known as the High Plains aquifer, often describe their water as thick or thin. This is shorthand for the aquifer itself. The Ogallala is a giant underground sponge made of a jumble of gravel, silt, sand, and clay. All the water is contained in crevices of the sponge. If the topsoil were rolled up like a carpet, Wilson says, the sponge beneath would look like an empty egg carton, with peaks and valleys of varying depths. In parts of western Nebraska, where the Ogallala is plentiful, the sponge extends as far as a thousand feet below the Earth's surface, meaning it is "thick" with water. In western Kansas, where we are, the aquifer undulates so much that "thin" water is often separated from thick water by only a few miles.

"It comes down to the luck of where your ancestors settled," Wilson says. "Or where you bought ground."

In midmorning we arrive at Mai Farms, a family enterprise that grows winter wheat for King Arthur Flour. The Mai family, Germans who emigrated from Russia, arrived in Greeley County just in time for the Dust Bowl but lacked the money to join the exodus to California. Their first farm dusted over and went bust. Their second farm, 20 miles away, survived and thrived. Bill Mai was born on it in 1936 and lives there today. That first well we measured was drilled in 1948 by Mai's father to carry his farm through cycles of drought. It was a marvel at the time, pumping a thousand gallons a minute, a rate that would fill an Olympic-size swimming pool in half a day. Most telling, however, is not the well's water level: It's that Mai hasn't irrigated crops in 16 years. His neighbors are pulling out so much from their wells that his well drops a foot every year. "The neighbor right across the road here is growing corn," he says. Irrigated corn makes a lot of money but uses a lot of water. I ask Mai what he can do about this. Nothing, he tells me. A legal battle over water rights "is pointless," he says, especially since his water will run out anyway.

Mai spent 20 years making the shift back to dryland—or unirrigated—farming, in anticipation that his water would not last. He hands me a yellowed newspaper clipping from 1976, which profiled him as Kansas District 10 farmer of the year. "We don't have enough water out here anymore," he warned then. Mai wasn't the first to say it. Reports on the aquifer as a diminishing resource date back to the 1930s, when President Franklin Roosevelt appointed a Great Plains committee to examine the cause of the Dust Bowl. Even then, the committee noted the contradiction in basing an expanding farm economy on a finite resource.

FOR THE EIGHT STATES that overlie the Ogallala, differences in the complex hydrology belowground—and in state law, politics, and farming tradition aboveground—conspire against sustaining the aquifer rather than mining it. The states monitor water usage, creating an important record for how much is pumped yearly. But cutting use is more difficult. Groundwater in Kansas and Nebraska, for example, belongs to the public. Water rights are granted to property owners by those states, which assign a certain amount that can be legally used. The problem is that in overstressed areas, what's available on paper often exceeds what's left in the ground.

Water law in Texas is vastly different. Groundwater is not publicly owned; Texans can pump as much as they can use from beneath their land. In the High Plains water district surrounding Lubbock, 88,000 irrigation wells were stuck into the aquifer like straws, with 73,000 still in use.

Irrigated land is worth more and earns more than dryland farming, and pressure is on to keep pumping—from seed salespeople, farm equipment dealers, bankers, insurers, and landlords. "We've overdone a good thing," says Jay Garetson, a proud fifth-generation farmer in Sublette, Kansas. His eldest son is studying aerospace engineering at the University of Kansas, as missions to Mars seem to hold more allure than becoming the sixth generation to farm the family land. "We know we are overdrafting the Ogallala. But we are all so landlocked into these microeconomic decisions that we can't manage on a larger level."

As I head south, I encounter a sense of inevitability and resignation. The phrase "managed depletion" becomes part of the Plains vocabulary in water district boardrooms and Elks lodges. Everywhere I stop, I ask people what will happen and what's to be done about it. Many are concerned that the water will dry up before the next generation, but they don't have a solution that won't cause financial pain—or worse, ruin. Others say they'll let the wells decide. Some farmers "think it's their water," one water manager tells me, "and they ought to be able to mine it like coal until it's gone." Beef feedlots, high-value enterprises, will endure, but corn will migrate to states that get more rain. Hope lies in technology; farmers show me iPhone apps that track water use so precisely that as little as a tenth of an inch can be applied to their crops. In Colby, Kansas, Lon Frahm, who farms 30,000 acres of wheat and corn, irrigates with two billion gallons of water yearly. He counts among his farmhands an IT technician who collects data to keep his yields ahead of his declining wells.

As a hedge against declining income when wells go dry, farmers are increasingly tapping into the High Plains' only truly inexhaustible resource: wind. Across the Plains, I pass wide belts of newly planted wind turbines. Outside Friona, Texas, northwest of Lubbock, Wesley Barnett leases wind rights to an energy company. The going rate runs about $10,000 a year per turbine. "We can't water our land anymore anyway. For some people, wind is a lifeline," he says.

Parts of the Ogallala could endure for a century or more. But the aquifer's heart is at greatest risk of depletion. This overstressed zone runs the width of the Texas Panhandle north 450 miles, from Lubbock to the Kansas-Nebraska state line. There, transition to a new era of permanent depletion is under way.

The aquifer's decline will be twinned with the increasing impacts of climate change, which will add more warm days and longer, more frequent droughts, scientists predict. Already, warmer-than-average evening temperatures in feedlots in southwest Kansas mean that beef cattle drink more water than they did in cooler years. As more farmers return to dryland farming, large farms are likely to swallow smaller family farms, because dry farming, with lower yields, requires more land to be profitable. Irrigation will disappear from most places, so more small towns will fade away. Countless towns across the Plains already teeter on the brink of extinction. The day I visited Lazbuddie, a hiccup of a community in Texas cotton country with fewer than a hundred residents, the postmistress sold a single stamp. This was a week before Christmas.

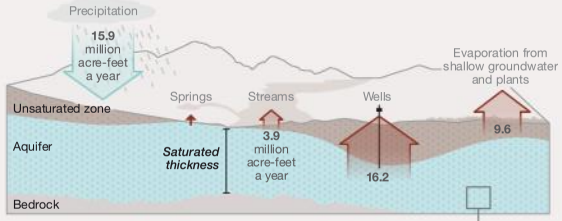
The irrigation era *(Continued on page 104)*

As an evening storm lights up the sky near Wood River, Nebraska, about 413,000 sandhill cranes—tall, bugling, crimson-capped birds—arrive to roost in the shallows of the Platte River, which is fed by the aquifer.

Invisible Crisis

A Vanishing Aquifer

The High Plains aquifer, the world's most voluminous groundwater basin, percolates below eight states and encompasses 174,000 square miles. The Ogallala aquifer makes up 80 percent of the High Plains aquifer, and the two names are used interchangeably. Thirty percent of all water used in U.S. agriculture is pumped here, nourishing wheat, corn, and cattle. But this underground oasis isn't keeping up with increasing demand.



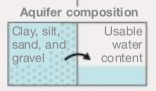
AVAILABLE WATER

The distance between the base of the aquifer and its height, known as saturated thickness, ranges from one foot to a thousand feet. Half of the aquifer has less than a hundred feet of saturated thickness.

HIGH PLAINS AQUIFER SYSTEM

Groundwater discharges at a faster rate than it replenishes. An aquifer can typically take hundreds of years to accumulate water, with recharge rates as low as half an inch a year. The rate of water flow from 2000 to 2009, above, is estimated.

