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The New Silk Road | The Tricky Lives of Lions

NATIONAL GEOGRAPHIC

THE END OF AGING?

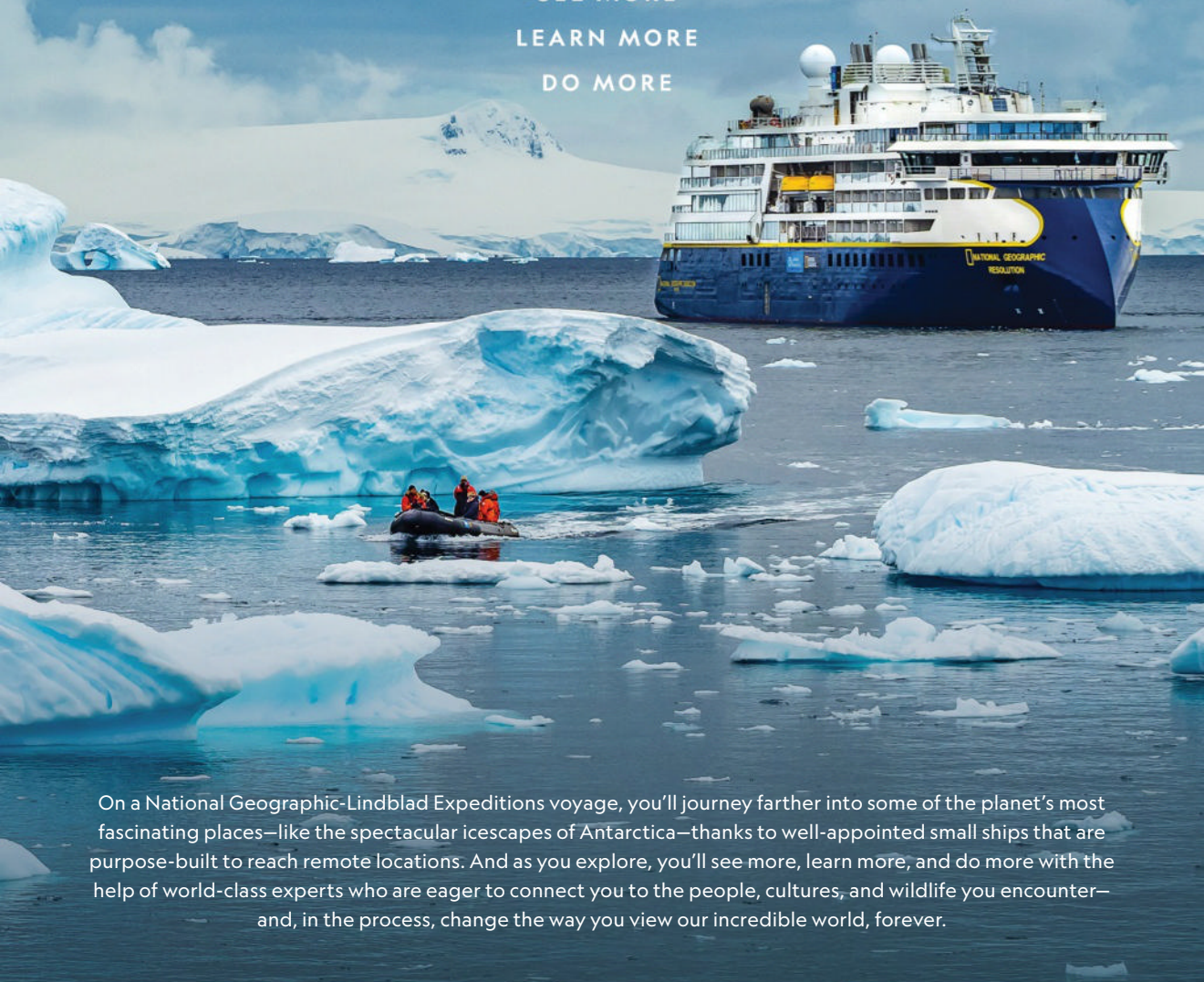
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to Turn Growing Old Into a Thing of the Past





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FROM *the* EDITOR

NATHAN LUMP

AS SO MANY of us know, getting older is not for the faint of heart. It comes, of course, with lots of mundane life changes that aren't too hard to bear. I now wear progressive lenses and manage my blood pressure, for example, and I definitely think twice before making that awkward reach into the back seat of the car, lest I pull a muscle that takes weeks to heal. But aging also makes us more vulnerable to a whole host of serious maladies: heart disease, osteoporosis, cancer. Every trip to the doctor these days is, for me, both a moment to feel gratitude for my overall good health and an opportunity to worry about exactly when my own aging process will catch up with me.

That is why this issue's cover story, featuring exceptional reporting and writing by D.T. Max, feels so relevant to me—and I expect will to you too. Scientists, in many cases funded

by deep-pocketed private investors, are today hard at work on actionable techniques to halt or reverse the aging process. Some of these are just entering their first human trials. To start, they are targeting specific diseases, like glaucoma, but the goal is broader: to ensure people live better, for longer.

The work is exciting and promising, and it raises plenty of thorny questions. If these therapies are effective, who will have access to them? What will they cost? And where do we draw the line? If we theoretically could extend life forever, would we want to? Our piece can't answer these questions, but we acknowledge that they are absolutely worth grappling with. Because this science is very real, and it's moving fast.

I hope you enjoy the issue.

A handwritten signature in black ink, which appears to be 'N. Lump', is located at the bottom right of the page, below the text 'I hope you enjoy the issue.'

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Figurines carved by Japanese Americans in World War II incarceration camps are symbols of dignity and resilience.

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With new threats facing the regal predators of the African savanna, a young lion's journey to adulthood has never been more hazardous.

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Fossilized skin is helping rewrite prehistoric science.

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MAKE WAY FOR GIANT ANTEATERS

Rapid development is nudging a distinctive Brazilian species onto ever busier roads. To protect the animals, researchers are leading a push to rethink what a highway can be.

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Cover illustration by JUSTIN METZ

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Our WORLD

BEHIND THE SCENES WITH NATIONAL GEOGRAPHIC



After escaping the debris of the South Tower on 9/11, New York State courts officer Patricia Mack radioed her colleagues.

THOSE WHO LIVED IT: 9/11 REMEMBERED

→ Twenty-five years on, the place in the American consciousness occupied by the attacks of September 11, 2001, is changing. Already, a whole generation without memories of that day has come of age. And as the events of 9/11 transition from a collective experience to a canonical piece of history, revisiting the attack and its aftermath continues to reveal new layers of meaning.

To mark the anniversary, we're launching an ambitious and immersive project focused on the

personal experiences of those whose lives were touched by the events of that day. In early September on *national geographic.com*, an interactive archive will feature hundreds of video clips from conversations our filmmakers have shared with survivors, first responders, and those who lost loved ones. And a new essay by **Garrett Graff**, the journalist behind the best-selling oral history *The Only Plane in the Sky*, will show how the initial 17 minutes of the attack—the

window of time between planes striking the Twin Towers—forever changed America. We'll also be telling the story of what it takes to create New York City's annual, ephemeral Tribute in Light, one of the world's most striking public art installations.

And the new three-part National Geographic docuseries **9/11 Reunited** brings together strangers who shared fleeting moments of aid and comfort that would shape the rest of their lives—some for the first time since that dark, defining day.

9/11 Reunited streams August 22 on Disney+. Check local listings.



PHOTOS: JASON FLORIO, REDUX (STREET); ROBERT CLARK



WHAT IT TAKES TO CAPTURE AFRICA'S MOST STORIED PREDATOR

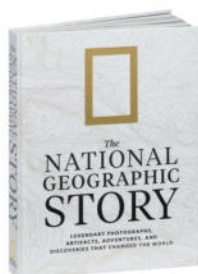
→ For illustrator and animator **Aaron Blaise**, who depicted the lifespan of African lions for this issue's feature on the challenges facing the great cats ("A Hard Reign," p. 104), there's no place more stirring than Kenya's Masai Mara National Reserve. Blaise made his first visit after working on Disney's 1994 film *The Lion King* and has returned many times to study the physiology and behavior of the animals there. The fieldwork informs both

his fine art and his animation, says Blaise, who also worked on films like *Aladdin* and *Pocahontas* and was a 2004 Oscar nominee for co-directing *Brother Bear*. His approach to illustrating lions for *National Geographic* isn't so different from how he renders an animated character: The former may lack anthropomorphic facial expressions, Blaise says, "but I still want to show the soul." His latest animation project is the short film *Snow Bear*.

"The city is really in need of not just optimism but also literal beautification—and native plants are the perfect way to do that."



Writer **Dana Goodyear**, who lost her home in last year's Los Angeles wildfires, reflects this month on how sowing native seeds in the city's burn zones helped her turn anguish into purpose ("Can Wildflowers Heal the Toxic Mess the L.A. Fires Left Behind?" p. 70). A longtime writer for the *New Yorker*, she's also the co-founder, with her son, of the Seed Bomb Project (theseedbombproject.com).

NEW FROM NATIONAL
GEOGRAPHIC BOOKS

→ The 138-year history of the National Geographic Society is filled with moments when relentless curiosity changed our understanding of the world: polar expeditions and first ascents, deep-sea discoveries and scientific breakthroughs, revelations about our past and the creatures who share our planet. ***The National Geographic Story*** offers new insights into this history alongside hundreds of extraordinary photos.



Jane Goodall, famed primatologist and National Geographic Explorer, in Tanzania in 1963.

A SEEKER ON
THE SILK ROAD

Writer Gary Shteyngart takes tea at the restaurant Ayvan, in a 19th-century merchant's mansion in Bukhara, one of the Silk Road oasis cities on his Uzbekistan itinerary.

→ Novelist and essayist **Gary Shteyngart** reports in this issue from Uzbekistan's increasingly popular tourist trail ("The Surprising Detour of the World's Oldest Superhighway," p. 76). His book *The Sensualist: Adventures in Pure Pleasure*, which will be published in November, collects his dispatches from China, Brazil, Italy, Cuba, and elsewhere, all in search of the sublime. But the well-traveled Shteyngart has long nursed a special fascination with Uzbekistan, ever since seeing pictures in his childhood books of the country's famed blue-tiled Islamic architecture. How did reality measure up? "It's like your eyes are in a turquoise bath," says the best-selling sensualist. "I've never seen anything like it." Shteyngart's most recent novel is *Vera, or Faith*.

SLINGSHOT CHALLENGE

The **Slingshot Challenge** is a global program for youth ages 13-18 that identifies and supports future problem-solvers, advocates and stewards for the planet. Youth were invited to create a one-minute video outlining an innovative solution to improving our environment.

A huge thank you to the 5,900 young changemakers who submitted creative ideas to the National Geographic Society to address environmental concerns across the globe through local solutions, and congratulations to all the award recipients!

Developed with the National Geographic Society and Allen Family Philanthropies.

2026 AWARD RECIPIENTS

Meet the young changemakers driving real, positive change in our world.



Learn more and sign up for the
Slingshot Challenge.



NATIONAL GEOGRAPHIC EXPLORERS

These contributors have received funding from the National Geographic Society, which is committed to illuminating and protecting the wonder of our world. Learn more about the Society's support of Explorers at natgeo.com/impact.



Revisiting a legacy of betrayal

→ Documenting the experiences of Japanese Americans unjustly incarcerated during World War II led **Haruka Sakaguchi** to the carved wooden birds she photographed for this issue, made by those confined (“When Art Becomes a Lifeline,” p. 102). The New York-based photographer spent two years traveling to the sites of 10 remote camps operated by the United States’ War Relocation Authority, where she interviewed survivors and their families. Her film and photo project, *The Camps America Built*, highlights more than 30 families making pilgrimages to where the camps once stood. “I was drawn to this idea of, instead of returning to a sacred place... you’re returning to a site of trauma,” Sakaguchi says. Her photos have also appeared in the *New York Times Magazine*, the *New Yorker*, and *Le Monde*. See more from her study of displacement at thecampsamericabuilt.com.

Mac Stone

“On the Run With the Atlantic’s Silver Surfers,” p. 56

Stone traveled along the Florida coast and into the Everglades to record the celebrated mullet migration. He also runs the conservation nonprofit Naturaland Trust, which protects land in his home state of South Carolina.

Fernando Faciole

“Make Way for Giant Anteaters,” p. 118

Faciole ventured across Brazil to photograph giant anteaters and the advocates helping design ways to keep them safe. In 2025 he won the Impact Award in the Wildlife Photographer of the Year competition in the United Kingdom.

Ákos Stiller

“Where a Million Falcons Go to Roost,” p. 44

An Explorer since 2022, Stiller traveled from his home in Budapest, Hungary, to photograph a newly discovered site in Angola that scientists call “Falconopolis,” where migratory raptors gather in huge swarms.



PHOTOGRAPH BY JASON GULLEY

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IN FOCUS

JUST IN FROM OUR PHOTOGRAPHERS



INSECTS

In this close-up of the parasitic wasp *Torymus calcaratus*, photographer **Thorben Danke** captured a defining feature: a needlelike organ called an ovipositor (at bottom right). The female uses it to inject eggs into the larvae of another species, enabling her newborns to feed off the host creatures. Danke took 289 photos of this preserved specimen at Germany's Stuttgart State Museum of Natural History, then used a stacking technique to create this hyper-detailed depiction.



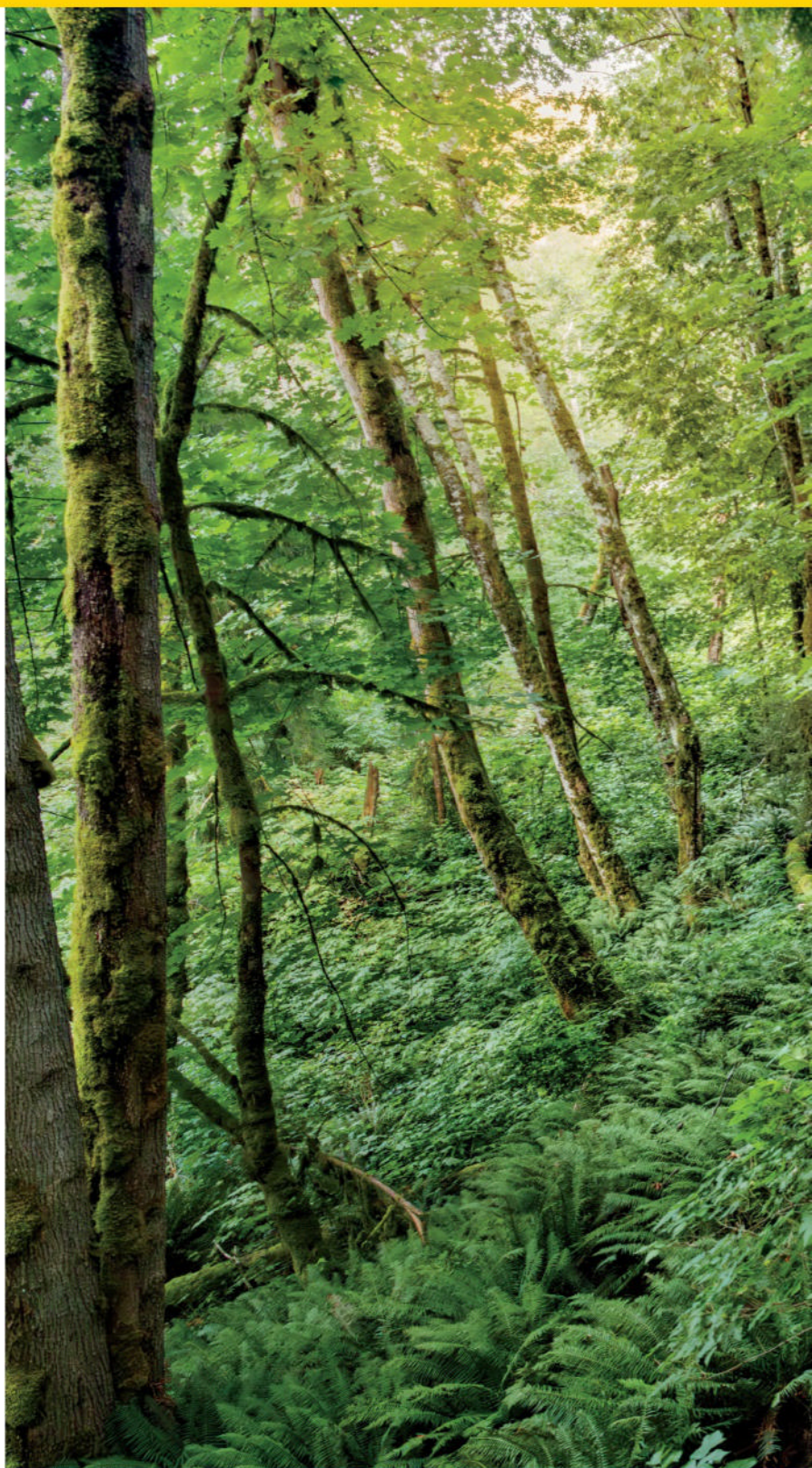
LIVELIHOODS

At a shipyard in Dhaka, Bangladesh, barefoot workers clamber up and down a pilot ladder while guiding a vessel into dry dock for repairs. Photographer **GMB Akash** says he was struck by “the vulnerability and physical effort” of the laborers, whose dangerous working conditions along this industrial waterfront have been criticized by human rights groups. Akash watched them plunge in and out of the polluted waters to help align the ship atop a wood frame before it was reeled ashore.

IN FOCUS

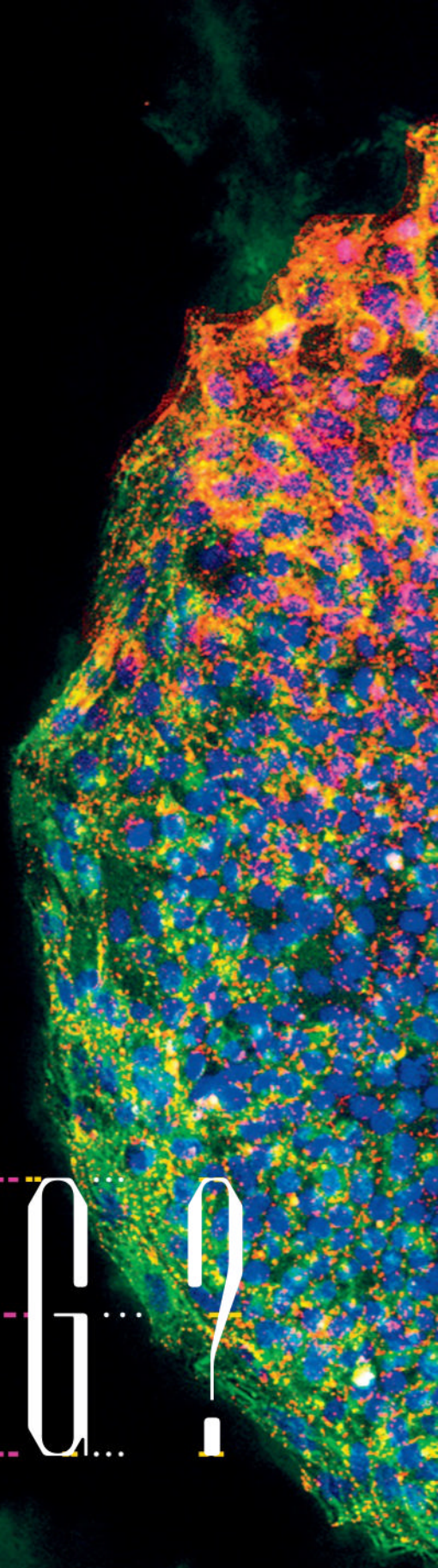
HABITAT

In Vancouver Island's temperate rainforests, black bears use cavities in old-growth trees as hibernation dens. But as industrial logging has claimed most of these giants, bears like this one, photographed with a camera trap by National Geographic Explorer **Ryan Tidman**, sometimes curl up on the stumps. Tidman says the animals use this spot as a "summer daybed," where they might snooze after fishing for salmon.





THE END OF AGING?





Every cell in your body contains a memory of its youth. Now a fiercely contested, billionaire-backed race is quietly underway to reawaken those memories. Doctors think this cellular reprogramming—just entering its first human trials—could wipe out dozens of ailments. Longevity experts are harnessing it for something even grander.

WORDS BY
D.T. MAX

PHOTOGRAPHS BY
ROBERT CLARK

In the lab, scientists can already turn back the clock on skin cells like these, returning them to their original state. The next step is to do it to the cells in a living human body.

WILLIAM COLLINS,
DEEPAK SRIVASTAVA LAB,
GLADSTONE INSTITUTES



THIS PAST APRIL, in a nondescript examining room in Glendale, California, molecular biologist David Sinclair watched as an ophthalmologist injected a small amount of a substance Sinclair helped invent, called ER-100, into the left eye of a man with advanced glaucoma.

The treatment was part of an FDA trial, and the ophthalmologist had disinfected the eye beforehand with iodine and then anesthetized it with lidocaine. Glaucoma is a disease that damages the optic nerves. It primarily affects the elderly and can leave an individual functionally blind. The man, who was in his early 70s, had lived with the condition for decades and had undergone multiple surgeries to try to slow it down. But by now he could see only about 50 percent of what was in front of him. For instance, he could see the aide as she put the needle into his eye, but he had someone drive him to the appointment. This new treatment was unprecedented, involving a substance never before injected into a human, one that could reverse his glaucoma by essentially getting his genes to turn back the clock on the affected optic nerve bundle to a time decades before, when it was healthy.

If the patient had been waiting a long time for this moment, so had Sinclair. A professor of genetics at Harvard Medical School, Sinclair had spent more than a decade developing the formula for ER-100, in tandem with Yuancheng Ryan Lu, one of his former grad students. The process involved not just modifying the proteins but also attaching a piece of viral material that would

Harvard molecular biologist David Sinclair, who co-founded Life Biosciences, has emerged as a scientific evangelist for the potential to reverse the aging process. In April the company launched the first human clinical trial of cellular reprogramming.



guide them to the right cells. Sinclair said he would be happy if ER-100 eased the patient's glaucoma, but that wasn't his primary goal. Glaucoma was really a convenient target for the substance because it damages the eye, which boasts a special immune defense system to tamp down the body's normal inflammatory response. "The FDA loves enclosed spaces for safety reasons," Sinclair told me. "We just thought it was a great place to start." If the injection succeeded, ER-100 would be one of the first medicines to reverse nerve damage in a human. This would be impressive on its own. But Sinclair developed the substance in the hope that it would be the first step toward reversing aging altogether.

ER-100 is a particle that contains the instructions for making transcription factors: proteins that switch genes on and off. The three transcription factors in ER-100 normally activate genes that the human embryo uses to keep its stem cells from differentiating into nerve, skin, heart, and other organs of the body. But the way ER-100 is designed, it actually sends the cells into reverse, essentially telling them to scrub away much of the instruction to grow into specific types of cells and the detritus—the years of exposure to things like radiation, chemicals in the air, smoking, and stress—that has settled on the cells' DNA. ER-100 works to return the cells to a more youthful state. Sinclair compares it to removing the scratches on the surface of a CD, but to me—substituting one out-of-date image for a soon-to-be one—it was more like taking a corroded penny and dipping it in vinegar to slough off the oxide, revealing the shiny surface underneath.

