SCIENTIFIC AMERICAN

Interspecies Organ Transplants

Materials Made in Space

The Legacy of the Endangered Species Act

Woman the Hunter

New science debunks the myth that men evolved to hunt and women to gather

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FEATURES

A copper nitrate solution for synthesizing metal organic framework crystals in space P. 40

ON THE COVER
The notion that men evolved to hunt and women to tend to children and domestic duties is one of anthropology's most influential ideas. But the available data do not support it. Evidence from studies of physiology, archaeology and fossils point to women having a long history of hunting animals for food.

Illustration by Samantha Mash.

Photograph by Spencer Lowell

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Eric Hanson/Getty Images

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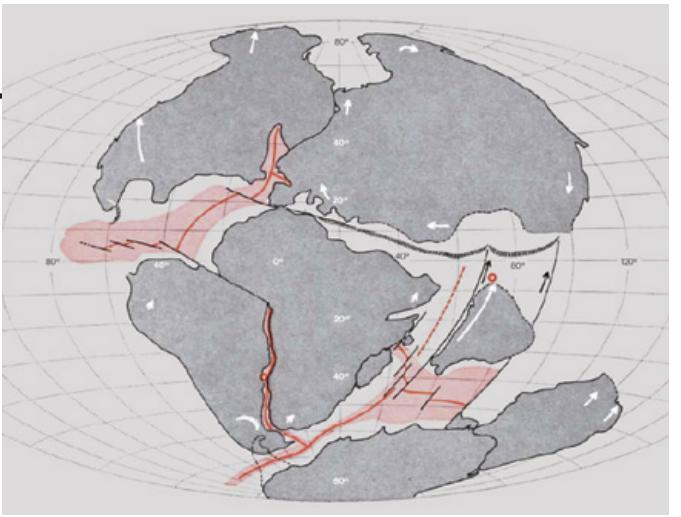
New Views



Map of global tectonics from the October 1970 issue of *Scientific American*

DON'T YOU LOVE IT when a paradigm shifts? When people realize that they've been looking at something all wrong and that there's a better way? My favorite example is plate tectonics. The notion that continents (continents!) could move across the surface of the planet was simply unthinkable for most of human history. It took a lot of research and, even more important, a lot of rethinking for people to accept that plate tectonics was real and could explain earthquakes and volcanoes and why South America and Africa look like they could snuggle together. We're proud that *Scientific American* published some of the first popular articles about plate tectonics and helped us look at the world in a new way.

In our cover story starting on page 22, human biologist Cara Ocobock and biological anthropologist Sarah Lacy upend a long-dominant theory of human evolution: that men alone evolved to hunt. Drawing on research from physiology, paleoanthropology, archaeology, and more, they show that women have always hunted and are better adapted to some endurance tests than men.

Apologies in advance, but our article on organ transplants on page 30 may well bring tears to your eyes (it did mine). Tanya Lewis, a *Scientific American* senior health editor, shares the technological and medical advances that are saving more lives—potentially many more. The generosity of donors and their families, the personal history of the surgeon at the center of the story, and Tanya's own family experiences make this one of our most touching articles of the year.

The Endangered Species Act is 50 years old. Have you seen any Bald Eagles lately? That used to be almost impossible throughout most of the U.S., but now they're thriving, and many species that could have gone extinct are still with us. On page 60 Robert Kunzig, a former *Scientific American* editor, evaluates the impact of the ESA and what wildlife needs from the next conservation laws.

Materials scientist and aeronautics expert Debbie G. Senesky designs electronics resilient enough to work on Venus—where the surface is hot enough to melt lead, and the skies rain sulfuric acid. As she describes on page 40, she's been running experiments on the International Space Station to grow materials that could serve as sensors, batteries, or other devices on future missions.

The Murrinhpatha language, spoken by some Aboriginal people in Australia, has a very different structure than English does. Words can occur in any order in a sentence, and a single word can have many pieces added on to express actions and intentions. As author Christine Kenneally writes on page 48, linguists have recently found that Murrinhpatha speakers prepare to speak in a previously unknown way, which adds to evidence that language influences our perceptions.

Why do so many people enjoy haunted houses, monster movies, horror books and true crime podcasts? In a spookily pictorialized story on page 72, behavioral scientists Athena Aktipis and Coltan Scrivner present some delightful research about morbid curiosity and scary play. Happy Halloween! ●

Laura Helmuth
is editor in chief
of *Scientific American*.

Scientific American, Vol. 223, No. 4; 1970

JUNE MINJU KIM

CAN WE PROTECT EVERY SPECIES? *PAGE 60*

During the height of the COVID-19 pandemic, graphs of hospitalization and infection rates dominated the news, catching the eye of June Minju Kim, then a producer for a South Korean broadcast news network. Now a recent graduate of Columbia University's master's program in data journalism, Kim spent the summer as an intern with *Scientific American*'s graphics team and designed this issue's spread on the 50-year history of the Endangered Species Act. She wanted to avoid collapsing the individuality of the species—from flowers to birds to lichen—while capturing the immense scope of the policy. "These are living things, and every species really deserves your attention," she says. Kim's work often focuses on the technology being used to quell climate change. She has reported on the tension between lithium mining in Nevada (which proponents say will power electric vehicles) and the preservation of an endangered flower. These complex stories "encourage more thinking," she says. "There's so much room for exploration."

DAVID MAURICE SMITH

HOW GRAMMAR CHANGES PERCEPTION, *PAGE 48*

Photojournalist David Maurice Smith (*below*), who is based in Australia's Gold Coast, traveled to the other end of that continent this past July to photograph speakers of an Aboriginal language called Murrinhpatha. He describes it as "incredibly sophisticated—really, really next level." Smith, originally from Vancouver, Canada, says he doesn't have an ear for learning languages but has always been drawn to learning from people from different cultural backgrounds. He previously worked in social services, often with First Nations communities, and pursued photography as a more creative outlet with a similar purpose. At 6′7″ tall, Smith knows he's rarely a fly on the wall when he arrives in a community with a camera. Instead, he says, the most genuine photos come from listening to and engaging with the folks he's there to photograph. "You're always going to influence what's happening around you," he says, "but you can minimize that by just taking the time to connect with people."

TANYA LEWIS

GIFT OF LIFE, *PAGE 30*

In 2021 Tanya Lewis's mother, Gail (*above left*), moved from Hawaii to California in the hopes of receiving a lung transplant. Her condition worsened as nearly four months on the waiting list passed. Then she got the call. Lewis, *Scientific American*'s senior health and medicine news editor, moved from her home in Brooklyn to care for her mother as she recovered. The surgery was successful, and the recovery was grueling. For months afterward, Lewis didn't want to even think about transplants. "I've just lived this whole experience," she recalls. But suddenly, transplant medicine was in the news. Doctors had performed the first pig heart and pig kidney transplants into humans, or "xenotransplants," and Lewis felt compelled to understand how we got to this point. These pioneering techniques might change the grim calculus of organ transplants in a way that no previous advances could, she writes in her feature story this month. "The fact that we have the technology and the know-how to do this is what's so compelling about it to me."

DEBBIE G. SENESKY

THE RIGHT STUFF, *PAGE 40*

Venus is one of our closest planetary neighbors, but probes visited its surface only briefly in the 1970s and 1980s and haven't gone back since. "It's hard! It's too hard," says Debbie G. Senesky, an aerospace engineer at Stanford University, who is developing technology for a return trip to the inhospitable planet. "Think of your cell phone working at 600 degrees Celsius. That's a challenge." In this issue, Senesky shares an unconventional approach she's exploring: creating materials with unique properties that can be manufactured in space. Making things that work in impossible conditions is her favorite kind of puzzle. She traces this passion to a formative moment in her childhood when she fixed her broken cassette player by fiddling with the gear train. Some of Senesky's latest materials—so light they can sit on a flower petal without bending it—recently returned from the International Space Station.

"Think of your cell phone working at 600 degrees Celsius. That's a challenge."
—Debbie G. Senesky

Tanya Lewis (*top*): James Brickwood/Oculi (*bottom*)

June 2023

THE CIRCULAR STATE OF PI

"Mimicking Matter with Light," by Charles D. Brown II, discusses a phase of matter called a Bose-Einstein condensate (BEC) acquiring a geometric phase, "a term in the mathematical description of its quantum phase that determines how it evolves." The article mentions the BEC picking up a geometric phase of pi (π) in one experiment, and it shows a full circle in an accompanying graphic. Later it depicts a phase of 2π with two full circles.

I understand that a geometric phase has no physical interpretation, which the article also mentions. But I am still confused because a single full circle is usually associated with 2π, as I remember from my telecommunications engineering studies, which had a lot of math as their base. Can you clear up this seeming contradiction?

ULRICH MESSERLE
STUTTGART, GERMANY

BROWN REPLIES: *As described in my article, the BEC's quantum state acquired a geometric phase of π when it was moved around a Dirac point—a position where two energy bands take on the same value—and a phase of 2π when it was moved around another type of singularity called a quadratic band touching point (QBTP). In both the Dirac point and singular QBTP experiments, we measured the quantum state of the BEC along the same circular path: it went around either point exactly once. We observed, however, that in the Dirac case, the BEC's quantum state rotated once, whereas in the singular QBTP experiment, it rotated twice.*

I don't make the claim that π is enough to complete a full circle. Rather, after completing a circle in momentum space, the BEC picked up a geometric phase of π. While 2π is associated with completing a circle in mathematics, our measurements are about the geometric phase accumulated by the BEC's wave function after it completes a circle around either the Dirac or singular QBTP.

PRIMAL POLITICS

In "Divided Mindset" [Mind Matters], Jer Clifton discusses his research finding that liberals and conservatives have fundamentally different beliefs about whether the world is inherently hierarchal. The article resonated with my own effort to understand the growing, and destructive, divide among free people. I would add that one especially significant dividing line that liberals see as blurry and conservatives see as well defined is the boundary between "us" and "them."

Like many of the "primal world beliefs," or "primals," that Clifton describes, the definition of *us* is context-sensitive. During a World War, all Americans and the country's allies are part of *us*. When their baseball teams compete in the World Series, New York City and Boston are clearly on opposite sides of a divide. The primal bias that keeps the definition of *us* smaller is more conservative, and making the definition larger is more liberal. This applies to race, religion, income level, national origin, profession, and so on. We need to understand why the distinction matters and how to soften the boundaries that divide *us*. If we learn to see our world with a broad enough perspective, we might be able to share the understanding that everything alive, on this small planet we share, is one of *us*.

ARI BERMAN *LEXINGTON, MASS.*

"If we learn to see our world with a broad enough perspective, we might be able to share the understanding that everything alive is one of *us*."
ARI BERMAN *LEXINGTON, MASS.*

PINPOINTING PAIN

"Origins of Pain," by Haider Warraich [Forum], mentions the shortcomings of magnetic resonance imaging as an indicator for spinal pain. If one looks only at mechanical and anatomical explanations of pain, this surely is true. Especially in the previous century, spinal imaging focused on findings associated with degenerative spinal changes, including disk degeneration and disk herniation. Although a disk herniation definitely can be a possible cause of pain irradiating in the leg, it is only rarely a cause of local back pain. In general, computed tomography and MRI are reliable indicators of these changes. So they do very well in identifying the cause of *radicular* pain, or pain originating from a nerve that is pinched by a herniated disk or a narrowing of the spinal canal and its outlets (a phenomenon called spinal stenosis).

But recently the interest of spine radiologists has shifted to finding the pain generator in local low back pain, which can be classified as *somatic* pain. By using newer MRI techniques, we are now able to reliably detect small inflammatory changes in the spine, mainly in the vertebrae. In many people, these inflammatory changes are believed to be associated with local pain, and as such, they can pinpoint the pain generator. This can be highly beneficial to a patient, for example, in the case of an inflamed facet joint, not an unusual finding in low back or neck pain. These small joints can be precisely targeted by interventional radiologists or pain physicians either with injections using local painkillers and anti-inflammatory drugs or, in patients with more persistent pain, by neurolysis, a procedure where the pain fibers are locally disrupted by thermal or chemical intervention.

Many radiologists need to be updated on these developments because they still believe that spinal imaging is all about spine degeneration. This can lead to un-

necessary treatments because degenerative changes that are normal for age can be identified as abnormal and suspected to be the cause of a patient's complaints. Failing to identify the pain generator and consequently treating something else without any beneficial result leads to disappointment and disbelief in spinal imaging's relevance, even among some radiologists.

Luckily, a new generation of radiologists is very active in research on spinal imaging in low back pain. Not only are we able to find the pain generator in a significant percentage of patients with low back and neck pain, but research is also focusing on chronic and *neuropathic* pain caused by a lesion or disease of the pain system itself. Although the approach is still in its infancy, researchers are starting to visualize the workings of the pain system in people with chronic pain in the hope of finding out what is going wrong and treating it effectively.

JOHAN VAN GOETHEM *EDITOR IN CHIEF,* NEURORADIOLOGY, *DEPARTMENT OF MEDICAL AND MOLECULAR IMAGING, VITAZ, BELGIUM, AND PROFESSOR OF NEUROIMAGING AND BIOMEDICAL IMAGING TECHNIQUES, UNIVERSITY OF ANTWERP*

PUBLIC HEALTH PRIORITIES

"Pandemic Reckoning," by the Editors [Science Agenda; May], calls for Congress and the Biden administration to support a COVID Commission to investigate why the U.S. didn't do a better job of responding to the recent pandemic and to prevent future catastrophes.

If politicians have a choice of funding a bridge that will reduce rush-hour delays in a town or building a warehouse in the same town to stock with supplies and equipment to prepare for the next pandemic, they will choose the bridge. The bridge will provide immediate traffic relief, which translates into votes in the next election. The warehouse full of pandemic supplies and equipment may never be of benefit to the residents of the town or people elsewhere, which isn't a vote getter.

A bipartisan COVID Commission could give us a better understanding of what went wrong, but I doubt that Congress would do much about it.

STEVE WRIGHT *VIA E-MAIL*

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CONSERVATION

Bird Flu Shots

The U.S. is vaccinating endangered California Condors for avian flu

THE THREAT OF AVIAN influenza became real for Ashleigh Blackford in March. Three years after the world took drastic steps to slow the spread of a human respiratory virus, she found herself living a twisted version of that experience—this time with the nearly 600 iconic birds she oversees as California Condor coordinator at the U.S. Fish and Wildlife Service.

California Condors are North America's largest wild birds, and some of its most endangered. In 1982 only 22 remained, but conservationists clawed them back from the brink of extinction by capturing and breeding them. By the beginning of this year there were 561 California Condors, more than half of them living in the wild across the western U.S. But come spring, these iconic birds were suddenly falling ill and dying.

"It was like, 'We've lost five birds today. We lost two more,' and it just kind of felt like it was snowballing on us," Blackford says. Many of these condors had roosted in Arizona's Vermilion Cliffs, where captive-bred birds were first released in 1996. By the end of this past spring, avian influenza had killed 21 condors from the flock that soars over Arizona and Utah—and Blackford says the outcome could have been much worse.

Now, for the first time, the FWS is testing an avian influenza vaccine in these birds, in the hope of eventually inoculating every living condor against the disease—which may come roaring back as temperatures drop this fall.

The many strains of avian influenza fall into two varieties. Wild birds tend to carry less pathogenic or even asymptomatic strains, whereas highly pathogenic strains are usually found in poultry. But in Europe, a highly pathogenic strain appeared in numerous wild species by 2021 and reached the U.S. the following year. That strain has now killed at least hundreds of thousands of wild birds, experts estimate. "This is very different from what we've seen historically" with avian influenza, says Samantha Gibbs, lead veterinarian at the FWS Wildlife Health Office. "I don't think it's just going to disappear."

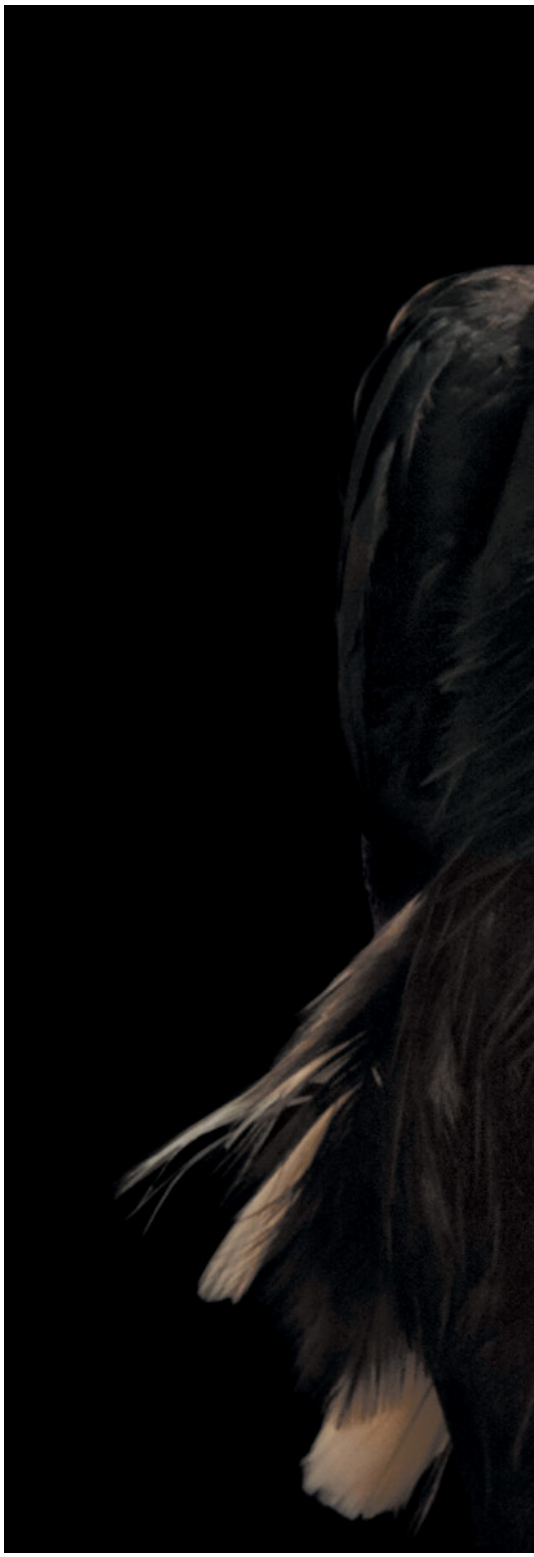
Although dead Caspian Terns, Mallards and Red-tailed Hawks are all bad news, none of these are as rare as the California Condor. Other wild birds have much larger populations that can bounce back from such losses, Gibbs says. "We just don't have that bench strength with the condors."

Condors are particularly vulnerable to avian influenza because they live in close quarters in extended family groups and kin networks, says Jonathan Hall, a wildlife ecologist at Eastern Michigan University who specializes in the massive birds. Like humans, "they really interact with each other quite a bit, so that makes this disease much more easily communicable," he says.

Blackford says the flock that suffered from the virus this spring may have inadvertently cultivated it in the cool, cliff-bound sanctuaries where they raise their chicks. "I think we had some little 'petri dishes' in our nest caves that unfortunately had a greater impact on our population than if they had known to social distance," she says.

Every condor is precious; the mighty birds mature slowly and lay just one egg every year or two. Although conservationists have found ways to slightly increase that low birth rate with a captive-breeding program, the small populations aren't yet self-sustaining, says Jacqueline Robinson, an evolutionary geneticist at the University of California, San Francisco. "This loss of so many individuals in such a short time is a pretty big setback for them," she says.

Desperate to protect the condors, the FWS asked the U.S. Department of Agri-



ADVANCES

An endangered California Condor

culture for permission to test an avian influenza vaccine in the birds. "We didn't know if there would be a vaccine even available," Gibbs says. "Because no birds have ever been vaccinated against highly pathogenic avian influenza in the U.S., we didn't think it was a high probability."

After some discussion, the USDA authorized the FWS to use a vaccine developed from a killed virus found in a Gyrfalcon in the mid-2010s, Gibbs says. First, the condor team tested the vaccine for negative side effects on 20 Black Vultures, which are not endangered. Now condors are receiving the shot—a process that involves a condor wrangler and a veterinarian. As of late August, 20 birds had been vaccinated, according to the FWS. The team has been monitoring the birds and preparing to measure virus antibody levels in their blood.

Blackford says that if all goes well, she and her colleagues will plan a rollout strategy to protect the condors before spring migration starts. Then the team will consider giving the birds boosters during their annual health checks, when each bird is vaccinated for West Nile virus—a mosquito-borne pathogen that also threatens them—and tested for lead exposure.

Those routine health checks are a testa-

CLIMATE

The Fire Species

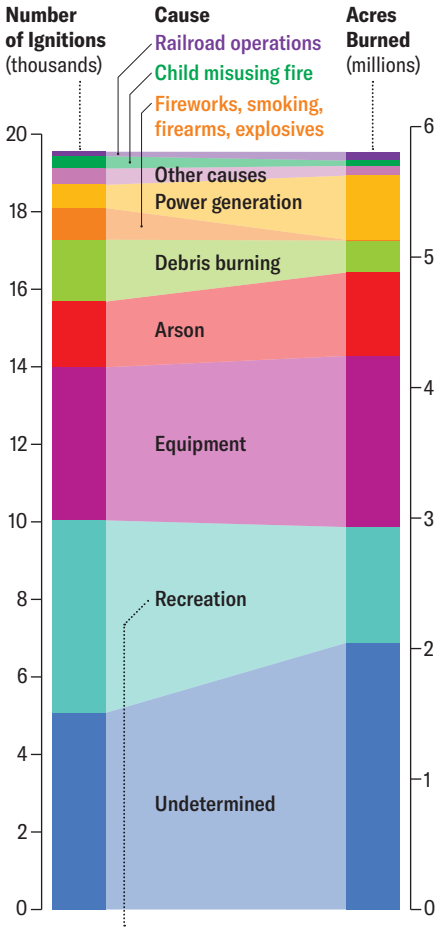
Data reveal how California's wildfires start

ON A SWELTERING summer day in 2021, fire suddenly swept through drought-dried underbrush and leaped across treetops in California's Sierra Nevada. A local father and son, charged with starting the 222,000-acre Caldor Fire with their target-shooting equipment, are among the thousands of humans accused of igniting nearly all the state's forest fires since 2000. In addition to executives of utility companies, whose faulty electrical equipment has contributed to the state's largest and deadliest wildfires, the list allegedly includes dirt bikers who remove spark arresters and couples celebrating anniversaries with sky lanterns. "It's human recklessness in one form or another," says Craig Thomas, founder of the nonprofit Fire Restoration Group.

California's forests are increasingly susceptible to wildfires because of climate change and poor forest management. As for the actual ignitions, scientists have been documenting a gradual increase in human involvement—but confronting the full extent of our responsibility remains daunting. Statewide, 95 percent of all wildfires are reportedly human-caused. Thomas, along with Brent Skaggs, a retired U.S. Forest Service forest fire management officer, used public Forest Service records to reveal an astounding 19,543 wildfires attributed to humans between 2000 and 2022 on Forest Service land in California. It's not just campfires and cigarettes. Careless use of trucks, chain saws or other equipment starts nearly a quarter of the fires. Others are caused by illegal fireworks, as well as power generation, according to agency statistics Thomas and Skaggs analyzed for *Scientific American*.

How We Start Wildfires

The chart shows the number and size of wildfires ignited by humans on U.S. Forest Service land in California from 2000 to 2022, by cause.



From 2000 to 2022, human recreational activities sparked nearly 5,000 wildfires, resulting in almost 900,000 acres burned.

Source: Brent Skaggs/USDA Forest Service (data)

Fire is a natural part of most forest ecosystems and has been around far longer than humans. For millennia, lightning sparked the vast majority of wildfires—but today it causes just 5 percent of California's. And human-caused blazes tend to be more destructive and deadly than those caused by lightning; they often start near developed land with fewer trees and later in the season when grasses are especially combustible. California wildfires blamed on humans between 2012 and 2018 were on average 6.5 times larger than those caused by lightning strikes and killed three times as many trees. They're also more expensive because they tend to threaten houses—more than half of wildfire-fighting costs come from defending homes.

Understanding the sources of the sparks that start the fires—not just the conditions that allow them to spread—could help save lives, homes and ecosystems, says Jennifer Balch, who studies fire ecology at University of Colorado Boulder. She emphasizes prevention in public messaging and enforcement of laws designed to reduce illegal fire starts. "We are the fire species," Balch says. "We can do a lot to change its course on the landscape."

With forests volatile and weather increasingly erratic, public responsibility is critical. "Don't be doing stupid stuff in the woods," Thomas says. "These forests can't tolerate human recklessness."

—Jane Braxton Little

Graphic by Amanda Montañez

ment to the effort people have poured into keeping condors in the sky. But ultimately the goal is "to not touch them, to not be able to capture them, because they're so wild and so self-sufficient," Blackford says.

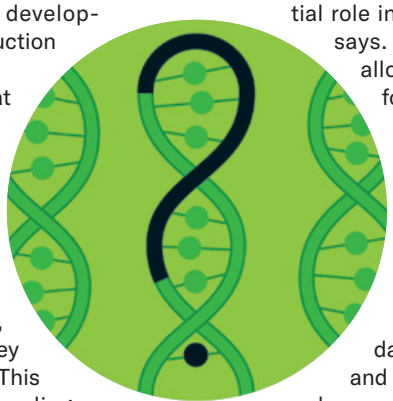
Unfortunately, entering that next phase of recovery will require changing human behavior, not just neutralizing a virus, she adds—because hunters' use of lead bullets (which condors ingest by scavenging mammal carcasses) remains these birds' biggest threat.

Combating the avian flu with a vaccine seems straightforward in comparison, Hall says: "The ongoing threats that condors face, really primarily because of the way that the environment has changed over the past 500 years on this continent due to colonization—that's a much harder issue to address." —*Meghan Bartels*

The Great "Unknome"

Scientists don't know what most protein-making genes do

GENETICS Among the vast contents of the human genome, geneticists are most interested in the tiny fraction—about 1.5 percent—that contains instructions for building proteins. Protein building is DNA's main function, and these complex molecules are essential for development, growth and reproduction across the entire body.



But we don't know what most of these protein-coding genes actually do. Only about 20 percent of human coding genes are well studied, leaving the function of the other 80 percent (about 16,000 genes, along with the proteins they make) largely a mystery. This is because of a long-standing bias in genetics research: scientists more often study genes and proteins already known to have important functions. These high-profile projects, such as studying genes with known implications for cancer, are the ones that seem "sexy" to funders, says University of Oxford cell biologist Matthew Freeman.

Freeman and his colleagues have dubbed the well of untapped genetic potential the "unknome," and they have been working for 10 years to create a database that compiles and catalogs these understudied genes. It ranks them by "knownness" and tracks which of the genes appear in various other species' DNA. Their research tool and accompanying paper in *PLOS Biology* were recently released online.

The ability to filter for genes found across various species sets this project apart from others with similar aims, says bioinformatician Avi Ma'ayan of the Icahn School of Medicine at Mount Sinai in New York City, who was not involved in the new work. "The concept of the unknome is not a new one," Ma'ayan says, but with so much undiscovered, researchers might not know which genes to prioritize. That's why the interspecies comparison can be so helpful. When genes are conserved across many species, that's a good hint that they play "an essential role in the organism," Ma'ayan says. The unknome database allows scientists to search, for example, for understudied genes that exist only in invertebrates, that are found in all living cells, or that are predicted to be found only in the cell membrane. As Freeman says, "it's very tunable."

To test the unknome database's utility, Freeman and his team isolated 260 unknown fruit fly genes that are also present in humans. Knocking out many of those genes in the flies either made the insects unviable or gave them various defects. "It validates the notion that these unknown genes do indeed have not only important biologic functions but also ones that are experimentally amenable," Freeman says. With such resources and technological advances, the researchers hope the unknome will be one knowledge base that only shrinks with time.

—*Hannah Seo*

Illustrations by Thomas Fuchs

An abstract illustration of sound waves

NEUROSCIENCE

A Little Brain Music

Artificial intelligence turns brain signals into a garbled Pink Floyd song

RESEARCHERS HOPE BRAIN implants will one day help people who have lost the ability to speak to get their voice back—and maybe even to sing. Now, for the first time, scientists have demonstrated that the brain's electrical activity can be decoded and used to reconstruct music.

A study published in *PLOS Biology* analyzed data from 29 people who already had brain implants that monitored them for epileptic seizures. As the participants listened to Pink Floyd's song "Another Brick in the Wall, Part 1," their implanted electrodes captured electrical activity in several brain regions attuned to musical elements such as tone, rhythm, harmony and lyrics. The researchers then ran these data through an AI model to partially reconstruct what participants heard.

The findings build on other recent studies that have successfully reconstructed words and visual images based on brain activity, says Shailee Jain, a neuroscientist at the University of California, San Francisco, who was not involved in the new study. "Now we're able to really dig into the brain to unearth the sustenance of sound," Jain adds.

The AI model analyzed patterns in how the participants' brains responded to the song, picking apart changes in pitch, rhythm and tone. Then another model reassembled this disentangled composition to estimate the sounds that the subjects heard. The reconstructed melody was roughly intact, and the lyrics were garbled but discernible if one knew what to listen for.

So why Pink Floyd? The song in question is "very layered," making it interesting to analyze, says cognitive neuroscientist Ludovic Bellier of the University of California, Berkeley, the study's lead author. But also, "we just really like Pink Floyd."

Beyond music, the results may be most useful for translating brain signals into human speech—which itself contains melodic nuances, including tempo, stress, accents and intonation. These nuances "carry meaning that we can't communicate with words alone," Bellier says. The researchers hope their new model will improve brain-computer interfaces, devices that turn brain activity into synthesized speech for those who can no longer speak on their own. "Instead of robotically saying, 'I. Love. You,' you can yell, 'I love you!'" says the study's senior author, Robert T. Knight, a cognitive neuroscientist also at U.C. Berkeley.

The current model relies on surgically implanted electrodes. But as brain-recording techniques improve, it may be possible to gather such data with ultrasensitive electrodes attached to the outside of the scalp. For now the researchers hope to generate crisper musical playback by packing the electrodes closer together on the brain's surface, enabling an even more detailed look at the electrical symphony the organ produces. "Today we reconstructed a song," Knight says. "Maybe tomorrow we can reconstruct the entire Pink Floyd album." —*Lucy Tu*

MR.Cole Photographer/Getty Images

OCEANOGRAPHY

Seal Team

Aquatic mammals help researchers map Antarctica's ocean floor

HUMANS HAVE SAILED the oceans' surfaces for millennia, but their depths remain effectively uncharted. Only about a quarter of the seafloor has been mapped at high resolution. Maps of most regions display only approximate depths and often miss entire underwater mountains or canyons.

So a group of researchers has recruited some deep-diving experts: Elephant Seals and Weddell Seals. Scientists have been placing trackers on these blubbery marine mammals around Antarctica for years, gathering data on ocean temperature and salinity. For a new study, the researchers compared these dives' location and depth data with some of the less detailed seafloor maps. They spotted places where the seals dove deeper than should have been possible according to the maps—meaning the existing depth estimates were inaccurate.

In eastern Antarctica's Vincennes Bay, the diving seals helped the scientists find a large, hidden underwater canyon plunging to depths of more than a mile. An Australian research ship called the RSV *Nuyina* later measured the canyon's exact depth using sonar, and the researchers have proposed naming their find the Mirounga-Nuyina Canyon—honoring both the ship and the involved Elephant Seals, genus *Mirounga*.

"The seals discovered the canyon, and the ship confirmed it," says Clive McMahon, a researcher at the Integrated Marine Observing System in Australia and a co-author of the new study, published in *Communications Earth & Environment*.

But seals can't map the entire ocean floor. The trackers used in the study could pinpoint a seal's geographical location only within about 1.5 miles, which allows for useful but not exactly high-resolution data. Plus, because the seals don't always dive to the bottom of the ocean, they can reveal only where the bottom is deeper than in existing maps—not shallower. McMahon notes that scientists could improve on these data by using more precise GPS trackers and analyzing the seals' diving patterns to determine whether they have reached the seafloor or simply stopped descending.

The current seal-dive data can still be valuable for an important task, says Anna Wåhlin, an oceanographer at the University of Gothenburg in Sweden, who was not involved in the new research. The deep ocean around Antarctica is warmer than the frigid waters at the surface, and seafloor canyons can allow that warmer water to flow to the ice along the continent's coast, Wåhlin explains. To predict how Antarctica's ice will melt, scientists will need to know where those canyons are and how deep they go. —*Ethan Freedman*

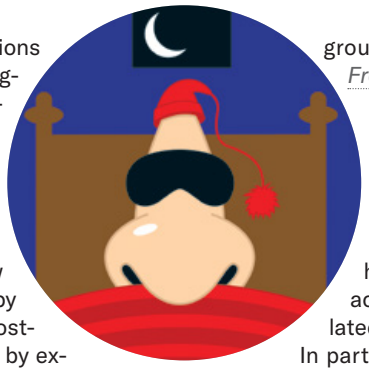
Southern Elephant Seal

D. Parer/E. Parer-Cook/Minden Pictures

The Nose Knows

To boost your memory, go to sleep and smell the roses

COGNITION Smell is probably our most underappreciated sense. "If you ask people which sense they would be most willing to give up, it would be the olfactory system," says Michael Leon, a neurobiologist at the University of California, Irvine. But a loss of smell has been linked to health complications such as depression and cognitive decline. And mounting evidence shows that olfactory training, which involves deliberately smelling strong scents on a regular basis, may help stave off that decline. Now a team of researchers led by Leon has successfully boosted cognitive performance by exposing people to smells while they sleep. Twenty participants—all older than 60 years and generally healthy—received six months of overnight olfactory enrichment, and all significantly improved their ability to recall lists of words compared with a control group. The study appeared in *Frontiers in Neuroscience*.



The scientists are unsure about how the overnight odors may have produced this result, but Leon notes that the neurons involved in olfaction have "direct superhighway access" to brain regions related to memory and emotion. In participants who received the treatment, the study authors observed physical changes in a brain structure that connects the memory and emotional centers—a pathway that often deteriorates as people age, especially in those with Alzheimer's disease.