Recharge Discharge



Like a sponge, an aquifer holds water in its crevices.

Change in saturated thickness

Present measurement compared to known baseline*

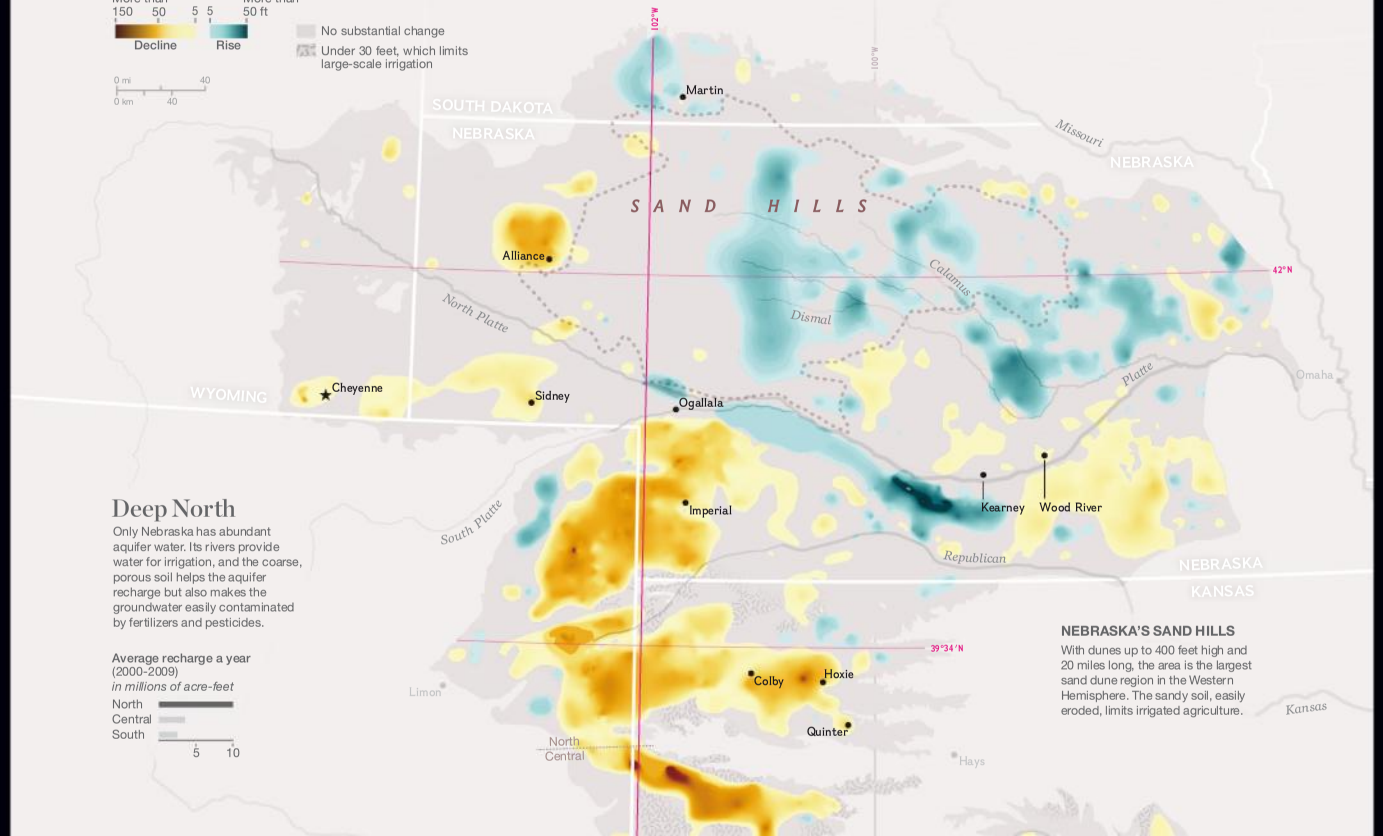
More than 150 50 5 — 5 More than 50 ft

Decline Rise

No substantial change

Under 30 feet, which limits large-scale irrigation

0 mi 40
0 km 40



Deep North

Only Nebraska has abundant aquifer water. Its rivers provide water for irrigation, and the coarse, porous soil helps the aquifer recharge but also makes the groundwater easily contaminated by fertilizers and pesticides.

Average recharge a year
(2000-2009)
in millions of acre-feet

North
Central
South

5 10

NEBRASKA'S SAND HILLS

With dunes up to 400 feet high and 20 miles long, the area is the largest sand dune region in the Western Hemisphere. The sandy soil, easily eroded, limits irrigated agriculture.

Dry Center

Southwest Kansas and the Texas Panhandle pump so much water and so little is recharged that the aquifer has been largely depleted. Parts of this central zone have high rainfall and coarse soils, which can lead to more contamination.

Irrigated cropland
percentage

North
Central
South
20 50 100

Shallow South

This region has the least surface water, and its deeper water resources have been largely tapped. It also has the poorest water quality, from natural and man-made contaminants.

Water quality in domestic wells
*percentage with contaminants***

North
Central
South
20 50 100

LAW OF THE LAND

Several key doctrines, ranging from lax to strict, address landowners' rights to withdraw aquifer water, 95 percent of which is used for irrigation.

Rule of capture
Texas

Owners may use any amount of water or even sell it, without regard to the effect on wells owned by adjacent landowners, even in times of shortage.

Reasonable use and shared rights
Nebraska, Oklahoma

Owners can pump what the state determines is a reasonable amount of water as long as it won't unduly affect other landowners. Landowners get shares of the regional water supply proportionate to their acreage.

Seniority
Colorado, Kansas, New Mexico, South Dakota, Wyoming

Water rights do not come with land ownership and must be obtained separately. In areas where water is scarce, new applications are denied and existing rights are protected in order of seniority.

Explore an interactive version of the High Plains aquifer at *ngm.com/Aug2016.*

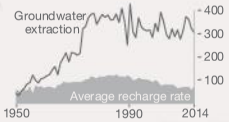
*Present measurement (2011-2013) and historic baseline (1950-2013)
**Has exceeded federal drinking water standards one or more times

Arkansas
FINNEY COUNTY
Garden City
Hutchinson
Dodge City
Wichita
Sublette
COLORADO
NEW MEXICO
KANSAS
OKLAHOMA
36°30′N
Dalhart
Ute Reservoir
Canadian
Logan
Central South
Amarillo
Red
Friona
Clovis
Lazbuddie
Muleshoe
Earth
Plainview
TEXAS
Elida
34°N
Lubbock
Slaton
LLANO ESTACADO
Hobbs
NEW MEXICO
TEXAS
Odessa
102°W
U.S.
MEX.

USE OUTPACES RECHARGE

Recharge rates cannot keep pace with water use. Farmers in places like Finney County adapt by irrigating a portion of some corn circles, leaving other parts brown.