Sinclair's lab has reported success with this therapy in mice and primates, but the Glendale trial is the first time ER-100 has ever been used in a human. FDA drug approval is divided into separate steps, and the job of the first phase, which will eventually encompass giving a single injection to 12 patients with glaucoma and last up to five years, is to show only that ER-100 does no harm. But Sinclair—and Life Biosciences, the company that licensed the

therapy and is running the trial—is hoping for much more. A substance that can undo damage in the optic nerve by reversing its history might be able to reverse damage in any cell by returning it to its earlier state. And assuming cells could be prevented from ever growing old, humans could—at least theoretically—live forever.

When someone pursues a goal as big as immortality, they tend to have company. And indeed, the injection in Glendale was the latest move in a fast-growing and lavishly funded race in antiaging biotechnology—an effort approaching the scale of AI aimed at rejuvenating human bodies rather than replacing human minds.

In 2013 Google co-founder Larry Page began the hunt for the new fountain of youth by funding a division called Calico Labs. (Calico stands for California Life Company.) The field was soon full of outsize enthusiasm. "Can Google Solve Death?" *Time* asked on its cover. Biomedical gerontologist Aubrey de Grey took to declaring that "the first person to live to 1,000 is probably already alive today." A drove of new antiaging start-ups followed, many of them flush with money from some of the richest people in the world. Brian Armstrong, the head of the cryptocurrency company Coinbase, helped start a firm called NewLimit in 2022. "Diseases, then longevity," its web page announces. The same year, Sam Altman, the CEO of OpenAI, invested in a company with a similar antiaging mission, named Retro Biosciences. Also in 2022 came the behemoth of the industry, Altos Labs, headquartered

THE THEORY OF GROWING OLD— AND YOUNG AGAIN

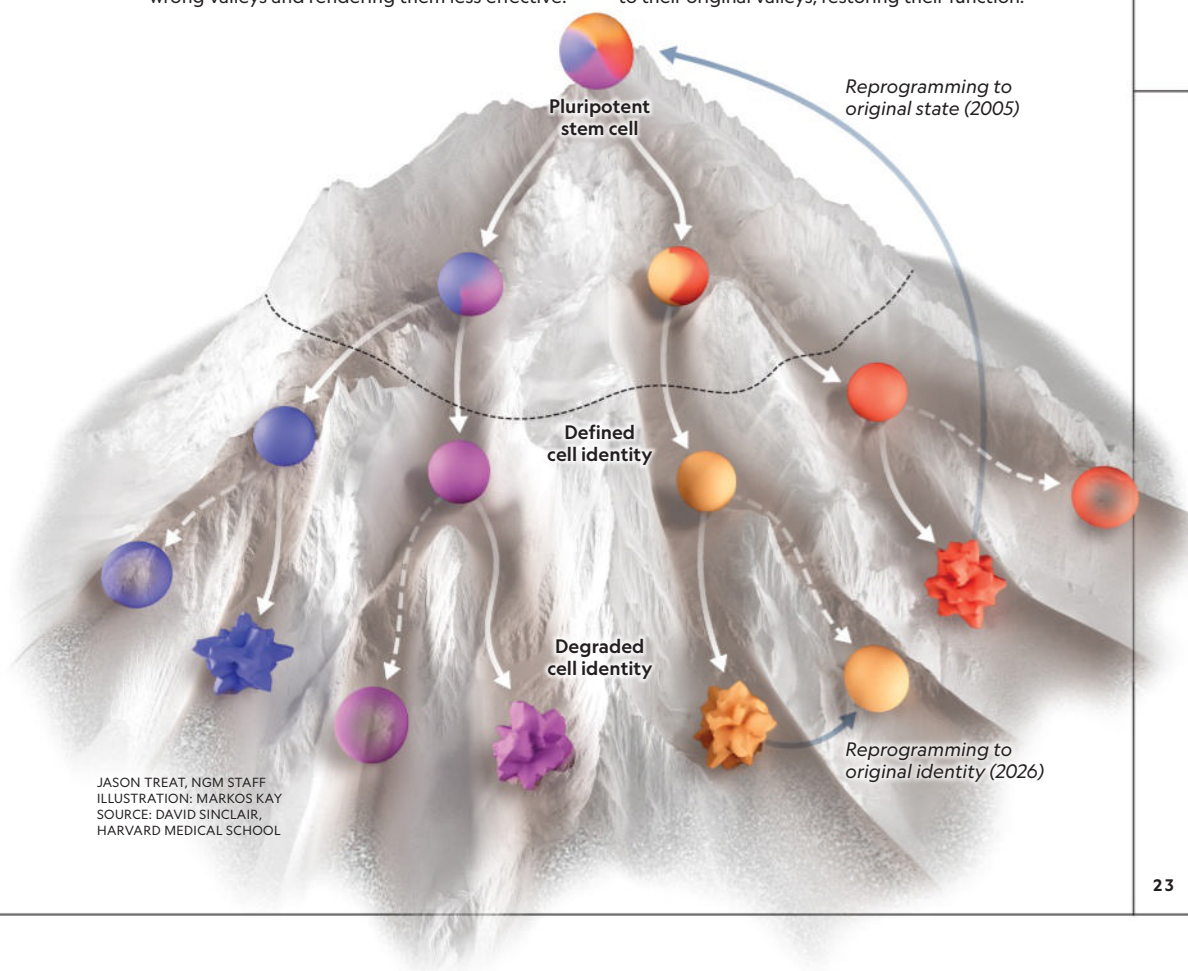
At birth, every cell in your body starts as a pluripotent stem cell capable of developing into any type of cell. In 1957 British biologist Conrad Waddington likened the process of aging to a marble rolling down a hill. The big question for scientists today is: Can we move the marble ourselves?

How Our Cells Age

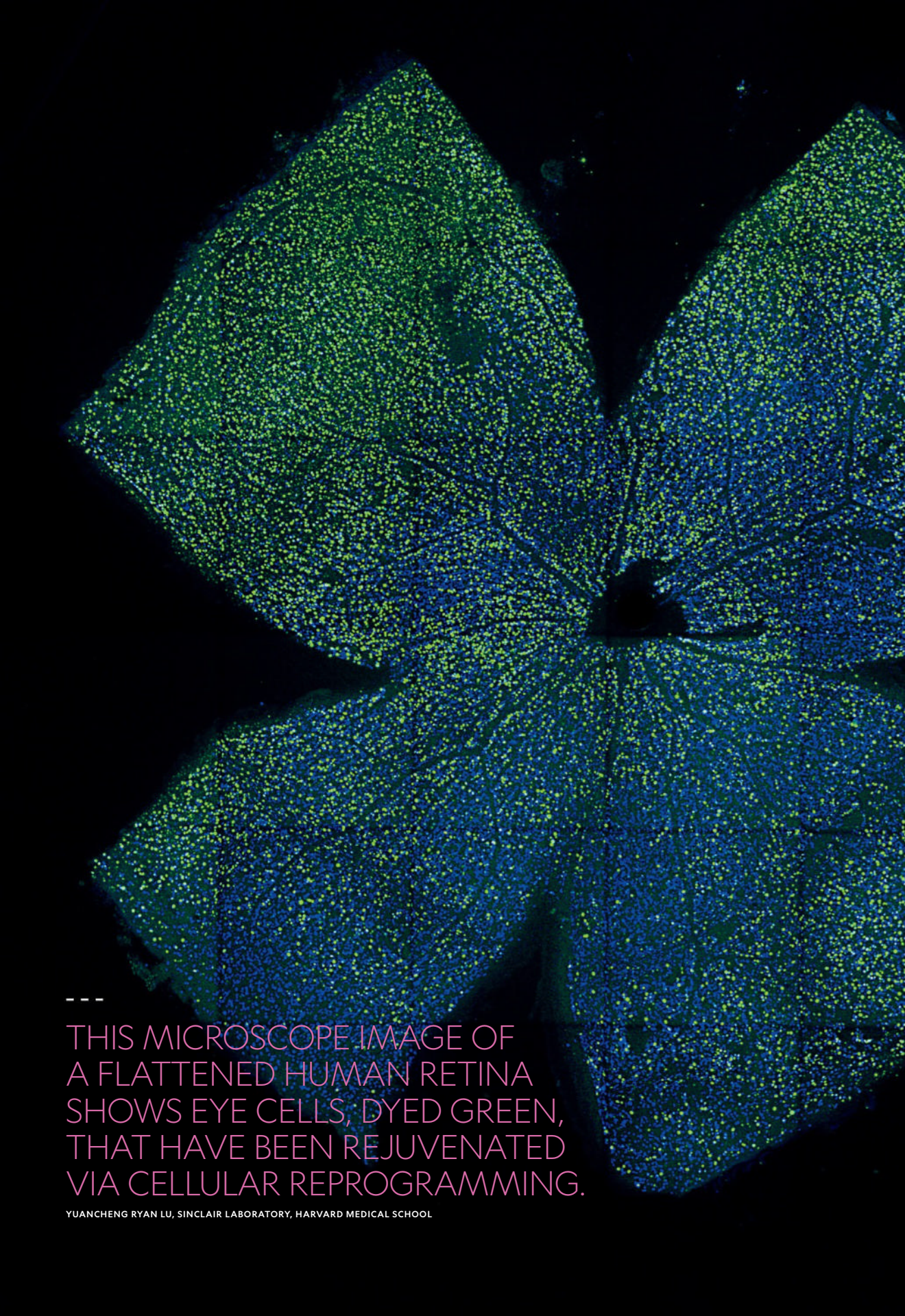
As cells “roll” down the mountain, they settle into valleys and acquire their ultimate identity, differentiating into skin, blood, or other cells. But as we age, our cells take on detritus that impedes the transcription of DNA—moving them into the wrong valleys and rendering them less effective.

How Our Cells Rejuvenate

In 2005 scientists discovered that cells could be rolled all the way back up the mountain to their original state. It was a huge feat but not very useful for extending lifespan. Since then, researchers have learned how to roll cells back to their original valleys, restoring their function.

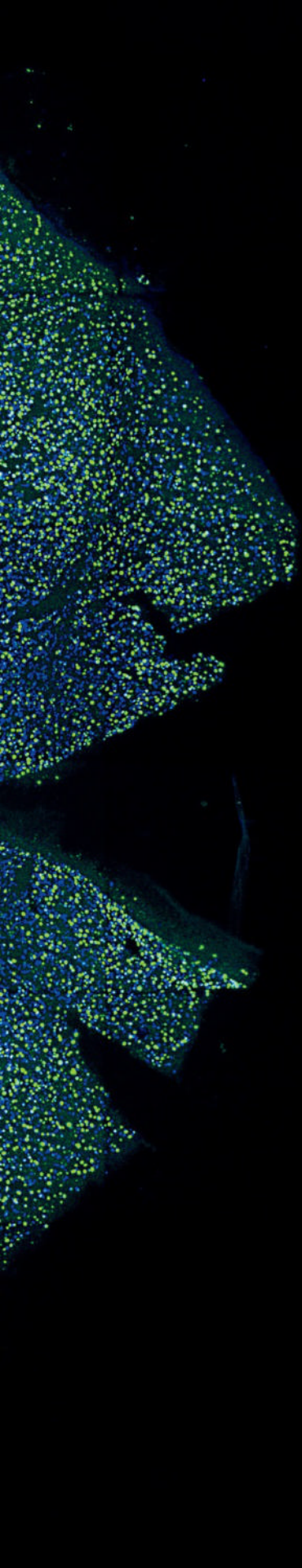


JASON TREAT, NGM STAFF
ILLUSTRATION: MARKOS KAY
SOURCE: DAVID SINCLAIR,
HARVARD MEDICAL SCHOOL



THIS MICROSCOPE IMAGE OF
A FLATTENED HUMAN RETINA
SHOWS EYE CELLS, DYED GREEN,
THAT HAVE BEEN REJUVENATED
VIA CELLULAR REPROGRAMMING.

YUANCHENG RYAN LU, SINCLAIR LABORATORY, HARVARD MEDICAL SCHOOL



in the San Francisco Bay Area. It was started with three billion dollars in investor money, part of which reportedly came from Jeff Bezos. Altos is likely the largest bioscience start-up ever. The stampede made me think of an irony immunologist Élie Metchnikoff noted over a century ago: “Although the duration of the life of a man is one of the longest amongst mammals, men find it too short.”

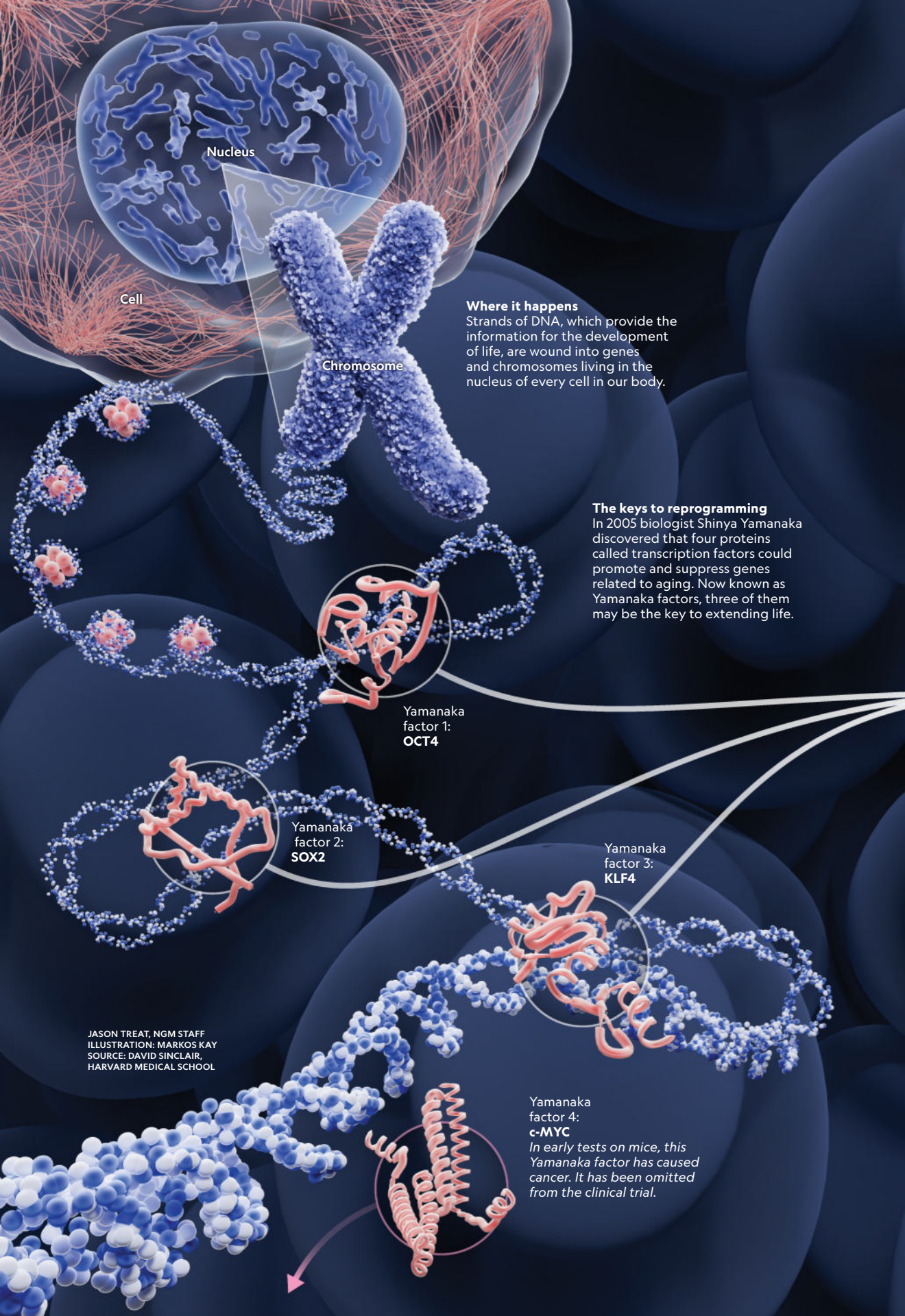
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ANY OF US can remember when we were little and learned the stunning fact that one day we would die. *Memento mori*. Even worse, before we die, most of us will experience years of debilitation. Physical weakness, dementia, failing sight and hearing, incontinence,

sexual dysfunction—the list goes on. There will be three times as many 80-year-olds on the planet by 2050, close to a half billion, and for many of us, our end will not be pleasant. But is this last act necessary? What if aging isn’t inevitable? What if even death isn’t?

For as long as mortality has existed, people have tried to outsmart it. The *Epic of Gilgamesh*, from around 2000 B.C., describes a plant called the-old-man-will-be-made-young (a serpent steals it before the protagonist can test it out), and Herodotus, the Greek historian from 500 B.C., wrote of a legendary spring that slowed aging, a vision that helped send the Spaniards chasing the fountain of youth fruitlessly to the New World.

In modern times, researchers have learned to ask less fanciful, more focused questions about aging. Does it progress only on the level of the organism? The tissue? The cell? Is its essence to be found in the nerves? The blood? The brain? Or is it glandular? Scientists tried out several theories over the years. One contemporary of Metchnikoff, Serge Voronoff, posited that youth lay in the reproductive organs. What could be more youthful, after all, than creating life? He grafted thin slices of



Nucleus

Cell

Chromosome

Where it happens

Strands of DNA, which provide the information for the development of life, are wound into genes and chromosomes living in the nucleus of every cell in our body.

The keys to reprogramming

In 2005 biologist Shinya Yamanaka discovered that four proteins called transcription factors could promote and suppress genes related to aging. Now known as Yamanaka factors, three of them may be the key to extending life.

Yamanaka factor 1:
OCT4

Yamanaka factor 2:
SOX2

Yamanaka factor 3:
KLF4

JASON TREAT, NGM STAFF
ILLUSTRATION: MARKOS KAY
SOURCE: DAVID SINCLAIR,
HARVARD MEDICAL SCHOOL

Yamanaka factor 4:
c-MYC

In early tests on mice, this Yamanaka factor has caused cancer. It has been omitted from the clinical trial.

THE HUMAN EXPERIMENT BEGINS

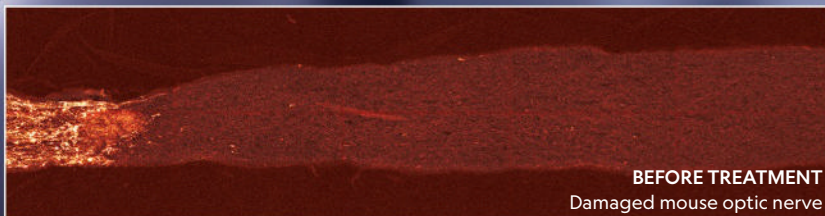
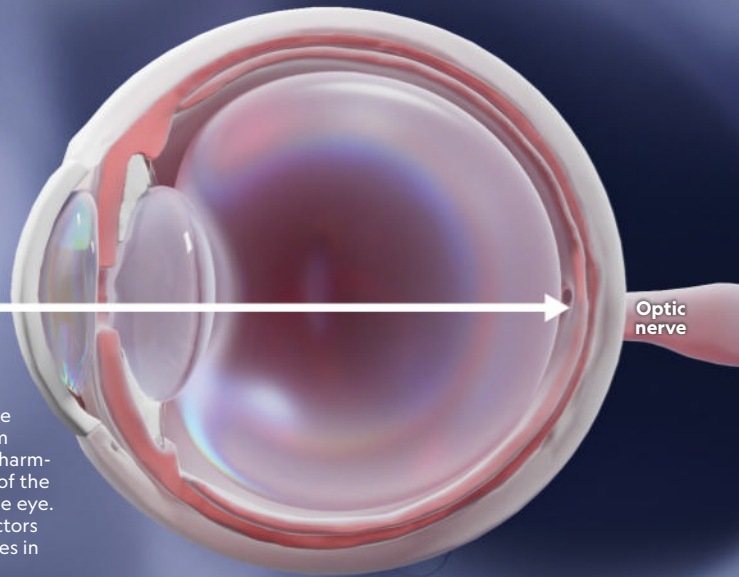
To combat aging, scientists are trying to return cells to a younger state. Last April researchers began the first human trial of cellular reprogramming, focused on curing glaucoma. They believe the treatment, if successful, could be used for any number of aging-related maladies, from heart to liver disease.

Starting with the eye

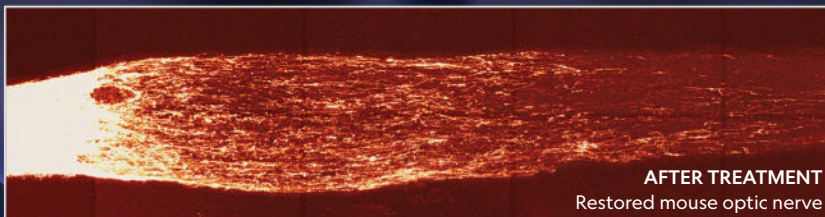
Researchers at the Sinclair Lab at Harvard are targeting the eye because it's a closed system with a confined immune response, which could limit negative outcomes if something goes wrong.

A new trial

Scientists hope to reverse optic nerve damage from glaucoma by injecting a harmless virus carrying three of the Yamanaka factors into the eye. The virus delivers the factors to specific DNA sequences in the optic nerves.



BEFORE TREATMENT
Damaged mouse optic nerve



AFTER TREATMENT
Restored mouse optic nerve

Early evidence

In 2018 the Sinclair Lab treated mice with three Yamanaka factors, successfully healing damaged optic nerves. The results helped persuade the U.S. Food and Drug Administration to approve this first human clinical trial.

YUANCHENG RYAN LU,
SINCLAIR LABORATORY,
HARVARD MEDICAL SCHOOL

tissue from the testicles of executed criminals onto the testes of rich men. Soon his procedure was in such high demand that he had to turn to monkeys for tissue. Voronoff noted overall improvement on the part of his subjects (more energy, better stamina, sharper minds, and keener eyesight), though modern historians of medicine have concluded that any perceived gain was a placebo effect—the subjects just felt younger. But in the end, how different is that from being younger?

An important clue in the hunt for the essence of aging came from a series of experiments that began in the mid-19th century, when researchers grafted two rats together, one young and one old. Sharing a blood supply with a juvenile, the older rat over time began to behave younger. His movements were faster, his senses more acute. The blood of the younger rat rejuvenated the older one. The younger rat, in turn, grew ill but soon recovered. The realization that aging was something palpable contained within an organism was strengthened in the 1960s by the discovery that cells themselves are mortal. Before then, scientists had assumed that though the body as a system may fail, a cell on its own could live forever. The new knowledge that normal cells can divide only roughly 50 times before they enter a senescent phase suggested that cells have a limited lifespan too.

It was not until the past 30 years—well into the age of genetics—that the possibility this limit might not be absolute began to receive serious research confirmation. An important early experiment to show that aging could be slowed down was undertaken at the University of California, San Francisco in 1993, when molecular biologist Cynthia Kenyon demonstrated that altering just one gene in the worm *Caenorhabditis elegans* could increase the organism's lifespan by half. A worm that had lived only two weeks could now live three. Because the genes of *C. elegans* often have counterparts in humans, the implications for human aging were hard to ignore.