CLIMATE CHANGE

Zeroing In

Supercomputer network could predict climate change effects down to the neighborhood

SCIENTISTS HAVE USED computer models to predict global warming's implications for more than five decades. As climate change intensifies, these increasingly precise models require more and more computing power. For a decade the best simulations have been able to predict climate change effects down to a 25-square-kilometer area. Now a new modeling project could tighten the resolution to one kilometer, helping policymakers and city planners spot the neighborhoods—or even individual buildings—most vulnerable to extreme weather events.

"Climate [science] has always had a computing problem," says Bjorn Stevens, director of Germany's Max Planck Institute for Meteorology. Recent technological advances such as shrinking transistors, however, have made computers far more capable, Stevens says. He and a group of climatologists and scientists from other disciplines are developing a network of global supercomputing centers called Earth Visualization Engines, or EVE, which they hope to complete within the decade. These centers would work together by running climate models, interpreted by machine-learning algorithms, on supercomputers to predict climatic shifts and severe weather events locally.

A residental area in Pakistan flooded after heavy monsoon rains in 2022.

Fida Hussain/AFP via Getty Images

This international push, which organizers have called "the CERN of climate science," could help municipalities miti-

Previous successful attempts to boost memory with odors typically relied on complicated interventions with multiple exposures a day. If the nighttime treatment proves successful in larger trials, it promises to be a less intrusive way to achieve similar effects, says Vidya Kamath, a neuropsychologist at the Johns Hopkins University School of Medicine, who was not involved in the recent study.

Larger trials may also help answer some remaining questions. The new study used widely available essential oils such as rose and eucalyptus, but researchers aren't sure if just any odor would get the same results. They don't know how much an odor's qualities—whether it's foul or pleasant to people, for example—affects the cognitive gains. It is also unclear how much novelty plays a role, says Michał Pieniak, a psychology researcher at the University of Wroclaw in Poland who has studied olfactory training.

Beyond stimulating the olfactory system, other interventions aimed at enriching people's sensory environment (such as dancing) have been associated with cognitive improvements in older people. Overnight odors could be a strong line for further study, but Pieniak cautions aromatherapy fans from running to buy diffusers. The results are promising but "preliminary" and should be replicated with more participants, he says. Leon plans to conduct a larger study later this year—work that he hopes will eliminate any whiff of doubt.

—Timmy Broderick

gate disasters, say supporters who plan to present the proposal at the 28th United Nations Climate Change Conference in November. Higher-resolution modeling could show how wind shear affects certain buildings, where floodwaters might go, or what areas are most vulnerable to damage. These details could inform measures taken before dangerous events such as heat waves, hurricanes or droughts, helping officials determine when and where to save water, set up cooling centers or shore up infrastructure.

Such fine-grained modeling may be enabled by a recent technological advance: a superchip called Grace Hopper, named after the pioneering computer scientist and developed by computer technology company Nvidia. Ten years in the making, it could be used to process models as many as six times faster than other superchips while using less energy, says Dion Harris, Nvidia's head of accelerated data center project marketing.

As EVE moves forward, Stevens and other planners envision making the data and models publicly available. Doing so—especially in developing countries hit hardest by the climate crisis—should be prioritized before rolling out new and expensive computing technologies, says Gavin Schmidt of NASA's Goddard Institute for Space Studies, who is not involved with EVE.

"There is a huge amount of useful climate information that isn't accessible," Schmidt says. Climate modelers are "trying to make the best of the information, get it out there, and help people make better decisions for adaptation."

— Susan Cosier

MACHO 80.7443.1718's smaller star causes waves on its massive companion.

Melissa Weiss/Center for Astrophysics | Harvard & Smithsonian

Surfing the Stars

Giant gas waves crash on a distant star

ASTROPHYSICS As the tide rolls in on an ocean beach, waves crash in a spray of saltwater and foam. Light-years from Earth a similar scene is playing out on a vastly larger scale as waves of hot gas swell to the height of three of our suns and then collapse onto the surface of a supergiant star, according to a recent study in *Nature Astronomy*.

In eccentric two-star systems called "heartbeat" stars, one star distorts its partner's shape as they orbit each other—a bit like how the moon creates ocean tides as it orbits Earth. These stellar tides of hot gas, which typically bulge to a height of about 0.1 percent of the star's overall diameter, cause variations in the star system's brightness that astronomers can detect on Earth.

There's something wildly different about MACHO 80.7443.1718, a system 200,000 light-years away, says study co-author Morgan MacLeod, an astrophysicist at the Center for Astrophysics | Harvard & Smithsonian. This system's smaller star has been causing tides on its giant companion with amplitudes reaching 20 percent of the larger star's size, distorting it into a shape "like a rugby ball," MacLeod explains. "How can it support a wave this big?" he wonders.

In short, it can't. MacLeod and his colleague Abraham Loeb created a computer model of the stars' movements and found that the system will eventually be unable to sustain such giant waves. The orbit distance is shrinking, and the spray of hot gas and debris from the waves is causing the larger star to lose mass. The researchers nicknamed this doomed pair "heartbreak" stars.

"In this system, the stars come quite close to each other during their orbit," says James Fuller, an astrophysicist at the California Institute of Technology, who was not involved in the new study. "You get a much more violent reaction than we normally see in other systems." The stars draw closer together with each passing year as the larger one, 35 times the mass of our sun, siphons energy from its smaller companion. MacLeod expects the waves will become only more powerful as the orbit shrinks further. Physicists don't know yet whether such stars eventually collide and merge into one.

Studying binary-star interactions might help astrophysicists predict the system's ultimate fate, says Susan E. Mullally, an astronomer at the Space Telescope Science Institute, who didn't take part in the study. At the end of their lives massive stars either collapse into black holes or stall out as neutron stars—but for these so-called heartbreak stars, scientists don't know which it will be.

"If a significant part of [a massive star's] life is spent interacting with another star," Mullally says, then this may have "interesting influences in the final evolution of what happens to binary stars."

—Allison Gasparini

PHYSICS

Nuclear Time

A new type of clock would lose one second every 31 billion years

FROM SATELLITE NAVIGATION to GPS, the world runs on ultraprecise timekeeping, usually based on atomic clocks. These devices use energy sources, such as lasers tuned to specific frequencies, to excite electrons orbiting atomic nuclei. The electrons jump or "transition" to a higher energy level before falling back down to a lower one at rapid, regular time intervals—an atomic clock's "tick."

But even atomic clocks aren't perfect, because environmental factors can affect

MEDICINE

Catching It Early

Scientists develop wearable breast cancer scanner

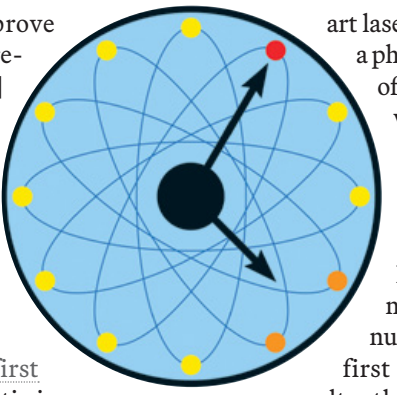
IF BREAST CANCER is caught early, its survival rate is nearly 100 percent. If not, that rate can quickly drop to roughly 25 percent. Women older than 50 in the U.S. are advised to get mammograms every two years, but the most aggressive tumors often arise and are diagnosed between screenings.

These "interval" cancers account for around a quarter of all breast cancer cases, "and by the time you're diagnosed, it [may be] too late," says Canan Dagdeviren, a materials engineer at the Massachusetts Institute of Technology. So Dagdeviren and her team have developed a wearable ultrasound scanner that could be used at home to detect breast tumors earlier, particularly in high-risk people. "Frequent

how electrons bounce. As our technological tools require ever more precision, physicists are devising a possible solution: move timekeeping *inside* the nucleus, which is insulated from such interference, by exciting protons and neutrons instead of electrons. Because protons and neutrons are relatively dense, a "nuclear clock" would require far more powerful tuned lasers—and a very particular kind of atom. Now breakthrough measurements of the isotope thorium 229, published recently in *Nature*, suggest that a practical nuclear clock may finally be within reach.

Whereas today's best atomic clocks lose one second every 100 million years, nuclear clocks would lose one second every 31.7 billion years (which is more than twice the age of the universe), explains the study's lead author, Sandro Kraemer. This enhanced precision could lead to advances in timekeeping, nuclear physics, and the quantum sensor technology used for satellite navigation and telecommunications.

"It will instantly improve nuclear physics measurements by a [factor of a] trillion to a quadrillion," says José R. Crespo López-Urrutia, a scientist at Germany's Max Planck Institute for Nuclear Physics, who was not involved with the new measurements.



In 2003 physicists first suggested that a synthetic isotope called thorium 229 could be the key to nuclear timekeeping. Theoretically, thorium 229's nuclear particles could transition into an excited state with a uniquely low amount of energy, making it the only isotope that current laser technology could feasibly excite for a nuclear clock. "Most [elements'] nuclear transitions have very large energies in the range of thousands or millions of electron volts," which is beyond the capabilities of even state-of-the-art lasers, says Adriana Palffy, a physicist at the University of Würzburg in Germany, who also was not involved in the new work.

In the study, a team of physicists at CERN's nuclear physics facility, ISOLDE, spotted and measured thorium 229's nuclear transition for the first time. At 8.3 electron volts, the transition would be small enough to be triggered by a specially tuned laser. Physicists are now developing lasers to make the thorium clock tick, says Piet Van Duppen, the ISOLDE team's spokesperson and a professor at the Institute for Nuclear and Radiation Physics at KU Leuven in Belgium. "Once the resonance [between thorium 229 and these new lasers] is observed," Van Duppen says, "we will make a major leap forward."

—Kenna Hughes-Castleberry

screening is the key for survival," she says.

Conventional—and bulky—ultrasound scanning machines use piezoelectric materials (which convert electrical signals into movement) to send out sound waves that penetrate the body. Denser tissue reflects more sound, signaling the presence of a tumor. Dagdeviren says she and her team miniaturized a scanner using a new type of piezoelectric material that performs better and requires less power. "You get better penetration of deep tissue, using lower voltage," she says.

The researchers incorporated the scanner into a flexible, honeycombed 3-D-printed patch that can be fixed into a bra. The wearer moves the scanner among six different positions on the breast, where it snaps into place with magnets, allowing reproducible scanning of the whole breast. The scanner, which could be used once a week or month, was recently described in *Science Advances*.

The device achieves resolution comparable to ultrasound scanners commonly used in medical centers, but it does not have to be operated by a trained technician. "If you have a wearable solution that individuals can use at their pleasure, you can capture a lot more data," says engineer Roozbeh Jafari of Texas A&M University, who was not involved in the work. That additional data can help doctors track a cancer's development and a treatment's efficacy.

Dagdeviren was inspired to develop the device when her aunt passed away from breast cancer at the age of 49, despite regular screening. "Just to comfort her, I sketched an ultrasound bra by her bedside," she says. "It was a dream on a piece of paper, but now it's in my hands." She and her colleagues believe the technology could have a profound impact. "With a very humble calculation, we found that this has the potential to save 12 million lives per year globally," she says.

Clinical trials are underway in a bid for approval from the Food and Drug Administration. The device must still be connected to a conventional ultrasound machine to view the scans, but the team is working on a phone-sized device to analyze and transmit the data. "Depending on cost, the notion of equity could also be addressed because you no longer need to pay for hospital settings, physicians, nurses, and so on," Jafari says. "This device could be used in ambulatory settings, remote areas and underserved communities."

—Simon Makin

The new scanner could help detect aggressive breast tumors early.

Canan Dagdeviren/Massachusetts Institute of Technology


Eastern Box Turtle

ECOLOGY

Bomb Shell

Turtle shells record ecosystems' nuclear history

THE INVENTION of nuclear weapons has shaped not only our planet's political history and systems but its natural history as well. A study in *PNAS Nexus* shows how scientists are examining the latter in a surprising place: the shells of turtles that lived near nuclear production and testing sites.

The researchers detected traces of uranium in the shells of four turtles, including one sea turtle and one tortoise, that lived near such sites before being collected as natural history specimens between the 1950s and the 1980s. Using a mass spectrometer, a device that detects a material's chemical makeup, the scientists matched the signatures of uranium isotopes in the shells to the distinct signatures produced by nuclear production and detonation. (Isotopes are varieties of an element that contain different numbers of neutrons in their nuclei.) In one of the specimens, they tracked the animal's uranium uptake over time by tracing isotope levels in individual concentric layers that form in shells like tree rings.

Nuclear weapons are powered by the fission, or splitting, of uranium or other radioactive elements. The creation and detonation of such weapons shed these elements into the environment, where they are taken up into the local ecosystem. The shells that the team analyzed weren't technically radioactive, because they contained such small amounts of uranium—around one part per billion—says study co-author Cyler Conrad, an earth scientist at Pacific Northwest National Laboratory. The turtles had survived their nuclear exposure, and their health probably wasn't affected, Conrad says.

Finding uranium in turtle shells is not necessarily surprising in itself; the element occurs naturally in soil, rock and water. But Conrad and his colleagues were amazed that they could detect such tiny amounts of it—and could match the isotope signature to a site's known nuclear history. Conrad hopes the study's new technique (which his team is adapting for use with plutonium) can help scientists determine where and when nuclear activity occurred, as well as how radioactive materials move from soil and water into plants and animals. He also thinks it could be used to trace exposure to nuclear fuel in addition to weapons.

For Laura Martin, an environmental historian at Williams College, the study is a reminder of the scars left by the U.S. nuclear program—and not just in Japan, where the U.S. deployed nuclear bombs as weapons in World War II. Production and experimental detonations also sent radiation and other pollution into American neighborhoods and ecosystems, particularly in the West and often on or near Indigenous lands, as well as in the Marshall Islands. "This paper points us to how nuclear colonialism is not just a human history," Martin says. "It has [affected] and continues to impact the whole biosphere." —*Meghan Bartels*

NEWS AROUND THE WORLD

Quick Hits

By Timmy Broderick

ANTARCTICA

Research stations in Antarctica have polluted surrounding ocean areas with heavy metals, fuel components and carcinogenic compounds, a new study shows. The contamination has accumulated because of poor waste management over decades.

FRENCH POLYNESIA

Thought to reproduce only at night, corals in reefs near French Polynesia were spotted doing the deed in broad daylight. It's unclear why, but researchers suggest this might help the species thrive in warming waters.

GERMANY

Paleontologists in Bavaria unearthed the first complete fossil of a 150-million-year-old turtle. It had stubby limbs and a flattened carapace, suggesting that—unlike modern sea turtles—this ancient reptile lived along shallow coastlines.

INDIA

A team of scientists in the Thar Desert discovered an entirely new dinosaur species: *Tharosaurus indicus*. This long-necked plant muncher lived more than 167 million years ago and is now the oldest known member of its family.

PORTUGAL

Archaeologists found 3,000-year-old mummified bees in rocks off Portugal's southwestern coast. Likely entombed by a flash freeze or flood, the insects were remarkably well preserved in bulb-shaped cocoons. It's the first such ancient nest to be found with intact mummified specimens.

U.K.

London mayor Sadiq Khan successfully expanded the city's Ultra Low Emission Zone to include all boroughs. The stricter standards on car exhausts have been politically divisive but have led to a 26 percent reduction in harmful pollution emissions.

U.S.

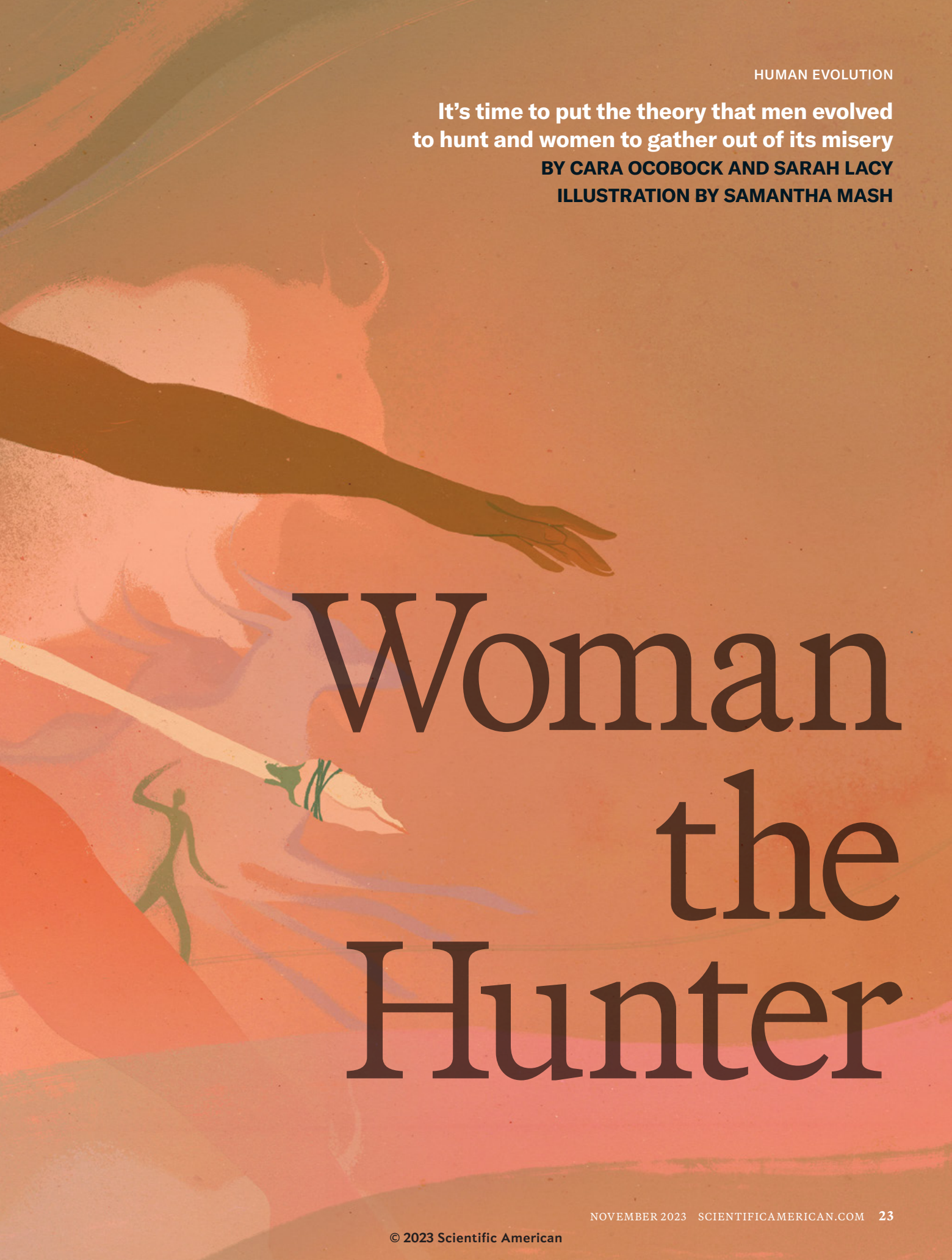
A Montana judge ruled that children have a constitutional right to a clean and healthy environment. This is a major victory for 16 young Montanans who sued their state, as well as for the growing movement for legal protection from damage related to climate change.

For more details, visit www.ScientificAmerican.com/nov2023/advances

Joe McDonald/Getty Images

It's time to put the theory that men evolved to hunt and women to gather out of its misery

BY CARA OCOBOCK AND SARAH LACY
ILLUSTRATION BY SAMANTHA MASH



Woman the Hunter

EVEN IF YOU'RE not an anthropologist, you've probably encountered one of this field's most influential notions, known as Man the Hunter. The theory proposes that hunting was a major driver of human evolution and that men carried this activity out to the exclusion of women. It holds that human ancestors had a division of labor, rooted in biological differences between males and females, in which males evolved to hunt and provide, and females tended to children and domestic duties. It assumes that males are physically superior to females and that pregnancy and child-rearing reduce or eliminate a female's ability to hunt.

Man the Hunter has dominated the study of human evolution for nearly half a century and pervaded popular culture. It is represented in museum dioramas and textbook figures, Saturday morning cartoons and feature films. The thing is, it's wrong.

Mounting evidence from exercise science indicates that women are physiologically better suited than men to endurance efforts such as running marathons. This advantage bears on questions about hunting because a prominent hypothesis contends that early humans are thought to have pursued prey on foot over long distances until the animals were exhausted. Furthermore, the fossil and archaeological records, as well as ethnographic studies of modern-day hunter-gatherers, indicate that women have a long history of hunting game. We still have much to learn about female athletic performance and the lives of prehistoric women. Nevertheless, the data we do have signal that it is time to bury Man the Hunter for good.

THE THEORY ROSE to prominence in 1968, when anthropologists Richard B. Lee and Irven DeVore published *Man the Hunter,* an edited collection of scholarly papers presented at a 1966 symposium on contemporary hunter-gatherer societies. The volume drew on ethnographic, archaeological and paleoanthropological evidence to argue that hunting is what drove human evolution and resulted in our suite of unique features. "Man's life as a hunter supplied all the other ingredients for achieving civilization: the genetic variability, the inventiveness, the systems of vocal communication, the coordination of social life," anthropologist William S. Laughlin writes in chapter 33 of the book. Because men were supposedly the ones hunting, proponents of the Man the Hunter theory assumed evolution was acting primarily on men, and women were merely passive beneficiaries of both the meat supply and evolutionary progress.

But *Man the Hunter*'s contributors often ignored evidence, sometimes in their own data, that countered their suppositions. For example, Hitoshi Watanabe focused on ethnographic data about the Ainu, an Indigenous population in northern Japan and its surrounding areas. Although Watanabe documented Ainu women hunting, often with the aid of dogs, he dismissed this finding in his interpretations and placed the focus squarely on men as the primary meat winners. He was superimposing the idea of male superiority through hunting onto the Ainu and into the past.

This fixation on male superiority was a sign of the times not just in academia but in society at large. In 1967, the year between the Man the Hunter conference and the publication of the edited volume, 20-year-old Kathrine Switzer entered the Boston Marathon under the name "K. V. Switzer," which obscured her gender. There were no official rules against women entering the race; it just was not done. When officials discovered that Switzer was a woman, race manager Jock Semple attempted to push her physically off the course.

At that time, the conventional wisdom was that women were incapable of completing such a physically demanding task and that attempting to do so could harm their precious reproductive capacities. Scholars following Man the Hunter dogma relied on this belief in women's limited physical capacities and the assumed burden of pregnancy and lactation to argue that only men hunted. Women had children to rear instead.

Today these biased assumptions persist in both the scientific literature and the public consciousness. Granted, women have recently been shown hunting in movies such as *Prey,* the most recent installment of

Cara Ocobock is a human biologist at the University of Notre Dame. A former powerlifter, she explores the physiological and behavioral mechanisms necessary to cope with and adapt to extreme climates and high levels of physical activity.

Sarah Lacy is a biological anthropologist at the University of Delaware. She studies the oral and respiratory health differences between Neandertals and early modern humans. Lacy is also a trained doula and an advocate for safer pregnancy and birth in the U.S.

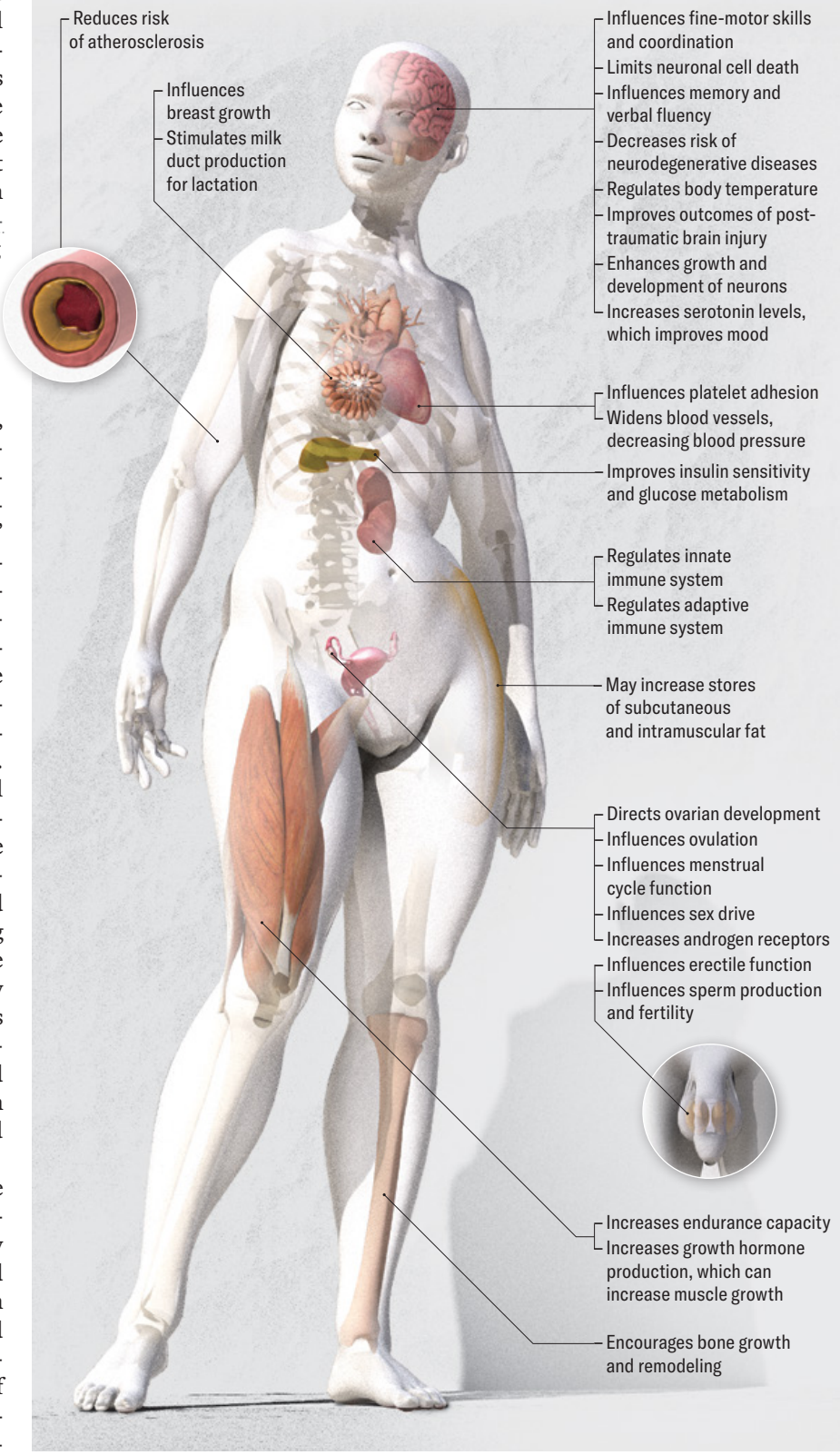
the popular Predator franchise, and on cable programs such as *Naked and Afraid* and *Women Who Hunt*. But social media trolls have viciously critiqued and labeled these depictions as part of a politically correct feminist agenda. They insist the creators of such works are trying to rewrite gender roles and evolutionary history in an attempt to co-opt "traditionally masculine" social spheres. Bystanders might be left wondering whether portrayals of women hunters are trying to make the past more inclusive than it really was—or whether Man the Hunter–style assumptions about the past are attempts to project sexism backward in time. Our recent surveys of the physiological and archaeological evidence for hunting capability and sexual division of labor in human evolution answer this question.

BEFORE GETTING INTO the evidence, we need to first talk about sex and gender. "Sex" typically refers to biological sex, which can be defined by myriad characteristics such as chromosomes, hormone levels, gonads, external genitalia and secondary sex characteristics. The terms "female" and "male" are often used in relation to biological sex. "Gender" refers to how an individual identifies—woman, man, nonbinary, and so forth. Much of the scientific literature confuses and conflates female/male and woman/man terminology without providing definitions to clarify what it is referring to and why those terms were chosen. For the purpose of describing anatomical and physiological evidence, most of the literature uses "female" and "male," so we use those words here when discussing the results of such studies. For ethnographic and archaeological evidence, we are attempting to reconstruct social roles, for which the terms "woman" and "man" are usually used. Unfortunately, both these word sets assume a binary, which does not exist biologically, psychologically or socially. Sex and gender both exist as a spectrum, but when citing the work of others, it is difficult to add that nuance.

It also bears mentioning that much of the research into exercise physiology, paleoanthropology, archaeology and ethnography has historically been conducted by men and focused on males. For example, Ella Smith of the Australian Catholic University and her colleagues found that in studies of nutrition and supplements, only 23 percent of participants were female. In studies focusing on athletic performance, Emma Cow-

Powers of Estrogen

The hormone testosterone gets all the attention in the fitness world. But the hormone estrogen, which females typically produce more of than males, actually plays a critical role in athletic performance. In addition to regulating the reproductive systems of both males and females, estrogen exerts effects throughout the body.

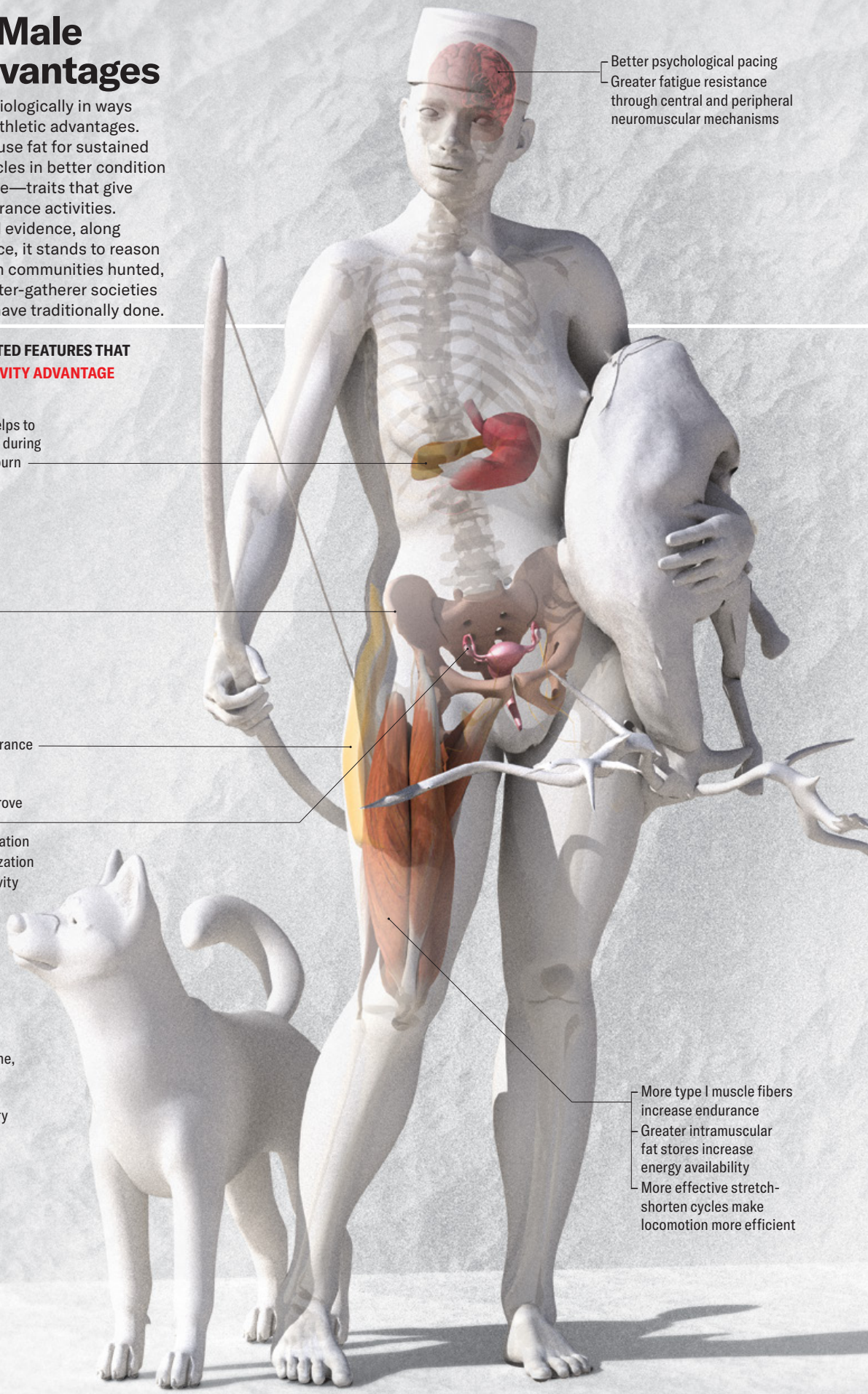


Graphics by Violet Isabelle Frances for Bryan Christie Design

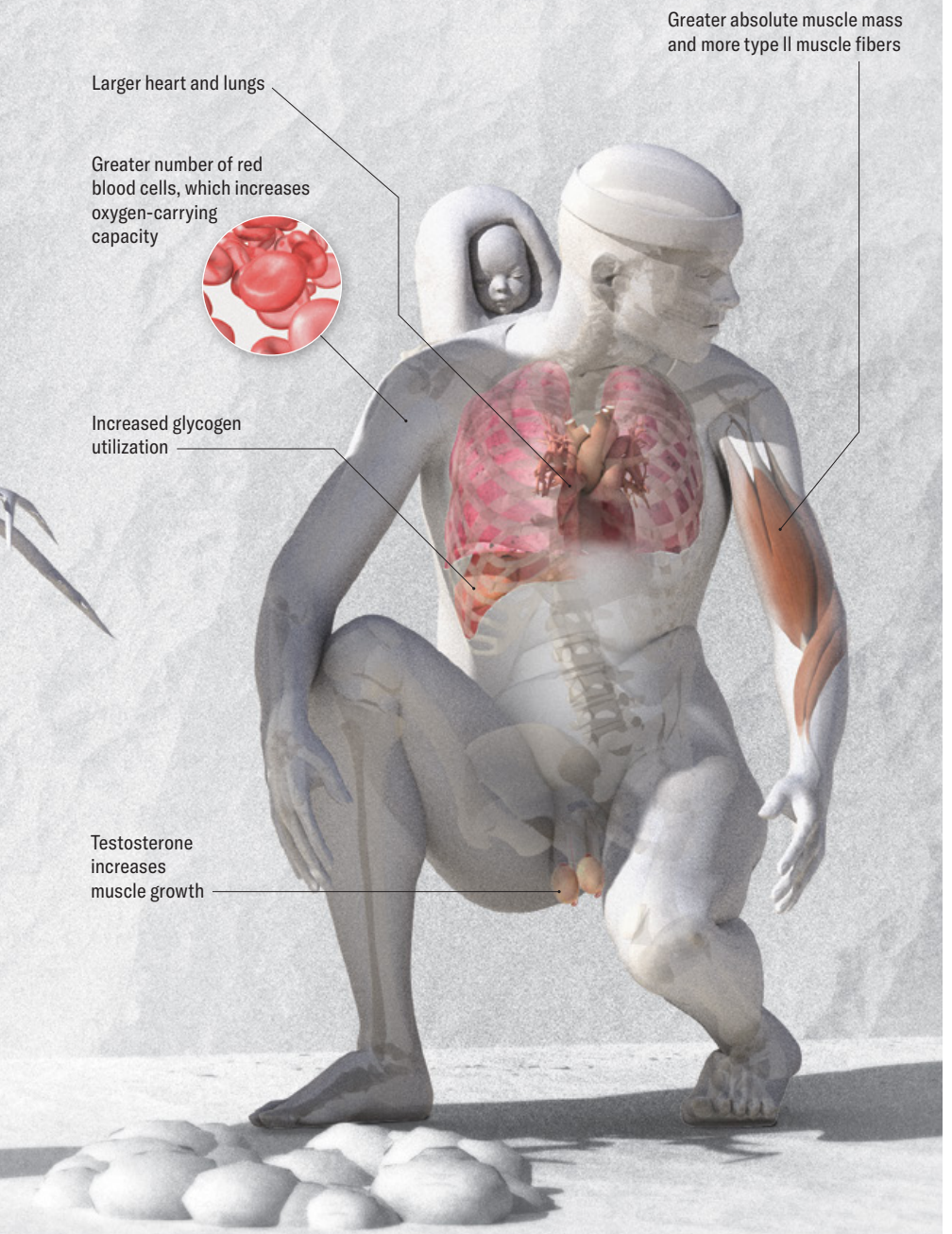
Female vs. Male Athletic Advantages

Females and males differ biologically in ways that translate to different athletic advantages. Females are better able to use fat for sustained energy and keep their muscles in better condition during exercise, for instance—traits that give them an advantage in endurance activities. In light of this physiological evidence, along with archaeological evidence, it stands to reason that females in early human communities hunted, just as females in later hunter-gatherer societies such as the Ainu of Japan have traditionally done.