Water use for irrigation
Finney County, Kansas
in thousands of acre-feet

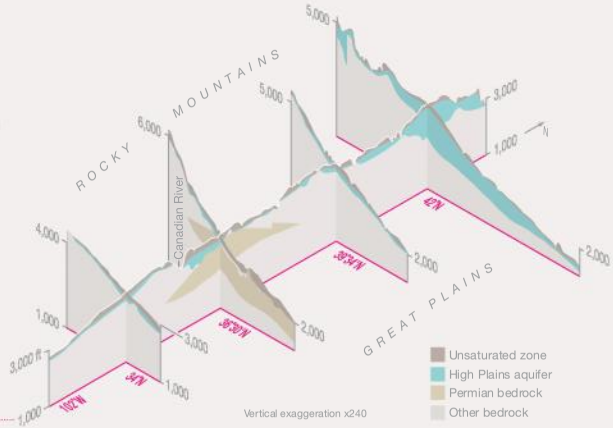


THE 100TH MERIDIAN

Annual rainfall increases approximately one inch per 25 miles east of this line dividing the arid west and the wetter east. Thirsty corn was traditionally planted well east of this meridian, but because of subsidies, farmers now grow it in the semiarid west.

THE 102ND MERIDIAN

A cross section of the High Plains aquifer (right) shows water thickness variations and proximity to salt-laden Permian bedrock.

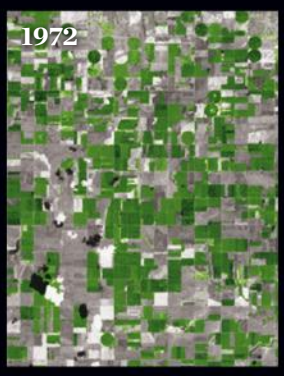


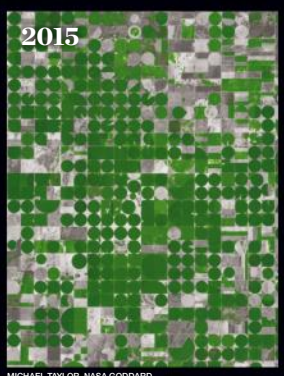
LAUREN E. JAMES, NGM STAFF; LAWSON PARKER. SOURCES: VIRGINIA McGUIRE, JENNIFER STANTON, AND PETER McMAHON, USGS; BROWNIE WILSON, KANSAS GEOLOGICAL SURVEY; BURKE GRIGGS, WASHBURN UNIVERSITY SCHOOL OF LAW, KANSAS

Circles of Grain

Center-pivot irrigation systems etch circles of grain and other plants in Finney County, Kansas. These self-propelled, rotating sprinklers revolutionized farming, enabling more land to be irrigated efficiently. As the aquifer declines, some farmers only irrigate partial circles. Generally, each sprinkler needs to draw from a well that can produce at least 400 gallons of water a minute.

Satellite images from 1972 and 2015 (below) show the transformation of farmland between Garden City and Sublette, Kansas, as rectangular fields gave way to crop circles across the High Plains.





MICHAEL TAYLOR, NASA GODDARD SPACE FLIGHT CENTER (BOTH)

The irrigation era may come to be called the 'great pump up,' bookending the other man-made High Plains disaster—the 'great plow up.'

may come to be called the "great pump up," bookending the other man-made High Plains disaster—the "great plow up," when 5.2 million acres of native grasses were torn out, setting the stage for the Dust Bowl. "A couple of generations from now," says Burke Griggs, a water law expert who teaches at Washburn University in Topeka, "people are going to look back and say: What the hell were they thinking?"

FOR AN EXPANDING NATION in the 1800s, the High Plains didn't hold much promise. The weather—blizzards, tornadoes, and heat waves—could kill. When it rained, it often rained all at once, triggering flash floods. By 1820 the territories that became Nebraska, Kansas, and Oklahoma had been condemned on maps as the Great American Desert, but the cruelest assessment came from the diarist of a U.S. Army survey expedition: "We do not hesitate in giving the opinion, that it is almost wholly unfit for cultivation, and of course uninhabitable by a people depending on agriculture for their subsistence." Homesteaders moved west anyway, lured by cheap land and railroad promotional schemes that played down climatic shortcomings. New arrivals in Plainview, Texas, stepped out of the train depot and gazed upon sailboats on Lake Plainview. The lake lasted five years, until the pump broke on the well that kept it full. The great plow up followed, as sodbusters converted grassland into wheat fields and put their faith in the mistaken theory that rain follows the plow.

One of the misconceptions about the Dust Bowl is that it could have been prevented if farmers had known what lay beneath their feet. They did. Most farms had shallow wells with windmill-driven pumps. What Plains residents lacked was the ability to drill deep and the horsepower to bring water to the surface in the volumes needed to irrigate more than a family farm. It took rural electrification and the diesel-powered centrifugal pump to launch large-scale pumping in the 1950s. After that, the invention of the center-pivot sprinkler remade agriculture. Irrigated acres on the Plains increased from 2.1 million in 1949 to 15.5 million in 2005. The change recolored dry earth into thousands of lush, green crop circles that can be seen from space.

Ogallala water made Kansas a leading producer of wheat. Ethanol production and the consolidation of beef feedlots in southwest Kansas and the Texas Panhandle made corn king. The world's largest contiguous cotton-producing land surrounds Lubbock, thanks to Ogallala water. Large scale hog-processing plants and dairies moved into Kansas, Oklahoma, and Texas. Cheese factories followed the dairies. One of North America's largest cheese plants is outside Clovis, New Mexico, on the aquifer's western edge. When I visited, it was undergoing a $140 million expansion to become the world's largest.

"People can fairly argue there is too much development," says Nate Jenkins, the assistant manager of the Upper Republican Natural Resources District in Imperial, Nebraska. "It was all legally developed, and it's tough to undo. You can't move the clock back."

Cattle feed and ethanol, made from corn, often are singled out as so water consumptive that they put the Ogallala at risk. But William Ashworth, author of *Ogallala Blue,* a history of the aquifer, argues that what pushed the Ogallala beyond its limits can't be blamed on dairies or cotton or corn: "It is dairies *and* cotton *and* corn. And alfalfa and millet and beef cattle and lawn sprinklers and every other use that demands a piece of the large but limited Ogallala supply. Individually, there ought to be enough water for any of them. Collectively, they are going to run

out, and each of them is going to demand that all of the others have to run out first."

ALL THE EARTH'S CONTINENTS contain aquifers, several larger than the Ogallala. By the beginning of the 21st century, a third of the world depended on aquifers for drinking water and farming. In China, plagued by drought, the North China Plain aquifer sustains 117 million people in Beijing and surrounding areas. Similar aquifers in the Ganges Brahmaputra Basin and the Indus Basin have helped lead to a population boom that will cause India to pass China as the world's most populous nation by 2022.

The story is virtually the same everywhere. These and other aquifers in several of the world's most productive, heavily populated regions are being drawn down at precipitous rates. NASA satellites, monitoring changes in Earth's gravitational pull, found that 21 of the world's 37 largest aquifers have passed the sustainable tipping point. California's prolonged drought has driven water levels in much of the Central Valley aquifer to historic lows. India now consumes more groundwater than any other country, and at a faster rate.

Perhaps Saudi Arabia provides the most spectacular example of overdrawing a resource. The Saudis went after the huge Arabian aquifer with a greater passion than they sought their oil, drilling 2,000 feet deep. The dunes turned green with grain, transforming the desert nation into a leading exporter in the 1980s and 1990s. Now the aquifer has been all but emptied. This year wheat wasn't even planted; the Saudis are growing alfalfa in Arizona and California.

