ScienceNews

CROWD CONTROL CHEMISTRY

Tear gas and pepper spray may have lasting health impacts

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Contents

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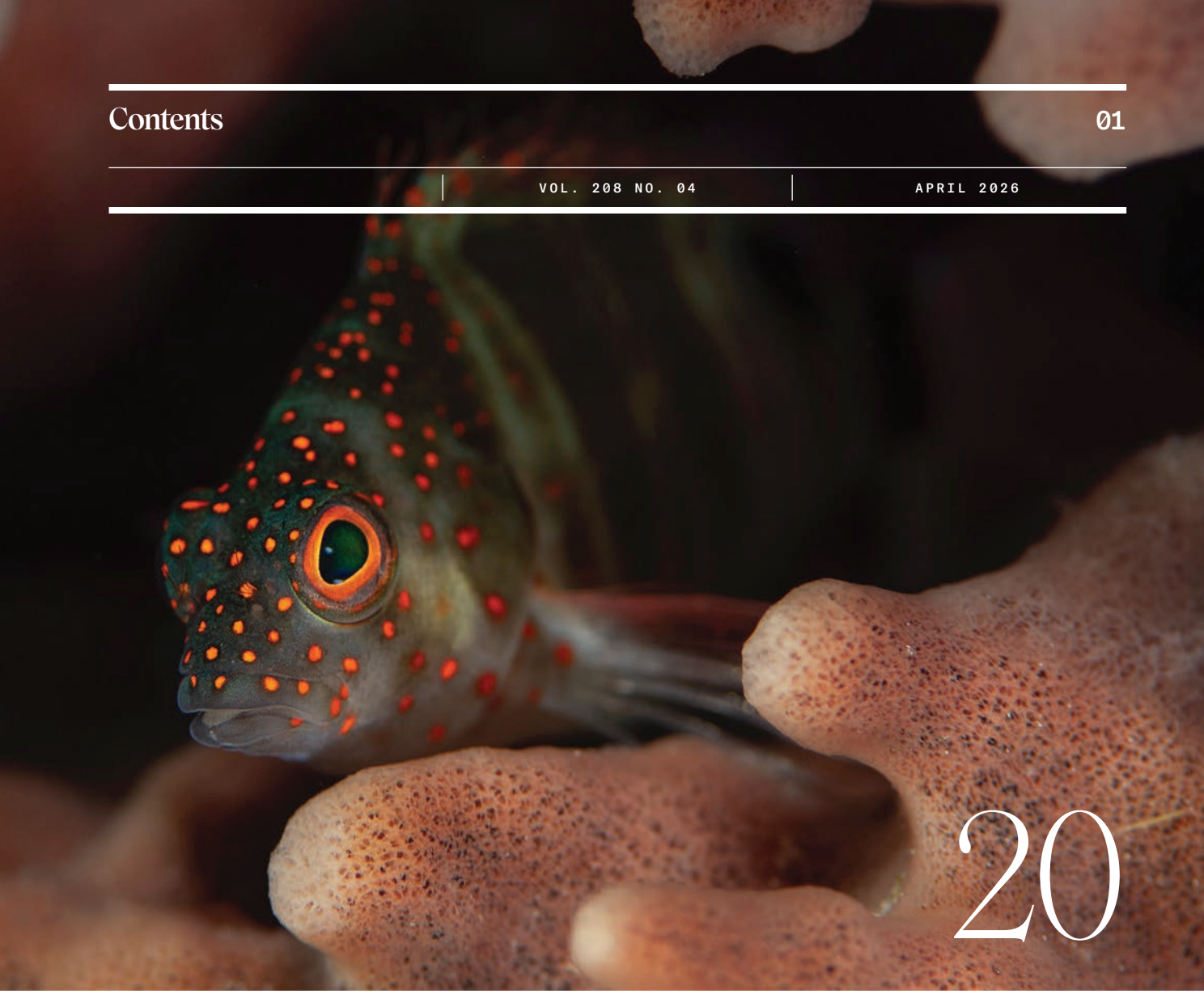

20

News

On the Cover

Tear gas engulfs a No Kings protestor in Los Angeles in June 2025. PHOTO BY APU GOMES/GETTY IMAGES

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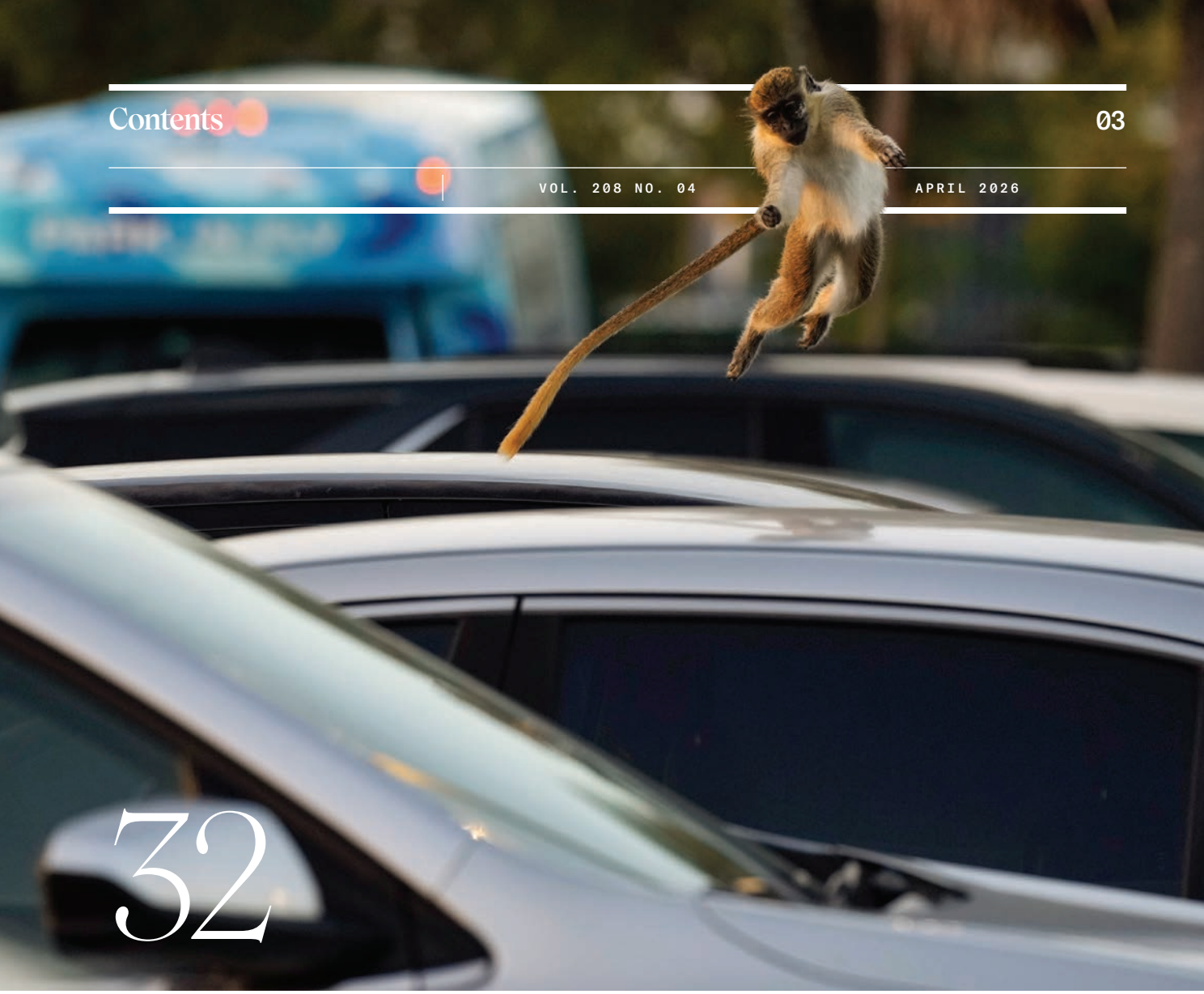
VOL. 208 NO. 04 APRIL 2026



32

Features

Curiosities

FROM TOP: REBECCA BLACKWELL/AP PHOTO; TUNG NAM

Science and armed conflict

Science has been intertwined with armed conflict for centuries. The Greek despot Dionysius the Elder of Syracuse is thought to have invented the catapult around 400 B.C., a technology upgrade that changed the course of battle through medieval times. Alchemists in China invented gunpowder around A.D. 850; initially used in fireworks, its use in cannons and handheld firearms followed. European forces enlisted hot air balloons for attacks and reconnaissance not long after they were invented in the 18th century. And airplanes were key to the course of World War II, including dropping atomic bombs on Japan in 1945.

In this issue, we examine the health effects of tear gas, which evolved from being one of the first chemical weapons made for World War I to a tool for civilian crowd control. In a bizarre twist, one of its first uses in the United States was against World War I veterans protesting delays in bonus payments from the federal government.

Though tear gas is sometimes considered more benign than other crowd control tools such as rubber bullets, it may cause long-term health problems, staff writer Nikk Ogasa reports (Page 40). Quantifying that risk has become salient due to the widespread use of tear gas against people protesting U.S. administration actions.

Connections between science and civil protest also resonate in space exploration, astronomy writer Lisa Grossman notes (Page 60). In gearing up to cover this year's Artemis II moon flyby, she imagined the mission as a unifying moment, like the 1969 Apollo 11 moon landing. The impact of U.S. Immigration and Customs Enforcement actions on her Minneapolis neighborhood made her question that premise. It turns out that people also questioned the value of Apollo 11, at a time when the country was riven by conflicts over civil rights and the Vietnam War. *Science News*' top editor was among them.

"It is impossible to minimize the astronauts' accomplishment," Warren Kornberg wrote in the July 26, 1969, issue. "But the verdict of history may well be that, while the world erupted, we ignored the real challenge and chased a rocket trail to the moon."

There's much to question in the world's current state. Finding value in supporting our fellow humans and in doing groundbreaking science should be a given.