THE SET OF FEMALE-ASSOCIATED FEATURES THAT CONFER AN ENDURANCE ACTIVITY ADVANTAGE



THE SET OF MALE-ASSOCIATED FEATURES THAT CONFER A POWER ACTIVITY ADVANTAGE



ley of the University of North Carolina at Chapel Hill and her colleagues found, only 3 percent of publications had female-only participants; 63 percent of publications looked exclusively at males. This massive disparity means we still know very little about female athletic performance, training and nutrition, leaving athletic trainers and coaches to mostly treat females as small males. It also means that much of the work we have to rely on to make our physiological arguments about female hunters in prehistory is based on research with small human sample sizes or rodent studies. We hope this state of affairs will inspire the next generation of scientists to ensure that females are represented in such studies. But even with the limited data available to us, we can show that Man the Hunter is a flawed theory and make the case that females in early human communities hunted, too.

From a biological standpoint, there are undeniable differences between females and males. When we discuss these differences, we are typically referring to means, averages of one group compared with another. Means obscure the vast range of variation in humans. For instance, although males tend to be larger and to have bigger hearts and lungs and more muscle mass, there are plenty of females who fall within the typical male range; the inverse is also true.

Overall, females are metabolically better suited for endurance activities, whereas males excel at short, powerful burst-type activities. You can think of it as marathoners (females) versus powerlifters (males). Much of this difference seems to be driven by the powers of the hormone estrogen.

Given the fitness world's persistent touting of the hormone testosterone for athletic success, you'd be forgiven for not knowing that estrogen, which females typically produce more of than males, plays an incredibly important role in athletic performance. It makes sense from an evolutionary standpoint, however. The estrogen receptor—the protein that estrogen binds to in order to do its work—is deeply ancient. Joseph Thornton of the University of Chicago and his colleagues have estimated that it is around 1.2 billion to 600 million years old—roughly twice as old as the testosterone receptor. In addition to helping regulate the reproductive system, estrogen influences fine-motor control and memory, enhances the growth and development of neurons, and helps to prevent hardening of the arteries.

Important for the purposes of this dis-

Sophie Power ran the 105-mile Ultra-Trail du Mont-Blanc race in the Alps while breastfeeding her child at rest stations.

Alexis Berg

cussion, estrogen also improves fat metabolism. During exercise, estrogen seems to encourage the body to use stored fat for energy before stored carbohydrates. Fat contains more calories per gram than carbohydrates do, so it burns more slowly, which can delay fatigue during endurance activity. Not only does estrogen encourage fat burning, but it also promotes greater fat storage within muscles—marbling if you will—which makes that fat's energy more readily available. Adiponectin, another hormone that is typically present in higher amounts in females than in males, further enhances fat metabolism while sparing carbohydrates for future use, and it protects muscle from breakdown. Anne Friedlander of Stanford University and her colleagues found that females use as much as 70 percent more fat for energy during exercise than males.

Correspondingly, the muscle fibers of females differ from those of males. Females have more type I, or "slow-twitch," muscle fibers than males do. These fibers generate energy slowly by using fat. They are not all that powerful, but they take a long time to become fatigued. They are the endurance muscle fibers. Males, in contrast, typically have more type II ("fast-twitch") fibers, which use carbohydrates to provide quick energy and a great deal of power but tire rapidly.

Females also tend to have a greater number of estrogen receptors on their skeletal muscles compared with males. This arrangement makes these muscles more sensitive to estrogen, including to its protective effect after physical activity. Estrogen's ability to increase fat metabolism and regulate the body's response to the hormone insulin can help prevent muscle breakdown during intense exercise. Furthermore, estrogen appears to have a stabilizing effect on cell membranes that might otherwise rupture from acute stress brought on by heat and exercise. Ruptured cells release enzymes called creatine kinases, which can damage tissues.

Studies of females and males during and after exercise bolster these claims. Linda Lamont of the University of Rhode Island and her colleagues, as well as Michael Riddell of York University in Canada and his colleagues, found that females experienced less muscle breakdown than males after the same bouts of exercise. Tellingly, in a separate study Mazen J. Hamadeh of York University and his colleagues found that males supplemented with estrogen suffered less muscle breakdown during cycling than those who didn't receive estrogen supplements. In a similar vein, research led by Ron Maughan of the University of St Andrews in Scotland found that females were able to perform significantly more weight-lifting repetitions than males at the same percentages of their maximal strength.

If females are better able to use fat for sustained energy and keep their muscles in better condition during exercise, then they should be able to run greater distances with less fatigue relative to males. In fact, an analysis of marathons carried out by Robert Deaner of Grand Valley State University demonstrated that females tend to slow down less as the race progresses compared with males.

If you follow long-distance races, you might be thinking, wait—males are outperforming females in endurance events! But this is only sometimes the case. Females are more regularly dominating ultraendurance events such as the more than 260-mile

Montane Spine foot race through England and Scotland, the 21-mile swim across the English Channel and the 4,300-mile Trans Am cycling race across the U.S. Sometimes female athletes compete in these races while attending to the needs of their children. In 2018 English runner Sophie Power ran the 105-mile Ultra-Trail du Mont-Blanc race in the Alps while still breastfeeding her three-month-old at rest stations.

The inequity between male and female athletes is a result not of inherent biological differences between the sexes but of biases in how they are treated in sports. As an example, some endurance-running events allow the use of professional runners called pacesetters to help competitors perform their best. Men are not permitted to act as pacesetters in many women's events because of the belief that they will make the women "artificially faster," as though women were not actually doing the running themselves.

The modern physiological evidence, along with historical examples, exposes deep flaws in the idea that physical inferiority prevented females from partaking in hunting during our evolutionary past. The evidence from prehistory further undermines this notion.

Consider the skeletal remains of ancient people. Differences in body size between females and males of a species, a phenomenon called sexual size dimorphism, correlate with social structure. In species with pronounced size dimorphism, larger males compete with one another for access to females, and among the great apes larger males socially dominate females. Low sexual size dimorphism is characteristic of egalitarian and monogamous species. Modern humans have low sexual size dimorphism compared with the other great apes. The same goes for human ancestors spanning the past two million years, suggesting that the social structure of humans changed from that of our chimpanzeelike ancestors.

Anthropologists also look at damage on our ancestors' skeletons for clues to their behavior. Neandertals are the best-studied extinct members of the human family because we have a rich fossil record of their remains. Neandertal females and males do not differ in their trauma patterns, nor do they exhibit sex differences in pathology from repetitive actions. Their skeletons show the same patterns of wear and tear. This finding suggests that they were doing the same things, from ambush-hunting large game animals to processing hides for leather. Yes, Neandertal women were spearing woolly rhinoceroses, and Neandertal men were making clothing.

Males living in the Upper Paleolithic—the cultural period between roughly 45,000 and 10,000 years ago, when early modern humans entered Europe—do show higher rates of a set of injuries to the right elbow region known as thrower's elbow, which could mean they were more likely than females to throw spears. But it does not mean women were not hunting, because this period is also when people invented the bow and arrow, hunting nets and fishing hooks. These more sophisticated tools enabled humans to catch a wider variety of animals; they were also easier on hunters' bodies. Women may have favored hunting tactics that took advantage of these new technologies.

What is more, females and males were buried in the same way in the Upper Paleolithic. Their bodies were interred with the same kinds of artifacts, or grave goods, suggesting that the groups they lived in did not have social hierarchies based on sex.

Ancient DNA provides additional clues about social structure and potential gender roles in ancestral human communities. Patterns of variation in the Y chromosome, which is paternally inherited, and in mitochondrial DNA, which is maternally inherited, can reveal differences in how males and females dispersed after reaching maturity. Thanks to analyses of DNA extracted from fossils, we now know of three Neandertal groups that engaged in patrilocality—wherein males were more likely to stay in the group they were born into and females moved to other groups—although we do not know how widespread this practice was.

Patrilocality is believed to have been an attempt to avoid incest by trading potential mates with other groups. Nevertheless, many Neandertals show both genetic and anatomical evidence of repeated inbreeding in their ancestry. They lived in small, nomadic groups with low population densities and endured frequent local extinctions, which produced much lower levels of genetic diversity than we see in living humans. This is probably why we don't see any evidence in their skeletons of sex-based differences in behavior. For those practicing a foraging subsistence strategy in small family groups, flexibility and adaptability are much more important than rigid roles, gendered or otherwise. Individuals get injured or die, and the availability of animal and plant foods changes with the seasons. All group members need to be able to step into any role depending on the situation, whether that role is hunter or breeding partner.

Observations of recent and contemporary foraging societies provide direct evidence of women participating in hunting. The most cited examples come from the Agta people of the Philippines. Agta women hunt while menstruating, pregnant and breastfeeding, and they have the same hunting success as Agta men.

They are hardly alone. A recent study of ethnographic data spanning the past 100 years—much of which was ignored by *Man the Hunter* contributors—found that women from a wide range of cultures hunt animals for food. Abigail Anderson and Cara Wall-Scheffler of Seattle Pacific University and their colleagues report that 79 percent of the 63 foraging societies with clear descriptions of their hunting strategies feature women hunters. The women participate in hunting regardless of their childbearing status. These findings directly challenge the Man the Hunter assumption that women's bodies and childcare responsibilities limit their efforts to gathering foods that cannot run away.

So much about female exercise physiology and the lives of prehistoric women remains to be discovered. But the idea that in the past men were hunters and women were not is absolutely unsupported by the limited evidence we have. Female physiology is optimized for exactly the kinds of endurance activities involved in procuring game animals for food. And ancient women and men appear to have engaged in the same foraging activities rather than upholding a sex-based division of labor. It was the arrival some 10,000 years ago of agriculture, with its intensive investment in land, population growth and resultant clumped resources, that led to rigid gendered roles and economic inequality.

Now when you think of "cave people," we hope, you will imagine a mixed-sex group of hunters encircling an errant reindeer or knapping stone tools together rather than a heavy-browed man with a club over one shoulder and a trailing bride. Hunting may have been remade as a masculine activity in recent times, but for most of human history, it belonged to everyone. ●

FROM OUR ARCHIVES

The Evolution of Human Birth. Karen R. Rosenberg and Wenda R. Trevathan; November 2001. ScientificAmerican.com/magazine/sa

Surgeons lean over a patient during a kidney transplant at NYU Langone Health in New York City.

Gift of Life

MEDICINE

Advances in transplant technology are saving lives. But dire organ shortages persist, so doctors are looking to other species as donors

BY TANYA LEWIS

PHOTOGRAPHS BY KHOLOOD EID

ROBERT MONTGOMERY WALKED deliberately down the hospital hallway carrying a stainless-steel bowl containing a living human kidney resting on a bed of ice. Minutes earlier the organ had been in one man's body. It was about to be implanted into another man to keep him alive.

It was about 11 A.M. on a Monday this past spring. I followed Montgomery, an abdominal transplant surgeon and director of the NYU Langone Transplant Institute, into an operating room where 49-year-old John Primavera was waiting to receive the precious kidney. Monitors beeped; Shakira played on the sound system. Montgomery, who has performed thousands of transplants, walked up to the operating table and gently lowered the organ into Primavera's abdomen. The kidney, offered to Primavera by his close friend Thomas Kenny, was pale and about the size and shape of a mango. Montgomery motioned for me to step toward the table. I watched as he removed the clamps on the artery he had just sewn onto the replacement organ. The kidney flushed pink with blood and began to pulse with life.

This kidney transplant was Primavera's second. He was born with a condition called renal hypoplasia, which prevented his own kidneys from fully developing. He had his first transplant at age 14, and that organ lasted about 35 years. But in 2022 it started to fail, and he had to go on dialysis and join the transplant waiting list. Kenny—who has been friends with Primavera since they were in elementary school—voluntarily got tested and found out he was a close tissue match for Primavera. For Kenny, the decision was easy. "I just felt it was the right thing to do at the right time," he told me a few weeks after the operation.

Not everyone is as fortunate as Primavera. More than 100,000 people in the U.S. are currently on waiting lists for an organ transplant, the vast majority of them for kidneys. Every day 17 people die waiting for a transplant. The procurement system uses only a small fraction of the available organs at any particular time because of logistical and medical hurdles and a controversial distribution system. Transplants remain out of reach for too many people, especially those of color and with low incomes; many never even get put on a waiting list.

Recent medical advances in treating infections such as hepatitis C and HIV have made previously unusable organs usable. In addition, technology has made it possible to keep organs viable for longer outside a body before a transplant and even to improve their quality. Yet the demand for organs still far outstrips the supply.

The persistent, tragic situation of people dying on long waiting lists has motivated Montgomery and several other scientists to begin a bold experiment: transplanting organs from other species—specifically, genetically modified pigs—into humans. In the past two years they have made significant progress in these operations, known as xenotransplants. The term has its roots in the Greek word *xenos,* for "alien" or "foreign." In tests this year, pig kidneys functioned in human bodies for up to two months without failing. Scientists have figured out genetic tweaks to these organs that make them more compatible with people, reducing the risk of bad reactions or outright rejection by a person's immune system.

Montgomery compares the current, inadequate organ transplant system to an economy running on fossil fuels. "You can have it burn cleaner, you can make all these various changes," he says, "but it's still never going to be what you really need, which is something that's renewable, that is sustainable." Xenotransplants, for Montgomery, are renewable energy.

They are, however, still very much experimental. They present thorny ethical issues such as the questions of who should receive one and how to communicate the risks involved. Some people criticize xenotransplantation as a distraction from addressing the problems with the existing transplant system. But Montgomery strongly disagrees. "I've spent my whole career trying to make these incremental changes," he says. Now is the time for something bigger, he argues, and xenotransplantation is the answer.

I CAN RELATE to the anxiety of waiting for an organ that may never come. My mother was diagnosed in 2019 with pulmonary fibrosis, a progressive and deadly lung-scarring illness with a two- to five-year prognosis, on average, after diagnosis. The disease has no cure, but a lung transplant offered the possibility of extending her life. Like many in need, we had to wait until she was sick enough to be listed for transplant (if she even qualified) while hoping that she would receive an organ before she got too sick to survive the surgery. I know the agony of hoping for a surgical miracle while simultaneously preparing to grieve a parent who is slipping away.

Montgomery also understands this anxiety: he received a heart transplant in 2018 to treat a life-threatening congenital heart condition, which his father and a brother both died from. "My interest in transplant

Tanya Lewis is a senior health and medicine editor at *Scientific American.*

In a procedure identical to the one that Thomas Kenny and John Primavera underwent, lead surgeon Robert Montgomery carries a live kidney from the donor's operating room to the recipient's (*left*) after inspecting the organ (*right*).

really goes back to when my father was sick," he told me a few months before Primavera's operation. We were in his office overlooking midtown Manhattan. The walls were decorated with photographs of presidents he had met at ceremonies honoring him or his wife, a mezzo-soprano singer with the Metropolitan Opera. Montgomery's father was diagnosed with dangerous heart disease at age 50, and a heart transplant might have saved him. But at the time, he was considered too old for the surgery. One of Montgomery's brothers died waiting for an organ; another got a transplant and is still alive. When Montgomery became very ill, he had no idea whether he would receive a transplant in time. A heart became available, and Montgomery's own colleagues performed the surgery at NYU Langone Health, where Montgomery currently practices.

Most transplant organs come from deceased donors, but kidneys and parts of other organs, including livers, can be obtained through the generosity of living donors. In the early 2000s, in an effort to increase the supply of organs from living donors, Montgomery performed some of the first "domino"-paired kidney transplants in the U.S., in which multiple donors and recipients provide and receive organs in a kind of surgical daisy chain. The process increases the number of possible matches: if an organ isn't the right blood or tissue type for a donor's intended recipient, it could match someone else in the chain, and another donor in that chain could have an organ that's a good match for the original recipient. Yet such procedures have not markedly increased the number of living-donor kidney transplants, Montgomery says.

The other major source of organs—deceased donors—relies on people who have suffered untimely deaths under circumstances that allow their organs to be retrieved in time for transplantation. These are usually victims of accidents or brain injuries who have been declared brain-dead but whose other organs will keep working as long as the body is kept on life support. Nearly 15,000 deceased people who were registered organ donors or whose families consented on their behalf provided organs in 2022 in the U.S. Historically, a large proportion of deceased donors have been victims of motor vehicle crashes. As traffic and vehicle safety have improved, crashes have become—thankfully—increasingly survivable. Yet the safety improvements have also decreased the number of organs available for transplant.

One development has been driving an increase in donor organs, but it's nothing to celebrate. It's the opioid epidemic. People who die of drug overdoses now constitute a significant fraction of donors—rising from 1 percent of donors in 2000 to more than 13 percent in 2017 —and it doesn't

seem like the crisis will abate anytime soon. "Our success right now is based on a failure in our society," Montgomery says. The increase in transplanted organs from people who died from overdoses is a result of the scale of those deaths, as well as of advances in medicine that have made more of those organs usable. Some people who suffer from opioid addiction are also infected with hepatitis C, a disease that causes severe liver inflammation. Until a few years ago, organs from such donors were considered unusable because of the risk of infecting the recipient. But new antiviral drugs have made the disease treatable. Building on work at Johns Hopkins University and the University of Pennsylvania, Montgomery and his colleagues helped to pioneer the first transplants from hepatitis C–positive donors; the heart Montgomery received came from such a donor. And in 2019 surgeons at Johns Hopkins Medicine performed the first kidney transplant in the U.S. between living people with HIV, something that is now done rarely but increasingly often.

These successes notwithstanding, the pool of potential organ recipients has outstripped supply for years. In 2022 more than 42,800 organs, a record number, were transplanted in the U.S.—an increase of 3.7 percent from 2021. With medical care for end-stage organ disease improving, more people are living long enough to make the transplant list, creating demand for more organs.

This unmet need has long disturbed Martine Rothblatt, who has the resources and ambition to do something about it. I first encountered Rothblatt, a biotech entrepreneur and lawyer who founded satellite radio company SiriusXM, at a 2013 conference on futurism and transhumanism, a field focused on enhancing humans using technology. She was giving a talk about her goal of achieving digital immortality by uploading human consciousness to computers. Despite these far-fetched ambitions, Rothblatt has funded a wealth of well-grounded research for decades, and her company United Therapeutics has propelled much of the recent progress in xenotransplantation.

Rothblatt became interested in transplants when her six-year-old daughter was diagnosed with pulmonary arterial hypertension, a lung disease that can be progressive and is sometimes fatal. Doctors told Rothblatt the only treatment was a lung transplant, but the chances of getting one were slim—especially for a child. Rothblatt started a foundation—and later United Therapeutics—to develop drugs for the condition, which have kept her daughter alive. But for many people with this disease, a lung transplant is still the only option, and it became clear to Rothblatt that there simply weren't enough organs to go around. "My near-term plan was that I was going to come up with something to save our daughter Jenesis before she needed a transplant," Rothblatt says. "My long-term plan was that I would come up with an unlimited supply of transplants."

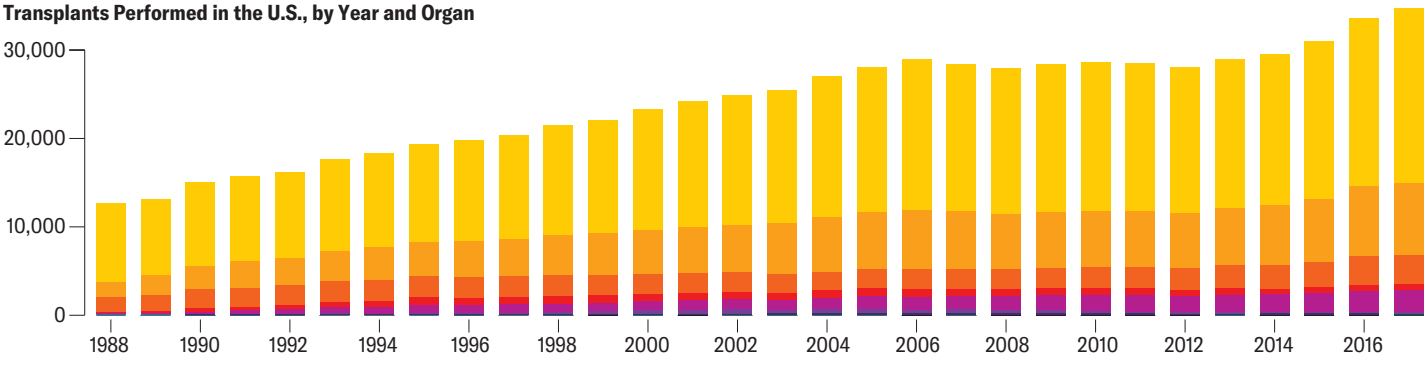
Rothblatt and United Therapeutics are pursuing several approaches to achieve this goal. The company is investing in systems that can keep lungs alive outside the body until they are ready to be transplanted. The machines pump oxygen and nutrients through the lungs and keep them warm—a process called ex vivo lung perfusion. Similar systems have been used for years for kidneys and in some cases livers. Only 20 percent of donor lungs are usable because the organs are so susceptible to damage or infection, according to Brandi Zofkie, senior director at Lung Bioengineering, a subsidiary of United Therapeutics. Lung Bioengineering uses a device called XPS, approved by the U.S. Food and Drug Administration and made by the company XVIVO, to perfuse and monitor donor lungs. Donor lungs are sent to Lung Bioengineering's facilities, and its staff conducts real-time video and audio calls with transplant surgeons to evaluate whether a pair of lungs is suitable. "We [try] to remove all the reasons they might say no to an organ," Zofkie says. The goal, she explains, is to maintain or improve the quality of the lungs prior to transplant by treating any infections and stabilizing their function.

Despite these advances, there are still not enough organs for all who need one. So Montgomery and other scientists have begun to explore a more plentiful source of organs by growing them in animals bred for this purpose.

XENOTRANSPLANTATION DATES at least to the 19th century, when doctors performed skin grafts using frog skin. Other attempts were more bizarre and grotesque: in the 1920s a surgeon in France transplanted chimpanzee testes into elderly men in an attempt to "rejuvenate" the men. More serious attempts happened in the 1960s, when a few intrepid surgeons transplanted kidneys, livers and hearts from chimpanzees and baboons into humans. Some people died soon after the transplants; others survived for months but

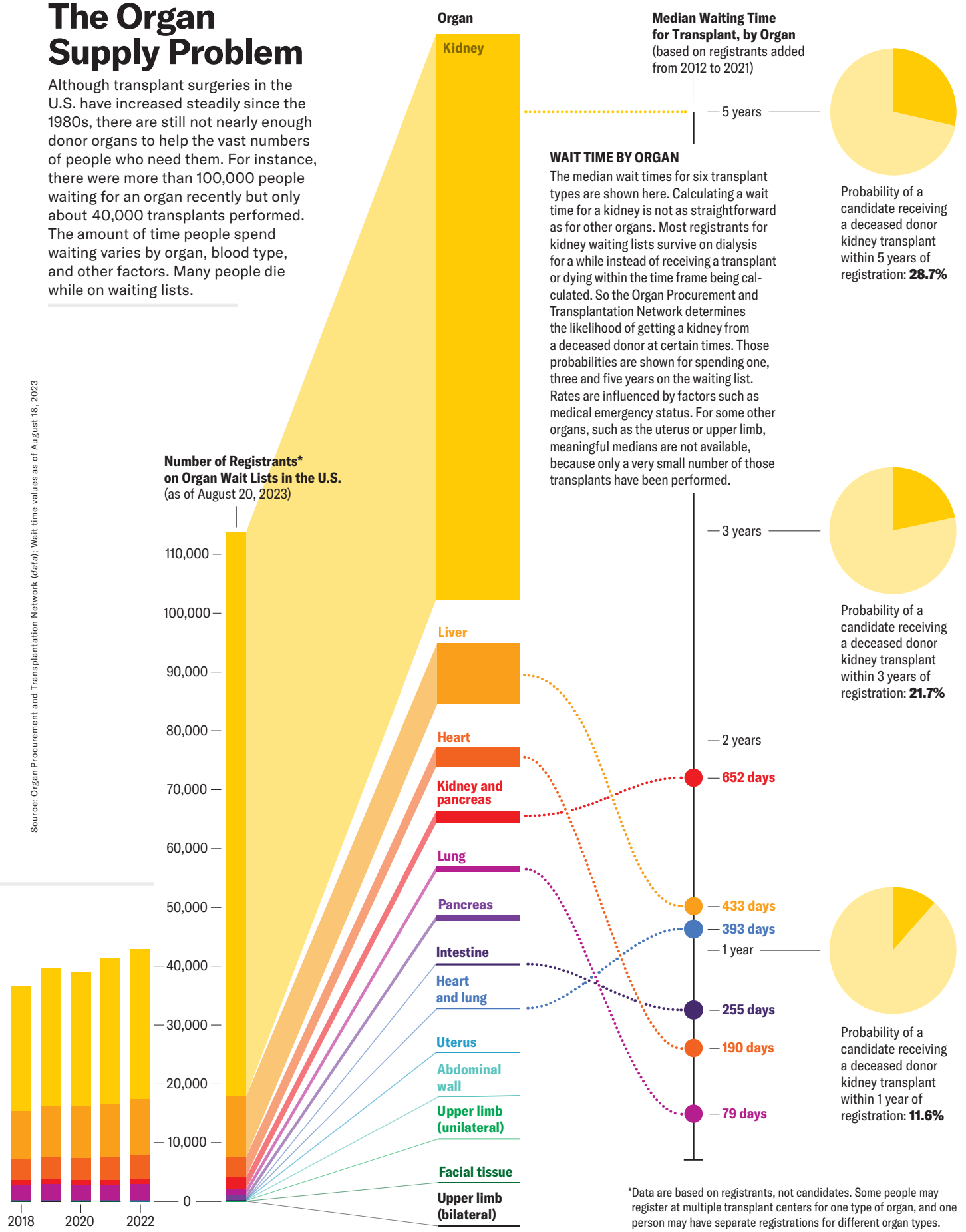
TOTAL NUMBER OF TRANSPLANTS IN THE U.S. OVER TIME

During the past 30 or so years, improvements in transplant technology and procurement have meant an increase in the the number of transplants in the U.S. Kidneys make up the vast majority of transplanted organs.



The Organ Supply Problem

Although transplant surgeries in the U.S. have increased steadily since the 1980s, there are still not nearly enough donor organs to help the vast numbers of people who need them. For instance, there were more than 100,000 people waiting for an organ recently but only about 40,000 transplants performed. The amount of time people spend waiting varies by organ, blood type, and other factors. Many people die while on waiting lists.



WAIT TIME BY ORGAN

The median wait times for six transplant types are shown here. Calculating a wait time for a kidney is not as straightforward as for other organs. Most registrants for kidney waiting lists survive on dialysis for a while instead of receiving a transplant or dying within the time frame being calculated. So the Organ Procurement and Transplantation Network determines the likelihood of getting a kidney from a deceased donor at certain times. Those probabilities are shown for spending one, three and five years on the waiting list. Rates are influenced by factors such as medical emergency status. For some other organs, such as the uterus or upper limb, meaningful medians are not available, because only a very small number of those transplants have been performed.

Source: Organ Procurement and Transplantation Network (*data*); Wait time values as of August 18, 2023

*Data are based on registrants, not candidates. Some people may register at multiple transplant centers for one type of organ, and one person may have separate registrations for different organ types.

Graphic by Jen Christiansen

ultimately experienced infection, rejection or other complications that proved fatal.

In the 1970s and 1980s advances in immunosuppressive drugs made the prospect of transplanting organs from other species more viable. In 1984 an infant known as Baby Fae received a baboon heart and lived for three weeks before her immune system rejected the organ. The surgery generated a lot of publicity around the lack of transplantable infant organs, but it also underscored the immunological challenges of cross-species transplants. After that, the field took a brief pause until the early 1990s. "There was sort of a moratorium on any further xenotransplantation until we were able to develop things further with the advent of some new technologies," Montgomery says.

There were a few more xenotransplants in the 1990s, but it became clear that better immunosuppression alone would not solve the problem. So scientists began modifying genes that triggered immune reactions. In 2000 PPL Therapeutics (now Revivicor) created the first cloned pigs and began genetically engineering them as a source of organs for human transplants. In 2011 United Therapeutics acquired Revivicor. The company chose pigs in part because the animals are easy to raise but also because their organs are similar to humans' and can be grown to the right size for a human recipient.

In addition, using pigs, which are plentiful and already bred for human use, was considered more ethically acceptable than using nonhuman primates. Revivicor's scientists bred a line of pigs in which they knocked out, or deactivated, the alpha-gal gene, which causes the animals to make a sugar that prompts an immune response in humans. In 2020 the FDA approved these "GalSafe" pigs for use in medical products or as food.

Two years later surgeons at the University of Maryland School of Medicine transplanted a Revivicor pig heart into a man named David Bennett, Sr., making headlines. Bennett had a fatal heart disease and was ineligible for a human heart transplant; he was offered the pig heart under an FDA expanded access protocol (sometimes called a "compassionate use" exception) because his death was otherwise imminent.

The transplanted heart worked for nearly two months before failing. It's not entirely clear why the heart failed; the cause might have been an undetected pig virus, although an analysis the University of Maryland team published in the *Lancet* suggested that runaway inflammation and reduced immunosuppression might also have played roles. "A surgeon doesn't like to lose a patient," says Bartley Griffith, Bennett's surgeon. "But it was such a ceiling-breaking event." Some people have argued that Bennett was too sick to benefit from the transplant, but Griffith says the pig heart was Bennett's best option and that the surgery provided valuable information about how pig organs can work in human bodies.

In 2021 Montgomery and his colleagues at NYU Langone and transplant surgeon

Aided by a magnifying camera, surgeons remove the donor organ (*left*). The medical team stitches up the recipient after the kidney is implanted (*right*).

Jayme Locke and her colleagues at the University of Alabama at Birmingham separately transplanted pig kidneys into people who had suffered brain death—known as decedents—with the families' consent. These experiments were done to show that pig organs could function in a human body without causing harm.

In the first two NYU surgeries, the kidney was attached to the recipient's upper leg near the groin, where it was more accessible for monitoring, and then connected to the leg arteries and veins. The University of Alabama team transplanted its kidney into the decedent's abdomen. All the transplanted kidneys produced urine—a sign of healthy kidney function. The team ended the experiments after several days, but in that time the organs showed no immediate signs of rejection. In June and July 2022 the NYU group, led by cardiac surgeon Nadar Moazami, transplanted two genetically modified pig hearts into deceased recipients. The transplanted hearts functioned well for the three-day duration of the experiment.

Locke, director of the University of Alabama's Comprehensive Transplant Institute, says she got involved in xenotransplantation to help translate the work of basic scientists into a life-extending therapy. "Every week I see a large number of patients that we ultimately wait-list," she says. "And I know that because of the organ shortage, many of these individuals will die before they ever have the opportunity to receive a transplant. I see xenotransplantation as a way to potentially give hope to many more people."

In July 2023 NYU invited me to observe its third pig kidney xenotransplant into a human decedent. I watched from the hospital roof as the kidney was delivered by helicopter over New York City's East River. A small team carried a cardboard box holding the organ on ice and pushed it through the hospital hallways in a wheelchair. I followed the team as far as the surgical floor—I couldn't go into the operating room because of the risk of being exposed to a pig virus. Pigs can carry viruses such as porcine cytomegalovirus, the one that was detected in Bennett, the person who received a pig heart transplant in 2022. NYU has developed a more sensitive test for such viruses, but as a precaution, the surgeons and observers receive regular blood tests for them as well.

I watched the transplant via a video feed from the hospital's "control room," which was packed with doctors and researchers labeling vials that would later contain urine, blood and tissue from both the kidney and the decedent for subsequent analysis.

We waited anxiously as Montgomery and his colleagues connected the pig kidney's blood vessels and ureter to the decedent's. A pig thymus gland—a source of

Donor Thomas Kenny (*left*) joined recipient and longtime friend John Primavera (*right*) at Kenny's house to celebrate in March 2023.

immune cells—was also transplanted to help reduce the risk of immune rejection. As the doctors removed the clamps on the new organ's blood vessels, the kidney started making urine. The graft was working.