Still, worms are one thing, mammals

another. The first key discovery about human aging wouldn't come for another decade. In 2005 Shinya Yamanaka, then a medical researcher at Kyoto University, was trying to solve a supply problem. Scientists needed immature stem cells—cells that exist in humans before they begin to differentiate into our organs, nerves, and blood—for much of their research work. But the naturally occurring sources, discarded embryos from assisted reproductive efforts, were tricky to obtain. The U.S. government, for instance, had all but prohibited their use since 2001. Yamanaka found that by using the transcription factors produced by four genes that were known to maintain stem cells in their immature state, he could take a mature cell and return it nearly to its pre-differentiated state. The transcription factors instructed the cell to reverse the instructions its genes had executed over the years. The proteins didn't change the genetics of the cell. They removed molecules around the genes, the so-called epigenome, including small molecules that bond to DNA, called methyl groups, that instruct other genes when to turn on or off. It is the methyl groups that help guide a fertilized egg along the process of human development.

The four proteins soon became known as Yamanaka factors in the scientist's honor, and in 2012 Yamanaka was awarded the Nobel Prize. By then, the fledgling longevity community had already begun to suspect that he had also provided a road map for how to reverse time at the cellular level.

OTHER WAYS TO OUTRUN AGING

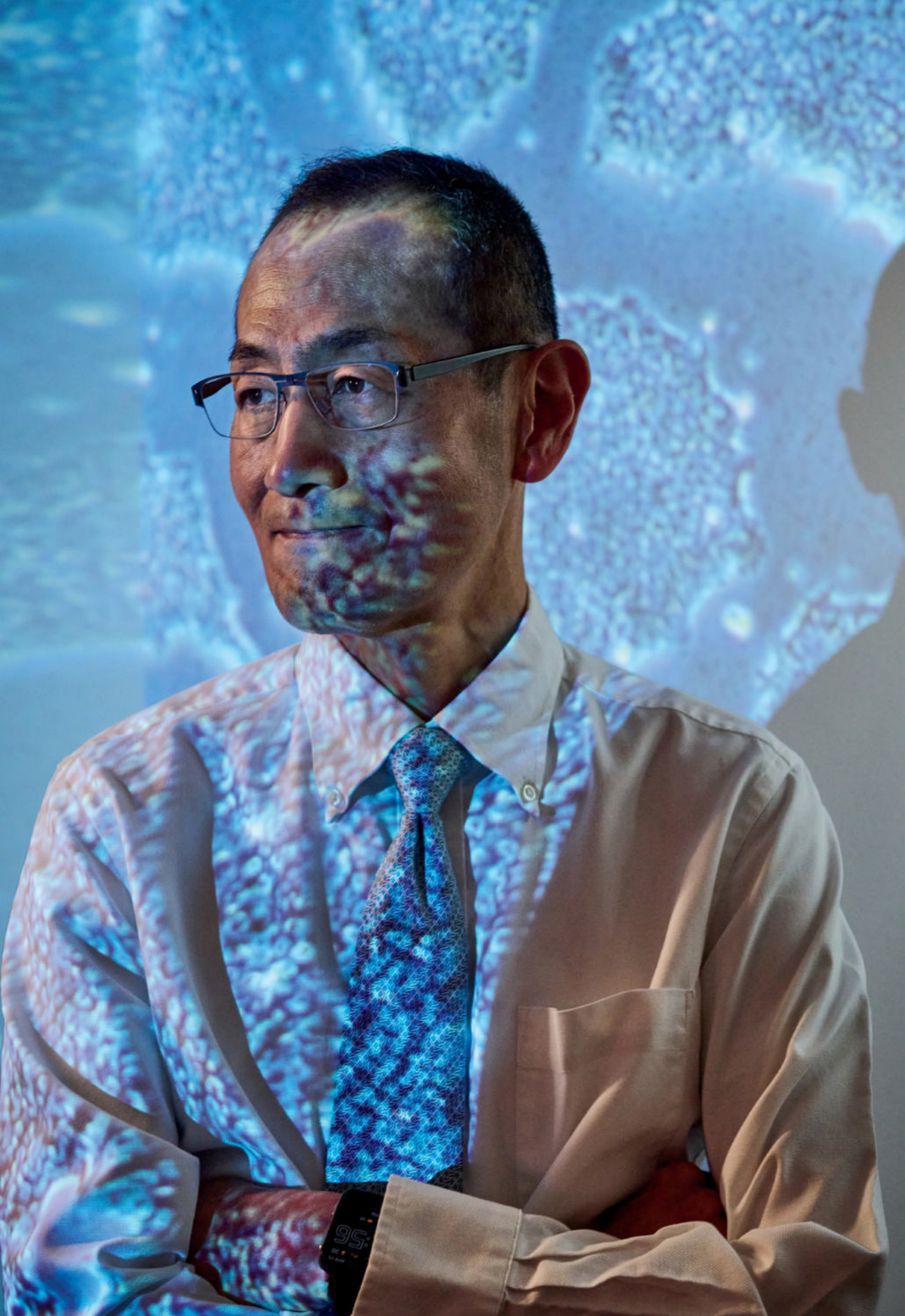
Cellular reprogramming is hardly alone. It joins a wave of experimental therapies opening up new—and sometimes controversial—ways we might extend human life.

METHOD 1

AN INFUSION OF YOUNG BLOOD

The idea that young blood can rejuvenate the old has been around at least since the Renaissance, but the modern quest is often traced to a series of experiments in the 1950s. A Cornell researcher surgically stitched

pairs of young and old rats together so they shared a circulatory system and found that the old rats' bones eventually looked younger. The technique mostly sat dormant, until researchers revived it in the 2000s and started attempting to better understand how blood affects the aging process. One procedure that's emerged, plasma dilution, is a little like an oil change. Blood gets pulled out, and old plasma—where inflammation-causing proteins can accumulate—gets filtered out and is replaced by saline and a protein called albumin. It's been studied in a lab at UC Berkeley, among others, to determine if it actually slows aging. Whether it does is not yet clear, and the FDA has twice warned consumers about the procedure. But that hasn't stopped a cottage industry of clinics from offering the service. —Chris Cohen



J

JUAN CARLOS Izpisua Belmonte stands atop the pyramid of antiaging researchers from his perch as the founding scientist of Altos Labs.

Rejuvenation science is largely funded by private partnerships, which means there's little obligation for the scientists involved to give other researchers—or the press—a peek at what they are working on, but this past May I received an invitation from Belmonte to visit his lab in San Diego. As I drove to the facility, part of the city's new biotech hub, I passed the renowned Salk Institute, where Belmonte had worked for some 30 years before Altos hired him away. At the lab, I was met by rows of gleaming, spotless shelves, bright red biohazard containers, and researchers in immaculate white coats, as if someone had doused a conventional university lab with Yamanaka factors and returned it to a state of dewy newness.

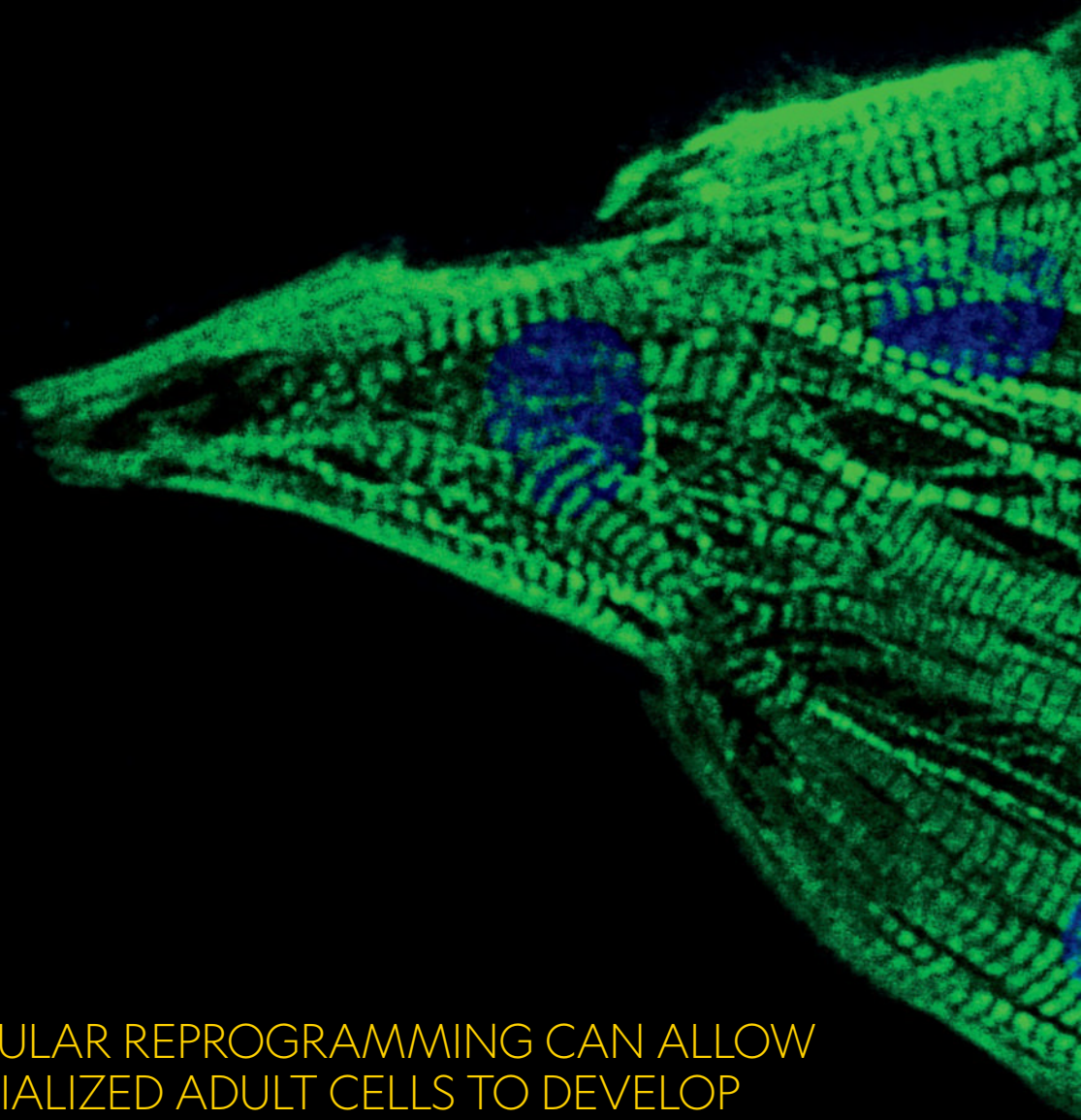
Belmonte, a fit man of 66 with a shaved head and a deeply ridged brow, is responsible for the experiment that launched the cellular reprogramming gold rush, one he conducted when he

was a professor at the Salk Institute 10 years ago. At that point, it had been several years since Yamanaka had taken mature cells and returned them to stem cells using the transcription factors he had found. But since then, the four Yamanaka factors had shown themselves to be less like a mild cleanser and more like bleach—no one could control the process, so their use killed cells or led to uncontrolled cell growth and cancer. To use the coin metaphor, the process was so powerful it stripped the face right off the penny. Belmonte's innovation was to calibrate just the right amount and frequency of Yamanaka factors to return cells to their state after they had differentiated but not so far back that the organism grew disorganized and collapsed. To control this process, he added an injection with doxycycline, the common antibiotic, which in genetically modified genes can be made to function as an on-off switch.

Belmonte's key experiment involved mice with a rare condition called progeria, a premature aging syndrome that also affects humans. After Belmonte's modified Yamanaka factor treatment, they on average lived 30 percent longer than untreated mice. He next tested his formula on injured but otherwise healthy mice, and he was able to show their deficits healed faster with Yamanaka factors—fast recovery is a signature of youthful cells. The experiment drew worldwide attention. Unlike some of his contemporaries, Belmonte is not the type to overstate things. "With careful modulation," he said at the time, his study showed that "aging might be reversed." He cautioned that it would take 10 years before there was a human trial.

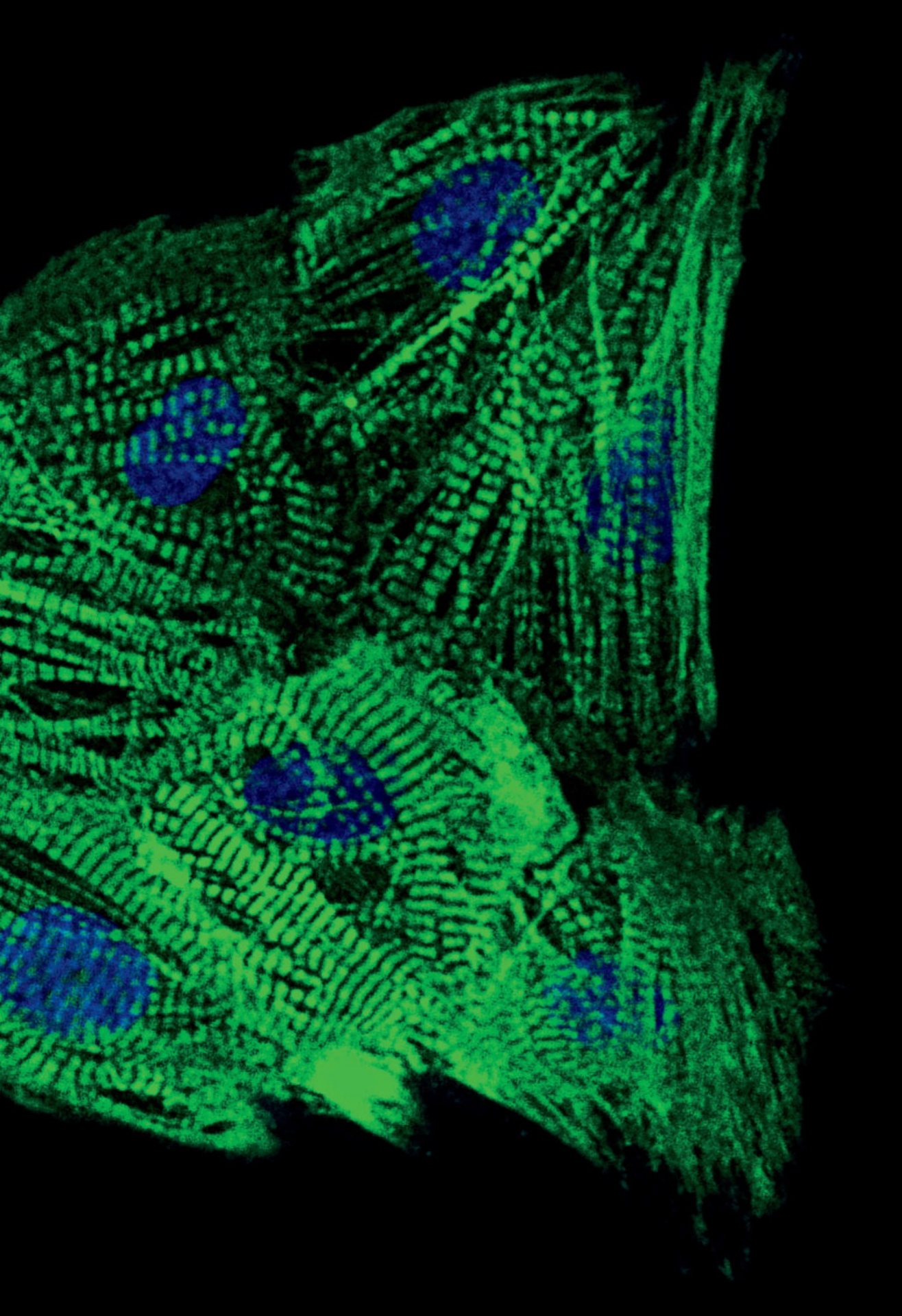
Belmonte has done a lot of thinking about aging in the years since, and while he's eager to go to trial, he recognizes this is a long-term effort. "The goal here," he told me at his lab, "is setting the basis for that future medicine, not going after one particular problem." He led me down a hall and past a bench that held a microscope and several skin samples in clear, sealed containers. Under the magnification, a

Research professor Shinya Yamanaka discovered cellular reprogramming in 2005. Though he continues to push the boundaries of antiaging research at the San Francisco-based Gladstone Institutes, he has since called for "broad societal dialogue" about the ethical implications of the field.



CELLULAR REPROGRAMMING CAN ALLOW SPECIALIZED ADULT CELLS TO DEVELOP INTO DIFFERENT CELL TYPES. THESE INDUCED PLURIPOTENT STEM CELLS HAVE BEEN TRANSFORMED INTO HEART CELLS.

BENOIT BRUNEAU LAB, GLADSTONE INSTITUTES



M E T H O D 2

AN
AGENT
TO FIGHT
ZOMBIE
CELLS

One reason we get age-related ailments like cardiovascular disease or Alzheimer's is that, at some point, our cells can stop dividing but refuse to die, which may lead to inflammation that damages nearby tissue. Two decades ago, researchers began identifying so-called senolytic drugs that target

these senescent cells, often referred to as zombie cells. Clear the zombies, the theory goes, and you turn back the clock. The practice has been less straightforward. In mice, senolytics extend lifespan and reverse age-related declines in muscle, kidney, and heart function. While human trials have been running for years, none have yet delivered a breakthrough result. James Kirkland, a pioneer in the field, is testing a common leukemia drug in combination with a promising plant compound as a treatment for frailty, osteoarthritis, and Alzheimer's in older adults. And a wave of biotech companies have been raising money chasing the same idea, including Unity Biotechnology, which reportedly raised hundreds of millions of dollars before collapsing because of disappointing results. Recent studies of both existing and newly formulated drugs designed specifically to kill senescent cells are a cause for optimism. —CC

sample from a 21-year-old woman looked like rows of half-curly grains of rice arranged by a very orderly chef. By comparison, in a sample from the skin of a 75-year-old woman, the strands looked like they were in disarray. Then he showed me a third sample, this one from the 75-year-old but corrected with the therapy containing Yamanaka factors. It didn't quite boast the 21-year-old's cell tidiness, but it looked at least like someone had neatly combed its hair.

Down the hall, a computational scientist and a microscopist were evaluating stressed skin cells and comparing which interventions reversed the damage most effectively. The microscopist wasn't looking into the microscope near his arm. He didn't have to. His partner had encoded an AI program to evaluate and select tissue that showed the best response to the treatments; they were just there to train it and watch. "It's actually running right now," he said. "This is a great way to basically eliminate all of the subjectivity."

Aging, Belmonte stressed to me when we returned to his tidy office, was not the result of a single process. He showed me an image of the hallmarks of aging, a wheel displaying the various factors that contribute to senescence. They range from chronic inflammation to something called telomere attrition, a process in which the protective caps on the spindles on the ends of our chromosomes shrink with time, causing our DNA to replicate wrongly or to stop copying itself entirely.

Belmonte explained that the hallmarks of aging give a hint as

to why the rejuvenation field is so challenging: It is really multiple fields. Yamanaka factors are clearly remarkable, but nearly 20 years after their discovery, there is little understanding of how they can reverse age in such varied cell types. The human body contains over 27 trillion cells divided into 200 kinds. Yamanaka factors appear to work well almost everywhere, but why? It seems too good to be true. Some skeptical scientists warn that it might be, citing among other possibilities that in some experiments the cells are responding to other changes in their environment and not Yamanaka factors.

To have such a huge question at the center of antiaging research has in turn promoted great diversity in the approaches competing labs take to solve the problem, from genetically altering Yamanaka factors to finding chemicals that can mimic their function. (No one has yet been able to safely give a human gene therapy orally, so Sinclair believes a truly universal solution would likely be a pill with a chemical cocktail that executes the same tasks as Yamanaka factors.) The entire rejuvenation research effort feels like a race where the basic learning is taking place at the same time early therapies are being concocted. NewLimit, the start-up backed by Coinbase's Armstrong, plans to begin human trials next year for its own medicine that restores youthful function in liver cells. It is possible that nothing will come of these initial efforts, at least not in their current form or not for a long time—think of how many times researchers have declared they are on the verge of curing cancer. But that won't likely calm things down in the near term with so much at stake.

Even Yamanaka, who until recently served as an unpaid senior scientific adviser to the Altos board, is surprised by the possibilities of the field he birthed. I had earlier written him to discuss what he thought its future might be. He did not think the use of the factors named after him was "the only possible approach to anti-aging," he replied to me by email. "Aging is influenced by multiple factors, including

not only epigenetic changes but also genomic damage, mitochondrial function, and the tissue environment. Therefore, it is likely that future strategies will involve a combination of different approaches." At Kyoto University, he was looking at a gene called NAT1 that affects embryonic development. When deleted, it also returns cells to a less mature state.

Belmonte told me he has been working on a way to unify the field. He thinks he has found an overarching machinery behind aging. The common mechanism is called mesenchymal drift. ("Sorry for the term," he warned me.) Mesenchymal drift is a normal cellular process by which genes turn specialized cells into fibroblasts, which heal wounds but also decrease tissue function and contribute to many diseases. He showed me the hallmarks-of-aging wheel again and described how each aspect could be explained by mesenchymal drift. "We have looked by now [at] more than 40 diseases in humans," he emphasized. "This is not mice now. This is humans." One way he saw to treat this meta-condition would be to use the basic cocktail of Yamanaka factors but introduce genetic modifications to make them more effective, he hoped, than Sinclair's ER-100. AI was speeding that process enormously. Even so, I asked him if he thought any of the hallmarks of aging would be reversible in his lifetime, and he was doubtful. He guessed maybe in 30 years, adding that he didn't expect to live to see it. "We're next," he said with a light laugh.

IF BELMONTE is the cautious super-ego of cellular reprogramming, David Sinclair is its instinctual id. Throughout the industry, I found that the early days of massive start-ups touting grand plans had been replaced by more careful talk, and companies now primarily highlight the practical, near-term benefits of their work. The CEO of Altos Labs, Hal Barron, told me that Altos wanted medicine to move

"from a disease-care model to a true health-care model." And Jerry McLaughlin, the CEO of Life Biosciences, which licensed Sinclair's ER-100 treatment, emphasized the focus of their work was "really on the quality of a life," not its length.

But Sinclair remained unafraid to make the claims others danced around. Belmonte had spoken generally of reversing the diseases of old age, like cardiac fibrosis. Sinclair's agenda was more specific: After glaucoma, he thought he might tackle hearing loss and then liver illness. "Would the liver be an easier subject because it would be sort of primed to fix itself?" he asked rhetorically. "It's super easy." (Sinclair's history of big claims has led to a considerable amount of critical press and his own chief operating officer calling him "both famous and infamous" in the *New York Times* earlier this year.)

After that would come the big trophy, aging itself—not just the diseases that come with it but the underlying cellular mechanism. Sinclair said he hoped to see widely available medicines reversing "aspects of aging" within 20 years. "And if we're lucky, we might even see something that does whole-body aging restoration." It frustrated him the way other scientists tiptoed around the implications of the work he and they were doing. "It's just a euphemism," he said. "Obviously, if you don't get sick," he pointed out, "you don't die."