Nancy E. Shute

Nancy Shute
Editor in Chief
nshute@sciencenews.org

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VOL. 208 NO. 04 | APRIL 2026

FREDA KREIER

FREELANCE SCIENCE JOURNALIST

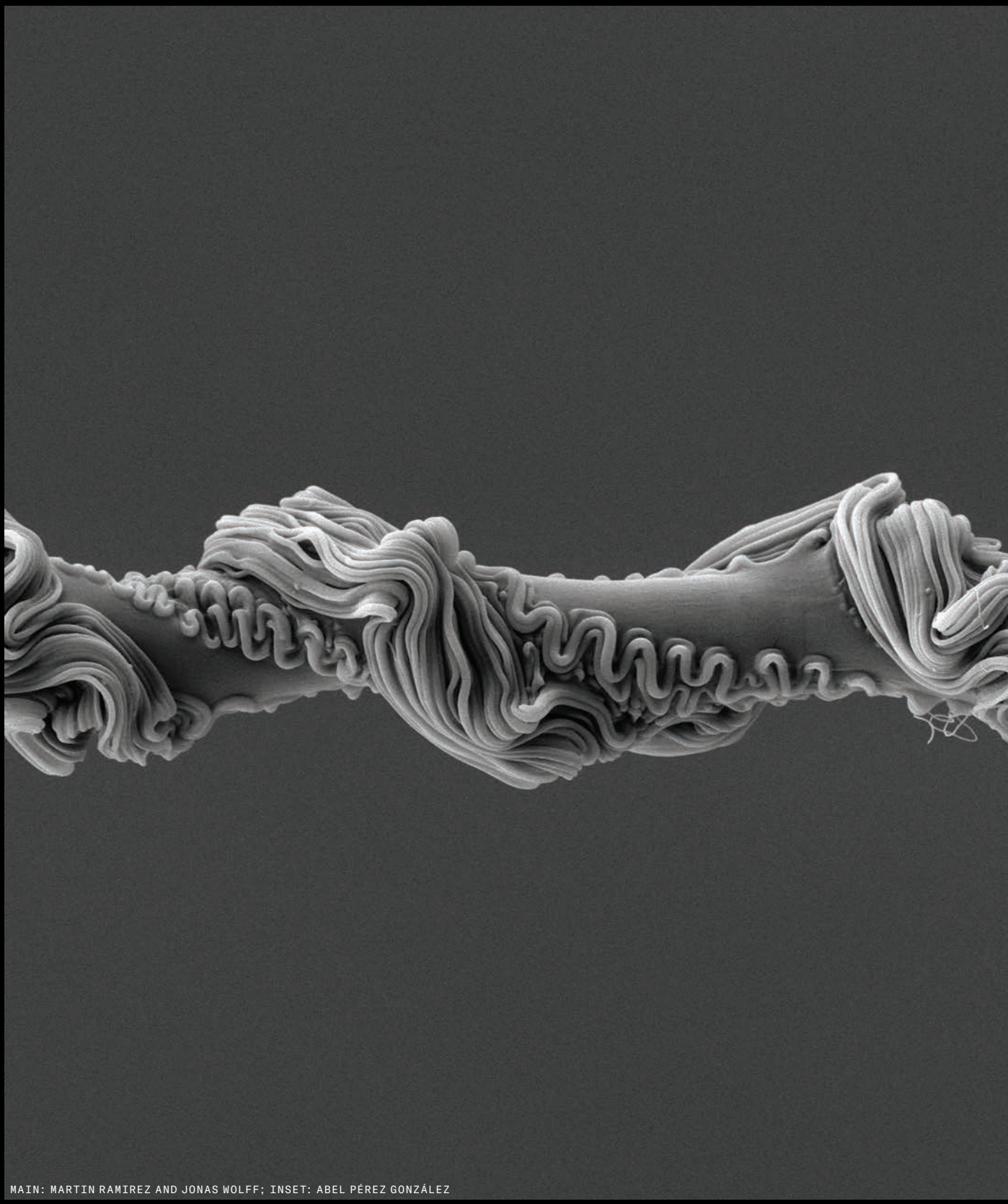
● WILD AFRICAN VERVET MONKEYS have called Florida home for decades, but they are still considered potentially harmful to the native ecosystem. Freda Kreier reports on the tension between people who want to protect the primates and those who don't (Page 32). Some scientists studying invasive species didn't return emails or refused to talk when Kreier reached out, fearing harassment. She understands what that's like. When she wrote about efforts to control invasive caimans, also in Florida, for the *New York Times* in 2023, Kreier received hate mail. Kreier hopes *Science News* readers will come away from her new story with a nuanced understanding of a complex subject. "These creatures are beloved, but they're also part of a larger issue that is very real," she says.

Erin Garcia de Jesús
Microbiologists are fretting over the future of tiny organisms in a warming world, staff writer Erin Garcia de Jesús reports (Page 48). The effects of climate change on people, plants and animals may capture a lot of attention, "but microbes have to do with everything that happens on this planet," Garcia de Jesús says. So if the changing climate harms microbial livelihoods, any effects could ripple to other branches on the tree of life. But the scientists aren't all doom and gloom, she says. "They say that the more we understand about this, the more we can think about solutions."

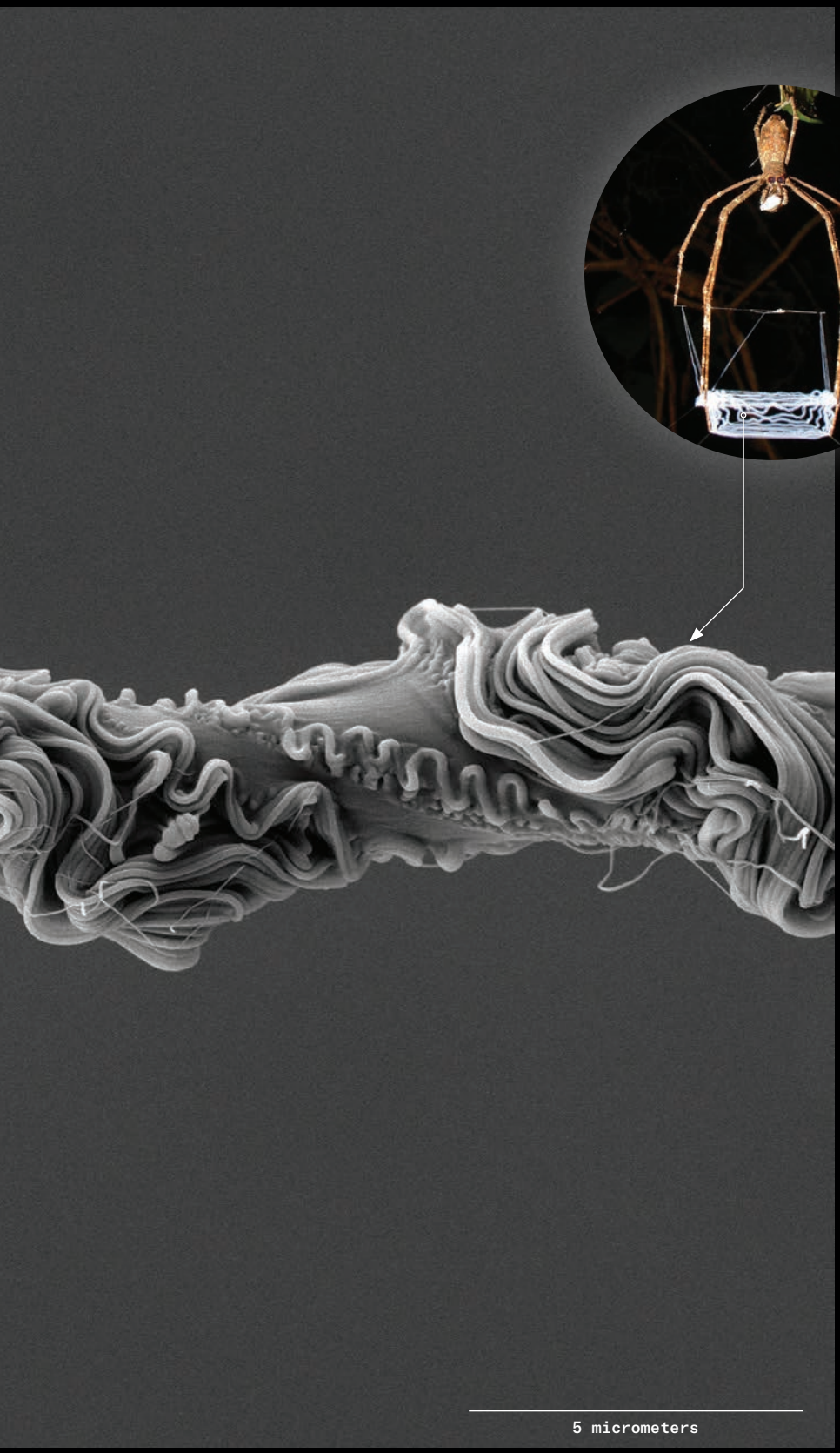
Carolyn Gramling
When Earth and climate writer Carolyn Gramling learned about an upcoming manga entitled *Snowball Earth*, "it immediately struck a chord with me," she says. In earth science, "Snowball Earth" refers to a specific period of time when our planet was mostly covered by ice. In this issue's Technically Fiction (Page 62), Gramling assesses three fictional works that imagine our planet as a frozen world. As a self-professed nerd and geek, she enjoyed this exploration. But when asked if any of these catastrophic climate stories haunt her, Gramling says: "The real world keeps me up at night."

Tung Nam
When *Science News* reached out to illustrator Tung Nam, who goes by Lam, about providing art for Technically Fiction, he was elated. Snow holds a special place in his heart: Lam's first collection imagines snowy landscapes in his hometown, Hanoi, Vietnam, where it never snows. "I was feeling blue at that time, feeling lonely, so I used snow as a metaphor to represent what I was feeling," Lam says. He thinks snow in Hanoi is unlikely. But Sa Pa, a northern town with the country's highest mountain, started getting snow in recent years. That wouldn't have happened a decade ago, Lam says. "So maybe I'll see snow in Hanoi before I die."

CLOCKWISE FROM TOP LEFT: F. KREIER; SOCIETY FOR SCIENCE; SOCIETY FOR SCIENCE; TUNG NAM



MAIN: MARTIN RAMIREZ AND JONAS WOLFF; INSET: ABEL PÉREZ GONZÁLEZ



MATERIALS SCIENCE

THE PHYSICS OF STRETCHY SPIDER SILK

By Emily Conover

● **For spiders that fling their webs** at prey, a sturdy net is essential.

Rufous net-casting spiders (*Asianopis subrufa*) dangle upside down, clutching a web in their legs before snapping it over an unsuspecting insect. In a tenth of a second, sections can stretch up to 24 times their original area without breaking.

That balance of strength and stretchiness comes from the net's architecture, researchers report in the *Proceedings of the National Academy of Sciences*. Electron microscope images (one shown) reveal loops of silk wrapped around a stretchy core fiber. As the strand elongates, the loops straighten and reinforce the core, keeping it from breaking. The spiders vary the amount of coiling across the web depending on how much each region must stretch.