After the surgery, Montgomery and his colleagues led a briefing at the decedent's bedside. I took a moment to privately acknowledge the tremendous generosity of the person's family, who, in the midst of immense personal tragedy, made the choice to donate their loved one's body to give someone in the future a better chance at life. The man, named Mo, had died from complications of a brain tumor. His sister, Mary Miller-Duffy, says she made the decision to donate his body because she felt he would have wanted to help people. Kidney disease claimed the life of her other brother when he was just three months old. She told me she struggled with the decision to donate Mo's body, but the compassion of the NYU doctors helped to make it easier. "If I had to do it again, I wouldn't change anything," she says.

Unlike previous xenotransplants, which were slated to go on for only a few days, this one was planned to last for a month as long as the body and the organ were working without signs of irreversible organ rejection. The procedure went better than expected. At the end of August the experiment was extended for another month. The kidney showed mild signs of rejection, which were reversed before the experiment ended. In August, Locke and her team at Alabama reported another kidney xenotransplant into a decedent. That organ was maintained for a week before the experiment was stopped.

ALTHOUGH EXPERIMENTS like these provide useful data, proving that such transplants are safe and effective will require clinical trials in live patients. The FDA has signaled that it is open to starting phase I clinical trials of xenotransplants once it has enough preclinical data. The teams at the University of Maryland, NYU Langone and the University of Alabama hope to be among the first the perform them. The prospect of trials in living people raises questions about who gets to participate and how to communicate the risks, says Karen Maschke, a senior research scholar at the Hastings Center who studies the ethics of xenotransplantation. "What kind of eligibility criteria should be in place?" she says. "Because not everybody's going to get access to that first trial."

Only a very small number of people will be in the first live tests. The researchers leading the trials will have to decide whether to enroll people on transplant waiting lists or people who are not eligible for human organ transplants and thus have no other option, Maschke says. Participants will probably also end up being people who live near the transplant centers doing the trials, for logistical reasons.

Although human welfare is the biggest concern, xenotransplants also bring up questions about the ethics of raising animals for their organs. Animal welfare groups have asked whether it is ethical to kill an animal to save a human life. Xenotransplant advocates counter that animals raised to feed people vastly outnumber any that would be used for transplants. The latter are likely to be strictly regulated by the FDA because their organs would be considered drugs, Maschke notes. The biggest hurdle may be a more existential one—the idea of putting pig organs into humans may disturb some people. Yet history shows that medical procedures once considered unnatural can become routine. Pig heart valves and cow heart tissue are now widely used in medicine, for instance.

Ambitious plans are in the works to produce more organs. Montgomery and other researchers are working on ways to take animal organs, strip away their cells and seed them with stem cells from a human recipient so the person's body won't reject the transplant. The NYU team plans to implant such "decellularized" organs in a recently deceased person sometime soon, Montgomery says. United Therapeutics is working on making 3-D-printed organs out of cells and tissues that could be customized to any person. And other research is changing the definition of death itself: researchers at Yale University have developed a perfusion system for keeping pig brain cells and bodies "alive" for hours after the animals have died. One day this system might be able to preserve human organs for transplantation or even revive people on the brink of death.

Even as scientists expand the boundaries of transplant science, however, there is enormous room for improvement in the current system. Surgeons frequently pass up good organs because they lack the staff and other resources to use them. Since the 1970s the United Network for Organ Sharing (UNOS) has been the sole entity responsible for matching organ donors and recipients in the U.S. It works with several dozen nonprofit groups contracted by the Department of Health and Human Services to get organs from donors to hospitals. But flaws in this system, such as lack of accountability and outdated software, have limited its effectiveness. In March the Biden administration announced plans to modernize the transplant system by making it more competitive, and in July the U.S. Congress passed legislation to break up UNOS's monopoly.

MY MOM MADE the transplant list in the fall of 2021. On December 15 of that year, she got "the call": a pair of lungs was available that might be a match for her, and could she please come to the hospital as soon as possible to get checked in for transplant surgery? Qualifying for the transplant list was an arduous process that took close to a year. It involved lots of testing, with many possible disqualifiers, and all the while my mom's health continued to deteriorate. After she made the list and spent several months on it, we endured an agonizing day of waiting in the hospital while the surgeon made sure the lungs were of suitable quality. (Too often they are not, and the patient is sent home.) The lungs were deemed good, and my mom was wheeled into the operating room. Seven hours later she was wheeled out with a new chance to live.

My mom has marked a year and a half with her new lungs. Recovery wasn't easy—she experienced a lot of pain in her rib cage, which her surgeons had to cut apart to put in the organs, and she had a brief lymphoma scare. The transplant recuperation process took a heavy emotional toll on my siblings and me, who spent nearly two months caring for her. But she has since recovered well.

With her gift of health and time, she has now moved back to Hawaii, where she lived for many years before her transplant. Among the first things she did after her return were to paddle in a Hawaiian outrigger canoe with her old canoe club and to swim in the Pacific Ocean without an oxygen tank for the first time in years. I have immense gratitude for her donor and their family, for the expert medical team that performed the surgery and cared for her afterward, and for the generations of medical advances that came before. Thanks to them, I still have my mom. ●

FROM OUR ARCHIVES

Graft and Host, Together Forever. Marguerite Holloway; February 2007. ScientificAmerican.com/magazine/sa

AEROSPACE

THE RIGHT STUFF

Materials grown in space are stronger and hardier than those created on the ground

BY DEBBIE G. SENESKY

PHOTOGRAPHS BY SPENCER LOWELL

Graphene aerogel, a promising material for insulation, energy storage, and more, is difficult to make on Earth but might be produced more easily in space.

WHEN I FIRST LEARNED about a material called silicon carbide, it blew my mind. It is one of the hardest synthetic materials, nearly as hard as diamond, and difficult to corrode. Its inner structure can take the form of more than 200 different crystal types. And here's the really cool part: at atmospheric pressure, it never melts—when it reaches 2,700 degrees Celsius, it skips a liquid form and turns straight from a solid into a gaseous vapor.

I was working toward my Ph.D. in mechanical engineering at the University of California, Berkeley, when I encountered silicon carbide, and its unreal properties got me hooked on materials science. I was inspired to investigate the challenges and opportunities of using this strange material to make electronics.

Only after I earned my Ph.D. did I learn that silicon carbide wasn't just tough on Earth—it could also withstand many of the extraordinary conditions found in space: radiation, space dust, wild temperatures and a lack of gravity. Cosmic radiation—high-energy particles such as protons, electrons and neutrons—degrades most electronics. But silicon carbide is 60 percent less sensitive to cosmic rays than silicon. And most materials can't handle the temperature extremes of, say, scorching Venus or frigid Uranus, let alone swing between such opposites. But silicon carbide can.

Realizing that silicon carbide might have the right properties to work in space set the direction for my career, which combines materials studies with space exploration. I'm fascinated by how space affects materials and how materials perform in space. Today I design electronics to fly on space missions and study how growing materials in orbit can improve them.

MOST OF MY WORK has focused on Venus. It's our closest neighbor, but humans have glimpsed only a handful of color panorama images of Venus's surface, taken during a Soviet mission in 1982. Scientists hypothesize that billions of years ago Venus looked like Earth, with flowing water and a cooler climate. Today its surface burns at 475 degrees C, hot enough to melt lead. The atmosphere is filled with carbon dioxide and sulfur dioxide, and sulfuric acid rain clouds cover the skies. Venus has crushing pressure at its surface—more than 90 times that of Earth—similar to the pressure you'd encounter a mile below the ocean here.

I would love to see, in my lifetime, a lander mission to Venus that could collect dynamic data about surface temperature and weather patterns. NASA has proposed conducting a 60-day mission to take a range of measurements from Venus's surface, but the agency doesn't yet know how to build the necessary instruments. At my EXtreme Environment Microsystems Laboratory (XLab) at Stanford University, my students and I construct tiny but tough electronics designed to survive everything Venus will throw at them.

Venus's high temperatures are among the biggest hurdles. Under that kind of heat, many materials will simply melt. Even if they don't, their elasticity and other properties can change, and it's hard to predict how these shifts will affect the materials' ability to function. If your cell phone, for instance, landed on Venus, the thermal energy would set off a flurry of electrons and send your device on the fritz.

Cell phones (and most of our everyday electronics) rely on semiconductor materials, primarily silicon. These are usually layered with a metal electrode on top. But when they get too hot, the metal can diffuse into the semiconductor material and turn it into an undesirable alloy, changing the material's mechanical and electrical properties.

This is where silicon carbide comes in. It and another material I study called gallium nitride are good alternatives to regular silicon. Gallium nitride is often used in power electronics, high-frequency electronics and blue LEDs. Both materials have semiconducting properties like silicon, but unlike silicon, they can also withstand high temperatures and radiation because of their wide electronic bandgap and high atomic binding

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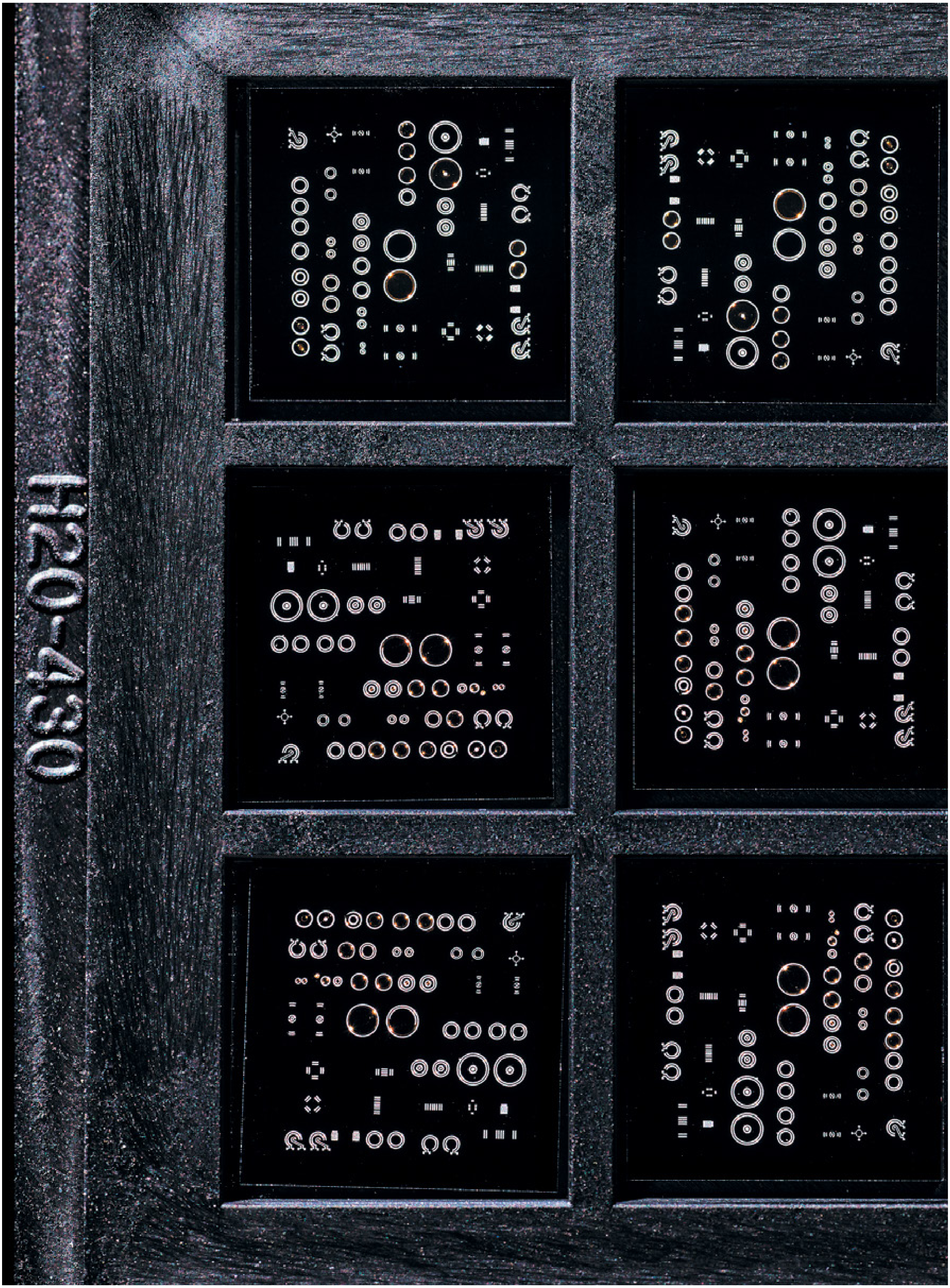
Debbie G. Senesky runs the EXtreme Environment Microsystems Laboratory (XLab) at Stanford University School of Engineering.

energy. In simple terms, it takes a lot of energy for electrons to reach the level required for conduction in these materials, so they maintain their normal conductivity even when hot. Gallium nitride can electrically function at temperatures higher than 1,000 degrees C.

In the clean rooms at the Stanford Nanofabrication Facility, my students and I build tiny gallium nitride transistors. Next we bring them over to the XLab, where we keep them heated to 470 degrees C for six days with our specialized testing equipment. Six days isn't as long as 60 days, the length of the planned NASA mission to Venus, but it's a lot longer than the two-hour mission the Soviets made 30 years ago, so we're headed in the right direction.

Sometimes we further subject our electronic components to the full simulated chemical experience of Venus in NASA's Glenn Extreme Environments Rig in Cleveland. Some of my experiments have used this facility, experiencing a temperature of 475 degrees C along with the sulfur dioxide and 90-bar pressure present on Venus. I don't want to have that kind of acidic chemistry in my lab, but I'm glad NASA does.



Chips with a variety of high-temperature gallium nitride electronic devices could potentially be used under the extreme conditions at Venus.

AS PROMISING AS silicon carbide and gallium nitride are for making extraordinarily resilient electronics, they are difficult to manufacture on Earth without a lot of defects—we can make only small wafers of them here. The situation might be different, however, in space, where the absence of several gravity-based phenomena should enable us to grow larger, more uniform crystals and other materials faster.

Here on Earth gravity limits the physics we rely on to construct semiconductors and other materials. Making materials without gravity offers a kind of freedom. To understand the difference, consider a cup of Turkish coffee on Earth. After gravity drags the fine coffee grounds to the bottom of the cup, you can drink your unclouded coffee from the top. But in the microgravity of space, Turkish coffee grounds would float evenly throughout the cup, and an astronaut taking a sip would end up with a mouthful of fine particles. Inconvenient for drinking coffee, sure, but beneficial for other purposes. When substances are suspended evenly within a fluid, as they are in space, we can engineer materials with more uniform properties and do so at a faster pace.

Another limiting factor on Earth, buoyancy, is absent in microgravity. Here air bubbles and other substances lighter than water float up through the liquid. When you synthesize a material on the ground, buoyancy can stop two substances from mixing evenly. But in microgravity, an air bubble weighs the same as water and won't rise to the surface, so the water and air mix better.

Thermal convection—the movement of particles in a fluid or gas caused by temperature changes, which can disrupt material synthesis and harm the quality of the end product—is yet another process that doesn't occur in microgravity. As a result, materials made in microgravity without convection show fewer imperfections.

I first became interested in growing materials in orbit about five years ago, when I was invited to a workshop to discuss nanomaterials fabrication in space. I didn't have much expertise in the topic, but the event piqued my interest. After the workshop, there was a call for proposals to manufacture materials on the International Space Station (ISS), and I jumped at the chance. The opportunity was a joint solicitation by the National Science Foundation and the Center for the Advancement of Science in Space (CASIS), which manages the space station and research conducted there.

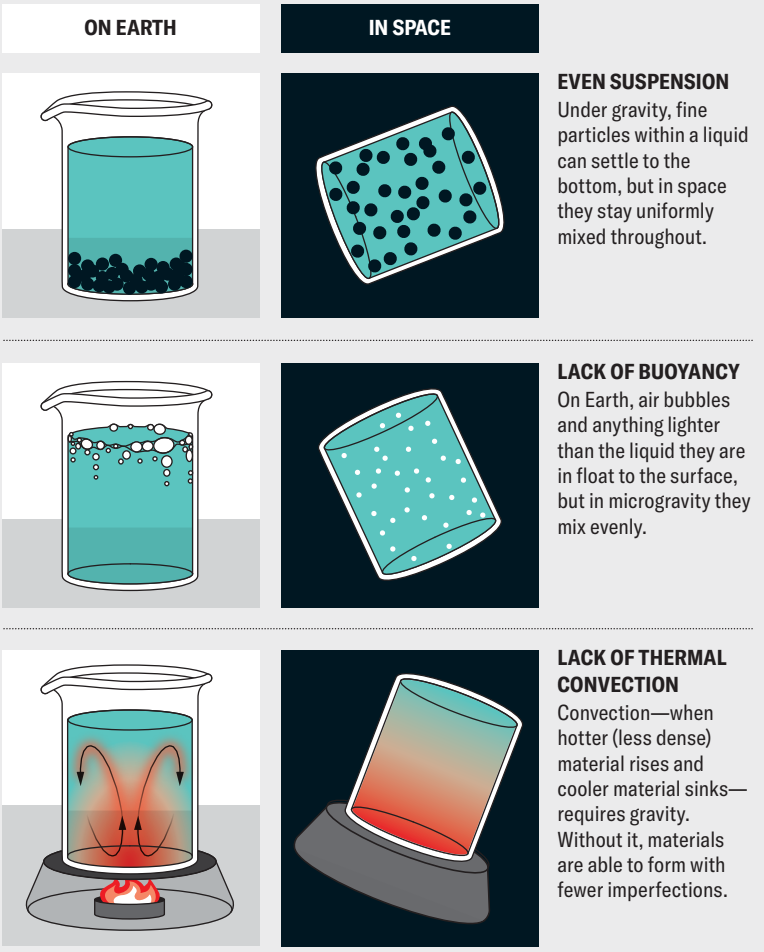
Up to that point I'd known how to make things only on Earth. Getting up to speed felt like a return to my graduate student years. For several days I stayed up all night reading papers about past work on the space station. The more I learned, the more excited I got about manufacturing in microgravity. It was like a lightbulb turned on in my mind—I knew microgravity was the new frontier for semiconductors and materials science.

Not only could materials made in space be superior to those made on Earth, but they also could be preferable for eventual use in space: making them there is certainly more convenient than building everything on Earth and schlepping it up on a rocket. When one of the ISS crew members lost a wrench somewhere on the spacecraft in 2014, for instance, engineers uploaded the first 3-D-printer design to space and built the astronaut a replacement wrench right there.

When I started studying this subject, I had no clue that NASA scientists had already made semiconductor crystals in space. In 1992 NASA launched the first U.S. Microgravity Laboratory onboard the space shuttle *Columbia,* and there astronauts produced two crystals of a material called gallium arsenide. More recently, scientists have made fiber-optic cable materials in space that can transmit lasers and Internet signals with enhanced clarity. After getting up to speed, I devoted myself to designing my own experiment for space. One of the challenges was figuring out what tools I had access to on the station. Making semiconductor crystals or materials often requires high temperatures, which can be dangerous. Most of the equipment on the ISS is tailored for biology experiments that run at cooler, safer temperatures. Luckily for me

Benefits of Microgravity

Space offers a chance to manufacture new materials or crystals without the downward pull of gravity. For instance, without the effects of sedimentation, buoyancy and convection, new materials can grow larger faster and without the kind of defects that often arise on Earth.



Graphic by Jen Christiansen

People in the semiconductor industry should start seriously considering mass-producing their products in space.

and my team, there is a small machine onboard called the SUBSA (Solidification Using a Baffle in Sealed Ampoules), akin to a furnace that you would see in a semiconducting clean room. It can reach 850 degrees C—plenty hot for our purposes.

My collaborators and I came up with the idea to grow a type of nanomaterial, a graphene aerogel, in the SUBSA furnace, and we won the NSF-CASIS award.

We triumphantly launched our experiment to the ISS onboard the Northrop Grumman NG-19 rocket on August 1. We sent a small autoclave—a machine that creates elevated temperatures and pressures—filled with water and flakes of graphene oxide, which we use as a starting ingredient. After it arrived, astronauts loaded the autoclave into the SUBSA furnace and turned the heat up to 180 degrees C. During this process the contents were converted into graphene hydrogel—basically a mixture of graphene and water. These samples are now back on the ground, having returned on September 4 via SpaceX's Crew-6 mission. It's exciting to think that our experimental products reentered Earth's atmosphere alongside four astronauts. Now we plan to dry the samples out to change the hydrogel into an aerogel, in which the water is replaced by air.

Graphene—a one-atom-thick sheet of carbon bonded in a hexagonal structure—is stronger than steel and is electrically conductive. When it's in the form of graphene aerogel, it's a bit spongy and has properties that could make it useful for lots of applications: thermal insulation, energy storage in batteries, environmental protection materials, sensing materials, and more.

When we make graphene aerogel in my XLab here on Earth, gravity can disrupt the way sheets link together during the process of becoming a gel. Plus, the material is prone to sedimentation. Graphene flakes can sink to the bottom of our container like the Turkish coffee grounds. This imbalance can lead to aerogels with less uniform conductivity, creating hotspots and failures.

But my students and I expect that on the ISS the flakes will float freely. We predict that we'll end up with a more even structure and uniform properties when sedimentation and buoyancy forces aren't in play. The end product might be able to insulate heat more uniformly across an area, for instance. In addition, our aerogel could serve as an electrode that has a more regular density of current, eliminating hotspots. We expect that batteries designed with this space material would run more reliably. Common metal electrodes suffer from swelling when they go through charge-discharge cycles; they fracture and break. Spongelike graphene aerogel reduces those potential breakages.

Now that we have our payload back from space, we'll look at the structure of the aerogel that we produced. We'll measure its mechanical, thermal and electrical properties and compare them with the properties of aerogels made on the ground. I'm curious about whether we'll see interesting shapes form in the microphysical structure of the space-grown aerogel, for example. When I zoom in on a conventional graphene aerogel with a scanning electron microscope, the structure looks very porous and tortuous, and the sheets are randomly bound together. I wonder whether we're going to see a more periodic structure, something more repeatable, in the sample made in microgravity.

If these space-made aerogels do grow more evenly and perform better than their terrestrially produced counterparts, they could be the building blocks of sensors, batteries and thermal insulation for future spacecraft.

Our experiment on the ISS is just a beginning. We hope it will help show that we can make superior materials in microgravity. Next we'll grow more types of materials that prove challenging or impossible to synthesize here. Our latest research program is focused on growing metal organic framework crystals in prolonged microgravity. In addition to discovering new materials, we'll also need to increase the size of our experiments and integrate the materials we make into actual products to be used on Earth. The diameter of the container we sent to the space station measures a mere five millimeters. If we want to produce larger materials for practical purposes, we'll eventually have to move beyond the ISS to a station dedicated for production, such as one of the free-flying commercial space stations being planned for the late 2020s.

I'm surprised more people aren't more excited about this potential. People in the semiconductor industry should start seriously considering mass-producing their products in space. They currently must toss out lots of material that contains defects. Without this waste they could possibly cover the cost of building factories in orbit. We could see semiconductors mass-produced with higher performance, reliability and scalability than we can achieve on Earth.

With the growth of the commercial space industry, we're soon going to see more frequent missions and more human activity in orbit. Industry should plan to piggyback on that ride. Factories in space may sound like science fiction, but I believe they should be a part of our everyday life. I'm thrilled that the work coming out of my lab will help move us toward that dream. ●

FROM OUR ARCHIVES

The Exoplanet Next Door. M. Darby Dyar, Suzanne E. Smrekar and Stephen R. Kane; February 2019. ScientificAmerican.com/magazine/sa

Three samples of metal organic framework crystals are about to undergo scanning electron miscoscopy. Senesky and her team plan to grow these materials in orbit.

Aboriginal elders locate landmarks at Da Ayimeli. The culturally significant site is near Wadeye, a town close to Australia's northern coast.

HOW GRAMMAR CHANGES PERCEPTION

An Australian Aboriginal language provides unexpected insight

BY CHRISTINE KENNEALLY

PHOTOGRAPHS BY DAVID MAURICE SMITH

IN THE EARLY 20TH century linguist Benjamin Lee Whorf thrilled his contemporaries by noting that the Hopi language, spoken by Native American people in what is now Arizona, had no words or grammatical elements to represent time. Whorf argued that this meant Hopi speakers had no concept of time and experienced what an English speaker might call "the passage of time" in a completely different way. This bold idea challenged the prevailing notion that there was a correct way to see the world—a way that lined up with the concepts already embedded in the languages of Western scholarship.

As it turns out, Hopi has quite a complex system for describing time, and those who speak it are perfectly capable of thinking about time in all kinds of ways, as indeed are all humans. In light of this realization, modern linguists assumed that even if the fundamental structures of language may differ—and even if languages specify things such as gender, number, direction and relative time in diverse ways—everyone must perceive the world in the same basic way.

Work on Australian Aboriginal languages has complicated that view, most recently in a groundbreaking study of Murrinhpatha. Spoken by most residents of Wadeye, a town of 2,500 people on Australia's northwestern coast, the language has many fascinating characteristics. Action, participants, ownership and intention may be expressed with a single word. This quality, which linguists describe as "polysynthetic," means that many affixes may attach to a verb—and with each additional affix another layer of story accrues. The meaning conveyed by such a word contains actors and acting entwined into a complex whole. For example, the single word *mengankumayerlurlngimekardi* means "he was going through our bags stealing from us."

Murrinhpatha also has free word order, which means subjects, verbs and objects can and do occur in any position in a sentence. In practice, this means the two-year-olds of Wadeye learn how to wield massively complex words that bear little relation to the content of a typical English-language book of ABCs.

Recently Rachel Nordlinger, a linguist at the University of Melbourne who has studied Murrinhpatha for 18 years, and her colleagues conducted the first psycholinguistic experiment in the language. Significantly, they found that when people are putting their thoughts into words, their mental processes may be shaped by the structure of their language.

FROM THE LATE 1950S onward one of the most important observations in modern linguistics was that any child can learn any language. It followed that all children must have the same mental equipment for acquiring language. In 2009 psycholinguist Anne Cutler observed that, in part because of this truism, researchers assumed the systems for adult language processing were also the same and would yield similar results across studies no matter what language they used to test them. Language-processing experiments were written up, replicated and discussed with no consideration of the fact that the different languages used may have had some effect on the findings. It wasn't that language diversity was entirely invisible, Cutler noted, but that the research objective was to unearth a universal system that all humans used.

Over time that view became less tenable, in part because of Cutler's contributions. One of her findings was that listeners segment a speech stream based on the cadence of their first language. French speakers segment a speech stream into syllables, whereas English speakers segment it by stress placement.

Field linguists, whose work brings them regularly into contact with the stunning diversity of the world's languages, also have long doubted the idea that a person's native language has no impact on their thought processes. And more recently, many researchers have been troubled by the fact that most work on universal properties of language and language processing has been carried out using English and a few other familiar languages—a group that probably represents less than 5 percent of the world's language diversity. "The focus was on finding universals and explaining away the differences," says psycholinguist Evan Kidd, one of Nordlinger's co-experimenters. "But the search for universals took place in only one corner of the language universe."

Australian languages are among the least explored

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Day breaks at Wadeye, an Australian Aboriginal community where people speak Murrinhpatha, one of the world's most intriguing languages.

by psycholinguists—a major gap given the size of the language family. Just 200 years ago at least 300 languages were spoken by people in Australia. Of that enormous group of languages, most belonged to the Pama-Nyungan family, with dozens of branches that descended from a protolanguage probably spoken 6,000 years ago in the northeastern part of the continent. Since colonization began in Australia in 1788, the number of Aboriginal languages still spoken in Indigenous homes in the country has been roughly halved. Of those remaining, only 13 are learned as a first language by children. Murrinhpatha, part of the relatively small group of non-Pama-Nyungan languages, is one of these 13—forming an unbroken thread of dynamic cultural inheritance that extends back many thousands of years. The language's survival is nothing short of astonishing.

Wadeye was first established as a mission in 1935, and many local Indigenous people there experienced forced assimilation. Children were taken from their families and incarcerated in a boarding school, where they were punished, sometimes sadistically, if they spoke their language. In many places where people experienced similar abuse, the local languages did not survive.

Moreover, the Wadeye mission brought together Indigenous Australians from 10 other language groups, but those languages did not survive in the same way. Now only a few elderly speakers who know them remain. But the children in Wadeye, Nordlinger says, speak Murrinhpatha. She once asked an elder, her friend and language consultant, how it was that despite the cruelty of the missions and the punishment by the nuns, her people still spoke Murrinhpatha. "We just used to whisper," the woman replied.

Margaret Perdjert, 61, and Stephen Bunduck, 41, elders and residents of Wadeye, learned Murrinhpatha from their elders and later learned English in school. As speakers of both languages, they find that the two have different uses. English is good for talking to outsiders, and it helps kids in the community find good jobs. But their culture and their worldview are completely embedded inside Murrinhpatha, and, they add, the language is vital for their community. In fact, the number of Murrinhpatha speakers who learn it as a first language is growing. It has become the lingua franca of many local Indigenous groups, all with distinctly different language histories.

Nordlinger, who has been working with Murrinhpatha since 2005 but says she speaks it like a three-year-old, long suspected that understanding the demands the language puts on its learners could open windows on human thought. As director of the University of Melbourne's Research Unit for Indigenous Language, she leads the biggest team of researchers devoted to both studying Australian languages and

Margaret Perdjert (*left*), at home in Wadeye, is an elder and guardian of the community's lands and traditions. Bridget and Marita Perdjert (*right*) are her granddaughters.

supporting Indigenous speakers in their language goals. For Nordlinger, each language represents a unique expression of the human experience and contains irreplaceable knowledge about the planet and people, holding within it the traces of thousands of speakers past. Each language also presents an opportunity to explore the dynamic interplay between a speaker's mind and the structures of language.

In 2015 Nordlinger and Kidd attended a talk about using eye-tracking technology in language experiments, presented by psycholinguist Stephen C. Levinson, now director emeritus of language and cognition at the Max Planck Institute for Psycholinguistics in the Netherlands. The studies Levinson described demonstrated a clear relation between the grammar of a participant's language—specifically, the way words were ordered in it—and the way the person assessed a picture. For example, with a picture of a woman washing a child, English speakers, who perceived the woman as the subject, tended to look at the woman first. "The thinking," Nordlinger says, "is that English speakers zoom in on the thing that they will express as their subject." So English-speaking participants focused on the woman and started speaking. Then they looked at the rest of the picture and finished the sentence. "This all happens in milliseconds," Nordlinger says.

Tseltal speakers did it differently. The grammar of Tseltal, spoken in Chiapas, Mexico, obliges speakers to produce a verb first. So when a group from Levinson's laboratory used eye tracking to understand sentence planning and production in Tseltal, the researchers found that speakers viewed the woman and the child more evenly, looking back and forth between the two. Psycholinguists call this relational encoding. "It makes sense," Nordlinger says. "If you have to produce the verb first, you have to look across the picture, work out what's going on and assess it."

At the talk Nordlinger asked Levinson what would happen if participants spoke a language with free word order. "We have no idea," Levinson said. Kidd, who was sitting next to Nordlinger, whispered, "We should do that!"

The obvious candidate was Murrinhpatha, which Nordlinger had been studying for a decade. But it took some planning to take a lab-based experimental method that closely tracks participants' utterances and eye movements and apply it to a language that had never been studied in that way before.

Finding a quiet space in Wadeye was step one. The first time Nordlinger ran the experiment she used a room in what is now a museum, although it was once a morgue. On other trips Nordlinger and Kidd used

their rented lodgings in the town's old nurses' quarters—three units made from gray breeze-block, joined together. They used many of the same pictures as Levinson, adapting some to make more contextual sense: replacing deer with kangaroos, giving some people darker skin, and taking out anomalous objects such as a horse and a carriage.

The researchers also worried about how the conditions of the experiment might affect the outcomes. Murrinhpatha has free word order, but Nordlinger and Kidd didn't know whether certain situations—such as being asked to sit in a room and look at a series of pictures—might induce people to put the same elements in the same order. They kept their instructions minimal so as not to cue people to use one order over another, and they ran the study with 46 Murrinhpatha speakers.

The experimenters showed pictures of an event—a woman washing a child, a crocodile about to bite a man, a kangaroo punching a cow—on a laptop screen and asked the participants to describe what they saw. Before each picture appeared, the speakers were asked to look at a black dot that appeared randomly in the center or to one side of the screen so they wouldn't be inadvertently focused on any character. Then a short tone played, and the picture appeared. As participants assessed the scene and spoke, an infrared tracker that sat below the screen recorded their eye movements.

The results were stunning. The Murrinhpatha speakers did something completely new. It was like Tseltal, Nordlinger says, in that the speakers were looking evenly across both characters in a scene, but the Murrinhpatha speakers were doing it much faster and much earlier. It was very rapid relational encoding. "What's amazing," Nordlinger says, "is that they were doing so much in the first 600 milliseconds."

In that initial window the Murrinhpatha speakers were looking evenly back and forth across both characters in the scene, getting a sense of the entire event. Then, once they had decided which word order they were going to use, they started to look primarily at the character they mentioned first. At that point a person who produced a sentence that started with, say, the woman instead of the child spent more time looking at the woman. If instead they produced a sentence that started with the child, they spent more time looking at the child. Essentially, Nordlinger explains, "what a speaker looked at first in a sustained way after the initial 400-millisecond window was the thing that they mentioned first."

The outcome was not a matter of a speaker simply mentioning the first thing their eye fell on. Sometimes speakers first looked at one of the figures in the picture

but then spent sustained time looking at the other figure—and it was the second figure who featured as the first element of their sentence.

The researchers also found that every individual Murrinhpatha speaker had, on average, more than five and a half different ways of ordering the subject, verb and object of a sentence. Nordlinger had always argued that many Australian languages had free word order, unlike other languages. German, she says, is often described as having free word order, but when the same experiment was run in German by another researcher, speakers used the same order more than 75 percent of the time. For the Murrinhpatha speakers, word order was truly free. Across the entire set of possible responses, the Murrinhpatha speakers produced 10 possible word orders. There was no preferred order.