Sinclair, who is 57, met me in his office in his Harvard Medical School lab. The entryway was lined with framed copies of his articles from *Cell* and *Nature*. I was the

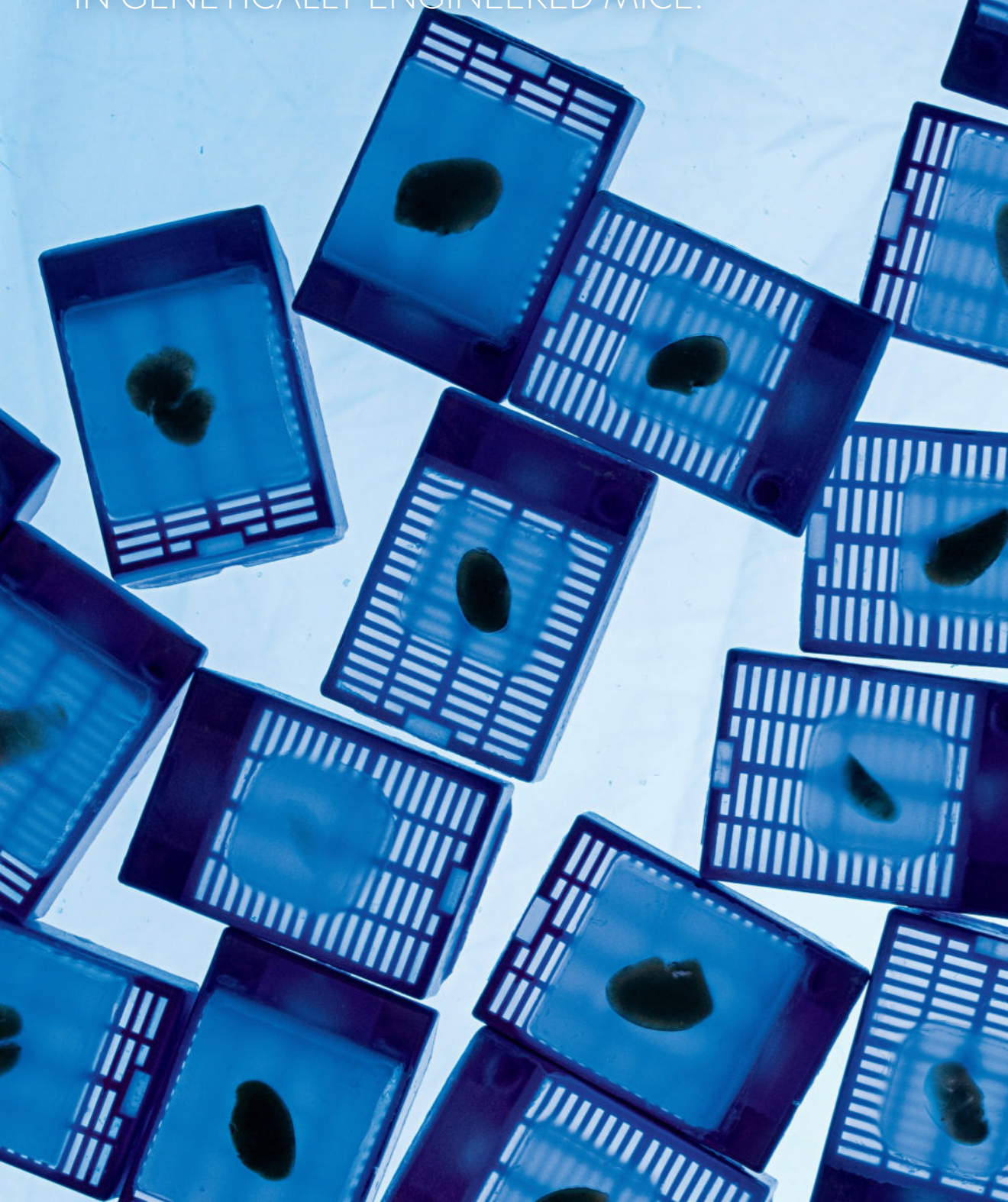
M E T H O D 3

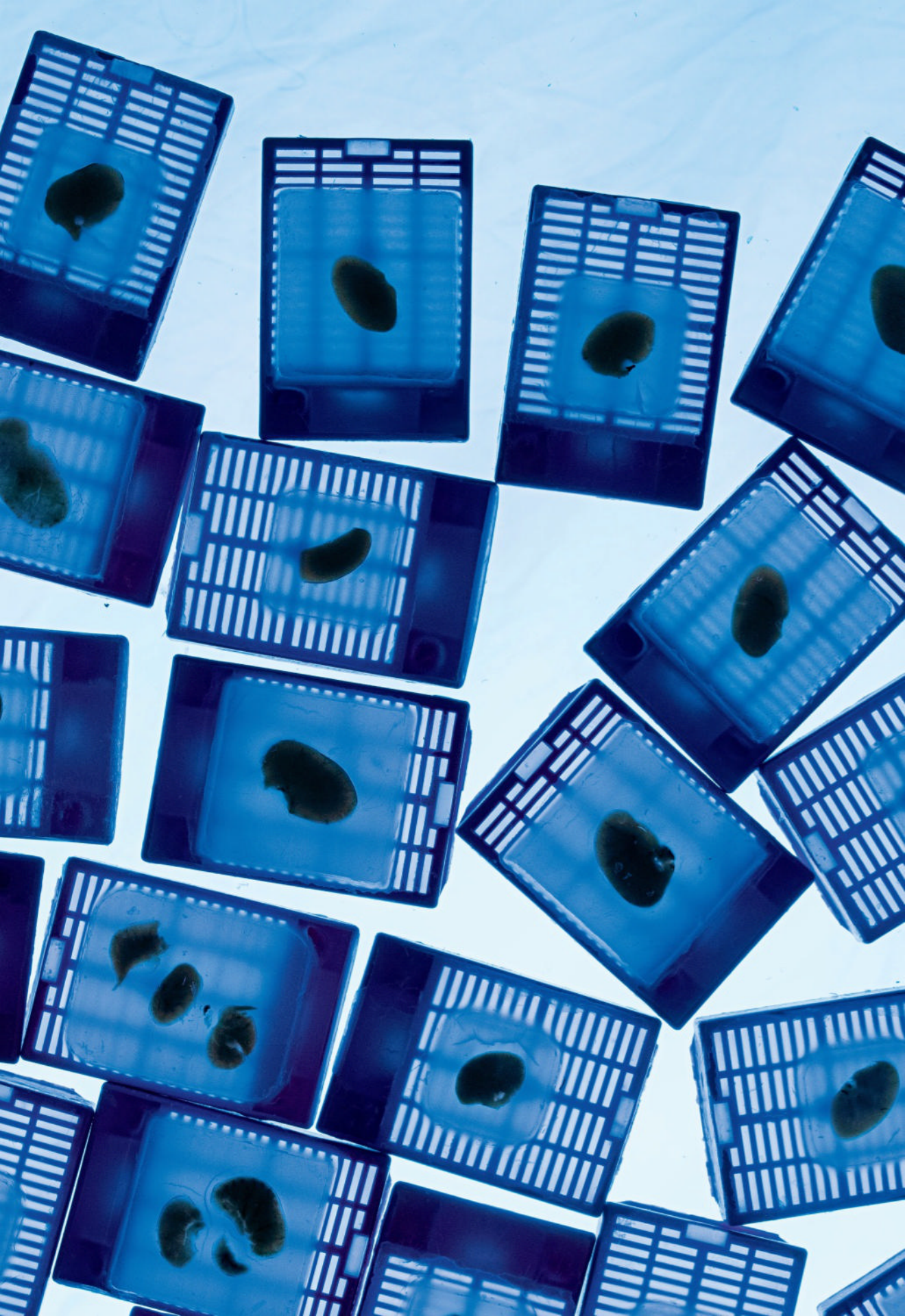
AN OFF-LABEL CANCER DRUG

Over the past 20 years, researchers have been reexamining a compound whose origins date back to a 1964 medical expedition to the South Pacific, where scientists hoping to document the biosphere of Rapa Nui (Easter Island) collected comprehensive soil samples. Years later, microbiologists isolated a compound from bacteria in the dirt that turned out to have potent immunosuppressive properties. The medication that resulted was named rapamycin, after

the island, and earned FDA approval in 1999 to keep transplanted organs from being rejected. In the 2000s researchers also noticed the drug extends lifespan in a variety of organisms—mice, worms, fruit flies, yeast—by acting on an enzyme called mTOR, which regulates cell growth and has been linked to the aging process. Rapamycin has been adopted by the longevity community, some of whom pop it off-label without medical supervision. But at least some of the early clinical results are inconclusive. Last year, a small trial showed modest gains in lean muscle mass and some quality-of-life measures and no evidence in the blood of any harmful effects. The potential side effects are real, though: mouth sores, elevated cholesterol, and undesirable immune-system suppression. A much larger study is underway at the University of Arizona and may provide a better answer as to whether this drug might be worth it anyway. —CC

RESEARCHERS AT THE BIOTECH
START-UP NEWLIMIT TEST CELLULAR
REPROGRAMMING ON THESE
HUMAN LIVER TISSUES, DEVELOPED
IN GENETICALLY ENGINEERED MICE.







only journalist allowed to visit his lab since the glaucoma trial had been announced.

He explained that his motivation to work on aging dated from childhood. He had been close to his grandmother, who had fled both the Nazis and the Communists in Hungary. When Sinclair was four, he asked her if she would always be there. “She said, ‘No, I won’t be. Everybody dies. And I’m going to be gone. Then your parents are going to be gone. The first thing that’s going to be gone is your cat.’” Sinclair fell to the ground crying. He told me he still does not want his grandmother to have

Jacob Kimmel left his job at Google’s antiaging lab, Calico, in 2022 to co-found NewLimit, which seeks to dramatically expand the average human health span—the number of years lived in good health.

been right. To that end, he takes several over-the-counter supplements—among them NAD⁺, a cellular coenzyme that may have antiaging properties and that he first brought to public recognition. He added that the soup he'd just eaten was his first meal in six days, the result of his research on the health benefits of calorie restriction. "I nibble on nuts," he clarified. "When I went to the doctor the other day," he said, "the receptionist asked for my ID because she didn't believe my age."

After touring his lab, I sat in on a meeting of his two dozen researchers, a mix of graduate students and postdocs. The presenter, a woman in her 20s, was researching whether Yamanaka factors could slow cancer. She referred to the current way the factors are used to reverse aging as "partial reprogramming," because Yamanaka factors are stopped before they take the cell all the way back to the time before it differentiated. Sinclair, seated at the head of the table, jumped in: "I want to ban those words from the lab," he said. "I don't want to spend the rest of my life being called 'partial.'" He suggested instead the team adopt the terms "in vivo reprogramming" or "rejuvenation," then settled on "iPSC programming" (short for induced pluripotent stem cells).

Sinclair's crucial innovation with Yamanaka factors was to find a way to make them safer. His team showed that of the four transcription factors, one was primarily concerned with cell growth—this was the cause of the risk of cancers that was associated with the treatment. His group began trying the

other three alone and found that they were far less harmful. The scientists first tried the new concoction in organoids—lab-derived mini-organs—then tested it on the eyes of living mice and then primates. They published an article in *Cell* in 2020, with the headline "Turning Back Time," that demonstrated they had successfully repaired the vision of the mice they had treated. Sinclair told me that though they have not yet published the data, they got similarly good results in primates.

Sinclair said the solution that worked in mouse eyes should work in other parts of the body. But he added that the technology of ER-100 had already been superseded. He had developed a new treatment called SL-100 (for Sinclair Lab), which was a chemical cocktail, not a gene therapy, so it could be taken as a pill. It didn't just target individual organs either. "This is whole-body rejuvenation," he said. "And we've been doing this for a while now. It's insane. We've been doing it for over a year." He was waiting on the pathology report on mice to see if it could move forward to human trials. If the pill were to succeed in trials, it might make antiaging medications something you could buy with a prescription at any drugstore.

Sinclair put on his white lab coat, and we walked through his lab. It was a sliver of the size of Belmonte's, and he says it costs just five million dollars a year to run. Life Biosciences has raised a mere fraction of the money Altos has. This has not made Sinclair's goals any less ambitious. First we walked by a postdoc working on nerve diseases, then another regenerating liver cells, both using SL-100.

"So now we've gone brain, kidney, muscle, motor neurons," Sinclair said. "We've rejuvenated brain tissue." Most researchers doubt that one treatment could be so versatile. As Johnny Kim, a researcher in regeneration at TRON, the biopharmaceutical institute in Germany, told *Nature* earlier this year, the spillover effect from an attempt to reprogram a large organ like the heart could easily overwhelm neighboring cells and

M E T H O D 4

AN
ENTIRELY
NEW SET
OF
ORGANS

At a summit in Beijing last year, a hot mic caught Russian president Vladimir Putin telling Chinese president Xi Jinping that continuously transplanting human organs could make it possible to “achieve immortality.” Xi agreed that humans might soon live to 150. While that might sound outlandish, the theory is

relatively straightforward: grow a new liver, kidney, or heart from the patient’s own cells and swap out the old one. (Unlike a donor organ, it’s a perfect match.) Research groups are pushing the frontiers of organ replacement through both lab-grown organs and genetically engineered pigs, typically for people with acute disease rather than for general life extension. The first pig heart recipient lived for two months. One patient lived a record 271 days with a pig kidney before later receiving one from a human donor. But scientists are also exploring how similar technologies might be used to simply slow the aging process in otherwise healthy people. One Bay Area start-up’s CEO has even reportedly pitched investors on growing brainless human clones, gestated by paid surrogates, to serve as spare parts banks or, eventually, as replacement bodies you could simply pop your brain onto. —CC

kill them. “It would be enough to transform them into cancer,” he commented.

We came to a bench where a graduate student was working on one of the key mysteries behind antiaging: How does a cell remember its former state? Borrowing from information theory, Sinclair believes in the existence of something he calls the observer, a molecule in the cell that retains all the data about the cell’s history. Thus, when Yamanaka factors send the cell back to an early stage, the cell has a memory of what that stage once was. If you imagine the cell as a smartphone, Sinclair is trying to find the location you would go to if you wiped the data from your phone and wanted to reload it again. Sinclair pointed out that there is an existing parallel in nature. Soon after an egg is fertilized, processes within the embryo delete all the epigenetic information that has come with the parents’ DNA. “There’s a switch that says we’re going to erase that and go back to being young,” he explained. “Otherwise, all babies would be born old and wrinkled and diseased.” And somewhere, he believes, the embryo stores the information about what that state looks like.

The researcher was testing the properties of various nucleic acids to see if they could be the observer molecule. “Well, we’re looking for instructions,” Sinclair said. “How does the cell encode youth? Is it a protein? Is it DNA? Is it something else?” He told me he and his team had already used AI to go through some eight billion

compounds before getting to this point. He wouldn’t say which nucleic acid he was now zeroing in on—it was proprietary information. Whoever controlled the backup would effectively control cell reprogramming (and, Sinclair has noted, likely win a Nobel Prize).

Antiaging is science for the age of entrepreneurial inequality, conducted by private companies that keep close what they learn rather than air any doubts they may have for broader academic consideration. As a result, it moves fast but also leaves huge ethical questions that no one seems to have the job of publicly debating. What if only some people could afford immortality? What would happen to new generations if the old didn’t die? Yamanaka brought up the idea that the field lacks ethical guidelines. I suggested it was comparable to the current debate over AI. “Significantly extending lifespan itself,” Yamanaka responded, “may involve questions that are even more deeply connected to human existence and values than AI. This is because such research directly touches on fundamental issues for humanity, including societal balance, life, and death.” He called for a “broad societal dialogue” before we move forward much further.

Back in his lab, Sinclair watched as a researcher loaded a droplet of clear goop containing a nucleic acid into a nanopore, a tiny sequencer that can quickly determine the nature of a molecule. The nucleic acid came from what is called junk DNA, the 98 percent of the human genome that appears to do nothing. Sinclair wasn’t so sure.

“You’ve got the nanopore going?” he asked.

“It’s primed and ready to go.”

“Doing this used to cost a billion dollars and take up a whole building,” Sinclair marveled. “If I’m right, this is the first time anyone has ever done this experiment.”

Sometimes in medicine you make history and sometimes you don’t, but you can’t know—at least not right away. The researcher hovered as the nanopore sequenced the nucleic acid, waiting for the answer. □

Where a Million
FALCONS
 GO TO ROOST

For years, the secret winter home of rare red-footed falcons remained a mystery. Then an ornithologist discovered the hidden world of 'Falconpolis.'

Words by ED YONG

Photographs by ÁKOS STILLER

→ **MOST BIRDS OF PREY** are loners. They might form huge flocks during migration, but for the rest of the year, they stick to themselves. The red-footed falcon is different. This kestrel-size bird frequently travels and roosts in large groups across Eastern Europe and Central Asia. It even nests in colonies, with hundreds of pairs of slate gray males and buffy-red females all living together in what Hungarian ornithologist Péter Palatitz calls “super-busy cities.” Within these avian metropolises, the falcons fight for nests, steal from each other, mate outside their partnerships, and leave eggs for others to raise. For scientists interested in how birds behave, “this system is a heaven,” says Palatitz, who has studied the falcons for 20 years.

These raptors don't build their own cities. Instead, they occupy the abandoned nests of the rook, a relative of crows. But rooks have long been seen as agricultural pests and were so thoroughly persecuted in the 1980s and '90s that their population crashed. The red-footed falcons, with nowhere to nest, plummeted to a quarter of their former numbers. In 2006, Palatitz launched a plan to reverse that decline by placing thousands of nest boxes throughout Hungary. The falcons responded enthusiastically. Over



Ornithologist Péter Palatitz raises an antenna near Mungo, Angola, to collect data from GPS trackers he and his team have put on red-footed falcons.



the next decade, their numbers doubled.

As the falcons rebounded, Palatitz took the opportunity to answer some long-standing questions about these little-studied creatures. For example, he knew that they winter in Africa but not their route or specific destination—key information for

understanding how the species spends half its life. So, between 2009 and 2015, Palatitz and his team fitted 28 individuals with satellite transmitters. The devices revealed that the birds, which weigh just four to seven ounces, can cross the Mediterranean and the Sahara in a nonstop five-day flight. A



For a few weeks each year, the falcons migrate to this tiny patch of Angola, where they roost in tall mango and eucalyptus trees rising above agricultural plots.

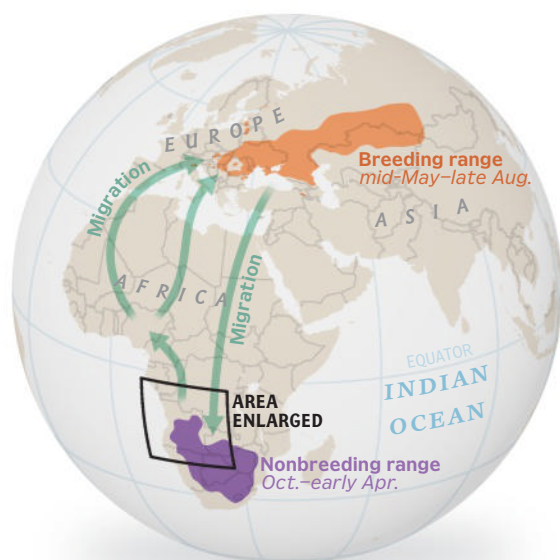
week later, they end their 6,000-mile trek in southern Africa, where they stay for months.

But in resolving one mystery, Palatitz unearthed another. The tracking data hinted that in March, before returning north, the red-footed falcons all pass through the same small stretch of central Angola. Why? Some of the team thought this was a coincidence, but Palatitz argued that the birds were gathering at a huge roosting site. He bet a beer that he was right, and began making plans to visit Angola.

Traveling in Angola can be risky, as more than 14,000 acres of land are still contaminated with mines—a legacy of the country's nearly three decades of civil war. For years,

Palatitz couldn't get permission to go outside the capital, Luanda. But in late 2018, he was introduced to José "Zeca" Agostinho, an Angolan who had spent decades doing de-mining work, including in Huambo Province, where the falcons seemed to be congregating. Agostinho lined up the right paperwork, and "our 10-year dreams came together in three months," Palatitz says. By March 2019, the team was on the road to Huambo. And on their second day of searching, Palatitz won his beer.

The team came across a site where falcons streamed in from all directions, blackening the sky. Some darted around at eye level. Others wheeled overhead. They perched



WIDE-RANGING RAPTORS

Red-footed falcons (*Falco vespertinus*) breed in Eastern Europe and Central Asia before flying thousands of miles to Africa to avoid northern winters and to hunt for abundant swarms of insects, especially termites.



shoulder to shoulder on every available branch. As he watched them, Palatitz started crying. It was like being “in a new dimension,” he says, “like I’m not part of the Earth but I’m more part of the sky.”

Palatitz knew the falcons were sociable, but he had completely underestimated just how sociable they could be. In the summer, the birds are spread across thousands of miles from Hungary to Kazakhstan. But for six weeks in February and March, every last one passes through this tiny, 1.5-square-mile region of central Angola, which the team now calls “Falcopolis.”

True to their scientific name, *Falco vespertinus*—“falcon of the evening”—the birds begin to gather as sunlight dims. For over an hour, hundreds of thousands of them swirl above the trees and hover in place as they look for perches. “You can actually feel the wind from their wings on your face,” Agostinho tells me. Their droppings whitewash

the underlying grass and fill the air with an ammonia-like scent. Their slate and red feathers blaze in the sunset, and he says that when they finally land, mere inches apart, “it’s like the trees are blossoming.”

No one knows exactly how many red-footed falcons congregate at Falcopolis. “Estimating them in the sky is impossible,” Palatitz says. Instead, his team is trying to count the birds by measuring the area over which they roost and the carrying capacity of those trees. If successful, the team will have an unprecedented way of counting a species that, in the summer, is scattered over a vast and largely unmonitored area. The red-footed falcon population has been estimated at up to 400,000 individuals. At Falcopolis, “I think I’ve seen one million birds in the air,” Palatitz says.

What compels these falcons to gather in such preposterous numbers? And why do they come to that particular part of Angola? “We don’t know,” Palatitz says. But he has some guesses. Falcopolis is on a peninsula surrounded by rivers and is easy to find from the air, he explains. Its climate is temperate and agreeable. It’s got plenty of large roosting trees. Human presence may have helped

N The nonprofit National Geographic Society, committed to illuminating and protecting the wonder of our world, funded the work of National Geographic Explorer and photographer Ákos Stiller featured in this story.





Palatitz (left) and José “Zeca” Agostinho, who leads a conservation nonprofit, release a male red-footed falcon into the skies above Falcopolis—now considered one of the largest raptor roosting sites on Earth.

the falcons by suppressing mammalian competitors and predators. And since agriculture isn't practiced intensively, there are still plenty of insects around. In particular, every March winged termites burst from the ground, swarming so densely that they look like static on an old television set.

Gorging on the termite bonanza, the falcons increase their weight by 20 to 30 percent, gaining the fat they need to return to their breeding grounds, against the Sahara's headwinds. And Palatitz suspects that their communal nature might help them find the unpredictable swarms. Every night, the falcons regurgitate pellets full of undigested

termite heads, which might allow the birds to see who among them is successfully hunting—and thus worth following to increase their own luck. This hypothesis is one of many ideas that Palatitz now wants to test. By collecting blood samples from the falcons, he hopes to figure out how they avoid a species-wide epidemic despite bringing in pathogens from across the world. And by tagging more individuals with GPS transmitters, he is trying to understand how their migratory behavior changes over time.