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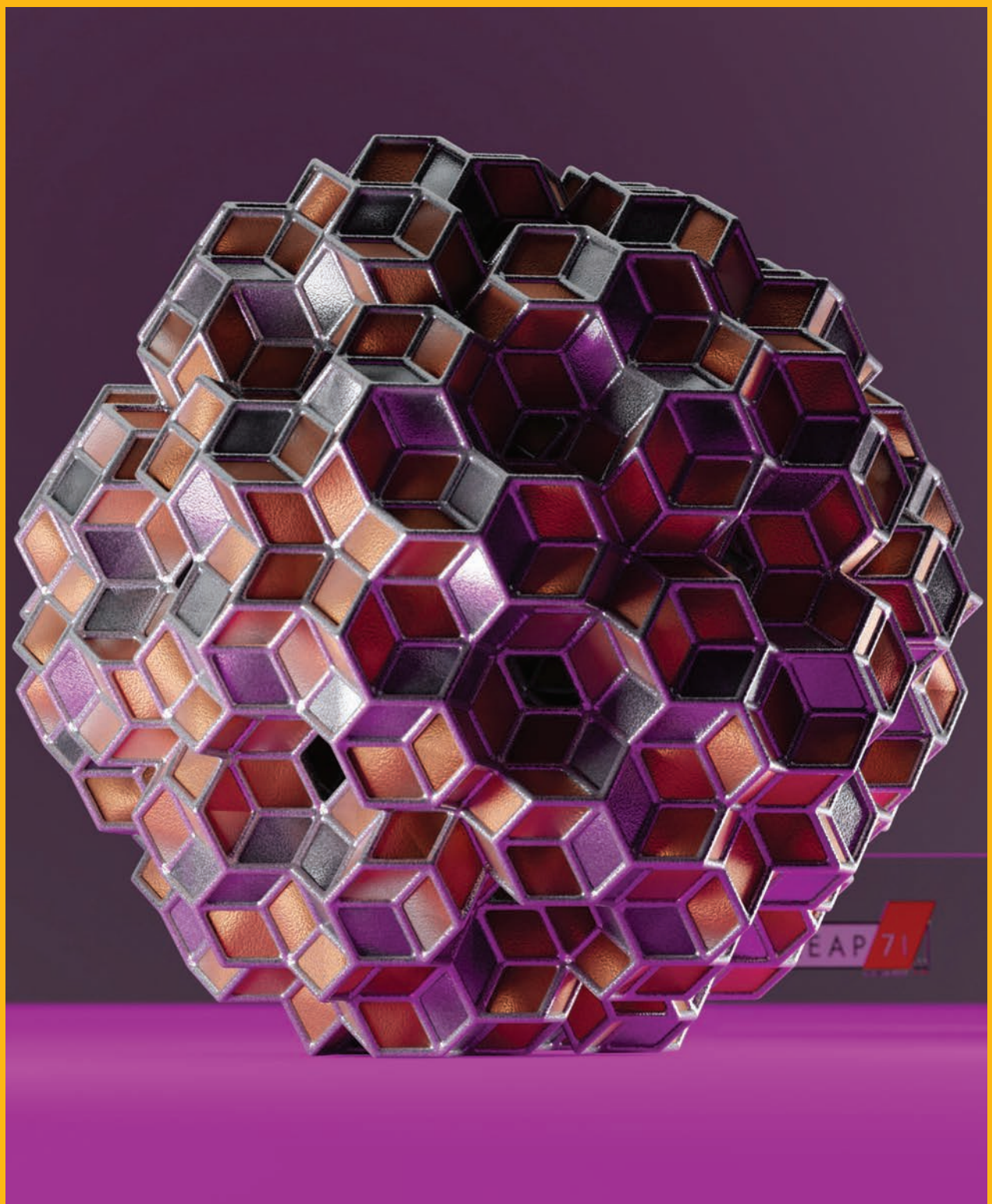
Scientists recently discovered that quasicrystals, orderly structures that don't repeat, could bridge space and time (see Page 19).

News



CLIMATE

CHOICES MADE TODAY WILL DETERMINE ANTARCTICA'S FATE FOR CENTURIES TO COME

BY CAROLYN GRAMLING

The Antarctic Peninsula is an early warning system for the southernmost continent when it comes to climate change. And the prognostications are grim — but it's not yet too late to avoid irreversible changes, researchers report in *Frontiers in Environmental Science*.

Glaciologist Bethan Davies and colleagues documented how the peninsula is already transforming as the planet warms and then assessed how different amounts of warming by 2100 could alter the peninsula's fate — with consequences for its marine and terrestrial ecosystems, land and sea ice, ice shelves and extreme weather events. Those global warming estimates — of 1.8, 3.6 and 4.4 degrees Celsius relative to preindustrial times — are based on three what-if scenarios of future greenhouse gas emissions.

"The Antarctic Peninsula is really the alarm bell for the continent," says Davies, of Newcastle University in England. The peninsula is relatively small but is disproportionately important due to fisheries, tourism and scientific research.

"Changes that happen in the Antarctic Peninsula also don't stay in the Antarctic Peninsula," Davies says. Retreating glaciers in the southern part of the peninsula can make glacial ice in West Antarctica more vulnerable to melting. Decreased sea ice around the peninsula increases warming around the Southern Ocean more broadly. That, in turn, can slow down the formation of a water mass that links the Southern Ocean to global ocean circulation. Less sea ice also means fewer krill, crustaceans at the base of the Southern Ocean food web.

In 2019, with Earth's average temperature about 1.2 degrees C above preindustrial times, the Antarctic Peninsula was already seeing significant changes. Relatively warm water swirling near the peninsula was speeding up melting; several massive chunks of ice had broken off of the mainland glaciers. But the nearby ocean food web, dependent on sea ice and krill, was still intact.

"Unfortunately, we're now at about 1.4 degrees of warming," Davies says. Limiting future warming to no more than 1.5 degrees has been targeted as a best-case scenario for the planet. In November, the United Nations indicated that there is now no chance the world will stay in that limit, as nations continue to not meet their own emissions reduction targets.

B. DAVIES

↗ The fate of the Antarctic Peninsula, and of wildlife such as this gentoo penguin, looks very different under three global warming scenarios.

Under a new best-case scenario of 1.8 degrees of warming by 2100, the Southern Ocean food web shrinks as winter sea ice shrinks and ocean temperatures rise, Davies' team found. Species less dependent on krill, such as fur seals and elephant seals, or sea ice, such as gentoo penguins, become more abundant.

Warming by about 3.6 degrees by 2100 would drastically shrink sea

ice concentration, and more warm water would eat away at the peninsula's ice shelves. Extreme events, including ocean heat waves and atmospheric rivers, would become more severe and more frequent.

Under the worst-case scenario, with warming by about 4.4 degrees by 2100, sea ice coverage could shrink by about 20 percent, devastating krill-reliant species such as whales and penguins and warming ocean waters globally. The Larsen C ice shelf, which lost a Delaware-sized chunk of ice in 2017, would probably collapse fully by 2100. By 2300, the George VI ice shelf might collapse; it's now helping to hold back inland ice from draining to the sea. That could raise sea levels by as much as about 12 centimeters. Many of these changes would be irreversible, Davies says, at least on human timescales.

The study, says glaciologist Peter Neff of the University of Minnesota in St. Paul, "illustrates what decision makers worldwide should know: Every decision we make to reduce carbon emissions today makes the challenges of the future more manageable." ✖

Y. GARFINKEL

MATH

ANCIENT POTTERY SOWED SEEDS OF MATHEMATICAL KNOWLEDGE

By Tom Metcalfe

● Floral designs on roughly 8,000-year-old Mesopotamian pottery may be the earliest evidence yet of mathematical thinking.

Painted decorations on more than 350 fragments of pottery from the Halaf culture exhibit regular numbers of petals determined by a geometric progression, archaeologists report in the *Journal of World Prehistory*.

Patterns of flowers with four, eight, 16, 32 or 64 petals imply the designs were inspired by powers of two, argue Yosef Garfinkel and Sarah Krulwich, both of the Hebrew University of Jerusalem. "This is evidence of mathematical knowledge that we are not aware of from any other source," Garfinkel says.

Halafians may have developed this type of mathematics, based on the progressive doubling of numbers, to divide land or crops into equal shares, the scientists suggest.

Halafian mathematics differ from the mathematics pioneered by the Sumerians in roughly the same region more than 2,000 years later. While Sumerians' base-60, or sexagesimal mathematics, has largely been supplanted by base-10 mathematics, it is still used in timekeeping, astronomy and geometry. "What we have here is an earlier mathematical system, before sexagesimal," Garfinkel says. ✖

PHYSICS

THE STANDARD MODEL PASSES A PROTON TEST

By Emily Conover

● Confusion over the size of the proton has long held scientists back. Disagreeing measurements of the subatomic particle's radius meant that scientists couldn't test one of their key theories with the extreme precision they aimed for.

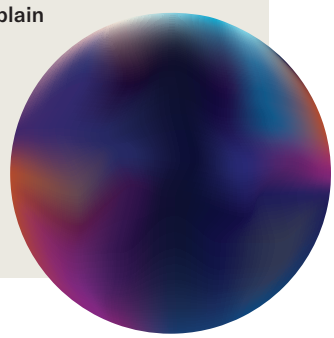
A new measurement pegs the radius of the proton precisely enough to enable a test of the standard model of particle physics, which describes subatomic particles and their interactions. The theory agreed with the experiment to better than a tenth of a billionth of a percent, physicists report in *Nature*.

Lothar Maisenbacher of the Max Planck Institute of Quantum Optics in Garching, Germany, and colleagues studied hydrogen atoms, measuring the frequency of the radiation needed to make the atom jump between two different energy levels. That information, combined with other measurements, revealed the proton's radius is about 0.84 trillionths of a millimeter.

The result agrees with a host of other measurements suggesting the proton (illustrated) is about 4 percent smaller than once thought. And the measurement is precise enough to rule out the old, larger radius.

The finding let the team test the standard model, which can predict the frequency of the radiation needed to make an atom jump between energy levels. Its prediction matched experimental observations.

Scientists eventually expect to find a test that the standard model fails. That's because it doesn't explain phenomena such as dark matter, the invisible stuff that binds galaxies together. ✖



ARTIFICIAL INTELLIGENCE

THIS AI PREDICTS HOW ONE TYPO CAN ALTER A GENETIC STORY

BY TINA HESMAN SAEY

A new deep learning AI model may help scientists better decipher the plot of the genetic instruction book and learn how typos alter the story.

AlphaGenome, created by Google DeepMind, is the latest in an ever-improving line of AI models built to analyze vast stretches of DNA. The previous front-runner, a model called Borzoi, could predict molecular signposts in stretches of DNA 500,000 bases long. AlphaGenome can analyze 1 million DNA building blocks at a time, researchers report in *Nature*.

The model may have practical implications for diagnosing rare genetic diseases, identifying cancer-driving mutations, designing synthetic DNA sequences or therapeutic RNAs and explaining basic biology.

"AlphaGenome is not just a bigger model in terms of context length, but it actually is quite a leap forward in its overall utility," says Anshul Kundaje, a computational biologist at Stanford University who develops AI models for genomics.

For instance, a genetic change may have no effect on nearby genes but could change activity of genes far away. Because AlphaGenome examines longer stretches of DNA, it is more likely to spot such long-distance relationships.

But AlphaGenome isn't perfect. Unpublished data from Kundaje's lab indicate the model struggles with predicting how gene activity changes in individuals. Right now, the model is a tool for uncovering basic biology, not something doctors could use to diagnose or treat patients.

It has "maxed out" what this type of model can do, Kundaje says. He predicts the next big leap will come from scientists generating new types of data for the model or its descendants to analyze.