Among the Ogallala states, Nebraska is an exception. Two-thirds of the aquifer's water lies beneath the Cornhusker State, which ranks first nationally in acres of irrigated cropland. Ogallala water is everywhere. Wetlands and little lakes that appear as brilliant blue jewels are embedded across native bluestem. Rivers boil up out of cattle pastures, gaining in width and strength as they flow east. I spent a day with Doug Hallum, a University of Nebraska hydrologist, wandering the Sand Hills to locate the headwaters of the Dismal River, which oozes to the surface in a sodden pasture not far from CNN founder Ted Turner's sprawling Blue Creek bison ranch. The region is really a great dune sea, the largest in North America. Rainfall and snowmelt easily percolate through the sand, giving Nebraska the most substantial recharge on the aquifer's 174,000-square-mile span.

From 2000 to 2008, the years of both a drought and a corn boom, the Ogallala declined at twice the rate of the previous decade, according to Leonard Konikow, a U.S. Geological Survey hydrologist. The aquifer lost, on average, 8.3 million acre-feet per year—equivalent to about half the annual flow of the Colorado River as it runs through the Grand Canyon. The findings did little to inspire cutbacks in water use. "Everyone wants to conserve, but no one wants to quit pumping," says Ray Luhman, manager of the northernmost groundwater management district in Kansas.

None of the three water districts in western Kansas that overlie the aquifer has agreed on a plan to cut pumping, although farmers surrounding the tiny town of Hoxie took the long view and agreed to a 20 percent reduction in a five-year trial. It is a small oasis of self-regulation in western Kansas—70 farmers over 99 square miles. Just accomplishing that took years of arm-twisting. "We knew something needed to be done," says Jeff Torluemke, a local banker and farmer. "We're looking at our kids and grandkids—not just water for irrigation, but water to live. If we continue to pump like there's no tomorrow, even that would be in jeopardy."

In southwest Kansas, one of the most severely depleted areas, hopes are invested in an unlikely-to-be-funded $18 billion aqueduct, a massive public works project of eras long past, that would carry Missouri River water 360 miles uphill. Few expect it to be built, and some call it a distraction from writing a plan, like Hoxie, to scale back water use. Missouri Governor Jay Nixon laughed off the aqueduct as "harebrained."

This past fall I attended a forum, optimistically titled Farming for the Long Haul, where

River “tanking” in plastic livestock-watering containers is a popular tourist draw along the shallow Calamus River in central Nebraska. With two-thirds of the Ogallala’s water underlying it, the state’s wealth of groundwater feeds countless springs, streams, and rivers.

Business is slow midday in downtown Muleshoe, Texas, a 103-year-old community northwest of Lubbock. Small towns struggle in the region, where the Ogallala aquifer is pumped for irrigation.

Sediment that formed the Ogallala aquifer sloughed off from the Rocky Mountains, creating gravel that is mined for construction materials. Sixteen acres of the gravel are stored near Slaton, Texas.

Julene Bair, author of *The Ogallala Road,* a memoir about love, loss, and selling the farm that had been in her family for three generations, recounted how her father had heard, as she put it, the Ogallala's "siren call" and switched from sustainable dryland wheat to unsustainable corn. She spoke emphatically about the failure of volunteer efforts to limit pumping of the aquifer. "Local control is not working," she told the farmers in the audience. "It asks too much of the farmer to regulate himself. It's not the farmer's job to decide about the aquifer, it's the government's job."

THE LLANO ESTACADO, the largest flat plateau in North America, spreads out from Odessa north to Amarillo, Texas, and west into New Mexico. The aquifer here is so dry that center-pivot sprinklers draw from multiple wells, the unofficial record being one pivot near Lubbock that draws from 21 wells. Not only is irrigated farming in trouble, but water supplies for surrounding towns are too.

"If people who live on the Ogallala want to see the future," Jeri Sullivan Graham, a senior scientist at the Los Alamos National Laboratory, tells me, "they should look south and west."

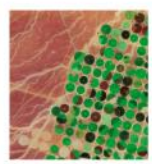
In Lazbuddie, School Superintendent Joanna Martinez, who also drives the school bus, had waterless urinals installed in the boys' restrooms. When the community well gave out, it coughed up so much sand it destroyed the school's plumbing fixtures. Even with a new well, water is so scarce that the football field last year was watered only to soften it up enough to prevent injuries—and then, not on the sidelines or in the end zones.

I cross over the state line into Clovis, a city with ambition but not enough water. Irrigation has drawn the aquifer down so low here that 73 wells deliver less water than what 28 wells delivered to Clovis residents in 2000. "We are in a race to the bottom," Mayor David Lansford says.

Salvation lies 70 miles north. The eastern New Mexico water authority plans to build a 150-mile pipeline from the Ute Reservoir on the Canadian River to carry water south to Clovis and neighboring towns along the Texas border. Residents in the village of Logan, on the reservoir's shoreline, fear that this new straw will draw the water down so far it will kill their tourism economy. "Just because you emptied your piggy bank doesn't mean you get to go break your little brother's piggy bank and take his money," says T. J. Smith, a former chamber of commerce head. The pipeline remains unfunded, and in any event, it wouldn't solve the problems of people such as Buffy Berdoza, who lives beyond the reach of Clovis city water.

Berdoza owns a home just two miles south of town, on Curry Road 5, where all the wells have gone dry. Berdoza is 46 and a home health care aide. Every night after work, she fills more than a dozen five-gallon buckets, sometimes more, in Clovis and hauls them home so her children can flush the toilet and bathe. She has been doing this for four years.

The heart surgeon down the road packed up and moved to Montana, but Berdoza has a mortgage and no chance to sell. Who buys a house without running water? At night, Berdoza says, she dreams about water. The dream is always the same. She is taking a shower or lying in a bath of warm water. She always has plenty. ▯



NASA

Groundwater reserves are being depleted all over the world. To read Laura Parker's extended coverage of aquifers that are disappearing in Asia, Africa, and the Middle East, go to *ngm.com/Aug2016.*

Oceanic whitetips and pilot fish share the water, but the sharks' relationship with humans has been troubled. Commercial fishing has vastly depleted the once ubiquitous species.

THE SHIPWRECK SHARK

Oceanic whitetips once ruled the open seas and inhabited the nightmares of sailors. Now they've all but vanished.

An oceanic whitetip with satellite and ID tags swims near the Bahamas' Cat Island, one of the last places the sharks reliably can be found. Before this tagging study, scientists knew little about the species.

By Glenn Hodges
Photographs by Brian Skerry

When the documentary *Blue Water, White Death* hit U.S. theaters in 1971, its footage of great white sharks crashing into diving cages became instantly iconic. But the footage that stands out 45 years later is a long scene showing oceanic whitetip sharks swarming a whale carcass a hundred miles off the coast of South Africa.

It is an amazing scene for two reasons: first, because the divers leave the safety of their cages to film the sharks, believed to be the first time anyone had ever tried the technique among feeding sharks. And second, because it's a scene that might never be replicated—a marine version of the last photograph of endless bison herds roaming the North American plains. "You couldn't count them, there were so many," says Valerie Taylor, one of the divers. "It will never happen again—not in your lifetime. Maybe in someone else's, but I doubt it."

At one time oceanic whitetips were thought to have been among the most numerous pelagic (open ocean) sharks on the planet. An authoritative 1969 book, *The Natural History of Sharks,* even characterized them as "possibly the most abundant large animal, large being over 100 pounds, on the face of the Earth." Once known for besieging shipwrecks and fishing boats, they've now all but disappeared because of commercial fishing and the shark fin trade—with surprisingly little scientific attention and even less public concern.