By migrating, the red-footed falcons exploit the riches of two hemispheres. But their versatility also creates vulnerability—a



bird that depends on several nations is susceptible to threats in any one. In Angola, hunting is a problem. The civil war decimated the country's native mammals and livestock, depriving many communities of protein. The falcons offer an alternative, and boys use flashlights to flush the birds out before killing them with slingshots and sticks. By surveying local markets, Agostinho at one point estimated that tens of thousands of falcons were being killed annually. And though hunting wild animals has been largely prohibited, regulations have been unevenly enforced and assumed by many to apply only to big game. The falcons'

habitat is also at risk. Pesticides, which are increasingly used, could devastate the termite swarms the falcons need. All of Falcopolis's trees could easily be cut for firewood or burned to clear space for agricultural land.

Conversely, Falcopolis's small size also means that a small number of communities will determine the birds' fate, and that Palatitz's team knows where to concentrate its efforts. Agostinho, who coordinates with national authorities and now leads a conservation nonprofit called Orbis Angola, has been raising awareness about the falcons at surrounding schools and churches, and with the local *soba*—influential traditional



When a falcon's wings get wet, it can't fly well and is susceptible to predators and poachers. Residents of Mungo (far left) bring these birds to local law enforcement who in turn hand them over to Palatitz's team.

Palatitz hopes to use GPS data from tagged falcons to study their hunting behavior and migration patterns.

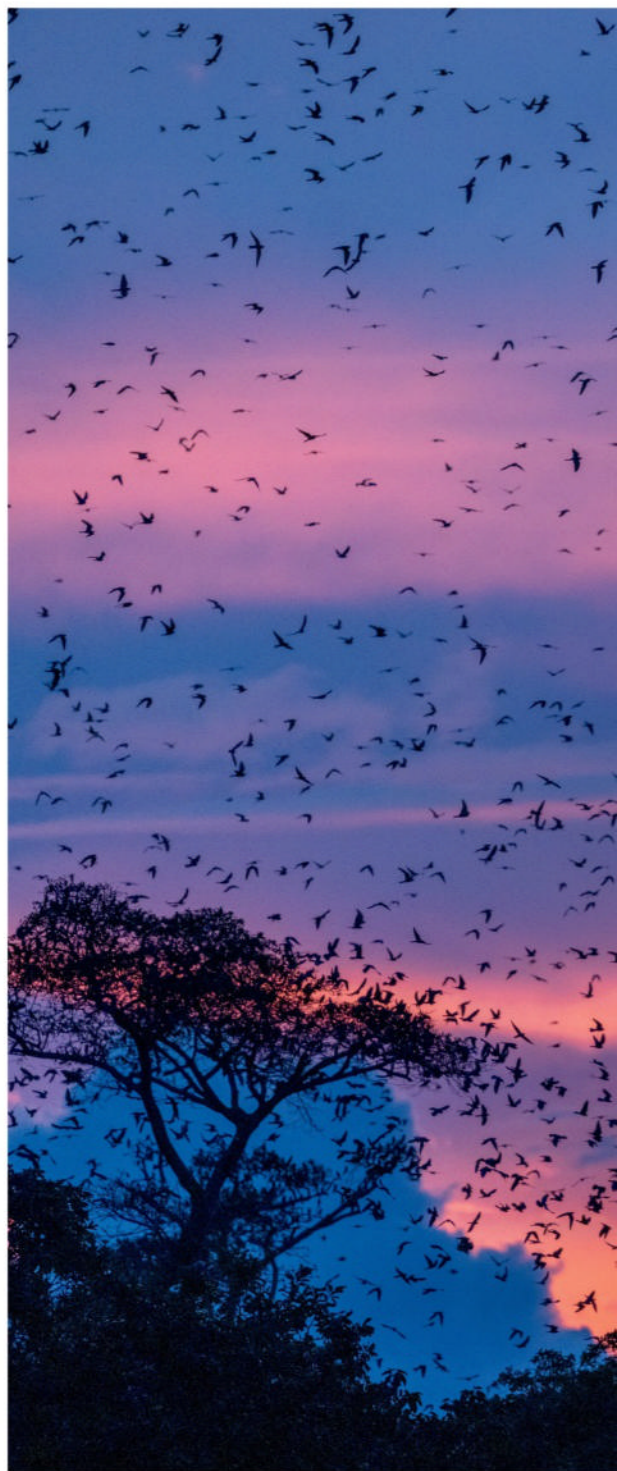
leaders. The teams have set up a research camp to document the locals' knowledge about the birds and enlist their help with banding and conservation measures. They're also talking with donors about supplying people with gas stoves or solar cookers to reduce their need for firewood.

Meanwhile, news of Falcopolis is spreading quickly. At a recent conference, Angola's president described it as a national treasure. The Ministry of the Environment went to the site, marking the first high-level governmental visit to the area in decades. A six-foot-tall falcon statue now stands in the main square of the nearest municipality, Mungo. And Palatitz's team has started bringing international volunteers to Falcopolis, where Agostinho is training locals to guide future tourists.

These efforts are already paying off. When Agostinho first visited Mungo, he found falcons on sale in the market. "That's gone completely," he says. Perhaps more important, locals are increasingly venturing out of their homes at night to see the birds for themselves. And as they become invested, they're coming up with their own ways of protecting the birds.

Earlier this year, five 12-year-old boys told Agostinho that they had formed a soccer team, the Mungo Falcons. They would use their matches as opportunities to educate similarly aged kids—the demographic most likely to hunt the birds—about protecting the raptors. They'd play for the falcons; they just needed a ball. So Agostinho bought this new generation of ambassadors their first one.

Red-footed falcons, like other spectacular migrants, show how connected our planet is—and needs to be. Their success depends on wild resources as disparate as rook nests in Europe and termite swarms in Africa. And their future will hinge upon equally far-flung feats of human grace, from nest boxes in Hungary to soccer balls in Angola. □



A large-scale photograph capturing a massive flock of red-footed falcons in flight. The birds, appearing as dark silhouettes, are scattered across a sky that transitions from a deep blue at the top to a vibrant orange and pink near the horizon. The silhouettes of trees and bushes are visible along the bottom edge of the frame, providing a sense of the birds' altitude and the landscape they inhabit.

At dusk, hundreds of thousands of red-footed falcons return from a long day of hunting in search of a place to roost. To witness it, says Palatitz, is like “being in a new dimension.”

Pulling Off a
**BALANCING
ACT**

BY MOONLIGHT

Reimagining an iconic photo
required a full moon, the right
vantage point—and someone
very unafraid of heights.

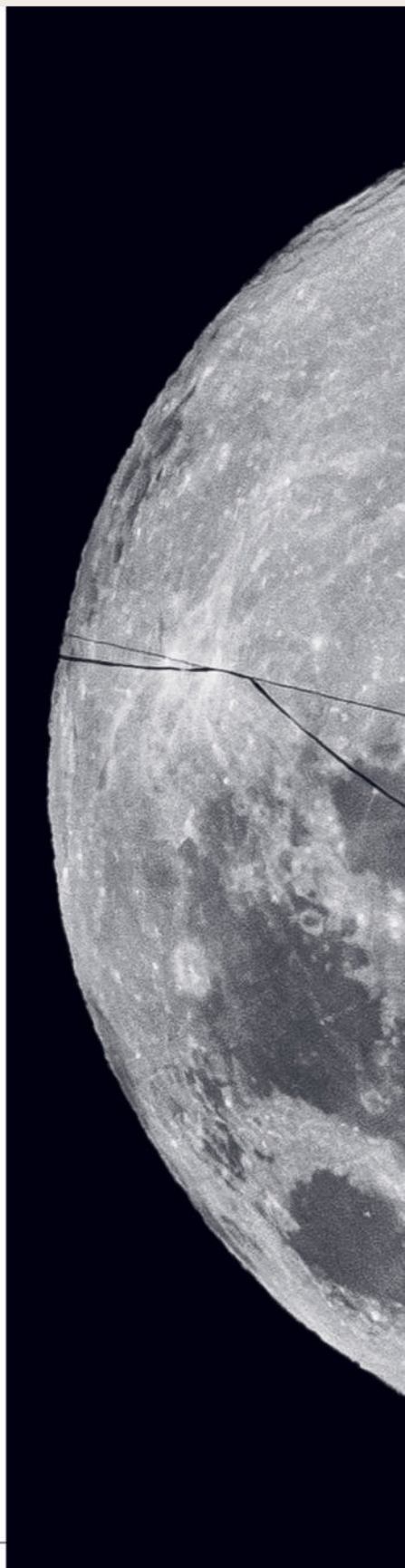
Photograph and words by
AIDAN WILLIAMS

→ **MY RADIO CRACKLED.** “Did you get it?”

“Dude, no,” I said. “I can’t even see you.”

It was 2 a.m., and I was sprinting through the dark with a tripod, trying to line up the full moon and professional unicyclist Gabriel Camolesi as he crossed a one-inch-wide highline stretched between two cliffs in Australia’s Blue Mountains. He’d already ridden across twice, but I couldn’t find him in my viewfinder, and the moon was setting fast.

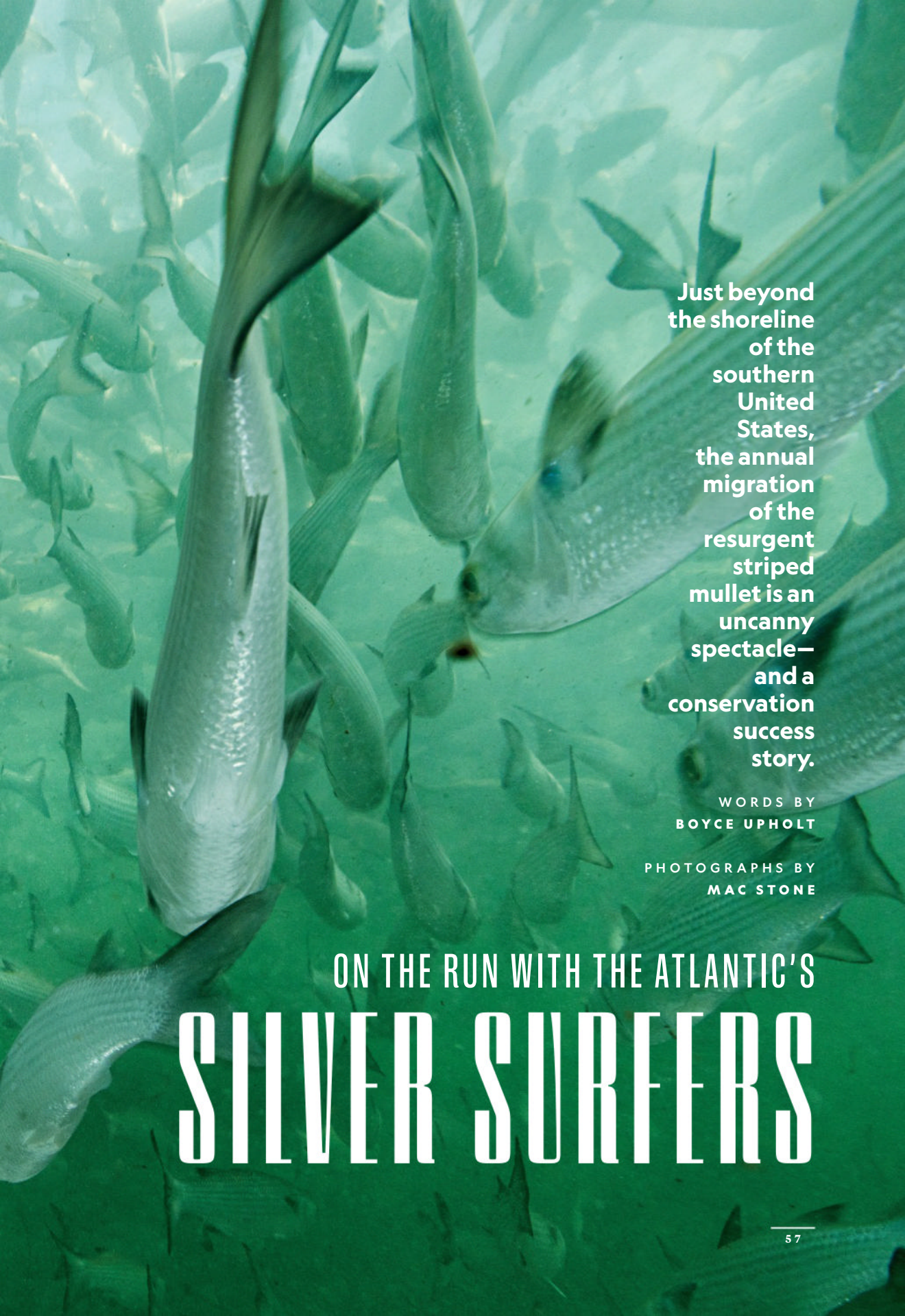
Seven years ago, when I first got into adventure photography, I saw Mikey Schaefer’s picture of climber Dean Potter walking a slackline in Yosemite National Park in front of a full moon. It completely changed what I thought was possible, and it sparked an idea: a moonlit image, this time with a unicycle. Gabe and I, along with a small support team, had tried the shot at four locations across Australia, only to get shut down by clouds, wind, or bad angles. By the final attempt, everyone was exhausted. I could barely see anything except the glowing moon itself. Just don’t miss the shot, I kept thinking. When Gabe rolled into position, I fired off thousands of frames. Then I radioed the team: “We have it.” It was the biggest relief of my life. —AS TOLD TO GORDY MEGROZ





A large school of striped mullet swimming in clear, shallow water. The fish are silvery with prominent dark vertical stripes. They are densely packed, filling the frame from the foreground to the background. The water is a clear, light blue-green color, and the sandy bottom is visible beneath the fish. The lighting is bright, creating a shimmering effect on the fish's scales.

Beginning each fall, vast schools of striped mullet—some comprising as many as a million fish—stream through Florida's inshore waters to reach spawning grounds, one of North America's most dramatic marine migrations.



Just beyond
the shoreline
of the
southern
United
States,
the annual
migration
of the
resurgent
striped
mullet is an
uncanny
spectacle—
and a
conservation
success
story.

WORDS BY
BOYCE UPHOLT

PHOTOGRAPHS BY
MAC STONE

ON THE RUN WITH THE ATLANTIC'S
SILVER SURFERS





Tarpon are among the game fish that feast on the teeming mass of mullet, making the run, as it's known, a windfall for anglers. Mullet were heavily fished by commercial fishermen before Florida banned the entangling nets used to catch them.



Y

OU CAN SEE THEM surging from the shore: a dark band across the water, a stream of silver fish paralleling the beaches along Florida's Gulf and Atlantic coasts. For several weeks each fall and winter, the schools of migrating mullet can be a million swimmers strong, up to 40 feet across and a half mile long. They look like writhing sea monsters or oil slicks come to life. Approach one in a boat, and you split the school like Moses parting the sea. Behind you, the swarm reassembles effortlessly, the fish unbothered by the interruption.

You sit in a bubble of empty water amid the rush of life.

For photographer and National Geographic Explorer Mac Stone, capturing the full majesty of the annual mullet run—one of North America's largest and most visible marine migrations—meant going even further, dropping into the clear waters south of the Everglades, free diving among the fishy millions. The experience was disorienting. "You can't see anything, no horizon line, no fixed point that you can focus on," Stone says. "You just have a wall of fish. My brain broke multiple times."



Seabirds like ospreys benefit from the abundance of the mullet run. When ospreys fly with a fresh catch, they angle the fish to make it aerodynamic.

Most people, if they know the striped mullet at all, know it as a humble bait-fish. Scientists' descriptions can sound almost contemptuous: The fish are "thick-bodied" and "blunt-snouted," according to one government report. Typically a foot or so long, they're bottom-feeders found all over the world, in tropical, subtropical, and

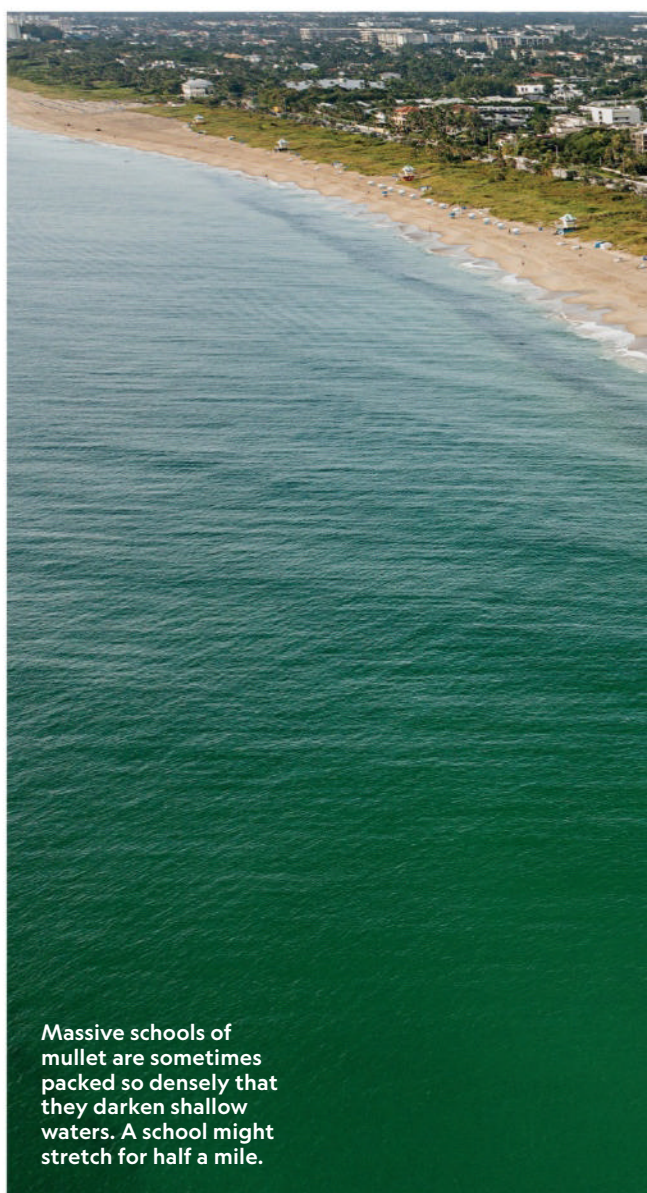
temperate waters. And since their massive schools make for easy pickings, mullet have long been a cheap staple of coastal kitchens, although their fatty flesh is too muddy tasting for some palates. Around the southeastern United States, they're caught mostly as bait and to harvest roe for export to Asia, where it's a delicacy.



The mullet that stream along the southeast coast often head to deeper water to spawn. Their movements in the open ocean are poorly understood, but some researchers think they migrate as far as the Gulf Stream—dozens of miles offshore, in some places.

Off Florida's coast, today's impressive runs are, in part, a testament to the impact of one forward-thinking policy. Some 30 years since the state banned the use of entangling fishing nets—underwater sieves that once made it easy to haul in staggering numbers of mullet—the population is robust. Florida's commercial mullet catch has dwindled, and some long-time mullet run observers say the migration has only become more spectacular.

And that abundance has a massive ripple effect for other species. "You can see tarpon, sharks, king mackerel just turning cartwheels," says Captain Jim Ross, owner of Fineline Fishing Charters on the state's Space Coast, near Cape Canaveral. For the mullet's many predators, the annual run prompts feeding frenzies, the little fish leaping out of the water to evade the bigger ones. The resulting churn looks like grenades being detonated. Seabirds hover overhead, waiting for their chance to dine.



Massive schools of mullet are sometimes packed so densely that they darken shallow waters. A school might stretch for half a mile.

The mullet may be humble, but their pursuers are often big-name sport fish, meaning the run creates a business opportunity for captains like Ross. During the migration, he says, the trophy fish are "so focused on their mission... that the fishing becomes extremely easy." Along the Space Coast, where a long line of beaches gives easy access to the schools, charters book clients months in advance.



When they're not luring anglers to the coast, mullet spend most of their lives in freshwater rivers and estuaries. But as the days shorten and the water cools, they gather and swim downriver, seeking brackish estuaries that serve as staging areas, before venturing off-shore to spawn. Many will travel less than 20 miles, but a hardy few migrate hundreds of miles along the coast.

The epic migration turns the mullet into an ecological bridge, linking profoundly different habitats into one food web. Before the run, the mullet Hoover up bits of bacteria and algae from the muck of the river bottoms. The mullet, in turn, are eaten by predators in the ocean or swooping from the sky. Their place in the middle makes mullet what biologists call an indicator species, a





*Clockwise
from top left:*

Bottlenose dolphins in the Everglades use their tail fins to stir up mud in rings around groups of mullet. To escape, the fish jump out of the water—often into the mouths of waiting dolphins.

The mullet share their migration route with drifting moon jellies, which contract and relax their bell-shaped bodies to stay suspended in the current.

Striped mullet are also known as jumping mullet. Hurling themselves out of the water may help them evade predators—but bottlenose dolphins like this one sometimes know to expect it.

Strength in numbers gives schools of mullet better odds against predators. As they travel, fish periodically move to the bottom of the formation, where they can feed on microorganisms in the sand.



way of monitoring the entire system. And the spectacle of their massive runs in Florida is suggestive of healthy habitats, says Stephen Kajiura, a biologist at Florida Atlantic University. “It’s interesting from a visual perspective,” Kajiura says, “but it’s also a good ecological indicator.”

Both impacts, visual and environmental, are what lured Stone to Florida’s Everglades, home to the mainland U.S.’s southernmost mullet run. (North Carolina is also known for impressive runs, but there, where fishing nets are less regulated, officials are seeing fewer older females—a warning sign of overfishing, which the state is working to address.) Stone followed the schools by boat and helicopter. From the latter, he watched for dolphins engaged in a behavior known only in a few places outside Florida, using their flukes to stir up mud rings that surround the schools. When the spooked fish jump from the water, the hungry dolphins are waiting to catch them.

But capturing a close-up of mullet leaping away from predators—what Stone calls the “holy grail” of mullet photo ops—proved tricky. Stone knew he’d have to get wet to do it. Swimming amid the rush of the silver fish, he says, made him feel like a “chicken nugget,” a vulnerable target for sharks—of which he saw several. Getting a mullet’s-eye view had an upside, though. After going a season in the water without photographing a jumping fish, Stone began noticing a tell-tale behavior. Right before a predator would swim into their midst, a few of the more perceptive mullet would switch direction instants before the whole school took evasive action.

“So I started to just cue into that little change in movement of fish,” he says. “As soon as fish started going the opposite way, I turned my camera back to the way that they came.” And soon enough, he managed to capture the leap, a small but mighty maneuver, a moment of acrobatic drama from a species known for putting on a show. □



Though they take to the sea during the annual spawning run, mullet spend most of their adult lives in rivers or brackish waters near river mouths.





Schools of mullet, like this one above a yellow stingray, may travel 50 miles or more during the run. Larval fish, spawned at sea, are under an inch long as they migrate into tidal creeks, where they'll adjust to fresh water.





Can
WILDFLOWERS
 HEAL THE
TOXIC MESS
the L.A. Fires Left Behind?

Last year, devastating blazes polluted soil in parts of Los Angeles. Native plants can help repair the damage—and sow the seeds of something more.

