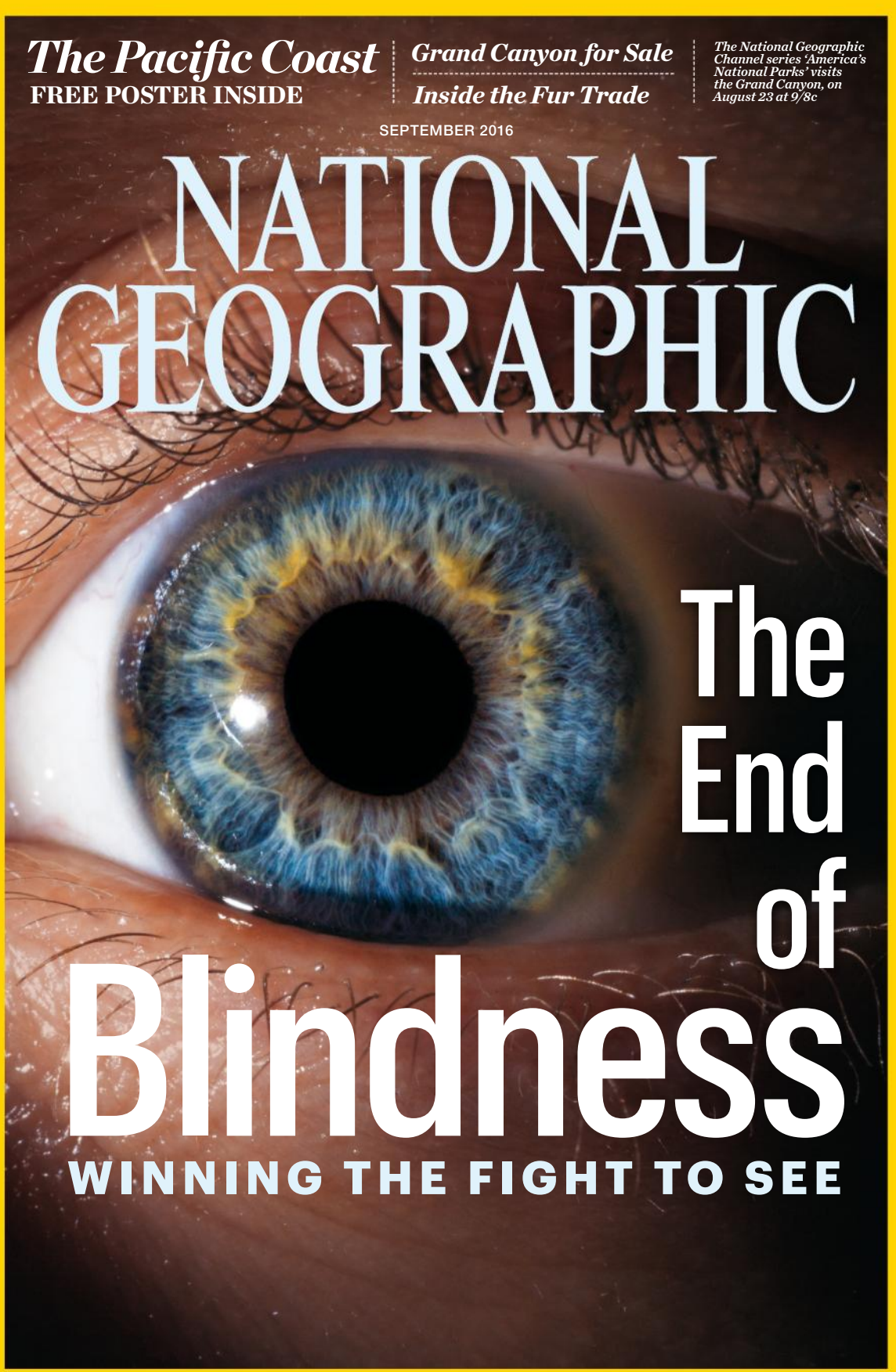
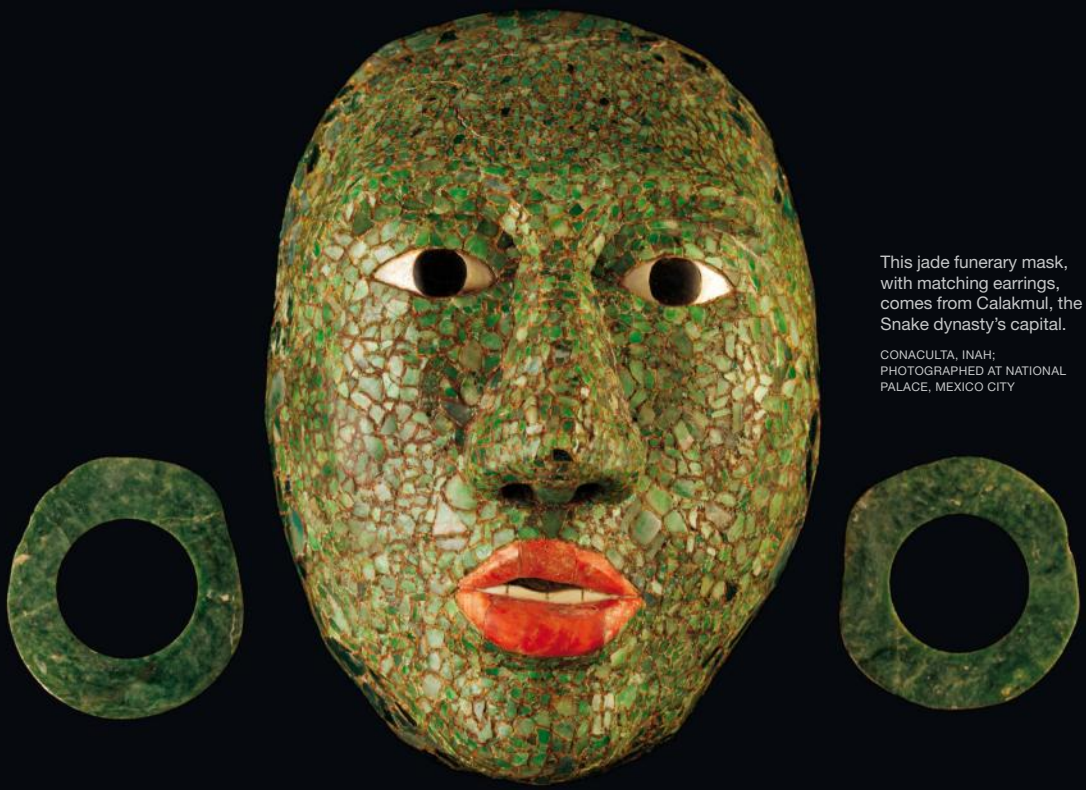


NATIONAL GEOGRAPHIC

SEPTEMBER 2016 • VOL. 230 • NO. 3



This jade funerary mask, with matching earrings, comes from Calakmul, the Snake dynasty's capital.

CONACULTA, INAH; PHOTOGRAPHED AT NATIONAL PALACE, MEXICO CITY

On the Cover Thirty-nine million people—about one in 200—are blind, but scientists are working to help them see. *Photo by David Liittschwager*

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

OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY

He Put a Bounty on Blindness

Fifty-five years ago Sanford Greenberg was 20, newly blind through bad luck and misdiagnosis, and rightly angry at the world when he made a vow from his hospital bed. "No one should have to go blind," he thought. "It was a promise I made not just to myself but to God."

It was, and remains, an enormous aspirational pledge. Around the world 39 million people—roughly one out of 200—are blind, as writer David Dobbs and photographer Brent Stirton reveal in this month's cover story. Another 246 million are moderately or severely visually impaired. The human costs are staggering, both for those with vision loss and for the hundreds of millions of people who assist them.

Sanford Greenberg (left) with his former college roommate, Art Garfunkel, who helped Greenberg get around after he lost his sight.

Greenberg is one of the fortunate ones. In 1961 he ignored the social worker who suggested he go home to Buffalo, New York, and make cane-backed chairs in a program for the blind. Instead, with the aid of the college roommate who read textbooks to him and helped him get around campus, Greenberg finished his bachelor's degree at Columbia. He earned a doctorate at Harvard. He worked at the White House. He helped create a device that made listening to recorded speech more convenient for blind people—and made him financially independent in the process. He serves on boards and commissions too numerous to name. He married Sue, whom he'd loved since sixth grade; they are married still. And he remains close friends with that Columbia roommate, who studied architecture but pursued a career in music: Art Garfunkel, of Simon & Garfunkel fame.

This brings us to the Sanford and Susan Greenberg Prize to End Blindness by 20/20—a reward of three million dollars in gold to the person or persons who contribute most to ending blindness by 2020. (Learn more at *endblindnessby2020.com*.)

"Clinical relief of blindness ... appears to stand at a point rather similar to that of the nascent American program of space exploration in the 1950s and early 1960s," Greenberg says. "Practically waiting."

Worldwide, half of all blind people lose their sight to cataracts—routinely fixed in the developed world but a tragically common cause of blindness in the developing one. Meanwhile other approaches are advancing rapidly, as our coverage explains: gene and stem cell therapies, bionic implants.

How does Greenberg regard all this? "My determination has not faltered," he says. "Blindness is an injustice—'unfair,' we say in our plainspoken American way. We must act to end it."

Susan Goldberg, *Editor in Chief*

PHOTO: BRENT STIRTON

Temminck's Ground Pangolin *(Smutsia temminckii)*
Size: Body length, 40 - 70 cm (15.8 - 27.6 inches); tail, 40 - 70 cm (15.8 - 27.6 inches) **Weight:** 7 - 18 kg (15.4 - 39.7 lb) **Habitat:** Found primarily in savanna woodlands with moderate or dense scrub **Surviving number:** Unknown

Photographed by Nigel Dennis

WILDLIFE AS CANON SEES IT

Roll with it. When a predator threatens, Temminck's ground pangolin simply rolls into a ball and counts on its sharp scales for protection. The shy and solitary insectivore's own favored prey are ants and termites, which it snatches up with its long tongue. But in searching for the next meal, it all too often has a fatal encounter with an electrified fence or runs afoul of poachers. No armor can prevent the pangolin from being captured and sold for the traditional medicine trade, which uses virtually every body part.

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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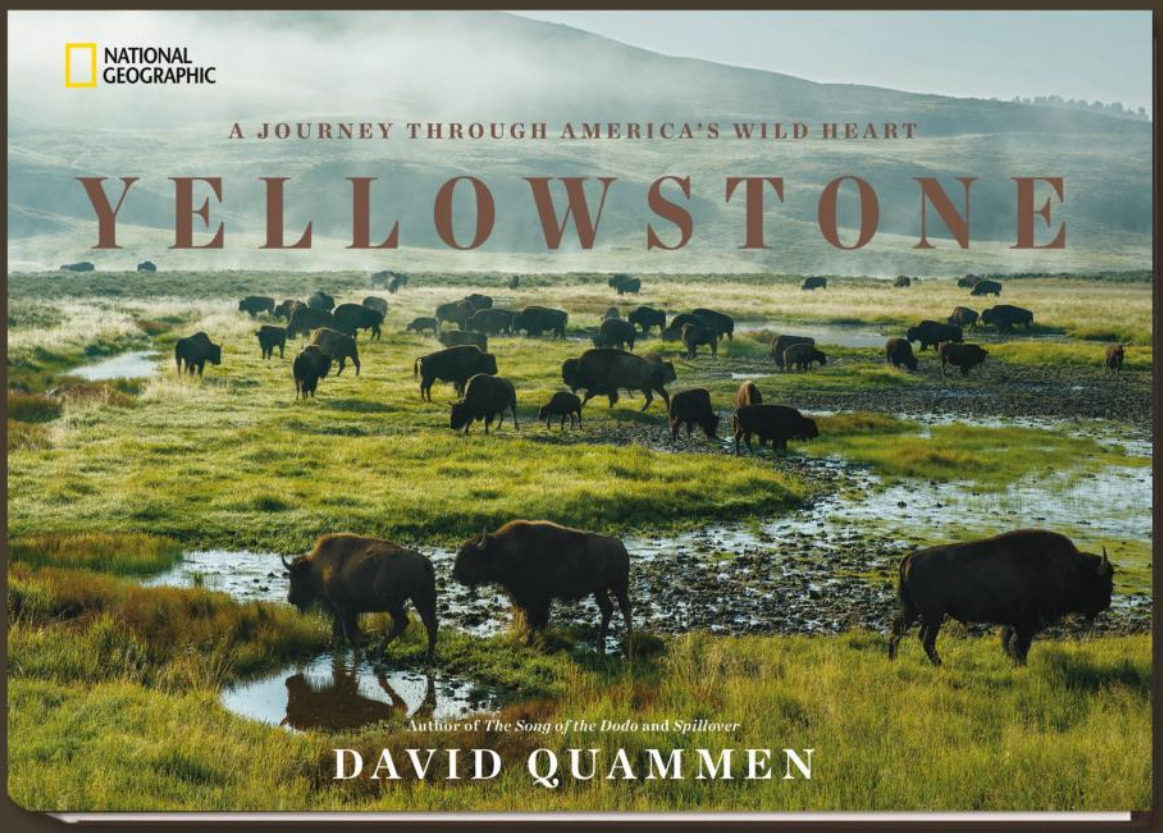

Yellowstone National Park represents America's finest—and most precarious—effort to preserve realms of primordial nature for human appreciation. Best-selling author David Quammen takes readers on a breathtaking journey through Yellowstone's storied past, rich ecosystem, and dynamic landscape, brilliantly captured through stunning photographs.

In this book, nature lovers, conservationists, and adventurers will discover this timeless American treasure and the challenges tied to its preservation.

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Why I Brew Ancient Beers

As a biomolecular archaeologist at the University of Pennsylvania, **Patrick McGovern,** 71, re-creates humankind's first alcoholic beverages. They include a beer likely served at King Midas's funerary feast and a 9,000-year-old fermented drink from China—which, he says, still "goes well with Chinese food."

Why did humans start drinking?
We were born to drink—first milk, then fermented beverages. Our sensory organs attract us to them. As humans came out of Africa, they developed these from what they grew. In the Middle East, it was barley and wheat. In China, rice and sorghum. Alcohol is central to human culture and biology.

How did alcohol shape civilization?
Anthropologists debate which came first, bread or beer. I think it was beer: It's easier to make, more nutritious, and has a mind-altering effect. These were incentives for hunter-gatherers to settle down and domesticate grain. In the process they set up the first permanent villages and broke down social boundaries between groups. Most of the world's religions use alcohol, and the earliest medicines involve wine. The beginnings of civilization were spurred on by fermented beverages.

How can we drink like our ancestors?
When analyzing something, I work from a minuscule amount of chemical, botanical, and archaeological data. I look for principal ingredients: Does it have a grain? A fruit? An herb? Then I take bits of information from texts or frescoes and re-create the process, replicating pottery or collecting local yeast. Some methods carry on for thousands of years. In Burkina Faso they still mash carbs into sugar exactly how the ancient Egyptians did in 3500 B.C.

PHOTO: BRIAN FINKE

VISIONS

United States
In Bodie, California, abandoned buildings and a rusted-out 1937 Chevy glow eerily in this hour-long exposure. The former gold-mining town—designated a National Historic Landmark in 1961—is preserved in a state of arrested decay.

PHOTO: BERTHOLD STEINHILBER, LAIF/REDUX

United States
Like will-o'-the-wisps on a humid summer night, male blue ghost fireflies illuminate the woods near Brevard, North Carolina. This image was made by digitally stitching together more than 300 30-second exposures spanning four hours.

PHOTO: SPENCER BLACK

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China
In this vertiginous view of Hong Kong, low clouds race above the Quarry Bay neighborhood, reflecting the city lights below. Most of the 18- to 20-story residential buildings in this shot were erected in 1972.

PHOTO: ROMAIN JACQUET-LAGRÈZE

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*Trulicity is not a weight loss drug. In studies, people who lost weight lost 2-6 lbs on average.

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Tell your healthcare provider if you:

- have or have had problems with your pancreas, kidneys, or liver.
- have severe problems with your stomach, such as slowed emptying of your stomach (gastroparesis) or problems with digesting food.
- have any other medical conditions.
- are pregnant or plan to become pregnant, or if you become pregnant while taking Trulicity. It is not known if Trulicity will harm your unborn baby.
- are breastfeeding or plan to breastfeed. It is not known if Trulicity passes into your breast milk. You should not use Trulicity while breastfeeding without first talking to your healthcare provider.
- are taking other medicines including prescription and over-the-counter medicines, vitamins, and herbal supplements. Trulicity may affect the way some medicines work and some medicines may affect the way Trulicity works.
- are taking other medicines to treat diabetes, including insulin or sulfonylureas.

The most common side effects with Trulicity may include: nausea, diarrhea, vomiting, decreased appetite, and indigestion. Talk to your healthcare provider about any side effect that bothers you or does not go away. These are not all the possible side effects of Trulicity. Call your doctor for medical advice about side effects.

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

Please see next page for additional information about Trulicity, including Boxed Warning regarding possible thyroid tumors including thyroid cancer.

Please see Instructions for Use included with the pen.

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Indication and Limitations of Use

Trulicity is a once-weekly injectable prescription medicine to improve blood sugar (glucose) in adults with type 2 diabetes mellitus. It should be used along with diet and exercise. Trulicity is not recommended as the first medication to treat diabetes. It has not been studied in people who have had inflammation of the pancreas (pancreatitis). Trulicity should not be used by people with a history of severe gastrointestinal (GI) disease, people with type 1 diabetes, or people with diabetic ketoacidosis. It is not a substitute for insulin. It has not been studied with long-acting insulin or in children under 18 years of age.

Important Safety Information

Tell your healthcare provider if you get a lump or swelling in your neck, have hoarseness, trouble swallowing, or shortness of breath while taking Trulicity. These may be symptoms of thyroid cancer. In studies with rats or mice, Trulicity and medicines that work like Trulicity caused thyroid tumors, including thyroid cancer. It is not known if Trulicity will cause thyroid tumors or a type of thyroid cancer called medullary thyroid carcinoma (MTC) in people. Do not take Trulicity if you or any of your family members have ever had MTC or if you have Multiple Endocrine Neoplasia syndrome type 2 (MEN 2).

Do not take Trulicity if you have had an allergic reaction to dulaglutide or any of the other ingredients in Trulicity.

Trulicity may cause serious side effects, including:

- **Inflammation of your pancreas (pancreatitis).** If you have pain in your stomach area (abdomen) that is severe and will not go away, stop taking Trulicity and call your healthcare provider right away. The pain may happen with or without vomiting. It may be felt going from your abdomen through to your back.
- **Low blood sugar (hypoglycemia).** If you are using another medicine that can cause low blood sugar (such as insulin or a sulfonylurea) while taking Trulicity, your risk for getting low blood sugar (hypoglycemia) may be higher. Signs and symptoms of low blood sugar may include dizziness, blurred vision, anxiety, irritability, mood changes, sweating, slurred speech, hunger, confusion or drowsiness, shakiness, weakness, headache, fast heartbeat, or feeling jittery. Talk to your healthcare provider about low blood sugar and how to manage it.
- **Serious allergic reactions.** Stop taking Trulicity and get medical help right away if you have symptoms of a serious allergic reaction, such as itching, rash, or difficulty breathing.
- **Kidney problems (kidney failure).** In people who have kidney problems, diarrhea, nausea, and vomiting may cause a loss of fluids (dehydration). This may cause kidney problems to get worse.
- **Severe stomach problems.** Trulicity may cause stomach problems, which could be severe.

Information for Patients about Trulicity (dulaglutide):

This is a brief summary of important information about Trulicity (Trū-li-si-tee). Please read the Medication Guide that comes with Trulicity before you start taking it and each time you get a refill because there may be new information. This information is not meant to take the place of talking with your healthcare provider or pharmacist.

What is Trulicity?

Trulicity is a once-weekly, injectable prescription medicine that may improve blood sugar (glucose) in adults with type 2 diabetes mellitus, and should be used along with diet and exercise.

- It is not recommended as the first choice of medicine for treating diabetes.
- It is not known if it can be used in people who have had pancreatitis.
- It is not a substitute for insulin and is not for use in people with type 1 diabetes or people with diabetic ketoacidosis.
- It is not recommended for use in people with severe stomach or intestinal problems.
- It is not known if it can be used with long-acting insulin or if it is safe and effective for use in children under 18 years of age.

What is the most important information I should know about Trulicity?

Trulicity may cause serious side effects including possible thyroid tumors, including cancer. Tell your healthcare provider if you get a lump or swelling in your neck, hoarseness, trouble swallowing, or shortness of breath. These may be symptoms of thyroid cancer. In studies with rats or mice, Trulicity and medicines that work like Trulicity caused thyroid tumors, including thyroid cancer. It is not known if TRULICITY will cause thyroid tumors or a type of thyroid cancer called medullary thyroid carcinoma (MTC) in people.

Who should not use Trulicity?

Do not use Trulicity if:

- you or any of your family have ever had a type of thyroid cancer called medullary thyroid carcinoma (MTC) or if you have an endocrine system condition called Multiple Endocrine Neoplasia syndrome type 2 (MEN 2).
- you are allergic to dulaglutide or any of the ingredients in Trulicity.

What are the possible side effects of Trulicity?

Trulicity may cause serious side effects, including:

- **Possible thyroid tumors, including cancer**. **See "What is the most important information I should know about Trulicity?"**
- **inflammation of the pancreas (pancreatitis).** Stop using Trulicity and call your healthcare provider right away if you have severe pain in your stomach area (abdomen) that will not go away, with or without vomiting. You may feel the pain from your abdomen to your back.
- **low blood sugar (hypoglycemia).** Your risk for getting low blood sugar may be higher if you use Trulicity with another medicine that can cause low blood sugar such as sulfonylurea or insulin.

Signs and symptoms of low blood sugar may include: dizziness or light-headedness; blurred vision; anxiety, irritability, or mood changes; sweating; slurred speech; hunger; confusion or drowsiness; shakiness; weakness; headache; fast heartbeat; feeling jittery.

- **serious allergic reactions.** Stop using Trulicity and get medical help right away, if you have any symptoms of a serious allergic reaction including itching, rash, or difficulty breathing.
- **kidney problems (kidney failure).** In people who have kidney problems, diarrhea, nausea, and vomiting may cause a loss of fluids (dehydration) which may cause kidney problems to get worse.
- **severe stomach problems.** Other medicines like Trulicity may cause severe stomach problems. It is not known if Trulicity causes or worsens stomach problems.

The most common side effects of Trulicity may include nausea, diarrhea, vomiting, decreased appetite, indigestion.

Talk to your healthcare provider about any side effect that bothers you or does not go away. These are not all the side effects of Trulicity.

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

Before using Trulicity tell your healthcare provider if you:

- have had problems with your pancreas, kidneys, or liver.
- have severe problems with your stomach, such as slowed emptying of your stomach (gastroparesis) or problems digesting food.
- have any other medical conditions.
- are pregnant or plan to become pregnant, or if you become pregnant while taking Trulicity. It is not known if Trulicity will harm your unborn baby.
- are breastfeeding or plan to breastfeed. It is not known if Trulicity passes into your breast milk. You should not use Trulicity while breastfeeding without first talking to your healthcare provider.
- **are taking other medicines**—including prescription and over-the-counter medicines, vitamins, and herbal supplements. Trulicity may affect the way some medicines work and some medicines may affect the way Trulicity works.
- are taking other medicines to treat your diabetes including insulin or sulfonylureas.

Before using Trulicity, talk to your healthcare provider about low blood sugar and how to manage it.

How should I use Trulicity?

- Read the **Instructions for Use** that comes with Trulicity**.**
- Use Trulicity exactly as your healthcare provider tells you to.
- Your healthcare provider should show you how to use Trulicity before you use it for the first time.
- Trulicity is injected under the skin (subcutaneously) of your stomach (abdomen), thigh, or upper arm. **Do not** inject Trulicity into a muscle (intramuscularly) or vein (intravenously).
- **Use Trulicity 1 time each week on the same day each week at any time of the day.**
- You may change the day of the week as long as your last dose was given **3** or more days before.
- If you miss a dose of Trulicity, take the missed dose as soon as possible, if there are at least 3 days (72 hours) until your next scheduled dose. If there are less than 3 days remaining, skip the missed dose and take your next dose on the regularly scheduled day. **Do not** take **2** doses of Trulicity within **3** days of each other.
- Trulicity may be taken with or without food.
- **Do not** mix Trulicity and insulin together in the same injection.
- You may give an injection of Trulicity and insulin in the same body area (such as your stomach), but not right next to each other.
- Change (rotate) your injection site with each weekly injection. **Do not** use the same site for each injection.

Do not share your Trulicity pen, syringe, or needles with another person. You may give another person an infection or get an infection from them.

Your dose of Trulicity and other diabetes medicines may need to change because of:

- change in level of physical activity or exercise, weight gain or loss, increased stress, illness, change in diet, or because of other medicines you take.

For more information go to www.Trulicity.com or call 1-800-LillyRx (1-800-545-5979).

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Give Us Your Best Shot

Each fall we ask readers to submit their best photographs to our annual contest. The entries are always spectacular: a mix of people, places, and nature captured in inventive and jaw-dropping ways. Last year we received 14,000 entries representing 171 countries. The winning images (on this page and the next) share a strong sense of modern geography—a new way to understand the human experience on a constantly changing planet.

This year we're taking our contest somewhere new, starting with a focus on nature photography. Submit your best nature image between August 15 and November 4 for a chance to win a trip for two to the Galápagos with National Geographic Expeditions as well as a portfolio review by a National Geographic expert. The grand prize winner will be named the National Geographic Nature Photographer of the Year.

To enter this year's contest, go to *natgeo.com/photocontest.*

NATURE **JAMES SMART** *Melbourne, Australia*
Smart, a storm-chasing photographer, spent a day following a system in Simla, Colorado. As he sped down a dirt road, he saw the funnel grow. He pulled over to set up his camera.

PLACES **FRANCISCO MINGORANCE** *Almuñécar, Spain*
Mingorance has spent years exploring Spain's Río Tinto, a river that's often transformed into strange colors and patterns by mine runoff. This time he thought it looked like an asteroid impact.

PEOPLE **JOEL NSADHA** *Vestal, New York*
In Kampala, Uganda's capital, Nsadha asked a boy with a bike to pose for a portrait. He scheduled a time at dusk for better light. The boy was hours late, but right before sunset, he arrived.

Small Cats

Assignment We spend a lot of time talking about big cats. We challenged the Your Shot community to demonstrate how small ones can be just as wild.

EDITOR'S NOTE

'Photos like Shukwit's help to reclaim cat photography from the trivial corners of the Internet, reminding us how majestic, wild, and beautiful domestic cats can be.'

Becky Harlan, *Your Shot photo editor*

Geralyn Shukwit
Brooklyn, New York

Shukwit and a friend were visiting Cachoeira, Brazil, when two kids invited them into their house to escape the heat. After one of the children put the family's kitten on the table, their pet bird tried to get as far away as possible.

Paul Elijah Kline
Hood River, Oregon

One evening while driving home, Kline saw a grassy field glowing in golden light. In it, a cat sat looking for field mice. Kline climbed on his car's roof to frame a shot. As he readjusted for another, the cat darted into the grass.