AlphaGenome can pinpoint biologically important spots down to single base pair resolution, says computational biologist Peter Koo of Cold Spring Harbor Laboratory in New York. That's much higher resolution than Borzoi, which flagged points of biological interest in 32 base pair bins.

The task is a big one considering that AlphaGenome's reference is the 3-billion-base-long human genome, often called a

SHAUMIAA VECTOR/GETTY IMAGES

Right now, AlphaGenome is a tool for uncovering basic biology, not something doctors could use to diagnose or treat patients.

genetic instruction book. The book is actually a multivolume, choose-your-own-adventure, pop-up encyclopedia.

Genes, the short stories of the book, are told in small phrases that can be rearranged, shortened or skipped. In between the story fragments are passages that may contain instructions for how to read a different story entirely. Pages and chapters are intricately folded into each other so that pulling a tab in one passage causes something to pop up chapters away.

Much of the book is filled with what many people thought was nonsense but is often essential reading material. Researchers have cataloged a dizzying array of punctuation marks, origami-like creases, syntax swaps, margin scribbles and other types of biological grammar that cells use to make sense of the book.

AlphaGenome's task is to take a string of DNA letters and predict how plot points, punctuation and other variations affect 11 distinct biological processes, including RNA splicing, gene activity levels and certain protein–DNA interactions. The model considers 5,930 data points from studies of human DNA and 1,128 data points from mouse DNA. With those data, the AI can predict how changing a single letter, or base, in the million-base string alters the story.

Specialized computational models that predict subsets of these biological functions have been in use for years, but AlphaGenome outperforms them on most measures and does particularly well at identifying some features in different types of cells, the researchers report. For example, AlphaGenome identified gene activity changes in certain cell types about 15 percent better than Borzoi.

"By doing well on so many different genomic tasks simultaneously, we believe this demonstrates that the model has learned a powerful general representation of DNA sequences and the complex processes these sequences encode," Natasha Latysheva, a biologist and machine learning researcher at Google DeepMind, said during a news briefing.

The tool could make things easier for researchers who are trying to understand how the genome works, says human geneticist Judit García González of the Icahn School of Medicine at Mount Sinai in New York City. Before AlphaGenome, a researcher "might need to use three different tools with their own caveats, and [have] to learn how they work, for predicting, say, 20 different genomic functional consequences," she says. Now, AlphaGenome unites all those in one tool.

AlphaGenome isn't an entirely new invention. It builds on previous models but uses aspects of those models in clever ways. "There is no single innovation in AlphaGenome that one can pinpoint as a critical innovation. It's really a system of lots of tricks and engineering," Koo says.

AlphaGenome used one trick called ensemble distillation, which Koo's lab has been experimenting with. That strategy pretrains multiple copies of the model each on computationally mutated DNA. Those models serve as teachers to a single student model that averages their outputs.

It's like having 60 historians give their account of an important event, Koo says. "If you consider the consensus ... what overlaps across their story lines, that is probably what might actually be true."

The consensus, Koo says, "tends to be more reliable than trusting any individual model." ✖

THE HEALTH CHECKUP

GLP-1 MICRODOSERS CHASE LONGER LIVES

BY JAMIE DUCHARME

More than 10 percent of U.S. adults take GLP-1 drugs. But not all of them are taking full doses. Around 1 in 7 injectable GLP-1 users has "microdosed," a recent survey by the health tracking app Evidation found. Some take tiny portions for practical reasons, such as cutting costs. Others have loftier ambitions: They hope to harness the drugs' effects to achieve better health and longer lives without losing a dramatic amount of weight or experiencing side effects.

Medications such as Ozempic and Wegovy mimic the body's GLP-1 hormone, which helps regulate appetite, metabolism and blood sugar. That has made the drugs blockbuster treatments for type 2 diabetes and obesity. But to date, "there is no rigorous scientific data to support microdosing," says bariatric medicine specialist Katy Williams of the University of Missouri Health Care in Jefferson City.

That hasn't stopped some intrepid biohackers from trying it. Companies like AgelessRx, a longevity-focused telehealth clinic, explicitly sell GLP-1 microdoses for this purpose, advertising them as "a powerful new path to promoting long-term wellness."

There is some research to suggest GLP-1s can promote healthy aging by improving overall health. The drugs have been found to reduce inflammation and oxidative stress, lower risks of major cardiovascular problems and more. Such findings have prompted scientists to study the drugs as potential treatments for illnesses as diverse as Alzheimer's disease and arthritis. Some experts have even wondered whether the drugs' systemic effects might slow cellular aging and prevent age-related chronic conditions, potentially making them the first true longevity drugs to hit the market.

But science hasn't caught up to the hype. There's scant published research on GLP-1 microdosing, although some teams are studying it. A 2025 study in *JAMA Psychiatry* found that low-dose semaglutide, the active ingredient in Ozempic and Wegovy, might reduce alcohol cravings. And AgelessRx is enrolling participants in a clinical trial focused on how GLP-1 microdosing affects health and quality of life.

Some people aren't waiting around for data. That includes many patients of Shamsah Amersi, an obgyn in Santa Monica, Calif. Amersi discusses microdosing with all patients entering perimenopause, she says, and about 60 percent of her patients over 40 use a GLP-1 drug this way. Though the medications aren't right for everybody, she says, the majority of microdosers under her care feel better and see improvements on lab tests measuring metabolic and overall health. "GLP-1 is one of the most transformative therapies in modern medicine," Amersi says. She thinks patients can benefit from microdosing now, even without data to prove its efficacy, if they work with a doctor to carefully monitor their response.

Other experts remain wary. There isn't enough data to confirm that microdosing can help you live longer, says clinical pharmacist practitioner Anne Komé of the University of North Carolina Medical Center in Chapel Hill. But it could help clinicians optimize therapy for patients who have trouble affording the drugs or who struggle with gastrointestinal issues or other side effects, she says.

All medications come with potential risks and side effects. It's not worth taking that chance when benefits are unproven, Williams says. She'd rather longevity seekers focus on diet, exercise and sleep. Plus, people may be entering the Wild West if they buy GLP-1s online or from compounding pharmacies, she says. These outlets are regulated and inspected less strictly than major drug manufacturers, and customers can't always be sure that the label matches what's in the vial. "Save your money," Williams says. ✖

ERIK TANNER FOR TIME

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PALEONTOLOGY

Fossil vomit exposes an ancient ecosystem

By Jay Bennett

● **Some 290 million years ago**, in a mountain valley within the central region of the supercontinent Pangaea, an apex predator snapped up at least three other animals. Later, it puked up the bones.

That material hardened over the ages and is now the oldest fossilized vomit ever discovered from a land-based ecosystem. The cluster of bones and digestive material provides rare information about the behavior of some of the world's earliest land predators.

"It's kind of like a photograph of a moment in the past that is telling us about the animal that was living," says paleontologist Arnaud Rebillard of the Museum für Naturkunde Berlin. "Any data that we can find about their behavior is very precious."

Paleontologists discovered the lime-sized specimen in 2021 at the Bromacker locality, a Permian Period site in central Germany. Rebillard and colleagues scanned the bones to create 3-D models showing a cluster of parts from different animals, suggesting the remains had come from a predator's gut. The team also chemically analyzed the material surrounding the bones and found that it was low in phosphorus, suggesting it was not a fossilized dropping.

While the predator that regurgitated the bones is unknown, the researchers strongly suspect that it was one of two animals: *Dimetrodon teutonis*, with a prominent sail on its back, or the sail-less *Tambacarnifex unguifalcatus*. Though these creatures strongly resemble modern monitor lizards, such as Komodo dragons, they actually belong to synapsids — a group of animals that includes mammals and their extinct relatives.

Among the 41 disgorged bones, the researchers identified two small lizardlike reptiles and a limb bone from a larger reptilelike herbivore. This collection of remains, along with several unidentified bones, indicates that the predator

↖ **A lizardlike predator tossed its cookies millions of years ago. The fossilized vomit gives a glimpse of an ancient food web.**

CHARLIE TOQUÉ

ate whatever it could find rather than specializing in a specific type of prey.

Because the fossilized vomit, or regurgitalite, contains three different animals eaten by one predator, "we can literally say, for sure, that these three animals were living at exactly the same place and exactly the same time, maybe to the week or even to the day," Rebillard says.

Several living predators habitually regurgitate bones and other body parts that are tough to digest after eating. Scientists don't know if this is why the ancient animal spit up the bones, but it is one of the most plausible explanations along with simply overeating, Rebillard says.

Fossils of partially digested material, including regurgitalites, as well as fossilized feces, are valuable clues for studying Earth's past. "We need fossils like this to really tie together how the ecosystem functioned and how the food webs were structured," says Martin Qvarnström, a paleontologist at Uppsala University in Sweden who reviewed the study.

The German regurgitalite is particularly exciting because the Bromacker site preserves a snapshot of an early terrestrial ecosystem. Before this time, predators that could travel on land often lived in semiaquatic environments where they hunted crustaceans and fish. During the Permian Period, large herbivores became prominent in inland environments, followed by new predators. Fossil dung and vomit are much rarer in inland environs than in aquatic ones.

"We're talking about almost 300-million-year-old ecosystems," Rebillard says. "So to have such a temporal vision about this to the day they were living, in the same area and the same moment, is extremely fascinating." ✖

PHYSICS

PHYSICISTS DREAM UP 'SPACETIME QUASICRYSTALS'

BY EMILY CONOVER

Mind-bending materials called quasicrystals have an orderly structure, but without a regularly repeating pattern. They've been found in meteorites and the debris from the first atomic bomb test. Scientists have now discovered that they can theoretically inhabit an even stranger realm: spacetime, the blended mixture of time and space of Einstein's special theory of relativity.

Instead of existing in two or three spatial dimensions, these quasicrystals' structures would bridge space and time, physicists report in a paper submitted to arXiv.org. Although the quasicrystals are theoretical, the researchers suggest that such spacetime quasicrystals may appear in nature, perhaps even underlying the structure of the universe.

A crystal is a structure that repeats itself. If you make a copy of a crystal and slide it over on top of itself, you can find spots where the patterns match up perfectly. You can imagine doing the same with the tiles on your bathroom floor or the patterns on wallpaper. But quasicrystals, despite their seemingly orderly structure, don't have such regular repetition.

Crystals and quasicrystals are mathematical concepts that also appear in the real world, typically in materials with two or three dimensions. It wasn't obvious that spacetime quasicrystals could exist.

"My feeling was probably it wouldn't be possible to make a proper spacetime quasicrystal," says theoretical physicist Felix Flicker of the University of Bristol in England. But the researchers appear to have done just that, he says. "The things they've come up with are ... the most elegant things you can have in spacetime as a combined entity."

Despite quasicrystals' lack of repetition, their orderliness means that their general characteristics are similar in different locations. An ant sitting atop one portion of a quasicrystal would see a structure similar to that seen by an ant in a different location. But different spacetime realms are another matter.