Words by DANA GOODYEAR

Illustrations by JIYEUN KANG

→ **ONE GLOOMY DAY** early last summer, my husband, our two children, and I put on our N95 masks and went “home.” The bulldozers had recently been through, clearing the charred wreckage of the house in Los Angeles’s Pacific Palisades neighborhood that we’d occupied for the better part of the kids’ childhoods. On January 7, 2025, a catastrophic wind-driven fire, which started in the Santa Monica Mountains, had obliterated Pacific Palisades and parts of Malibu; on the same day, a separate blaze, the Eaton fire, tore through Altadena, a community in the foothills of the San Gabriel Mountains, 30 miles to the east. Between the two fires, some 16,000 structures were destroyed, rendering tens of thousands of people temporarily homeless and turning the lush places where they had lived into wastelands.

My family had come back to the Palisades

to witness the damage and, we hoped, make a small gesture toward repair. Around us, the neighborhood lay flat and blank and uncertain. Retaining walls, steps to nowhere, chimneys, stone Buddhas, and the odd structure (including our unaccountably extant garage) proved there had been a world there. But the landscape was disordered, catastrophically transformed: Blackened trees were marked with ominous runes, portending future removal; others were singed at the crown, their trunks furred with determined new leaf growth. There were no dogs, hardly any birds. The people—not that there were many—drifted ghostlike down the middle of the vacant streets. Why shouldn’t they?

For my son, Rummy, who was 14, and my daughter, Willa, who was 12, the loss felt all-encompassing—not just our home and its contents but also trees they’d climbed,

their favorite restaurants, their friends' homes, the sense of where they would grow into young adults. The rousing talk of children's inherent resilience was easy to invoke and difficult to envision. How would we ever get through this, much less get over it? There is no handbook for the victims of nature, no survivor's guide for ways of weathering. No one to tell you what to do when everything is gone—broken, smashed, flattened, sunk, or burned, done in by a force of such enormity you would have to go to your old children's mythology books (if only you still had them) to find its ancient yawning name: Chaos.

Not long after the fires, an unlikely image came into my mind. It was of bright orange poppies cascading down from the mountains, replacing the wall of flames that had wiped out life as we knew it. The image had a source deep in the region's past. Spanish explorers, first viewing the coast of California from the sea five centuries ago, had declared it *la tierra del fuego*, the land of fire. They were referring, apparently, to the poppies, whose abundant orange-gold blossoms looked like flames lapping at the hillsides.

The explorers were on to something, whether they knew it or not. California is the land of fire; fire is the essential force shaping the mountains' chaparral ecology. For certain native plants, periodic burns create conditions for survival. The fragile, fleeting fire poppy and the manzanita require the smoke and heat of wildfire to germinate; ecologists call them "fire followers." Other species, while not dependent on fire, have adapted to exploit the nutrients, sunlight, and visibility to pollinators that result from large blazes. These include the common sunflower, bush sunflower, yarrow, buckwheat, evening primrose, and even the ubiquitous California golden poppy, the bright orange state flower. "These are really opportunistic plants," Tim Becker, a horticulturalist

with the Theodore Payne Foundation for Wild Flowers and Native Plants, told me recently. "They love disturbance. They're excellent at capturing nutrients, preventing the soil erosion that is really common in postfire environments, and creating habitat for wildlife." Could we be like the plants, I wondered, and make a virtue of the loss?

My kids grew up with the classic bedtime book *Miss Rumphius*, the story of the so-called lupine lady who scattered seeds along the coast of Maine. I told them I knew what we needed to do: spread native seeds in the ruined places and help bring them back to life.

I have never been much of a gardener. I don't have the patience, and I used to think I didn't have the time. I appreciate gardens but don't know how to make one. Obviously, we couldn't go around digging in other people's burned-out lots—too dangerous, too illegal. I considered what Miss Rumphius would do and Googled a recipe for seed bombs: doughnut-hole-size balls of seeds, compost, and clay, used by urban guerrilla gardeners and habitat restorers to plant in tricky spots. The compost provides nutrients for the seeds, and the clay protects them from animal predation, giving seeds the best chance for survival while they wait for rain.

I bought compost and powdered clay and placed a large order for native wildflower seeds. In the yard of one of several rentals we occupied that year, the kids and I made our inaugural batch of seed bombs. Wetting the mixture and rolling the seedy slurry between our hands was surprisingly relaxing but also felt purposeful, like making bread. When the seed bombs dried, we started sharing them with friends and neighbors who'd also lost their homes. Rummy and a friend made a batch for their eighth-grade service-learning



Could we be like
the PLANTS
and *make a virtue*
of the loss?

project, then threw them in the Palisades. In May, Rummy led a schoolwide workshop where students made thousands of seed bombs that he and I distributed in Altadena and the Palisades. I began to picture spring: wildflower meadows blanketing both neighborhoods, a color-field painting in petals. We'd be graffiti artists, creating punky bursts of blooms throughout the burn scars.

Not long after, on that overcast summer day, we returned to our old address as a family. My kids stood on the brick threshold of our vanished home and hurled seed bombs into the void. Then we all climbed down into the pit and stood in what had been the living room. It was where we'd always spent Christmas, with a roaring fire. I thought about our last Christmas there, an especially sweet one, less than two weeks before the house burned down. We put a pile of seed bombs on the hard, scraped earth and, standing in a tight circle, crushed them with our boots, right where the hearth had been.

FOR THE LONGEST TIME, nothing happened. The summer was unrelentingly hot, and no rain fell. Rummy began to question if

the seeds were duds—dead, like so much else. I didn't blame him for feeling cynical, and I can't explain why I did not. I just believed the seeds would work.

In October, heavy rain triggered mudslide warnings in the burn scars, and I wondered if our seeds were washing out to sea. A couple of weeks later, Rummy and I had plans to meet a neighborhood beautification group to seed-bomb the parkway alongside Sunset Boulevard, which runs through the Palisades. On the way, we stopped by our lot. In the spot where our fireplace had been, there was a soft green mound made from a thousand poppy starts. Rummy's face broke into a huge, involuntary smile. We had growth.

It rained heavily throughout December, January, and February. Our rental house leaked, but I did not care. The rain meant one thing to me now: happy plants. Weekends, holidays, whenever possible, we made seed bombs. Rummy recruited his friends, his sister, her friends, friends of friends. We named our effort the Seed Bomb Project, and we reached out to everyone we could think of who would want to help or might want seed bombs for their empty lots. We held workshops at elementary schools in Altadena and the Palisades, at school fairs and neighborhood gatherings, at a community center established to aid fire victims. A company donated 10 huge bags of organic compost. Gardeners and seed companies started sending seeds. With the help of hundreds of volunteers—many of them people who had lost their homes, schools, and communities—we churned out thousands of seed bombs.



Meanwhile, preliminary reports about the fires' toxic aftermath began to come out. High levels of heavy metals, such as lead and arsenic, were detected on lots in Altadena and the Palisades: So many cars, electronics, and plastics had burned, along with treated wood and leaded paint. As part of our insurance claim, we commissioned a report from a toxicity expert, who determined our garage was irreparably contaminated with cyanide, lithium, lead, chromium, beryllium, cobalt, and arsenic, as well as various other toxins. When the toxicologist finished her assessment, she made my husband promise never to set foot in the garage again. We resigned ourselves to throwing away the sentimental items we'd hoped to salvage from inside.

In March, I visited our lot with another toxicologist, Danielle Stevenson, along with UCLA environmental engineer Sanjay Mohanty. Through her research, Stevenson has established protocols for phytoremediation, plant-based solutions to toxic cleanups. The wet winter had left our lot covered in a patchy blanket of growth; tufts of poppies lined the perimeter, and a small hedgerow of sunflowers was growing in what used to be our front entry, the spot where the kids always dumped their backpacks after school.

The day was bright and clear. A ladybug crawled up the stem of one sunflower, and a bee dug around in the blossom of another. Stevenson peered at a delicate vine with tiny yellow flowers threading its way along the ground at the base of the sunflower stalks. "This is a non-native sweet yellow clover,"

she said, "but in my studies we found that it accumulates lead." The bush sunflower we'd planted, she noted, removes arsenic.

Stevenson turned her attention to the common sunflowers, those cheerful stalwarts of fall bouquets. They're known as hyperextractors, proficient at sucking lead from soil. With lead contamination in the nearby garage, we figured there could be lead all over the lot. Maybe the sunflowers were doing more than feeding bees. Maybe they were cleaning our dirt.

Mohanty pulled out a handheld laser resembling a highway patrolman's radar gun and pointed it at the soil, taking a quick reading. The lead was surprisingly low—16 parts per million—possibly because bulldozers had removed several feet of soil and debris. Below 80 parts per million does not require remediation. We walked two blocks to Sunset Boulevard, close to where Rummy and I had dispersed seed bombs in the fall. A friend had planted the parkway there with sunflowers and thrown in a few of our seed bombs for fun. In that unscrapped soil, lead readings were shocking. "This is a crazy number," Mohanty said, reading 414 off his laser gun. He moved over a few feet and got a finding of 643. "These are brownfield levels."

Stevenson collected leaves from the sunflowers. Later, Mohanty would dry them, digest them in acid, and analyze the solution for lead using a mass spectrometer.



Given the levels in the soil, they expected to find it in the leaves. Stevenson cautioned that phytoremediation is a slow, complex process and works best in conjunction with fungi that help metabolize metals. “When levels are high, you might only get one percent removed per year,” she said. “If you want it below 80, it will take a long time.”

THE PALISADES, until last year, had been green and lovely but filled mostly with imported plants, not drought-tolerant, fire-adapted natives. Unexpectedly, an opportunity had opened—to restore something that was lost long before the fires came. This has been the key to my family’s recovery.

The fire stole our sense of place and robbed us of our time. Restoring native plant communities to the Santa Monica Mountains feels like a way to reclaim our connection to our former home. And the waiting—for a speck of green, a shoot, the first extravagant bright bloom—has made time’s passage feel productive and loaded with meaning. By now, the Seed Bomb Project has made and distributed some 10,000 seed bombs. Though the community we had before the fires is gone, we have formed a new and more expansive one, spanning the city. For my kids, the meadow on our lot is the metaphor I don’t need to

spell out. Chaos is the void where creativity is born. This is the fire’s surprising gift.

This spring, the growth in the Palisades and Altadena was explosive. Between the burn and the rain and the lack of human interference, the neighborhoods transformed into a wild hodgepodge, with pomegranates alongside telegraph weeds and morning glories, blowsy fields of dandelions, and lot line to lot line sow thistle, bristly and unpleasant. On our lot, along with a few unwanted sprouts of invasive black mustard, we had bursts of poppies growing around the perimeter, their foliage extravagant as the ruffs of Tudor queens—wallflowers but for the lack of walls. Our home never felt more chaotic, unruly, or delightful, a children’s book come to life, the way, when I was a kid, I always wished they would.

When the first flowers that bloomed in our lot started to die—sunflowers bowing their heads, poppies shedding their bright petals—I wasn’t sad. I celebrate their impermanence. It is the key to their resilience and the most critical knowledge they could impart. The 10,000 seed bombs and the flowers they grew are leaving new seeds in the ground, and when the conditions are right—enough water, enough sunlight, enough space—the flowers will come back. □



THE SURPRISING DETOUR OF THE WORLD'S OLDEST



TASHKENT

Visitors ride a virtual reality simulator at a new entertainment complex in Uzbekistan's capital. Surging tourism is helping fuel a building boom across the Central Asian country, including in cities known for their historic character.

SUPERHIGHWAY

Tourism is booming along the former trade routes of the ancient Silk Road. To understand its recent transformation, **Gary Shteyngart** took to Uzbekistan's caravan trail.

PHOTOGRAPHS BY INGMAR BJÖRN NOLTING



SAMARKAND

Part of a new resort development, the attraction called the Eternal City reimagines a Silk Road oasis town filled with restaurants and boutiques—all housed in replicas of the iconic architecture that's authentically preserved elsewhere in the city.





ARRIVED ONE MORNING LAST WINTER AT

the great blue-domed Chorsu Bazaar with the bleary disorientation of a man who'd just flown 11 hours into a strange city. Tashkent, Uzbekistan's boisterous capital, was my entry point for a whistle-stop tour of a country I had dreamed about since my first dreary winter days growing up in Leningrad. Uzbekistan! As a child, I had pored over books about Central Asia. The combination of warm sun on desert sands and food that wasn't boiled to death, as it was in my hometown, inspired an aching reverie. The cities in the photos bristled with turquoise minarets, architectural remnants of the 1,500-ish years that Central Asia spent as the world's sunny crossroads, the hub of the fabled Silk Road network, carrying tex-

tiles, spices, technologies, and ideas between China and the Mediterranean.

Back then, during my childhood, Uzbekistan was part of the Soviet Union—a republic in the very country I lived in—but it might as well have existed on another planet. And for most of my adult life, it hasn't felt much more accessible. After its independence, in 1991, the country spent the better part of 30 years nursing a post-Soviet hangover, rampant with surveillance and bureaucracy and largely unwelcoming to foreigners. Only in the past decade has it really begun to open up—which is maybe why it felt so surreal to sit through an Uzbekistan Airways safety video, watching a grinning, camel-mounted caravanner showing me how to tighten my seat belt and a rug merchant at an oasis bazaar demonstrating the proper fit of an oxygen mask.

Today Uzbekistan is in the middle of an aggressive tourism push, and to woo visitors, it's leaning hard on the strongest brand it has: the Silk Road, that mutable, time-honored signifier of exotic adventure and cultural connection. The country is also undergoing a building boom—conspicuous, as I taxied around Tashkent, from the clutter of cranes and gleaming new high-rises. All across Uzbekistan, sprawling tourism developments are popping up that use Silk Road iconography as something like theme park fodder: Silk Road-themed hotels and restaurants and water parks set among showy replicas of tiled madrassas and brickwork caravansaries.



KHIVA

Tourists pose with their hands against the Kalta Minor minaret, designed as a place to call for prayer. The desert oasis city of Khiva once welcomed caravans traveling the Silk Road network of trade routes, which linked China and the Mediterranean for some 1,500 years.



Plenty of Central Asian countries could use the dollars, euros, and yuan that tourists bring, but no place is leveraging its Silk Road heritage as effectively as Uzbekistan, which suddenly boasts one of the world's fastest growing tourism economies, receiving some 12 million international travelers last year, up from scarcely two million a decade ago. And the government of reformer president Shavkat Mirziyoyev wants 20 million by 2030—putting Uzbekistan on par with, say, the Netherlands, Morocco, or Vietnam.

Earlier this year, the Uzbek government stopped requiring U.S. citizens to obtain entry visas, formerly some of the most cumbersome and expensive to get in the post-Soviet

states. The government has also subsidized a flurry of hotel construction and invested heavily in high-speed rail. Fast trains now link Tashkent to the triple crown of Uzbekistan's Silk Road oasis cities: Samarkand, the jewel of the East, once an intellectual seat of the Islamic world and today full of preserved mosques and madrassas; Bukhara, in central Uzbekistan, a quieter mercantile hub with a labyrinthine old town and a burgeoning arts scene; and Khiva, to the arid west, where khans ruled a desert kingdom, now billed as a "living museum" for its UNESCO-protected walled fortress of Itchan Kala.

Each city is a few hours' train ride from the next—journeys that once took merchant





TASHKENT

Among the new high-rises overlooking Tashkent City Park are the 874-foot Nest One (center), Uzbekistan's first skyscraper, and several new hotels. The government has subsidized hotel construction across the country to meet its ambitious goals for attracting tourists.



caravans days or weeks. And each is in a moment of flux, with ancient monuments to humanity's first cosmopolitan ideals rubbing up against the modern trappings of commodity leisure.

One perverse yet positive effect of the Soviet Union's economic stasis was that it preserved many cities, including my native Leningrad turned St. Petersburg, from intense modernization and overbuilding. With the Soviet era now a fading generational memory, I wanted to travel the route of those classic oasis cities to see whether the country I dreamed of as a child still existed in genuine form.

I chose Tashkent's Chorsu Bazaar for my first stop, figuring few places could better

capture, and perhaps demythologize, the spirit of the Silk Road. Its Soviet-era pavilion covers a site that's been a market for perhaps 2,000 years, still delivering today what the Silk Road was always all about: trade. The silk and spices once trafficked along the route can still be found there—fragrant piles of saffron, turmeric, and the wild cumin called *zira*—but so can just about everything else. The food hall was awash in many kinds of creamy cheese, glistening livers, and *kazi*, an absolutely delicious horse sausage. Women of Koryo-saram heritage—descendants of Koreans that Stalin deported to Uzbekistan for the usual paranoid Stalinist reasons—hawked tubs of *morkovcha*, a garlicky Korean-style carrot salad that



TASHKENT

At Beshqozon, a restaurant franchise, cooks prepare orders of *plov*, Uzbekistan's national dish, traditionally a medley of rice, lamb, carrots, onions, garlic, and fragrant spices, cooked in a cast-iron cauldron called a *kazan*.

qualifies as the best use of carrots in culinary history. On a more Silk Road-y note, I found carpets and daggers for sale, right alongside Winnie the Pooh-branded local honey and many, possibly too many, roach-killing products.

What made the khanates of medieval Uzbekistan great and their cultural and architectural legacy in need of our protection? The inability of any one nation to create a full range of products, the need for roach-killing potions and garlic-carrot salads to traverse the wide steppe and make life more livable for everyone along the way. Today, for under a dollar, you can buy a cup of coffee and a delicious meat pastry at the Chorsu—travelers take note, the food in Uzbekistan might as well be free—and get jostled by men running around with cow heads on their shoulders, who will put a hand to their heart in apology after they almost knock you over.

The word *chorsu*, by the way, comes from a Persian term for “crossroads”—a name given to the site back when crossroads were fewer and farther between, before a bullet train could rocket you in hours to another oasis waiting around the bend.

I HE NEXT MORNING, I got on the Afrosiyob high-speed train, named for an ancient settlement of early Silk Road merchants, and rode beyond the suburbs of Tashkent. Outside, an occasional cow puttered in a daze around the bleak post-industrial landscape the Uzbeks inherited from Soviet rule. Inside, I was plied with strawberries and ice cream and free Wi-Fi.

The rail corridor was once a small part of the vast, shifting lattice of routes that we now call the Silk Road, which branched and rejoined one another for thousands of miles between China and Europe. From the second century B.C. until the late 15th century A.D. and the dawn of the age of sail, caravans navigated these corridors, adjusting their itineraries as politics, weather, and business needs demanded. Empires like the Hans and the Romans anchored either end, but trade goods moved through intermediaries and middlemen all across Eurasia—and with them, of course, philosophies, arts, myths, and religions. The interconnected planet we now live on, where countless strands of commerce and culture connect Topeka to Taipei? The Silk Road was its prototype.

For a millennium and a half, the Uzbeks had visitors from much of the world wandering through their cities, and I got the sense from their warmth and eagerness that a lot are delighted to have a slew of new visitors to chat up. I was glad to speak fluent Russian, a language still much in use



TASHKENT

A light show draws a crowd to the Seoul Mun district, where fountains, shops, and cafés are inspired by South Korea's capital. Many ethnic Koreans in Uzbekistan, known as Koryo-saram, descend from those forcibly relocated from the Russian Far East under Joseph Stalin.



in Uzbekistan (much less so English), and to meet so many Uzbeks who've worked in St. Petersburg or who have family in New York, where I've lived since 1979. When I arrived in Samarkand, a city of about 600,000, my taxi driver politely asked if I earned more than \$5,000 a month in New York and was genuinely happy for me when I answered in the affirmative. "Very good," he said, before asking whether the sheep in my part of the world had, as he had heard, curly tails.

Walking the streets of Samarkand's old town, I began to suspect that every building I passed, no matter how humble, dreamed of growing up to become a boutique hotel. They were everywhere. The one I stayed in was exceptionally tasteful, its rooftop affording a great view of Samarkand's most famous landmark, the Registan. If you have seen photos of Uzbekistan, you have probably seen the mighty blue-green-yellow portals of the three madrassas that flank this famed public square, impossibly ornate gateways into the academies that once made Samarkand the Oxford of the East. The oldest was built in the 15th century by the scholar-king Ulugh Beg, a mathematician and astronomer who ushered in an era of flourishing Islamic art and science (his restored observatory, across town, attracted scholars from all over Asia). The others went up in the 17th century to complement it.

Today all three are preserved exhibit spaces, and I spent hours ogling the geometric patterns of their glazed ceramic tiles. First they drew in the eye, and then the intellect followed: Were these stars or fractals or other kinds of geometries? The buildings rippled with three-dimensionality, with nooks and alcoves everywhere. There is no Islamic architecture, or any other architecture, quite like this, and even a jaded traveler like myself felt blessed to be there in the depth of winter, sharing the space with only a few forlorn tour guides and a handful of Japanese visitors who'd braved the cold and were now alone with their sense of wonder.

The main sights of Samarkand are spread out, so that one walks between them through quieter parts of the city, full of Soviet-era buildings. Outside restaurants, men stand at sizzling cauldrons called *kazans*, mixing the afternoon *plov*—a rice dish of such aromatic intensity that I have swooned at its rich currents of onion, garlic, carrot, and mutton steaming off of a plate.

Perhaps the most beautiful site in Samarkand is the Gur-e-Amir, a cascading complex of mausoleums where Ulugh Beg is buried, along with his less nerdy and more blood-thirsty grandfather, Timur. An Uzbek national hero (better known as Tamerlane in the West), Timur conquered and ruled a territory that extended across Central Asia and modern-day Afghanistan and Iran, and he built Samarkand into his splendid capital. The mausoleums' ceilings and domes, covered in tessellated tiles that form polygon patterns of mind-boggling intricacy, show how science and architectural know-how and a sublime set of aesthetics went hand in hand in the Timurid era. I left with a crick in my neck and a phone full of images I'll never erase.

This spring, the Uzbek government announced plans for a new Silk Road Museum a few blocks from the Gur-e-Amir, showcasing archaeological finds, traditional crafts, and more on a 22-acre campus—roughly the size of New York's sprawling American Museum of Natural History. But it's not the only new, gargantuan Silk Road-themed project in Samarkand, and after a couple of days exploring the city's historic sites, I hopped a taxi to Silk Road Samarkand, a four-year-old \$580 million resort development on the eastern edge of town.

I'd heard about the place weeks before from historian Svetlana Gorshenina, an Uzbek expat at France's National Center for Scientific Research and co-founder of a preservation group called *Alerte Héritage*. She described, with some bemusement, what the resort bills as the Eternal City complex, a replica Silk Road oasis town made up of restaurants, boutiques, and performance spaces, all designed

CREATING A CROSSROADS

Uzbekistan's varied geography shaped the trade routes of the ancient Silk Road—and with them, the itineraries of today's tourists. Merchant caravans followed water sources across windswept deserts and over mountain passes. Now their trading posts and resupply hubs are becoming destination cities.



— Ancient Silk Road corridor, ca 130 B.C.–A.D. 1450

— Modern high-speed rail

50 mi
50 km



Fortified oasis

The walled city along the Amu Darya served as a crucial, isolated way station surrounded by desert.

Riverside respite

At the desert's edge, the town became a commercial and cultural nexus of ancient Persia thanks to its site on a fertile delta.