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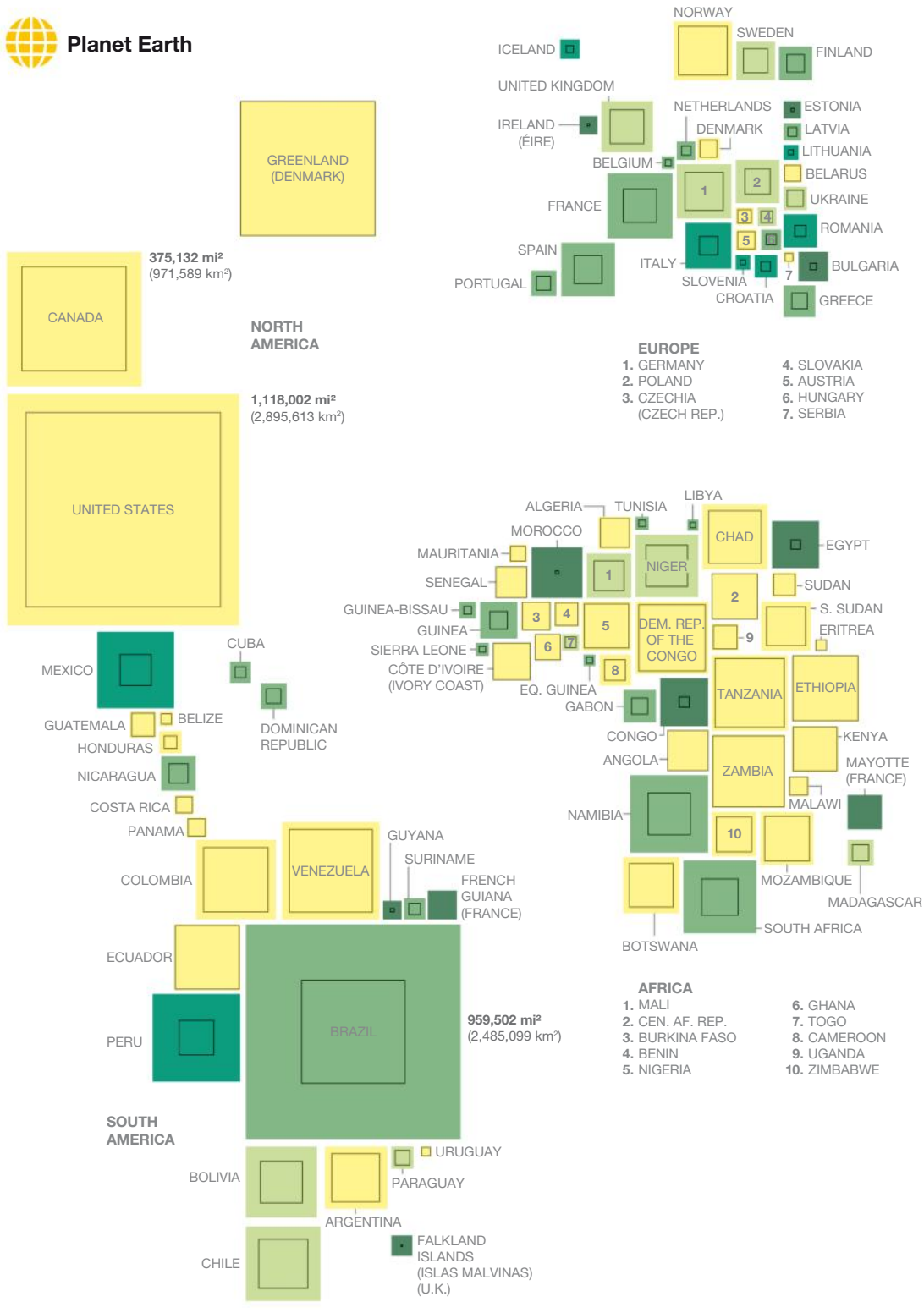
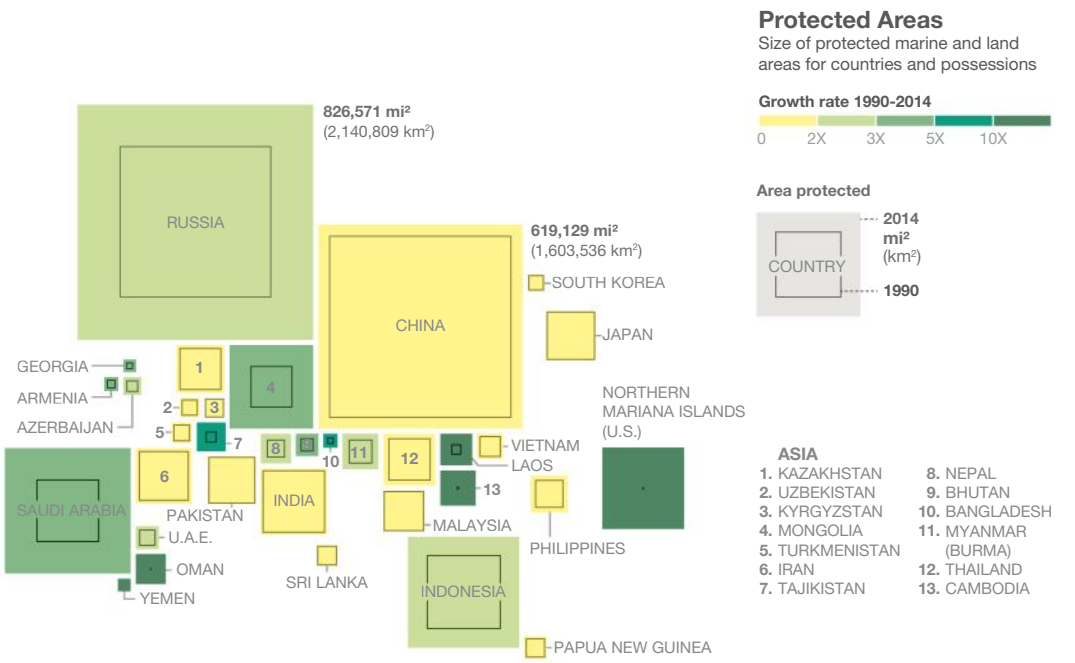
EXPLORE

Planet Earth





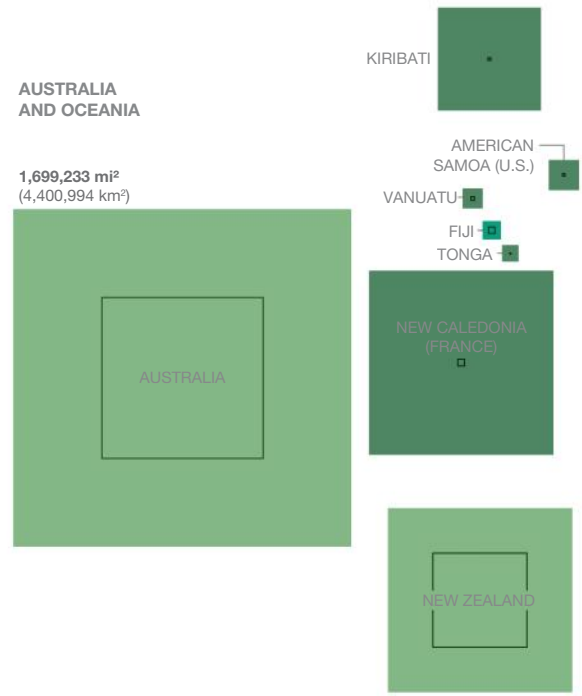
Protected Areas Proliferate

Nearly 13 million square miles of the planet, an area larger than Africa—that's the total amount of land and water that countries have set aside for conservation. Since 1990 the number of marine reserves, national parks, wilderness areas, and other protected areas has risen from fewer than 50,000 to more than 229,000.

"Most countries are doing their best" to protect these assets, says Pedro Rosabal of the International Union for Conservation of Nature (IUCN). But there's much more to do. Though about 15 percent of Earth's land has protected-area status, half the sites are small and isolated, pointing to the need for biological corridors.

Only 3.5 percent of marine areas now are protected, but more soon will be. A 2012 expedition by National Geographic's Pristine Seas project built the case for protecting the United Kingdom's Pitcairn Islands in the South Pacific. And in 2015 the U.K. government pledged to create what will be the world's largest continuous ocean reserve, some 322,000 square miles.

To protect more areas and foster biodiversity, Rosabal says, global cooperation and financial support will be crucial. That will be on the agenda at the IUCN's World Conservation Congress in Hawaii early this month. —*Kelsey Nowakowski*



Countries With Conflict
War-torn countries like Liberia, Somalia, Afghanistan, and Syria are not shown because they have few protected areas.

ONLY COUNTRIES AND POSSESSIONS WITH MORE THAN 5,000 KM² (1,930 MI²) OF PROTECTED AREAS ARE REPRESENTED.

GRAPHIC: MONICA SERRANO, NGM STAFF. SOURCE: IUCN AND UNEP-WCMC, WORLD DATABASE ON PROTECTED AREAS (2016)

Power Plants

Scientists in Sweden have taken ordinary roses, from a local flower shop, and electrified them by incorporating circuits into the plants' living tissue.

The transformation is not as far-fetched as it may seem. A plant's vascular system transmits chemical signals much as electronic circuits transmit currents. To merge the two, physicist Eleni Stavrinidou and her colleagues placed the cut end of a rose into a diluted polymer solution (below). Once absorbed, the polymer reorganized itself into an electrical wire that extended through the xylem, the system of water transport channels inside the rose's stem. Add voltage, and the plant could conduct electricity.

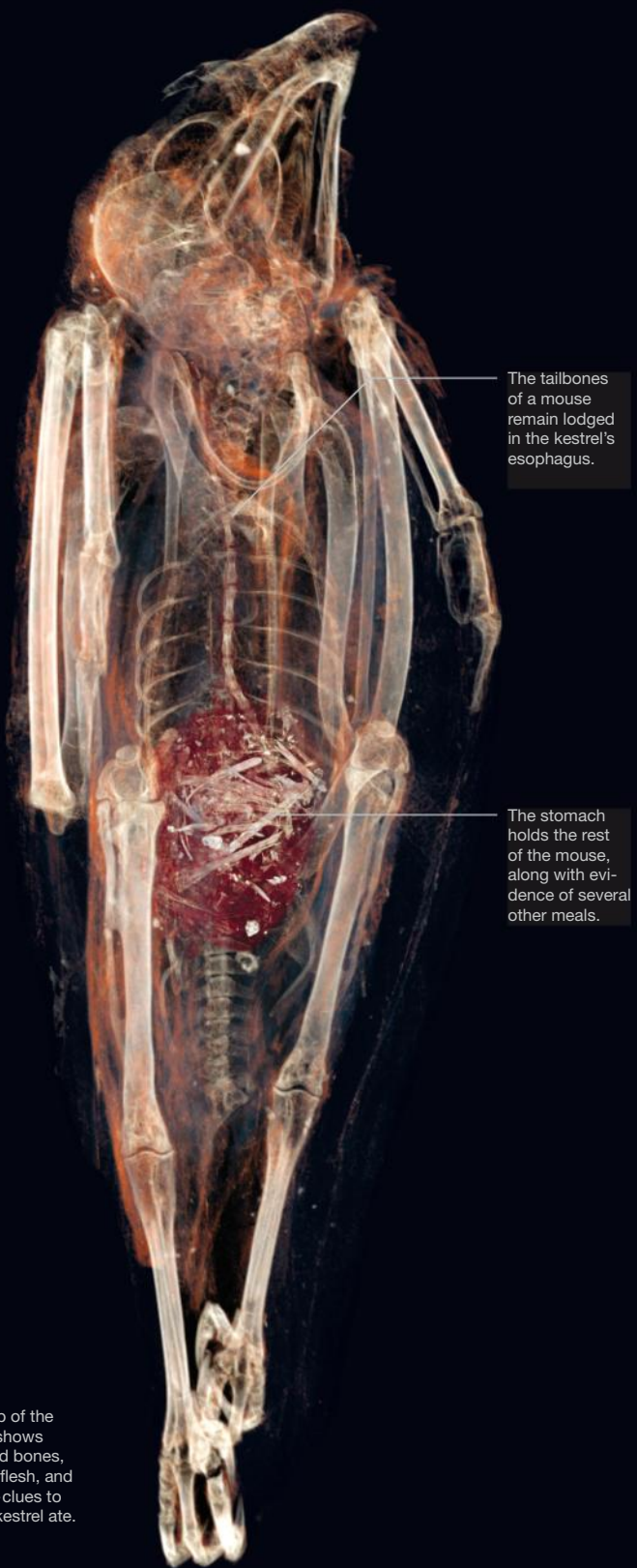
Why would anyone besides a green-thumbed Dr. Frankenstein want to create an electronic plant? Stavrinidou says this technology could produce sensors able to analyze and alter plant physiology at the cellular level. Another possibility: harvesting electricity from the process of photosynthesis. Someday, says Stavrinidou, "you may be able to plug your phone into a plant." —*Rachel Hartigan Shea*

PHOTO: ELIOT GOMEZ

Death by Mouse

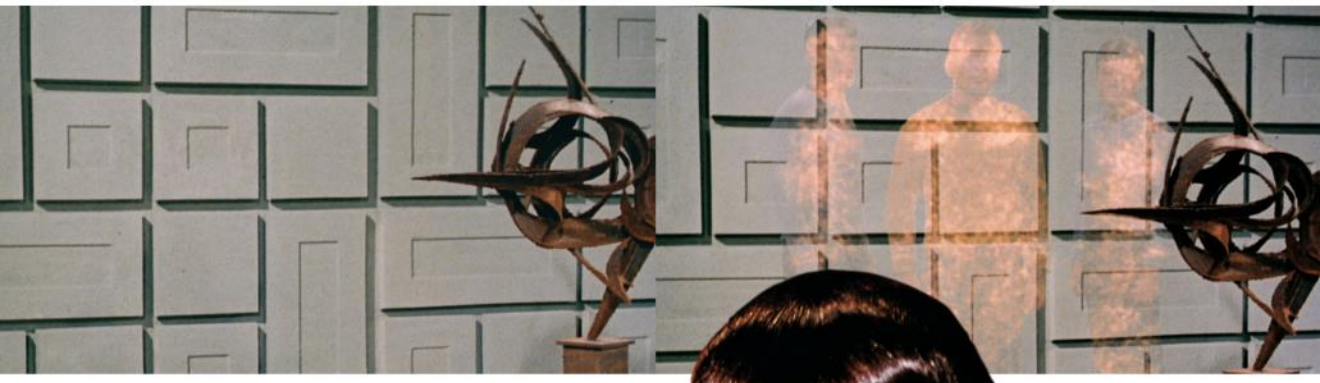
Peering inside the linen wrappings of an ancient Egyptian bird mummy, a CT scan has revealed a true rara avis—a kestrel that appears to have choked to death on a mouthful of mouse. Scientists were stunned to see tailbones descending the length of the esophagus. The rest of the rodent lay in the stomach, which also held traces of at least two other mice and a sparrow's bones and claws. "That means the bird had eaten way too much," says mummy expert Salima Ikram.

In the wild a raptor like this would have eaten its prey, digested what it could, and regurgitated parts such as bones and teeth. This bird was so stuffed it hadn't had a chance to throw up, suggesting to Ikram that it was kept in captivity and force-fed. It was probably one of the many millions of animals that were bred to be sacrificed, mummified, and offered to the gods between about 600 B.C. and A.D. 250. In this case the kestrel was likely presented to the sun god Re, a fate it would have met even if it hadn't gagged in unnatural gluttony. *—A. R. Williams*



A close-up of the stomach shows undigested bones, teeth, fur, flesh, and feathers—clues to what the kestrel ate.

IMAGES (FROM CT SCANS): SALIMA IKRAM AND OTHERS, SOUTH AFRICAN MUMMY PROJECT TEAM



The Real Science of Star Trek

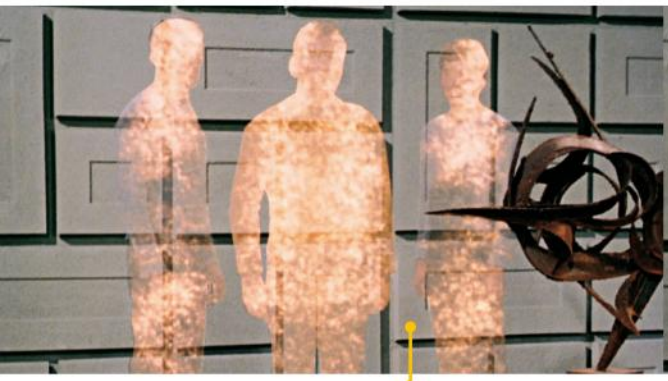
Since its first TV episode aired 50 years ago this month, *Star Trek* has boldly gone where no science fiction has gone before. Through 13 films, six TV series, and a small galaxy of books, games, and other spin-offs, it's won new fans, inspired real-world innovators, and been a fixture in the pop culture firmament.

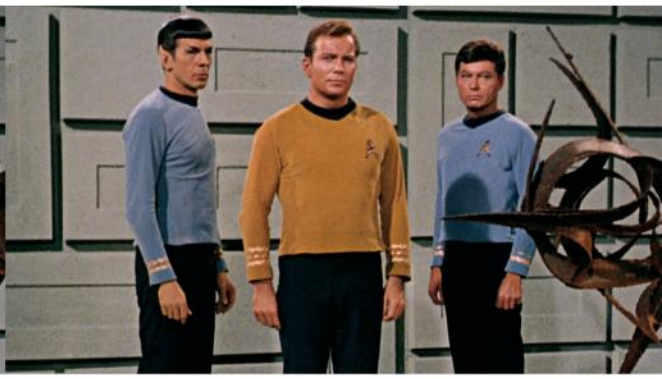
The secret of its highly logical success? "Taking real science seriously," says Andrew Fazekas, author of a new book on the series' fact-based astronomy and prescient technology. Unlike more far-fetched sci-fi, *Star Trek* plots are built on plausible science, he says. Yet they're always rooted in the spirit of adventure—the innate human urge to explore.

Carolyn Porco, a planetary scientist at the University of California, Berkeley and an adviser on the 2009 film, has been a fan of the franchise since its debut. For her, *Star Trek* offers optimism—"a golden utopian vision of ourselves" and the comforting assurance that humanity has "a future beyond Earth." —*Jeremy Berlin*

Explore the real astronomy and technology of *Star Trek* in a new book by National Geographic writer Andrew Fazekas, available where books are sold and at *shop.nationalgeographic.com.*

PHOTOS: NBC VIA PHOTOFEST (SPOCK);

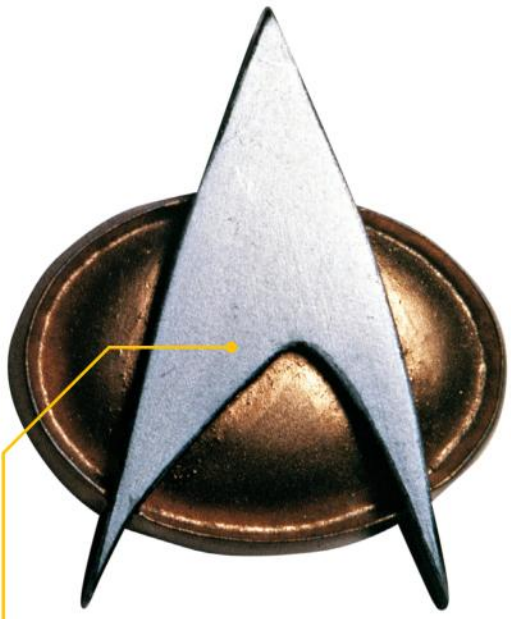




TRANSPORTER

Light-years away

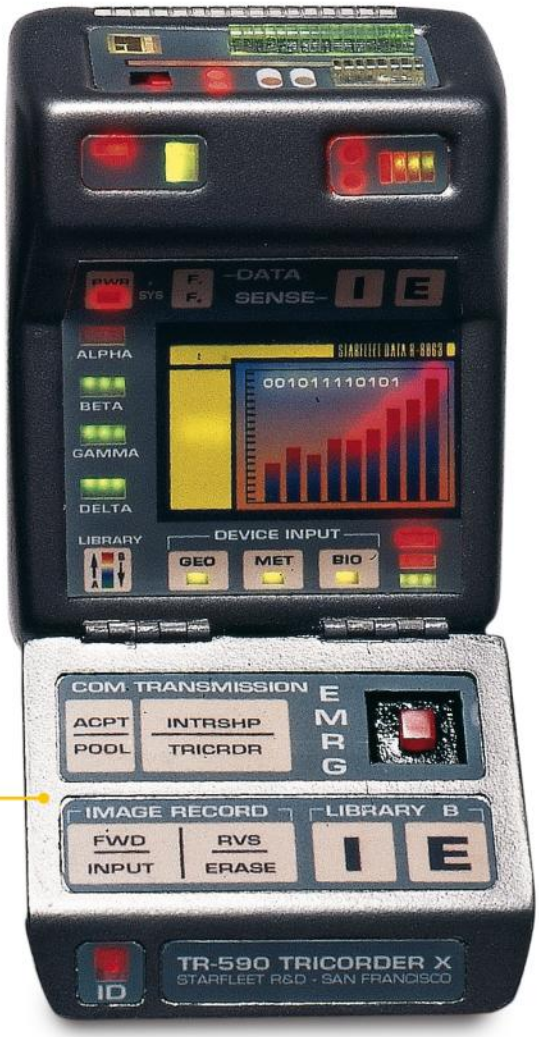
Scotty won't be beaming us up anytime soon. But he may one day. Physicists have long been intrigued by teleportation. So far they've been able to move information encoded into particles of light via optical fiber—a process called quantum teleportation.



COMBADGE

Mission accomplished

Smartphones—the real-world prototypes of *Star Trek*'s combadges—have been with us for years. Now hands-free communicators are starting to hit the market. As technology develops apace, such wearable devices could become ubiquitous.



MEDICAL TRICORDER

Getting there

Helping people live long and prosper is a universal goal of medicine. Wearable devices that can noninvasively gauge heart rate, body temperature, and blood pressure already exist. Clinical-grade handheld monitors may be on the way.

Bangladesh

A floating farm or school? It's part of adapting to warming.

ALIZÉ CARRÈRE *Cultural ecologist*

For years Alizé Carrère had heard about the disastrous effects of climate change, especially in developing countries. But in 2012 Carrère learned of a very different situation: a group of farmers in Madagascar who were figuring out how to farm in fields eroded by deforestation and heavy rains. Instead of depending on development aid to reforest washed-out areas, the farmers adapted. Soon they began to *prefer* farming in the eroded gullies, which became rich with water and nutrients.

That sort of ingenuity in the face of hardship launched Carrère, a National Geographic grantee, on a journey to study climate change adaptation. "It's such an abstract concept, so I wanted to know what it actually looked like," she says. This year she and a film crew are documenting cases in which environmental change has spurred human inventiveness and turning the stories into a video series called *Adaptation*.

Her first stop? Bangladesh, a low-lying, densely populated country where scientists expect rising water to displace 18 million people by 2050. In the southern district of Gopalganj, Carrère watched people build floating gardens from water hyacinth, bamboo, and manure to help them fish, raise ducks, and grow produce. She saw how ingenuity can beget more of the same: A Bangladeshi architect took inspiration from the floating fields and engineered boats to serve as floating schools, hospitals, libraries, and playgrounds.

Since Bangladesh, Carrère has visited northern India to see how glacial melt is being repurposed to feed a desert ecosystem and will go next to Vanuatu, where grinding sea stars into fertilizer helps grow food.

Some of the best adaptation ideas come from kids, Carrère says. They're creative, malleable, and excited to dream up new things. They also have the most at stake. *—Daniel Stone*

Buoyant fields made of plants and manure can support crops in Bangladesh. Carrère (at right) toured several with Bangladeshi reporter Tania Rashid.

Follow Carrère on Instagram and Twitter: @alizecarrere

Japan

What your lunch can reveal about you

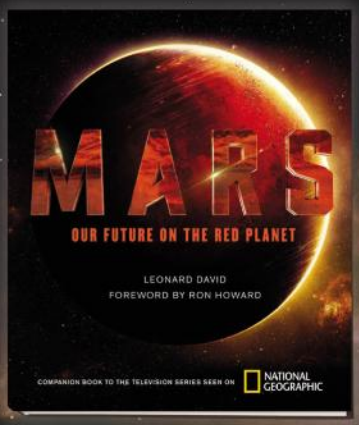
ELIZABETH UNGER *Documentarian*

Middle school is hard. Kindergarten can be even harder in a status-conscious society, where judgment extends to school lunches. Elizabeth Unger, a National

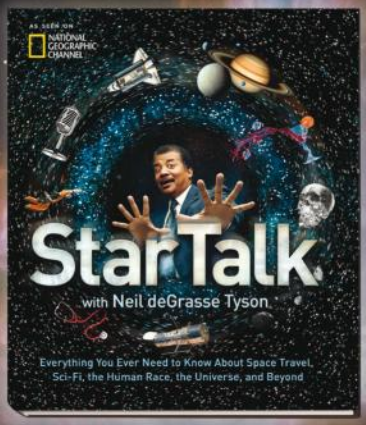
PHOTO: ALIZÉ CARRÈRE. NGM MAPS

TRAVEL the UNIVERSE

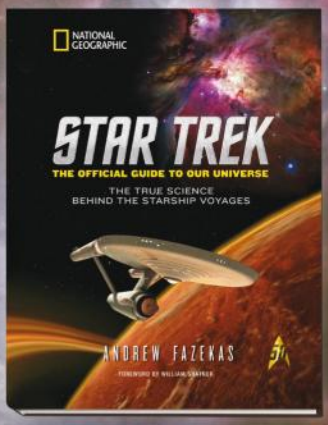
with books from National Geographic



The next frontier in space exploration is Mars, the red planet—and human habitation of Mars isn't much further off. In this official tie-in book to the National Geographic Channel series, go years into the future as humans land on and learn to live on Mars.



Neil deGrasse Tyson and the StarTalk team take the curious reader on an eye-opening journey to discover the complexities of our universe, exploring science's most challenging topics in a relatable, humorous way.



Discover the science behind the science fiction! Many of the destinations featured in ***Star Trek***—alien worlds, supernova explosions, voracious black holes—are scientifically valid, so much so that you can step outside and view them in the night sky!

Get ready to blast off to the red planet! This fun, fact-filled book fires up kids' imaginations about the most recent scientific discoveries, the future of space travel, and how we could build a human colony on Mars.

This visually spectacular reference book presents the most exciting discoveries in the universe, featuring cutting-edge research, the latest explorations, amazing imagery, and specially commissioned artwork.

This introduction to the vast realm of outer space features engaging illustrations and activities, sparking young children's curiosity about everything under the sun and beyond.

NATIONAL GEOGRAPHIC

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NatGeoBooks @NatGeoBooks

Geographic young explorer, studied the curious history of immigration between Brazil and Japan in hopes of understanding what happens, particularly with food, when cultures collide.

As early as 1908, hundreds of Japanese workers headed to Brazil for jobs on coffee plantations. Their community flourished until an economic downturn in the 1980s convinced many of them to return to Japan. Emigrants and their descendants, known as *nikkei,* "were under the impression they would be welcomed back into Japanese society, but they were outcast as foreigners," says Unger.

Food proved to be a good vehicle to study the ethnic identity of an outcast people. Unger spent time in kindergartens, restaurants, and people's homes in both Brazil and Japan, observing the culinary contortions required to fit in. One woman in Japan cooked Brazilian dishes at home but sent her five-year-old daughter to school with elaborate bento boxes filled with Japanese ingredients, including small pandas she made from white rice and seaweed. The goal was for her daughter to eat well—and for her lunch to be seen. *—Daniel Stone*

U.S. and Canada

Ice climbing is notoriously dangerous, especially on waterfalls that can freeze with air pockets between sheets of ice. That's one reason why climbers rarely receive permission to attempt Niagara Falls, the waterfalls on the U.S.-Canada border that flow 190,000 tons of water a minute at more than 20 miles an hour. But in 2015 National Geographic photographer **KEITH LADZINSKI** watched and preserved the scene as professional climber Will Gadd, with approval from officials, made the first ever successful climb of the falls.

PHOTO: KEITH LADZINSKI. NGM MAPS

Somalia

Can this day get any worse? Yes.

ÇAĞAN H. ŞEKERCIOĞLU *Biologist*

Şekercioğlu reports:

I am in Somaliland, an autonomous region of Somalia, to survey vultures and other birds. Today was a bad day.

First my AK-47–toting government escorts nearly mutinied after I tried to get them up at 4 a.m. Mornings are best to spot birds—and to avoid the frequent kidnappings by al Shabaab and Puntland separatists, including one here a few weeks ago.

We ran out of gas 30 kilometers south of Maydh, in the disputed territory between Somaliland and Puntland. Then our brake shoes overheated and stopped working on a road with sheer cliffs. Then I tripped while looking for endemic Somali pigeons in a rocky area. I fell on my camera lens, my elbow, and my wrist. Based on the excruciating pain, I'm inclined to think it's a compound fracture, made no better by needing to drive on bumpy roads. After eight hours of searching for relief, the coldest thing my driver could find was Jell-O. Will my university insurance cover a medevac for an arm injury? Probably not.

And now, as if things couldn't get worse, we've been hit by two cyclones, dumping buckets of rain and turning the roads into fields of mud. Under the best circumstances, with roads passable tomorrow, I'm 86 hours, two days of bad road, and two flights away from Istanbul.