For example, in response to a picture of a falling man whose outstretched leg projects toward the gaping jaws of a crocodile—a picture where, essentially, a crocodile is about to bite a man—Murrinhpatha speakers offered the following sentences:

Ku kanarnturturt	**baleledha**	**kardu**
Crocodile	might bite	person
Ku kanarnturturt	**kardu one**	**balele**
Crocodile	one person	will bite
Kardu nugarn	**ku kanarnturturt-re**	**baleledha**
Man	crocodile	might bite
Kardu kigay	**bangamlele**	**ku kanarnturturt-re**
Young man	bit	crocodile
Ku kanarnturturt	**bamlele**	
Crocodile	bit	

Why did Murrinhpatha speakers bounce back and forth between subject and object faster than the speakers of any other language? Nordlinger and Kidd suspect that when someone speaks a language that has a truly free word order, they are under pressure to swiftly make decisions about the sentence they will say. "You have to get your head around the whole event much earlier so that you can decide how you want to express it," Nordlinger says.

Did Murrinhpatha's polysynthetic verb structure affect the pattern of language processing? To answer this question, Sasha Wilmoth, who was then one of Nordlinger's Ph.D. students, ran the experiment with speakers of Pitjantjatjara. The language is spoken by people in the Anangu Pitjantjatjara Yankunytjatjara lands, where South Australia abuts the Northern Territory. Pitjantjatjara also has free word order, but unlike Murrinhpatha, the language is not polysynthetic. Excitingly, Wilmoth got the same results.

The Pitjantjatjara speakers spent the first 600 milli-

At a “smoke ceremony” at Da Ayimeli, community members ritually burn the clothes of a deceased person to set their spirit free. The event also features music, dancing and feasting.

seconds rapidly shifting back and forth between the two characters in the depicted scene and then started to focus primarily on the character that became the first element of their sentence. And like the Murrinhpatha speakers, the Pitjantjatjara speakers used a range of word orders, with each individual speaker using multiple word orders across the collection of pictures and the entire group using all the possibilities.

All human brains are of course the same, Nordlinger emphasized. But when people are putting thoughts into words, their mental processes may be different, depending on the language they are using.

TO BE FAIR to Whorf, even if his claims about Hopi were incorrect, there was significant merit in the questions he posed. Nordlinger and her colleagues focused on the impact of free word order at a critical moment in forming a sentence. Yet sentence structure is only one aspect of the complex, multipart system that is language. The question of how much language may influence thought should in fact be many questions.

Gary Lupyan, a psychology professor at the University of Wisconsin–Madison, says that words can organize the way we think about the world and shape the way we perceive it. In a recent experiment, he and his colleagues measured how hard it was for English speakers to assign circles colored in diverse ways to a random category (such as "A" or "B") if the colors were easy to name (for instance, "red" or "blue") or hard to name ("slightly neutral lavender" or "light dusty rose"). All the colors, regardless of how nameable they were in English, were equally easy to discriminate visually from one another. Even so, Lupyan and his colleagues found strong differences in participants' ability to learn which circles went into the different categories based on how easily nameable the colors were.

The vocabularies of languages are "systems of categories," Lupyan explains. "Language entrains us into these systems, one set of categories versus another." For speakers of different languages, he says, "many of these categories then become entrenched as basic units of thought." With Lera Boroditsky of the University of California, San Diego, a cognitive scientist who has long pursued these questions, Lupyan and others recently surveyed a large set of studies on the effects of language on visual perception. They found compelling evidence that language influences our ability to discriminate colors.

For Murrinhpatha, beyond the window that Nordlinger, Kidd and their colleagues have opened on how the language is produced, we cannot say without rig-

orous research how individual speakers' perception might be further shaped by their language. Yet we can clearly see, Nordlinger says, that over time the culture has shaped the structure of the language. "Kinship has central importance in Murrinhpatha culture, and we see that encoded in the grammatical structure," she explains. "When you're talking about a group of people in Murrinhpatha, you have to inflect the verb according to whether the people are related as siblings or not."

Similarly, Murrinhpatha divides all nouns into 10 different classes. Nordlinger asks her students what 10 categories they would use if they were going to divide up all the objects in their language. (English doesn't have categories of nouns that are grammatically differentiated.) The Murrinhpatha noun classes are: familiar humans; all other animate beings; vegetables and other plant-based foods; language and knowledge; water; place and time; spears (used for hunting and ceremonies); weapons; inanimate things; and fire. Things become grammatical, Nordlinger notes, when people talk about them a lot.

Culture shapes language because what matters to a culture often becomes embedded in its language, sometimes as words and sometimes codified in its grammar. Yet it is also true that in varying ways a language may shape the attention and thoughts of its speakers. Language and culture form a feedback loop, or rather they form many, many feedback loops.

At one level, of course, we already understand this reasoning. Over the minutes and days of our lives, we see how perception and judgment and words wind together and influence one another. But as Nordlinger, Lupyan and their colleagues show, some of those loops form tight millisecond whorls that tie together our instantaneous perception of the world and our habitual way of framing it in words. There are much larger interconnected loops, too, that bind speakers throughout history. The things distant generations discussed may shape the structure of a speaker's language today, and that in turn may influence at the micro level how that speaker assesses the world and produces words to describe it.

To Perdjert, the language comes first—because that is how she and other elders pass on sacred knowledge to their young people. But language, culture and knowledge are actually forever entwined and integral to one another. Murrinhpatha, she and Bunduck explain to me, is translated as "*Murrinh,*" meaning "language," and "*patha,*" meaning "good": good language. "Strong language," Perdjert says.

What's clear now is that the more we ask empirical

Tradition and language remain strong in Wadeye, despite great odds. People travel (*left*) to Da Ayimeli for a smoke ceremony. At Our Lady of the Sacred Heart Thamarrurr Catholic College in Wadeye, elder Dominica Walbinthith Lantjin teaches Murrinhpatha (*right*).

As the day ends, children play outside a home in Wadeye.

questions about language and its many loops in *all* the world's languages, the more we will know about the diverse ways there are to think like a human.

Even as researchers devise ways to explore all the corners of the language universe, it is shrinking at a frightening rate. The Language Conservancy, a nonprofit organization founded by Indigenous educators and activists in the U.S., estimates that 61 percent of languages around the world that were spoken as a first language in 1795 "are doomed or extinct." Early in Nordlinger's career, when she worked with a community that spoke Wambaya, another non-Pama-Nyungan language used in the Barkly Tablelands of Australia's Northern Territory, the elders requested that the work be done so younger generations would have a chance to learn the language of their ancestors. At the time there were eight or 10 fluent speakers remaining. All have since died.

A deeper understanding of Murrinhpatha may help here, too. As with other Australian language communities, there are many Indigenous-guided efforts to maintain the language. Linguists and educators, including Nordlinger, work with the people of Wadeye to support their learning goals and to contribute to a constantly evolving understanding of the language.

Scholars at the Research Unit for Indigenous Language have studied how children first acquire Murrinhpatha, with a view to informing how the language is taught in school. They have worked with Perdjert and other elders to run Murrinhpatha literacy programs in a Darwin prison and have explored how children tell stories in Murrinhpatha. They have tracked how the language has changed over three generations, finding that its grammar has not been influenced by English, although—as all languages do—it has changed in that time. The Literature Production Center at the Wadeye community school works with locals to produce bilingual curriculum materials to support children's Murrinhpatha literacy as much as their English literacy. Being able to read and write Murrinhpatha as well as speak it gives the children confidence, Perdjert says.

But even before the children get to school, Perdjert and Bunduck explain, elders take them out to the bush and sit with them around a fire to "teach them in language." They describe the natural world and tell stories from the dreaming about the beings that created their world. Bunduck also teaches the songlines, stories in ceremonial song that include sacred sites and the routes ancient beings took across the land. When Bunduck learned the songlines from his grandparents, it was a gift they gave him, he says. Now he passes on the songlines to youths in the next generation, giving that gift to them. ●

FROM OUR ARCHIVES

How Language Shapes Thought. Lera Boroditsky; February 2011. ScientificAmerican.com/magazine/sa

BIODIVERSITY

The Endangered Species Act requires that every U.S. plant and animal be saved from extinction, but after 50 years, we have to do much more to prevent a biodiversity crisis BY ROBERT KUNZIG

Can We

Protect Every Species?

Snail Darter
Percina tanasi
Listed as Endangered: 1975
Status: Delisted in 2022

A **BALD EAGLE DISAPPEARED** into the trees on the far bank of the Tennessee River just as the two researchers at the bow of our modest motorboat began hauling in the trawl net. Eagles have rebounded so well that it's unusual *not* to see one here these days, Warren Stiles of the U.S. Fish and Wildlife Service told me as the net got closer. On an almost cloudless spring morning in the 50th year of the Endangered Species Act, only a third of a mile downstream from the Tennessee Valley Authority's big Nickajack Dam, we were searching for one of the ESA's more notorious beneficiaries: the Snail Darter. A few months earlier Stiles and the FWS had decided that, like the Bald Eagle, the little fish no longer belonged on the ESA's endangered species list. We were hoping to catch the first nonendangered specimen.

Dave Matthews, a TVA biologist, helped Stiles empty the trawl. Bits of wood and rock spilled onto the deck, along with a Common Logperch maybe six inches long. So did an even smaller fish; a hair over two inches, it had alternating vertical bands of dark and light brown, each flecked with the other color, a pattern that would have made it hard to see against the gravelly river bottom. It was a Snail Darter in its second year, Matthews said, not yet full-grown.

Everybody loves a Bald Eagle. There is much less consensus about the Snail Darter. Yet it epitomizes the main controversy still swirling around the ESA, signed into law on December 28, 1973, by President Richard Nixon: Can we save all the obscure species of this world, and should we even try, if they get in the way of human imperatives? The TVA didn't think so in the 1970s, when the plight of the Snail Darter—an early entry on the endangered species list—temporarily stopped the agency from completing a huge dam. When the U.S. attorney general argued the TVA's case before the Supreme Court with the aim of sidestepping the law, he waved a jar that held a dead, preserved Snail Darter in front of the nine judges in black robes, seeking to convey its insignificance.

Now I was looking at a living specimen. It darted around the bottom of a white bucket, bonking its nose against the side and delicately fluttering the translucent fins that swept back toward its tail.

"It's kind of cute," I said.

Matthews laughed and slapped me on the shoulder. "I like this guy!" he said. "Most people are like, 'Really? That's it?' " He took a picture of the fish and clipped a sliver off its tail fin for DNA analysis but left it otherwise unharmed. Then he had me pour it back into the river. The next trawl, a few miles downstream, brought up seven more specimens.

In the late 1970s the Snail Darter seemed confined to a single stretch of a single tributary of the Tennessee River, the Little Tennessee, and to be doomed by the TVA's ill-considered Tellico Dam, which was being built on the tributary. The first step on its twisting path to recovery came in 1978, when the U.S. Supreme Court ruled, surprisingly, that the ESA gave the darter priority even over an almost finished dam. "It was when the government stood up and said, 'Every species matters, and we meant it when we said we're going to protect every species under the Endangered Species Act,'" says Tierra Curry, a senior scientist at the Center for Biological Diversity.

Today the Snail Darter can be found along 400 miles of the river's main stem and multiple tributaries. ESA enforcement has saved dozens of other species from extinction. Bald Eagles, American Alligators and Peregrine Falcons are just a few of the roughly 60 species that had recovered enough to be "delisted" by late 2023.

And yet the U.S., like the planet as a whole, faces a growing biodiversity crisis. Less than 6 percent of the animals and plants ever placed on the list have been delisted; many of the rest have made scant progress toward recovery. What's more, the list is far from complete: roughly a third of all vertebrates and vascular plants in the U.S. are vulnerable to extinction, says Bruce Stein, chief scientist at the National Wildlife Federation. Populations are falling even for species that aren't yet in dan-

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Bald Eagle
Haliaeetus leucocephalus
Listed as Endangered: 1967
Status: Delisted in 2007

Gopher Tortoise
Gopherus polyphemus
Listed as Threatened: 1987
Status: Still threatened

ger. "There are a third fewer birds flying around now than in the 1970s," Stein says. We're much less likely to see a White-throated Sparrow or a Red-winged Blackbird, for example, even though neither species is yet endangered.

The U.S. is far emptier of wildlife sights and sounds than it was 50 years ago, primarily because habitat—forests, grasslands, rivers—has been relentlessly appropriated for human purposes. The ESA was never designed to stop that trend, any more than it is equipped to deal with the next massive threat to wildlife: climate change. Nevertheless, its many proponents say, it is a powerful, foresightful law that we could implement more wisely and effectively, perhaps especially to foster stewardship among private landowners. And modest new measures, such as the Recovering America's Wildlife Act—a bill with bipartisan support—could further protect flora and fauna.

That is, if special interests don't flout the law. After the 1978 Supreme Court decision, Congress passed a special exemption to the ESA allowing the TVA to complete the Tellico Dam. The Snail Darter managed to survive because the TVA transplanted some of the fish from the Little Tennessee, because remnant populations turned up elsewhere in the Tennessee Valley, and because local rivers and streams slowly became less polluted following the 1972 Clean Water Act, which helped fish rebound.

Under pressure from people enforcing the ESA, the TVA also changed the way it managed its dams throughout the valley. It started aerating the depths of its reservoirs, in some places by injecting oxygen. It began releasing water from the dams more regularly to maintain a minimum flow that sweeps silt off the river bottom, exposing the clean gravel that Snail Darters need to lay their eggs and feed on snails. The river system "is acting more like a real river," Matthews says. Basically, the TVA started considering the needs of wildlife, which is really what the ESA requires. "The Endangered Species Act works," Matthews says. "With just a little bit of help, [wildlife] can recover."

The trouble is that many animals and plants aren't getting that help—because government resources are too limited, because private landowners are alienated by the ESA instead of engaged with it, and because as a nation the U.S. has never fully committed to the ESA's essence. Instead, for half a century, the law has been one more thing that polarizes people's thinking.

IT MAY SEEM impossible today to imagine the political consensus that prevailed on environmental matters in 1973. The U.S. Senate approved the ESA unanimously, and the House passed it by a vote of 390 to 12. "Some people have referred to it as almost a statement of religion coming out of the Congress," says Gary Frazer, who as assistant director for ecological services at the FWS has been overseeing the act's implementation for nearly 25 years.

But loss of faith began five years later with the Snail Darter case. Congresspeople who had been thinking of eagles, bears and Whooping Cranes when they passed the ESA, and had not fully appreciated the reach of the sweeping language they had approved, were disabused by the Supreme Court. It found that the legislation had created, "wisely or not … an absolute duty to preserve all endangered species," Chief Justice Warren E. Burger said after the Snail Darter case concluded. Even a recently discovered tiny fish had to be saved, "whatever the cost," he wrote in the decision.

Was that wise? For both environmentalists such as Curry and many nonenvironmentalists, the answer has always been absolutely. The ESA "is the basic Bill of Rights for species other than ourselves," says *National Geographic* photographer Joel Sartore, who is building a "photo ark" of every animal visible to the naked eye as a record against extinction. (He has taken studio portraits of 15,000 species so far.) But to critics, the Snail Darter decision always defied common sense. They thought it was "crazy," says Michael Bean, a leading ESA expert, now retired from the Environmental Defense Fund. "That dichotomy of view has remained with us for the past 45 years."

According to veteran Washington, D.C., environmental attorney Lowell E. Baier, author of a new history called *The Codex of the Endangered Species Act,* both the act itself and its early implementation reflected a top-down, federal "command-and-control mentality" that still breeds resentment. FWS field agents in the early days often saw themselves as combat biologists enforcing the act's prohibitions. After the Northern Spotted Owl's listing got tangled up in a bitter 1990s conflict over logging of old-growth forests in the Pacific Northwest, the FWS became more flexible in working out arrangements. "But the dark mythology of the first 20 years continues in the minds of much of America," Baier says.

The law can impose real burdens on landowners. Before doing anything that might "harass" or "harm" an endangered species, including modifying its habitat, they need to get a permit from the FWS and present a "habitat conservation plan." Prosecutions aren't common, because evidence can be elusive, but what Bean calls "the cloud of uncertainty" surrounding what landowners can and cannot do can be distressing.

Requirements the ESA places on federal agencies such as the Forest Service and the Bureau of Land Management—or on the TVA—can have large economic impacts. Section 7 of the act prohibits agencies from taking, permitting or funding any action that is likely to "jeopardize the continued existence" of a listed species. If jeopardy seems possible, the agency must consult with the FWS first (or the National Marine Fisheries Service for marine species) and seek alternative plans.

"When people talk about how the ESA stops projects, they've been talking about section 7," says conservation biologist Jacob Malcom. The Northern Spotted Owl is a strong example: an economic analysis suggests the logging restrictions eliminated thousands of timber-industry jobs, fueling conservative arguments that the ESA harms humans and economic growth.

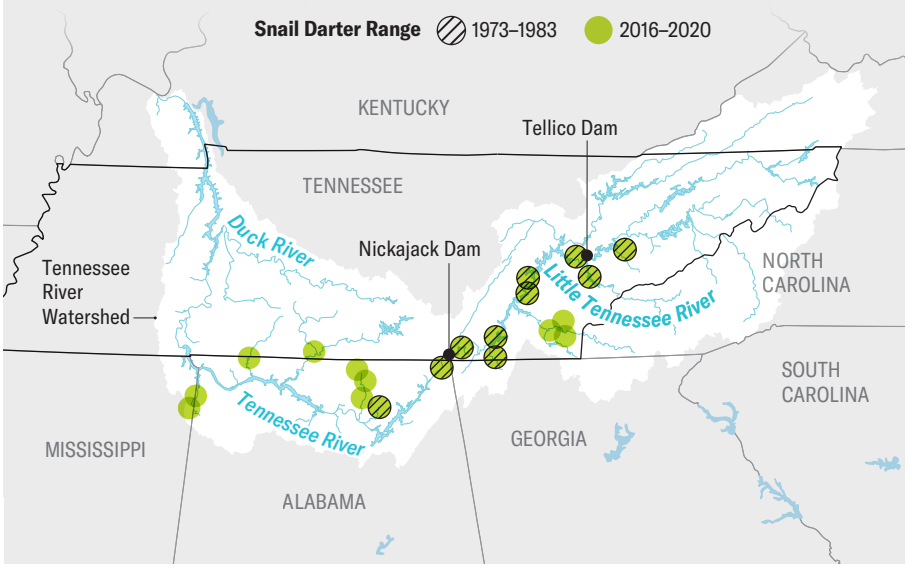
In recent decades, however, that view has been based "on anecdote, not evidence," Malcom claims. At Defenders of Wildlife, where he worked until 2022 (he's now at the U.S. Department of the Interior), he and his colleagues analyzed 88,290 consultations between the FWS and other agencies from 2008 to 2015. "Zero projects were stopped," Malcom says. His group also found that federal agencies were only rarely taking the active measures to recover a species that section 7 requires—like what the TVA did for the Snail Darter. For many listed species, the FWS does not even have recovery plans.

Endangered species also might not recover because "most species are not receiving protection until they have reached dangerously low population sizes," according to a 2022 study by Erich K. Eberhard of Columbia University and his colleagues. Most listings occur only after the FWS has been petitioned or sued by an environmental group—often the Center for Biological Diversity, which claims credit for 742 listings. Years may go by between petition and listing, during which time the species' population dwindles. Noah Greenwald, the center's endangered species director, thinks the FWS avoids listings to avoid controversy—that it has internalized opposition to the ESA.

He and other experts also say that work regarding endangered species is drastically underfunded. As more species are listed, the funding per species declines. "Congress hasn't come to grips with the biodiversity crisis," says Baier, who lobbies lawmakers regularly. "When you talk to them about biodiversity, their eyes glaze over." Just this year federal lawmakers enacted a

Snail Darter, Back in Action

In the 1970s the Snail Darter, a tiny fish, seemed confined to a segment of the Little Tennessee River, right where the huge Tellico Dam was being built. A 1978 U.S. Supreme Court decision upheld the fish's protection under the Endangered Species Act. Relocating the fish while the dam was finished in 1979, and reducing pollution in waterways, helped to expand its range (*black circles*). In the past decade researchers have found the Snail Darter more widely across the Tennessee River watershed (*green circles*); it was taken off the endangered species list in 2022.



Source: David Matthews, Tennessee Valley Authority (*map reference*)

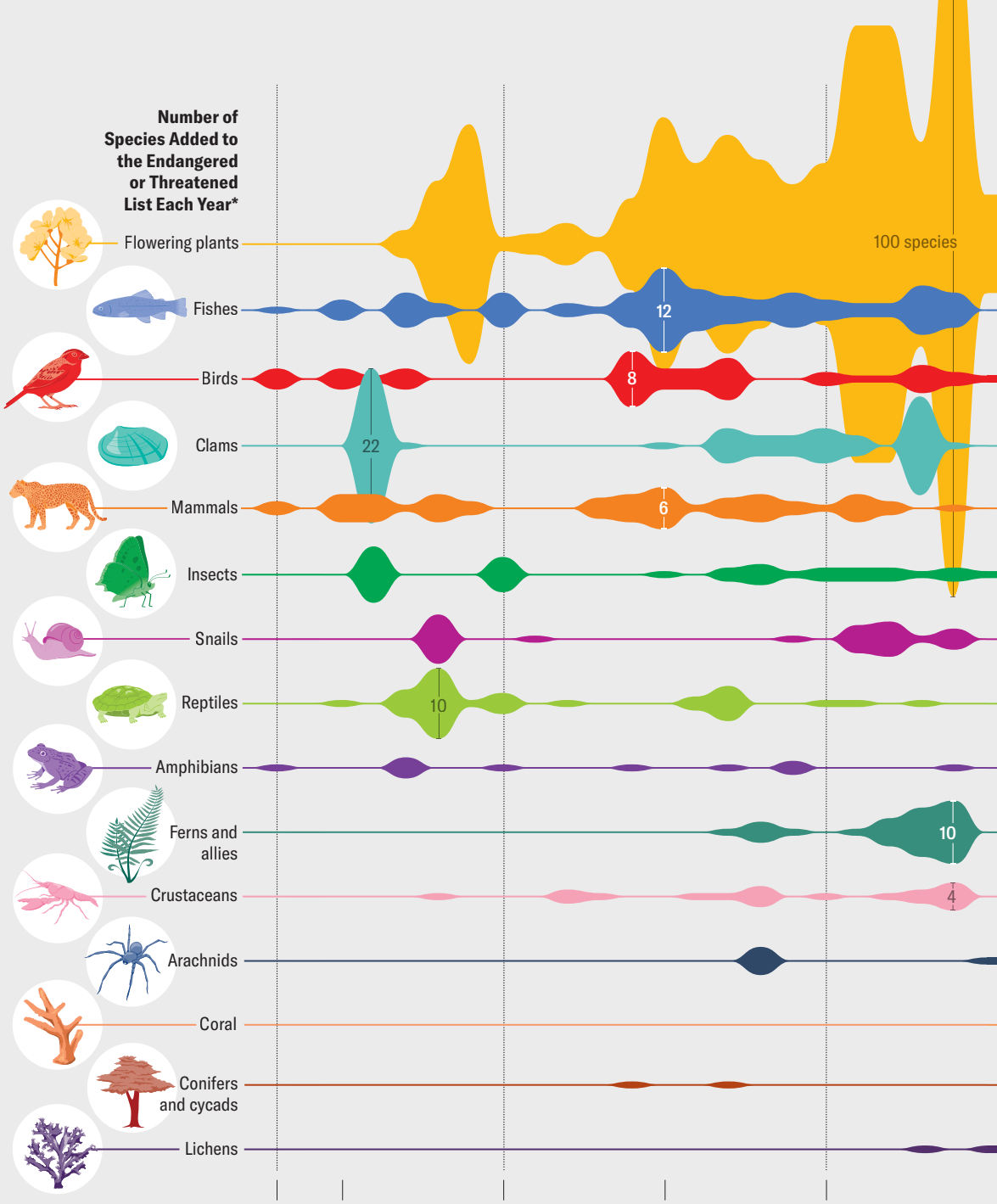
Map by June Minju Kim

50 Years of Protection

Since 1973 the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, under the Endangered Species Act, have listed plants and animals as endangered (susceptible to extinction) or threatened (likely to become endangered). More than 1,600 species had been listed from 1973 to 2022 (*top, colored shapes*). At that time, roughly 90 had been delisted—most because their numbers had recovered, they had gone extinct, or they had been listed erroneously (*bottom, diamonds*).

*The number of species shown as listed or delisted each year includes subspecies and "distinct population segments"—two or more groups of a species that are geographically far apart from one another.

Sources: U.S. Fish & Wildlife Service Environmental Conservation Online System; U.S. Federal Endangered and Threatened Species by Calendar Year *https://ecos.fws.gov/ecp/report/species-listings-by-year-totals (annual data through 2022)*; Listed Species Summary (Boxscore) *https://ecos.fws.gov/ecp/report/boxscore (cumulative data up to September 18, 2023, and annual data for coral)*; Delisted Species *https://ecos.fws.gov/ecp/report/species-delisted (delisted data through 2022)*

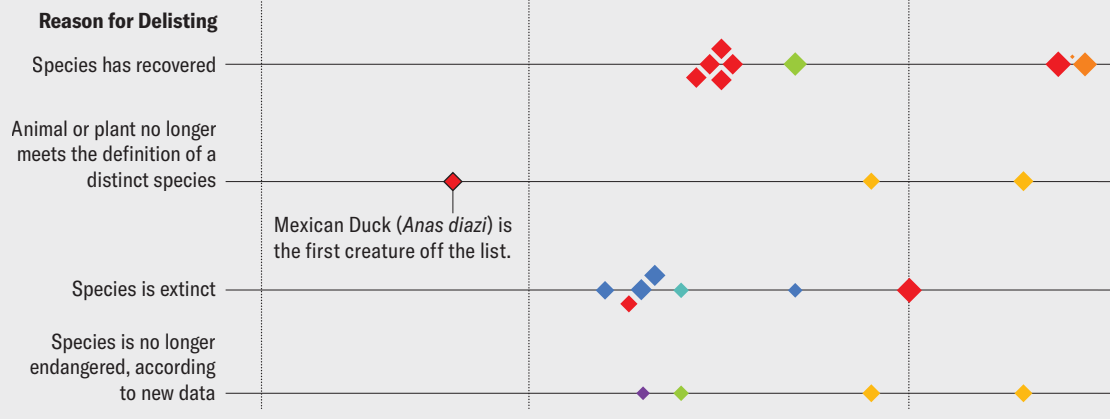


SPECIES REMOVED FROM THE ENDANGERED OR THREATENED LIST*

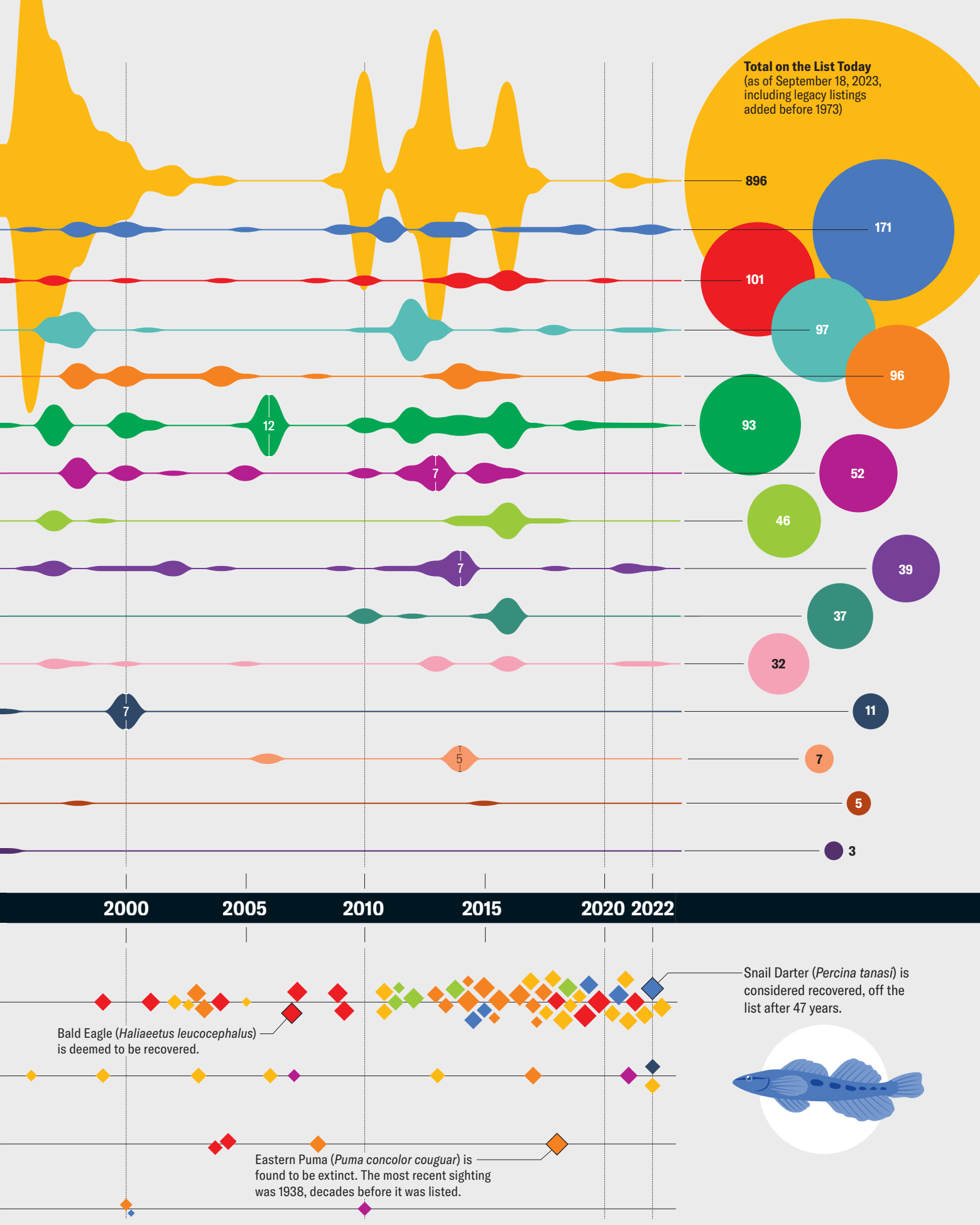
At the end of 2022, some 90 U.S. species had been removed from the Endangered or Threatened lists. Each diamond represents one animal or plant. Diamond size reflects the amount of time the species was listed.

◆ Less than a year

◇ 50 years



Graphic by June Minju Kim, Illustrations by Brown Bird Design



special provision exempting the Mountain Valley Pipeline from the ESA and other challenges, much as Congress had exempted the Tellico Dam. Environmentalists say the gas pipeline, running from West Virginia to Virginia, threatens the Candy Darter, a colorful small fish. The Inflation Reduction Act of 2022 provided a rare bit of good news: it granted the FWS $62.5 million to hire more biologists to prepare recovery plans.

The ESA is often likened to an emergency room for species: overcrowded and understaffed, it has somehow managed to keep patients alive, but it doesn't do much more. The law contains no mandate to restore ecosystems to health even though it recognizes such work as essential for thriving wildlife. "Its goal is to make things better, but its tools are designed to keep things from getting worse," Bean says. Its ability to do even that will be severely tested in coming decades by threats it was never designed to confront.

THE ESA REQUIRES a species to be listed as "threatened" if it might be in danger of extinction in the "foreseeable future." The foreseeable future will be warmer. Rising average temperatures are a problem, but higher heat extremes are a bigger threat, according to a 2020 study.

Scientists have named climate change as the main cause of only a few extinctions worldwide. But experts expect that number to surge. Climate change has been "a factor in almost every species we've listed in at least the past 15 years," Frazer says. Yet scientists struggle to forecast whether individual species can "persist in place or shift in space"—as Stein and his co-authors put it in a recent paper—or will be unable to adapt at all and will go extinct. On June 30 the FWS issued a new rule that will make it easier to move species outside their historical range—a practice it once forbade except in extreme circumstances.

Eventually, though, "climate change is going to swamp the ESA," says J. B. Ruhl, a law professor at Vanderbilt University, who has been writing about the problem for decades. "As more and more species are threatened, I don't know what the agency does with that." To offer a practical answer, in a 2008 paper he urged the FWS to aggressively identify the species most at risk and not waste resources on ones that seem sure to expire.

Yet when I asked Frazer which urgent issues were commanding his attention right now, his first thought wasn't climate; it was renewable energy. "Renewable energy is going to leave a big footprint on the planet and on our country," he says, some of it threatening plants and animals if not implemented well. "The Inflation Reduction Act is going to lead to an explosion of more wind and solar across the landscape."

Long before President Joe Biden signed that landmark law, conflicts were proliferating: Desert Tortoise versus solar farms in the Mojave Desert, Golden Eagles versus wind farms in Wyoming, Tiehm's Buckwheat (a little desert flower) versus lithium mining in Nevada. The mine case is a close parallel to that of Snail Darters versus the Tellico Dam. The flower, listed as endangered just last year, grows on only a few acres of mountainside in western Nevada, right where a mining company wants to extract lithium. The Center for Biological Diversity has led the fight to save it. Elsewhere in Nevada people have used the ESA to stop, for the moment, a proposed geothermal plant that might threaten the two-inch Dixie Valley Toad, discovered in 2017 and also declared endangered last year.

Does an absolute duty to preserve all endangered species make sense in such places? In a recent essay entitled "A Time for Triage," Columbia law professor Michael Gerrard argues that "the environmental community has trade-off denial. We don't recognize that it's too late to preserve everything we consider precious." In his view, given the urgency of building the infrastructure to fight climate change, we need to be willing to let a species go after we've done our best to save it. Environmental lawyers adept at challenging fossil-fuel projects, using the ESA and other statutes, should consider holding their fire against renewable installations. "Just because you have bullets doesn't mean you shoot them in every direction," Gerrard says. "You pick your targets." In the long run, he and others argue, climate change poses a bigger threat to wildlife than wind turbines and solar farms do.

FOR NOW HABITAT LOSS remains the overwhelming threat. What's truly needed to preserve the U.S.'s wondrous biodiversity, both Stein and Ruhl say, is a national network of conserved ecosystems. That won't be built with our present politics. But two more practical initiatives might help.