Spacetime obeys a rule known as Lorentz symmetry. Lorentz symmetry means that something is CONT. ON PAGE 20

CONT. FROM PAGE 19 unchanged whether you're sitting still or moving at close to the speed of light. For example, the laws of physics respect Lorentz symmetry: They don't change for fast-moving observers. Lorentz symmetry doesn't hold for previously known quasicrystals, or for normal crystals either: An ant sitting still would observe a different structure than would a near light-speed ant. In relativity, observers traveling at high speeds observe an apparent shortening of objects, and that distorts the materials' structure.

But the new spacetime quasicrystals obey Lorentz symmetry. They would appear the same to an ant sitting still as to one on a speeding rocket.

The researchers mathematically formulated their quasicrystals by taking a four-dimensional slice through a grid of points in higher dimensions and projecting those points onto the slice. The slice has a slope that is an irrational number — one that can't be written as a fraction of two whole numbers, such as pi. The irrational slope means the slice never directly intersects the points on the grid, and that helps produce the structure that never repeats.

Quasicrystals are a mathematical concept that shows up in the structure of real materials, but the concept could appear elsewhere. "The spacetime that we live in could be a quasicrystal," says study coauthor Sotiris Mygdalas of the Perimeter Institute in Waterloo, Canada.

Spacetime quasicrystals could be relevant for certain quantum gravity theories that propose that, on very small scales, spacetime is broken up into individual points, Mygdalas says. The quasicrystals' structure could be a framework for breaking up spacetime while respecting Lorentz symmetry.

The team also investigated potential applications to string theory, which describes fundamental particles as tiny vibrating strings and suggests that the universe may have 10 dimensions. Since the universe we experience has only three dimensions of space and one of time, proponents of string theory typically suggest the extra dimensions are curled up so small that we can't interact with them.

Alternatively, the quasicrystals suggest a way that all 10 dimensions could be curled up while still allowing the seemingly infinite space and time we experience to exist. That endless space and time could be constructed out of the curled up space if an irrationally sloped slice of it is taken, similar to how the team devised its mathematical quasicrystals.

More work must be done to see if these ideas pan out. The team calls them "admittedly half-baked" in the paper.

The appeal of a spacetime quasicrystal, however, exists regardless. "It's beautiful mathematics," says theoretical physicist Gregory Moore of Rutgers University in New Brunswick, N.J. "The physics is very highly speculative." ✖

CONNOR HOLLAND/OCEAN IMAGE BANK

ECOSYSTEMS

CARIBBEAN REEF FISH GET SHORTCHANGED

By Erin Garcia de Jesús

● Some Caribbean fish seem to have lost their lunch. Food chains on coral reefs near the Dominican Republic and Panama are up to 70 percent shorter than they were 7,000 years ago, scientists report in *Nature*.

Habitat loss and overfishing have pushed more species to compete for fewer resources and repositioned some groups within the food chain. As a result, fish may be less able to adapt if food sources suddenly become scarce, the scientists say.

The team examined otoliths, ear stones important for balance and hearing, unearthed from coral reef sediment. Otolith shape depends on species, and the team measured the amount of a heavy form of nitrogen in the stones to determine which critters were lower or higher in the food chain. The higher the nitrogen levels, the higher the animals are in the chain.

Today's reefs have less diversity at the top and bottom of the food chain than prehistoric reefs did, the team found. It's as if neighborhoods replaced diverse local restaurants with just a few national chains, says study coauthor Jessica Lueders-Dumont, a fisheries ecologist at Boston College in Massachusetts. "If the supply chain … gets messed up, then everybody is affected." ✖

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The Gladiators Paycheck

Roman bronze coins were the "silver dollars" of their day. They were the coins used for daily purchases, as well as for the payment of wages. Elite Roman Gladiators—paid to do battle before cheering crowds in the Colosseum—often received their monthly 'paycheck' in the form of Roman bronze coins.

But this particular Roman bronze has a gladiator pedigree like no other! Minted between 348 to 361 AD, the Emperor's portrait appears on one side of this coin. The other side depicts a literal clash of the gladiators. One warrior raises his spear menacingly at a second warrior on horseback. Frozen in bronze for over 1,600 years, the drama of this moment can still be felt when you hold the coin. Surrounding this dramatic scene is a Latin inscription—a phrase you would never expect in a million years!

Happy Days are Here Again

The Latin inscription surrounding the gladiators reads: "Happy Days are Here Again" (Fel Temp Reparatio). You see, at the time these coins were designed, the Emperor had just won several important military battles against the foes of Rome. At the same time, Romans were preparing to celebrate the 1100th anniversary of the founding of Rome. That's why this joyful inscription was added – to mark these momentous occasions.

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EARTH

EARTH'S CORE HIDES A HYDROGEN HOARD

By Nikk Ogasa

● The oceans are the largest entity on Earth's surface. But all that blue may be dwarfed by a hydrogen reservoir in the planet's heart. Experiments indicate that enough hydrogen to form dozens of oceans may have been entombed in Earth's core during its formation, scientists report in *Nature Communications*.

Hydrogen does not exist as liquid water in the core, but it becomes water as it escapes upward into the mantle and reacts with oxygen, says geodynamicist Motohiko Murakami of ETH Zurich. Earlier efforts to gauge the core's hydrogen reserves measured how iron's volume changed when hydrogen was added, with widely varying results.

Murakami and colleagues took a more direct approach. The team squeezed pieces of artificial core — iron shards in hydrogen-bearing glass — in a diamond vise and heated them to 4,827° Celsius. The samples melted into iron blobs laced with silicon, hydrogen and oxygen. The early core coalesced from such blobs, Murakami says, since much of early Earth was a magma ocean.

Once the samples cooled, the team mapped out the distribution of elements, finding tiny structures that had solidified amid the iron. Silicon and hydrogen were found only within these structures — and in equal amounts of atoms.

That one-to-one ratio was key, as earlier studies had suggested the core is 2 to 10 percent silicon by weight. Based on the new data, the core is roughly 0.07 to 0.36 percent hydrogen by weight. That's enough to make nine to 45 oceans' worth of water.

Some of the hydrogen has probably leaked into the mantle and become water. That water would help melt mantle rocks, Murakami says, generating magma and fueling volcanic eruptions. ✖

NEUROSCIENCE

Sound cues may turn sleep into a problem-solving tool

By Bethany Brookshire

● **When solving a puzzle,** the answer could lie in your dreams.

In a study of lucid dreamers, people who are aware that they're dreaming while it's happening, playing soundtracks linked with unsolved puzzles helped the sleepers solve the problems the next day, researchers report in *Neuroscience of Consciousness*.

Stories of brilliant insights after a nap or daydream abound, but scientists have struggled to successfully influence people's dreams and rigorously test the idea. "This study provides one of the first experimentally grounded demonstrations of

JULIA DUFOSSÉ

↖ In a small study, replaying sounds linked to brain-teasing puzzles nudged sleepers to dream about the puzzles and boosted their odds of solving the puzzles the next day.

such a link," says cognitive scientist Giulio Bernardi of IMT School for Advanced Studies Lucca in Italy, who was not involved in the work.

Whether or not we remember our dreams, we have countless each night, says cognitive neuroscientist Karen Konkoly of Northwestern University in Evanston, Ill. "Your dreams are such a big part of your inner life." Under the right circumstances, manipulating those dreams could help people think of problems in new ways.

While some scientists have shown that sleeping on a problem increases the odds of solving it the next day, others have found no benefit. Of course, it might help if you actually think about the problem in your sleep.

Konkoly and colleagues were especially interested in helping sleepers think about specific topics using targeted memory reactivation, or TMR. "It's this research technique where you have a sensory stimuli that's associated with a memory," Konkoly says. "It could be a very soft sound or a smell that's presented to a sleeper, and it functions to remind the sleeping brain of the full memory."

TMR typically has the strongest effect during deep, slow-wave sleep, Konkoly says. She wanted to look at its effects during a different sleep stage: rapid eye movement, or REM, sleep. REM sleep could be helpful for creative thinking.

The team recruited 20 volunteers who would lucid dream. These people can realize they are dreaming and potentially change their dreams.

The participants were given sets of brain-teasing puzzles to solve — some they could and some they couldn't. Each puzzle was accompanied by an unrelated soundtrack, such as a brief clip of instrumental music. The scientists next hooked the participants up to electrodes to monitor their sleep and put them to bed.

At 4 a.m., the participants were woken up and encouraged to lucid dream as they returned to sleep. Then, the scientists started playing sounds associated with the puzzles the participants couldn't solve, asking them to sniff to indicate they were working on the puzzles in their sleep. The next morning, 75 percent of sleepers reported dreaming about the unsolved puzzles, though there were only nine instances of participants lucidly dreaming about them.

Sleepers who heard the sound cues in their sleep and dreamed about the puzzles — even if they weren't lucid dreaming — solved the puzzles about 42 percent of the time. Those who didn't dream about the cued puzzles solved them only 17 percent of the time.

Though the effects were modest, the idea of hacking dreams to increase productivity and problem-solving may be appealing to some people. But that's not why Konkoly does this research. "I don't think that all our dreams should be corrupted for creative problem-solving," she says. "I want people to value dreams more," for their own sake, as what can be disjointed reflections of our inner lives and experiences. ✖

ANIMALS

KANZI SHOWED IMAGINATION ISN'T JUST FOR HUMANS

BY RJ MACKENZIE

↑ Kanzi, a bonobo famous for his communication skills, was the first known nonhuman animal to grasp the concept of make-believe.

Humans may not be the only primates with the power to imagine. During a make-believe tea party, a bonobo named Kanzi kept track of invisible juice and imaginary grapes, researchers report in *Science*.

The findings add to a growing body of work suggesting that ape minds can imagine scenarios beyond the here and now, a skill once thought to be unique to humans. Human children begin playing pretend as early as age 1 and master this ability by age 3. Many high-level thinking tasks are possible only because of imagination.

The study centered on the late Kanzi, a bonobo who communicated using word-linked symbols called lexigrams and who died in 2025 at age 44. When Amalia Bastos, a comparative psychologist at the University of St. Andrews in Scotland, met Kanzi in 2023, the bonobo asked her and a colleague to chase each other. Kanzi enjoyed watching them even though they only pretended to play, Bastos noticed. This observation fueled tests of make-believes that she and Christopher Krupenye, a cognitive scientist at Johns Hopkins University, designed for Kanzi.

In the first test, Kanzi sat beside a table with two glasses. An experimenter pretended to pour a glass of "juice" into both cups from a see-through empty jug. The experimenter then poured the nonexistent contents of one cup back into the jug before asking Kanzi which cup still held the "juice." Kanzi guessed correctly 68 percent of the time, significantly above chance. The team then tested whether Kanzi could identify real from make-believe juice. An experimenter presented a cup containing orange juice and an empty cup that they filled with pretend juice. When asked which he wanted, Kanzi picked the real juice nearly 80 percent of the time, suggesting he had little issue identifying his reward. The third test that mimicked the first but with pretend grapes indicated Kanzi understood where pretend food was located.