When Sex Is Shocking

An emerald ash borer hovers, checking out the female forms below him. He's drawn by how light plays across their bodies. He picks one, approaches, initiates physical contact—and is zapped by 4,000 volts.

Trying to mate with an electrified decoy is a grisly way to go. But entomologist Michael Domingue has no qualms about killing the emerald ash borer, or EAB for short. Since 2002 EABs have killed hundreds of millions of North America's native ash trees.

To catch them, Domingue and his Pennsylvania State University colleagues created a literal femme fatale: a faux female, battery-powered so it would lethally shock any male that mounted it. The scientists made a rough version of the decoy on a 3-D printer; EAB males looked but didn't land. The researchers also made a more realistic model, with a similar emerald hue and light-scattering surface texture as a real EAB shell. In tests using both real dead females and high-fidelity decoy females (above), virtually the same number of EABs alighted on each.

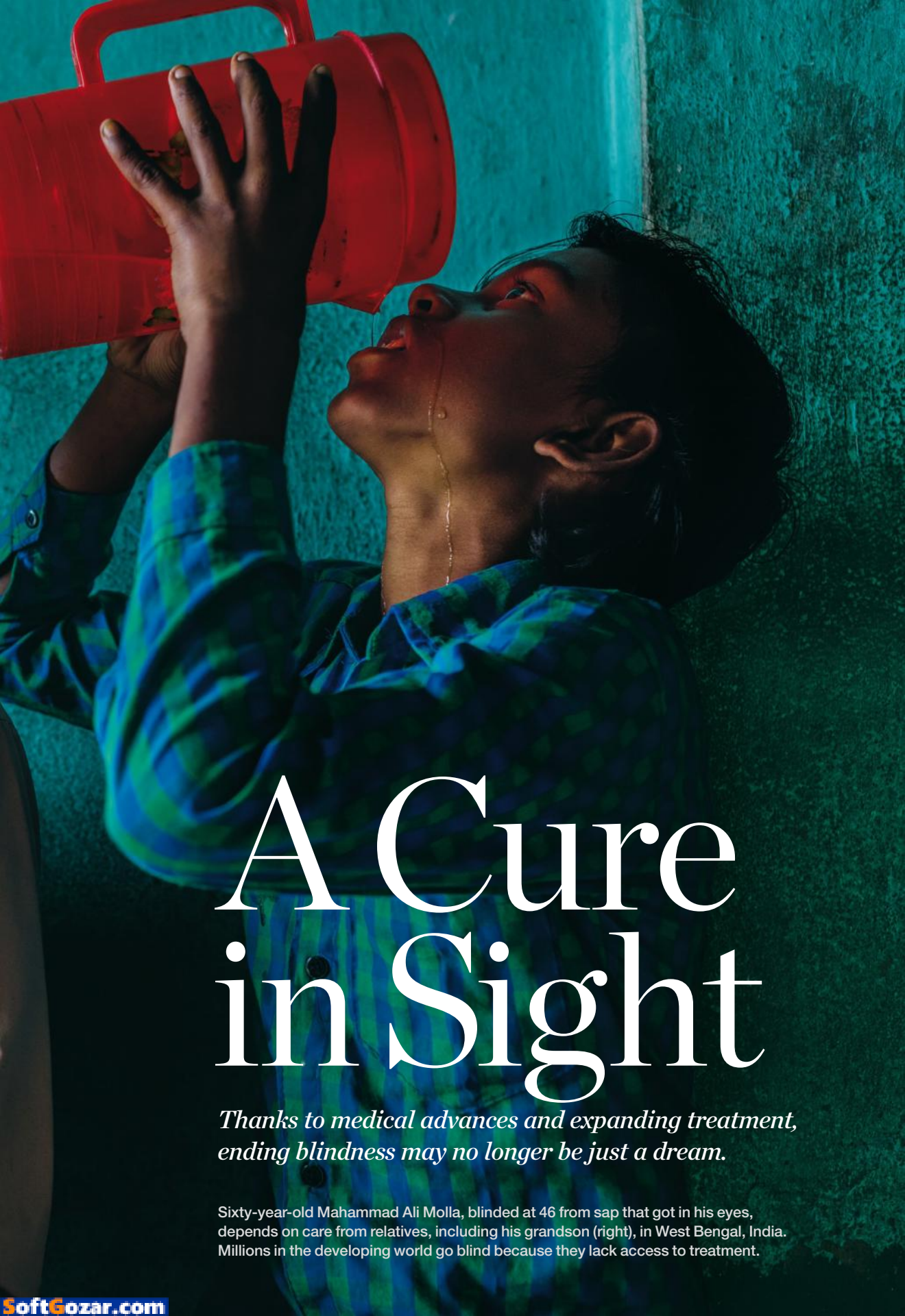
Placing decoy-baited traps in areas not yet affected by EABs could help scientists detect the beetle's spread in time to attempt preventive measures. "If we know sooner where it's showing up," Domingue says, "there might be more we could do about it." *—Patricia Edmonds*

HABITAT/RANGE
Native to China, the emerald ash borer (EAB) was found in Michigan in 2002. It's now in 25 U.S. states and Canada.

OTHER FACTS
EAB larvae kill ash trees by eating the inner bark, which impairs the circulation of water and nutrients.

The decoy is a literal femme fatale: a fake female beetle wired to deliver a lethal shock.

PHOTOS: REBECCA HALE, NGM STAFF. BEETLES: JONATHAN LELITO, USDA. DECOY: AKHLESH LAKHTAKIA AND STEPHEN SWIONTEK



A Cure in Sight

Thanks to medical advances and expanding treatment, ending blindness may no longer be just a dream.

Sixty-year-old Mahammad Ali Molla, blinded at 46 from sap that got in his eyes, depends on care from relatives, including his grandson (right), in West Bengal, India. Millions in the developing world go blind because they lack access to treatment.

Residents of India's Sundarbans region don test-lens frames for eye exams. The eye-care team, led by Asim Sil, travels this remote, river-laced region by boat. The team's goal: to help reduce India's blind population of more than eight million.

By David Dobbs
Photographs by Brent Stirton

From the day Christian Guardino was born, his mother, Elizabeth, knew that something was wrong with his eyes. They would jiggle and jerk and roll up into his head. One eye turned inward. When she fed him, instead of gazing up at her, Christian would stare at the brightest light around—a lamp if they were indoors, the sun if they were out. It was unsettling.

The first eye doctor who saw Christian grimly referred the family to a specialist at New York's Mount Sinai Hospital. The specialist performed an electroretinogram (ERG), a procedure in which a tiny electronic sensor placed on the eye measures the retina's response to bursts of light. A healthy retina will respond by firing an electrical signal down the optic nerve that produces, on the ERG machine's printout, a deep valley followed by a tall peak. Christian's ERG produced no such thing: only squiggles, ill-formed and weak.

Christian, the doctor told Elizabeth, had a retinal disease called Leber congenital amaurosis (LCA). His vision, already bad, would never significantly improve. Nothing could be done. The boy would see little of the world and would always walk, once he learned how, with a cane.

Christian did need a cane, and his mother's guiding hand, when in 2012, at age 12, he first visited a clinic run by the University of Pennsylvania's Scheie Eye Institute. Yet this January he walked through the institute's main building cane free and seemingly fearless. Joking and chatting, the teen led a klatch of Ph.D.'s, M.D.'s, lab techs, and me through the airy lobby. He marveled at the towering atrium, the shiny balconies where people sat having coffee.

"Whoa!" he said as we neared the building's exit—for before us an enormous revolving door turned its huge blades. His mother was some distance behind; he was on his own. Christian neither stopped nor paused. He walked calmly through the opening of the spinning wedge of steel and glass and held his pace as one glass wall closed behind him and another smoothly swung out of his way. He stepped into the sunlight.

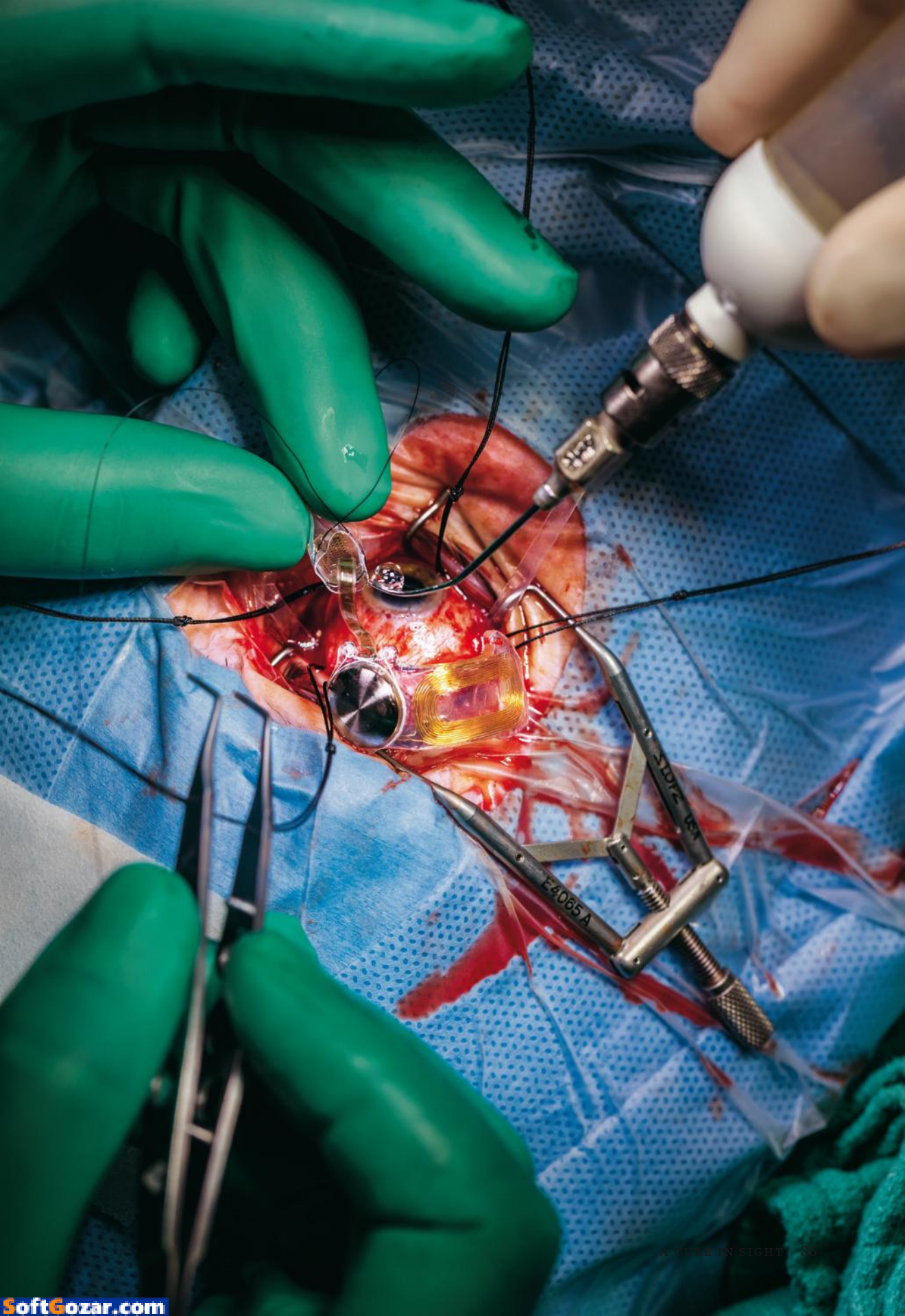
Christian Guardino could see. Everything that had posed an obstacle before—light and dark, steel and glass, the mobile and the immovable—now brought him pleasure. The world had opened before him.

"Can you believe this?" Elizabeth asked a few minutes later. Ahead of her, Christian walked with Jean Bennett, whose lab at Penn produced the gene-laced fluid that gave Christian sight. "It happened so fast," Elizabeth said. Just three days after his first eye was treated, Christian could see her. "I went from wondering if my son would ever know what I looked like to ... well, this," she said, gesturing at him walking unaided. "It's like a miracle."

Christian's miracle was hard-won. It rose from 20 years of unrelenting work by Bennett and her collaborators, who identified the genetic mutation that crippled Christian's retina, then figured out how to sneak a good copy of that gene into his eye. Bennett started trials for the therapy merely hoping "that we could detect some hint of improvement." Nine years later she is astonished that it seems to have worked so well.

Bennett takes care not to aggrandize her work or underplay the obstacles to further

Duke Eye Center surgeons attach an Argus II implant to the eye of Karen Brown, 59, blind from retinal disease. The Argus bypasses faulty retinal cells to send data from a camera down the optic nerve to the brain.



Rhian Lewis, 50, uses a pointer to interpret the images her retinal implant sends to her brain as research optometrist Charles Cottriall, of England's Oxford Eye Hospital, looks on. Patients' decoding of such signals is revealing the great degree to which neural connections can reorganize and regenerate.

progress. Yet the gains so far for Christian and other patients give Bennett guarded hope that this basic gene-replacement approach might work for other forms of blindness. She and others believe that variations on her technique might soon help doctors find and fix similar genetic defects early enough—perhaps even in utero—to reverse or prevent eye damage.

Within roughly the past decade, efforts in two other areas, stem cells and biomedical, or "bionic," implants, have also given at least some sight to people previously sightless. Stem cells—cells in early stages of development, before they differentiate into the building blocks of eyes, brains, arms, and legs—show increasing promise to replace or revive the failing retinal cells that underlie many causes of blindness. And the first generation of bionic retinas—microchips that replace failed retinal cells by collecting or amplifying light—is bringing a low-resolution version of sight to people who for years saw nothing.

These advances encourage talk of something unthinkable just 10 or 20 years ago: ending human blindness, and soon.

Is this even remotely realistic? Some advocates and fund-raisers are suggesting so. Businessman Sanford Greenberg, who lost his sight to glaucoma while in college, has founded End Blindness by 20/20, which offers three million dollars in gold to the person or persons who contribute most to ending blindness by that date. The National Eye Institute, one of the U.S. National Institutes of Health, is aggressively funding eye research with large awards from an Audacious Goals Initiative. The World Health Organization and the International Agency for the Prevention of Blindness's Vision 2020 initiative states a goal of "eliminating avoidable blindness by 2020." Meanwhile many a breathless media story about work like Bennett's seems to assume we'll pull this off.

Anyone following Christian Guardino around town might be tempted to agree. Yet as University of California, Irvine stem cell researcher Henry Klassen put it, "You want to quickly find ways to cure the hardest cases? Good luck. This is not an easy job."

Most researchers agree. Jean Bennett, for instance, knows that the genetic therapy that gave Christian sight (and still needs replication elsewhere) is remarkable because it defies a long history of disappointment, delay, even disaster.

Bennett has seen countless gene-therapy efforts fail. In a recent paper she bluntly lists the daunting obstacles to expanding her therapeutic approach even to other genetic causes of LCA. For example, the gene she inserted into Christian's eye, known as *RPE65,* fits nicely in the modified, benign virus she used to carry it into his cells—but many other genes that lead to LCA are too big to fit. In addition, most other harmful LCA mutations do their damage far earlier in life, or operate in areas of the eye less friendly to gene replacement, and so can't be treated well with the currently available viruses.

Such barriers—and similar ones affecting

In a Riverside, California, movie theater, Terry Byland (center) can see shapes on the screen thanks to the Argus II retinal implant. From 2004 to 2010, Byland—who lost his sight to retinitis pigmentosa—helped scientists develop the implant system, which includes an eyeglass-mounted camera and portable processor.

stem cells and bionic implants—won't fall overnight. Most gains will be hard-won and incremental. Many a miracle cure will prove fleeting.

When assessing the sight-restoring potential of gene therapy, stem cells, and retinal implants, it's fair to view them as a sort of three-legged stool. Right now it's unsteady—but strong enough to support our weight if we move carefully in our quest to end untreatable blindness.

The challenge of ending treatable blindness, though, is another matter altogether.

ROUGHLY ONE IN EVERY 200 people on Earth—39 million of us—can't see. Another 246 million have low vision to degrees that impose moderate or severe limits. Vision loss also affects hundreds of millions more people, often relatives, devoted to aiding those who can't see.

These burdens alone justify the search for new treatments. Yet the eye is also getting increased attention because it provides a safe, accessible spot to test treatments that might also be used elsewhere in the body.

To start with, researchers can look directly into the eye to see what's wrong and whether a treatment is working. Likewise, the eye's owner can see out of it (or not), providing a quick, vital measure of function. The eye also offers feedback such as pupil dilation or electrical activity in the optic nerve. In addition, a researcher

Roughly one in every 200 people on Earth—39 million of us—can't see. Another 246 million have reduced vision.

running an experimental treatment on one eye can usually use the other as a control—and as a backup in case something goes awry.

The eye is also tough. Within the eye's spherical refuge, the immune system restrains itself in a way that makes the eye "immune privileged," tolerant of invaders that might cause troublesome inflammation in other organs. This means you can more safely try a remedy in the eye, such as gene therapy, that might wreak havoc elsewhere.

Neuroscientists love the eye because "it's the only place you see the brain without drilling a hole," as one put it to me. The retina, visible through the pupil, is basically a bowl of neurons tied to the brain by the optic nerve; the eye as a whole is an "outpouching of the brain," formed during fetal development by stretching away from it. Like the eye, the brain enjoys immune privilege, so treatments that work in the eye may readily transfer to the brain or spinal cord.

These advantages take on extra importance because experimental strategies now focused on the eye may drive future treatments for the whole human organism. Gene therapy offers the promise of fixing faulty genes that cause illnesses of all kinds. Stem cells offer the promise of replacing entire tissue structures; bionic implants may replace failing organs. The eye is becoming a window not just to the soul, but also to the possibilities—and limits—of therapeutic approaches on which medicine is betting its future.

IMAGINE A HIGH-CONTRAST, low-resolution, flickering black-and-white picture—a downgrade from the first television images of the 1920s—and you've imagined something close to what Rhian Lewis sees with her bionic eye. Lewis, 50, of Cardiff, Wales, has retinitis pigmentosa, a disease in which photoreceptors die because of a gene deficiency and vision dims from the periphery. Over time the tunnel of sight shrinks to nothing—"like a dimmer switch slowly going dark," Lewis says.

The condition struck Lewis early. While still crawling, she wouldn't leave a room if it meant going into an unlit hall; she once ran headlong into a barbwire fence. She nonetheless got through school and college; tended bar by knowing the precise location of every bottle, glass, and tap pull; and later, even as her right eye completely failed, worked 20 years in a book and stationery shop by memorizing every section and learning to tell pens apart by the feel of their barrels or packages. Since the bookstore closed, she has mostly stayed home raising her twins, who are now in their late teens.

In June 2015 she went to Oxford Eye Hospital, lay on a table, surrendered to anesthesia, and, 10 hours later, awoke with a bionic eye. In what was "without doubt the most complex operation I've ever done," says surgeon Robert MacLaren, the Oxford team slipped between her retina's delicate layers a freckle-size microchip laden with 1,600 tiny photodiodes. MacLaren's clinical trial is exploring whether this chip, known as the Alpha, can replace the dead photoreceptors (the famous rods and cones) in the center of Lewis's retina by translating light into bursts of current that the existing neural network will relay to the brain.

When they turned on the device, Lewis told me last November, "I couldn't believe it. Suddenly—oh, my God—there's something there."

But what? Her brain interpreted the chip's electrical signals not as objects or scenes, but as strongly contrasting flashes and shimmers. "Not an image as such," she says, "just sort of an awareness that there's a difference."

Since then she's been learning to interpret these bursts of light as sight. This includes formal training at MacLaren's lab that "is like triple maths," she says, laughing. "I hate it." But it's paying off. She has learned to recognize

Eyes Under Threat

Multiple diseases can afflict the same eye. Three common and treatable diseases occur in the front of the eye. There currently is no cure for age-related macular degeneration, which occurs in the back of the eye near the retina.

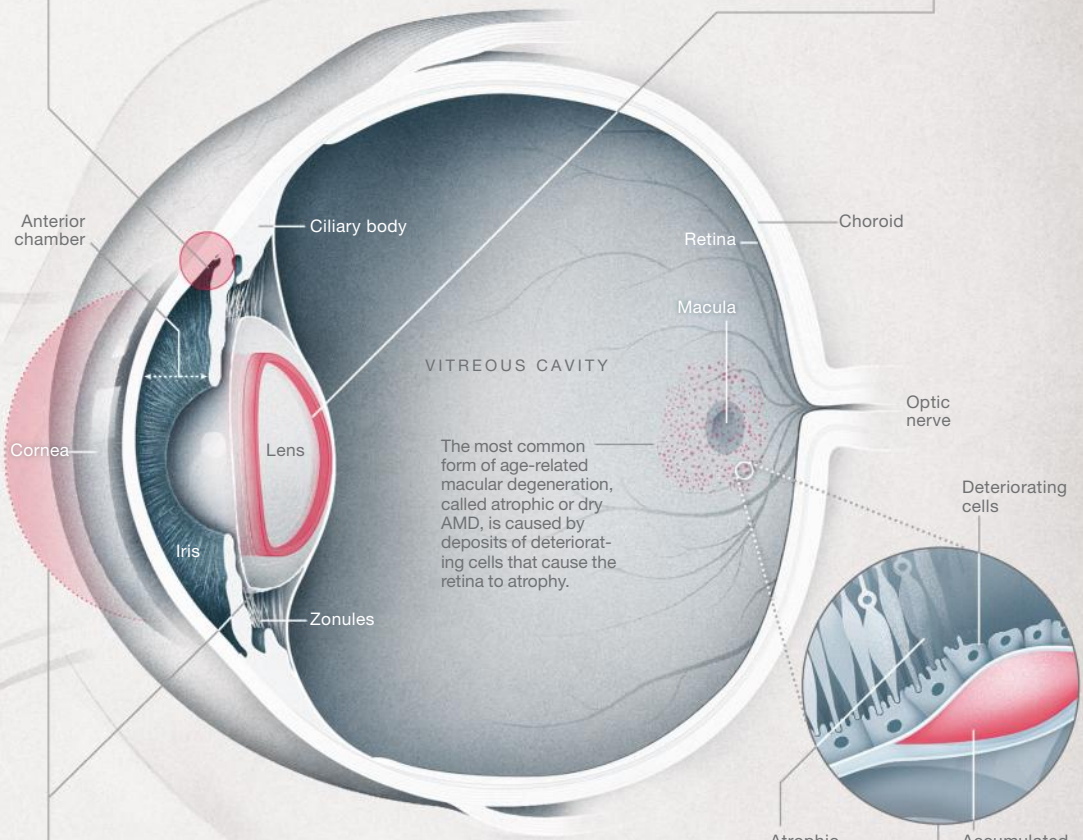
Normal vision

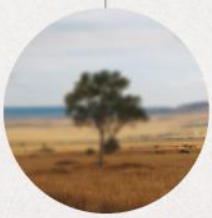
GLAUCOMA

Glaucoma is caused by fluid buildup in the eye, resulting in pressure that can damage the optic nerve. If it's caught early enough, surgery and medication may slow its advance.

CATARACTS

The world's leading cause of blindness, cataracts are caused when proteins in the lens clump together, blocking and distorting light to the retina. Surgery can restore sight.





REFRACTIVE ERRORS

Nearsightedness, farsightedness, and astigmatism are types of refractive errors, flaws that keep the eye from focusing light sharply on the retina. Absent lenses or surgery, they're the most common causes of impairment.

AGE-RELATED MACULAR DEGENERATION

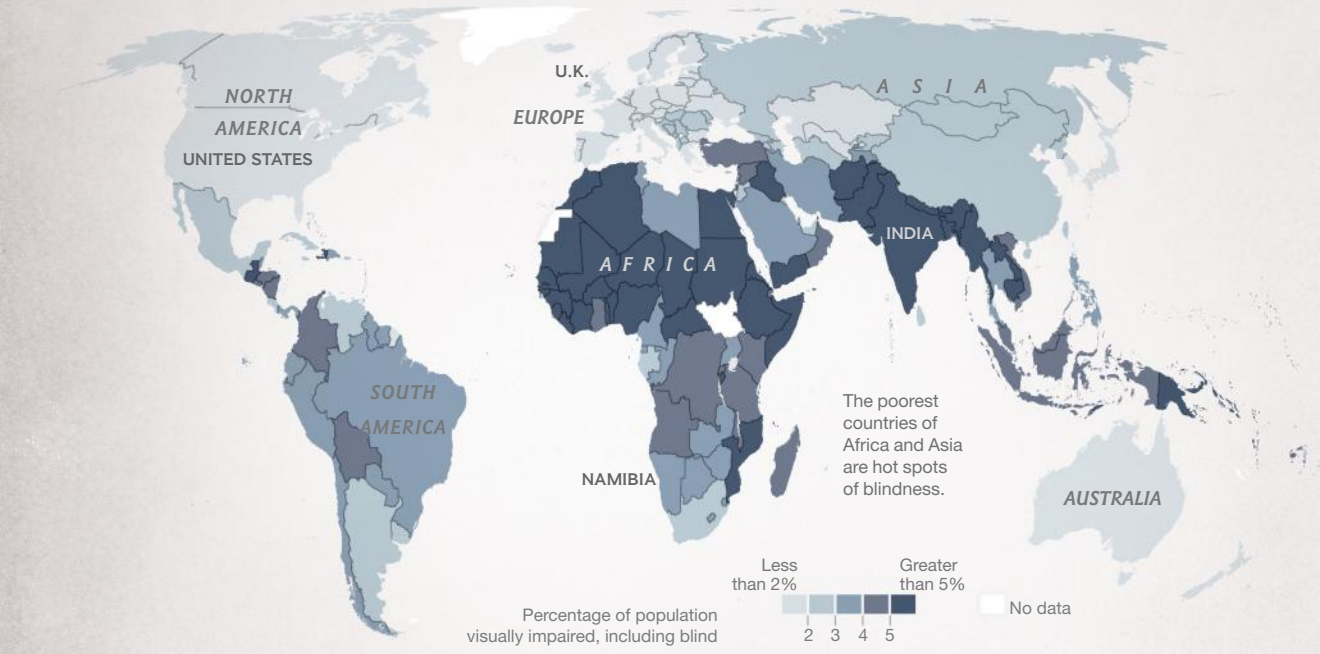
Caused by an alteration of the underlying layers of the retina's macular area, AMD affects photoreceptors that process images. There is no cure.

MANUEL CANALES, NGM STAFF; PATRICIA HEALY. PHOTO: DESIGN PICS INC, NATIONAL GEOGRAPHIC CREATIVE; MANIPULATIONS BY NGM STAFF
SOURCES: VISION LOSS EXPERT GROUP; SILVIO PAOLO MARIOTTI, WORLD HEALTH ORGANIZATION; UNITED NATIONS DEVELOPMENT PROGRAMME

Hand in hand, blind students at the Vivekananda Mission Asram school in West Bengal, India, walk to gym class. A mix of standard and vocational studies helps them avoid the fate of many blind people in India: a life begging on the streets.

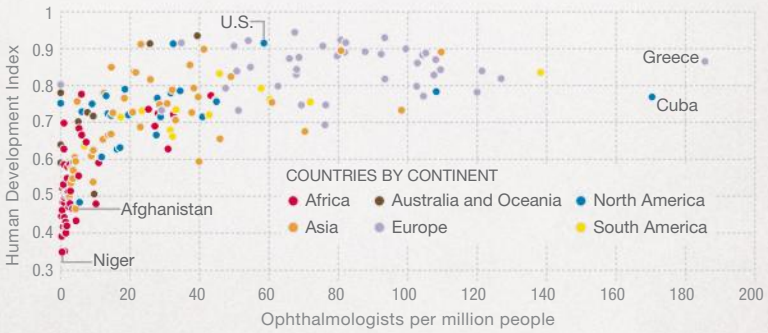
Blindness: A Global View

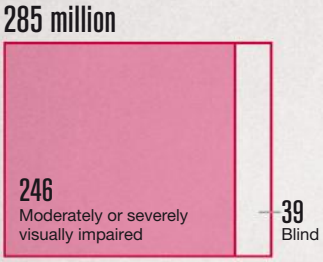
Eye disease is predominantly a problem of the poor, with a wide gulf between developed and developing countries when it comes to care. More than just an individual problem, visual impairment, including blindness, is a societal one that can broadly affect economic productivity and access to education.