The first is the Recovering America's Wildlife Act, which narrowly missed passage in 2022 and has been reintroduced this year. It builds on the success of the 1937 Pittman-Robertson Act, which funds state wildlife agencies through a federal excise tax on guns and ammunition. That law was adopted to address a decline in game species that had hunters alarmed. The state refuges and other programs it funded are why deer, ducks and Wild Turkeys are no longer scarce.

The recovery act would provide $1.3 billion a year to states and nearly $100 million to Native American tribes to conserve nongame species. It has bipartisan support, in part, Stein says, because it would help arrest the decline of a species before the ESA's "regulatory hammer" falls. Although it would be a large boost to state wildlife budgets, the funding would be a rounding error in federal spending. But last year Congress couldn't agree on how to pay for the measure. Passage "would be a really big deal for nature," Curry says.

The second initiative that could promote species conservation is already underway: bringing landowners into the fold. Most wildlife habitat east of the Rocky Mountains is on private land. That's also where habitat loss is happening fastest. Some experts say conservation isn't likely to succeed unless the FWS works more collaboratively with landowners, adding carrots to the ESA's regulatory stick. Bean has long promoted the idea, including when he worked at the Interior Department from 2009 to early 2017. The approach started, he says, with the Red-cockaded Woodpecker.

When the ESA was passed, there were fewer than 10,000 Red-cockaded Woodpeckers left of the millions that had once lived in the Southeast. Humans had cut down the old pine trees, chiefly Longleaf Pine, that the birds excavate cavities in for roosting and nesting. An appropriate tree has to be large, at least 60 to 80 years old, and there aren't many like that left. The longleaf forest, which once carpeted up to 90 million acres from Virginia to Texas, has been reduced to less than three million acres of fragments.

In the 1980s the ESA wasn't helping because it provided little incentive to preserve forest on private land. In fact, Bean says, it did the opposite: landowners would sometimes clear-cut potential woodpecker habitat just to avoid the law's constraints. The woodpecker population continued to drop until the 1990s. That's when Bean and his Environmental Defense Fund colleagues persuaded the FWS to adopt

Oyster Mussel
Epioblasma capsaeformis
Listed as Endangered: 1997
Status: Still endangered

"safe-harbor agreements" as a simple solution. An agreement promised landowners that if they let pines grow older or took other woodpecker-friendly measures, they wouldn't be punished; they remained free to decide later to cut the forest back to the baseline condition it had been in when the agreement was signed.

That modest carrot was inducement enough to quiet the chainsaws in some places. "The downward trends have been reversed," Bean says. "In places like South Carolina, where they have literally hundreds of thousands of acres of privately owned forest enrolled, Red-cockaded Woodpecker numbers have shot up dramatically."

The woodpecker is still endangered. It still needs help. Because there aren't enough old pines, land managers are inserting lined, artificial cavities into younger trees and sometimes moving birds into them to expand the population. They are also using prescribed fires or power tools to keep the longleaf understory open and grassy, the way fires set by lightning or Indigenous people once kept it and the way the woodpeckers like it. Most of this work is taking place, and most Red-cockaded Woodpeckers are still living, on state or federal land such as military bases. But a lot more longleaf must be restored to get the birds delisted, which means collaborating with private landowners, who own 80 percent of the habitat.

Leo Miranda-Castro, who retired last December as director of the FWS's southeast region, says the collaborative approach took hold at regional headquarters in Atlanta in 2010. The Center for Biological Diversity had dropped a "mega petition" demanding that the FWS consider 404 new species for listing. The volume would have been "overwhelming," Miranda-Castro says. "That's when we decided, 'Hey, we cannot do this in the traditional way.' The fear of listing so many species was a catalyst" to look for cases where conservation work might make a listing unnecessary.

An agreement affecting the Gopher Tortoise shows what is possible. Like the woodpeckers, it is adapted to open-canopied longleaf forests, where it basks in the sun, feeds on herbaceous plants and digs deep burrows in the sandy soil. The tortoise is a keystone species: more than 300 other animals, including snakes, foxes and skunks, shelter in its burrows. But its numbers have been declining for decades.

Urbanization is the main threat to the tortoises, but timberland can be managed in a way that leaves room for them. Eager to keep the species off the list, timber companies, which own 20 million acres in its range, agreed to figure out how to do that—above all by returning fire to the landscape and keeping the canopy open. One timber company, Resource Management Service, said it would restore Longleaf Pine on about 3,700 acres in the Florida panhandle,

perhaps expanding to 200,000 acres eventually. It even offered to bring other endangered species onto its land, which delighted Miranda-Castro: "I had never heard about that happening before." Last fall the FWS announced that the tortoise didn't need to be listed in most of its range.

Miranda-Castro now directs Conservation Without Conflict, an organization that seeks to foster conversation and negotiation in settings where the ESA has more often generated litigation. "For the first 50 years the stick has been used the most," Miranda-Castro says. "For the next 50 years we're going to be using the carrots way more." On his own farm outside Fort Moore, Ga., he grows Longleaf Pine—and Gopher Tortoises are benefiting.

The Center for Biological Diversity doubts that carrots alone will save the reptile. It points out that the FWS's own models show small subpopulations vanishing over the next few decades and the total population falling by nearly a third. In August 2023 it filed suit against the FWS, demanding the Gopher Tortoise be listed.

The FWS itself resorted to the stick this year when it listed the Lesser Prairie-Chicken, a bird whose grassland home in the Southern Plains has long been encroached on by agriculture and the energy industry. The Senate promptly voted to overturn that listing, but President Biden promised to veto that measure if it passes the House.

BEHIND THE DEBATES over strategy lurks the vexing question: Can we save all species? The answer is no. Extinctions will keep happening. In 2021 the FWS proposed to delist 23 more species—not because they had recovered but because they hadn't been seen in decades and were presumed gone. There is a difference, though, between acknowledging the reality of extinction and deliberately deciding to let a species go. Some people are willing to do the latter; others are not. Bean thinks a person's view has a lot to do with how much they've been exposed to wildlife, especially as a child.

Zygmunt Plater, a professor emeritus at Boston College Law School, was the attorney in the 1978 Snail Darter case, fighting for hundreds of farmers whose land would be submerged by the Tellico Dam. At one point in the proceedings Justice Lewis F. Powell, Jr., asked him, "What purpose is served, if any, by these little darters? Are they used for food?" Plater thinks creatures such as the darter alert us to the threat our actions pose to them and to ourselves. They prompt us to consider alternatives.

The ESA aims to save species, but for that to happen, ecosystems have to be preserved. Protecting the Northern Spotted Owl has saved at least a small fraction of old-growth forest in the Pacific Northwest. Concern about the Red-cockaded Woodpecker and the Gopher Tortoise is aiding the preservation of longleaf forests in the Southeast. The Snail Darter wasn't enough to stop the Tellico Dam, which drowned historic Cherokee sites and 300 farms, mostly for real estate development. But after the controversy, the presence of a couple of endangered mussels did help dissuade the TVA from completing yet another dam, on the Duck River in central Tennessee. That river is now recognized as one of the most biodiverse in North America.

The ESA forced states to take stock of the wildlife they harbored, says Jim Williams, who as a young biologist with the FWS was responsible for listing both the Snail Darter and mussels in the Duck River. Williams grew up in Alabama, where I live. "We didn't know what the hell we had," he says. "People started looking around and found all sorts of new species." Many were mussels and little fish. In a 2002 survey, Stein found that Alabama ranked fifth among U.S. states in species diversity. It also ranks second-highest for extinctions; of the 23 extinct species the FWS recently proposed for delisting, eight were mussels, and seven of those were found in Alabama.

One morning this past spring, at a cabin on the banks of Shoal Creek in northern Alabama, I attended a kind of jamboree of local freshwater biologists. At the center of the action, in the shade of a second-floor deck, sat Sartore. He had come to board more species onto his photo ark, and the biologists—most of them from the TVA—were only too glad to help, fanning out to collect critters to be decanted into Sartore's narrow, flood-lit aquarium. He sat hunched before it, a black cloth draped over his head and camera, snapping away like a fashion photographer, occasionally directing whoever was available to prod whatever animal was in the tank into a more artful pose.

As I watched, he photographed a striated darter that didn't yet have a name, a Yellow Bass, an Orangefin Shiner and a giant crayfish discovered in 2011 in the very creek we were at. Sartore's goal is to help people who never meet such creatures feel the weight of extinction—and to have a worthy remembrance of the animals if they do vanish from Earth.

With TVA biologist Todd Amacker, I walked down to the creek and sat on the bank. Amacker is a mussel specialist, following in Williams's footsteps. As his colleagues waded in the shoals with nets, he gave me a quick primer on mussel reproduction. Their peculiar antics made me care even more about their survival.

There are hundreds of freshwater mussel species, Amacker explained, and almost every one tricks a particular species of fish into raising its larvae. The Wavy-rayed Lampmussel, for example, extrudes part of its flesh in the shape of a minnow to lure black bass—and then squirts larvae into the bass's open mouth so they can latch on to its gills and fatten on its blood. Another mussel dangles its larvae at the end of a yard-long fishing line of mucus. The Duck River Darter Snapper—a member of a genus that has already lost most of its species to extinction—lures and then clamps its shell shut on the head of a hapless fish, inoculating it with larvae. "You can't make this up," Amacker said. Each relationship has evolved over the ages in a particular place.

The small band of biologists who are trying to cultivate the endangered mussels in labs must figure out which fish a particular mussel needs. It's the type of tedious trial-and-error work conservation biologists call "heroic," the kind that helped to save California Condors and Whooping Cranes. Except these mussels are eyeless, brainless, little brown creatures that few people have ever heard of.

For most mussels, conditions are better now than half a century ago, Amacker said. But some are so rare it's hard to imagine they can be saved. I asked Amacker whether it was worth the effort or whether we just need to accept that we must let some species go. The catch in his voice almost made me regret the question.

"I'm not going to tell you it's not worth the effort," he said. "It's more that there's no hope for them." He paused, then collected himself. "Who are we to be the ones responsible for letting a species die?" he went on. "They've been around so long. That's not my answer as a biologist; that's my answer as a human. Who are we to make it happen?" ●

FROM OUR ARCHIVES
Pesticides and the Reproduction of Birds.
David B. Peakall; April 1970.
ScientificAmerican.com/magazine/sa

Whooping Crane
Grus americana
Listed as Endangered: 1967
Status: Still endangered

why we need scary play

PSYCHOLOGY

Monster movies and haunted houses are safe spaces that let us practice coping skills for disturbing real-world challenges

BY ATHENA AKTIPIS AND COLTAN SCRIVNER

At Dystopia Haunted House in Denmark, visitors pay to be terrified by zombies.

CHAIN SAWS ROAR, and spine-chilling screams echo from behind a dense wall of trees. You know you're at a scary attraction in the woods of Denmark called Dystopia Haunted House, yet everything sounds so real. As you walk into the house, you become disoriented in a dark maze filled with strange objects and broken furniture; when you turn a corner, you're confronted by bizarre scenes with evil clowns and terrifying monsters reaching out for you. Then you hear the chain saw revving up, and a masked man bursts through the wall. You scream and start running.

This might sound like the kind of place nobody would ever want to be in, but every year millions of people pay to visit haunts just like Dystopia. They crowd in during Halloween, to be sure, but show up in every other season, too. This paradox of horror's appeal—that people want to have disturbing and upsetting experiences—has long perplexed scholars. We devour tales of psychopathic killers on true crime podcasts, watch movies about horrible monsters, play games filled with ghosts and zombies, and read books that describe apocalyptic worlds packed with our worst fears.

This paradox is now being resolved by research on the science of scary play and morbid curiosity. Our desire to experience fear, it seems, is rooted deep in our evolutionary past and can still benefit us today. Scary play, it turns out, can help us overcome fears and face new challenges—those that surface in our own lives and others that arise in the increasingly disturbing world we all live in.

THE PHENOMENON of scary play surprised Charles Darwin. In *The Descent of Man,* he wrote that he had heard about captive monkeys that, despite their fear of snakes, kept lifting the lid of a box containing the reptiles to peek inside. Intrigued, Darwin turned the story into an experiment: He put a bag with a snake inside it in a cage full of monkeys at the London Zoological Gardens. A monkey would cautiously walk up to the bag, slowly open it, and peer down inside before shrieking and racing away. After seeing one monkey do this, another monkey would carefully walk over to the bag to take a peek, then scream and run. Then another would do the same thing, then another.

The monkeys were "satiating their horror," as Darwin put it. Morbid fascination with danger is widespread in the animal kingdom—it's called predator inspection. The inspection occurs when an animal looks at or even approaches a predator rather than simply fleeing. This behavior occurs across a range of animals, from guppies to gazelles.

At first blush, getting close to danger seems like a bad idea. Why would natural selection have instilled in animals a curiosity about the very things they should be avoiding? But there is an evolutionary logic to these actions. Morbid curiosity is a powerful way for animals to gain information about the most dangerous things in their environment. It also gives them an oppor-

Jacob Pepsø (*preceding pages*)

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Customers at Dystopia are threatened by ghouls that could break past a thin wire barrier at any moment.

Henriette Klausen

tunity to practice dealing with scary experiences.

When you consider that many prey animals live close to their predators, the benefits of morbidly curious behavior such as predator inspection become clear. For example, it's not uncommon for a gazelle to cross paths with a cheetah on the savanna. It might seem like a gazelle should always run when it sees a cheetah. Fleeing, however, is physiologically expensive; if a gazelle ran every time it saw a cheetah, it would exhaust precious calories and lose out on opportunities for other activities that are important to its survival and reproduction.

Consider the perspective of the predator, too. It may seem like a cheetah should chase after a gazelle anytime it sees one. But for a cheetah, it's not easy to just grab a bite; hunting is an energetically costly exercise that doesn't always end in success. As long as the cheetah isn't starving, it should chase a prey animal only when the chances of capturing it are reasonably high.

If it's best for gazelles to run only when the cheetah is hunting, then they benefit if they can identify when a cheetah is hungry. And the only way for a gazelle to learn about cheetahs is by closely observing them when it's relatively safe to do so. For example, if the surrounding grass is short and a cheetah is easily visible, a gazelle feels safer and is more likely to linger a while and watch the cheetah, especially if the gazelle is among a larger group. The age of the gazelle matters, too; adolescents and young adults—those fast enough to escape and without much previous exposure to predators—are the most likely to inspect cheetahs. The trade-off makes sense: these gazelles don't know much about dangerous cats yet, so they have a lot to gain from investigating them. Relative safety and inexperience are two of the most powerful moderators of predator inspection in animals—and of morbid curiosity in humans.

Today people inspect predators through stories and movies. Depictions of predators are found in stories passed along through oral traditions around the world. Leopards, tigers and wolves are frequent antagonists in regional folklore. We also tell stories and see films about monstrous fictional predators such as

A menacing figure looms out of the darkness at Dystopia.

Jacob Papsø

ferocious werewolves, mighty dragons, clever vampires and bloodthirsty ogres.

Indulging in stories about threats is a frighteningly effective and valuable strategy. Such tales let us learn about potential predators or menacing situations that other people have encountered without having to face them ourselves. The exaggerated perils of fictional monsters create strong emotional and behavioral responses, familiarizing us with these reactions for when we have to deal with more down-to-earth dangers.

Children are often the intended audience for scary oral stories because these stories can help them learn about risks early in their lives. Think about the key lines of *Little Red Riding Hood:*

> "Grandmother, what big eyes you have!"
> "All the better to see with, my child."
> "Grandmother, what big teeth you have got!"
> "All the better to eat you up with."

The tale teaches a young audience, in a safe and entertaining way, what wolves look like and what certain parts of a wolf do. The story takes place in the woods, where wolves are typically found. It's scary, but told in a secure space, it delivers a valuable lesson.

Our fascination with things that can harm or kill us is not limited to predators. We also can be morbidly drawn to tales of large-scale frightening situations such as volcanic eruptions, pandemics, dangerous storms and a large variety of apocalyptic events. This is where the magic of a scary story really shines: it's the only way to learn about and rehearse responses to dangers we have yet to face.

MOST PEOPLE WERE FEELING pretty uncertain about the future in 2020. COVID had thrust the world into a global pandemic. Governments were restricting movement, businesses were closing, and the way of living that many were used to was screeching to a halt.

But some of us had seen something like it before. Less than a decade earlier meningoencephalitic virus 1, or MEV-1, was wreaking havoc. It spread with terri-

fying speed and without requiring close contact in subways, elevators and outdoor public spaces. Society's response to MEV-1 foreshadowed what would happen in 2020 with COVID: travel stopped, businesses closed, and people started stockpiling supplies. Some of them began touting dubious miracle cures.

If you don't remember the worldwide devastation of MEV-1, you must not have seen the movie *Contagion,* a 2011 thriller starring Matt Damon, Kate Winslet and Laurence Fishburne. Watching it might have benefited you when COVID spread across the planet. In a study that one of us (Scrivner) conducted in the early months of the pandemic, those who had seen at least one pandemic-themed movie reported feeling much more prepared for the societal surprises that COVID had in store. The stockpiling of supplies, business closures, travel bans and miracle cures were all things fans of *Contagion* had seen before; they had already played with the idea of a global pandemic before the real thing happened.

Learning to regain composure and adapt in the face of surprise and uncertainty seems to be a key evolutionary function of play. Engaging in play that simulates threatening situations helps juvenile mammals such as tiger cubs and wolf pups practice quickly regaining stable movement and emotional composure. Humans do this as well. Call to mind a backyard party where young children squeal with fear and delight as they are chased by a fun-loving parent who threatens, with arms outstretched in monster pose, "I'm gonna get you!" It's all just fun and games, but it's also a chance for the kids to try to maintain their motor control under stress so they don't tumble to the ground, making themselves vulnerable to a predator—or a tickle attack from the parent.

Researchers who study human fun and games have argued that the decline of thrilling, unstructured play over the past few decades has contributed to a rise in childhood anxiety over that same time period. School and park playgrounds used to be arenas for this kind of play, but an increased emphasis on playground safety has removed opportunities for it. Don't get us wrong: safety is a good thing. Many playgrounds of the past were dangerous, with ladders climbing upward of 20 feet to rusty slides with no rails. But making playgrounds *too* safe and sterile can have unintended consequences, including depriving children of opportunities to learn about themselves and their abilities to manage challenging and scary situations. Kids need to be able to exercise some independence, which often involves a bit of risky play.

Many scientists who study play have proposed that adventurous play can help build resilience and reduce fear in children. In line with this research, organizations such as LetGrow have created programs for schools and parents to foster independence, curiosity and exploration in children. Their solution is simple: let kids engage in more challenging, unstructured play so they can learn how to handle fear, anxiety and danger without it being too overwhelming.

Morbid fascination with danger is widespread in the animal kingdom—it's called predator inspection.

Even virtual scary experiences provide many of these same benefits. The Games for Emotional and Mental Health Lab created a horror biofeedback game called *MindLight* that has been shown to reduce anxiety in children. The game centers on a child named Arty who finds himself at his grandmother's house. When he goes inside, he sees that it has been enveloped in darkness and taken over by evil, shadowy creatures that can resemble everything from blobs to catlike predators. Arty must save his grandmother from the darkness and bring light back to her house. He has nothing to defend himself with except a light attached to his hat—his "mindlight." Players controlling Arty must use the mindlight to expose and defeat the creatures.

But there's a catch: as a player becomes more stressed (as measured by an electroencephalogram), their mindlight dims. The player must stay calm in the face of fear by practicing techniques such as replacement of stress-producing thoughts or muscle relaxation, borrowed from cognitive-behavioral therapy. As they regain their composure, their mindlight grows in power, and they are able to defeat the monsters with it. This combination of therapeutic techniques and positive reinforcement (kids defeat the monsters and conquer their fear) makes *MindLight* a potent anti-anxiety tool. Randomized clinical trials with children have shown the game to be as effective at reducing several anxiety symptoms as traditional cognitive-behavioral therapy, a widely used anxiety treatment.

SCARY PLAY CAN HELP adults navigate fear and anxiety, too. Scrivner tested this idea with visitors to Dystopia Haunted House. Haunted house goers could take personality surveys before they entered and answer questions about their experience when they exited. After about 45 minutes of being chased by zombies, monsters and a pig-man with a chain saw, the visitors ran out of the haunted house and into some members of the research team, who then asked them how they felt. A huge portion said they had learned something about themselves and believed they had some personal growth during the haunt. In particular, they reported learning the boundaries of what they can handle and how to manage their fear.

Other research from the Recreational Fear Lab in Aarhus, Denmark, has shown that people actively regulate their fear and arousal levels when engaging in scary play. This means that engaging with a frightening simulation can serve as practice for controlling

arousal and may be generalizable to other, real-world stressful situations, helping people bolster their overall resilience.

In one study that supports this idea, real soldiers played a modified version of the zombie-apocalypse horror game *Left 4 Dead* that incorporated player arousal levels. In the game, zombies pop out of nowhere, chasing players and clawing them to the ground, generating visceral fear even in experienced video game players. In the study, some players were given visual and auditory signals when their arousal increased: a red texture partially obscured the player's view, and they heard a heartbeat that got louder and faster as their stress increased. Later, during a live simulation of an ambush, soldiers who played the video game and received biofeedback had lower levels of cortisol (a stress biomarker) than those who did not play. Strikingly, these people also were better at giving first aid to a wounded soldier during that simulation.

These rehearsals for stress may be especially effective when people do them in groups. Collectively experiencing a dangerous situation ties people together. There are many anecdotal examples of this in history, from post-9/11 America, to military platoons, to the high levels of cooperation and assistance that often occur in the aftermath of natural disasters. There are also experimental studies showing that danger and fear can be powerful positive social forces. For example, engaging in rituals such as fire walking can physiologically synchronize people with one another and promote mutually beneficial behavior.

We don't need exposure to real danger to reap these cooperative benefits, however. Collectively simulating upsetting or dangerous situations through scary play could confer similar benefits without the physical risk. In the health-care industry, simulations are often used to teach medical skills by creating situations that are intense. In public health, simulations have been used to teach people ways to cooperate and coordinate in pandemic preparedness and response.

IN OTHER SPECIES, learning about risks is often a social endeavor. Stickleback fish investigating predators often do so with others. One stickleback will begin approaching, then wait to see whether another will approach a little closer. Then the first stickleback will go a little further, taking its turn being the one nearest the predator. The results of studies into this behavior even suggest that sticklebacks from regions with higher predation risk are more cooperative than those from places with lower risk.

In humans, morbid curiosity seems to be associated with cooperation and risk management. For example, in many societies people tell stories about dangers in their environments, whether those are natural disasters such as fires, earthquakes and floods or threats of war, theft or exploitation from nearby groups. The Ik people of Uganda, whom one of us (Aktipis) has studied as part of the Human Generosity Project, have a collective and emotionally compelling way of engaging with concerns about raids from other groups. They enact entire plays with music, dancing and drama where they reexperience both the tragedy and the triumph of helping one another during such difficult times. Such stories and dramatic enactments can bring shared attention to these kinds of challenges, and we know that shared attention is one mechanism that can help people cooperate and solve coordination dilemmas.

A failure of group imagination, in contrast, can lead to vulnerability. Some researchers have suggested that zombie-apocalypse fiction can lead to more creative solutions during unexpected and risky events by helping people become more imaginative. With CONPLAN 8888, a fictional training scenario, the U.S. military used a hypothetical zombie apocalypse to make learning about disaster management more fun for officers. The Centers for Disease Control and Prevention did something similar with a comic they produced called *Preparedness 101: Zombie Pandemic*. Organizations have recognized that couching fears in imaginative play is productive. Right now our research team is developing a set of scary group games to help people manage shared risks and fears.

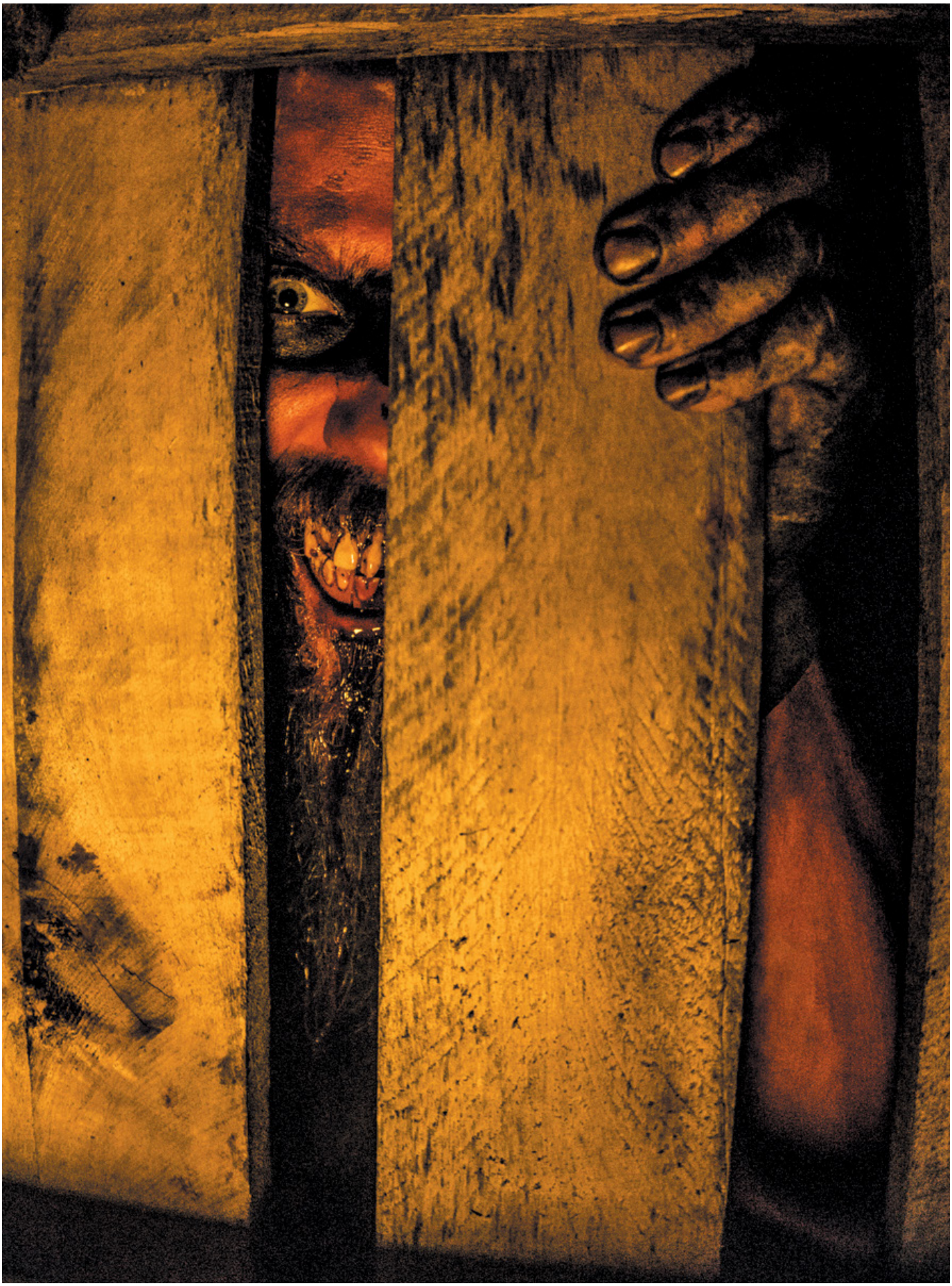
WHAT CAN WE LEARN from the human propensity for scary play? First, don't be afraid to get out there and explore your world, even if it sometimes provokes a little fear. Second, make sure that your morbid curiosity is educating you about risks in a way that is beneficial to you. In other words, don't get stuck doomscrolling upsetting news on the Internet; it's a morbid-curiosity trap that, like candy, keeps you consuming but does nothing to satisfy your need for nourishment.

Instead of doomscrolling, take on one or two topics you want to know more about and do a deeper dive that leaves you feeling satisfied that you've assessed the risk and empowered yourself to do something about it. Be intentional about gathering more information through your own experience or by talking with others who are knowledgeable on the subject.

You can also tell or listen to scary stories with others and use them as a jumping-off point for thinking about real risks we face. Watch a movie about an apocalypse, go to a haunted house, get in costume to go on a "zombie crawl," or have a fun night at home chatting with your friends about how you'd survive the end of the world. And finally, invite creativity and play into spaces where the gravity of a situation might otherwise be overwhelming. Make up horror stories or dress up as something frightening and have a laugh about how silly it all is. In other words, embrace the Halloween season with abandon—and then bring that same energy to the challenges of the times we're living in now. ●

FROM OUR ARCHIVES

Friends Can Make Things Very Scary. Susana Martinez-Conde and Stephen Macknik; May 2023. ScientificAmerican.com/magazine/sa



Andrés Rein Baldursson

People who confront monstrous predators in a relatively safe space, such as a haunted house, can learn to manage anxiety felt during distressing real-life situations.

Protect Habitats to Preserve Species

The Endangered Species Act turns 50 years old this year. Let's do more to prevent plants and animals from ever needing it BY THE EDITORS

Texas wild rice has been on the endangered species list since 1978. Its habitat is shrinking because of development and water availability.

IN THE 1950S and 1960s farmers, municipalities and even homeowners were widely spraying the insecticide DDT to kill pests. The chemical also polluted the food web and destroyed the eggs of Bald Eagles. By the early 1970s America's national symbol was almost extinct. Concern for the birds helped to prompt Congress to pass the Endangered Species Act (ESA), which was enacted on December 28, 1973. More than 1,600 animals and plants have been listed as threatened or endangered, and more than 60 species have recovered enough to be taken off the list—including the Bald Eagle.

The ESA is now 50 years old. It is a vital part of our nation's conservation efforts, but it comes into play only when a species is nearly gone. The act is an emergency room for revitalizing species already in dire condition. Just as preventive medicine keeps people out of the ER, there is much we can do to prevent our vulnerable creatures from needing the act in the first place. Recent studies have shown convincingly that the best way to protect species is to protect their ecosystems and habitats. Yet climate change is stressing ecosystems mightily, and urban, suburban and rural sprawl are eliminating natural habitat fast.

To preserve habitats is to preserve species. To that end, we must greatly expand our conservation efforts. Reviving a species is difficult and costly and can disrupt human communities. And according to the National Wildlife Federation, roughly one third of all vertebrates and vascular plants are in danger of vanishing. If we preserve habitats, we won't need to triage so many plants and animals.

Ideally, the federal government should create a national ecosystem-conservation plan that sets aside land and water from development. Although the country's polarized politics make that a long shot, other legislative initiatives that have bipartisan support but are languishing could go a long way toward that goal. We urge Congress to pursue legislation like the Recovering America's Wildlife Act (RAWA). The House of Representatives passed the bill in 2022, but it failed to pass in the Senate before the 117th Congress ended in January 2023.

The bill would provide significant funding for conservation or restoration of wildlife habitat that supports species at risk. RAWA essentially modernizes the Pittman-Robertson Act, one of the country's first species-protection acts. Supported by hunters dismayed at the loss of deer, ducks and turkeys, the 1937 act created an excise tax on guns and ammunition, and the funds went to states to create wildlife refuges where these animals could thrive. Deer, ducks and turkeys are now commonplace across America, proof that the effort worked. Yet RAWA has been stagnating in Congress since the bill was reintroduced in March.

This year the Supreme Court did a disservice to conservation efforts with its ruling in *Sackett v. EPA,* which limits the types of watery environments that can be considered wetlands. The decision weakens the 1989 North American Wetlands Conservation Act, which authorizes grants to be given to public-private partnerships to protect and enhance wetland ecosystems that waterfowl, other migratory birds and fish depend on. Almost 3,000 projects have conserved an estimated 2.98 million acres of habitat. We hope the courts avoid such antiscientific meddling in the future, and we ask Congress to find ways to strengthen the act's original provisions.

The North American Wetlands Conservation Act's many successes inspired a new effort in the summer of 2022, when a bipartisan group of senators introduced the North American Grasslands Conservation Act. It would provide incentives for

private landowners across the country to conserve and restore grasslands, which are important for wildlife in general, as well as for teetering species such as the Sage Grouse and Prairie Grouse. The idea behind the wetlands and grasslands acts is to conserve ecosystems so species can thrive, and both measures enhance resources such as freshwater that in some parts of the country are waning. Congress never got to the bill; we hope it is reintroduced soon.

An even broader initiative is "30 × 30," a global plan to protect at least 30 percent of lands and waters by 2030. More than 100 countries, including the U.S., have joined a global coalition championing this goal. Under President Joe Biden's version of the plan, called Conserving and Restoring America the Beautiful, several tracts have been designated as protected—notably, the Bears Ears National Monument in Utah. Bears Ears was created in consultation with tribes in that region, granting them access for traditional plant gathering. The country could use many more such protected areas.

These conservation initiatives, and more like them to come, protect ecosystems, habitat and therefore species because they follow a sound, nature-based logic. Bruce Stein, chief scientist at the National Wildlife Federation, recently told SCIENTIFIC AMERICAN that conservation is most effective when built on three pillars: representation, meaning some of every ecosystem; resilience, or enough of each ecosystem for it to last; and connectivity—multiple, connected locations of each ecosystem so that as climate change and human development pressure species, they have enough space and time to move or adapt. Congress and the Biden administration must keep these principles in mind when finalizing RAWA and acting further on 30 × 30.

People and progress depend on nature for enormous benefits. Preserving ecosystems doesn't just protect wildlife; it protects humanity. As Earth's dominant species, we are stewards of our world. If the aspiration to care for our world because we can is not enough, it's wise to remember that if you destroy your home, you destroy your life. ●

A Murder Mystery Puzzle

The literary puzzle *Cain's Jawbone,* which has stumped humans for decades, reveals the limitations of natural-language-processing algorithms **BY KENNA HUGHES-CASTLEBERRY**

ARTIFICIAL-INTELLIGENCE programs that analyze and produce text are transforming the way we read and learn. To parse writing, AI models sleuth through textual clues, such as word choices, to see their connections. But what happens when those clues are deliberately confusing? I tried to answer this question in December 2022, when I challenged AI developers to solve *Cain's Jawbone,* a murder mystery puzzle book from 1934.

For me the mystery started in October 2022 with a random package that arrived on my doorstep with no accompanying note or return address. I had never heard of the book inside, *Cain's Jawbone,* but learned that it is both a murder mystery and a brain-teasing puzzle. The book was published with all its pages out of order; to crack the case, the reader must reorder the pages and then figure out who killed the story's six victims.