Inventive tool use in apes is often dismissed as a product of accidental discovery, says cognitive scientist Cathal O'Madagain of the University of Mohammed VI Polytechnic in Morocco. But scientists might need to reconsider: Human invention is tightly linked to imagination. "You can't invent a bicycle if you can't imagine one first," O'Madagain says. If animals truly can imagine as humans do, it would cast their tool use in a new light, he says. ✖

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ASTRONOMY

A Greek star catalog from the dawn of astronomy, revealed

By Adam Mann

● **Surrounded by metal pipes** and tangles of cables, two researchers point to bright orange squiggles on a computer screen. The squiggles are a poem written in ancient Greek about heavenly phenomena, seen by human eyes for the first time in more than a millennium.

"There's an appendix which includes coordinates of the stars discussed in the poem, and then little sketches of the star maps," says physicist Minhal Gardezi of the University of Wisconsin–Madison.

Gardezi is part of a team working at the SLAC National Accelerator Laboratory in Menlo Park, Calif., to uncover these star maps. The maps originated in a catalog created by the Greek astronomer Hipparchus of Nicaea around 150 B.C. and were copied down sometime in the 5th or 6th century A.D. Transcribed onto animal hide, the poem and maps were later erased and overwritten with new text. By exposing the hide to powerful X-rays from SLAC's particle accelerator, the invisible writing is once again revealed.

Direct knowledge from the ancient world is scarce. Most Greek scholars wrote on papyrus, a material that rarely survives the centuries. Essentially none of Hipparchus' writing has been found, though secondhand sources indicate that he created one of the earliest star catalogs and helped invent trigonometry. The copy at SLAC is a treasure trove for researchers hoping to better understand the birth of science more than 2,000 years ago.

The document, roughly the size of a paperback, is known as a palimpsest — a piece of parchment made from goat or sheepskin whose original text was scraped off and then written over. This particular palimpsest, the Codex Climaci Rescriptus, comes from Saint Catherine's Monastery in Egypt's Sinai desert. Sometime in the 9th or 10th century, a scribe used the document — which had been erased by either the monks or someone before them — to record monastic treatises.

A particle accelerator's powerful X-rays have uncovered star maps that haven't been seen in over a thousand years. ↓

JASON LYON

While the expunged text is no longer visible to the naked eye, advanced imaging techniques had already partially revealed the hidden writing. This is possible because chemical residues from the ink used in the original document soaked into the parchment, subtly changing how the material absorbs light. By exposing these faint marks to different wavelengths of light — some within our visible range and others slightly beyond — portions of the erased text can be recovered.

To get the full picture, researchers exposed the manuscript to SLAC's focused and intense X-rays — which can be millions of times as strong as those used in a dentist's office — on the manuscript, taking precautions to avoid damaging the material. The X-rays excite the ink's chemical elements, causing them to fluoresce. "You don't see them, but they're still there," says physicist Uwe Bergmann, also of UW–Madison. The X-rays discerned calcium signals in the older, hidden writing that were more prominent than in the new.

The palimpsest's first text was the poem "Phaenomena" by Greek poet Aratus of Soli. Composed around 275 B.C., it describes the rising and setting of different constellations. Whoever copied the poem onto the palimpsest also included appendix-type sections that described the positions of stars in the constellations. The researchers know those sections came from Hipparchus because their precise and distinct coordinate system match later descriptions of his work.

Gardezi says it's like an editor adding footnotes to a copy of Shakespeare's "Hamlet" that "gave us fun facts, like a recipe for food that was eaten in the play."

Having recovered some snippets, the team now plans to scan the remaining palimpsests in the codex. Computer algorithms will help further enhance the writing and maps so that the team can glean more data from these scant squiggles.

The advanced imaging has so far helped settle a long-standing debate about whether the Greco-Roman astronomer Ptolemy, who lived during the 2nd century A.D., plagiarized Hipparchus' work. It turns out Ptolemy's star catalogs used Hipparchus' as a reference but also incorporated material from other scholars. "That's not plagiarism, that's science," says study coauthor Victor Gysembergh, a historian of science at CNRS in Paris. "We still do that today, combining sources to get the best data possible."

Other researchers are looking forward to seeing what additional secrets the palimpsests might contain. Previous experiments from the SLAC team revealed descriptions of the foundations of calculus, generally believed to have been invented during the late 1600s, in a copy of Archimedes' writings from the 3rd century B.C.

"Who knows what the star chart study will show?" says chemist Graham George of the University of Saskatchewan in Saskatoon, Canada. "I can't wait to find out." ✖

HEALTH & MEDICINE

A FEW CUPS OF JOE PER DAY MAY HELP KEEP DEMENTIA AT BAY

By Aimee Cunningham

● Downing a few cups of coffee each day may reduce the risk of developing dementia.

In a long-term study, the lowest risk was associated with drinking about two to three cups of regular coffee per day, compared with having none, researchers report in *JAMA*. Consuming more coffee didn't lower the risk further. There wasn't a link between decaffeinated coffee and dementia risk.

The analysis included data from the 1980s to early 2023 collected for the Nurses' Health Study and the Health Professionals Follow-up Study. Researchers selected over 130,000 participants who had not had cancer, Parkinson's disease nor dementia. Participants took dietary surveys every few years. The team tallied cases of dementia from death records or from reported medical diagnoses.

Moderate daily coffee consumption for women was about 2.5 cups and high consumption was about 4.5 cups. Men who were moderate and high consumers drank less than their female counterparts. Overall, the top coffee drinkers tended to be younger and more likely to smoke.

For those who didn't drink coffee, there were 330 new cases per 100,000 people per year. That rate fell to 229 cases per 100,000 people per year for moderate consumers. And it was even lower for high consumers. But with adjustments for factors such as age and smoking, moderate and high consumption lowered the risk of dementia by similar degrees, 19 percent and 18 percent.

It is unclear why coffee might reduce dementia risk. How much diet contributes to the development of dementia, which is not fully understood, is complex to study. But the risk is unlikely to come down to just a cup or two of joe. ✖

SPACE

SEISMOMETERS CAN TRACK FALLING SPACE JUNK

BY JAVIER BARBUZANO

As part of the Chinese spacecraft Shenzhou-15 tumbled back to Earth, its disintegration was tracked by a surprising source — seismometers.

Seismic networks in Southern California picked up ground vibrations induced by shockwaves as the spacecraft entered Earth's atmosphere on April 2, 2024. Using that data, scientists were able to track the trajectory of spacecraft bits, the team reports in *Science*. That suggests that networks designed to detect earthquakes can also track space junk.

As space debris plunge toward Earth, it travels faster than the speed of sound, generating sonic booms. Those shockwaves set off ripple effects below that seismometers can detect. By analyzing the intensity and timing of those signals, the scientists estimated debris altitude and trajectory. They even tracked how the spacecraft broke into several pieces, each one producing its own shockwaves.

Space debris is typically monitored in orbit using ground-based radar, which can follow objects as small as 30 centimeters across. Once fragments descend into the upper atmosphere, interactions with the air cause them to break apart, slow down and change direction in complex ways. Predicted re-entry paths can be off by hundreds of kilometers. That's a problem: Falling fragments can hurt people or damage infrastructure, and debris often contains toxic fuels, flammable materials or, rarely, radioactive power sources.

↑ Space junk streaks through the sky over California as falling bits of a Chinese spacecraft disintegrate in Earth's atmosphere.

The new work was inspired by NASA's InSight mission, which uses the first working seismometer on Mars to track meteoroids, says study coauthor Benjamin Fernando, a planetary scientist at Johns Hopkins University.

But the precision of detections on Earth depends on the density of seismometer networks, since sonic booms propagate through the atmosphere for only about 100 kilometers. This might limit the usefulness of the technique at a global scale, says seismologist Daniel Stich of the University of Granada in Spain.

Uncontrolled re-entries are becoming more common as more and more spacecraft enter orbit. Seismic monitoring is unlikely to provide advance warning, but it could help assess where debris fall and identify areas at risk of contamination. ✖

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Features

STATE ARCHIVES OF FLORIDA

ANIMALS

MONKEYING AROUND IN FLORIDA

● Self-styled naturalist Joseph DuMond set loose six long-tailed macaques onto 10 acres near Miami in 1933, beginning Florida's first adventure with free-ranging wild monkeys. As the colony grew, DuMond opened the site as a tourist attraction: Monkey Jungle (ads shown). This observation park isn't the only place you can find untrammeled monkeys in the state. Rhesus macaques have been roving around Silver Springs State Park for nearly 90 years. And wild vervet monkeys have called Dania Beach home for almost as long (see next page). — *Cassie Martin*

where the WILD monkeys are

A colony of African vervets in Florida raises big questions about how humans can and should manage nonnative species

By Freda Kreier

Vervet monkeys play on top of a car at an airport park-and-fly near Dania Beach, Fla.

It was a typical Florida story. In January 2014, Missy Williams stood at the edge of a park-and-fly in Dania Beach near Fort Lauderdale-Hollywood International Airport. She watched the boundary where a chain link fence stood between a strip of mangroves and the parking lot. Williams waited. Less than 20 minutes later, she saw them: wild African vervet monkeys climbing the fence.

"I was just in a state of awe," Williams recalls. "I couldn't believe it was really happening."

Then a graduate student at Florida Atlantic University in Boca Raton, Williams had been preparing to travel to Gombe National Park in Tanzania to study wild monkeys. But as the mother of a young boy, Williams was finding balancing foreign fieldwork and childcare difficult. Then, a Miami local mentioned that there might be wild primates closer at hand.

That conversation led Williams to the airport, and her chance meeting in the parking lot sparked a love affair — one that has made her the number one advocate for one of South Florida's best kept secrets.

No primates, aside from humans, are native to the United States. But at least 10 species of primates have been introduced to the country since 1930. In Florida, three species of monkeys have established breeding populations. Among them are the Dania Beach colony, a small population of vervet

monkeys that has lived in and around the city's mangrove forest for nearly 80 years.

Despite their nonnative status, this colony is beloved by some Dania Beach residents. They are fed by office workers, mentioned in megachurch sermons and are even mascots for local beers. But their continued survival is threatened. Monkeys are frequently run over by cars, electrocuted or simply disappear — potential victims of the illegal exotic pet trade. And according to Williams' research, the Dania Beach colony will likely go extinct within the next century.

Some local residents, including Williams, are now advocating for the colony to be protected. These wishes run counter to federal and state policies, which aim to remove or manage nonnative species of concern. The Florida Fish and Wildlife Conservation Commission considers the Dania Beach vervets an invasive species because of their potential to have negative impacts of native wildlife, ecosystems and agriculture.

"Nonnative species do not belong in Florida's environment," Commission spokesperson Lisa Thompson said to *Science News* in an emailed statement.