"We've absolutely annihilated the species on a global scale," says Demian Chapman, one of the few scientists who have studied the shark. "And yet when I say 'oceanic whitetips,' a lot of people have no idea what I'm talking about."

If you've seen *Jaws,* you know something of oceanic whitetips. They're likely the predominant sharks that plagued the crew of the U.S.S. *Indianapolis* after it was sunk by a Japanese submarine near the end of World War II—an event made infamous to recent generations by Captain Quint's monologue about his experience as a survivor of the sinking. It's impossible to capture the chilling effect of Quint's speech in words—let's just say it's full of screaming and bleeding—but the last line sums it up: "Eleven hundred men went into the water, 316 men came out, and the sharks took the rest."

The problem with Quint's story, though, is that while it gets the tangible facts more or less right, it badly misrepresents the crew's experience. This much is true: Of the nearly 1,200 crew members on the *Indianapolis,* about 900 made it into the water alive, and most of those men died in a hellish ordeal over the next five days. Only 317 survived. There were sharks—lots of them—and gruesome shark attacks.

But when I asked Cleatus Lebow, 92, a soft-spoken Texan who was a crewman on the *Indy,* what the hardest part of his time in the water was, before I even finished my question he said, "Being thirsty. I'd have given anything for a cup of water." What about the sharks? "You could see them swimming around sometimes,

With its winglike pectoral fins, the oceanic whitetip is built to glide through vast expanses of the ocean in search of prey. When it finds something that might be edible, it investigates relentlessly.

Filmmaker Joe Romeiro captures a close-up of an oceanic whitetip off Cat Island. The species' reputation as ravenous killers is overblown, but divers still need nerve. The sharks aren't shy. Their hello: a quick bump.

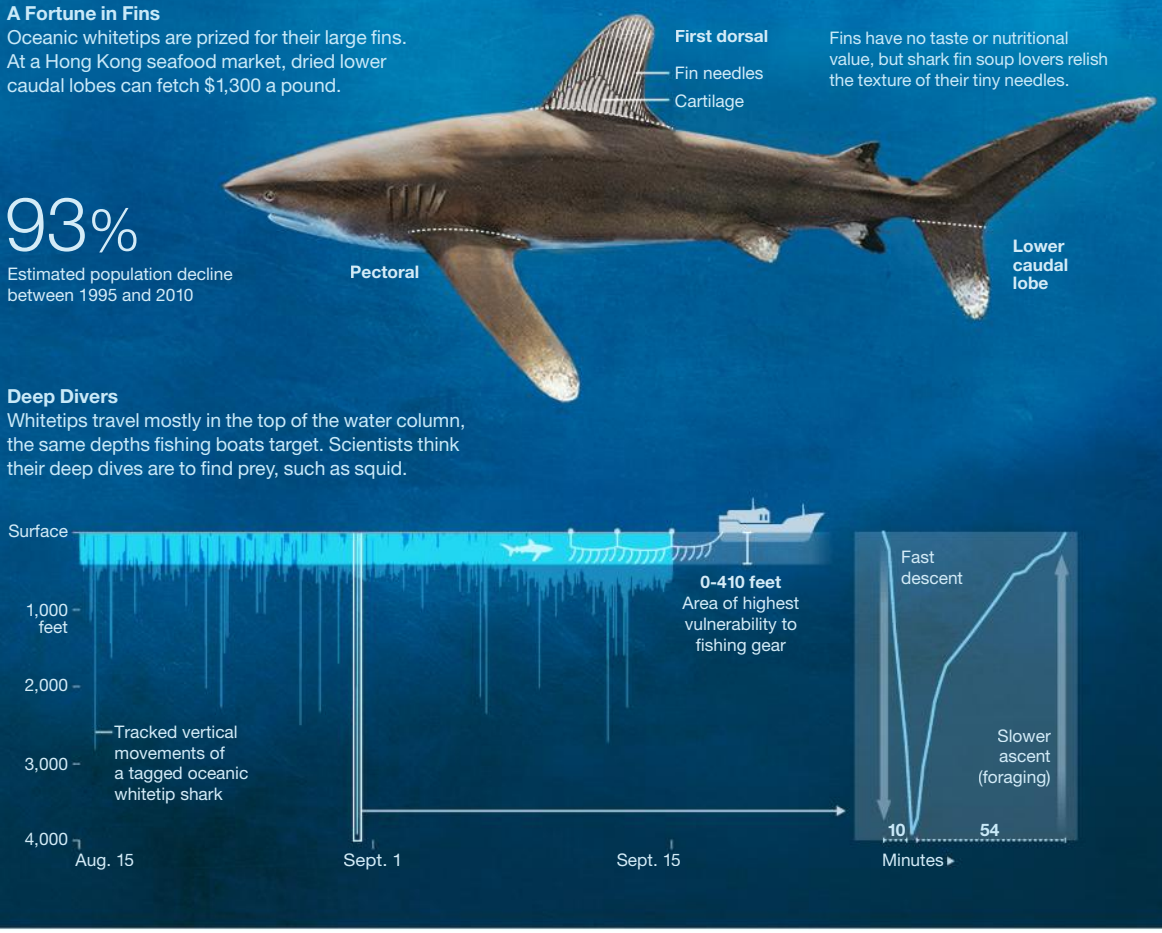
Whitetip Tipping Point

Hunted for their fins and often hooked as bycatch by longline commercial vessels, oceanic whitetip sharks are in steep decline. They have few offspring (two to three pups in a litter) and don't reach sexual maturity until around seven years—traits that impede population recovery. They tend to inhabit remote parts of open ocean, making them difficult to study.

but they didn't bother us." Lyle Umenhoffer, 92, told me, "You had to be alert when those sharks were around, and if they got too close, you'd kick them away. But I don't think I was really afraid of them. We had other problems." (Umenhoffer has since passed away.)

Now it should be said that by the time they were rescued, the survivors were spread across an area of more than a hundred square miles, and their experiences varied. And it should also be said that the dead might tell different tales. But no man I spoke to at a survivors' reunion last summer—14 of the remaining 31 survivors were present, and I interviewed most of them—would put sharks at the top of his list of concerns during the ordeal. Technically, Quint was right that the sharks took "the rest"—that is, the men who never made it out of the water—but most of those men actually died from other causes: injuries, hypothermia, drowning, dehydration, and saltwater poisoning. "I seen men die from sharks—a few of them," said survivor Dick Thelen, 89. But he saw two or three times as many men die from drinking seawater. As one person at the reunion put it to me, "Quint doesn't say anything about being thirsty."

It's important to get the story straight because the portrayal of oceanic whitetips as voracious killers and, as such, an expendable species may have damaging consequences. On land, the effect of removing dominant predators is well understood: It creates ecological havoc. (In parts of Africa, for example, diminished lion and leopard populations have led to a rise in both baboons and their intestinal parasites, which are increasingly infecting humans.) What effect has oceanic whitetips' virtual disappearance had on ocean ecosystems where these animals once loomed so large? We have no idea. Zero. So little research has been done



on the species that even trying to understand the story of its own decline—never mind how that decline affects other species—feels like trying to assemble a jigsaw puzzle with most of the pieces missing. And if we mistake these sharks for villains, we're not likely to feel any urgency about finding those missing pieces. If the *Indianapolis* sinking happened today, its crew would almost surely not be bothered by hordes of oceanic whitetips—and that should not be taken as good news.