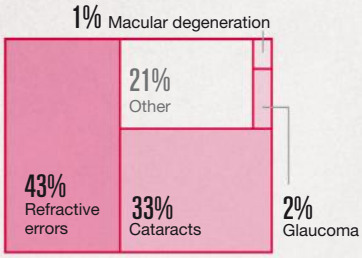
THE ACCESS GAP

The gap in care is evident when comparing the Human Development Index—an amalgamation of data on life expectancy, education, and gross national income per capita—with the number of ophthalmologists per million people in each country. Afghanistan has 140 ophthalmologists for its nearly 33 million people. Niger's 18 million people are served by only seven.





Worldwide, some 285 million people suffer from vision loss that interferes with daily activities; 39 million of them are totally blind.



Impairment is caused by eye disease and conditions like structural abnormalities and aging. Some 80 percent of cases are preventable or treatable.

Most of the visually impaired live in developing nations. Eye disease increases as populations age; 82 percent of the blind are 50 or over.

MANUEL CANALES AND MATTHEW W. CHWASTYK, NGM STAFF; PATRICIA HEALY

SOURCES: VISION LOSS EXPERT GROUP; SILVIO PAOLO MARIOTTI, WORLD HEALTH ORGANIZATION; UNITED NATIONS DEVELOPMENT PROGRAMME

Gerd Gamanab, 67, sought treatment too late: Fifty years of farm labor in the Namibian sun and dust had destroyed his corneas. Like much of the world's blindness, his likely could have been prevented by regular care.

If experimental treatments restore only partial vision, that's still a miracle for blind patients: light replacing dark.

one kind of patterned flashing as a person, another as a tree. She's getting better at distinguishing contrast in the dreaded task she calls the "50 shades of gray test" (it's really seven). She can read a big high-contrast clockface at arm's length. The week before I visited, she took a walk around Oxford with MacLaren's team and found that she could tell, for the first time in years, a building's windows from its walls.

Yet the gains are modest, and Lewis still does almost everything—dresses, bathes, moves around the house, gets the kids out the door, feeds Chopsy the dog, gets the mail—by feel and the fading sight of her good eye. Her bionic eye is taxing to use; she usually leaves it turned off.

Such limits are to be expected with these early prototypes, says Eberhart Zrenner, the German eye surgeon who began developing the Alpha more than 20 years ago. "The idea was never to get full vision," he says, "but to improve a patient's ability to recognize objects and move around." It's doing that. Lewis again sees the lights of her Christmas tree. Zrenner describes a patient who can again read his own name; another who can again see the kitchen sink; another who beheld for the first time his fiancée's face "and saw that it was laughing." Nearly half the 29 patients who received a similar, previous version of the implant, he says, find it truly useful.

Lewis also has found hers useful, and for this she is grateful. Even if it gets no better, she says, the chip's often indecipherable image constitutes a miracle of sorts—light replacing dark. She expects that as her left eye inevitably fails altogether, this bionic eye, or perhaps a successor, will allow her to still do all the things she does now.

She's also glad to be part of this wild experiment. "My motivation is for my kids," she says, both of whom see fine now but stand at increased risk of developing retinitis pigmentosa, which is inheritable. "Anything I can do now can help people down the line."

MacLaren says the implant project is teaching valuable lessons. For starters, its demonstration that photodiodes can substitute for natural photoreceptors is a huge stride: In the exacting machine that is the eye, we've fashioned a cog that fits, even if imperfectly. The devices also show that patients can learn to interpret new presentations of visual stimuli. In addition, MacLaren says, the implants show that "there's still visual potential once the photoreceptors are gone, because the other nerves are still intact. This is something I never thought could be shown."

MacLaren says that these lessons learned are already spurring advances in the other two cutting-edge areas: gene therapy and stem cells.

IN CALIFORNIA an eyeball dream team is running a stem cell trial that evolved almost directly from an implant. One of the leaders is Mark Humayun, a courteous, efficient, impeccably besuited man. Like MacLaren, Humayun seems to be running projects in every possible therapy for every part of the eye.

His first big project was co-inventing the Argus II, which in the early 2010s became the first retinal implant to go to market. Like Zrenner's Alpha, the Argus uses an electrode array embedded in the back of the retina. But rather than collect light, this grid of just 60 electrodes pulls signals from a tiny eyeglass-mounted camera that relays them through a processing unit carried on a belt or in a bag. All this gear imposes a stiffer set of limitations and demands than the Alpha does. In addition, the Argus's external camera means that, unlike the Alpha, it cannot exploit the eyeball's constant small movements, known as microsaccades, that play a mysterious but vital role in vision.

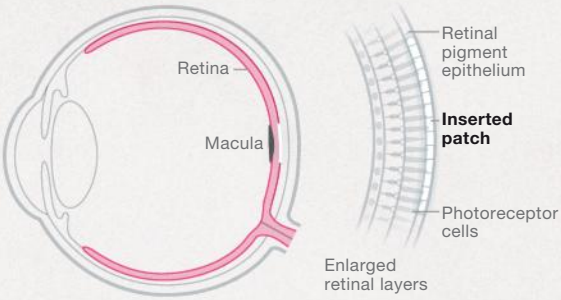
Fitting that implant into people's retinas, however, helped inspire the stem cell device Humayun is now developing. He and his fellow

Revitalizing the Retina

Vision may account for nearly half the activity in the brain. Failures in the retinal layers, which sense light and transmit signals, can lead to blindness that's at present untreatable. This prognosis may change, however, if retinal treatments currently being tested (described below) prove effective.

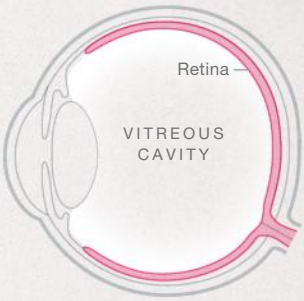
CELL PATCH

A patch coated with stem cell–derived epithelial cells is set behind deteriorating photoreceptors, replacing dead cells to slow or reverse age-related macular degeneration.



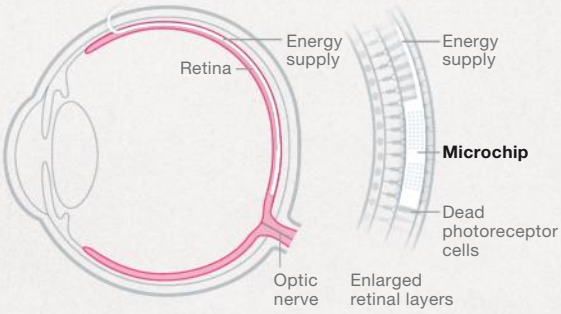
CELL INJECTION

Retinal progenitor cells are injected into the eye's vitreous cavity, where they release factors to slow the progression of hereditary degeneration and blindness.



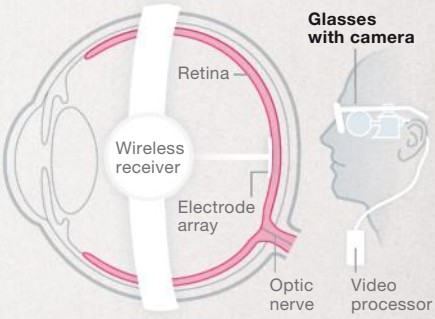
SUBRETINAL IMPLANT

A microchip that converts light into currents is implanted amid dead photoreceptors in the retina's macular region, allowing the optic nerve to pick up electronic signals.



RETINAL IMPLANT

The Argus implant, now approved, bypasses damaged photoreceptors with the help of glasses, an external camera, a video processor, and an electrode array.



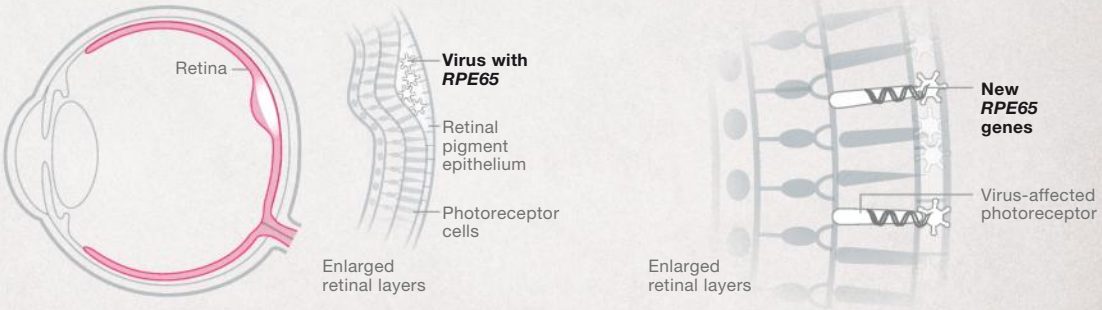
GENE THERAPY

Step 1

A solution carrying a benign virus laden with the *RPE65* gene—which provides instructions for a protein essential to vision—is injected near damaged photoreceptor cells.

Step 2

The virus delivers healthy *RPE65* genes, and the protein products of these genes allow the photoreceptors to translate light into sight.



MANUEL CANALES, NGM STAFF; PATRICIA HEALY. ART: EMILY M. ENG

SOURCES: MARK S. HUMAYUN, UNIVERSITY OF SOUTHERN CALIFORNIA; HENRY KLASSEN, UNIVERSITY OF CALIFORNIA, IRVINE; ROBERT MACLAREN, UNIVERSITY OF OXFORD; JEAN BENNETT, UNIVERSITY OF PENNSYLVANIA

principal investigator, University of California, Santa Barbara stem cell biologist Dennis Clegg, call it simply a patch. That patch's chassis, made of the same stuff used to coat wiring for pacemakers and neural implants, is a thin wafer about the shape of this *d* but twice as large. Onto this speck Clegg distributes 120,000 cells derived from embryonic stem cells.

Humayun and Clegg propose to use this patch to treat a condition called age-related macular degeneration (AMD). Going blind from AMD is the reverse of what happens in retinitis pigmentosa: A blurry spot fogs the middle of one's vision, then slowly darkens and spreads until you're functionally blind. It's the most common untreatable cause of vision loss, accounting for five percent of all blindness.

AMD rises from cell decay in the eye's rearmost layer, the retinal pigment epithelium. The RPE gives key support for the photoreceptor layer lying just in front of it. Humayun and Clegg hope the patch's stem cell–derived RPE cells will replace these failed RPE cells.

The cells can't just be injected. In animal studies that Humayun and Clegg conducted, the cells integrated most effectively with the photoreceptor layer's complicated architecture if they were on a well-placed patch. Positioning the patch in just the right spot will be tricky business—precisely the kind of challenge that surgeons like Humayun crave.

The trial just started and should end by 2018. If it works—a big if, as with all these projects—it could be useful in treating AMD and other forms of blindness. Humayun and Clegg also might learn things about how to fuse such cells into biological structures in other organs, paving the way for other cell-patch implants.

The untapped potential of stem cells has drawn others pursuing blindness cures, including Henry Klassen of the University of California, Irvine. Klassen has spent 30 years studying how to coax progenitor cells—former stem cells that have begun to move toward being specific cell types—into replacing or rehabilitating failed retinal cells. Having successfully used retinal progenitor cells to improve vision in mice, rats, cats, dogs, and pigs, he's testing a similar treatment in people with advanced retinitis pigmentosa.

In a procedure that Klassen calls "Zen-like" in its simplicity, a surgeon uses a needle to quickly inject into the eye a half million to three million progenitor cells meant to play multiple roles in rescuing the failed retina. Some retinitis pigmentosa patients who've had the procedure are seeing significantly more light and shape. Kristin Macdonald, a 50-something California resident who was nearly totally blind from retinitis pigmentosa, received the treatment in one eye in June 2015. Now she can see more of her furniture, a van across a street, and, at a swimming pool, "a pale hue"—the reflected turquoise of the water that once was just black and white. Klassen hopes such gains will prove his premise that if you send the right cells to the right spots, they'll know what to do.

These Herero women, whose traditional hats evoke the horns of the cattle vital to their culture, await bandage removal at a "cataract camp" last year in Omaruru, Namibia. The surgery takes about 20 minutes. Lack of access to it in many areas makes cataracts the world's leading cause of blindness—half of all cases.

NAMIBIAN EYE SURGEON Helena Ndume likes to recount what patients do when they're given sight after years of blindness. She tells of a man who, having once almost walked into an elephant, thanked Ndume after treatment because he could now see wandering animals; of a woman whom, after treatment, Ndume found utterly absorbed in removing every last bone from the fish she was eating; of a woman who, at 46, could finally see her young son.

Ndume has collected many such stories during the past 20 years as she has pursued her own experiment in ending blindness. The experiment's findings are in one sense unambiguous: In two decades some 30,000 patients have received treatment, and some 30,000 regained their sight. Clearly the cure works. Yet the treatment—a simple, thoroughly proven cataract operation—is not what Ndume's experiment is testing. She and others doing similar work are testing whether humanity, once possessing a cure, will bother to deliver it to all who need it.

Cataracts, a disease of poverty, cause half of all blindness on Earth. In the developed world, people with cataracts routinely get treated as soon as they have trouble seeing the TV. In the developing world, people with cataracts routinely go blind. The treatment everywhere is simple: Get clinician and patient in the same room, prep the latter, spend 15 to 20 minutes

Antonia Nuses, 85, sees her grandson, Brendon, after surgery at the cataract camp in Omaruru. The procedure gives many patients sight for the first time in decades.

replacing the cloudy natural lens with a clear artificial lens, do a post-op checkup. In developing countries, treatment usually costs $15 to $100. Yet it reaches few who need it.

Working with Namibia and other African governments and the nonprofit SEE International, Ndume is trying to fix this by running "cataract camps." At these gatherings in underserved areas, Ndume and other surgeons operate on up to 500 people a week. The United Nations last year recognized Ndume's "service to humanity" with its inaugural Nelson Rolihlahla Mandela Prize.

It's a fitting honor for someone who 41 years ago, as a girl of 15, left a different kind of darkness when she fled the apartheid that the South African government had imposed on Namibia. With three friends she made her way to a camp in Angola run by the Namibian resistance movement SWAPO; survived a machine gun attack soon after she arrived; braved hippo-infested rivers and hostile helicopter patrols to find safety in Zambia; told SWAPO she'd like to go to fashion school but was sent instead to medical school in Leipzig, Germany; and there married a countryman who soon after was killed in Angola. She bore their baby alone, finished her ophthalmology training, rejoiced when Namibia won its independence in 1990, and returned for good in 1996 with her child, her education, and a determination to help those who could not see.

MY FAVORITE NDUME STORY is about a woman she treated in the first year of the camps, at a clinic in Rundu, on Namibia's northern border. More than 200 patients had signed up. Only 82 came, because so many were scared of having their eyes cut open. This woman was one of the brave ones.

When Ndume held the camp at Rundu the next year, the same woman came in, exultant. She wanted to show the doctor her farm, which she'd been able to vastly expand: "I make so many crops now!" she told Ndume. But first she pulled Ndume by the hand to the clinic door.

"I brought some of my friends," the woman said. Outside were scores of people eager for the surgery after seeing what it did for others. "They talk of it like a miracle," the woman said.

Ndume treated hundreds that week. As her colleague Sven Obholzer put it, patients "walked in with their hands on the shoulders of the people in front of them and walked out on their own."

The UN honor was a great boost. Yet despite Ndume's work and others', some 20 million people worldwide remain blind from cataracts. Treat them all, and you've cured half of all blindness. Doing that, however, will require not just camps but also permanent infrastructure to make treatment routine. This is one reason former NBA star Dikembe Mutombo built a hospital in his

Blindness is prevalent on the remote islands of India's Sundarbans region. Determined to help, Asim Sil collects patients by boat and takes them to a hospital for surgery. Watch a video of his story at *ngm.com/Sep2016.*

Anita (left) and Sonja Singh were born with cataracts that their rural Indian family could not afford to treat. When the sisters were five and 12, donors paid for surgery. Eye-brain pathways are more malleable at younger ages, so Anita gained more vision than Sonja—but both now savor new sights, such as these towering reeds.

hometown of Kinshasa, Democratic Republic of the Congo. When Ndume visited, the hospital's value, and inadequacy, were made clear. Scheduled for five days, she stayed for seven, did more than a hundred operations, and left a waiting list of hundreds. "It is like this everywhere," she told me. For every patient she treats, dozens go unseen and unseeing: "Always more."

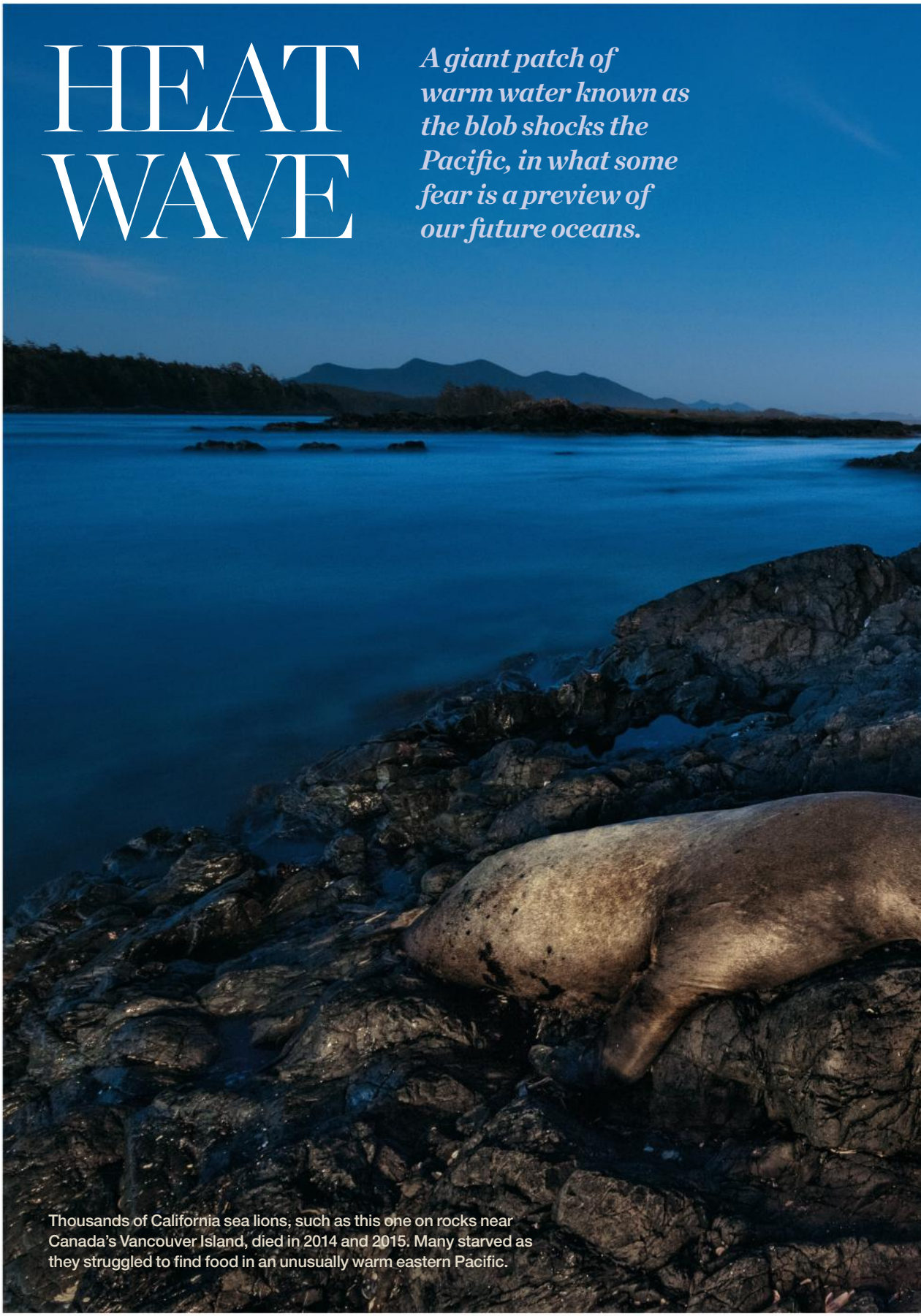
When I mentioned to Ndume the causes of blindness this story would address, this was her gentle response: "These other things, macular degeneration, retinitis pigmentosa, they are nothing next to cataracts." The most generous of souls, Ndume did not mean those conditions are inconsequential or that no one should seek cures for them. She meant that in the quest to end blindness, medicine's biggest challenge is not just finding cures but also delivering them.

That day Ndume performed nine cataract operations before lunch. Observing one, I saw for the first time a knife slice into an eyeball. The sight disturbed me—in part, I realized, because nothing symbolizes awareness as much as an eye wide open. Here was an eye absurdly wide open, thanks to the ophthalmic speculum holding back its lids—yet utterly oblivious to the steel carving a curve in its cornea.

Recognizing that made it easier to watch. I knew that the anesthetic would soon fade and that once it did, the eye would see clearly. □

HEAT WAVE

A giant patch of warm water known as the blob shocks the Pacific, in what some fear is a preview of our future oceans.



Thousands of California sea lions, such as this one on rocks near Canada's Vancouver Island, died in 2014 and 2015. Many starved as they struggled to find food in an unusually warm eastern Pacific.

Near Petersburg, Alaska, a worker examines the dorsal fin of an orca. This animal likely died of natural causes, but exposure to toxic algae created by unusually warm water is a suspected cause in the deaths of many humpback and fin whales.

Jellyfish-like animals known as “by-the-wind sailors” blanket an Oregon beach near an old shipwreck. Some of the same unusual wind patterns and currents that recently warmed the Pacific pushed these floating creatures by the millions onto beaches from Southern California to British Columbia.

TIFFANY BOOTHE, SEASIDE AQUARIUM

By Craig Welch
Photographs by Paul Nicklen

THE FIRST FIN WHALE appeared in Marmot Bay, where the sea curls a crooked finger around Alaska's Kodiak Island. A biologist spied the calf drifting on its side, as if at play. Seawater flushed in and out of its open jaws. Spray washed over its slack pink tongue. Death, even the gruesome kind, is usually too familiar to spark alarm in the wild north. But late the next morning, the start of Memorial Day weekend, passengers aboard the ferry *Kennicott* spotted another whale bobbing nearby. Her blubber was thick. She looked healthy. But she was dead too.

Kathi Lefebvre is talking about the whales as we crunch across a windy, rocky beach, 200 miles north of Kodiak. In a typical year eight whales are found dead in the western Gulf of Alaska. But in 2015 at least a dozen popped up in June alone, their bodies so buoyant that gulls used them as fishing platforms. All summer the Pacific Ocean heaved rotting remains into rocky coves along the more than 1,000-mile stretch from Anchorage to the Aleutian Islands. Whole families of brown bears feasted on their carcasses.

Lefebvre, a research scientist at NOAA's Northwest Fisheries Science Center in Seattle, Washington, had examined eye fluid from one of the carcasses in a failed attempt to winnow the cause of death. Now the two of us are on

Humpback whales feast on fish in Monterey Bay, California. Anchovies were scarce in many areas in 2015, but so many congregated in the bay that Jim Harvey, director of Moss Landing Marine Labs, watched from his window as 50 or 60 whales dined on them at once. "That's not normal," he says.

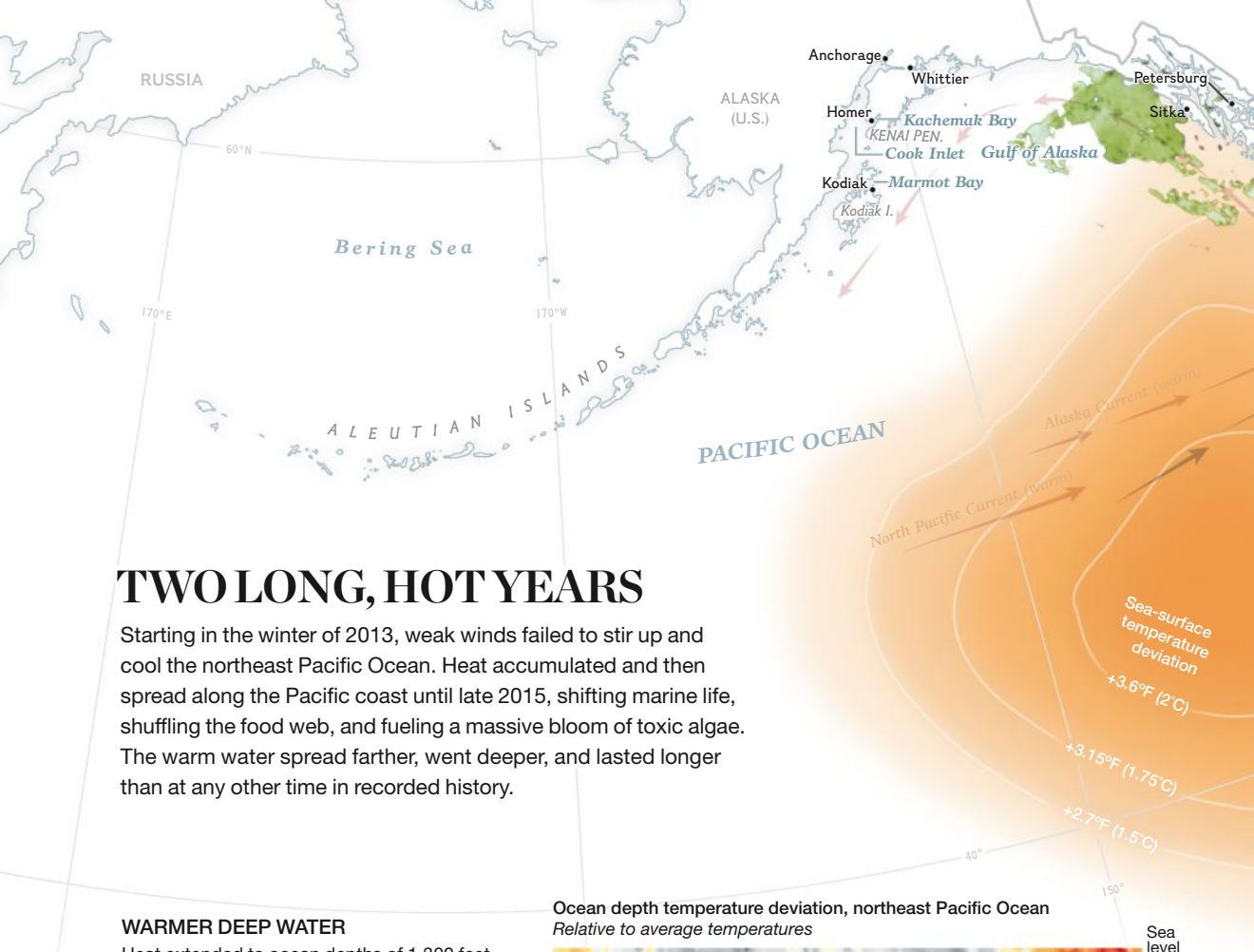
Kachemak Bay in Homer, Alaska, inching toward a wheezing, dying sea otter sprawled out on the shore. Otter deaths are skyrocketing on the shoreline beneath the snowcapped Kenai Mountains, so Lefebvre is here to see whether the fates of these otters and whales are somehow intertwined.

In the past few years death had become a bigger part of life in the ocean off North America's West Coast. Millions of sea stars melted away in tide pools from Santa Barbara, California, to Sitka, Alaska, their bodies dissolving, their arms breaking free and wandering off. Hundreds of thousands of ocean-feeding seabirds tumbled dead onto beaches. Twenty times more sea lions than average starved in California. I watched scientists lift sea otter carcasses onto orange sleds as they perished in Homer—79 turned up dead there in one month. By year's end, whale deaths in the western Gulf of Alaska would hit a staggering 45. Mass fatalities can be as elemental in nature as wildfire in a lodgepole pine forest, whipping through quickly, killing off the weak and clearing the way for rebirth. But these mysterious casualties all shared one thing: They overlapped with a period when West Coast ocean waters were blowing past modern temperature records.