Foothills stronghold

Trade routes met at the base of formidable mountains, making the city a prize for conquerors like Alexander the Great and Genghis Khan.

Eastern gateway

Nomadic peoples of the northern steppe traded here with merchants traveling the mountain valleys northeast of the city.

To China

To India

To Southwest Asia





SAMARKAND

The Registan public square is among Uzbekistan's most visited attractions, renowned for its three tiled madrasahs, the oldest of which dates back to the city's 15th-century heyday as the Silk Road's locus of Islamic scholarship.



to look like the Timurid buildings back in the city center. “Very beautiful, but not real,” Gorshenina told me, lamenting that the funds to build it might have been used for upkeep of actual historic structures.

My taxi driver took me past Samarkand’s city limits, to a checkpoint staffed by a bored-looking guard. The Eternal City is built alongside a large rectangular canal, with several skyscraper hotels towering overhead. It was eerily quiet on my winter visit, but during the summer season, boats evidently ply the canal between the Hilton and the 18 waterslides of Silk Road Waterland.

The place was strange in a David Lynchian kind of way, dreamlike and disquieting.

After seeing the Registan and the Gur-e-Amir, the patina and age and soulful wear on their ceramic tiles, it felt absurd to walk among the shiny and lifeless re-creations of the same. Who would want to come here? I wondered. But the waitress at the cavernous and entirely empty restaurant (the passing staff looked almost concerned to see me) told me the Eternal City is full of tourists during the warmer months. I walked to the silent water park, past the go-kart track and the closed Quran Museum, wondering what it would be like to stay at the top of that Hilton, so far from the sound of stray dogs and the muezzin’s call to prayer, without which I would not want to wake up in Samarkand.



SAMARKAND

A young girl plays with a kite on the hills of the Afrasiyab archaeological site in the middle of the city. Ancient Afrasiyab was a trading hub from the earliest days of the Silk Road until the settlement was destroyed by Genghis Khan.

ALL COUNTRIES HAVE their mythologies to sell: The United States has its cowboys, Spain its bullfighting, and Germany its wurst. It's only natural that a developing country like Uzbekistan should harness its heritage by slapping the phrase "Silk Road" and the outline of trekking camels onto everything from passenger trains to shopping malls in order to entice moneyed tourists. "After the collapse of the Soviet Union, all the countries are trying to find their national identity," Gorshenina had told me. What worries her are projects that seem so determined to exploit the Silk Road mystique, they threaten the character of their centuries-old surroundings.

One place where her organization has sounded some alarm is Bukhara, another storied oasis city, half Samarkand's size and two hours west on the Afrosiyob. Bukhara's compact old town is more cohesive than Samarkand's. Fewer modern buildings interrupt its low-slung historic ones, which cluster along slim alleyways that can barely hold one-way car traffic, much less the vehicular free-for-all that nearly did me in during my first nighttime foray. Data does not roam these streets—my phone was wonderfully useless. The fifth-century Ark of Bukhara is the Platonic ideal of a fortress, its undulating walls recalling sand dunes, its interior a city-within-a-city-within-a-city, full of courtyards where emirs once received dignitaries. Nearby, the Kalon Mosque is one of Central Asia's largest, with room for some 10,000 worshippers, and its 150-foot brick minaret is so impressive that even Genghis Khan couldn't make himself tear it down during his plunder of the city.

And let us not forget the plov, more layered and fragrant than any I'd had so far. ("We use five types of oil and yellow and orange carrots," one proud waiter told me.)

But Bukhara's old town also had the feel of a place in transition. I spotted a seemingly endless array of "Building for Sale" signs, in Russian, as if all the locals are in the process of cashing out their dwellings. And along the old town's edge was a massive construction zone for a tourism development called Eternal Bukhara. I strolled along its substantial fenced perimeter, which begins right where the UNESCO-protected old city ends—a point of contention for Gorshenina's group, which has appealed to UNESCO and the Uzbek government to intervene. According to Uzbekistan's state news agency, Eternal Bukhara will be a "historical and ethnographic park" with hotels, replica historic architecture, cafés, and an arcade full of folk artists around a musical fountain. According to what appeared to be AI-generated





BUKHARA

On a trip from her home in Tashkent, Madina Usmanova wears a flowing robe called a *chapan* for a photo shoot to celebrate the birthday of a friend visiting from the United States.



HOW TO TRAVEL UZBEKISTAN'S SILK ROAD BY TRAIN

As Uzbekistan expands rail options, Silk Road journeys once measured in days or weeks now unfold in hours—and give travelers increasingly comfortable views of the country's changing landscape. Several different types of trains traverse the classic routes. Here's what to know.

TO SAVE MONEY

Uzbekistan Railways' most economical options (its booking platform simply calls them passenger trains) tend to be bumpier, Soviet-era cars. Air-conditioning isn't guaranteed. Tashkent to Samarkand is a four-hour trip, Samarkand to Bukhara just over three, and Bukhara to Khiva six to seven.

TO SAVE TIME

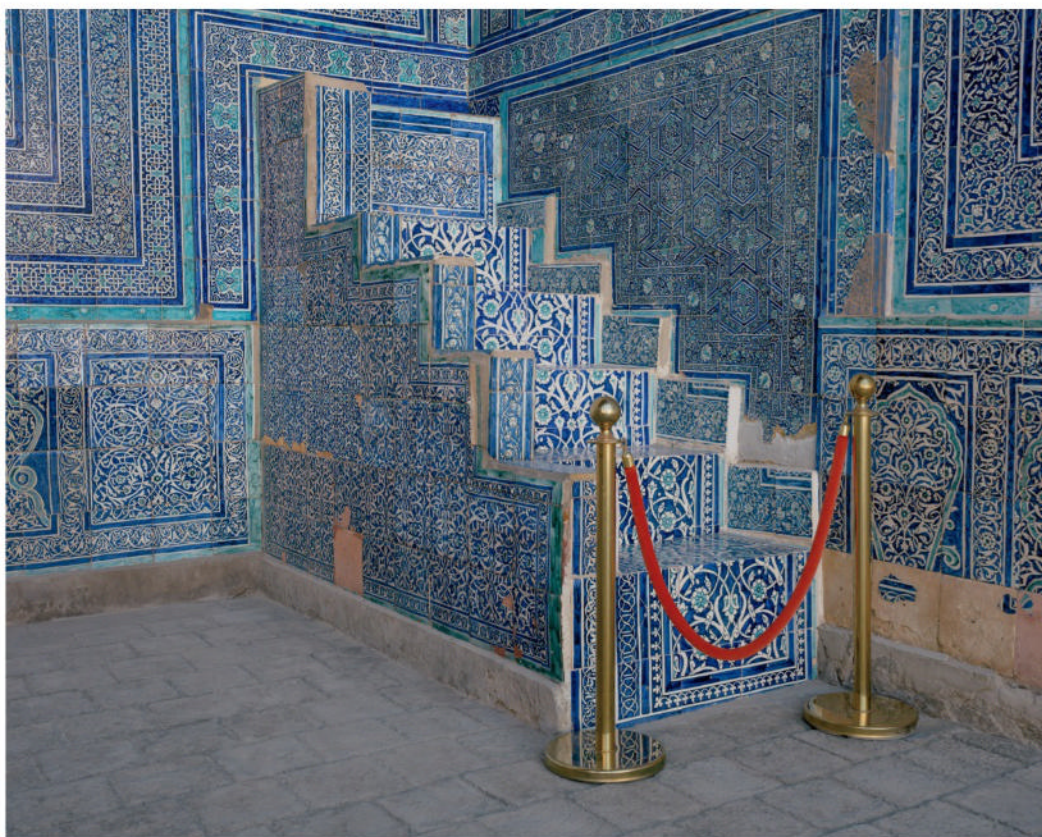
The railway's speedy Afrosiyob trains link Tashkent to Samarkand (a roughly 2.5-hour trip) and Samarkand to Bukhara (1.5 to two hours). Economy seats include Wi-Fi and air-conditioning, and a dining car sells packaged snacks and plov. The Afrosiyob often sells out faster than passenger trains.

TO SKIP THE SLEEPER

Launched last spring, Uzbekistan's newest high-speed train service is the Jaloliddin Manguberdi, named for a 13th-century general and the first fast train to reach the desert oasis city of Khiva. The trip from Bukhara takes about three hours—half the time of the alternative overnight train.

TO SEE IT ALL

Golden Eagle Luxury Trains offers an 11-day cross-Uzbekistan itinerary aboard an en suite private train, with guided off-train excursions. National Geographic Signature Expeditions launches an 11-day itinerary in 2027, crossing Uzbekistan by rail before traveling by air to Ashgabat, Turkmenistan.



KHIVA

At left: During the city's annual melon festival, visitors are carted through Arda Khiva, another of Uzbekistan's new, theme-park-like tourism complexes, designed around ersatz versions of Silk Road landmarks.

Above: The open-air summer mosque of the Kuhna Ark citadel in the walled city of Itchan Kala is a marvel of intricate tilework, like many centuries-old structures at the UNESCO World Heritage site.

banners surrounding the site, it will be filled with sad-looking, sandy-haired men lifting small weights on exercise platforms outside glossy residential palaces.

And yet, Bukhara—for the moment and perhaps only for the moment—felt like my childhood dream of Uzbekistan fulfilled. In one old-town square, I found a statue of a character from a Soviet-era novel I'd loved as a kid: Hodja Nasreddin, with his beloved donkey. He's a wise fool character, a Silk Road-era folk hero across the Muslim world, and in *The Tale of Hodja Nasreddin: Disturber of the Peace*, he'd used his wit and smarts to overcome all sorts of villains and calamities in his native city of Bukhara. I petted the ears of Nasreddin's donkey and thought of myself as an asthmatic child in a crumbling Soviet apartment, wishing to be in exactly this spot. Then I retired to a nearby restaurant and had the juiciest lamb kebab of my life.

But not until I arrived in Khiva, some 250 miles farther west, did I genuinely feel like I'd time traveled. I rode a Soviet-era sleeper seven hours across the Qizilqum Desert (although a new high-speed electric train cuts the journey

TASHKENT

The massive dome covering the capital's lively Chorsu Bazaar was built by the Soviets in the 1980s, but the site has been a marketplace since the days of the Silk Road caravans.







nearly in half). After pulling into Khiva's gleaming train station, I headed almost straight to Itchan Kala, the city's walled UNESCO World Heritage site and one of the planet's most glorious examples of historic Islamic architecture.

Itchan Kala's 30-foot brick walls surround 64 acres of preserved and restored monuments and dwellings, a site where caravans once rested before launching desert treks east to Bukhara or south to ancient Persia. The oldest structures date to the 14th century, but the city was built primarily in the 18th and 19th centuries by the khans of the Kungrad dynasty, a refined aristocracy of warrior kings. It's less a bustling old-town district, in

the way of Samarkand or Bukhara, and more an open-air museum. During the Soviet era, the government relocated many of the walled city's residents to preserve Itchan Kala as a historic site. Today 300 or so remaining families live in a quiet, all but car-free zone where time seems to stand still.

In its tourist-free winter silence, Itchan Kala was perfect—sunny and arid and romantic, like Santa Fe with minarets instead of bell towers. I gazed up at the perfect, squat form of Kalta Minor, a minaret built in the 1850s but famously unfinished, known for its striking turquoise tiles. For a whole hour, I sat inside the baroque patterned mausoleum of an ancient poet-wrestler and just let my



KHIVA

Gondolas drift on the statue-studded canal that encircles water parks, a food court, souvenir stands, and other amenities at Arda Khiva, a splashy modern counterpart to the hallowed monuments at Itchan Kala, all of two miles away.

heart sing. I ate *shivit oshi*, a local specialty of dill-infused noodles, topped with beef stew, that were as soft as cotton and as flavorful as hell.

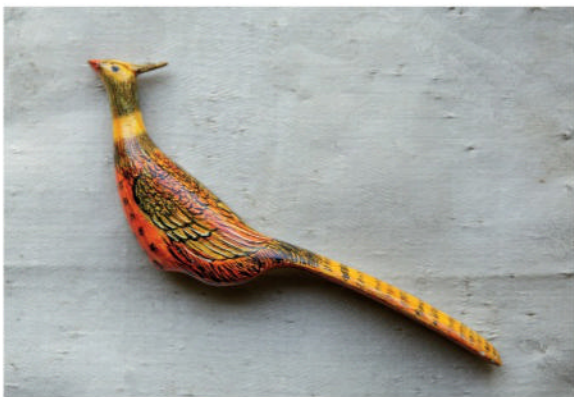
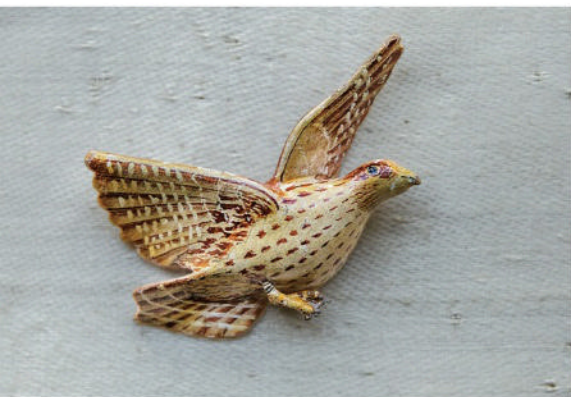
Quasi museum though it may be, Itchan Kala still showed signs of life, even in the quiet of the offseason: schoolkids wandering with backpacks in the early morning light, socks set out to dry outside a lovely, tiny mosque. Later that week, I talked to Lola Mirzaeva, a tourism industry veteran who runs the fancy Farovon Khiva Hotel, outside Itchan Kala's walls. The site occupies a gray area between a community and a historic attraction, she said. "People still live there," Mirzaeva told me. "They make the bread. The kids are running there. It is like a staged performance, but it is real life."

And Mirzaeva told me something else, about—you guessed it—a huge new tourism complex that opened last year on the outskirts of town. Arda Khiva, as it's called, isn't related to Silk Road Samarkand or Eternal Bukhara, but it is cut from the same cloth, with faux Silk Road architecture, gondola rides, 17 hotels, five movie theaters, and all the rest. The thing is, Mirzaeva said, plenty of locals seem to appreciate the place, with families visiting as if it's a theme park.

And so, of course, I went. I passed by a replica of Kalta Minor that felt bland and off, the colors not quite right, not yet tempered by time. I saw gondolas piled woefully atop one another, awaiting the return of the tourists in the spring. But I also saw, there in the offseason, what I could only presume to be Khivans walking through the silent grounds: holding hands, scanning the closed shops, crossing fake bridges over the fake canal. Who knows what people want, I thought. Or need.

My last stop in Khiva was the Nurullaboy Palace, built by one of the region's last khans after he'd visited St. Petersburg and come away inspired by the architecture of my birthplace. The palace is full of beautifully carved wood and elaborate plasterwork, and unlike, say, Arda Khiva, it struck me as being both over-the-top and tasteful. It was completed in 1912, at a significant cost to the khanate—which would fall to the Soviets all of eight years later, the grand palace becoming a mere government administration building.

It's hard to know what will endure. Crossroads come and go. But Uzbekistan's Silk Road cities—undertaking the big, messy project of welcoming the world again—are proof that a place can keep accruing beauty long past its heyday. Right now, they remain in a near perfect balance: newly accessible, still enchanting. Wise old Hodja Nasreddin could come plodding through on his donkey and still recognize them. What the future holds, not even he would know. □



WHEN ART *Becomes a* LIFELINE

The wooden birds carved in
World War II incarceration camps
suggest a shared longing: escape.

Photographs by
HARUKA SAKAGUCHI

→ **BY THE TIME** Junso Kawamoto entered Arizona's Gila River "relocation center" in 1942, he'd shed nearly all his possessions—but not his copy of John James Audubon's *Birds of America*, which he consulted while whittling exquisite wooden birds during his family's three-year confinement. Carving intricate bird pins was a popular pastime among the 120,000 people of Japanese descent forced into camps during World War II, says Delphine Hirasuna, the author of two books about the crafts created there. Art, she says, was embraced by those confined as a means of enduring injustice with patience and dignity—a concept called *gaman* in Japanese. As dehumanizing as the camps were, Hirasuna suggests, birds might have represented "the ability to fly beyond all that." When photographer Haruka Sakaguchi encountered Kawamoto's birds, the National Geographic Explorer was struck by their artistry and moved to think of how carving bird after bird must have channeled the craftsman's yearning for freedom. "They weren't just objects he made," she says. To Kawamoto's seven children, the pins later became treasures—tokens of a father imagining, perhaps, his imprisoned family taking flight. —JAMES ROSS GARDNER

A HARD RE

A pride of lions heads for the shade of a nearby hill after feasting on a wildebeest in Tanzania's Serengeti.

MALINI CHANDRASEKAR

AFRICA'S LION
PERILOUS JOUR
THE RAPID

LION



NS FACE AN INCREASINGLY
JOURNEY TO ADULTHOOD AMID
Y CHANGING SAVANNA.

IT ISN'T EASY BEING KING. Lions once ruled over Africa, but this mighty species is now on the retreat. Estimates suggest that less than 25,000 remain in the wild, a roughly 35 percent reduction in the past two decades, according to the International Union for Conservation of Nature. Challenges begin at birth. A new National Geographic television series, *Lion*, tracks the life of a cub named Kio during his precarious journey to adulthood. If youngsters don't fall victim to disease or predators like hyenas, they face another deadly prospect: humans. "As the human population has grown everywhere in Africa, people have transformed over 90 percent of lion habitats," says Craig Packer, a biologist and National Geographic Explorer. Here's how lions are responding to these threats.



One-month-old-cub paw print, actual size



As few as two out of 10 lion cubs live to see their first birthday.



LION, a four-part docuseries, premieres August 19 on National Geographic and streams the next day on Disney+. Check local listings.

A PERILOUS LIFE

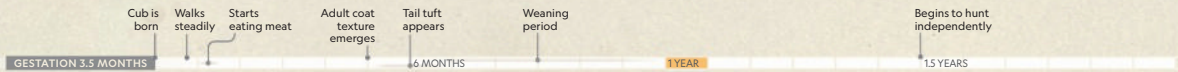
For lions, the first four years are the most critical. Here's what cubs must overcome to grow into fearsome predators.

SMALL CUB - 0 TO 1 YEAR OLD

Females give birth every two years to two to three cubs, on average. After six weeks, cubs are raised communally by the pride, a group of related females.

LARGE CUB - 1 TO 2 YEARS OLD

Cubs grow rapidly and start hunting independently at around 18 months, though they still rely on the pride for food and protection until about age two.



Milestones are estimated and vary by individual and population.

Resident males father cubs and defend their territory.

Lion cubs are born with faint dark spots for camouflage. Their eyes turn amber at two to three months.

While adult lions can reach a top speed of about 35 mph, they learn at a young age to use stealth and teamwork to hunt.

— Stalking — Chasing

Cubs often play by stalking and wrestling with small animals and each other as a prelude to hunting.

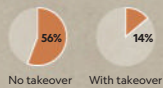
Threats to survival

Life for a lion has never been easy. But an escalating number of challenges has made their journey into adulthood even harder.

CUB MORTALITY

A 30-year study found that male lions often kill the existing cubs when taking over a pride so they can more quickly father their own offspring.

Cub survival to 9 months of age
Serengeti and Ngorongoro Crater

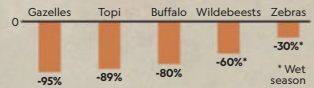


PREY DEPLETION

In Africa, new settlements, roads, railways, and fences have disrupted the migration of the wild prey that lions depend on. In Kenya's Mara region, the numbers have declined by 70 percent.

Decline in prey abundance

Narok-Masai Mara ecosystem, change from 1977 to 2024



SUBADULT - 2 TO 4 YEARS OLD

Male lions leave their birth pride, forming nomadic coalitions that roam into new areas to scavenge, hunt, and eventually take over another pride. One in four females also disperses.

Adult teeth are in place (except canines)

2 YEARS

Females reach full body size

2.5 YEARS

Males disperse and become sexually mature

Permanent canines have erupted; females start breeding

3 YEARS

3.5 YEARS

Males start breeding

Females live up to 19 years and males up to 16 years, on average

4 YEARS

A young lion's mane develops first on its head and neck.

Elastic ligament
Larynx
Strap muscle

Larynx cross section
Vocal pad
Vocal fold

A lion's roar—often used to mark territory—can be heard up to five miles away. Vibrating vocal pads, combined with an elastic ligament and long strap muscles to lower the larynx, produce a loud, deep sound.

ADULT - 4 YEARS AND OLDER

Coalitions of young adult males typically stay two to four years after taking over a pride, reproducing with multiple females and fathering a collection of cubs that are born around the same time.

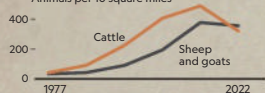
GRAPHIC: MONICA SERRANO AND AMANDA HOBBS, NGM STAFF. ART: AARON BLAISE
SOURCES: CRAIG PACER, UNIVERSITY OF MINNESOTA; JOSEPH O. OGUTU, UNIVERSITY OF HOHENHEIM; TIGWAH FRYCH, UNIVERSITY OF VIENNA; ANTONIO MARCHELLI, WILDLIFE SO TRACKING; JEREMY DELCAMBRE, LOUISIANA STATE UNIVERSITY; DENVER ZOO

Manes grow thicker, longer, and darker with age. Females are attracted to darker manes, a sign of health and high testosterone.

HABITAT LOSS

Increased livestock grazing has forced lions into smaller areas. Drought, rising temperatures, and expanding settlements have recently reduced the number of cattle, but predators remain under pressure.

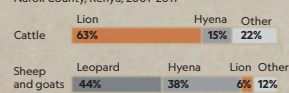
Livestock inside Masai Mara National Reserve
Animals per 10 square miles



HUMAN-PREDATOR CONFLICT

When prey is scarce, lions increasingly target cattle, one of the most valuable kinds of livestock. Herders may retaliate against offenders by illegally leaving out poisoned bait or setting traps.

Attacks on livestock by predators
Narok County, Kenya, 2001-2017





Adult male lion paw print, actual size

Dewclaw

Front right foot

A lion's forelimb supports a four-toed paw, with an elevated fifth toe, or dewclaw.