SCUBA PIONEER JACQUES COUSTEAU once called the oceanic whitetip "the most dangerous of all sharks," but divers with extensive shark experience tend to have a more nuanced take on the species. Stan Waterman, another diver from the *Blue Water, White Death* expedition, says part of what made their dive unique was that it allowed them to see how oceanic whitetips actually behave, compared with how they were thought to behave. "It was a great learning experience," he says, "because we weren't sure what would happen when we got out of the cages."

They found the same thing so many of the *Indianapolis* survivors reported: Whitetips are not shy about approaching and bumping, even repeatedly, but if you stay in a group and fend them off, they're not likely to attack—at least not when there's plenty of other food in the water. "We got sussed out hundreds of times," Valerie Taylor says, "and then they decide you're not worth bothering about and go away."

Nine to 13 feet long at maturity, the oceanic whitetip is certainly large enough to be dangerous, and it is a bold and persistent shark. The open ocean is an ecological desert, and oceanic whitetips are geared to spend as little energy as possible exploring it and as much time as necessary investigating the things they come

FERNANDO G. BAPTISTA AND MATTHEW W. CHWASTYK, NGM STAFF; LAWSON PARKER
SOURCES: IUCN; FISHERIES AND AQUACULTURE DEPARTMENT, FAO; LUCY HOWEY, MICROWAVE TELEMETRY, INC

across that might be good to eat. So they glide through the water with their long, winglike pectoral fins, and when they come across a potential food source—sailors flailing around a shipwreck, a dead whale, a school of tuna—they lock in to check it out. If you're the only food around, the oceanic whitetip is going to be a very dangerous shark. Otherwise, it's apt to be mostly unnerving.

One of the most interesting anecdotes about the behavior of oceanic whitetips has nothing to do with shipwrecks or divers, though. In the 1950s, fishery researchers in the Gulf of Mexico were surprised when they opened up the stomachs of whitetips and found five- and 10-pound tuna in them, because the sharks aren't fast enough to chase down small tuna. Then one day they saw a large group of whitetips swimming through a school of tuna, at the surface, with their mouths open. "No attempt was made by the sharks to chase after or snap at the hundreds of tuna," the researchers reported. "The whitetips were merely waiting and ready for those moments when tunas would accidentally swim or leap right into their mouths."

Of course, it's doubtful anyone would be able to observe behavior like that now, and the great irony is that the researchers who recorded the spectacle were helping pave the way for its end. "They were out there to see what kinds of commercial fisheries could be developed in U.S. waters," says Julia Baum, a marine ecologist who compared the data from the 1950s with more recent longline catch data to gauge the change in oceanic whitetip populations in the Gulf. "They were setting out these longlines for tuna, and the sharks were just everywhere," eating the tuna on the hooks and getting hooked on the lines themselves. "They didn't know if they'd be able to develop commercial tuna fisheries because the sharks were so numerous."

The fishermen came up with two solutions: shoot the sharks before they ate the hooked tuna, and set separate lines to catch the sharks, the fins of which, they realized, were worth money. Perhaps enough money to justify catching them. And together, these two forces—a callous disregard for sharks and a growing demand for shark fin soup in Asia—have decimated global shark populations in the past several decades and have taken a particularly steep toll on oceanic whitetips. Baum's research led her to conclude in 2004 that whitetip populations had fallen by as much as 99 percent in the Gulf of Mexico, and though her study has critics, other research has found similarly dramatic declines in the Atlantic and Pacific.

It became so clear by 2010 that oceanic whitetips were in trouble that the five major international fishery organizations that oversee swordfish and tuna fishing forbade vessels from keeping any oceanic whitetips they caught—the only shark species so far to receive that

Grant Brian Skerry's fieldwork was funded in part by your National Geographic Society membership.

Two whitetips are now a crowd, but 50 years ago they could be seen by the hundreds. Though tales of their man-eating are overblown, they were once notorious for swarming shipwreck survivors.

protection. And in 2013 the Convention on International Trade in Endangered Species (CITES) enacted restrictions that severely curtail legal trade in their fins.

The question is whether the protections are too little, too late. Many bony-fish populations can quickly repopulate after being overfished, because they spawn relatively early in their life cycles and lay thousands of eggs at a time, but most sharks reach sexual maturity slowly and then give birth to small litters of pups every one or two years. These factors make them extremely vulnerable to overfishing and susceptible to extinction. And in the case of oceanic whitetips, "we still don't even know whether they give birth every year or every two years," says marine biologist Edd Brooks. "How do you begin to conserve an animal when you have so little information about how it lives its life?"

Brooks is one of the scientists trying to fill in some of those gaps. He's part of a team of researchers that since 2010 has been tagging and studying oceanic whitetips off Cat Island, in the Bahamas. "Cat Island is the last place we know of on the planet where you can reliably find them in serious numbers," he says. It was not just the first time he or any of his colleagues had done comprehensive, hands-on research on the species. It was the first time anyone had, anywhere.

Cat Island is right at the edge of the continental shelf, bringing the deep waters of the Atlantic close to shore and making it a perfect spot to find

big pelagic fish such as marlin and tuna. About 10 years ago rumors started to circulate that fishermen off Cat Island were having trouble with oceanic whitetips stealing their catches. Photographer Brian Skerry sensed a rare opportunity and hired a dive operator to help him get underwater shots of the sharks. Their success led to regular dives off Cat Island. Word got out, and scientists got in on the action.

"This was the project we always wanted to do," says marine biologist Lucy Howey. "We never actually thought it would happen, because we didn't think we'd be able to find them."

Howey's team, which included Brooks and Demian Chapman, tagged nearly a hundred oceanic whitetips with satellite tracking devices, which recorded movement patterns and other data. They made several significant discoveries: First, although the sharks traveled broadly through the Atlantic, they spent much of the year in the protected waters of the Bahamas, where longline fishing was prohibited in the 1990s and a commercial trade ban on all sharks was enacted in 2011. So having protected areas where sharks are free from fishing pressures could be crucial to the restoration of the species.

Second, oceanic whitetips spend 93 percent of their time between the surface and a hundred meters (328 feet), which suggests that early commercial fishing, when tuna and other fish were abundant at those depths, may have taken an outsize toll on the sharks. So regulating fishing in that range could aid conservation.

But the third finding is the alarming one: The population that frequents Cat Island may be as small as 300. After five years of tagging, the high number of individuals being recaptured suggests far fewer sharks inhabit these waters than the researchers initially thought.

Let that sink in: There may have been more oceanic whitetips swarming that whale carcass in *Blue Water, White Death* in a single day than there are in the course of an entire year at the best known stronghold the species has left.

It's possible that relatively robust populations exist in other places. Oceanic whitetips are frequently seen in the Red Sea, off the Cayman Islands, and around Hawaii. But sightings in those areas are typically of lone individuals or very small groups, so it's impossible to make an educated guess about their overall numbers.

Howey says the crucial question now is to find their birthing grounds. The fourth thing her team discovered is that many of the whitetips off Cat Island are pregnant females. But there are no signs that the sharks give birth there. "We've never seen pups in the Bahamas," she says. "If we know where they give birth, we can protect those areas. That's how we're going to make headway in protecting the species."