As hotter oceans destroy coral reefs in the tropics and melting ice alters life in the Arctic, it's been easy to overlook how much warm water can reshape temperate seas. No more. Between 2013 and earlier this year, some West Coast waters grew so astonishingly hot that the marine world experienced unprecedented upheaval. Animals showed up in places they'd never been. A toxic bloom of algae, the biggest of its kind on record, shut down California's crab industry for months. Key portions of the food web crashed. It's not clear if greenhouse gas emissions exacerbated this ocean heat wave or if the event simply represented an outer edge of natural weather and climate patterns. But the phenomenon left daunting questions: Was this a quirk, an unlikely confluence of extremes that conspired to make life harsh for some sea creatures? Or was it, as one scientist says, a "dress rehearsal"—a preview, perhaps, of what hotter seas may one day bring as climate change unleashes its fever in the Pacific?

While Lefebvre and I are pondering our next move, a radio call comes in. Another dead otter has surfaced on Homer Spit, five miles away. We retrace our steps to a dusty parking lot, pile into a pickup, and head off.

BEGINNING IN LATE 2013, a bewildering patch of warm water formed in the Gulf of Alaska. A stubborn atmospheric high-pressure system, nicknamed the "Ridiculously Resilient Ridge," was keeping storms at bay. Just as blowing across hot coffee frees heat, winds usually churn and cool the sea's surface. Instead, heat within this shifting mass, which University of

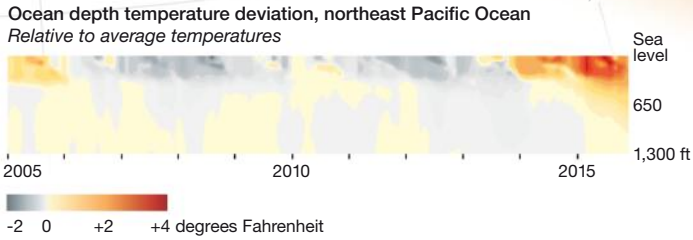


TWO LONG, HOT YEARS

Starting in the winter of 2013, weak winds failed to stir up and cool the northeast Pacific Ocean. Heat accumulated and then spread along the Pacific coast until late 2015, shifting marine life, shuffling the food web, and fueling a massive bloom of toxic algae. The warm water spread farther, went deeper, and lasted longer than at any other time in recorded history.

WARMER DEEP WATER

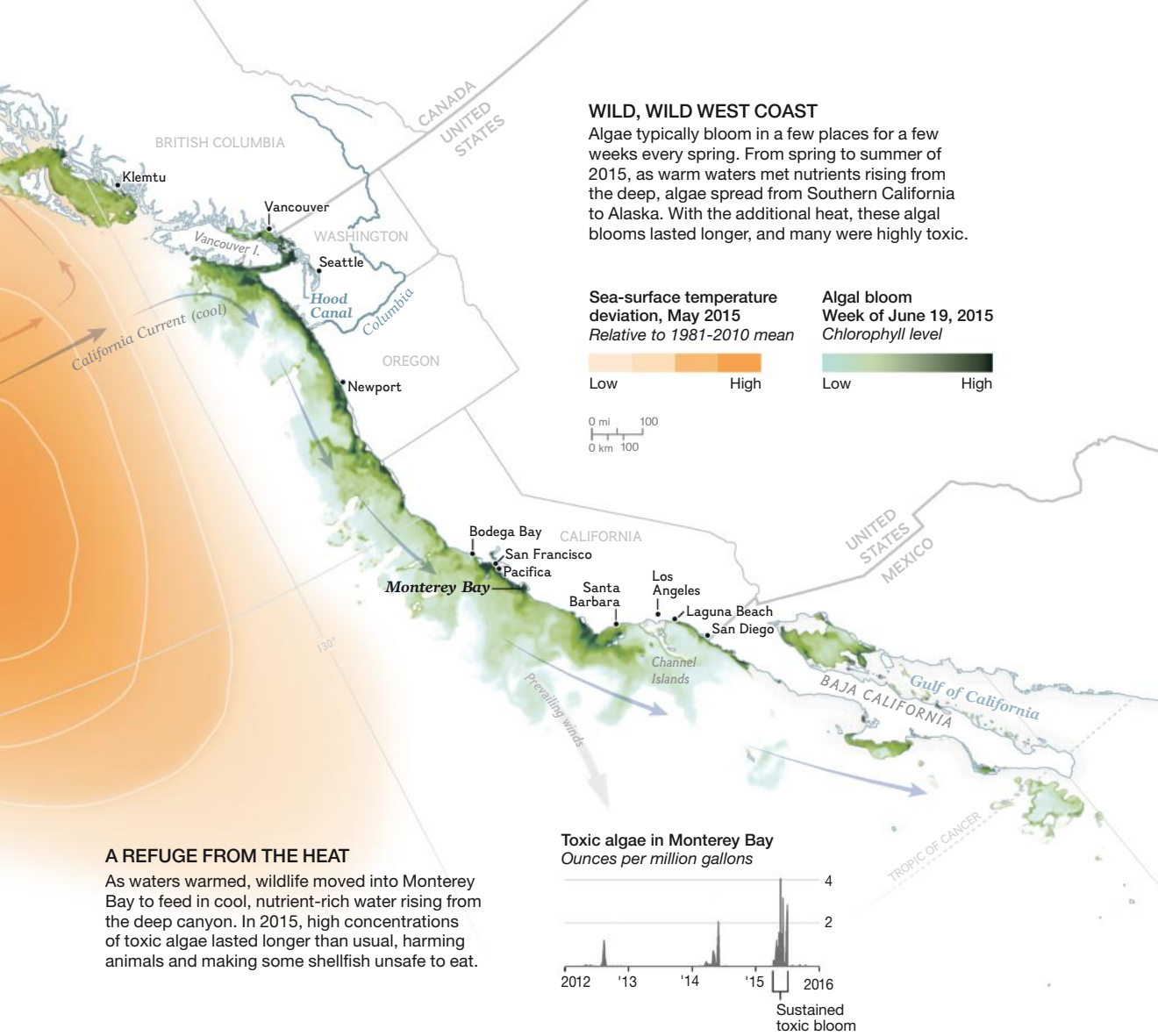
Heat extended to ocean depths of 1,300 feet in some places. A temperature rise of even a single degree can disrupt an ecosystem. Heat remains deep in the ocean, even though the surface cooled in late 2015.



Washington climatologist Nick Bond dubbed "the blob," built up and morphed into a wider patch along North America's West Coast, where it met warm-water masses creeping north. Sea temperatures in some places rose seven degrees Fahrenheit higher than average. Some patches of ocean were hotter than ever recorded. At its peak the warm water covered about 3.5 million square miles from Mexico to Alaska, an area larger than the contiguous United States.

Did planet-warming carbon dioxide from fossil fuels contribute to this event? No one knows for sure. One controversial notion suggests that the rapid retreat of Arctic sea ice is making the polar jet stream wavier, allowing weather systems to persist longer. A more accepted theory pegs this heat to normal atmospheric fluctuations in the jet stream triggered by warmth in the tropics. But even researchers subscribing to that theory don't necessarily rule out a secondary role for climate change. "Is long-term warming somehow the puppeteer controlling things in the background?" asks Nate Mantua, at NOAA's Southwest Fisheries Science Center in Santa Cruz, California. "I haven't seen proof, but it's clearly a prime suspect."

Unscrambling this weird behavior is difficult because the world's largest ocean is so confounding to begin with. Overlapping patterns that can last for decades already drive temperature swings. Every few years or decades the eastern Pacific flips from a food-rich, cold-water place to something warmer, a cycle called the



WILD, WILD WEST COAST

Algae typically bloom in a few places for a few weeks every spring. From spring to summer of 2015, as warm waters met nutrients rising from the deep, algae spread from Southern California to Alaska. With the additional heat, these algal blooms lasted longer, and many were highly toxic.

Sea-surface temperature deviation, May 2015
Relative to 1981-2010 mean
Low — High

Algal bloom
Week of June 19, 2015
Chlorophyll level
Low — High

A REFUGE FROM THE HEAT

As waters warmed, wildlife moved into Monterey Bay to feed in cool, nutrient-rich water rising from the deep canyon. In 2015, high concentrations of toxic algae lasted longer than usual, harming animals and making some shellfish unsafe to eat.

Toxic algae in Monterey Bay
Ounces per million gallons

Pacific Decadal Oscillation. El Niño, the periodic tropical warming, boosts temperatures in North America. An ocean freeway, the California Current, ushers cool water south from Canada to Baja California. Along the way, winds push warm surface waters offshore, causing upwelling, which draws much cooler, nutrient-rich seas from below.

All these volatile shifts can redistribute marine life. It just doesn't usually wind up like this. "When all is said and done, I think people will see this as the most economically and ecologically consequential event in our historical record," Mantua says of the recent warming.

Seeking to understand the magnitude of this episode, I am miles off the Oregon coast, weeks before visiting Alaska. The *Elakha,* a 54-foot research boat, is cutting through rolling chop beneath a milky sky. Bill Peterson, in jeans and a weathered craft-beer T-shirt, kneels on deck, face pressed into a red cooler. It holds the contents of a net his colleagues just hauled up from the sloshing depths. The NOAA oceanographer is here to show me how thoroughly the eastern Pacific has changed. "Oh my, that's ugly," he says. Over his shoulder, I glance down at the bottom of the ocean food web. I see only slop the color of motor oil. That's his point.

Every two weeks for 20 years, Peterson's team has come here to gather the minuscule plants and animals that form the foundation of one of the planet's most productive marine systems. The prize course in this buffet is supposed to be inch-long krill. Shaped like

LAUREN E. JAMES, NGM STAFF. SOURCES: NICK BOND, UNIVERSITY OF WASHINGTON; RAPHAEL KUDELA, UNIVERSITY OF CALIFORNIA, SANTA CRUZ

The Pacific Marine Mammal Center in Laguna Beach, California, took in hundreds of emaciated sea lion pups in 2015. As anchovies and sardines dwindled, thousands of sea lions had to rely on less nutritious food or search harder for prey driven away by warm waters, leading many to starve.

JAE C. HONG, AP PHOTO

Market squid, which typically spawn off California, swim by their eggs near Klemtu, British Columbia. In 2015 squid eggs in the eastern Pacific were found as far north as Alaska.

A mola, or ocean sunfish, chases a by-the-wind sailor. With temperatures in some places reaching seven degrees Fahrenheit above average, many subtropical marine animals, such as this sunfish, came close to Pacific shores.

shrimps, they are gobbled by auklets, cohos, basking sharks, and whales. Anchovies and sardines eat them and then get wolfed by bigger fish and sea lions. At this time of year, krill should be abundant, but Peterson's haul reveals mostly soupy algae and small jellyfish, which provide little sustenance. His team hasn't seen krill in months. "It's been like this nonstop," he says.

Higher ocean temperatures have thrown this system out of whack. Not long after the warmth arrived, shelled octopuses more common in the South Pacific appeared off Southern California. Tropical sunfish and blue sharks were caught in the North Pacific. Market squid, common off California, laid eggs in southeast Alaska. A few venomous yellow-bellied sea snakes from Central America slithered across beaches near Los Angeles. Peterson's team caught tropical or subtropical zooplankton he'd never seen: rainbow-hued, beetle-shaped copepods; minuscule iridescent creatures from Hawaii; tiny crustaceans with cobalt egg sacs. He cataloged nearly 20 new species that belonged far away.

Compared with krill, these zooplankton were limp-lettuce side salads: smaller and less nutritious. As this low-cal diet coursed through the food web, larval walleye pollock, common in the Gulf of Alaska, reached their lowest numbers in three decades. Halibut caught in Cook Inlet had mushy flesh—a syndrome associated with poor nutrition. Coho salmon returned to West Coast streams as malnourished runts. These changes coincided with other shifts. Sardines, already in decline, decreased so much that an industry made famous by John Steinbeck's novel *Cannery Row* shut down for the first time since rebounding from its collapse in the 1950s. Sardine and anchovy populations are cyclical; their precipitous drop likely had little to do with warm water. But the impact was more pronounced because the unusual heat redistributed the remaining fish.

Dead pelagic red crabs, also known as tuna crabs, crowd the sea surface near Monterey Bay. These crabs appeared in unusually high numbers in 2015, frequently washing ashore and coating California coastlines.

Anchovies, already dwindling, seemed to vanish almost everywhere except Monterey Bay, where they gathered in great numbers, creating a weird feeding frenzy. At one point, 50 or more whales dined in the bay at once. In the Pacific Northwest humpbacks cruised into the Columbia River in search of food. Birds suffered too. At least a hundred thousand blue-footed Cassin's auklets, small gray-feathered island nesters that eat krill, starved to death. It was one of the biggest die-offs of birds in U.S. history. Then, months later, hundreds of thousands of common murres died too.

Perhaps most visible were the skinny, sick sea lion pups that surfed ashore in California, loose fur drooping over bones, looking like children wrapped in parents' clothes. They collapsed under porches and parked trucks. One curled into a chair on a hotel patio. Another slipped into a booth at a seaside restaurant. Without sardines or anchovies, their mothers ate junk-food diets of squid, hake, and rockfish, and weaned pups early. More than 3,000 were stranded in five months.

Chugging back to his office in Newport, Oregon, Peterson is baffled. After a lifetime studying the sea, he finds this warm ocean unfamiliar and disorienting, "like looking out the window and seeing a macaw fly by."

IT'S NOT THAT THE BLOB is the new normal. It isn't. Few if any of these changes are permanent. Even if they were, it wouldn't mean the sea was dying. Ocean life will continue. But the blob offers something of an analogue for future seas under climate change. And marine life in this sea of tomorrow will look very different.

Warmer temperatures speed fish metabolisms, requiring them to eat more, just as their food declines. Some fish may see tinier bodies, more disease, and, in many cases, falling populations, according to recent studies. Already, according to the Intergovernmental Panel on Climate Change, many fish and plankton are

A giant Pacific octopus moves along the coast of British Columbia. Recent changes in the Pacific temporarily altered migration patterns and food for many creatures, but it will take years for scientists to fully understand how marine life was affected.

heading toward the poles in search of cooler temperatures. As productive areas grow scarcer with less cold water, fish and predators will congregate in fewer places, creating new challenges. During the recent heat wave, more West Coast whales appeared to get tangled in fishing gear or debris. From 2000 to 2012, rescue crews fielded about 10 reports a year. Forty-eight were confirmed in 2015.

And when creatures show up somewhere new, our relationship with the sea can shift too. In Pacifica, California, I visit Richard Shafer, a lanky 58-year-old electrician who free-dives for fish with a speargun. As the heat wave drove game fish north from Mexico, fishing charters off Los Angeles had their best season in memory. So in August 2015, Shafer took a charter to an offshore bank west of San Diego. He speared a yellowtail, and then a hungry sea lion darted past. Knowing that sea lions steal big fish, especially in the absence of sardines, Shafer pulled his yellowtail close and swam toward the boat, only to be bitten on the wrist by a seven-foot smooth hammerhead. These sharks are rarely seen in California, and rarely attack, yet there were several encounters in 2015 during what one scientist called "an endless parade of hammerheads" lured by warm water. The animal severed Shafer's tendon and fractured a pinkie and knuckle, requiring 40 stitches. Each change in the sea can trigger another that no one sees coming.

THE SKY PINKS WITH the dying day as Kathi Lefebvre hops from a pickup truck onto a pebbly stretch of Homer Spit and stares down at the dead otter. Sea wash muddies the pale fur of its face. Otters in previous years mostly died from complications of a streptococcal infection. This year some of the dead look emaciated, while others look almost fit. Interns with the Alaska Maritime National Wildlife Refuge don blue latex gloves and begin an examination. One intern is moved nearly to tears. Another tells

A dying wolf eel curls up among dead prawns in Washington State's Hood Canal. Eels and other animals died when warm seawater washed into the canal in 2014. The canal's southern reaches didn't fully flush, which depleted oxygen.

Lefebvre about an otter she'd seen shuddering in spasms the week before. Lefebvre perks up.

"The thing you're describing, the tremors in the whole body?" Lefebvre says. "I've seen that. In sea lions."

In 1998, as a Ph.D. student at the University of California, Santa Cruz, Lefebvre learned that dozens of sea lions were turning up sick and twitchy. Lefebvre had a hunch why: Each spring, a single-celled toxic alga called *Pseudo-nitzschia* blooms in small patches, usually for a week, maybe two, producing a neurotoxin called domoic acid, which accumulates in shellfish. When ingested by people, this toxin can cause seizures, memory loss, even death. It also can harm wildlife. In 1961, a Santa Cruz newspaper told of a mysterious invasion of sooty shearwaters "fresh from a feast of anchovies." The seabirds bashed into windows and died on streets. Alfred Hitchcock used the incident as part of his inspiration for *The Birds*. Scientists tracking the mystery decades later unearthed old samples of plankton pulled from Monterey Bay in 1961. They detected high levels of *Pseudo-nitzschia*.

When Lefebvre found domoic acid in the feces of sick sea lions in 1998, it was the first evidence that this type of toxic bloom could hurt marine mammals. And blooms that year were particularly bad. El Niño had brought withering ocean heat to California, igniting the most ferocious bloom on record—until last year.

In April 2015 algae bloomed, but instead of dissipating after a few weeks, the bloom grew into a monster, morphing and shifting, stretching over 2,000 miles, from California's Channel Islands to Kodiak. No one had seen anything like it. Some shellfish harvests closed along the coast. Toxin concentrations were 30 times greater than what would normally be considered high. Tests found domoic acid in some fish, such as anchovies, at amounts too dangerous for people to eat, a rarity. The toxin appeared to sicken hundreds of sea lions,

Biologist Debbie Boege-Tobin struggles with her emotions as she calms a dying sea otter on a gravel beach in Homer, Alaska. In just one month—September 2015—79 dead otters were found there.

seabirds, porpoises, and seals. Video from Washington State showed a sea lion suffering a toxin-induced seizure, something never seen that far north. Blooms dragged into November.

Then there were Alaska's dead whales, primarily fins and humpbacks. Most were too remote or too far gone to test. A few that washed up in British Columbia showed traces of domoic acid, but the toxin flushes so quickly it's impossible to know if the dose was large or small. Scientists lacked proof, but most shared a theory: Whales ate krill, copepods, or fish dosed by algal toxins, which killed them outright or scrambled their brains, hampering navigation and feeding. "Given that we've ruled out most other scenarios, what is most prominent in my mind is toxic algae," says Andrew Trites, director of the Marine Mammal Research Unit at the University of British Columbia.

Standing on Homer Spit, Lefebvre wonders aloud if algae played a role in killing Alaska's otters. She sets down plastic bags to collect specimens and pulls on gloves. Leaning over the stiffening otter, she bends to her work.

TRUE TO ITS B-MOVIE NAME, the blob began fading in December 2015, its heat sinking deep into the sea with the arrival of a powerful El Niño. But divining what this heat portends will take years. New research suggests that heat waves like the blob may become more common and intense because of climate change. Scientists foresee "higher extremes, more unusual events. It gets more chaotic," says Raphael

A biology student stands amid dead sea otters in Homer. Most of the otter deaths were linked to an infection; scientists wonder if toxic algae also weakened many of the animals.

Kudela, an ocean sciences professor at the University of California, Santa Cruz. Scientists project that toxic blooms will be more frequent, more widespread, and more toxic.

That could spell trouble for people too. I meet Dick Ogg in his paint-splattered khakis, strolling down a wooden ramp at Bodega Bay's Spud Point Marina. He's rebuilding a hold on the *Karen Jeanne*. The commercial fisherman chases salmon, albacore, and sablefish but makes his real money gathering Dungeness crab. Yet his boat hasn't moved much in months. Crab remained unsafe to eat long after toxic blooms vanished, so California delayed its crab harvest for months, at a loss of $48 million. The governor sought disaster relief from the U.S. government. Out-of-work deckhands lived off gift cards and a marina food bank. The closest Ogg came to fishing was helping regulators catch crab to test for toxins. "A lot of folks are really hurting," Ogg says glumly.

Yet not all of what the blob produced is a harbinger of something. Given warming over decades, rather than the blob's span of roughly two years, plants and animals may adapt or move. Some die-offs might have happened without the blob. Sea star deaths, while hastened by the warm water, were actually caused by a virus that hit well before the blob. California sea lion populations may simply have grown too large.

And more changes are coming. Rising seas are reshaping coastlines. Natural low-oxygen zones in deep waters are expanding. Ocean acidification is making life harder for shellfish. Predicting the future is messy—especially when we barely understand the present.

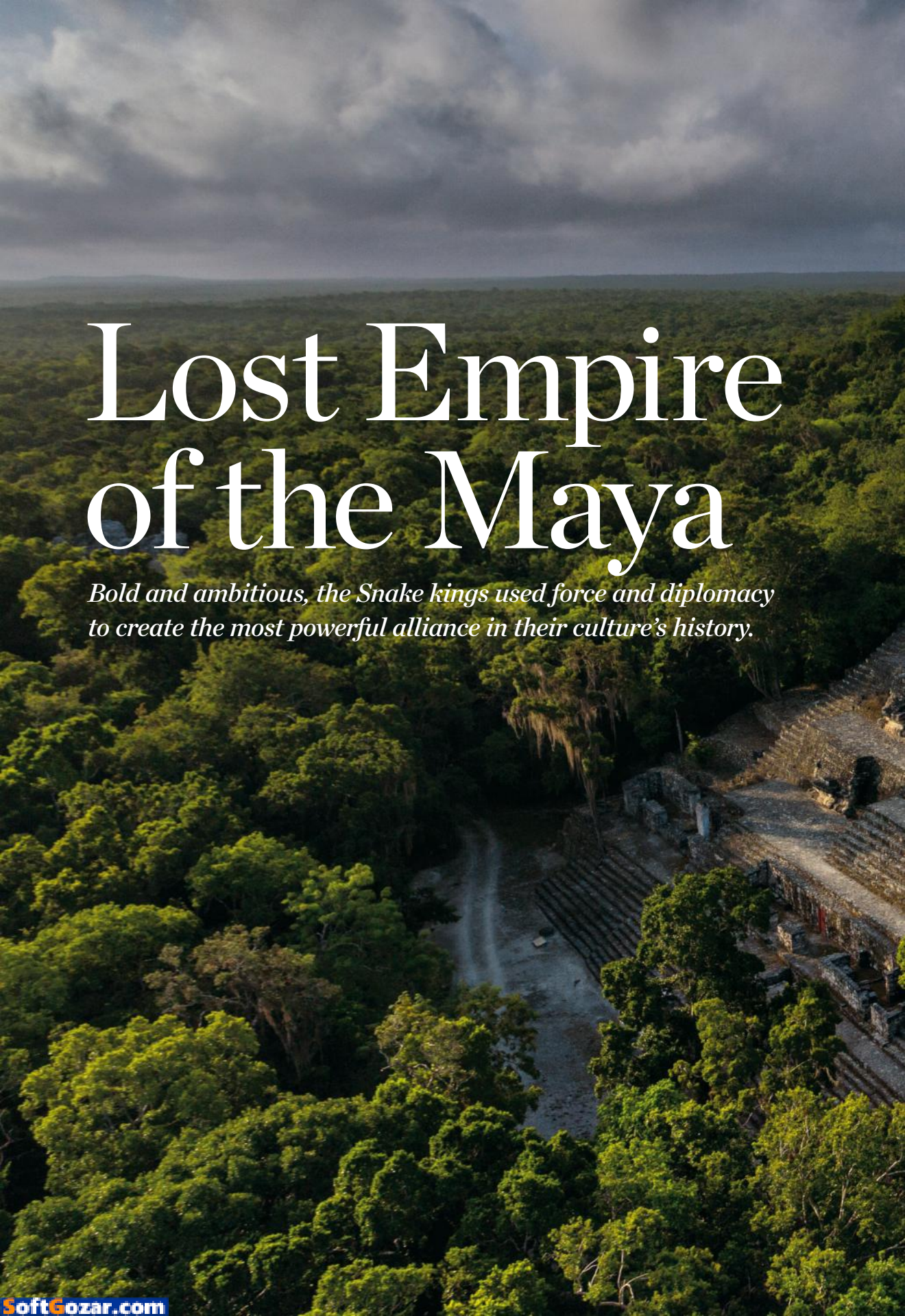
Lefebvre never solved the otter mystery. By year's end, 304 were dead—nearly five times the recent average. One-third of the carcasses that scientists tested were positive for toxic algae. But strep infection was diagnosed as the primary cause of death for most otters. Any role that the blob played in exacerbating the infection remains a riddle. Did algal toxins weaken the animals? Did warm water somehow make things worse? "We still don't know how all these tweaks in our world come together," Lefebvre says.

Weeks later, I have a similar chat with Julia Parrish, a bird expert at the University of Washington, who has been tracking the murres' deaths. She doesn't know if the seabirds chased scarce food to strange places, got mixed up by domoic acid, or were pushed ashore by winds. "I am still just mystified," she tells me.

And that, more than anything, I now realize, may be our new normal: the unfathomable gulf between the sea we thought we knew and the one we're rapidly creating. ▯

MARK THIESSEN, NGM STAFF

Craig Welch has won numerous awards for his environment reporting. Read more from him about climate change, marine life, and the future of our oceans at *ngm.com/Sep2016*.



Lost Empire of the Maya

Bold and ambitious, the Snake kings used force and diplomacy to create the most powerful alliance in their culture's history.

CALAKMUL

In the seventh century A.D. the Snake rulers presided over this capital city—in what today is southern Mexico—and its largest structure, a pyramid 180 feet tall. From Calakmul they managed an intricate web of alliances.

CONSEJO NACIONAL PARA LA CULTURA Y LAS ARTES (CONACULTA), INSTITUTO NACIONAL DE ANTROPOLOGÍA E HISTORIA (INAH), MEXICO

Masks from the tombs at Calakmul were meant to ease the passage of the Snake elite into the next world. Royal visages made of green jade, more valuable than gold to the ancient Maya, evoked the annual agricultural cycle and regeneration.

CONACULTA, INAH, MEXICO (BOTH) PHOTOGRAPHED AT (LEFT TO RIGHT): NATIONAL PALACE, MEXICO CITY; MUSEO DE SITIO DE COMALCALCO, MEXICO

By Erik Vance
Photographs by David Coventry

The ancient city of Holmul isn't much to look at. To the casual observer it's just a series of steep, forested hills in the middle of the jungle in northern Guatemala, near the Mexican border. The jungle here in the Petén Basin is thick and warm but drier than you might expect. And silent, except for the drum of cicadas and the occasional calls of howler monkeys.

Take a closer look, and you may notice that most of these hills are arranged in massive rings, like travelers huddled around a fire on a cold night. An even closer look reveals that parts of the hills are made of cut stone, and some have tunnels carved into their sides. In fact they're not hills at all but ancient pyramids, left to decay after the collapse of the Maya civilization a millennium ago.

The site was a thriving settlement during the Classic Maya period (A.D. 250-900), a time when writing and culture flourished throughout what is today Central America and southern Mexico. But it also was a time of political upheaval: Two warring city-states were locked in perennial conflict, grappling for supremacy. For a brief period one of those city-states prevailed and became the closest thing to an empire in Maya history. It was ruled by the Snake kings of the Kaanul dynasty, which until just a few decades ago no one even knew existed. Thanks to sites around this city-state, including Holmul, archaeologists are now piecing together the story of the Snake kings.

Holmul isn't a big, famous site like nearby Tikal, and it was mostly ignored by archaeologists until 2000, when Francisco Estrada-Belli arrived. An Italian-born Guatemalan, he's ruggedly handsome with scruffy hair and a relaxed demeanor. He wasn't looking for anything fancy, such as Classic-era written tablets or ornate burials—just some insight into the roots of the Maya. One of the first things he found was a building a few miles from what appeared to be Holmul's central cluster of pyramids. In it were the remnants of a mural portraying soldiers on a pilgrimage to a faraway place.

Oddly, parts of the mural had been destroyed, apparently by the Maya themselves, as if they'd wanted to erase the history it depicted. Hoping to understand why, Estrada-Belli tunneled into several nearby pyramids. Ancient Mesoamericans built their pyramids in stages, one on top of the other, like Russian nesting dolls. When the people of Holmul added a new layer, they preserved the one beneath, which has allowed researchers to tunnel in and see previous structures almost exactly as they were left.

In 2013 Estrada-Belli and his team worked their way into one of the larger pyramids, tracing an ancient staircase to the entrance of a ceremonial building. Climbing up through a hole in the floor, they discovered a 26-foot-long frieze, marvelously preserved, above the entrance to an ancient tomb.

Stucco friezes are very rare and fragile. This one depicted three men, including a Holmul king, rising from the mouths of strange monsters flanked by underworld creatures, entwined by two giant, feathered serpents. The artwork was iconic and strikingly vibrant.