Graphics and map by **MONICA SERRANO, SOREN WALLJASPER, and AMANDA HOBBS**
Art by **AARON BLAISE**

ROAMING INTO DANGER

Southern Kenya remains one of the last of the lion strongholds. Here, humans have infringed on the animal's habitat. To save the lions, the Mara Predator Conservation Program in Nairobi has spent years using humane practices to collar nearly three dozen lions in the Mara National Reserve and nearby conservancies. Among the lions are males rather than territorial females tend to venture far from the most populated areas, where they target livestock. Herders manage the risk by lining animal carcasses with pesticides. Here, we discover how different ages faced this difficult terrain—and how they



CUB

Mother with her cubs
Name: *Mama Kali*



SUBADULT

2-year-old male that joins coalition
Name: *Lejonka*



SUBADULT

3-year-old male roaming alone
Name: *Nkoeki*



Fencing

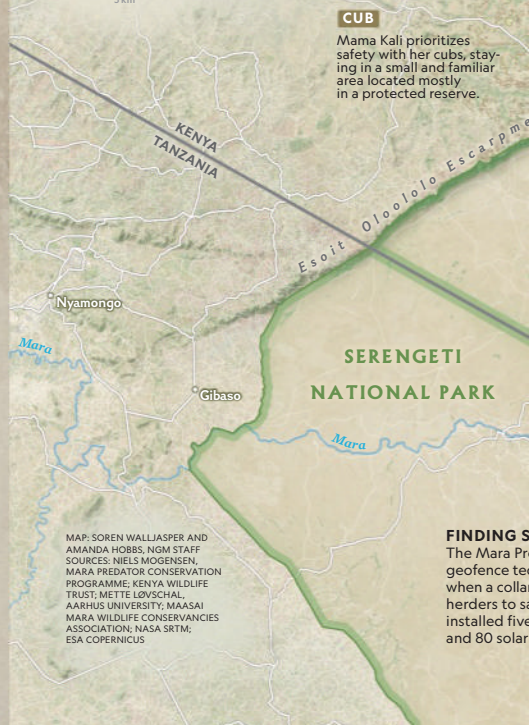
More than roads or cropland, fenced pastures are a good indicator of human-dominated terrain that's dangerous for lions.

◆ **Predator-proof enclosure**

Road

5 mi
5 km

Conservancy boundary



CUB

Mama Kali prioritizes safety with her cubs, staying in a small and familiar area located mostly in a protected reserve.

SERENGETI NATIONAL PARK

MAP: SOREN WALLJASPER AND AMANDA HOBBS; NOM STAFF
SOURCES: NIELS MOGENSEN, MARA PREDATOR CONSERVATION PROGRAMME; KENYA WILDLIFE TRUST; METTE LOVSCHAL, AARHUS UNIVERSITY; MAASAI MARA WILDLIFE CONSERVANCIES ASSOCIATION; NASA SRTM; ESA COPERNICUS

FINDING S

The Mara Predator Conservation Program has installed five solar-powered geofence technology when a collar is installed five and 80 solar

R
gholds. But even
see the effects, the
nt over a decade
s in the Masai Mara
findings: Dispersing
rther into more
ay poison offenders
er how lions of
y fared.

ADULT
5-year-old male
in a pride
Ole Cook

ator

nt

nt

SOLUTIONS

edator Conservation Programme uses
chnology to contact community leaders
red lion enters their territory, allowing
safeguard their cattle. Last year, it
e predator-proof livestock enclosures
-powered lights in high-risk areas.

SUBADULT

Lerionka roams north from
the Ol Kinyei Conservancy
looking for a new pride, but
along the way he passes
through more dangerous,
populated areas.

Kipkeigai

Ngorengore

Lerionka is
killed by humans

Lerionka speeds through
human-occupied area

Lerionka's
movements

ADULT

Ole Cook belongs to a pride,
meaning he can dominate a
smaller, safer area instead of
wandering into harsher or
more hazardous terrain.

Lerionka's tracking begins

Nkoeki's
tracking begins

Nkoeki's movements

Nkoeki stays in
the hills

Nkoeki is
killed by
humans

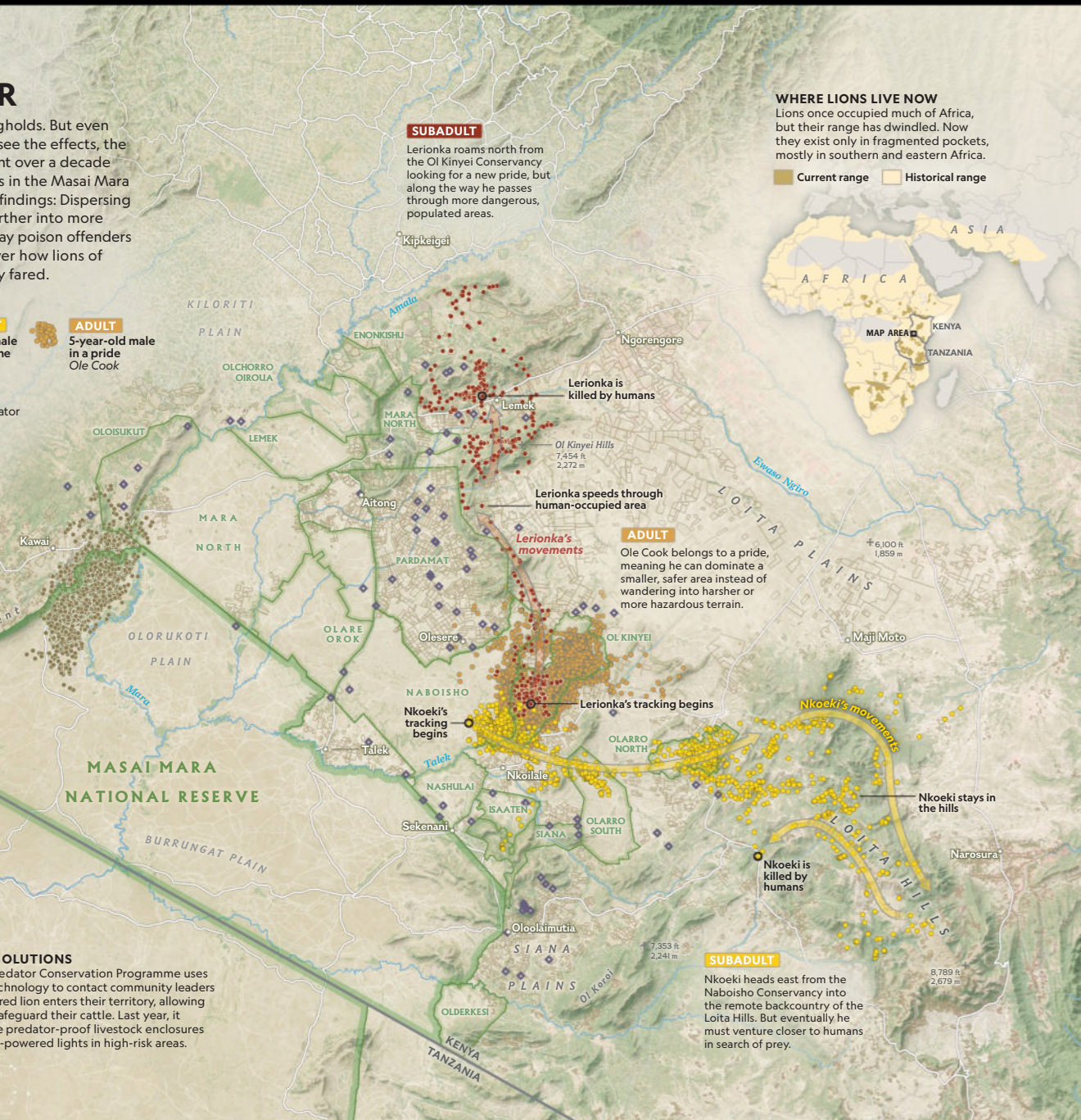
SUBADULT

Nkoeki heads east from the
Naboisho Conservancy into
the remote backcountry of the
Loita Hills. But eventually he
must venture closer to humans
in search of prey.

WHERE LIONS LIVE NOW

Lions once occupied much of Africa,
but their range has dwindled. Now
they exist only in fragmented pockets,
mostly in southern and eastern Africa.

Current range Historical range



How Dinosaur
‘MUMMIES’
Are Rewriting
PREHISTORIC SCIENCE

Beyond bones and teeth, fossilized skin is now
offering a fresh glimpse into the lost world.

Words by RILEY BLACK
Photographs by REBECCA HALE



→ **THE BULK OF WHAT WE KNOW** about dinosaurs comes from bones. But all the ribs, jaws, and other pieces can go only so far in revealing what they actually looked like in life. Fortunately, paleontologists sometimes find fossils with impressions of soft tissues like feathers and scales. Scientists call these rare specimens “dinosaur mummies.” But of course, these aren’t like Egyptian mummies, prepared through chemical embalming. Instead, they’re dinosaurs that were typically engulfed by sediment so soon after death that the finer details of their soft tissue were preserved. At least that’s what researchers

long assumed. But a recent discovery by paleontologist and National Geographic Explorer Paul Sereno is unveiling a new way that dinosaur tissue might have gotten “mummified”—one that could help scientists find even more of the exceptional fossils.

Twenty years ago, Sereno and his team found two *Edmontosaurus annectens*, a species of hadrosaur, in an arid stretch of eastern Wyoming. But it wasn’t until 2023, when they were carefully cleaning the specimens, that they realized that what they thought was skin was actually clay, sandwiched between harder layers of sandstone.

NEW FINDINGS

1. Full-Length Crest

The fossil reveals a fleshy crest beginning at the neck and running down to the trunk, dramatic display that suggests the animals were brightly colored.



2. Extra-Thin Skin

Crested wrinkles after desiccation suggest that the species’ skin, long thought to be thick, was exceedingly thin, possibly to help release heat.



3. Tiny Scales

Pebbly scales are unusually small compared with the thick armor of other species found nearby, indicating that the animals may have been highly agile.



"It's a hundredth of an inch thick," says Sereno, so thin that it would be easy to miss in the excavation and preparation process. Both animals had been preserved in a clay mask that adhered to their bodies as they decayed, creating a three-dimensional rendering of everything it coated—bones, skin, muscles, and all. It's a "complete fleshy profile," the team wrote in a study published recently in the journal *Science*. It reveals new clues about how the *Edmontosaurus* looked and moved, from a neck-to-trunk crest that transitions directly to what Sereno calls "dragonlike" tail spikes to detailed impressions of what appear to be hind hooves—which could be the first time such hooves have been discovered in reptiles.

Scientists have long suspected these hooves existed, but the clay impressions detail one twice as large as they had previously imagined. "We often tend to underestimate soft structures, because you don't want to invent things," says Sereno. "It's big." And its internal structure is almost identical to a horse's hoof. "You could go to a vet and say, 'Hey, could you fix my hadrosaur?' It's that close. It's just beautiful to see evolution working its wonders to create a hoof in a lineage that would lead to birds."

Soft-tissue impressions like these are crucial clues that can help scientists differentiate skeletally similar species, understand a dinosaur's coloring, and help answer questions about social patterns, movement, and more. But to find them, it helps to know how they were made in the first place. Now that Sereno has discovered this unexpected path to preservation, he hopes to find more on the rocky plains of Wyoming, or, as he calls it, the "mummy zone." □





4. Hooflike Feet

This clay impression of a hind foot is a clue to how the species moved: propelled by what could be rudimentary hooves that capped toes like cleats to push off from hard ground.

5. 'Dragon' Spikes

This may be the most extensive detail of tail spikes ever seen in an *Edmontosaurus*, revealing how the keratin points interlock into each other. This discovery, combined with the others, creates an ever clearer picture (left) of what these dinosaurs truly looked like.

MAKE WAY FOR GIANT ANTEATERS

IN BRAZIL'S
VANISHING
SAVANNAS,
DEVELOPMENT IS
PUSHING GIANT
ANTEATERS
CLOSER TO EVER
MORE DANGEROUS
ROADWAYS—
PROMPTING
CONSERVATIONISTS
TO THINK
CREATIVELY
ABOUT HOW TO
KEEP THE BELOVED
AND SLOW-MOVING
CREATURES SAFE.

WORDS BY BEN GOLDFARB
PHOTOGRAPHS BY FERNANDO FACIOLE





Biologist Arnaud Desbiez (at left) and veterinarian Rafael Ferraz perform a health check on a giant anteater outfitted with a tracking harness. In 2017, Desbiez founded the Giant Anteater Conservation Program, which today monitors the animals' movements to devise new ways to protect them.



H

Had Charles Dickens ever written a novel about Brazilian wildlife, he might have invented a protagonist like Jane, a three-year-old giant anteater whose short life has been rife with misfortune. Before she was born, one brother was likely killed by a puma, another by a car. Jane herself—endowed, like all of her kind, with a toothless tubular snout and resplendently bushy tail—came into the world not in a forest but on a ranch in western Brazil, the sort of environment where anteaters face human-related threats such as dog attacks and exposure to pesticides. When she was one, her mother, too, was run down as she attempted to cross a nearby highway. A year later, the ranch's owner harvested its eucalyptus trees, robbing Jane of important protection. Jane, now roughly the size of a golden retriever, hunkered down among the logs and eked out a tenuous living, ever endangered by the highway that had left her an orphan and circumscribed her territory.

A giant anteater in west-central Brazil lumbers through the Pantanal, the world's largest tropical wetland. In the past decade, the species has faced a dramatic decline across Central and South America due to wildfires, disappearing habitat, and vehicle collisions.

GIANTS ON THE MOVE

Giant anteaters' lumbering pace and dark fur make them vulnerable on roadways. To protect both wildlife and drivers from vehicle collisions, scientists first had to track where the animals were being hit—data that now inform the placement of safe crossings.

Probability of vehicle-giant anteater collision

High — Extreme

Road segment identified for fences, underpasses, or other safety measures

50 mi
50 km



Giant anteaters spend their days shuffling between anthills and termite mounds, lapping up insects with a sticky, two-foot-long tongue. In Brazil, the country with the world's fourth largest road network, that means they sometimes cross highways. Such a peripatetic lifestyle has become dangerous in Jane's rapidly changing home ecosystem, the Cerrado, a rich but underappreciated tropical savanna that's being transformed by an agricultural boom. From 2019 to 2023, around 12,800 square miles of Cerrado habitat were replaced by soy, corn, eucalyptus, and other commodity

crops. The encroaching development has also brought more highway construction and truck traffic, resulting in a disastrous spike in anteater collisions. (The animals' slow gaits, dark bodies, and nocturnal habits make them especially susceptible.) Arnaud Desbiez, a biologist and National Geographic Explorer who founded the Giant Anteater Conservation Program, the research effort that has tracked Jane and many other anteaters, calls roadkill "the biggest threat to giant anteater survival in Brazil."

Even a few years ago, the decline of Brazil's anteaters, and perhaps the eventual

extinction of some populations, seemed an intractable problem. But Desbiez and his collaborators have recently made headway by reframing anteater roadkill as a risk to drivers as well. Giant anteaters can tip the scales at more than a hundred pounds, over five times larger than any other anteater species, meaning that motorists are often injured and sometimes even killed when they crash into the hefty beasts. Helping anteaters and other large mammals cross roads, Desbiez argues, is thus a matter of public safety—logic that’s begun to persuade Brazilian road agencies to address the crisis by redesigning highways at a scale never before seen in Latin America. “Our mission is to make roads safe for all,”

Desbiez says. “This is not [only] about saving anteaters; this is about saving human lives and biodiversity.”

Like their fellow oddballs sloths and armadillos, giant anteaters are xenarthrans, members of a superorder of mammals that arose in South America shortly

In the state of Mato Grosso do Sul, highway BR-267 runs through the giant anteater’s native ecosystem, which is being reshaped by agriculture. Land on the left side of the road is still dominated by savanna, while on the right, it has been cleared for farming.



MAP: CHRISTINE FELLEZ, NGM STAFF. SOURCES: YURI GERALDO GOMES RIBEIRO AND OTHERS, AUSTRAL ECOLOGY, 2023; ARNAUD DESBIEZ, WILD ANIMAL CONSERVATION INSTITUTE; FERNANDA ABRA, VIAFAUNA; GREEN MARBLE





after the fall of the dinosaurs. Capable of living roughly 15 years in the wild, the animals play an important role in their ecosystem by controlling insect populations. Giant anteaters can slurp up around 30,000 insects over the course of a day. Females are devoted to their young and will gestate a single baby for six months, which may then ride like a backpack atop its mother for an additional six months.

While Desbiez's first passion is actually giant armadillos, in the mid-2010s he began to notice that it was anteaters, not rare and furtive 'dillos, whose carcasses littered Brazilian roadsides, and in 2017 he launched a formal investigation of the issue. Over three years, he and a small army of patrollers drove more than 50,000 miles—enough to circle the Earth twice—on four Brazilian roads, counting every dead creature they saw. Ultimately, his crew tallied more than 12,000 road-killed animals, among them caimans, capybaras, crab-eating foxes, and 766 giant anteaters. And that alarming figure likely underestimates the true toll. Their research suggests that scavengers drag away roughly a quarter of anteater carcasses and that more than half of all car-struck anteaters may stagger far from the shoulder to die, eluding surveyors.

Yet Desbiez's team didn't just document a catastrophe. They glimpsed solutions. In addition to tallying roadkill, the group collared live anteaters with tracking devices and trailed them across the Cerrado. (Each collared anteater was named for

Veterinarian Grazielle Soresini inspects the carcass of a giant anteater that was hit by a vehicle on BR-267. After each loss, she and her team collect tissue samples and move the animal away from the road as needed to protect scavengers from traffic.

one of the project's collaborators or supporters; Jane got her moniker in honor of a beloved veterinarian.) Although tagged anteaters often wandered blithely over the pavement, they also on rare occasions followed forested stream banks to bridges and cattle passages, which they then used to safely stroll beneath highways, appearing on camera traps that Desbiez placed within these *de facto* underpasses. If highway authorities installed more passageways, he realized, with fences on either side to guide anteaters to their entrances, it might be enough to forestall the species' collapse.

Such animal-friendly infrastructure is hardly a novel concept. Wildlife crossings and roadside fences have helped imperiled animals from panthers in Florida to pangolins in Singapore, and ample research suggests that they dramatically

reduce roadkill and reconnect fractured habitats. In the southeastern state of São Paulo, many highways are outfitted with underpasses for tapirs, pumas, capybaras, and other animals, and an overpass allows golden lion tamarins to frolic over four lanes of dense traffic in the country's Atlantic coastal forest. Yet when Desbiez's team first approached government highway authorities in the southwestern state of Mato Grosso do Sul about anteater crossings, they found little appetite for spending millions of Brazilian reais on underpasses and fencing. "We had some major disagreements," Desbiez acknowledges.

The anteater conservation program, which operates under the umbrella of the Brazil-based Wild Animal Conservation Institute, broke through by emphasizing human safety, a subject close to the heart of every transportation planner. In the United States, where the average deer collision costs society more than \$8,000 in hospital bills, vehicle repairs, and other expenses, research suggests that many wildlife crossings are shrewd investments. A network of overpasses, underpasses, and fences along a mule deer and pronghorn migration corridor in Wyoming, for instance, prevented so many crashes that it should recoup its own costs in under two decades.

The same logic holds in Brazil, where around 20 motorists die annually in collisions with anteaters, tapirs, and other animals in São Paulo alone. Desbiez and his colleagues calculated that fences along anteater roadkill hot spots in Mato Grosso do Sul would pay for themselves within 10 years. The anteater conservation program even studiously changed the language it used to describe the problem, from "roadkill" to "collisions," a word that better connotes the danger to human life and property.

Armed with these arguments, Desbiez and his collaborators have had more

**AROUND 20
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OTHER ANIMALS IN
SÃO PAULO ALONE.**





success—particularly on BR-262, a major two-lane highway that crosses the Cerrado and the Pantanal, the world’s largest tropical wetland. Crushed animals are so ubiquitous on the notorious road that it’s been dubbed the highway of death, yet this high-speed thoroughfare is rapidly becoming safer. In 2025, the Brazilian Department of Transport Infrastructure and private contractors began retrofitting BR-262 for the sake of wildlife, an initiative that includes more than 100 miles of fencing at roadkill hot spots, 10 new wildlife underpasses, and the modification of dozens of existing bridges and culverts to make them more appealing to animals.

Workers in Mato Grosso do Sul assemble a wildlife crossing beneath roadkill-strewn highway BR-262. In 2024, federal officials resolved to build 100 miles of fencing and 10 new passages near collision hot spots.

Seven new rope bridges will reconnect the forest canopy for howler monkeys and other primates. “With this project, we raise the bar for all sorts of highways in Brazil,” says Fernanda Abra, a road ecologist and National Geographic Explorer who founded ViaFauna, the company that



A baby clings to the back of its mother as she travels through the Pantanal. Female anteaters give birth to only one pup annually, and their offspring must be nurtured for around six months. That slow reproduction rate makes the species vulnerable to decline.



designed the highway of death's make-over. Abra hopes the plan will motivate other Latin American countries, such as Colombia, Costa Rica, and Mexico, which have lately begun building crossings of their own. "Brazil can be an inspiration for other countries here in Latin America," she says.

Wildlife crossings and fences alone, for all their virtues, won't save giant anteaters. They can't prevent industrial agriculture from overrunning the Cerrado, nor protect wild animals from other threats, like dogs and fires. And some dangerous roads will inevitably remain unredressed. In December 2023, a female anteater was found dead on one of the many unfenced

Below

Veterinarians in Mato Grosso do Sul perform an echocardiogram to visualize the heart of a wild giant anteater. Researchers study the animals and monitor their movements to come up with ways to protect them from such hazards as vehicle collisions, dog attacks, and wildfires.

Right

An orphaned giant anteater pup follows its caretaker around a rehabilitation facility in the southeastern state of Minas Gerais. After nearly two years of observation, the pup was released back into the wild.





municipal roads in the southeastern state of Minas Gerais—a tragedy compounded by the helpless young pup clinging to her dead mother’s fur. The pup, close to death herself, was transferred to CETAS-Belo Horizonte, one center within Brazil’s growing network of wildlife rehabilitation facilities equipped to care for anteaters, where she was named Cali and fell under the care of Érika Procópio, a veterinarian and rehabber. Cali’s prospects weren’t bright: Her immune system weakened from stress, she developed a fungal infection and lost hair. Improbably, though, Cali hung on, accepting a special cocktail of vitamins, medications, and a blend of goat’s milk and pet kibble—yes, really—formulated by

veterinarians. Eventually, she graduated into an open-air paddock and then the wild, where Procópio and her colleagues expect her to thrive and reproduce. “We have very high expectations,” Procópio says.

Jane, the tough young female orphaned by a car, has also flourished amid difficult circumstances. In November 2025, she fled her clear-cut eucalyptus grove and, in the dark of night, ventured onto the same highway that had claimed her mother’s life. Jane survived the crossing and began to walk northeast in search of a vacant territory in which to someday raise pups of her own. As of this spring, she’d covered nearly 20 miles—no small accomplishment in a road-choked world. □



Desbiez, Ferraz, and veterinarian Mario Alves release a giant anteater that underwent a health exam into a eucalyptus grove in Mato Grosso do Sul. By studying this species and guiding the installation of wildlife crossings, they hope to create a model other communities can use to save vulnerable animals.



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GLASS PLATE TRANSPARENCY, 1930

THE PHOTOGRAPH *That Changed Our* PERSPECTIVE FROM THE AIR

→ **SOME OF THE** earliest aerial photos taken in color were committed to gelatin-coated glass plates now held in our archives. They include this shot of the Statue of Liberty—shown here on the back of a transparency, the image reversed. To take it, Assistant Editor (and future Editor in Chief) Melville Bell Grosvenor relied on two groundbreaking technologies. One was the Finlay color process, a technique that exposed a glass negative through a screen of colored filters. The other was a metal-hulled, helium-filled dirigible, the U.S. Navy's ZMC-2. It drifted slowly enough that the 28-year-old editor figured he could take a vivid photo that didn't blur from movement. One brilliant June day, he hitched a ride with the Navy over New York, pressed his shutter, and pushed the boundaries of possibility. —RACHEL SLADE

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Ω
OMEGA