IT IS IMPOSSIBLE to rewind time, and impossible to recapture lost innocence. The relatively unspoiled seas of the 1950s, full of so many fish that nations were more worried about not making use of the resource than about exhausting it, seem almost incomprehensible now. But Cuba, which stretches like a long bridge from the southern Bahamas to the Gulf of Mexico, may be something of a bridge to a bygone time. The more than 50-year trade embargo imposed by the United States has not just slowed Cuba's economic development; it has also dampened the exploitation of its natural resources, and as a result the marine preserves off Cuban shores are among the world's most pristine.

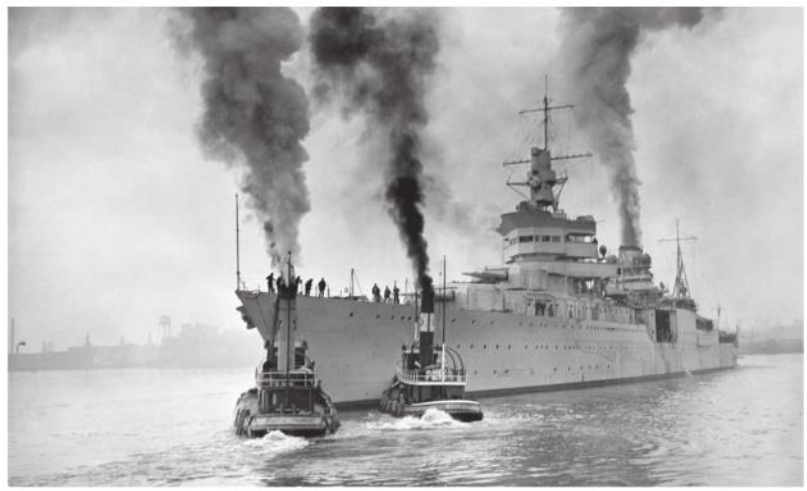
Right now the Cuban government is working on a shark conservation plan. For the past six years Cuban scientists have been taking detailed surveys of the sharks fishermen are catching offshore, and they're finding something their U.S. colleagues will be happy to hear. On the north coast of Cuba, off the small village of Cojímar, fishermen are catching sharks in droves. The third most abundant species they're catching: oceanic whitetips. Mostly juveniles, and some of them small pups. □

JON LOWENSTEIN

Interviewed last summer with other survivors of the U.S.S. *Indianapolis,* **Lyle Umenhoffer** (left) died on October 27. At press time, only 23 survivors of the disaster were living. See videos of them at *ngm.com/Aug2016*.

THE U.S.S. *INDIANAPOLIS*

BEYOND THE SHARK TALES



On July 26, 1945, the heavy cruiser U.S.S. *Indianapolis* landed on Tinian Island in the northern Pacific and delivered components for the atomic bomb that 11 days later would be dropped on Hiroshima. World War II was almost over. But for the crew of the *Indy,* the worst of the war was yet to come. Four days later, en route to the Philippines, the ship was torpedoed by a Japanese submarine. The ship sank in 12 minutes, taking some 300 men down with it. The remaining 900 men were set adrift for the better part of five grueling days. Only 317 survived. It was the worst disaster at sea in U.S. naval history.

It was also perhaps the U.S. Navy's most shameful debacle. The stranded sailors died in many ways, all horrible: injury, hypothermia, saltwater poisoning, shark attack—even homicide, when men began slipping into hallucinatory madness, stabbing and drowning shipmates they mistook for enemies. But most of those deaths had the same ultimate cause: the Navy's failure to notice the *Indianapolis* was overdue at its next port of call and its failure to investigate. No search party was dispatched; the survivors were rescued only after a passing plane spotted them. To deflect blame, the Navy court-martialed the ship's captain, Charles McVay, for failing to elude the attack—the only U.S. captain court-martialed for losing a ship in the war. He later committed suicide. After a campaign to clear his name, McVay was exonerated in 2000, and the *Indy* survivors had something to celebrate at last: their story told truly. *—GH*

BETTMANN/GETTY IMAGES

Net Worth

By **CHRISTY ULLRICH BARCUS**
Photographs by **TODD FORSGREN**

Jogging in Boston 11 years ago, artist Todd Forsgren spied the remains of a black-crowned night heron entangled in a chain-link fence. Struck by the contrast of the bird's silhouette against the grid-like wires, he suddenly envisioned a unique way to photograph birds.

"Both of my parents are birders," Forsgren says. "My earliest memory of art is looking through the works of John James Audubon and Roger Tory Peterson." Inspired by the night heron, Forsgren set out to create a series of photographs that integrated Audubon's famously flamboyant illustrations with Peterson's pragmatic field-guide images.

Working closely with ornithological researchers, Forsgren traveled across the Americas from 2006 to 2014, making portraits of birds temporarily caught in mist nets—finely woven nylon nets hung between two posts. During this time he documented 57 species in the continental United States and Puerto Rico, Mexico, Costa Rica, and Brazil. The first bird he photographed was a white-crowned sparrow in California (opposite page, bottom left).

Scientists who work with mist nets check them regularly, typically every 20 to 30 minutes. Bruce Peterjohn, chief of the Bird Banding Laboratory at the U.S. Geological Survey's Patuxent Wildlife Research Center, says it's an effective technique to temporarily capture birds for study. He says that less than one percent of birds caught in mist nets are injured or killed when scientific experts are involved (unlike when hunters use the nets, often illegally).

When a bird is caught, Forsgren quickly sets up his portable studio. He uses a white cloth for the background and a photographic light with reflectors to evenly illuminate his subjects. After he's finished, trained mist-net operators carefully extract the bird from the net, measure and weigh it, identify its species, and sometimes band its leg. Then the bird flies away.

By gaining insight into different species this way, Peterjohn says, scientists can identify key information and trends—songbird migration routes, for instance, or species demographics and the reasons for a population's decline—that help bird conservation.

Forsgren says such research is vital to understanding what's happening to avian populations. But he also hopes his work will get people to identify with the birds as individuals. "I want to create photographs that very concretely consider individual birds," he says. "I definitely want people to empathize with these creatures."

While that empathy may make it difficult for some people to look at these photographs, Forsgren says, his art is ultimately inspired by science. "I want to show these beautiful, scientific encounters to celebrate the important research that is happening." ▯

Keel-billed toucan *(Ramphastos sulfuratus),* Costa Rica

Swallow-tailed manakin *(Chiroxiphia caudata),* Brazil

Summer tanager *(Piranga rubra),* Costa Rica

White-crowned sparrow *(Zonotrichia leucophrys),* U.S.