Puzzle expert Edward Powys Mathers published *Cain's Jawbone* at the height of the so-called golden age of detective fiction. Only two people managed to solve it before the book went out of print shortly thereafter. John Mitchinson of book publisher Unbound came across the story and its solution at a literary museum in the U.K., and in 2019 he reprinted 5,000 copies of the 100-page puzzle. "How difficult could it be to put in order?" he recalls thinking.

It's difficult—after that initial reprint only one more person was confirmed to have found the solution. Then, in 2021, the book went viral thanks to a couple of TikTokers who tried to reorder the pages using a colorful "murder wall." Its new popularity spurred Mitchinson to print more copies.

When my package arrived, instead of a wall, my husband and I spread *Cain's Jawbone* out on our guest bed. As we pored over the flowery and intentionally fuzzy language, I suggested using an AI algorithm to unravel the narrative.

Most AIs are not trained to reorder book pages or to analyze the linguistic quirks of 1930s English. After searching for a suitable program, I connected with Zindi, an Africa-based company that hosts AI competitions in which 50,000 data scientists use algorithms to solve puzzles and win prizes.

With Zindi I created the 2022 *Cain's Jawbone* Murder Mystery Competition. Initially Unbound would let us use only 75 of the 100 pages of the book in the contest to avoid any widespread leaks of the answer, so with that restriction, we challenged the world to try to reorder the pages using natural-language-processing (NLP) algorithms.

NLP algorithms, such as the extensively covered ChatGPT, try to understand the information in a piece of writing by comparing its context and language with prior training data. Such algorithms can analyze never before seen text by transforming each word into a "token" and then deciding how each token fits into the complete work. I nobly resisted using AI to crack the case of who sent me this intriguing book, instead texting friends and posting on Instagram to uncover the culprit.

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For our competition, participants started with an existing NLP model called BERT, developed by Google and available in an open-source library, where it can be modified for specific uses. "These models are . . . trained on just gobs of the data that the model creators can get their hands on and then are refined to follow a certain set of instructions," says Jonathan May, a computer scientist at the University of Southern California. We gave participants Agatha Christie's first mystery novel, *The Mysterious Affair at Styles,* to use as training data. In addition to demonstrating the context clues of a classic mystery, it contains similar language as *Cain's Jawbone* because it was written during the same period.

AI has a long history of writing novels, including murder mysteries. In 1973 computer scientist Sheldon Klein proposed an "automatic novel writer" that he claimed could produce 2,100-word murder mystery stories in less than 20 seconds. Since then, programmers and engineers have improved the output of these kinds of models by using more input data. "In a way, a murder mystery is easy," says Mike Sharples, an emeritus professor of educational technology at the Institute of Educational Technology at the Open University in England. "There is a standard plot structure to it: find the body, the sleuth comes, you've got a red herring, and so on." This plot structure not only is helpful to authors dashing off a quick story but also could help AI language programs trying to put the mixed-up pages of those stories back into the right order—in theory.

> "Natural-language processing does have some comprehension to it, like knowing thunder and rain go together. The problem is that the book tries to throw you off with false clues."
> —M. G. Ferreira *South Africa*

Unfortunately, *Cain's Jawbone* creates the ultimate challenge for language-analyzing algorithms: the language is highly stylized and purposefully ambiguous to make ordering the pages as difficult as possible. Plus, the story abounds in false clues, such as fake names for some characters and misleading names for others, all designed to trick human solvers and likely to confuse AI models as well. Some of the developers made a little headway, but in the end no one managed to crack the puzzle.

M. G. Ferreira, a mathematician from South Africa, correctly ordered 42 of the 75 given pages. "NLP does have some comprehension to it, like knowing that thunder and rain go together," Ferreira says. "But the problem here is that the book is trying to throw you off with false clues." To solve the puzzle, he explains, the AI needs a human to step in, look at the context and identify which ideas go together. Eventually, he says, the mystery will be solved, but with so much human involvement that it will be more of a machine-assisted process than something AI accomplished alone. Since the time of the contest many hundreds of people have attempted to reorder and solve the book, so the human element is important.

This murder mystery competition has revealed that although NLP models are capable of incredible feats, their abilities are very much limited by the amount of context they receive. This constraint could cause issues for researchers who hope to use them to do things such as analyze ancient languages. In some cases, there are few historical records on long-gone civilizations to serve as training data for such a purpose.

This experience did help me solve one puzzle: I tracked down the person who sent me the book—an elementary school friend, a person who doesn't have social media but does have a penchant for murder mysteries, just like me. ●

Illustration by Thomas Fuchs

Healthspan Can Matter More Than Life Span

The biology of aging holds clues to extending your healthy years BY LYDIA DENWORTH

OVER THE PAST century the average life expectancy in developed countries has increased by 30 years, from roughly age 50 to 80. Vaccines, sanitation, antibiotics, and other advances allow many more people to survive infectious diseases that used to kill them during childhood. (In the U.S., though, the span dropped by nearly three years during the COVID pandemic, a testament to the power of infections to shorten lives.)

Longer life spans overall have been a public health success. But they have also created a new and important gap: healthspans, usually defined as the period of life free of chronic disease or disability, do not always match longevity. In this, my 12th year of caring for a relative with Alzheimer's disease, I know this fact well.

By one calculation, based on the World Health Organization's healthy life expectancy indicator, an American who expects to live to 79 might first face serious disease at 63. That could mean 15 years (20 percent of life) lived in sickness. Indeed, aging is the biggest risk factor for cancer, heart disease and dementia.

One reason for this gap is that, for decades, biomedical research and clinical practice have focused on treating individual diseases, which can extend lives but not necessarily healthspan.

During the past 10 years medicine has started to take a different approach based on the biology of aging (a field called geroscience). "We're now saying our focus should be on extending healthy life rather than just length of life, and slowing aging is the tool to do it," says Jay Olshansky, a longevity expert at the University of Illinois at Chicago. There are molecular and cellular processes in all our tissues and organs that determine both life span and healthspan. These "pillars of aging" include DNA damage, the aging or senescence of individual cells, inflammation, and stress responses.

Natural variations in these factors are mostly the result of environmental differences. Genes also play a role, accounting for about 25 percent of the variability, more in extreme cases. (Very long-lived smokers probably won the genetic lottery.) The upshot is that some people age faster than others, and with biological aging comes susceptibility to disease and disability.

How do you assess biological age? Molecular markers such as chemical modifications to DNA are one way, says computational biologist Morgan Levine of Altos Labs in San Diego. "Do your cells have a pattern of chemical tags like someone who is 20 or 30 or 40?" she asks.

Geroscientists have yet to deliver a pill or treatment that can slow or reverse what the pillars of aging do. But they are excited about some possibilities. For example, senolytic drugs target senescent cells, which no longer divide but linger in the body instead of being cleared by the immune system. Research has shown that these "zombie cells" secrete proteins that interfere with other cells' health. The zombies have been linked to osteoarthritis, cancer and dementia. For a 2015 study, researchers used senolytics to remove senescent cells in mice and delayed, prevented or alleviated multiple disorders. Clinical trials are underway in people but are years from completion, so researchers are cautious. They also note that few popular wellness claims about "prolonging your youth" are grounded in evidence.

For now, one way to extend healthspan is through unsurprising preventive maintenance. Experts recommend checkups, staying on top of cholesterol levels and blood pressure, and following guidelines such as those from the *American Journal of Clinical Nutrition* for body fat percentage, lean body mass and bone density. "Know where you are so if something needs to be tweaked you can take steps to do that," says Matt Kaeberlein, founding director of the University of Washington Healthy Aging and Longevity Research Institute and now chief executive officer of Optispan, a health tech company.

Those steps are also familiar: common-sense nutrition, sleep, exercise and social connection are the four main factors. "The reason those things work is because they modulate the biology of aging," Kaeberlein says. For example, regular low- or moderate-intensity exercise helps to prevent cardiovascular disease and type 2 diabetes. How much extra health can these steps get us? "Ten years is probably pretty realistic," Kaeberlein says. ●

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Illustration by Jay Bendt

Sleep Sustains Emotional Health

Sleep loss dampens brain regions that help to manage our emotions

BY ETI BEN SIMON

WHEN I WAS a graduate student, my colleagues and I studied how losing one night of sleep affects a person's ability to manage their emotions. Once a week, typically on a Friday evening, I would stay up all night to monitor our participants and ensure that they followed the protocol. At about noon the next day, we would all stumble out of the laboratory, exhausted and eager to get home and rest.

Two months into the experiment, I was in my car at a traffic light when a silly love song started playing on the radio. Suddenly, I was crying uncontrollably. I remember feeling surprised at my reaction. It then hit me that I was not just studying sleep deprivation—I had become *part* of the study. Weeks of missed sleep had taken their toll, and I was no longer in control of my emotions.

That research project, and many that have followed since, demonstrated a strong and intimate link between better sleep and emotional health. In healthy individuals, good-quality sleep is linked with a more positive mood—and it takes just one night of sleep deprivation to trigger a robust spike in anxiety and depression the following morning. Moreover, people who suffer from chronic sleep disruption tend to experience daily events as more negative, making it hard to escape a gloomy mindset. Indeed, in a national sleep survey, 85 percent of Americans reported mood disruption when they were not able to get enough sleep.

Studies from our lab and others are now beginning to illuminate just how a lack of sleep frays the inner fabric of our mind. One of its many impacts is to disrupt the brain's circuitry for regulating emotions.

For decades researchers and medical professionals considered sleep loss a by-product or symptom of another, more "primary" condition, such as depression or anxiety. In other words, *first* comes the anxiety, and then sleep loss follows. Today we know that this order can be reversed. In fact, sleep loss and anxiety, depression or other mental health conditions may feed into one another, creating a downward spiral that is exceedingly difficult to break.

Much evidence in this area comes from chronic sleeplessness or insomnia. People who suffer from insomnia are at least twice as likely to develop depression or anxiety later in life, compared with individuals who sleep well. For instance, a study that followed 1,500 individuals—some with insomnia and others without—found that chronic sleeplessness was associated with a three times greater increase in the onset of depression a year later and twice the increase in the onset of anxiety.

Insomnia symptoms also raise the risk of developing post-traumatic stress disorder and track closely with suicidal behavior among at-risk individuals. They often precede a mood episode in people with bipolar disorder. Even after adequate treatment for depression or anxiety, people who continue to suffer from sleep difficulties are at greater risk of relapse relative to those whose sleep improves. Understanding sleep's role in this pattern could unlock insights for helping

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Illustration by Anna Godeassi

to prevent and treat many emotional and mental disorders.

Older research already revealed that sleep loss can precede serious mental health symptoms in otherwise healthy individuals. In studies conducted mostly in the 1960s, volunteers who stayed awake for more than two nights reported difficulties forming thoughts, finding words and composing sentences. They suffered from hallucinations, such as seeing inanimate objects move or experiencing the sensation of another's touch despite being alone. After three days without sleep, some participants became delusional and paranoid. They believed they were secret agents or that aliens were contacting them. (If that sounds like a psychotic episode, that's because it is.) After five days, several participants entered a state resembling a full-blown clinical psychosis and were unable to fully comprehend their circumstances.

In one study from 1947, volunteers from the U.S. military attempted to stay awake for more than four nights. A soldier who was described by his friends as quiet and reserved became extremely aggressive after three nights without sleep. He provoked fights and insisted he was on a secret mission for the president. Eventually he was forcibly restrained and dismissed from the experiment. Six others exhibited outbursts of violence and persistent hallucinations. In all cases, after sleeping for an entire day, the soldiers behaved normally again and had no recollection of the earlier mayhem. In another study, in which participants stayed awake for four nights, researchers were unprepared for the "frequent psychotic features" they encountered, such as intense hallucinations and paranoid delusions.

Given these destructive effects, studies of prolonged sleep loss are now considered to be unethical, but they still offer a powerful reminder of just how sleep-dependent our minds and mental health truly are.

Even with these startling results, scientists have been skeptical about the consequences of restless nights, particularly given that (fortunately) few of us endure such extreme deprivation. That's where the newest wave of research comes in.

Impaired emotional control makes us more vulnerable to anxiety and poor mood, so that even silly love songs can trigger sobbing.

In recent years a neuroscientific explanation has emerged that is beginning to illuminate what it is about sleep, or the lack of it, that seems to have a direct link to our emotions.

Whenever we face a nerve-wracking or emotionally intense challenge, a hub deep in the brain called the amygdala kicks into gear. The amygdala can trigger a comprehensive whole-body response to prepare us for the challenge or threat we face. This flight-or-fight response increases our heart rate and sends a wave of stress hormones rushing into our bloodstream. Luckily, there's one brain region standing between us and this cascade of hyperarousal: the prefrontal cortex, an area right behind the middle of our eyebrows. Studies show that activity in this region tends to dampen, or downregulate, the amygdala, thus keeping our emotional response under control.

In studies where my colleagues and I deprived healthy volunteers of one night of sleep, they discovered that the activity of the prefrontal cortex dropped drastically, as measured using functional magnetic resonance imaging (fMRI). Moreover, the neural activity linking the amygdala and the prefrontal cortex became significantly weaker. In other words, both the region and the circuit meant to keep our emotional reactions under control are essentially out of order when sleep is disrupted. Other studies have found that this profile of neural impairment can occur in people after they experience just one night of sleep deprivation, in people who are habitual short sleepers, or when participants' sleep is restricted to only four hours a night for five nights.

This impairment can be so robust that it blurs the lines around what people consider emotional. For example, when my colleagues and I exposed participants to neutral and emotional pictures (think bland images of commuters on a train versus photographs of children crying), fMRI revealed that the amygdala responded differently to these prompts when people were well rested. But after losing a night of sleep, a person's amygdala responded strongly to *both* kinds of images. In other words, the threshold for what the brain deems emotional became significantly lower when the amygdala could not act in concert with the prefrontal cortex. Such impaired emotional control makes us more vulnerable to anxiety and poor mood, so that even silly love songs can trigger sobbing.

The effects on the amygdala, the prefrontal cortex and the circuitry between the two may have many other consequences as well. In January we published findings that show that changes in this brain circuit, together with other regions involved in arousal, relate to increases in blood pressure after one night of sleep loss. The brain-level mechanisms my colleagues and I have observed may contribute to changes that negatively affect the entire body, increasing the risk for hypertension and cardiovascular disease.

Stepping back, it becomes clear that—like our physical well-being—mental and emotional health rely on a delicate balance. Myriad choices we make throughout the day *and* night maintain that balance. Even a single sleepless night can therefore do damage. We need to be mindful of this reality, for both ourselves and one another. Inevitably we all miss out on sleep from time to time. But our societies should critically examine structures—such as work norms, school cultures, and the lack of support for parents or other caregivers—that prevent people from getting enough rest. The science of sleep and mental health suggests that failing to address those problems will leave people vulnerable to serious harm. ●

The Milky Way's Secrets

Our galaxy's night-sky spectacle sparked scientific revolutions **BY PHIL PLAIT**

THE UNIVERSE IS filled with immense structures of mind-crushing proportions. They wield energies that vastly exceed our most fevered dreams.

Yet from Earth these configurations can barely be seen at all, even when you live inside one.

Case in point: Find yourself a dark spot where you can see lots of stars when the moon rises late—and look up. Stretching from the northern horizon to nearly directly overhead and then down again to the southern horizon, a broad whitish swath will be visible across the sky, faintly glowing like a dimly seen celestial river.

That is the aptly named Milky Way. It spans 360 degrees of the sky in a continuous circle, enveloping Earth like a pale ring. It can be seen in the winter passing through familiar constellations such as Orion and Gemini. But for Northern Hemisphere observers, it's brightest and easiest to spot in the summer, when it appears as a wide trail of light splitting the sky. Near Deneb, the brightest star in the constellation Cygnus, the Milky Way appears to split in half, separated lengthwise by a dark lane poetically (if not ominously) called the Great Rift. This darkened cleft continues down toward the southern horizon even as the Milky Way itself broadens noticeably, and it bulges out into a lumpy blob near Sagittarius and Scorpius.

That's one of my favorite sights in the sky, actually. Sagittarius is generally depicted as the Archer, a centaur holding a bow. But to modern eyes the stars can uncannily resemble a teapot, with the traditional bow depicting the spout. In fact, the glow of the Milky Way looks like steam coming from the teapot, which is tipped over and ready to pour boiling water onto the tail of Scorpius!

That's a fanciful interpretation, sure. But once you see it for yourself, you'll appreciate why ancient people mythologized the heavenly scene. The most famous example, perhaps, is the Greek myth in which Hera pushes baby Heracles away from her bosom, and her breast milk spills from horizon to horizon. The Romans called this feature in the sky the *via lactea* ("milky road" or "milky way"), which is the origin of the modern name. The Greeks called it the *galaktikós kyklos* ("milky circle"), which is the source of the term "galaxy." There's amusing redundancy in calling it the Milky Way galaxy, as many do. (Mea culpa: I'm guilty, too.)

But what causes this glow? Astronomers have learned that its subtle impression on the eye belies its true nature.

Over the centuries many observers hypothesized that the Milky Way's soft luminescence was the collective glow from myriad stars that were too faint and close together in the sky to be individually distinguished. But the details of this structure stayed fuzzy (pardon my pun) until 1610, when Galileo confirmed the basic idea by turning his small telescope to the Milky Way and finding it was indeed composed of countless (at the time) stars. (Now we know it has at least 100 billion.)

The Milky Way's true shape—implied in its riverlike path across the sky—offers an important clue as well. If our galaxy were a huge spherical structure of stars with Earth near its center, its glow would be everywhere we look. But the fact that it appeared relatively flat suggested to 18th-century astronomers that the Milky Way was a disklike assemblage of stars, more like a pancake than a sphere.

As telescopes improved, astronomers spied in the sky many small spiral and elliptical "nebulae" (from the Latin word for "fog" or "mist"). No less a thinker than philosopher Immanuel Kant speculated that these objects might be "island universes," of which the Milky Way was but one among many. But it was also possible the nebulae might just be small clouds inside a Milky Way that made up the entire universe.

Either way, the question remained:

The Milky Way shines bright over the southern Utah desert (*left*). Like many others such as the galaxy NGC 6744 (*right*), the Milky Way is a spiral galaxy.

Eric Hanson/Getty Images (*left*); ESO (*right*)

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Where are *we* in the Milky Way? What position does our sun hold? To find out, in 1785 sibling astronomers William and Caroline Herschel used a clever method: they counted stars in various parts of the sky. They assumed that if the Milky Way were elongated, stars would be more abundant along its long axis than through its shorter one. The map they made from these observations shows the Milky Way as a squashed inkblot with the sun near the center.

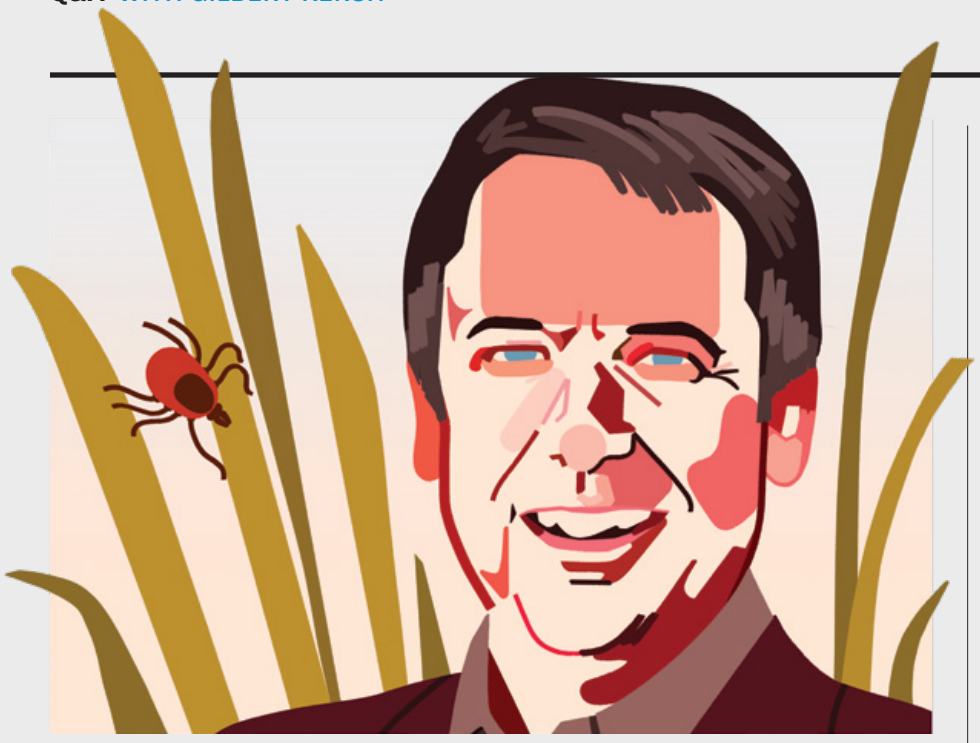
In the 1920s astronomer Jacobus Kapteyn took this research a step further. He measured stellar velocity and brightness to try to make a more accurate map. In the end his work mostly agreed with the Herschels' results.

Both methods suffered from an inherent error, however: they assumed that the space between stars was empty. But interstellar space is littered with opaque clouds of cosmic dust, tiny grains of rocky or sooty material that block our view of what lies beyond. The Great Rift that splits the Milky Way in Cygnus is a sprawling collection of these clouds, which are silhouetted against the more distant stars. Such clouds are why the star-count methods failed: from almost any viewpoint in the galaxy, they would occlude your line of sight and produce the illusion of gazing out from near the center. In reality, the sun is not particularly close to the Milky Way's center. Instead it is almost halfway out to the edge of the galaxy's disk.

In the 1920s astronomers Edwin Hubble and Vesto Slipher were able to show that some of the spiral and elliptical nebulae were terribly distant and not inside the Milky Way at all. Kant was right: such nebulae truly were island universes, and the Milky Way was merely one among many. We now generically call them galaxies—we've extrapolated the name from our own.

From there many decades elapsed before the true nature of the Milky Way's shape became clear when radio astronomers began measuring the overall movement and distances of gas clouds in our galaxy. Because radio waves can pass through dust unscathed, these studies were able to pierce the shadows cast by the Great Rift and other starlight-blocking interstellar clouds. They revealed our galaxy as a vast disk with a central bulge—the same lumpy blob seen toward Sagittarius—that has star-spangled spiral arms winding around it. Many such spiral galaxies dot the skies, and the ones we view edge-on mirror the starry band of the Milky Way we see by eye in the sky. Modern measurements put the disk at 120,000 light-years across, an immense size. Most stars are so far away from Earth that their apparent brightness is only an infinitesimal fraction of their true glory.

So when you stand outside and take in the Milky Way over your head, remember that you live in the stellar suburbs of an enormous spiral galaxy's dust-strewn disk, which is more than a quintillion kilometers across and stuffed full of hundreds of billions of stars and perhaps trillions of planets. And our cosmic home is but one of countless galaxies scattered across the universe. How remarkable it is that we know all this just because curious people once looked up into the night and thought, "I wonder what that faint, fuzzy glow is?" ●



Meat Allergy Alert

The bite of the lone star tick can cause an allergy to red meat, as well as to dairy and some medications

BY TANYA LEWIS

TICKS ARE ANNOYING creatures. These nasty, blood-sucking parasites glom on to you when you least expect it. And if they're not removed in time, they can transmit a startling range of pretty horrible diseases.

The bite of the lone star tick, found in the U.S. South, Midwest and mid-Atlantic, can trigger bizarre and sometimes dangerous allergies to red meat (such as beef, pork and venison), dairy, gelatin and some medications. Known as alpha-gal syndrome, the condition is caused by an immune reaction to the sugar alpha-gal (galactose-α-1,3-galactose), which is found in the flesh of most nonprimate mammals. More than 110,000 people in the U.S. tested positive for alpha-gal antibodies from 2010 to 2022, according to a July report from the Centers for Disease Control and Prevention. But researchers think there might be closer to half a million people living with the condition—and the number of cases is increasing.

Many health-care providers still don't know about alpha-gal syndrome at all. A 2022 CDC survey found that 42 percent of them had never heard of the condition, and more than a third of those who were aware of it were not confident in diagnosing or managing the allergy. If people with the syndrome consume animals or products containing alpha-gal sugar, they can suffer reactions ranging from diarrhea to hives to anaphylactic shock. There is no treatment, and many patients are forced to radically alter their diet for years—or for life.

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A Blacksburg, Va.–based company called Revivicor raises pigs that are genetically engineered to lack the alpha-gal gene with the aim of growing organs that can be transplanted into humans. The U.S. Food and Drug Administration approved these "GalSafe" pigs in 2020 for meat as well as medical use (though not specifically for transplants). Revivicor occasionally provides GalSafe pork to people with an alpha-gal allergy, but it does not sell the meat. "We try whenever possible to make GalSafe meat available to alpha-gal patients, but we are not meat producers," says Dewey Steadman, head of investor relations at Revivicor's parent company United Therapeutics. "We've been unsuccessful in our efforts to find a partner to produce GalSafe meat on a larger scale." The company is focused more on manufacturing organs, he adds.

SCIENTIFIC AMERICAN talked to Gilbert Kersh, one of the authors of the CDC reports and chief of the Rickettsial Zoonoses Branch at the CDC's Division of Vector-Borne Diseases, about what alpha-gal syndrome is and what doctors and the public should know about it.

An edited transcript of the interview follows.

What causes alpha-gal syndrome?

Alpha-gal syndrome is a tick-bite-associated allergic condition. We think people, a few weeks or maybe a couple of months after getting a tick bite, start having allergic reactions when they consume red meat or other products that contain the alpha-gal sugar. Alpha-gal is a sugar that is in most mammalian meat. But it's not present in humans, so humans [with the condition] recognize it as foreign and have a reaction to it. These reactions take place when people are exposed to mammalian meat or other products derived from animals, including dairy products for many patients. These reactions will come two to six hours after they consume the meat or other product.

What are the most common symptoms?

There's a group of patients who report primarily gastrointestinal symptoms, so they'll have diarrhea or vomiting. Often this will come late at night because they've had an evening meal that included red meat. And there are other patients who have more

Illustration by Shideh Ghandeharizadeh

traditional allergic reactions—who will have hives—and some develop anaphylaxis. They may have trouble breathing, swelling of the tongue, those kinds of symptoms—which can be quite serious and often result in visits to the emergency department. It's often difficult to tie these reactions to the consumption of meat earlier in the day, and it's also difficult to associate them with tick bites that might have happened weeks or months before any of the symptoms started. All these factors make the syndrome difficult to recognize and diagnose.

And do doctors know how to diagnose the condition?
We did a survey of health-care providers, and 42 percent of them had not heard of alpha-gal. An additional 35 percent were not too confident in their ability to diagnose or manage a patient who had it. We think there's really a gap in awareness among health-care providers about recognizing these symptoms and the sequence of events that leads to alpha-gal syndrome. One of our objectives is to increase awareness both among the public and among health-care providers so it can be recognized and managed appropriately.

Is there a treatment for the condition?
There's no treatment or cure for alpha-gal syndrome, but patients can manage the condition by avoiding eating things that have the alpha-gal sugar. You can use chicken or fish as a protein source but not pork or venison or beef—all those mammalian meats have the alpha-gal sugar.

Is it a lifelong allergy?
In some patients, the antibodies responsible for the reaction will decline over time. Some patients have reported success in adding back mammalian products over a few years. But for others, it's a lifelong condition.

Is alpha-gal syndrome widespread?
Yes, and it is increasing as well. There is no formal national surveillance for alpha-gal syndrome. In the recent article on cases of alpha-gal syndrome that we published in the CDC's *Morbidity and Mortality Weekly Report,* we used kind of a proxy for formal surveillance. There was a laboratory that did most of the testing for alpha-gal-specific antibodies in the U.S., and it was willing to share its data with us. Looking at those data, we could estimate that over the past 12 years there were at least 110,000 "suspected" cases of alpha-gal—that means they had a positive lab result, but we didn't have other information about those patients. Given the lack of awareness among health-care providers, however, we suspect that 110,000 is quite a bit of an undercount, and we estimate as many as 450,000 people may be living with the syndrome in the U.S. And the number of positive tests has been going up year by year.

Where are most of the cases occurring?
The majority of cases are in a region starting in Missouri and Arkansas, going east through Tennessee, Kentucky, Virginia and North Carolina, and then stretching up the Eastern Seaboard a little bit. This pattern overlaps what we expect the distribution of the lone star tick to be. We think this tick is the one responsible for most cases in the U.S. In fact, Suffolk County, New York, which is on Long Island, had the most positive test results of any county in the U.S. That's a region that has a large number of lone star ticks, but we also think there's more awareness in that area, so people are getting diagnosed in a more timely manner there.

If you're bitten by this tick, what can you do?
We recommend that anytime you go outdoors, you follow that up with checking for ticks and remove any ticks that you find as soon as possible. We're not certain how long the tick has to be embedded for the alpha-gal antibodies to be introduced, so the safest thing to do is to remove a tick as soon as you find it. But it's better if you don't get bitten by the tick at all. Taking personal protective measures is really important for preventing alpha-gal syndrome: using Environmental Protection Agency–registered repellents, checking yourself for ticks when you return from outdoors, walking in the middle of a trail—those are tick-bite preventions that are applicable to any tickborne disease.

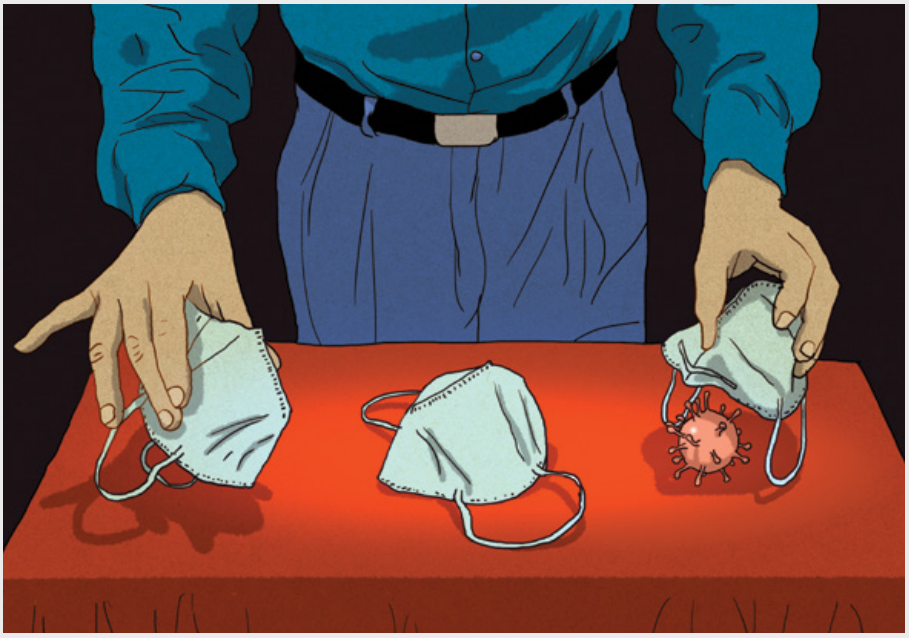
But in this case, that's really the only prevention we have for reducing cases of alpha-gal syndrome. It's also an issue that once you have alpha-gal syndrome, subsequent tick bites can boost the alpha-gal antibodies. So if you want to be one of those people who, over time, improves and can tolerate some mammalian products, you really need to avoid any subsequent tick bites after you have it.

Do people with alpha-gal syndrome react to other things besides red meat and dairy products?
Patients report that it's difficult to completely avoid all the products—the sugar is present in some pharmaceuticals such as gelatin-coated tablets. Marshmallows can contain mammalian products. There's not a comprehensive list of what potentially might have mammalian products. This is the difficulty for patients, especially if they eat out: they don't know exactly how the food's been prepared or what's in there. So it can be quite challenging. But most report that avoiding products with alpha-gal is much better than the symptoms they were having when they were eating meat and having severe reactions.

It's also possible to have a reaction to a vaccine. Those do not seem to be very common, but if you have alpha-gal syndrome, it's important to talk to your health-care provider when you're considering a vaccine. Most vaccines do not cause this problem. Definitely it's not a reason to avoid getting vaccinated.

What should people with alpha-gal syndrome do if they ingest red meat or another product with alpha-gal?
Some patients, after they have these reactions, will carry an EpiPen. But once they get diagnosed and know what to avoid, typically there's less of a risk of a severe reaction.

Tickborne diseases, including Lyme disease, are on the rise in general. Should health-care providers be aware of these illnesses so they can diagnose patients?
Yes, definitely. Over the past 25 years we've seen a steady increase in basically all tickborne diseases, and a lot of new tickborne diseases have been identified in the past 20 years. So we would encourage awareness about all tickborne conditions—both alpha-gal syndrome and infectious tickborne diseases. That is something to think about when a patient comes in and it's unclear what their diagnosis is. ●



Masked Confusion

A trusted source of health information misleads the public by prioritizing rigor over reality

BY NAOMI ORESKES

THE COVID-19 PANDEMIC is ongoing, but in May officials ended its designation as a public health emergency. So it's now fair to ask if all our efforts to slow the spread of the disease—from masking, to hand washing, to working from home—were worth it. One group of scientists has seriously muddied the waters with a report that gave the false impression that masking didn't help.

The group's report was published by Cochrane, an organization that collects databases and periodically issues "systematic" reviews of scientific evidence relevant to health care. This year it published a paper addressing the efficacy of physical interventions to slow the spread of respiratory illness such as COVID. The authors determined that wearing surgical masks "probably makes little or no difference" and that the value of N95 masks is "very uncertain."

The media reduced these statements to the claim that masks did not work. Under a headline proclaiming "The Mask Mandates Did Nothing," *New York Times* columnist Bret Stephens wrote that "the mainstream experts and pundits ... were wrong" and demanded that they apologize for the unnecessary bother they had caused. Other headlines and comments declared that "Masks Still Don't Work," that the evidence for masks was "Approximately Zero," that "Face Masks Made 'Little to No Difference,'" and even that "12 Research Studies Prove Masks Didn't Work."

Karla Soares-Weiser, the Cochrane Library's editor in chief, objected to such characterizations of the review. The report had *not* concluded that "masks don't work," she insisted. Rather the review of studies of masking concluded that the "results were inconclusive."