A relief from La Corona, Guatemala—once the ancient city of Saknikte—shows future Snake King Yuknoom Cheen II playing ball during a visit. Hieroglyphics give the date: February 11, 635.

As Estrada-Belli gazed at the frieze, he noticed a series of carvings at the bottom. Kneeling down, he saw a ribbon of characters, or glyphs, listing the kings of Holmul. Near the center was a glyph that he knew at once was the most electrifying discovery of his career: a grinning snake.

"Among the various glyphs, I saw the [name of the] Kaanul," he says. "Before this we were anonymous; Holmul was anonymous. And then, all of a sudden, we were in the middle of the most exciting part of Maya history."

THE STORY OF THE discovery of the Kaanul, or Snakes, and their effort to create an empire begins in Tikal, the city of their most hated enemy. Just as Tikal dominated the Maya lowlands for centuries, it has dominated Maya archaeology since the 1950s. The sprawling city once had a population approaching 60,000, and its elegant buildings surely dazzled visitors in A.D. 750, much as they do tourists today.

It also had hundreds of beautifully carved tombstone-like blocks called stelae. Using the inscriptions on them, scientists reconstructed Tikal's history until its fall in the ninth century. But there was an odd gap—roughly from 560 to 690—when no stelae were carved and little else was built. Baffled by this 130-year break, archaeologists called it the Tikal hiatus and chalked it up as a mystery of the ancient Maya.

Archaeologists began filling in the gap in the 1960s, when they noticed an odd glyph scattered around various Classic sites—a snake head with a clownish grin and surrounded by markings associated with royalty. In 1973 archaeologist Joyce Marcus recognized it as an emblem glyph—words for a city and ruling title that served as a sort of coat of arms. She wondered if it could be related to the Tikal hiatus. What if some unknown warriors had conquered

GUATEMALAN MINISTRY OF CULTURE AND SPORTS. PHOTOGRAPHED AT LA CORONA LAB, GUATEMALA CITY

the city? If they had, where would such a force have come from, and wouldn't archaeologists be familiar with it?

The jungles of the Petén are hot and parched in the dry season and nearly impassable in the wet season. They're infested with poisonous plants and insects and menaced by armed drug runners. Nevertheless Marcus explored them for months, visiting ruins and collecting photos of glyphs. Everywhere she went, she saw references to the grinning snake, especially around the ancient city of Calakmul, in what's now Mexico, near its southern border.

"These satellite sites were mentioning this city in the center. So in that way it was kind of like a black hole," Marcus says. "It was the hub of a network of sites around it that were equidistant from Calakmul."

When she got to Calakmul, whose two central pyramids were easily visible from the air, she was amazed by its size—roughly 50,000 people once lived there. Stelae were strewn everywhere, but most of them were blank. The limestone was so soft that centuries of erosion had wiped them clean. She found only two snake glyphs in the city.

The mystery of the snakes prompted a young British researcher, Simon Martin, to assemble all the information he could about the snake glyphs from Calakmul and smaller sites. He used hints of battles and political intrigue from around the Maya world to form a picture of the Snakes and their dynasty.

"We only really know about Tikal from Tikal. Whereas in Calakmul's case, we know about them from everybody else," Martin says. "It just sort of coalesced out of the mist. Little by little the significance of all these random appearances began to point in the same direction."

Eventually Martin and archaeologist Nikolai Grube published a book called *Chronicle of the Maya Kings and Queens,* which described the intertwining histories of the kingdoms of the ancient Maya world. At the center of that world, for one shining century, were the Snakes. Like Marcus, Martin says the Snake kingdom was a

Society Grant Your National Geographic Society membership helped fund recent excavations at Holmul and La Corona, Guatemala.

The reconstructed burial of a Snake king, thought to be Claw of Fire, who died in 697, includes jade and shell beads placed on a shroud and some of the ceramics interred with him at Calakmul.

sort of black hole—one that sucked in all the cities around it and created what might have been a Maya empire. Of course there are still many questions about the Snakes: how they lived, ruled, and fought—and even whether some of them were real.

AT THE END OF THE fifth century, Tikal was one of the most powerful city-states in the region. Archaeologists suspect that it held its position with the help of a much larger city high in the mountains 650 miles to the west called Teotihuacan, near today's Mexico City. For centuries these two cities shaped Maya painting, architecture, pottery, weapons, and city planning. But all that changed in the sixth century, when Teotihuacan disengaged from the Maya region, leaving Tikal to fend for itself.

Enter the Snakes. No one's sure where they came from; there's no evidence of them ruling Calakmul before 635. Some experts imagine them hundreds of years before the Classic era, moving from place to place, creating one megacity after another. But this is guesswork. The first obvious snake glyphs seem to appear in Dzibanché, a city in southern Mexico, 80 miles northeast of Calakmul.

Wherever the Snakes were based, we know that starting in the early sixth century two successive Snake kings recognized that Tikal was vulnerable and made a bold play for political control. The first, Stone Hand Jaguar, spent decades making courtesy calls throughout the Maya lowlands.

These visits might seem innocuous now—orchestrating a wedding, playing an ancient Maya ball game (a sport involving a ball, several sticks, and stone hoops), perhaps just dropping by to say hello. But this was how conquest often happened in the Maya world—by offering gifts, paying respects, building crucial allies. No one seems to have been better at this than the Snakes.

Soon Tikal's southeastern ally, Caracol, was siding with the Snakes, as was Waka, a warlike

CONACULTA, INAH, MEXICO. PHOTOGRAPHED AT MUSEO ARQUEOLÓGICO DE CAMPECHE FUERTE DE SAN MIGUEL

HOLMUL

A 26-foot-long frieze in this city-state depicts a complex mythical scene that suggests close ties with the Snake dynasty. The central figure is the Holmul king who died around 590 and was buried in the tomb the frieze adorns.

GUATEMALAN MINISTRY OF CULTURE AND SPORTS. COMPOSITE OF 130 IMAGES

WAKA (EL PERÚ)

In about 656, another Snake ally, King Jaguar Throne, was laid to rest in this city-state. His tomb contained painted ceramic figurines four to nine inches tall depicting a mythical ritual from the underworld. Snake King Yuknoom Cheen II (top row, far left) plays the role of king. His daughter Lady Water Lily Hand (left) has conjured up a magical deer (bottom row, far left), which prays for the spiritual resurrection of the deceased. Other participants include the king's widow and royal courtiers.

GUATEMALAN MINISTRY OF CULTURE AND SPORTS (ALL). PHOTOGRAPHED AT NATIONAL MUSEUM, GUATEMALA CITY

GAME OF THRONES

Tikal was a superpower until the rise of the Snake kings in the sixth century. The future overlords, perhaps based at Dzibanché, made alliances with cities (in red) around Tikal (its allies in black) that allowed them to crush their rival in 562. By 635 the Snake dynasty had moved its capital to Calakmul. A king named God That Clears the Sky kick-started Tikal's return to supremacy with a decisive victory over Calakmul (now with two more allies, in gray) on August 5, 695.

city to the west. The Snakes patiently gathered the loyalty of other cities to the north, east, and west of Tikal, forming a giant pincer to squeeze their foe. Stone Hand Jaguar and his allies were finally ready to make their move on Tikal, but the Snake lord died before his political maneuvers could pay off. It fell to his successor (and perhaps son), Sky Witness, to spring the trap. The young king must have cut an impressive figure. Scientists who've examined his remains say he was powerfully built and that his skull was battered from untold battles, with scars on top of previous scars.

According to inscriptions on an altar in Caracol, Sky Witness put an end to Tikal's reign on April 29, 562. The king put all the pieces in place, then struck. He led the Snake army east from Waka, while forces from Caracol, the nearby city-state of Naranjo, and probably Holmul moved west.

The Snakes and their allies quickly crushed Tikal, sacked it, and likely sacrificed its king with a stone blade on his own altar. It's probably at this time that the people of Holmul nearly destroyed the mural that Estrada-Belli would find more than 1,400 years later—which honors Tikal and Teotihuacan—as a sign of loyalty to their new Snake lords. The reign of the Snakes had begun.

The next 30 years of Maya history are a bit fuzzy. Thanks to Mexican archaeologists Enrique Nalda and Sandra Balanzario, we know that Sky Witness died 10 years after his victory, when he was in his early 30s. In 2004 they uncovered a series of tombs in a pyramid at Dzibanché in which they found a bone needle used for blood rituals amid jade masks, obsidian, and pearls under a thick coating of cinnabar dust. Markings along one side of the needle read, "This is the blood offering of Sky Witness." Of the eight Snake kings who ruled during Tikal's hiatus, he's one of just two whose remains have been found.

The next time the Snakes appeared was far to the west, in the lavish city of Palenque. Unlike the drier lowland metropolises of Tikal and Calakmul, Palenque was refined and sophisticated, its elegant stucco-covered pyramids and watchtower nestled in the foothills of the mountains that led to the Gulf of Mexico and the central highlands. Thanks to its ample rivers and waterfalls, it had plenty of water and even may have had toilets with running water.

It wasn't a big city—maybe 10,000 people—but it was a beacon of civilization and a gateway

JEROME N. COOKSON, NG STAFF
SOURCE: DAVID FREIDEL, WASHINGTON UNIVERSITY IN ST. LOUIS

for trade to the west, a prime target for an ambitious young power. The Snakes were led then by a king named Scroll Serpent who, like his predecessors, invaded using proxies and allies. Palenque's queen, Heart of the Windy Place, defended her city against the Snake onslaught but surrendered on April 21, 599.

Such expansionist impulses were rare among the Classic Maya, who often are described as quarrelsome and disjointed, focused on their territories without larger ambitions. The Snakes were different.

"The attack on Palenque was part of a larger plan," says Guillermo Bernal, an epigraphist at the National Autonomous University of Mexico. "I don't think the reasons were material in nature—they were ideological. The Kaanul envisioned creating an empire."

The idea of empire building is controversial among Maya archaeologists. For many the concept is culturally and geographically implausible. Still, looking at the Snakes, it's hard not to see a pattern of expansion. They made allies of the biggest cities to the east, conquered those to the south, and traded with people to the north. Palenque represented the edge of the Maya world to the west. Yet without horses and standing armies, how could they hold it?

Influencing such a far-flung region, perhaps as large as the U.S. state of Kentucky, required a kind of organization never before seen among the Maya. It also required a new seat of power, one closer to the jade-rich cities in the south. Dzibanché was almost 100 miles from Calakmul, an impressive distance for people on foot in thick jungle. There are no records of the move to the new capital of Calakmul, but in 635 the Snakes erected a monument declaring themselves the masters of the city, having displaced a dynasty there known as the Bats.

Within a year the greatest of the Snake rulers—perhaps the greatest Maya king ever—took the throne. His name was Yuknoom Cheen II, or Shaker of Cities, as he is sometimes called. Sky Witness and Scroll Serpent had been adept conquerors, but Yuknoom Cheen was a true king. Like Cyrus in Persia or Augustus in Rome, he deftly played one city against another—bribing some, threatening others—while consolidating his hold on the Maya lowlands unlike any Maya king before or after. And he kept up this political balancing act for 50 years.

THE BEST WAY TO UNDERSTAND a king can be to meet his servant. Similarly, the best way to understand an empire is often to look at a client city. Perhaps the most interesting servant to the Snakes was a small, otherwise unremarkable city called Saknikte.

In a sense, archaeologists discovered the site twice. By the early 1970s they'd come across a series of stone panels circulating on the black market. Gorgeously crafted with intricate texts, the panels had been looted by thieves and sold abroad with no way to trace their origin. Sprinkled among them were glyphs of a grinning snake. Archaeologists named the unknown place where the looters had found them Site Q.

Site Q became a sort of Ark of the Covenant for archaeologists such as Marcello Canuto. One hot afternoon in April 2005 he accompanied researchers mapping a site nicknamed La Corona in the Petén jungle. Looking for ceramics to help date the site, he walked into a looter's trench that sliced into a pyramid and saw a wallet-size patch of exposed carved stone on the wall. "I could see some squiggles on the rock," Canuto says. "I sort of jumped back. 'Whoa, did I just see what I think I just saw?' Then I looked again, and I could see more than just squiggles—it was script." Under layers of dirt and vegetation were the finest, most elegant carvings he'd ever seen in the field. "As soon as we cleared it off, we said, 'This is Site Q.'"

Canuto has been there ever since. Saknikte, the site's Maya name, seems to have had a special status in the Snake kingdom. Its princes went to Calakmul for education, and three of them wedded Snake princesses. Unlike the martial city of Waka just to the south, Saknikte didn't fight many battles. Its kings had peaceful names that translate roughly as Sunny Dog, White Worm, and Red Turkey. Panels tell of nobles drinking alcohol and playing flutes.

In a bid to dominate the heart of the Maya region, Snake forces attacked the rival city-state of Tikal on April 29, 562. In this interpretation of the moment of victory, King Sky Witness stands in triumph over Tikal King Double Bird, who is bound at the Snake king's feet. The loss sent Tikal into a 130-year decline.

ART: TOMER HANUKA. SOURCE: SIMON MARTIN, UNIVERSITY OF PENNSYLVANIA

According to carved panels found by Canuto's team, Yuknoom Cheen paid a visit just before the Snake capital officially moved to Calakmul. The elegant portrait shows Yuknoom Cheen seated, looking relaxed, glancing off to the side as Saknikte's king looks on.

Saknikte wasn't the only place where the Snakes were building influence. Yuknoom Cheen's name appears throughout the Maya region. He married off his daughter Water Lily Hand to a Waka prince; she later became a powerful warrior queen. He installed new kings in Cancuén, to the south, and Moral-Reforma, nearly a hundred miles to the west. In Dos Pilas he conquered the brother of Tikal's new king and turned him into a loyal vassal.

He also established a new trade route on the western side of his kingdom, linking various allies. Scientists have noticed an oddity of these vassal cities. It seems that certain close allies didn't have their own emblem glyphs, and their kings, though sumptuously adorned, didn't use kingly titles once they fell in with the Snakes.

Meanwhile, the Snake kings of Calakmul took on a more sweeping title: *kaloomte*. King of kings.

"I think they changed the way politics were done. I think they created something fairly new," says Tomás Barrientos, a Guatemalan archaeologist who co-manages the Saknikte site. "I personally see it as a breakthrough in Maya history."

All the while the Snakes kept their eye on their old enemy, Tikal, which repeatedly tried to rise up and take revenge. In 657, after shoring up his allies, Yuknoom Cheen and a nearby puppet king, an ambitious man named God That Hammers the Sky, struck Tikal. Two decades later Tikal rose up yet again, and the Snake king once more orchestrated its defeat, killing its king in the process.

How was Tikal still able to threaten the seemingly omnipotent Snakes? Experts say Maya kings had to be careful when maintaining alliances and often left defeated kings alive. It could be that Classic Maya battles were mostly ceremonial. Or perhaps the allies of defeated kings—worried that their own throats could be next—pushed for mercy. Or maybe Maya kings typically didn't have big enough armies to wipe out a city.

The dynastic emblem glyph of the Snake kings shows up across the Maya region.

Whatever the reason, Yuknoom Cheen played a delicate game of politics. Rather than hand over Tikal to his ally God That Hammers the Sky, he held a peace summit with Tikal's new king. It was then that he introduced his successor (and likely son), Claw of Fire, who one day would inherit the kingdom. And ultimately lose it forever.

AROUND THE ADVANCED age of 86, Yuknoom Cheen died. Most Calakmul citizens would have been lucky to live half as long, but their kings were a pampered breed, dining only on soft tamales, so that even their teeth looked unusually young. Malnutrition was pervasive in the poorer classes, but elites could be overweight and some may have had diabetes.

Some suggest that Claw of Fire was just such a man. He likely was running the kingdom long before his father died. But as with the sons of many great kings, he fell far short of his father. Despite multiple crushing defeats, Tikal rose up again in 695. This time it was led by a young king, impressively named God That Clears the Sky. Claw of Fire raised another Snake army to face the Tikal upstart.

We don't know exactly what happened that August day. Some experts think that God That Hammers the Sky, bitter about various snubs,

BOTH: CONACULTA, INAH, MEXICO

betrayed his Snake allies on the battlefield. Others say Claw of Fire, middle-aged and suffering from a painful spinal disease, didn't inspire confidence in his troops. Perhaps the stars simply weren't aligned.

The Snakes were routed. A few years later, his rule in tatters, Claw of Fire died and took with him the dreams of a Snake empire. Most archaeologists say the Snakes never recovered but continued to wield influence. In 711 the Snakes' strongest ally, Naranjo, declared it was still loyal to the Snakes, and 10 years later another Snake princess showed up at Saknikte.

But by mid-century the Snakes had lost their bite. A Calakmul neighbor even erected a stela celebrating the return of the Bat kings that shows a warrior stomping on a snake. For the next century Tikal punished the city-states that had helped the Snakes—Waka, Caracol, Naranjo, and Holmul.

The people of Saknikte, known as lovers not fighters, invited a Tikal princess to marry one of their nobles in 791. Yet Tikal would never attain the power reached by the Snakes, and by the mid-800s the Classic Maya were in collapse. Whether because of overpopulation, instability, or prolonged drought, the Classic cities fell into chaos and eventually were abandoned.

Could the Snakes have prevented the collapse? What would have happened if Claw of Fire had beaten Tikal in 695?

"I think the collapse could have been avoided," says archaeologist David Freidel, who leads the excavations in Waka. "The failure to unite the central area of the Maya world under one government was a major factor in the descent into anarchy, endemic warfare, and vulnerability to drought."

Someday we may have the answer. Forty years ago the Snake kings were a rumor. Twenty years ago they were viewed merely as the masters of Calakmul. Today we know they ruled the largest and most powerful Maya kingdom ever.

Such is the maddeningly slow work of archaeology. Through glimpses and snippets, experts try to cobble together a coherent picture of the past.

And often the experts disagree. Ramón Carrasco, an archaeologist who oversees the Calakmul site, says the Snakes never lived in Dzibanché and never declined from glory. He's worked alongside Simon Martin and other researchers and seen the same evidence, yet he's come to different conclusions.

And so archaeologists keep looking for clues. In 1996 Carrasco was excavating Calakmul's largest structure, a graceful pyramid dating to before 300 B.C. Near the top, as he carefully cleaned and pulled up stones, he discovered the remains of a body. And below that, a chamber.

"We lifted the lid, and we could see down," says Carrasco, a distinguished-looking man with a gravelly voice from too many cigarettes. "We saw some bones and offerings and a lot of dust. It was like seeing the dust of time."

It took nine months to safely dig into the tomb and excavate it. When Carrasco finally got in, he knew that he'd found a powerful king. The body had been wrapped in a fine shawl and covered with beads. The king was not alone—a young woman and a child had been sacrificed and laid in a nearby chamber.

The king's body, Carrasco says, "was covered with mud and dust. You could see some jade beads, but you couldn't see the mask." So he pulled out a brush and began gently cleaning it. "The first thing I saw was an eye—looking at me from the past."

The eye was from a beautiful jade mask meant to honor the king in the afterlife. Later analysis showed that he was a portly man, perhaps even fat, with hardened ligaments in his spine. His tomb was elegantly ornamented.

Nearby sat a headdress of jade, the center of which had once held the paw of a jaguar. Next to that was a ceramic dish with a grinning snake head and the inscription "Claw of Fire's plate." ▯

Fly over the ancient ruins of Calakmul and listen to an archaeologist describe what it's like to unearth a Maya death mask. Watch the video at *ngm.com/Sep2016.*

Back in Fashion

Furs and skins are being embraced by designers, hip-hop stars, and China's wealthy, amid a push to make the life and death of captive animals more humane.

At a farm in Poland, a mink crouches in a wire cage where it will spend its entire life, about six to eight months. Some fur farmers, particularly in Europe, are adopting new standards that aim to improve conditions for mink and other animals, but animal welfare advocates say they don't go far enough.

A worker at a farm in Colombia prepares a brown caiman—killed earlier by a single cut to the back of its neck—to be skinned. He will slice the animal from head to tail, and then another worker will peel off the hide. Caiman leather is not considered as luxurious as American alligator and is thus less expensive.

On this ostrich farm in Thailand, workers kill, pluck, and skin the birds by hand. Fashion designers prize ostrich leather as supple, durable, and distinctive, with a texture and pattern created by raised quill follicles. Native to Africa, ostriches are now raised around the world for their skin, feathers, and meat.

PAOLO MARCHETTI, ALEXIA FOUNDATION

By Richard Conniff
Photographs by Paolo Marchetti

It was frozen-toe, mid-February, north-country cold, under a cloudless sky, sun glinting off fresh snow. We were tromping out onto a wetland frozen nine inches deep. It felt like how the fur trade began, someplace long ago, far away.

Bill Mackowski, in his 60th year of trapping, mostly around northern Maine, pointed out some alder branches sticking through the ice. Beavers start collecting poplar after the first cold snap, he explained, then pile on inedible alder to weigh down the poplar below the ice, where they eat it throughout the winter. He hacked through the ice with a metal pole, then passed it to me to try. "Feel how hard the bottom is on the run?" Beaten down by beaver traffic, he said.

Breaking through the ice in another spot, Mackowski said, "Did you hear those air bubbles?" He widened the hole and began hauling up until a peculiar steel device broke the murky surface. It was a trap, snapped tight around the neck of an enormous beaver. Those air bubbles, a moment locked in ice, were its final breath.

"That's what we call a superblanket," said Mackowski. "That's a nice beaver." The pelt would bring no more than $25, he calculated, but all the way home he wore the satisfaction of a thousand generations of successful hunters and trappers. Still glorying in the day and in his own deep reading of the landscape, he recalled what another winter visitor once told him: "If people could get past killing the beaver, they would pay to come out here like this."

IN TRUTH, GETTING PAST the killing doesn't seem like much of an issue anymore. Top models who once posed for ads with slogans like "We'd rather go naked than wear fur" have gone on to model fur. Fashion designers who were "afraid to touch it" 15 or 20 years ago have also "gotten past that taboo," said Dan Mullen, a mink farmer in Nova Scotia. Many in the fur trade now readily acknowledge that activists who protested so loudly had a point: Farmers were not providing a decent standard of care for their animals. But they add that the trade has changed, though activists dispute this. In any case, many people now seem to regard wearing fur as a matter of individual choice. In some cities you are more likely to be glowered at for texting while walking.

Fur farms dominate the trade, and production

Models wait to walk a runway in Milan to show the newest collection of coats and hats by Simonetta Ravizza, who is renowned for her fur clothing. Her designs include clothes made from mink, fox, and ermine, as well as from common fur, such as goat, printed to look like leopard or other rare species.

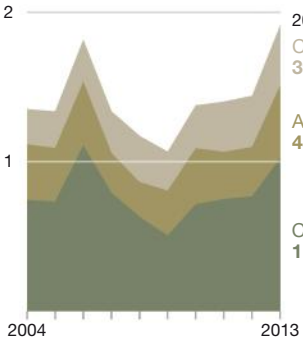
has more than doubled since the 1990s, to about a hundred million skins last year, mostly mink and some fox. Trappers typically add millions of wild beaver, coyote, raccoon, muskrat, and other skins. That's besides untold millions of cattle, lambs, rabbits, ostriches, crocodiles, alligators, and caimans harvested for food as well as skins.

But you hardly need the numbers. Just look around. Once the resolutely conventional winter-fashion choice of Park Avenue matrons and country club partygoers, fur has gone hip-hop and Generation Z. It turns up now in all seasons and on throw pillows, purses, high heels, key chains, sweatshirts, scarves, furniture, and lampshades. There are camouflage-pattern fur coats, tie-dyed fur coats, and fur coats in an optical illusion M. C. Escher box pattern. There's even a fur pom-pom that's a Karl Lagerfeld Mini-Me, created by the designer in his own image and dubbed Karlito.

So how has fur made such a comeback from the intense social ostracism of the 1990s? Or for that matter, from the notoriety of the 1960s, when the cartoon character Cruella de Vil hankered after the fur of Dalmatian puppies, and the real-life trade was threatening the survival of

A tagged mink, killed by carbon monoxide, rides on a conveyor belt to machines that will remove its hide. Mink carcasses, which have little use other than to make fertilizer, are dumped into a trash bin. In fall, when fur thickens for winter, farms such as this one in Poland process thousands of mink a day.

Global exports of crocodilian skins (in millions)



Crocodilian skin exports declined in the three years after 2006 due to a global recession and the impact of Hurricanes Katrina and Rita on American alligators. Since 2009 the trade has rebounded, reaching almost 1.9 million skins in 2013.

leopards, ocelots, and other species in the wild? New restrictions in the 1970s ended the use of endangered species in fashion. But the current revival is a story of the fur trade responding to its critics and often outmaneuvering them, combined with increased demand from the newly wealthy in China, South Korea, and Russia.

I suppose I should acknowledge here that I come to this story from a tangled perspective. My great-grandfather was a fur trapper, and I have a lingering sense that the intimate knowledge from hunting, fishing, and working with living things has a value largely lost in our urbanized lives. At the same time, my wife and I once inherited an ocelot jacket, and its 15 pelts haunted us until we finally donated it as an educational tool to a national wildlife refuge. So tangled, yes. I set out to see for myself.

I HEADED NORTH in a snowstorm to Nova Scotia, a center of the trade. Mullen had invited me to see how his mink live and also how they die. "We're very aware that we have to maintain a social license to do what we're doing," he said.

Mullen grew up in the old style of mink ranching, with long, narrow, open-sided wooden sheds and a row of tight little cages on each side. When he went into business for himself, he opted for the larger cages now required in Europe, housed six rows across under translucent plastic roofs in barns the length of a football field. "You'll probably think it stinks," he warned. "But I go in there, and it's the smell of my childhood." He drew in a long breath and exhaled: *"Ah,* mink."

A worker drives a feed wagon down the rows multiple times a day, depositing a scientifically formulated meal that looks like raw hamburger atop each cage, portioned out by computer. A frost-free line provides 24-hour-a-day drinking water, and a trough underneath the cages automatically sweeps away wastes to be processed into fertilizer or, via a biodigester, into electricity.

These changes have come largely in response to pressure from animal welfare advocates. But they have often worked to the benefit of the farmers too. Mullen's cages, for instance, each contain an elevated shelf for the nursing mom to get away from her kits—and it turns out that less harried mothers rear healthier young. Toys in the cage—as simple as a length of plastic pipe—reduce stress and seem to translate into better quality pelts. The peculiar result is

GRAPHIC: NGM STAFF. SOURCE: JOHN CALDWELL, UN ENVIRONMENT PROGRAMME, WORLD CONSERVATION MONITORING CENTRE

This farm in Colombia produces more than 40,000 caimans a year, moving the animals from tank to tank as they grow. Here, hundreds of caimans, measuring about 20 inches, splash into one of the pools. They're killed before they reach about four feet, when they can become territorial, start fighting, and scar their skins.

that people in the trade now often boast of the reforms their old adversaries forced on them. Frank Zilberkweit, a London fur retailer, balked at the confrontational methods activists use but added, "They have made us aware of what we do. And so, for that, thank you. Why not?"

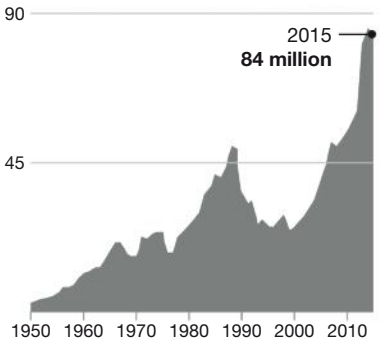
Mullen's mink were surprisingly large and healthy looking—twice the weight of their wild counterparts, with broad, curious faces. They were, of course, also doomed. I had arrived to see the killing. Farmworkers, wearing welding gloves to avoid being bitten, went from cage to cage, lifting each animal by the base of the tail. Some animals screeched in protest, but most seemed accustomed to being handled, up to the moment they dropped, like packages into a mailbox, through the swinging door of the carbon monoxide killing box. They were unconscious within a minute and dead a few minutes later.

"If you were to watch other types of livestock being killed," said Mullen, "they're usually taken from their homes, trucked hundreds of miles to the slaughterhouse, and it's bloody and horrific. This is the most humane form of killing of livestock there is." The next day we visited

This female ostrich lost some of her plumage to her mate. Adult males are extremely aggressive and are kept separate from one another. At this farm in Thailand, each male shares his enclosure with one or two females. Farmers harvest the offspring when they are about a year old.