Prothonotary warbler *(Protonotaria citrea),* Costa Rica

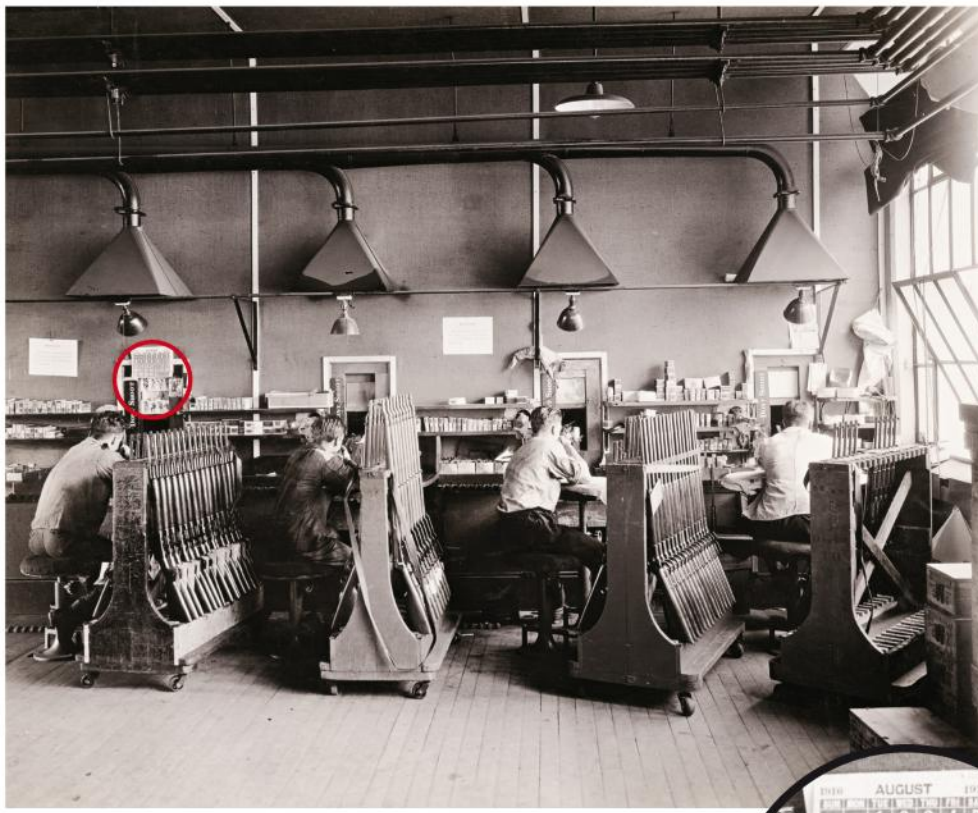
Wedge-tailed sabrewing *(Campylopterus curvipennis),* Mexico

Blue mockingbird *(Melanotis caerulescens),* Mexico

Northern saw-whet owl *(Aegolius acadicus)*, U.S.

In the Loupe

With Bill Bonner, National Geographic Archivist



Straight Shooters

A hundred years ago this month, workers at the Winchester Repeating Arms Company in New Haven, Connecticut, were hard at work. After creating the "Gun that Won the West"—the Winchester Model 1873 rifle—they had a new task: manufacturing guns that could help win World War I.

At this indoor range, men—perhaps motivated by pinup pictures and the urgency of a calendar (inset)—adjusted the sights and tested the accuracy of each gun. Demand was heavy: In 1915 they made nearly 250,000 rifles for the British Army and some 300,000 muskets for Russian troops.

After April 1917, when the U.S. joined the fight, the Model 1917 Enfield would become the most widely used rifle by American troops in the war. By then, instead of testing their rifles indoors, these men may have been firing them on the battlefield. —*Eve Conant*

PHOTO: NATIONAL GEOGRAPHIC CREATIVE

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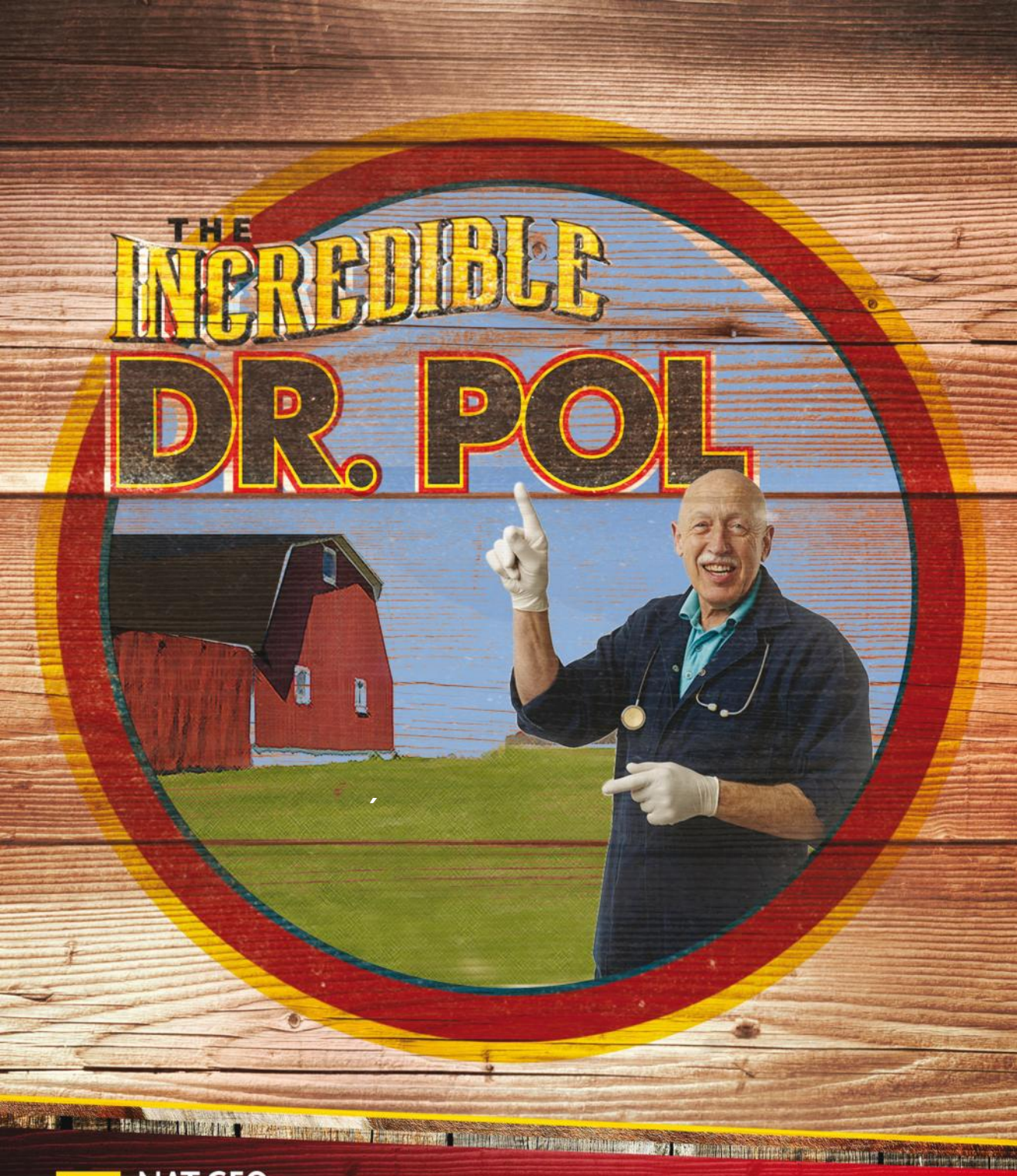

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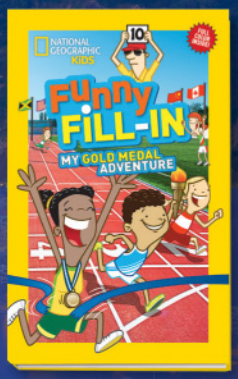

This fun activity book will keep kids entertained and right at the center of the gold-medal action.

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