Some invasive species researchers are also dubious about proposed protections for the monkeys. "People probably feel drawn to primates because they're cute and fuzzy," says wildlife ecologist Steve Johnson of the University of Florida, Gainesville. But monkeys and other introduced species, he says, "will never be native to Florida."

Whether these vervets survive largely depends on how they are perceived. Are they valued Dania Beach residents? Or are they a nonnative threat that should be allowed to slowly vanish into extinction? And who gets to decide which view about these monkeys matters more?

INVASIVE SCIENCE IS BORN

There is nothing new about people transporting other species to novel environments. As far back as 5,000 years ago, hunter-gatherers brought the dingo — a type of feral dog — to the islands of New Guinea and Australia from mainland Southeast Asia. Across centuries, people have carried plants, microbes, fungi and animals with them on their journeys around the globe.

The rate of species exchange has only increased. In the last few hundred years, "humans have become extremely good at moving things," says Martín Nuñez, an invasion biologist at the University of Houston in Texas. Airplane and boat travel have introduced species to one another that evolved over millennia in isolation. Sometimes these meetings have had disastrous consequences.

Take the infamous chestnut blight. The American chestnut (*Castanea dentata*) was once the dominant tree type in U.S. eastern forests, a key food source for people and animals and so common that many streets still bear the name. But the arrival of a fungus from Asia sometime around the turn of the 20th century devastated the keystone species. Today, the species is considered functionally extinct.

Scientists recognized the breadth of invasive species' impact only relatively recently. In 1980, ecologists gathered for a conference in South Africa to talk about threats to Mediterranean ecosystems. It didn't take long for researchers to realize that the bulk of their presentations centered on the impact that introduced species had on their various study sites. That conference helped launch a global effort to understand how introduced species were reshaping not just local ecosystems, but the world.

This work "started a real science of invasions," says ecologist Dan Simberloff of the University of Tennessee in Knoxville.

By pooling their data, researchers found that most newly introduced plants and animals quickly perished upon arrival or never established a breeding population. But a handful of newcomers survived — and even thrived — in environments without established predators or diseases

↓ Primatologist Missy Williams guides a graduate student through the swamps near Fort Lauderdale-Hollywood International Airport where many of the wild monkeys live. ↗ One of the monkeys frolics through an airport parking lot.

PREVIOUS SPREAD: REBECCA BLACKWELL/AP PHOTO; THIS PAGE: SUSAN STOCKER/*SUN SENTINEL*/GETTY IMAGES

"It's pretty cool to have wild monkeys in your backyard."

—KYLE JONES, BREWERY OPERATIONS MANAGER

REBECCA BLACKWELL/AP PHOTO

to keep their populations in check.

Any species introduced to a new ecosystem by people is considered nonnative. These introduced species only become invasive when there is evidence that they can, or do, bring harm to human health, the environment or the economy. There is no established method for determining whether a species is invasive, but there are some general signposts, including when a species rapidly spreads from its area of introduction, or evidence of a species outcompeting or actively preying on native species.

Nonnative species can also earn the invasive title if they are considered pests, such as the emerald ash borer (*Agrilus planipennis*), which likely arrived in North America from Asia during the mid-1990s and is reviled for the damage the insect has done to the continent's ash trees.

Today, the International Union for Conservation of Nature considers invasive species to be one of the biggest threats to biodiversity and a major driver behind extinctions. Invaders are also expensive. From 2010 to 2020, invasive species cost the U.S. economy around $21 billion a year in agricultural loss, forestry issues and other management costs, researchers reported in 2022 in *Science of the Total Environment*.

In 1977, then-President Jimmy Carter had signed an executive order that forbade new species from being released on federal lands and waterways. But it was too little, too late. The executive order was powerless against people bringing nonnative species onto private or state property. And by then, hundreds of species had already made their way into the country — with more to come.

Florida is one of the nation's hot spots for invasive species; it is now home to over 600 nonnative species. At least 139 of these are established and breeding in the wild, according to the Florida Fish and Wildlife Conservation Commission.

Part of the agency's job is to manage existing nonnative species and prevent new introductions. Some of the species managed by Florida Fish and Wildlife — such as the invasive Burmese python (*Python bivittatus*) — are highly publicized by the media and are the targets of mass management campaigns.

But the sheer scale of the problem means that many introduced species can't be prioritized or simply fly under the radar. For instance, that small colony of vervet monkeys in South Florida.

THE GREAT ESCAPE

Vervet monkeys are well suited to the invasive lifestyle. Six species of vervet monkeys, belonging to the genus *Chlorocebus*, live across sub-Saharan Africa. Most species are thriving and can be found anywhere from the savanna to dense city centers.

The success of this genus, especially at a time when many animal species are threatened, can be tied in part to their adaptability. Vervet monkeys are omnivores, live in flexible social groups, are quick learners and can survive pretty much anywhere they have access to trees, water and warm weather, Williams says. Their flexible lifestyles allowed early escapees to colonize several Caribbean islands starting in the 1600s, where they continue to raid farms and charm tourists to this day.

Primatologists have studied

vervet monkeys for decades. But when Williams started her Ph.D. research in 2014, next to nothing was known about the Dania Beach colony. A literature review revealed just one paper written on the topic: a 1995 study published in *Florida Scientist* that counted 36 vervet monkeys in Dania Beach of suspected East African origin.

Everything else was a mystery. How had African monkeys made their way into Florida? And what did people think of them?

Williams set out to answer these questions will the help of her Ph.D. advisor at Florida Atlantic University, Katie Detwiler. As a primatologist, Detwiler was accustomed to traveling outside of the country to study free-roaming primates. Having wild primates so close at hand seemed like an incredible opportunity, she recalls.

However, habituating the monkeys to their presence was hard work. The team had to ask for permission from landowners to access the mangroves — and many were reluctant to give it.

"The whole area has known about them for a very long time, and they protect them," Detwiler says. Some landowners worried that the scientists would harm the colony or try to trap them for biomedical research (another of Florida's nonnative monkeys, rhesus macaques, have been trapped and sold to labs). One particularly reluctant business owner was so protective of the monkeys that he'd previously dropped the basket of a backhoe onto the car of a suspected trapper.

↑ Photos taken in 1909, 1910 and 1911 show the rapid decline of an American chestnut tree infected with blight in Pennsylvania. Since the late 1800s, a fungus from Asia has killed almost all of the country's native chestnuts.

The wild monkeys were also extremely nervous around people, and sneaking up to them proved next to impossible in the muddy, sulfuric, insect-ridden mangroves. The team lost shoes and much of their sanity before deciding to stick to the parking lots, which the monkeys also patrolled.

With time, Williams habituated some monkeys to her presence. She was also starting to make headway with the Dania Beach community, who started to refer to her as "the monkey lady." Interviewing residents was key to answering one of Williams' most pressing questions: Where had the colony come from?

Newspaper clips suggested the monkeys had been around since at least the 1950s. Her interviews with older residents eventually led Williams to investigate a biomedical research organization–cum–zoo that used to import primates from West Africa. The organization was opened in 1939 by Leila Roosevelt Denis, first cousin to President Theodore Roosevelt. Primates from the center were sold to private universities and the National Institutes of Health for polio and tuberculosis research, as well as the Air Force for early space flight studies.

In 1947, 50 monkeys ran off into the surrounding mangroves after a zookeeper either failed to properly lock a cage or the imprisoned monkeys figured out how to jerry rig the door. Most were eventually recaptured. But around 15 were never accounted for.

The timing of this disappearing act suggested to Williams that this was the founding population for the Dania Beach colony. But the story didn't line up with the 1995 study suggesting that the colony was made up of hybrids from two vervet species originating in Uganda, in East Africa.

Williams collected DNA from fecal samples and one dead monkey. The DNA soon confirmed what Williams suspected: The Dania Beach monkeys belong to the vervet species *Chlorocebus sabaeus*, otherwise known as the green monkey, which can be found from Senegal to Ghana in West Africa. The ancestors of these monkeys, it seemed, were indeed the lucky escapees of the biomedical trade.

LIVING ON THE EDGE

It's a beautiful October day in Dania Beach, and the setting sun is filtering through the tops of the mangroves when Williams calls me on FaceTime. We're going to see some monkeys.

"I don't think that it's fair that just because they're a nonnative species, that they should be maligned."

— MISSY WILLIAMS, PRIMATOLOGIST

USDA

Williams finished her Ph.D. research in 2019. She now works as an adjunct professor at Florida Atlantic University, where she's helped some students access the Dania Beach colony for research projects. Williams is also the director of the Dania Beach Vervet Project, a nonprofit that advocates for the protection of the Dania Beach colony.

Scientists are often uncomfortable with outward displays of affection for their research subjects. That's not the case for Williams. Her "interest in the beginning has always been in animal welfare," Detwiler says.

In 2022, Williams opened a 3.5-acre sanctuary at the same spot where she first saw the colony over 10 years ago. Wooden enclosures wrapped in chicken wire are now the permanent homes of eight vervets. Most are surrendered pets, but two — Spock and Betty — were born in the mangroves just outside their enclosures.

Williams approaches the enclosure that Spock and Betty share with a surrendered pet, Margarita. Spock, the old man of the group, is tearing apart a cardboard box in search of a snack. It's a bit unusual for him, Williams says. "Spock is a lazy forager. Normally, he'll wait for the girls to open it, and then he swoops in to take the goods."

Betty gets up from the swing where she's been lazing and climbs down toward Williams. She's fast-moving, despite her missing leg and amputated tail. "Hi, Betty!" Williams calls out in a singsong voice. Betty reaches through the chicken wire trying to grab Williams' smartwatch.

Betty was one of the sanctuary's first residents. As an infant, she was electrocuted while climbing a utility pole. She would likely have died without veterinary care, Williams says.

There are few medical options for a member of a nonnative species like Betty. Before the sanctuary opened, most injured monkeys "were basically neglected," Williams says, and were either euthanized or given to a breeder.

Betty is far from alone in her infirmities. Many of the Dania Beach monkeys sport injuries. One wild monkey, dubbed Baby Billy after a character in the TV series *The Righteous Gemstones*, self-amputated an arm after getting electrocuted. Other monkeys have been maimed or killed by cars.

These constant injuries might explain why the population hasn't grown much in over a decade, Williams says. Green monkeys are among the select 22 percent of primate species that aren't considered threatened or endangered by the IUCN. Females can give birth once a year, usually to a single infant, and Caribbean islands have borne witness to how their population can boom under the right conditions. For example, the island of St. Kitts — just 176 square kilometers — could be home to more than 37,000 green monkeys.

But the Dania Beach colony isn't growing. In fact, it's likely to shrink in the coming decades. A population model run by Williams in her thesis counted 41 monkeys split between social groups, a measly 14 percent increase compared to the 1995 count.