PAOLO MARCHETTI, ALEXIA FOUNDATION

Global production of mink (in millions)



Farming of mink, which accounts for 85 percent of the global fur trade, has grown dramatically. In recent years China has become a major producer of pelts.

a processing plant, where machines sliced the skin away from each carcass and pulled it off in a single piece, like a T-shirt.

FOR THE WORLD'S LARGEST FUR AUCTION, at Kopenhagen Fur in Denmark, an assembly line of robots, x-ray machines, vision technology, and a human had sorted 6.8 million pelts, bar-coded to identify the farmer, into 52 different skin types and then into thousands of bidding lots. In the auction room, buyers consulted their catalogs, bantered, and maneuvered for the lots they wanted.

At Kick, an atelier for Kopenhagen Fur, a designer from Beijing named Ran Fan was working with a furrier's knife to cut a mink pelt, dyed lavender, into a latticework for a lightweight vest. "I love fur," she said, and so do her customers, often in bright colors and unusual patterns. Chinese consumers now buy almost half the world's fur products, so she had come to Kick to learn new techniques.

Much of the fur trade's recovery stems from its strategic wooing of young designers like Fan and, in turn, young customers. The leading fur auction houses began bringing in designers and design students at the height of the antifur movement. The ambition was for all designers to have "flirted with the material" early in their careers, said Julie Maria Iversen of Kopenhagen Fur. The aim has always been to move beyond furrier shops and fur departments, and make fur just another fine fabric, available wherever clothes are sold.

These zealously cultivated relationships have paid off, as designers have learned to use fur in ways conventional furriers never imagined, aided by innovations in dyeing that can produce fur in whatever color happens to be hot this season, from airy blue to green flash. New sewing techniques have also helped, yielding more garment from less fur. Affordability, a word not formerly associated with fur, serves what Iversen called "the fur journey."

"We start with the young consumer buying a fur key ring, then maybe a little later she has more money for a fur bag," she said. "Eventually she buys a full coat." It's "all part of the agenda, to inspire the upcoming generation of women."

SO HOW SHOULD WE FEEL about the resurgence of fur? Should the upcoming generation of women be inspired? Or should they

GRAPHIC: NGM STAFF. SOURCE: HENNING OTTE HANSEN, UNIVERSITY OF COPENHAGEN

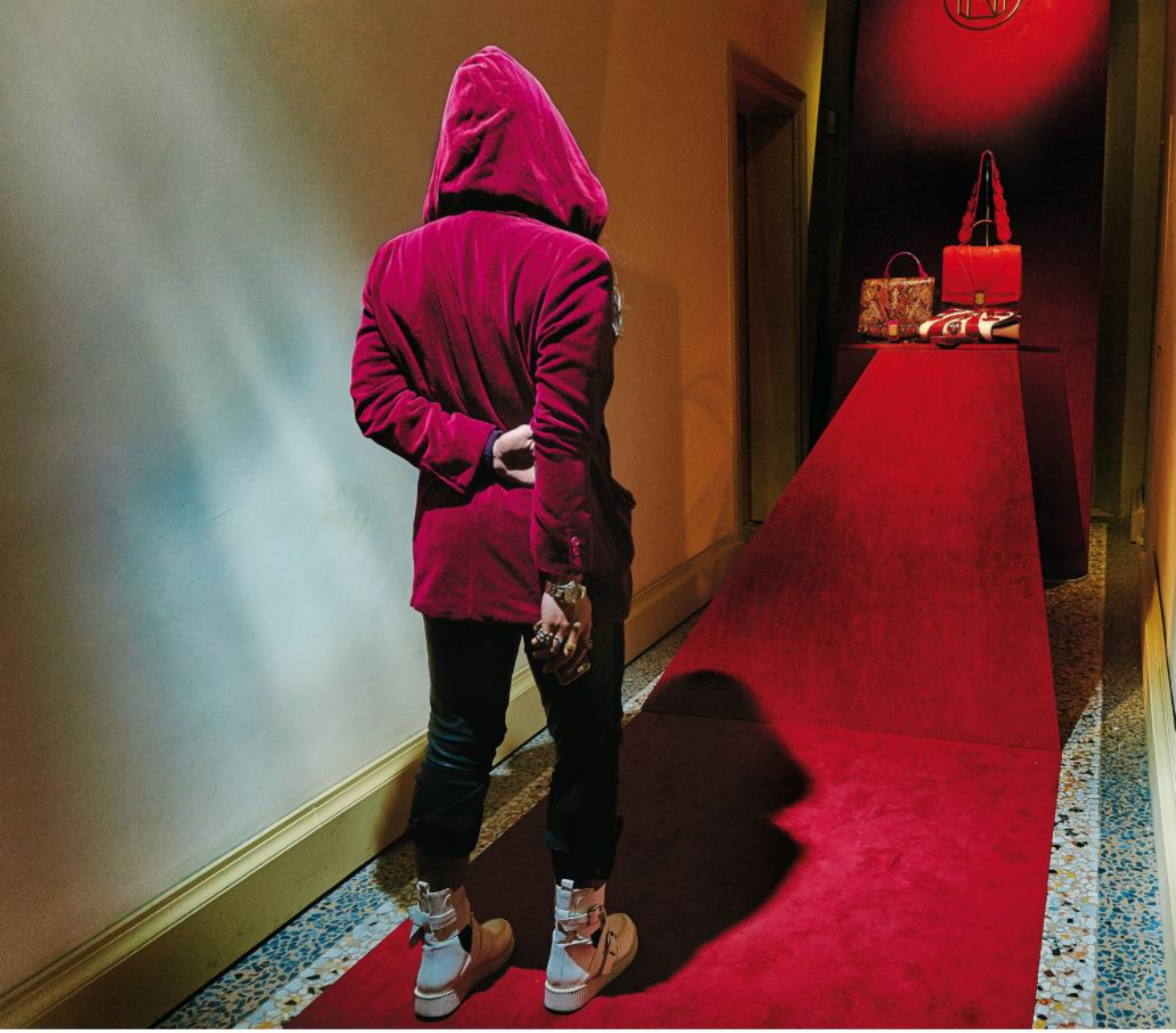
At a Bangkok tannery, skins from ostrich feet dangle from a bamboo rod after being washed. Fashion designers are enamored with this part of the ostrich skin because it has an unusual look and feel. Ostrich skins, like other hides, can be dyed many colors. Increasingly, those colors don't resemble any found in nature.

PAOLO MARCHETTI, ALEXIA FOUNDATION

be outraged, as animal rights activists insist? Should we applaud the advances the fur industry has made in animal welfare? Or do such measures merely "make us feel better about exploiting animals," as Gary Francione, a Rutgers University law professor who advocates ending all human use of animals, has argued?

Like pig or chicken farming, fur farming is about keeping animals in captivity their entire lives and then killing them. It entails practices many people would consider unthinkable. Some fox farmers, for example, kill their animals by anal electrocution. It's supposedly the quickest practical method, though with what one farmer described mildly as "a perception problem."

Industrializing our relationships with animals has also created problems. Many fur farmers manage to provide humane care on a large scale, but others can't or won't. And in the auction house sorting process, pelts from as many as 300 farms, good and bad alike, can end up together in the same lot. That's a problem for any designer label wanting to assure customers of its reliance on humane, sustainable methods. The European fur industry says it is working on a fix, but its new WelFur program must

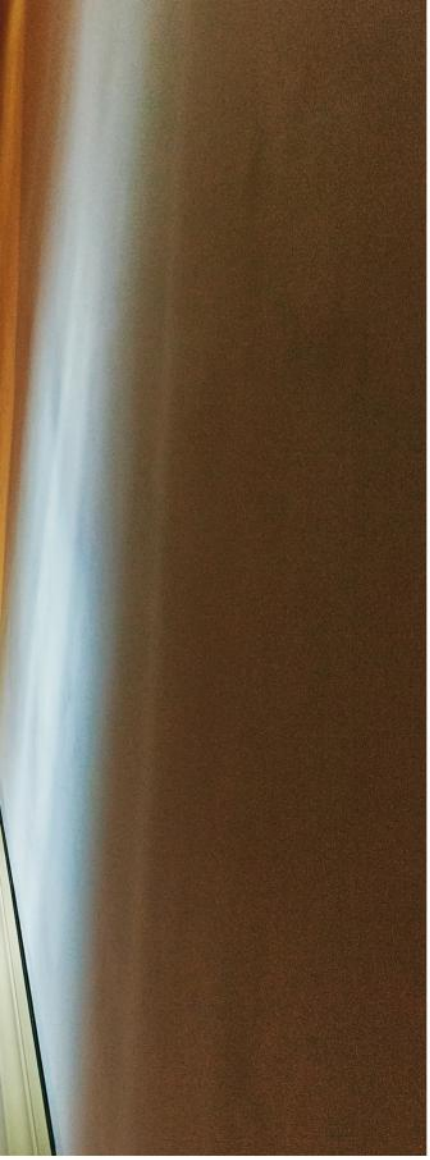


Luxe handbags, arrayed like sacred objects, hold the attention of a visitor to a Bianchi e Nardi showroom. Run by the grandchildren of the founders, the 70-year-old firm has two factories in Florence that craft about 80,000 handbags a year from ostrich, crocodile, lizard, python, and other skins.

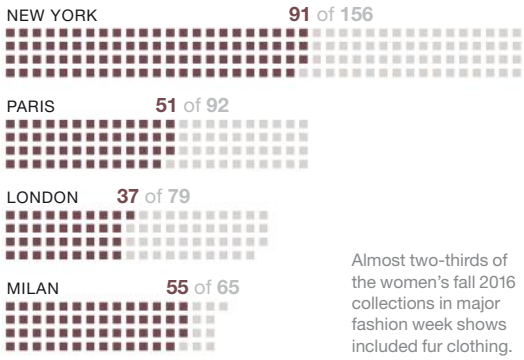
first inspect and grade thousands of farms.

When I visited a mink farm in Denmark with Steen Henrik Møller, an Aarhus University agronomist helping to develop the protocol, the inspection was dauntingly thorough. He checked the nest box attached to each cage for size and the amount of straw for winter insulation. He examined the animals for body condition, injuries, and repeated back-and-forth motions that indicate stress. He inserted a tongue depressor in each cage to see if the animal responded with fear, aggression, or curiosity. A WelFur visit requires about six hours to inspect a 120-cage sample for 22 features. "I hope we don't find anybody in the worst category," the farmer ventured tentatively, and Møller replied, "I hope we do, because if the system cannot distinguish among farmers, it doesn't work."

Either way, will people who buy fur actually care? "You'll get a much different answer if you ask in Shanghai or in Zurich," said Tage Pedersen, chairman of Kopenhagen Fur. "But in the future more and more people will care. Not just for fur, but for everything we buy. They will ask at the shop, Is the animal welfare OK? And if the retailer says yes, they'll ask, How do you know



Furs in the top fashion shows



Almost two-thirds of the women's fall 2016 collections in major fashion week shows included fur clothing.

that?" Pedersen said the fur business won't be able to afford the inspection process if customers are unwilling to pay a premium for the WelFur label. But he believes they will.

I came away with a contrarian idea. The ambition in the animal rights movement has always been to ban fur farming. The United Kingdom, Austria, and Croatia have done so, and the Netherlands is working on a ban. But banning doesn't stop people from wearing fur. It just moves production to areas where no rules apply. At the auction I asked a broker who has a mink farm in China if that country has made much progress on animal welfare. He bristled, then tersely answered, "Not much."

Banning fur farming also does nothing about other livestock farming we take for granted. It's a gesture that affords us moral righteousness without actual sacrifice, since most people have never bought a fur product and probably never will. Yet most of us go on eating meat, drinking milk, wearing leather shoes, and otherwise exploiting animals, as humans always have, on a scale that makes the fur industry a sideshow.

People in the fur trade like to dwell on the implied hypocrisy. "I just read that Americans consumed 1.3 billion chicken wings on Super Bowl Sunday," said Zilberkweit, the fur retailer. "I can do the math: That means 650 million chickens were killed for one day's entertainment." At some point almost everyone in the fur trade notes that other livestock producers have not had to improve their practices nearly as systematically as they have. "We knew we could have a ban if we didn't," said Pedersen. "Other animal producers haven't been afraid of that."

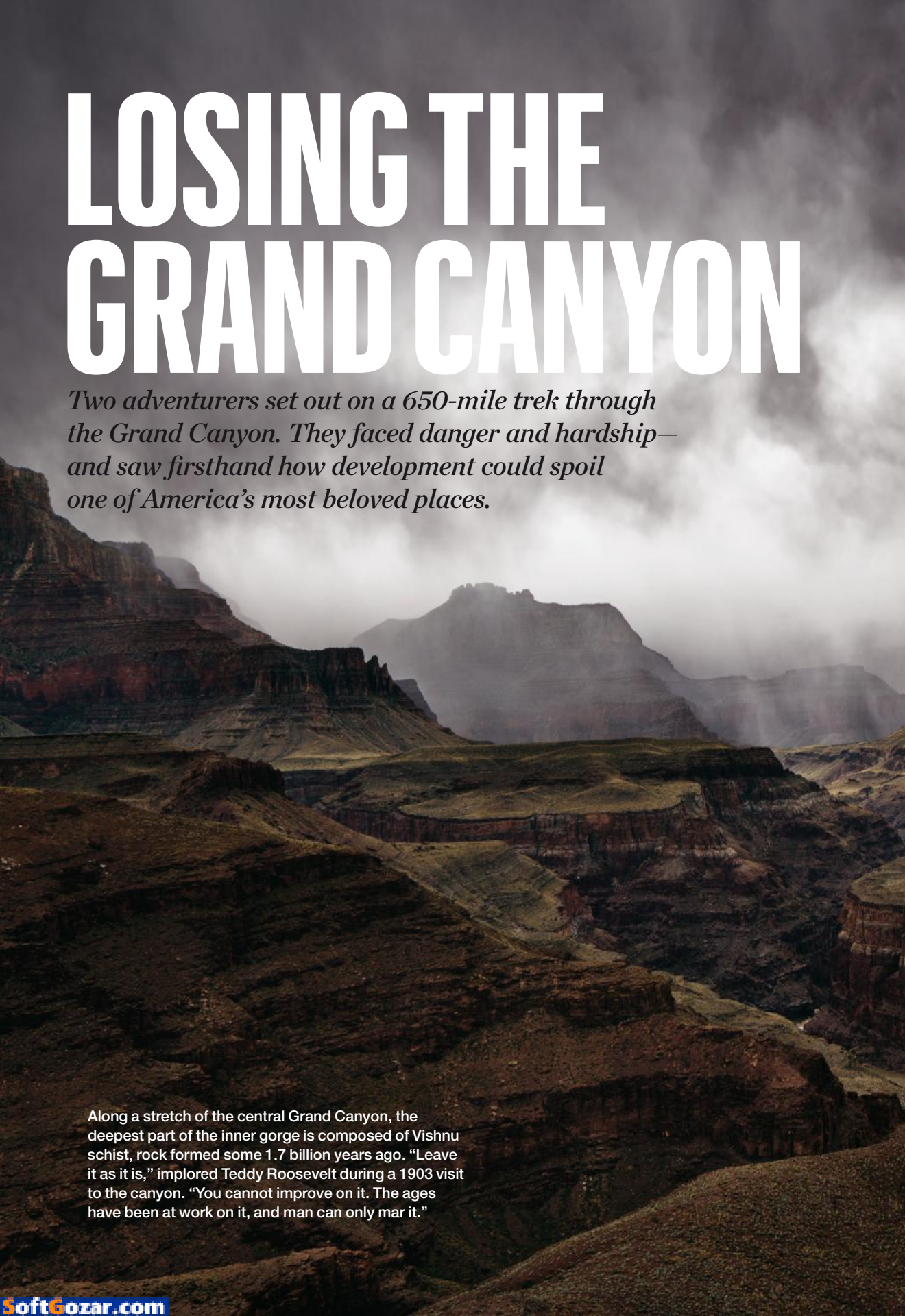
So here's my idea: Instead of banning fur production, keep applying pressure to push out the worst farmers. Then take the most progressive fur farmers and the improvements they've made that are not only feasible, but even at times profitable—containment of agricultural runoff, measures to reduce stress, better housing, routine welfare inspections—and make them the model for all the forms of animal production on which our pampered lives depend. ▯

To see more of **Paolo Marchetti**'s photographs—and to tell us what you think about raising animals for their skins—please visit *ngm.com/Sep2016.*

GRAPHIC: NGM STAFF. SOURCE: FUR COMMISSION USA

LOSING THE GRAND CANYON

Two adventurers set out on a 650-mile trek through the Grand Canyon. They faced danger and hardship—and saw firsthand how development could spoil one of America's most beloved places.



Along a stretch of the central Grand Canyon, the deepest part of the inner gorge is composed of Vishnu schist, rock formed some 1.7 billion years ago. "Leave it as it is," implored Teddy Roosevelt during a 1903 visit to the canyon. "You cannot improve on it. The ages have been at work on it, and man can only mar it."

A group of Havasupai, whose reservation lies within the Grand Canyon area, protest at Canyon Mine, expected to start producing uranium in 2017. “We are on the front lines of a contamination,” says Carletta Tilousi (second from right). Mines have poisoned springs in the region before, but Energy Fuels, which operates the mine, says it’s safe.

Hualapai boat tours ply a section of the Colorado River adjacent to the tribe's reservation. In principle the river divides the reservation and Grand Canyon National Park, but the tribe and the Park Service disagree on the exact boundary. The tribe believes their land extends to the middle of the river. The Park Service says it ends at the high-water mark on the south bank.

By Kevin Fedarko, Photographs by Pete McBride

"If you break loose here, you can't stop. You're going into the abyss," barks Rich Rudow. Normally he is unflappable, but as he knows too well, this is no place to let down one's guard. We're on a cliff roughly 3,500 feet above the Colorado River at the tip of the Great Thumb Mesa, a spectacular formation that thrusts out from the South Rim of the Grand Canyon like the bow of an immense ship. It is one of the canyon's most remote spots, rarely seen even by the most hard-core backpackers. If you come this far out on the Thumb, there is no way to get down to the river without climbing gear, and the dwindling food in your pack won't allow you to make the eight-day trek back the way you came. You have to move forward.

Just ahead, the ledge that we've been walking on for the past several days vanishes into a deep indentation, or bay, in the wall of the canyon. This place is known as Owl Eyes, named for two enormous oval holes punched into the center of the cliff that looms over the middle of the

Mathieu Brown (left), Kelly McGrath (center), and the author negotiate the Walter Powell Route to the South Rim.

An end-to-end trip through the Grand Canyon isn't a particularly sane thing to attempt on foot.

bay. It's a spooky place. Besides its ominous skull sockets, Owl Eyes is part of a tragic story. Nearly four years earlier, on a sunny February day, a beautiful young woman, a friend of Rudow's, was crossing this passage when she fell to her death.

Now we're staring across the same terrain, in far worse conditions. A storm had lumbered in the previous evening and coated the canyon in nine inches of snow. This is not what we'd imagined when we started this venture, an end-to-end hike of the Grand Canyon.

It isn't a particularly sane thing to attempt. There is no single trail or network of trails that stretches along the entirety of the North or South Rims. The most efficient way to travel the length of the canyon is to float down the Colorado River, which winds through the canyon for 277 sinuous miles. That's why John Wesley Powell—who led the first documented traverse of the canyon—did so by boat.

After Powell's achievement in the summer of 1869, more than a century would pass before the first known traverse by foot. During that time the canyon progressed from a forest reserve to a national monument until finally taking its place as the crown jewel of the National Park System and arguably the most recognized and beloved landscape in America. It became a vacation destination for hundreds of millions of families, its image captured on innumerable postcards. Yet nobody figured out how to walk all the way through the thing until a 25-year-old river guide named Kenton Grua completed it in the winter of 1976, some 65 years after both the North and South Poles had finally been reached, and 23 years after Mount Everest was first summited.

Think about that for a moment—and consider what it says about how complicated and wild this place truly is.

No one is sure of the exact distance Grua covered, but thanks to the countless bays, he probably walked more than 700 miles during his 37-day thru-hike along the south side of the river from Lees Ferry to the Grand Wash Cliffs.

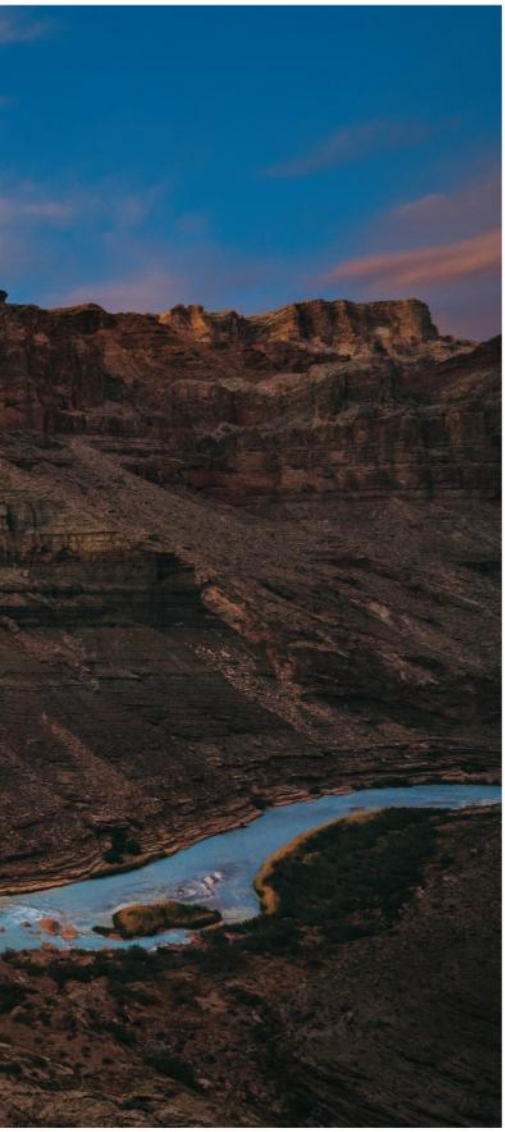
He never publicized his feat. But as word of what he'd done slowly spread, a new challenge

Local tribes regard the Confluence, where the Little Colorado's blue waters merge with the Colorado, as sacred. Developers hope to build a tramway here to carry up to 10,000 tourists a day to a riverside retail and food complex.

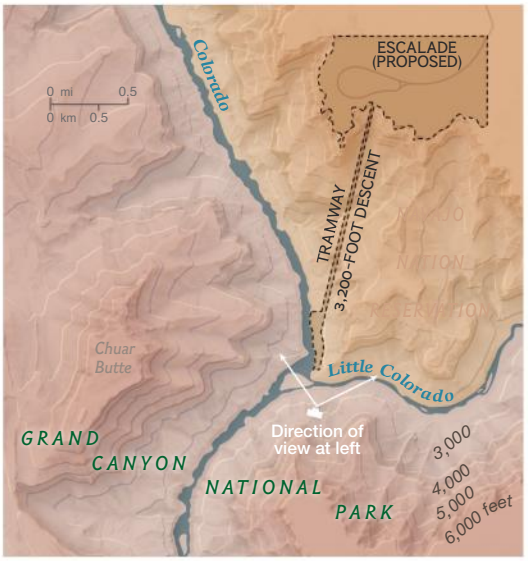
opened up to a tiny community of extreme backpackers, including an electrical engineer from Phoenix named Rich Rudow. By the autumn of 2015, Rudow had completed hundreds of hikes and slot canyon explorations in the canyon and felt he was ready for his biggest challenge: a 57-day trek moving east to west across the canyon's north side.

By the time Rudow and two companions were ready to launch—almost 40 years after Grua's thru-hike—fewer than two dozen people had approximated his feat by stringing together a chain of separate hikes along the length of the canyon, known as a "sectional" thru-hike. The

The canyon provokes two reactions: the urge to protect it, and the temptation to make a pile of money from it.



The proposed Escalade Tramway project would be built on the western edge of Navajo land. Supporters say it will bring tourism revenue to the impoverished reservation.



number of trekkers who had completed a "continuous" thru-hike in a single push was even smaller. Before 2015 more people had stood on the moon (12) than had completed a continuous thru-hike of the Grand Canyon (eight).

When photographer Pete McBride heard about Rudow's plans, he called him and asked whether we could join his group. Pete and I had years of experience boating in the canyon, but we were woefully unprepared for what lay ahead. The only explanation for Rudow's agreeing is that he was swayed by our primary reason for wanting to do it: to look into disturbing reports we'd been hearing about the canyon's future, which included new tourist developments, increased helicopter flights, and a uranium mine.

SINCE IT ENTERED the American consciousness, the Grand Canyon has provoked two major reactions: the urge to protect it, and the temptation to make a whopping pile of money from it. During the years after the Powell expedition, miners rushed into the canyon to lay claims for copper, zinc, silver, and asbestos. During the 1880s one tycoon wanted to turn the bottom of the canyon into a railroad corridor to haul coal from Denver to California. (He drowned in the Colorado, along with two members of his survey expedition.) In the 1950s a mining company tried to get rich by building a giant cableway to move bat guano from a cave and sell it to rose gardeners; that didn't last long. There was even a government plan to build a pair of giant hydroelectric dams in the heart of the canyon, a project that would have transformed large parts of the Colorado River into a series of reservoirs whose shorelines today would undoubtedly

CHARLES PREPPERNAU, NGM STAFF. SOURCES: GRAND CANYON ESCALADE; USGS

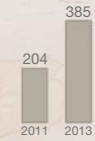
WEST

Crowded Skies

The Federal Aviation Administration caps air tours at 93,971 flights a year. This limit doesn't apply to the Hualapai, who are free to run unlimited air tours from their land. The FAA doesn't track Hualapai flights, and the tribe declined to say how many they allow a year.

HELICOPTER FLIGHTS NEAR QUARTERMASTER CANYON

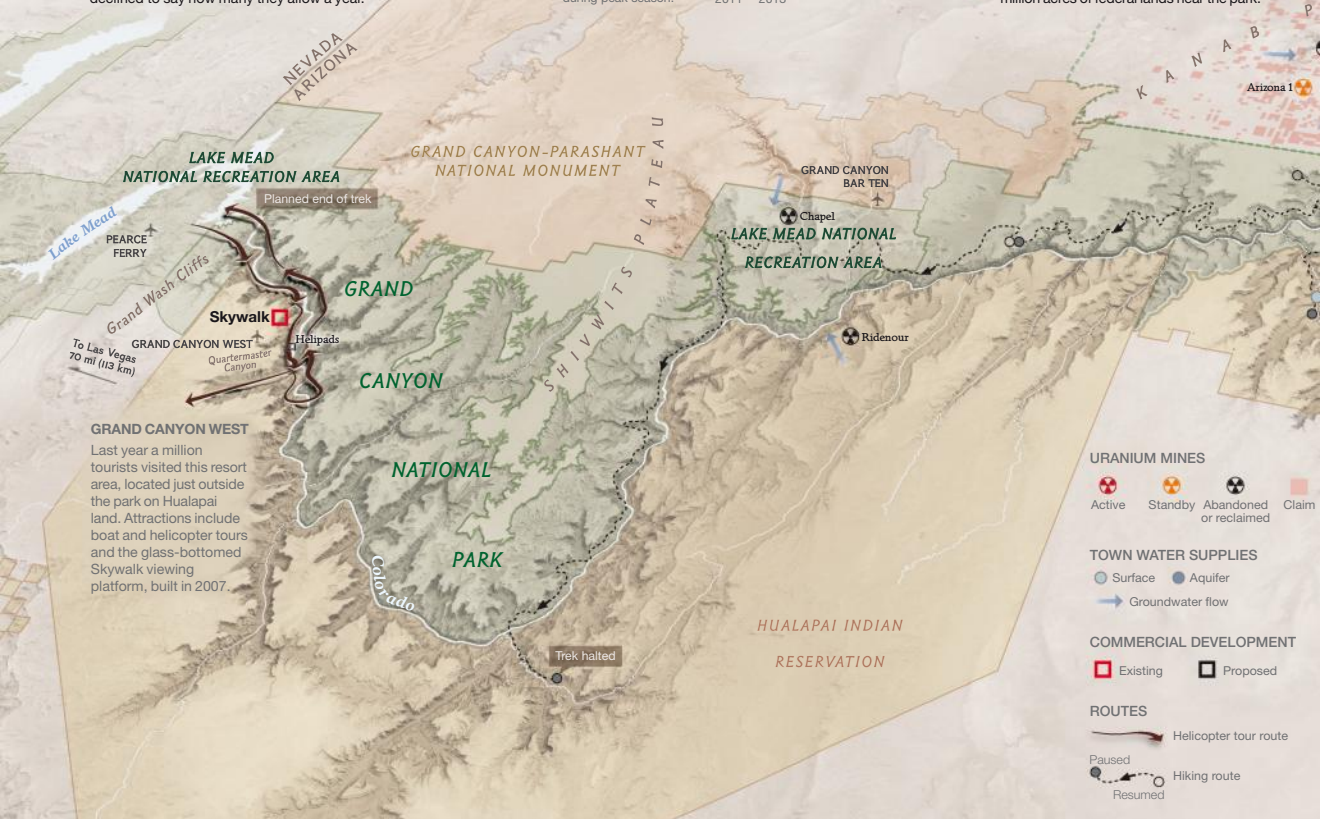
Average number of flights over three days during peak season.