In fairness to the Cochrane Library, the report did make clear that its conclusions were about the *quality* and *capaciousness* of available evidence, which the authors felt were insufficient to prove that masking was effective. It was "uncertain whether wearing [surgical] masks or N95/P2 respirators helps to slow the spread of respiratory viruses." Still, the authors were also uncertain about that uncertainty, stating that their confidence in their conclusion was "low to moderate." You can see why the average person could be confused.

This was not just a failure to communicate. Problems with Cochrane's approach to these reviews run much deeper.

A closer look at how the mask report confused matters is revealing. The study's lead author, Tom Jefferson of the University of Oxford, promoted the misleading interpretation. When asked about different kinds of masks, including N95s, he declared, "Makes no difference—none of it." In another interview, he called mask mandates scientifically baseless.

Recently Jefferson has claimed that COVID policies were "evidence-free," which highlights a second problem: the classic error of conflating absence of evidence with evidence of absence. The Cochrane finding was *not* that masking didn't work but that scientists lacked sufficient evidence of sufficient quality to *conclude* that they worked. Jefferson erased that distinction, in effect arguing that because the authors couldn't prove that masks did work, one could say that they didn't work. That's just wrong.

Cochrane has made this mistake before. In 2016 a flurry of media reports declared that flossing your teeth was a waste of time. "Feeling Guilty about Not Flossing?" the *New York Times* asked. No need to worry, *Newsweek* reassured us, because the "flossing myth" had "been shattered." But the American Academy of Periodontology, dental professors, deans of dental schools and clinical dentists (including mine) all affirmed that clinical practice reveals clear differences in tooth and gum health between those who floss and those who don't. What was going on?

The answer demonstrates a third issue with the Cochrane approach: how it defines evidence. The organization states that its reviews "identify, appraise and synthesize all the empirical evidence that meets pre-specified eligibility criteria." The problem is what those eligibility criteria are.

Cochrane Reviews base their findings on randomized controlled trials (RCTs),

Naomi Oreskes is a professor of the history of science at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and co-author of *The Big Myth* (Bloomsbury, 2023).

Illustration by Izhar Cohen

often called the "gold standard" of scientific evidence. But many questions can't be answered well with RCTs, and some can't be answered at all. Nutrition is a case in point. It's almost impossible to study nutrition with RCTs because you can't control what people eat, and when you ask them what they have eaten, many people lie. Flossing is similar. One survey concluded that one in four Americans who claimed to floss regularly was fibbing.

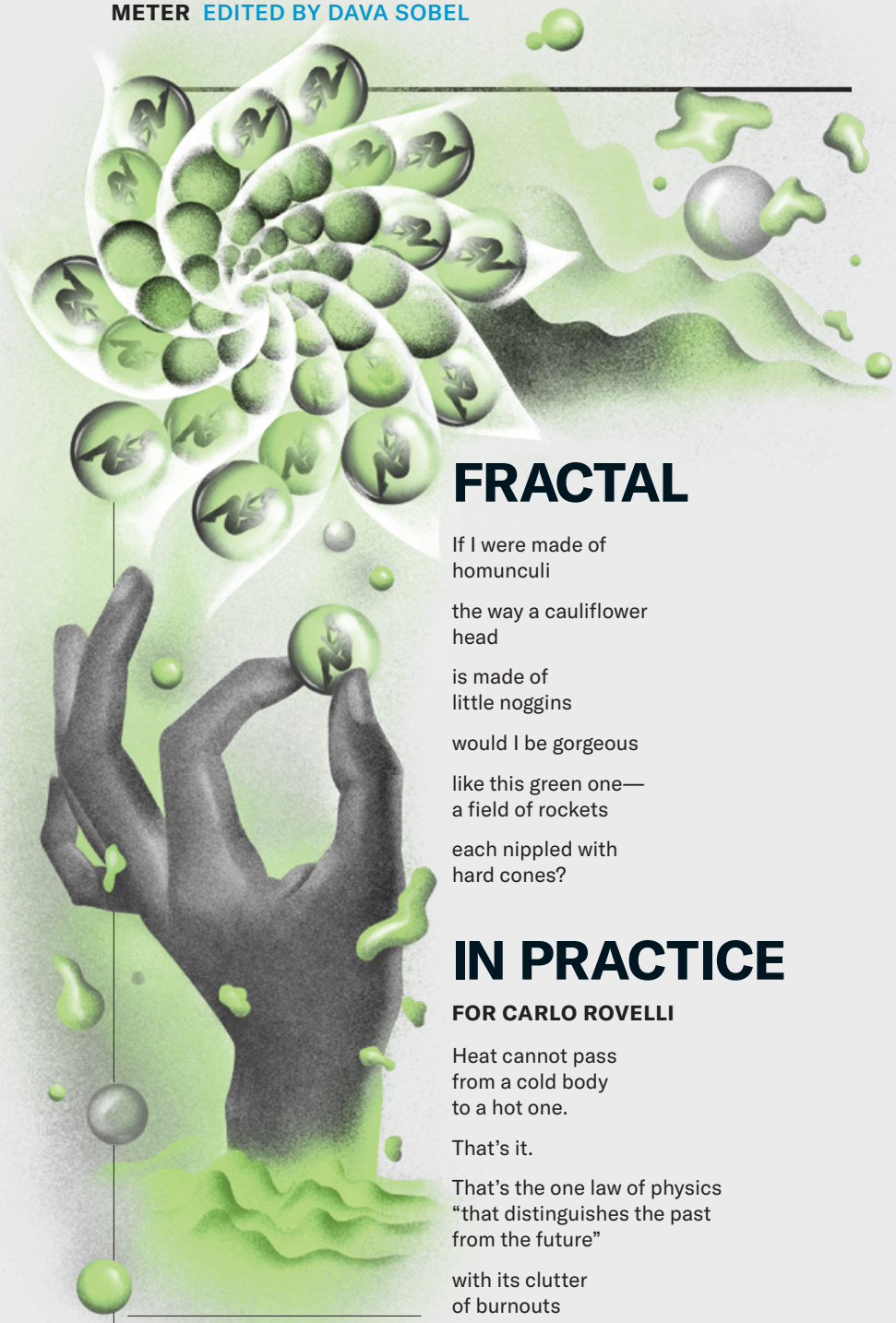
In fact, there is strong evidence that masks do work to prevent the spread of respiratory illness. It just doesn't come from RCTs. It comes from Kansas. In July 2020 the governor of Kansas issued an executive order requiring masks in public places. Just a few weeks earlier, however, the legislature had passed a bill authorizing counties to opt out of any statewide provision. In the months that followed, COVID rates decreased in all 24 counties with mask mandates and continued to increase in 81 other counties that opted out of them.

Another study found that states with mask mandates saw a significant decline in the rate of COVID spread within just days of mandate orders being signed. The authors concluded that in the study period—March 31 to May 22, 2020—more than 200,000 cases were avoided, saving money, suffering and lives.

Cochrane ignored this epidemiological evidence because it didn't meet its rigid standard. I have called this approach "methodological fetishism," when scientists fixate on a preferred methodology and dismiss studies that don't follow it. Sadly, it's not unique to Cochrane. By dogmatically insisting on a particular definition of rigor, scientists in the past have landed on wrong answers more than once.

We often think of proof as a yes-or-no proposition, but in science, proof is a matter of discernment. Many studies are not as rigorous as we would like, because the messiness of the real world prevents it. But that does not mean they tell us nothing. It does not mean, as Jefferson insisted, that masks make "no difference."

The mask report—like the dental floss report before it—used "standard Cochrane methodological procedures." It's time those standard procedures were changed. ●



FRACTAL

If I were made of
homunculi

the way a cauliflower
head

is made of
little noggins

would I be gorgeous

like this green one—
a field of rockets

each nippled with
hard cones?

IN PRACTICE

FOR CARLO ROVELLI

Heat cannot pass
from a cold body
to a hot one.

That's it.

That's the one law of physics
"that distinguishes the past
from the future"

with its clutter
of burnouts

when what matters
is who's wearing
the kitty tail
right now!

Who thinks she knows
where meaning is.

Just wait.

"Times are legion, a different
one for every point
in space"

no matter how close;

how lonesome

Rae Armantrout,
a professor emerita at the University of California, San Diego, has written 17 volumes of poetry, including *Versed* (Wesleyan University Press), which won the 2010 Pulitzer Prize and a 2009 National Book Critics Circle Award.

EDITOR'S NOTE:
A kitty tail worked its way into this poem when the poet's granddaughters, arguing over a cat costume, interrupted her reading of theoretical physicist Carlo Rovelli's *The Order of Time,* excerpts from which appear here in quotation marks.

Illustration by Masha Foya

Waste Not

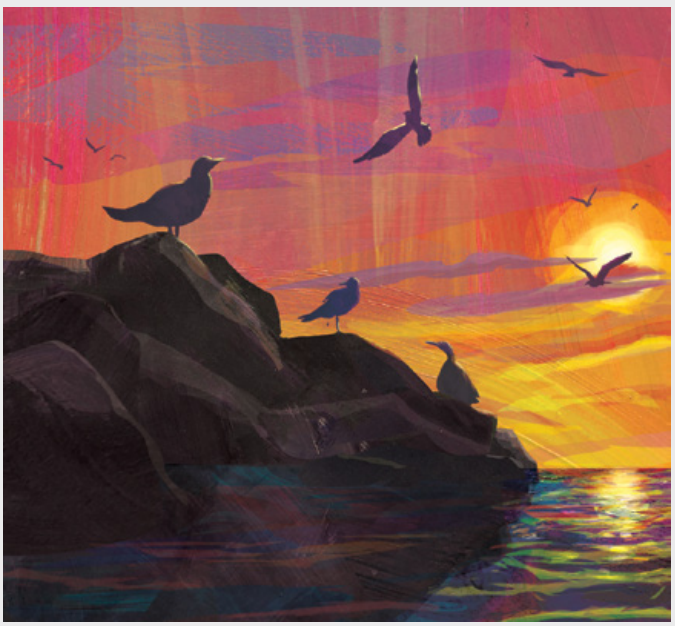
A surprising climate solution in wildlife restoration BY LUCY COOKE

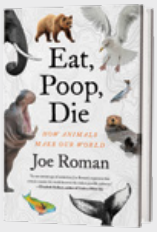
NONFICTION Looking across the Serengeti at herds of honking wildebeest, most of us would be awed by the exuberance of these migrating masses, resplendent in their magnitude. Not Joe Roman. The conservation biologist sees a vital distribution network that flows through the bodies of all those grazers, dispensing valuable mineral resources across ecosystems. To put it another way, Roman sees dumped feces and rotting carcasses.

To Roman, these features are no less wonderful. The author is something of a whale scat specialist, having spent 20 years collecting their excrement. "At times, they sparkle with scales, like the sun glinting on the water. Every whale defecation is unique," he writes. Long ago Roman had a hunch that whales played a crucial role in moving nutrients from seabed to surface. The whales would dine on krill at the bottom of the ocean, then rise up to breathe and relieve themselves, releasing great clouds of fertilizer to feed the phytoplankton at the top, which in turn fed the krill.

In the same way that trees function as Earth's lungs, migrating animals—eating, pooping and dying along the way—circulate nitrogen and phosphorus from deep-sea gorges to mountain peaks and from the poles to the tropics. These elements form the basic building blocks of DNA and help to power our cells. "Animals are the beating heart of the planet," Roman tells us. This becomes evident at the start of the book, when he visits the island of Surtsey off the coast of Iceland.

Surtsey was formed by a volcanic explosion in 1963, making the island younger than most of the scientists studying it. This fresh land offered an opportunity to document how animals build an ecosystem, poop by poop. The pioneers are the seabirds, whose fishy guano provides a nutritive anchor for air and seaborne seeds. Their feathers harbor invasive invertebrates, which in turn attract insect-eating birds. Then come the gray seals, whose fecal plumes generate green algal blooms that can be seen from space.





Eat, Poop, Die: How Animals Make Our World by Joe Roman. Little, Brown Spark, 2023 ($30)

All this guano doesn't just spark life; it also can change the weather. The stench of ammonia hooks up with sulfur to form droplets that coalesce into dense clouds, reflecting the sun. Colonies of seabirds, then, are helping keep the Arctic cooler and dampening the effects of climate change "one splat at a time."

Measuring the impact of guano may seem unglamorous—the ultimate crappy job, even—which may explain why such systems went overlooked for so long. In the past decade their study has sprouted a fresh science called zoogeochemistry. Roman travels the world to uncover salmon, bison and hippopotamus conveyor belts that nourish trees, savannas and rivers. He deftly dissects these otherwise invisible relationships with infectious curiosity—and a healthy dose of potty humor—to reveal the exquisite interconnectedness of life and death.

Not all waste is welcome, however. On the island of Surtsey, researchers are forced to perch atop lava boulders to deposit theirs straight into the crashing ocean. This strategy became necessary after an errant tomato plant sprouted from a visitor's night soil back in the 1960s. Elsewhere, human contamination has been significantly more catastrophic.

"The arrival of humans was like the onset of coronary disease to the animal circulatory system," Roman writes. Humans and the domestic animals we consume today account for 96 percent of all mammals and 70 percent of all the birds on this planet. Together we produce about eight trillion pounds of poop a year. That's too much waste to simply wash away.

Humans have become the architects of giant industrial loops that push biological cycles over planetary boundaries. The artificial sequestering of nitrogen into fertilizer sparked a green revolution that enabled the human population to double. Phosphorus dug up in Morocco and dumped on agricultural land in the U.S. runs off into oceans causing algal blooms the size of Connecticut that suffocate all other marine life.

There is hope for change, however, and it starts with altering our relationship with our own bodily waste. Recycling urine, for example, could offset 13 percent of the demand for agricultural fertilizer and generate enough energy to power 158 million households. It would also save thousands of gallons of freshwater from being flushed down the toilet and reduce those suffocating algal blooms.

Roman sees the restoration of wildlife as equally essential. When sea otters were reintroduced to an Alaskan island, they triggered a trophic cascade that led to the return of offshore kelp. As well as harboring hundreds of biodiverse species, these towering algal forests also sequester carbon. Anecdotes like these help to make this one of those rare books that truly changes the way you look at the world.

Lucy Cooke is a zoologist, documentary filmmaker, author, and National Geographic Explorer based in Britain.

Illustration by London Ladd

A Space Settler Walks into a Dome ...

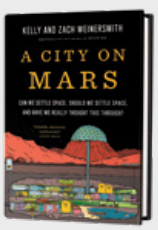
A very funny book about why living on Mars is a terrible idea

NASA/Pat Rawlings/SAIC

NONFICTION If the space race in the 1960s was solely about geopolitics, the latest rush off Earth is, at least at times, about something slightly more ineffable. By building a future in space, human society has a chance to reinvent itself, to forge something different—and maybe better. Right?

For their latest book, the husband-and-wife team—Kelly Weinersmith is a biologist, and Zach Weinersmith is a cartoonist who draws the Saturday Morning Breakfast Cereal comic—spent four years researching how humans are becoming space settlers. During that time, they began referring to themselves as "space bastards" because they found they were more pessimistic than almost anyone else in the spacefaring industry. The result is a breezy peek at the near-term future of humanity in space, and the upshot is that this future is as cold, dark and unfriendly as the cosmos itself. "Space: quite bad," the Weinersmiths declare.

The authors write in a witty voice that still commands authority, like a middle school science teacher who celebrates Pi Day but most assuredly wants you to accurately calculate circumference. Many nonfiction books about space, especially the history and future of exploration, are suffused with an almost religious degree of optimism and zeal. The Weinersmiths are not optimistic, but their book remains approachable rather than overtly cynical. It helps that the chapters read like a conversation over drinks, where the writers are as comfortable discussing the ramifications of sex on Mars as they are expounding on the economies of coal towns in early 20th-century Appalachia.



A City on Mars: Can We Settle Space, Should We Settle Space, and Have We Really Thought This Through?
by Kelly Weinersmith and Zach Weinersmith. Penguin Press, 2023 ($32)

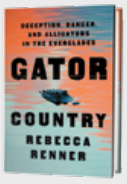
Alongside the lighthearted tone, the illustrations on nearly every page lend a surprising amount of heft. Even when the cartoons can't fully explain the phenomena the authors are describing, the drawings are still delightfully useful. In one example, the Weinersmiths describe harmful cosmic radiation, contrasting DNA-damaging charged particles to the width of a human hair, which is about 50 microns across. The cartoon is labeled as "not even kind of sort of vaguely close to scale," which manages to convey tininess that is inherently difficult to grasp.

As the Weinersmiths grapple with psychology; rotating space stations; inhospitable worlds; the truth about space diapers; and the inevitability of space politics and, perhaps, war, you can tell they are doing so only half-cheekily. "There's no political corruption on Mars, no war on the Moon," they write in the opening lines. The subtext is that we're humans, so we'll probably get there. Or maybe, they say, we should consider the rarely discussed alternative: hanging out here, in the grass, by our home.

—Rebecca Boyle

IN BRIEF

Gator Country: Deception, Danger, and Alligators in the Everglades
by Rebecca Renner. Flatiron Books, 2023 ($29.99)



Journalist Rebecca Renner returns to her home state of Florida determined to uncover the truth (if any) behind the exploits of a legendary Everglades alligator poacher. She also follows a reclusive wildlife officer's infiltration of a poaching operation. As Renner wades through the complex tangle of gator poaching's social, political and cultural roots, she stirs up the cloud of assumptions lurking within our attitudes toward nature and the proper stewardship of its resources. Filled with vivid descriptions of Florida's wild places and backcountry cultures, this well-paced account both celebrates and transcends its iconic swamps.

—Dana Dunham

The Blue Machine: How the Ocean Works
by Helen Czerski. W. W. Norton, 2023 ($32.50)

Learning, it's often said, begins with realizing how much you don't know. *The Blue Machine* proves this saying about the ocean, a behemoth that, superficially, may appear monolithic. Helen Czerski shows that forces such as temperature, gravity and salinity not only create an endlessly varied seascape but also shape life and conflict on Earth. Despite focusing on a terrestrial system, her descriptions of invisible physics and the deep sea frequently evoke the otherworldly. Like an early underwater explorer, a reader taking in the book's teachings will feel like "a land mammal cast fully into this alien world of seawater."

—Maddie Bender

Same Bed Different Dreams
by Ed Park. Random House, 2023 ($30)

Ed Park's acerbic commentary permeates what is three novels rolled into one. First, hasbeen Korean American writer Soon Sheen now works for GLOAT, which uses algorithms to extract every last iota of information from customers. Second, Sheen reads the magnum opus of a rising star Asian writer, *Same Bed Different Dreams,* which offers snippets of alternative history of the supersecret Korean Provisional Government, established in 1919 under Japanese occupation. Third, an African American sci-fi pulp writer composes a space opera about the end of the world set in 2333. Park's triumvirate taps into humanity's desire to rewrite history and into the chilling reach of technology.

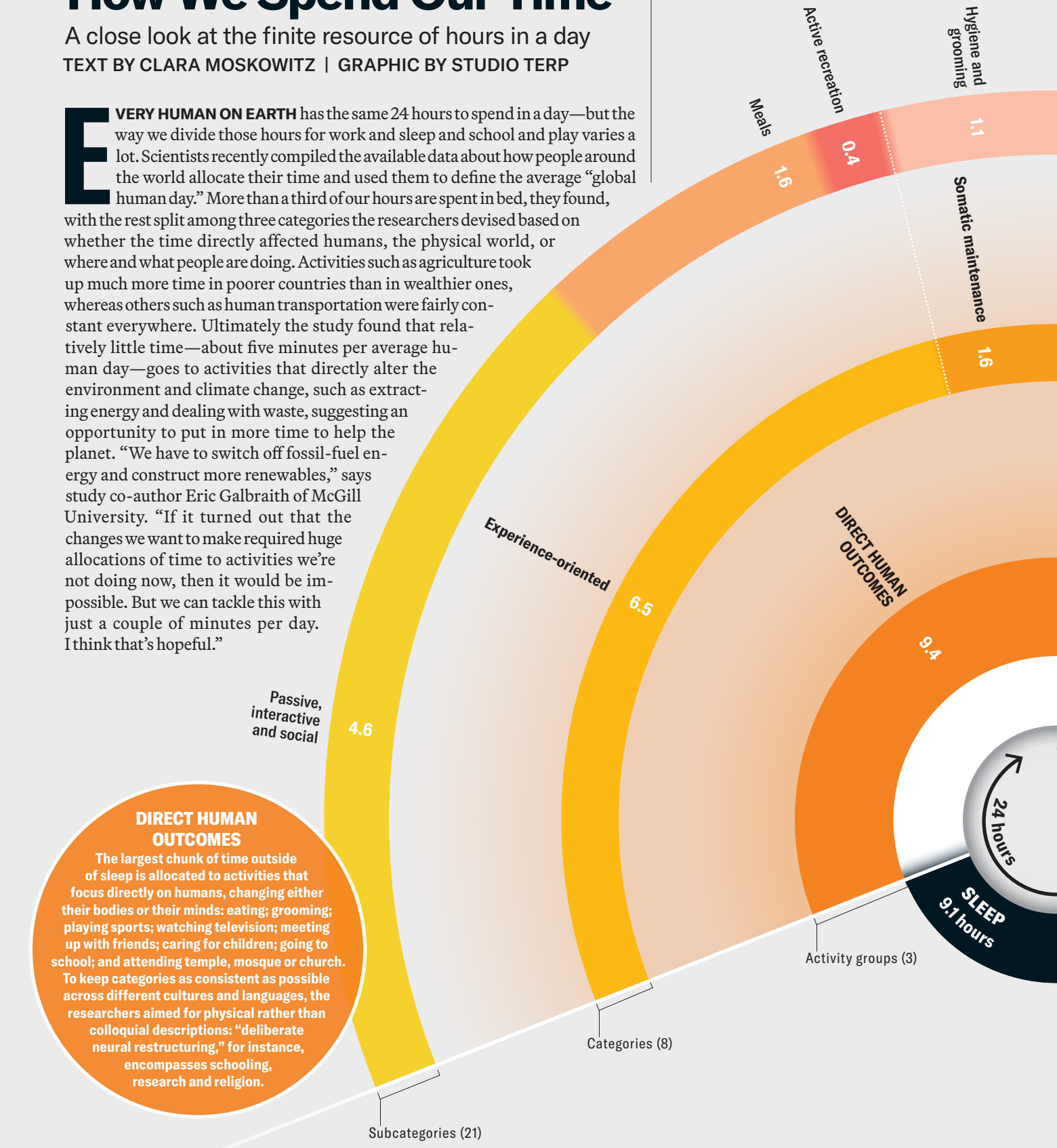
—Lorraine Savage

How We Spend Our Time

A close look at the finite resource of hours in a day

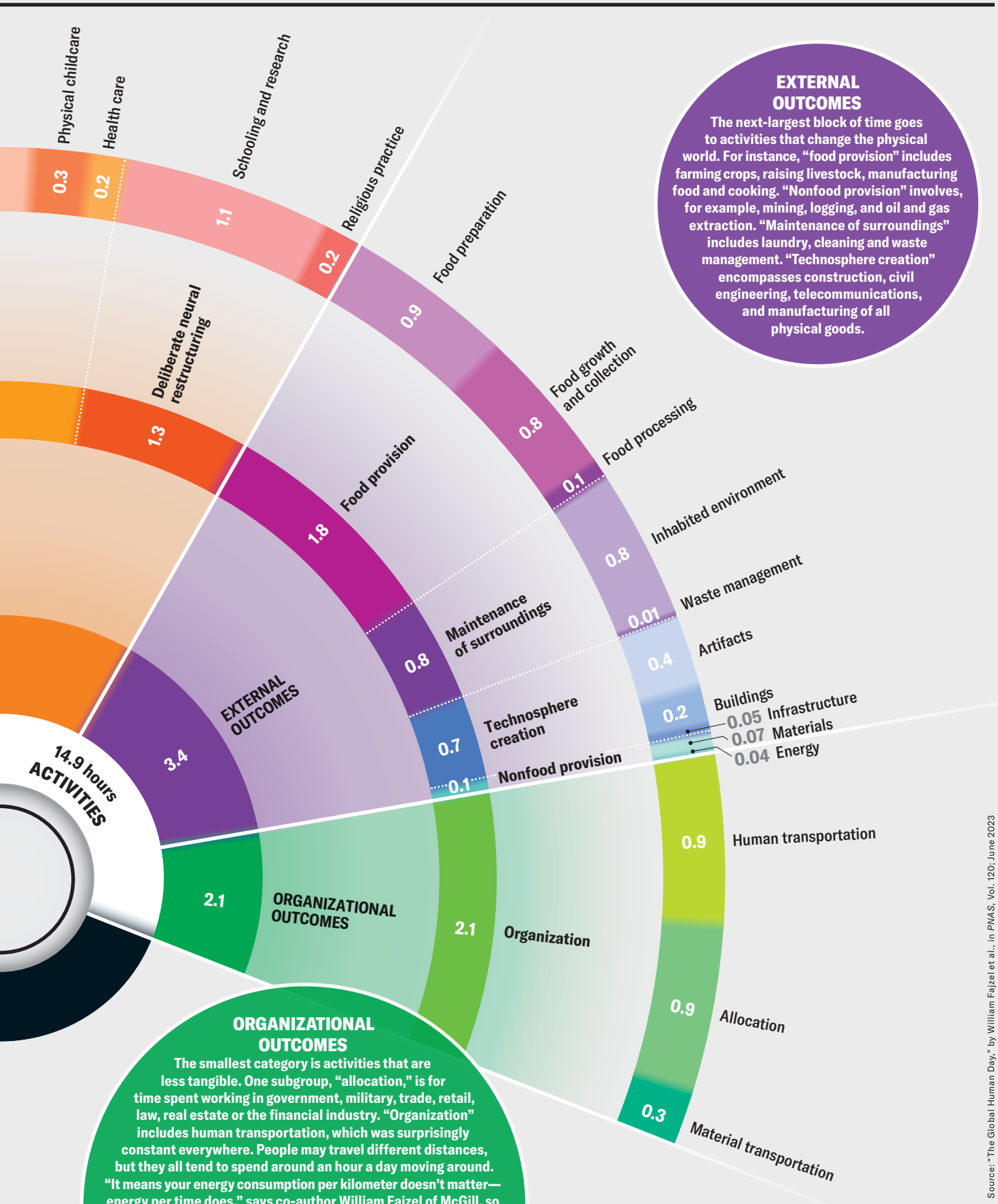
TEXT BY CLARA MOSKOWITZ | GRAPHIC BY STUDIO TERP

EVERY HUMAN ON EARTH has the same 24 hours to spend in a day—but the way we divide those hours for work and sleep and school and play varies a lot. Scientists recently compiled the available data about how people around the world allocate their time and used them to define the average "global human day." More than a third of our hours are spent in bed, they found, with the rest split among three categories the researchers devised based on whether the time directly affected humans, the physical world, or where and what people are doing. Activities such as agriculture took up much more time in poorer countries than in wealthier ones, whereas others such as human transportation were fairly constant everywhere. Ultimately the study found that relatively little time—about five minutes per average human day—goes to activities that directly alter the environment and climate change, such as extracting energy and dealing with waste, suggesting an opportunity to put in more time to help the planet. "We have to switch off fossil-fuel energy and construct more renewables," says study co-author Eric Galbraith of McGill University. "If it turned out that the changes we want to make required huge allocations of time to activities we're not doing now, then it would be impossible. But we can tackle this with just a couple of minutes per day. I think that's hopeful."



DIRECT HUMAN OUTCOMES

The largest chunk of time outside of sleep is allocated to activities that focus directly on humans, changing either their bodies or their minds: eating; grooming; playing sports; watching television; meeting up with friends; caring for children; going to school; and attending temple, mosque or church. To keep categories as consistent as possible across different cultures and languages, the researchers aimed for physical rather than colloquial descriptions: "deliberate neural restructuring," for instance, encompasses schooling, research and religion.



EXTERNAL OUTCOMES

The next-largest block of time goes to activities that change the physical world. For instance, "food provision" includes farming crops, raising livestock, manufacturing food and cooking. "Nonfood provision" involves, for example, mining, logging, and oil and gas extraction. "Maintenance of surroundings" includes laundry, cleaning and waste management. "Technosphere creation" encompasses construction, civil engineering, telecommunications, and manufacturing of all physical goods.

ORGANIZATIONAL OUTCOMES

The smallest category is activities that are less tangible. One subgroup, "allocation," is for time spent working in government, military, trade, retail, law, real estate or the financial industry. "Organization" includes human transportation, which was surprisingly constant everywhere. People may travel different distances, but they all tend to spend around an hour a day moving around. "It means your energy consumption per kilometer doesn't matter—energy per time does," says co-author William Fajzel of McGill, so getting people to spend their transportation time walking instead of driving will help more than improving cars' gas mileage.

Source: "The Global Human Day," by William Fajzel et al., in *PNAS*, Vol. 120; June 2023

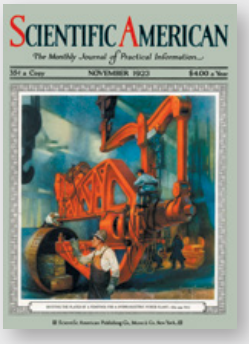
50, 100 & 150 Years

MAYAN ASTRONOMERS PREDICTED ECLIPSES

1973 "The Maya were skilled naked-eye astronomers. It now seems that they could even forecast eclipses of the sun. That is the conclusion of a new analysis of the 'Venus Table' and the 'Lunar Table' contained in the Maya book the Dresden Codex. Calculating in multiples of their own 260-day 'sacred year,' Maya astronomers appear to have detected two different kinds of periodicity in the recurrence of eclipses: a 'short' interval of 9,360 days (36 sacred years) and a 'long' interval of 11,960 days (46 sacred years). For solar eclipses visible in Central America, the table would have provided satisfactory predictions from A.D. 42 to 886."

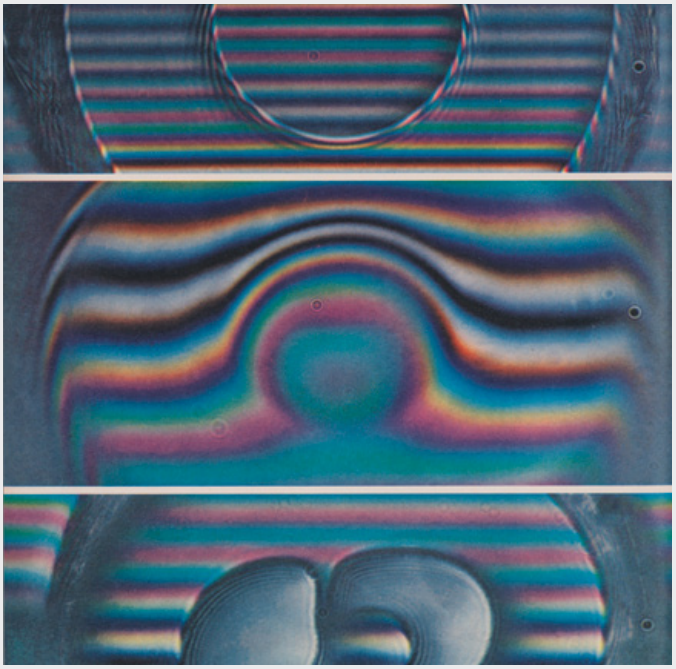
SOURDOUGH BACTERIA

"Early prospectors in the American West carried the ingredients of a highly acidic bread that earned them the name 'sourdoughs.' The bread is now baked commercially in San Francisco, but only recently was the organism responsible for its characteristic sourness identified. Leo Kline and T. F. Sugihara of the U.S. Department of Agriculture found a fortuitous combination of a yeast—*Saccharomyces exiguus*—and a bacterium, apparently of the genus *Lactobacillus.* For rapid growth the bacteria require the sugar maltose, from which they produce lactic acid and acetic acid, which account for the sour taste. The yeast is tolerant of this acidic environment, and it ferments carbohydrates other than maltose to produce the carbon dioxide that leavens the bread. The name proposed for the new species is *Lactobacillus sanfrancisco.*"



ANESTHESIA FROM SLEEPING FLOWERS

1923 "As far back as 1908 florists complained that carnations when placed in greenhouses would go to sleep, and those which had not opened would fail to do so, causing great loss in their business. Investigation proved that ethylene from leaky gas fixtures was the cause. This led Dr. Luckhardt and Mr. Carter of the University of Chicago recently to test the gas as an anesthetic. The gas was tried first on numerous animals. The experimenters then tried it on themselves. They describe the effect of the gas mixed with oxygen as giving a sense of well-being. They became unconscious and then recovered. Several students then volunteered. Subjects had pins thrust through their arms, and were pinched severely enough to leave black and blue areas. It is claimed that the new anesthetic gives loss of sensation without any sign of asphyxia, shortness of breath or effect upon the blood pressure. The only after-effect was slight weakness and slight nausea."



1973, Optical Fibers: "Rapid progress is being made toward a system in which a light signal will be transmitted through a hairlike optical fiber with little loss. The photographs show the refractive-index characteristics of three kinds of fiber, magnified about 500 times: a fiber with an inner core and an outer cladding (*top*); a parabolic-index fiber (*middle*); a single-material fiber (*bottom*). The gray shapes are air."

NO NEUTRONS (YET)

"We have gradually learnt that electricity exists in two forms, the negative form, which is called an electron, and the positive form, which is now beginning to be called a proton. The material universe seems to be built of these two elements. Both the electron and the proton are very much smaller than an atom of matter. Both probably have weight, though the proton weighs as much as 1,830 electrons. But it is not appreciably bigger. The fact is, we do not know much about it. Whether the proton is an ultimate unit, or whether it can be resolved into a close-packed assemblage of simpler ingredients, which would account for its remarkable weight or massiveness, remains for future discovery."

CAN BIRDS SENSE CHOLERA?

1873 "It is probable that birds, in some manner, become aware of cholera infection in the air. Recent European journals state that at Munich, where several cases of cholera have occurred, the rooks and crows, which flew about the steeples and through the trees of the public promenades, have all emigrated. The same thing happened during the cholera seasons of 1836 and 1854. The same phenomena occurred at Mauritius, where the martins, which exist in immense numbers the year round, wholly disappeared during the prevalence of the cholera."

Scientific American, Vol. 229, No. 5; November 1973

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