CENTRAL

Toxic Legacy

The discovery of uranium in the 1940s led to decades of mining in the Grand Canyon area. One mine on Forest Service land is still active. In 2012 the interior secretary banned new uranium mining claims for 20 years in a million acres of federal lands near the park.



GRAND CANYON WEST

Last year a million tourists visited this resort area, located just outside the park on Hualapai land. Attractions include boat and helicopter tours and the glass-bottomed Skywalk viewing platform, built in 2007.

URANIUM MINES

Active · Standby · Abandoned or reclaimed · Claim

TOWN WATER SUPPLIES

Surface · Aquifer

Groundwater flow

COMMERCIAL DEVELOPMENT

Existing · Proposed

ROUTES

Helicopter tour route

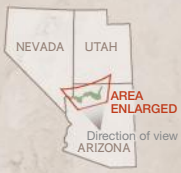
Paused

Hiking route

Resumed

CONTESTED CANYON

Human activities may seem dwarfed by the 1,904 square miles of the Grand Canyon, but their impact could be wide reaching. Rising tourist numbers, air traffic, mining, and development have increasingly encroached on the park's landscapes. Meanwhile the complex patchwork of federal, state, and tribal landownership complicates conservation efforts.



POLLUTED WATER

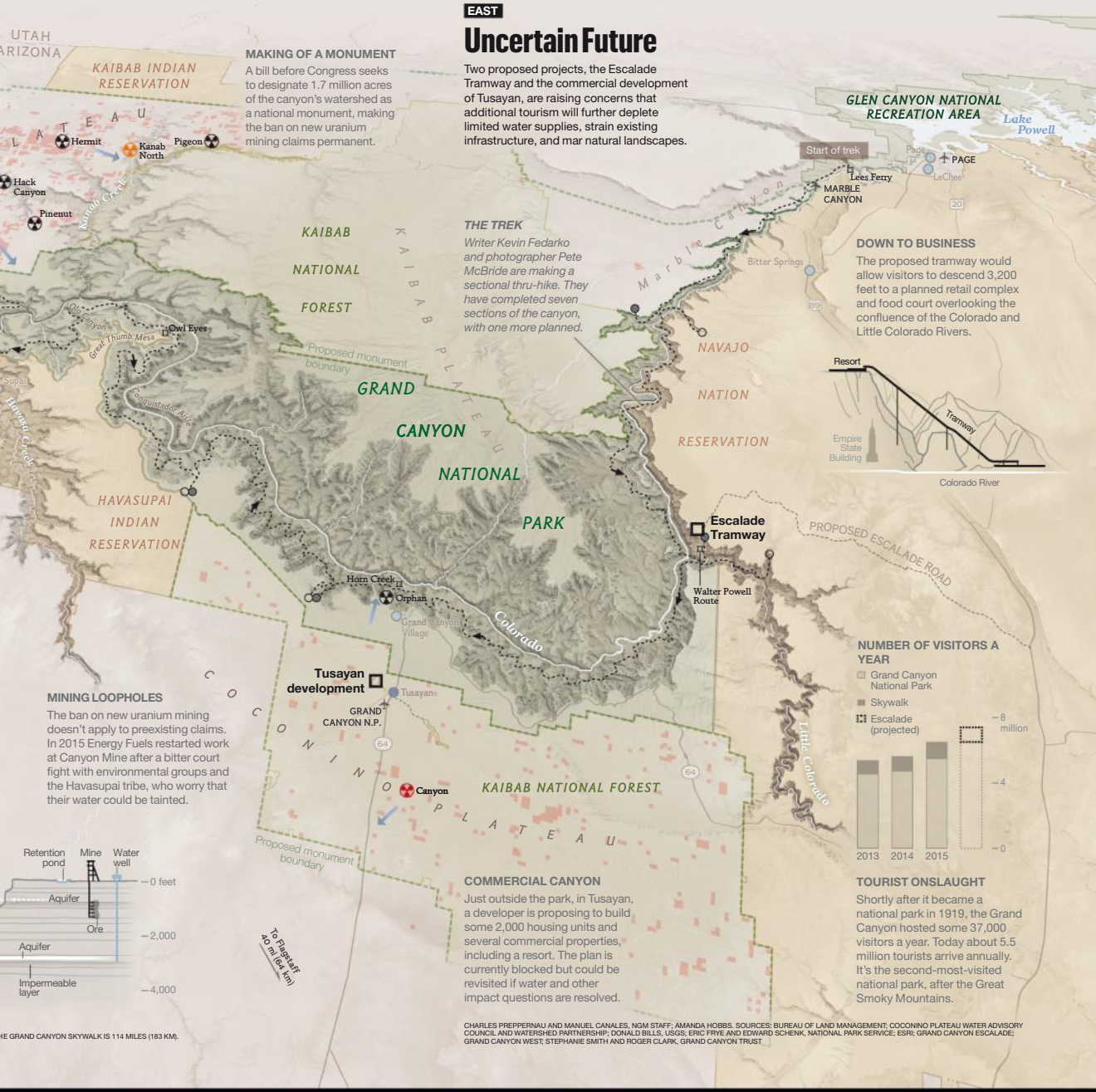
Contamination has occurred near older sites, including Hack Canyon and Orphan Mines, where erosion and problems with containment have allowed uranium to seep into waterways such as Horn Creek.

SCALE VARIES IN THIS PERSPECTIVE.
THE LINEAR DISTANCE BETWEEN THE GRAND CANYON ESCALADE SITE AND TI

EAST

Uncertain Future

Two proposed projects, the Escalade Tramway and the commercial development of Tusayan, are raising concerns that additional tourism will further deplete limited water supplies, strain existing infrastructure, and mar natural landscapes.



MAKING OF A MONUMENT

A bill before Congress seeks to designate 1.7 million acres of the canyon's watershed as a national monument, making the ban on new uranium mining claims permanent.

THE TREK

Writer Kevin Fedarko and photographer Pete McBride are making a sectional thru-hike. They have completed seven sections of the canyon, with one more planned.

DOWN TO BUSINESS

The proposed tramway would allow visitors to descend 3,200 feet to a planned retail complex and food court overlooking the confluence of the Colorado and Little Colorado Rivers.

MINING LOOPHOLES

The ban on new uranium mining doesn't apply to preexisting claims. In 2015 Energy Fuels restarted work at Canyon Mine after a bitter court fight with environmental groups and the Havasupai tribe, who worry that their water could be tainted.

COMMERCIAL CANYON

Just outside the park, in Tusayan, a developer is proposing to build some 2,000 housing units and several commercial properties, including a resort. The plan is currently blocked but could be revisited if water and other impact questions are resolved.

NUMBER OF VISITORS A YEAR

TOURIST ONSLAUGHT

Shortly after it became a national park in 1919, the Grand Canyon hosted some 37,000 visitors a year. Today about 5.5 million tourists arrive annually. It's the second-most-visited national park, after the Great Smoky Mountains.

HE GRAND CANYON SKYWALK IS 114 MILES (183 KM).

CHARLES PREPPERNAU AND MANUEL CANALES, NGM STAFF; AMANDA HOBBS. SOURCES: BUREAU OF LAND MANAGEMENT; COCONINO PLATEAU WATER ADVISORY COUNCIL AND WATERSHED PARTNERSHIP; DONALD BILLS, USGS; ERIC FRYE AND EDWARD SCHENK, NATIONAL PARK SERVICE; ESRI; GRAND CANYON ESCALADE; GRAND CANYON WEST; STEPHANIE SMITH AND ROGER CLARK, GRAND CANYON TRUST

Former Grand Canyon ranger Amy Martin watches a winter sunrise over a section of the Colorado called Conquistador Aisle. No trails exist along 95 percent of the canyon's North Rim or along 80 percent of its South Rim. Fewer people have now hiked the canyon's length in a single trip (10) than have walked on the moon (12).

be clotted with houseboats and Jet Skis.

The successful campaign to stop those dams, spearheaded by the Sierra Club during the 1960s, established the idea that the Grand Canyon is inviolable. And yet Pete and I had heard about a range of new proposals—many of them driven by savvy entrepreneurs operating just outside the canyon's boundaries in areas that were controlled not by the National Park Service but by the U.S. Forest Service or one of the five Native American tribes whose federally recognized reservations are located around the canyon. From every point of the compass, threats ranging from colossal tourist developments and unlimited helicopter tours to uranium mining were poised to spoil one of the world's premier parks.

It seemed to Pete and me that the best way to understand what was really at stake was to follow Kenton Grua's example and hike straight through the heart of it all.

"DUDE, ARE YOU ALL RIGHT?" Pete murmurs, shaking me gently. "Wanna try and eat something before you totally pass out?"

It's late September, the sun is about to set on our first day of walking, and I'm splayed across the narrow patch of dirt where we're supposed to spend the night.

One of the many things that I hadn't prepared for is that there's nothing gradual about this initial stretch of the journey. The canyon sucker punches its challengers with some of the most punishing territory right out of the gate. Add to that our 50-pound packs and an early autumn heat wave that pushed temperatures to 110 degrees, which wrung every bit of moisture out of our bodies and had begun peeling away the soles of our hiking shoes.

By the next morning Pete felt even worse than me. He had muscle cramps so intense that when he removed his shirt, it looked as if a mouse had wriggled into his abdomen and was scurrying from his shoulders to his stomach and back, just beneath the skin.

On day six we acknowledged that we were in over our heads and bailed, leaving Rudow and his partners to continue. On the trek out, Pete was delirious and disoriented, and once back in Flagstaff, he was diagnosed with hyponatremia, a heat-induced imbalance of salts and minerals, which, left untreated, could result in death.

In late October, intimidated but not defeated, we descended back into the now much cooler canyon and resumed our journey at the milepost where we'd pulled out three weeks earlier. Over the next several days, we threaded a route along a dizzying set of limestone ledges that dropped almost a thousand feet straight down to the river. Near river mile marker 32, we could discern the shadowy portal of the cave where archaeologists have found artifacts of the ancestral Puebloans, who inhabited this landscape for more than 10,000 years, as well as the remains of Harrington's mountain goat *(Oreamnos harringtoni)* and yesterday's camel *(Camelops hesternus),* now extinct creatures that flourished until the end of the Pleistocene, about 12,000 years ago.

A daily pattern emerged: Each morning we would stuff ourselves with oatmeal, then set out on a 12- to 14-mile slog that usually involved hauling our packs up as much as a thousand vertical feet, descending impossibly steep slopes, or pushing through thickets of thornbushes. This would go on until the sun began to set, at which point, battered, scratched, and bone-tired, we would boil water, wolf down some rehydrated dinner, then lie back and gaze at the night sky while listening to the words of Edward Abbey on an audiobook Pete had downloaded onto his phone.

The book was *Desert Solitaire,* Abbey's homage to the country of the Grand Canyon's sister parks, Canyonlands and Arches. Although I was usually too exhausted to stay awake for more than a few sentences, I often asked Pete to replay the part where Abbey warns readers not to jump into their cars next June and rush out, hoping to see some of the wonders he had attempted to evoke:

In the first place you can't see anything *from*

a car; you've got to get out of the goddamned contraption and walk, better yet crawl, on hands and knees, over the sandstone and through the thornbush and cactus. When traces of blood begin to mark your trail you'll see something, maybe. Probably not.

Although that passage seemed to speak most directly to me in the moment, I always willed myself to stay awake for what followed:

In the second place most of what I write about in this book is already gone or going under fast. This is not a travel guide but an elegy. A memorial. You're holding a tombstone in your hands.

Those words, which Abbey wrote in 1967, carried a disturbing prescience because the wilderness of Arches that he once reveled in is now overwhelmed by so many visitors—1.4 million in 2015—that the entrance to the park had to be closed intermittently on Memorial Day weekend last year. And due to a dam project, the wonders of Glen Canyon, said to rival the beauty of the Grand Canyon, now lie beneath the surface of a 186-mile-long reservoir named after John Wesley Powell.

As Pete and I were about to discover, changes that bear a disturbing resemblance to the forces that Abbey had warned against—growth, development, and the pursuit of money—are unfolding inside Grand Canyon.

SIXTY-TWO RIVER MILES downstream from Lees Ferry, the reddish brown Colorado encounters its largest tributary within the canyon, a river known as the Little Colorado, whose waters often run a brilliant shade of turquoise. The point where the two streams merge, known as the Confluence, holds profound spiritual significance for many Native Americans whose ancestral lands lie within the canyon, including the Havasupai, the Zuni, the Hopi, and the Navajo.

On the morning of November 2, we emerged on the north side of the river, inflated a pod of tiny rafts that we'd been carrying at the bottoms of our packs, and paddled across to begin an arduous 3,500-foot climb through a series of steep breaks in the cliffs that eventually delivered us to a remote stretch of the canyon's eastern rim and the western border of the Navajo Reservation. We selected this route because it runs parallel to the path along which a group of developers from Scottsdale intend to construct the Escalade Tramway. Eight-person gondolas would shuttle tourists from the rim to near the river's edge, where the developers plan to erect a retail complex, food court, and amphitheater overlooking the Confluence.

The tramway would be capable of delivering as many as 10,000 people a day to a spot that now rarely hosts more than a few dozen people on a typical summer day, and often none during the winter. There has never been a development like it inside the canyon.

The driving force behind this project is R. Lamar Whitmer, a political consultant who has persuaded a group of Navajo politicians that it would bring much needed revenue to the tribe. The opposition includes environmentalists as well as virtually every tribe in the region, including a group of Navajo who say that Whitmer and his associates tricked some tribespeople into supporting the project with misleading promises. (Whitmer denies he misled anyone.)

This group calls itself Save the Confluence. When one of its members, Renae Yellowhorse, got word that Pete and I were scheduled to pop out of the canyon at a spot overlooking the Confluence, she telephoned a friend and asked him to drive her 41 miles from her home on the western edge of the Navajo Reservation, so that she could share a pot of traditional mutton stew and give us a piece of her mind.

According to Yellowhorse, the reservation was now abuzz with rumors that Whitmer and his allies were assembling investors to finance the billion-dollar project while simultaneously forging new alliances with Navajo legislators in the hopes of making an end run around Navajo president Russell Begaye, a prominent opponent of the project. "We're not opposed to development, but it's not appropriate here," declared Yellowhorse, a fiercely determined woman in wire-rimmed glasses and leather moccasins. "When my grandchildren come, I want them to see this place the way that my

Tourists document a flight into Grand Canyon West. In 2015 helicopter tours helped draw over a million visitors to Hualapai land. Last spring, in an area known as Helicopter Alley, National Geographic counted 262 flights in five hours. Busy days can see 450 or more.

ancestors saw it. We don't want this area developed—we do *not* want to see Disneyland on the edge of the canyon."

As it turned out, the friend who had driven Yellowhorse to meet us, a man named Roger Clark, was able to provide some context for that statement. As a program director of the Grand Canyon Trust, a conservation group that has spent 30 years battling an array of threats against the canyon, Clark is deeply troubled by the tramway plan. But he is even more worried

'We do *not* want to see Disneyland on the edge of the canyon.'

Renae Yellowhorse, Navajo tribe member

Society Grant Your National Geographic Society membership helped fund this expedition.

that this project is part of a larger ring of threats that present an unprecedented assault on the integrity of the canyon.

One of the other issues that concern Clark and many other environmentalists is Tusayan, a small town composed of a strip of modest tourist motels and gas stations two miles from the park's main entrance at the South Rim. Tusayan has been taken over by a consortium of investors who want to transform it into a resort, with potentially thousands of new homes and millions of square feet of commercial space, including luxury hotels, a European-style health spa, and a dude ranch.

All of this will require lots of water. The developers, led by an Italian company called Stilo, say they are reviewing ways to bring in water, including by train or a pipeline tapped into the Colorado River. But they also have the right to punch wells through the surface of the arid South Rim to access an aquifer that drives many of the springs and seeps deep within the Grand Canyon. These tiny pockets where water trickles from cracks in the bare rock make up less than 0.01 percent of the surface area inside the canyon, but each little oasis supports a web of complex plant and animal life. Thanks to the 6,000-foot elevation difference between the Colorado River and the North Rim, the canyon boasts five of North America's seven "life zones"—more than any other national park. In latitudinal terms, it's the equivalent of walking from the deserts of northern Mexico to the boreal regions of Canada, all in the span of little more than a vertical mile. Biologists say anything that might taint these springs or induce them to dry up would reverberate throughout the canyon's biome.

Clark didn't know it at the time, but the U.S. Forest Service would soon refuse to review the town's application for a road easement that is crucial for the project to go forward. But Tusayan's backers already have overcome many obstacles, and if they find a way to clear this final hurdle, little will stand in their way.

Tusayan, however, isn't the only threat to the region's aquifers. Just six miles to the southeast of the town—also outside the park—a company called Energy Fuels has reopened a mine after a bitter court fight with environmental groups and the Havasupai tribe and soon will be hauling out uranium ore. A company official dismissed the possibility of a major accident. But according to U.S. Geological Survey data, 15 springs and five wells inside the Grand Canyon area have levels of uranium that are considered unsafe to drink, due in part to incidents in older mines, where erosion and problems with containment have allowed uranium to leach into the groundwater.

Meanwhile a 22-mile stretch of the river corridor at the bottom of the western end of the

Backcountry explorer Rich Rudow (at left) and the author eat dinner beside a spring in Olo Canyon, one of the Grand Canyon's numerous tributaries. Similar oases could be damaged by proposed developments near the park, which, if built, could diminish or contaminate the aquifer that supports life on the South Rim.

A flight over the upper Grand Canyon offers a view of the edge of the Navajo Reservation (far side of the canyon). No single spot provides a view of the whole canyon. Its scale disguises its fragility, says Roger Clark of the Grand Canyon Trust. “Our greatest challenge is making people understand just how truly vulnerable this place actually is.”

canyon has been opened to unlimited air traffic by the Hualapai, a tribe whose reservation borders the south side of the Colorado River. Thanks to a Federal Aviation Administration rule change requested by the Hualapai, the tribe may operate an unrestricted number of helicopter flights. These are filled with sightseers, many from Las Vegas, and fly below the canyon's rim from sunrise to sunset. The noise they generate is so intense, and so continuous, that the area is locally known as Helicopter Alley.

"When you look across this vast landscape now, it's hard to believe that it could possibly be damaged or lost due to acts of man," Clark said. "But each of these threats is capable of eroding a piece of the canyon's majesty, and together they will strip the landscape of its ability to do the thing that makes it unique, which is to instill humility by demonstrating that human beings are tiny in relation to the forces that have shaped this planet, and that we are not the center of the world."

The bigger threat, Clark contends, is that Tusayan, the tramway, and Helicopter Alley have the potential to accelerate neighboring development projects. He noted that the Hualapai's wildly successful helicopter operation has drawn interest among some Navajo, who believe that the cable-driven gondola system could be an anchor for a similar explosion of air tours along the eastern flanks of the canyon. If that vision were realized and if Tusayan's development were to move forward, Clark said, the impact would be enormous. "You would have a mega-resort perched directly above the central portion of the canyon and bookended by a pair of massive air-tour operations, each anchored to its own new development," he said. "In a very real sense, the entire sweep of the canyon would be transformed into something that looks less like a national park and more like an amusement park."

AFTER THANKSGIVING Pete and I headed back to where we'd ended our previous push and began hiking downstream. One hundred twenty-two miles later, we climbed back out, at the park's South Rim entrance. Next came a 66-mile push that began just after New Year's. Our pace each day was determined by the location of springs, which we relied on for drinking water, hopscotching from one to the next. At a place called Horn Creek, we had to bypass a large spring contaminated by an abandoned uranium mine just below the South Rim that has poisoned its water since the 1960s.

At the end of January, as we were preparing for the most formidable leg of all—a 155-mile thrust around the Great Thumb Mesa—our friend Rich Rudow reentered the picture. He and his partner, Chris Atwood, had passed through the Grand Wash Cliffs in late November, becoming the ninth and 10th people to ever complete a continuous thru-hike of the entire canyon. (Their friend Dave Nally had pulled out early with respiratory problems.) Rudow had been tracking our progress via satellite texts we'd been sending and was worried about the challenges Pete and I would face on the Thumb in winter, when storms can blow in with little warning and dump several inches of snow.

Rudow had decided that he needed to return to shepherd us through. Which is how, on the afternoon of February 1, we all came to be standing in almost a foot of snow at the edge of Owl Eyes, wondering how we were going to make it across.

At the far end of the horseshoe-shaped bay was a massive ledge. If we could reach that flat piece of ground, we'd be OK. But getting there would require navigating directly across a steep slope of shale, hoping that if we slipped, we'd be able to stop our slide before shooting over the 400-foot cliff. It was already late in the afternoon, and if we failed to make it to safe ground before dark, we'd confront the appalling prospect of having to spend the night on the treacherously slick slopes of Owl Eyes.

After more than two hours, we'd only made it to the middle of the horseshoe, where a small promontory extended out from the slope. It was no more than 20 yards long, but there was a flat space on top, and at the far end there was a small pile of stones. When we reached the stones, Rudow halted and bowed his head for a moment.

Then he removed his glasses and wiped his eyes.

"I'm so sorry," he said softly. "It's very emotional to be standing here." Then he told us the story of what had happened to the young woman in whose memory the stones had been placed.

HER NAME WAS IOANA ELISE HOCIOTA. She originally was from Romania, spoke four languages, and had degrees in mathematics and biology. She was 24, newly married, and she and her husband, Andrew Holycross, were close to completing a sectional thru-hike of the canyon.

By the winter of 2012, Hociota had set her sights on the 20-mile stretch of ledges near the Great Thumb Mesa. When Holycross realized that his work schedule would prevent him from going, Hociota paired up with Matthias Kawski, a math professor and her academic mentor.

They were in the middle of Owl Eyes when they stopped for lunch. Afterward Kawski headed farther up into the shale. Hociota opted for a more direct line that took her out of Kawski's sight. A minute or two later Kawski heard a rock fall, followed by a sharp scream, and then, after a few seconds, a hollow *thump*. Scrambling to the edge of the cliff, he peered down, looking in vain for Hociota. He called out over and over. Nothing.

The next day Hociota's body was discovered, and a ranger tethered to a helicopter was lowered to retrieve it. When Rudow finished his story, he looked west, where the sun was angling toward the canyon's rim. "Guys," he announced. "We're gonna have to spend the night here."

That night all of our water bottles froze, even though we stashed them inside the two tents that we pitched on the tiny patch of flat ground next to Hociota's memorial. Our shoes froze too, and the next morning we had to hold them over our camp stoves to thaw them out.

We broke camp and trudged the rest of the way across the snow-encrusted slopes to the flat ledge on the far side of Owl Eyes, where we dried our gear in the sun and looked back at the ground we had crossed.

It was a sad and dangerous place, and I was glad to be done with it. But I couldn't help but note that it was also quite beautiful. In the morning sunlight, even the face of the cliff down which Hociota had fallen was coated in a honey-colored glaze that seemed to glow from within. In that moment I may have glimpsed part of what Edward Abbey meant when he wrote about how it's necessary to crawl across this terrain and bleed before you finally see something.

What I saw—or rather, what I understood—was that of the many things that had drawn a math prodigy from Romania into this landscape was that the canyon is emphatically not an amusement park. It is without handrails, a place where the dangers are real. But no less real are the rewards—among them the fact that when you move through an ancient wilderness that has not been compromised, you are reminded of our species' humble place in it and the fragility of life. Apparently Ioana Hociota understood that she needed places like that. And I suspect that the rest of us may need them too.

Four days later we hiked out. And after resupplying in Flagstaff, Pete and I resumed our thru-hike in a series of pushes that, by the middle of March, brought us to within 50 miles of the end. But the canyon wasn't through with us. One morning the thermometer on Pete's watch hit 111 degrees, hotter than the temperature that had triggered his hyponatremia six months earlier. Thirty minutes later we started hiking out.

When we began this quest, we had no way of knowing that even after flinging ourselves at the canyon on nine separate trips over the course of a year, the end would still lie before us. As you're reading this in September 2016, it's likely we're back on the trail, trying to finish our thru-hike. If you're reading this story decades from now, say in 2066, hopefully a vast Grand Canyon wilderness, in the truest sense of the word, still exists. □

Discover much more of *National Geographic*'s adventure coverage, including updates on the final section of Kevin Fedarko and Pete McBride's 650-mile thru-hike across the Grand Canyon, at *ngadventure.com*.

Backstage at the Big Top

Story and Photographs by
CHRISTIAN RODRIGUEZ

Circuses are spectacles that enchant an audience. But for me the real magic happens behind the scenes. The daily life I witnessed backstage at two Vietnamese circuses—before, during, and after performances—was a captivating parallel to the performers' onstage personas.

During three trips from 2009 to 2012, I spent eight months in Vietnam. When I saw a circus in Hanoi, I was fascinated by its glamour. But as I got to know the performers personally, I felt compelled to show another aspect—to dignify their work and document their dedication.

Gaining intimate access wasn't easy: Circus artists prefer that people focus on their feats, not their lives. To win their confidence I had to go slowly. On my last trip I lived as they did then, taking up residence for four months in an abandoned theater in Hanoi, where the performers had to build their own rooms out of wood and plastic.

My approach worked. When I showed a sincere interest in my subjects and tried to present their situation as honestly as I could, they invited me into their lives. Once they'd accepted me, I was simply there among them, taking pictures and sharing life each day. This is what it looked like. ▯

Ma Hoang An rehearses with his wife, contortionist Nguyen Thi Thu Hiep, in Ho Chi Minh City. The two members of the city's circus troupe married in 2012 after training together in Hanoi. They practice twice a day for the aerial act they perform.

Nguyen (center) limbers up before a performance in Ho Chi Minh City. Circus artists in Vietnam make about $150 a month, plus another four dollars for each performance. It's not enough to live on, so most augment their salaries by performing at private parties or nightclubs.

Minutes before a performance in Hanoi's Lenin Park, members of the colorful Vietnam Circus Federation stand at the ready (clockwise from top left): Nguyen Linh Chi; Luu Van Cuong; Khanh Chi; and Pham Thi Huong and Duong Thi Quyen. Founded in 1956, the VCF is the oldest troupe in Vietnam. Unlike the one in Ho Chi Minh City, it's funded by the government, which also pays for the artists' housing.

In Hanoi purple light and a plume of smoke suffuse the Vietnam Circus Federation's tent before a show. The performers—most of whom hail from small rural towns—begin training early every morning and stage several shows a day. Here and in Ho Chi Minh City, life behind the bright lights is full of sacrifice.

Out on a Limb

In 1915 Paul Popenoe gave 26 photos of giant trees to *National Geographic.* One of them was this shot mailed from San Antonio—a massive pecan over five feet in diameter and ornamented with a daring, suspendered soul (inset).

Popenoe wrote widely on topics from date palms to the promotion of eugenics; he was later known in the United States as the father of marriage counseling. This photo came from a contest to find America's largest hardwood, the results of which were published by Popenoe.

This shot didn't win, but the pecan would become the Texas state tree in 1919. Its popularity had been growing since 1906, when former Governor James Hogg's last wishes included a walnut tree at his feet and a pecan tree as a headstone, the nuts to be "given out among the plain people so that they may plant them and make Texas a land of trees." *—Eve Conant*

PHOTO: PAUL POPENOE, NATIONAL GEOGRAPHIC CREATIVE

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