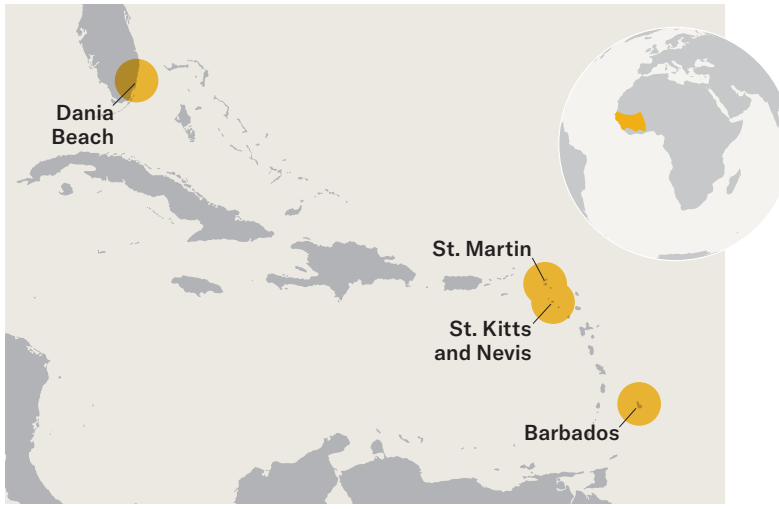
Williams' work suggests that the colony will go extinct within a century, with most models averaging extinction in around 50 years.

Williams has mixed feelings about this finding. On one hand, it means that the monkeys are unlikely to expand outside of their current range — something that might earn them a bad reputation if they start showing up where people think they shouldn't be.

That's what seems to have happened in St. Kitts, where green monkeys are now considered invasive and are a major priority for removal by the government. The population was previously controlled by the sugar industry, which routinely shot green monkeys. But the end of large sugar plantations around 2005 led to a population explosion, and today, green monkeys routinely raid and damage half of all farms on the island.

Monkeys on the move

Genetic samples from the Dania Beach monkeys helped scientists trace their origins to West Africa (highlighted area of the inset map). Monkeys from this region are also found scattered across the Caribbean.



D. M. WILLIAMS *ET AL*/*PRIMATES* 2021, ADAPTED BY B. PRICE

"People probably feel drawn to primates because they're cute and fuzzy."

—STEVE JOHNSON, WILDLIFE ECOLOGIST

Dania Beach's vervets have escaped censure in part because there simply aren't enough of them to be considered pests, Detwiler says. They don't raid farms or garbage bins. Keeping a lid on their growth could help keep them in their human neighbor's good graces.

But for Williams, it's also bittersweet to imagine the mangroves empty of vervets. "I love them," she says. "I don't think that it's fair that just because they're a nonnative species, that they should be maligned."

BELOVED NEIGHBORS

"Maligned" isn't the best way to describe how Dania Beach residents typically feel about the wild monkeys. For one thing, most people simply don't know they exist, says Eugen Bold, former director of policy and public affairs for Broward County, Fla.

People who do know about the monkeys tend to greet their primate neighbors with delight. In an anonymous survey Williams ran from 2015 to 2018, 70 percent of over 230 respondents said the monkeys were "openly welcomed." Only 7 percent said the monkeys shouldn't receive protection because of their nonnative status.

This lines up with Bold's experience. While working for the county commissioner, Bold sometimes received calls from residents worried about the monkeys' welfare. Concerns about the monkeys — such as their risk for passing on disease — were few and far between, he says.

"It's pretty cool to have wild monkeys in your backyard," says Kyle Jones, cofounder and operations manager of LauderAle Brewery & Tap Room, one of the businesses that backs up against train tracks where the vervets roam. People sometimes show up at the brewery asking to see the monkeys, and he hosts fundraisers for the sanctuary.

This goodwill doesn't just extend to tolerance. Some Dania Beach residents want the monkeys protected — including Bold, who is now running for Broward County commissioner. If he wins the election in November, Bold sees the colony as a "great opportunity" to incorporate the county's "unique history" into the areas' public education system, which currently serves nearly 250,000 students.

In contrast to the current Florida Fish and Wildlife stance, "I would redefine them as Florida wildlife," Bold says.

Not everyone is thrilled with this take.

"For me, it's wrong," says Nuñez, the invasive species biologist from the University of Houston. Nonnative species — even beloved ones — can make life extremely difficult for native species. For instance, free-roaming cats in North America kill somewhere in the realm of 1.3 billion to 4 billion birds a year in the U.S. alone. Even if there isn't current evidence that the vervets are causing harm to Florida's mangroves, "we don't know the real impact" they are having now or will have in the future, Nuñez says.

He adds that it isn't unusual for people to become attached to nonnative species. People can hate native species like mosquitoes even while they feel deep affection for the nonnative ornamental plants in their gardens.

These emotions can translate into policy. Take feral horses in North America, which were brought over from Europe by

Spaniards sometime in the 1500s. More than 73,000 wild horses now roam on land overseen by the U.S. Bureau of Land Management. Some research suggests that they graze on native plants and contribute to soil erosion. But the cultural associations between horses and the American West — along with concerns for their wellbeing — mean that feral horses are protected under federal law.

Something similar may be at work in Florida, Nuñez says. No one is currently calling for removal of the Dania Beach monkeys. But an attempt to remove Asian rhesus macaques in the state's Silver Springs State Park between 1988 and 2012 was met with fierce opposition. The sympathy people feel for monkeys may spare Dania Beach's population from any attempt to remove them, and may even spur people to actively protect them.

OH, THE HUMANITY

Then there's the fact that Williams isn't so sure that the Dania Beach vervets meet the definition of an invasive species. For one thing, the population isn't growing, probably because "there's no place for them to go," Detwiler says. The area around the mangroves is so developed that monkeys cannot easily spread from their original habitat.

Meanwhile, it's still not clear how the monkeys impact the local ecosystem. Locals sometimes call the vervets "bougie" because of their picky eating habits — unwilling to eat lettuce, tomatoes or shortbread cookies, which their counterparts in West Africa would be glad for, Williams says.

These picky habits seem to extend to foraging. One of the ways that scientists establish whether monkeys are invasive is by seeing whether they take eggs from nests. One study of Silver Springs' rhesus macaques found that those monkeys did go after quail eggs placed in the wild, which implied they could also go after the nests of native species.

But a similar study conducted by one of Williams' students found no evidence that the vervet colony was going after eggs in the mangroves. Instead, the most frequent egg raiders were native raccoons.

Which isn't to say that the Dania Beach monkeys don't go on raids. Williams calls me while I'm walking back to my bike after running errands in mid-October. Some free-roaming moneys are paying Williams' sanctuary a visit. It's part of their daily foraging routine, one that involves harassing the sanctuary's resident monkeys through the chicken wire.

On the call, monkeys line up on the roof of the sanctuary's office shed, peering down at the camera. Williams shows me each of their faces, naming them one by one.

As with all introduced species, the ancestors of these monkeys were brought to Florida by people. And with that involuntary relocation, the survival of the Dania Beach vervets is now in human hands.

To Williams, it's clear that her vervets are "100 percent just nonnative" rather than invasive. In an ideal world, Williams would like the monkeys to be "grandfathered in" as a new native species to Florida. "If the science and the data say, 'Hey, this is going to be OK, they're not going to become invasive,' then why not make an exception?" she says.

Other scientists aren't sure it's that simple.

"The field has discovered more and more impacts that are subtle and hadn't been recognized right away," Simberloff says. The true impact of the vervets on the mangroves — one of Florida's most endangered ecosystems — may not yet be obvious.

Still, whether the monkeys are invasive may be a moot point for Dania Beach residents, and ultimately, how the colony is managed. "Could *you* shoot a monkey?" Simberloff asks. "I couldn't." ✖

↖ Many Dania Beach residents openly welcome their vervet monkey neighbors, a survey found. ↓ An employee at the airport park-and-fly feeds trail mix to some of the wild vervet monkeys that live nearby.

REBECCA BLACKWELL/AP PHOTO

Freda Kreier is a freelance journalist who writes about the natural world.

A canister of tear gas flies toward demonstrators on January 24, 2026, in Minneapolis, where the Department of Homeland Security has been executing its largest ever immigration enforcement operation in the city.

The Health Risks of Crowd Control

Tear gas and pepper spray are widely used by law enforcement, but their long-term health effects are poorly understood **By Nikk Ogasa**

Stinging clouds of tear gas explode from beneath a car full of children, forcing them to flee onto the snowy sidewalks to seek air that's safe to breathe. A man, face painted orange with pepper spray, is pinned to the icy ground by masked federal agents, unable to wipe the pain from his burning eyes. For weeks during the winter, reports of incidents like these were coming out of Minnesota, where the Department of Homeland Security had been facing daily protests over the largest immigration enforcement operation in the agency's history.

DHS claims it has arrested thousands of undocumented immigrants, and Secretary of Homeland Security Kristi Noem has justified the widespread use of tear gas and pepper spray, even though visual evidence shows agents deploying the chemicals largely against peaceful protesters and bystanders. Tear gas and pepper spray have also been deployed against protestors in Portland, Ore., and Chicago as part of immigration operations. These chemicals are banned in warfare by international treaties, but they have been used by U.S. law enforcement against civilians for decades (see Page 46).

While it's clear these crowd control agents are designed to cause an immediate, debilitating reaction, health experts have raised serious concerns about their enduring effects on the body.

"These are chemical weapons that are harmful to the human body and harmful to particularly vulnerable folks, like children," says Asha Hassan, an epidemiologist at the University of Minnesota in Minneapolis. "We know that tear gas causes tears, but it also causes other things that are a lot more severe," she says.

But the long-term health risks are poorly understood. No large, systematic studies have investigated the health problems that emerge long after exposure to these chemicals, says Anthony Szema, chair of the American Thoracic Society's Section on Terrorism and Inhalation Disasters. Some research has painted a picture of lasting repercussions. For weeks and even months after the immediate moments of exposure, crowd control agents may continue to sabotage the organs that allow us to breathe, pump blood and even make life.

Here's a closer look at these chemicals and what's known about their immediate and long-term health impacts.

What's in crowd control agents

Tear gas and pepper spray are broad terms that encapsulate a slew of chemicals.

Tear gas has been used by U.S. law enforcement against civilians for over a century. The compound 2-chlorobenzalmalononitrile, or CS, is the most common tear gas irritant used today. It is commonly deployed via exploding gas canisters and sometimes mixed into liquids shot from water cannons.

Pepper spray typically contains oleoresin capsicum, or OC, a resinous mixture of chili pepper extracts that includes capsaicin, the compound that gives chiles their heat. Its use became common for crowd control in the 1960s. It can be particularly harmful to people with allergies to peppers, says Szema, a pulmonologist at Hofstra University in Hempstead, N.Y. Alternatively, pepper spray can contain PAVA, which contains a lab-made version of OC. These chemicals are often sprayed from handheld canisters, and they're also found in pepperballs — paintball-like projectiles fired from specialized guns.

That's a big-picture look. But a major problem with studying the effects of crowd control compounds is that it's often unclear which chemicals are being used and in what concentrations. There is no national regulation on using these chemicals against civilians, and manufacturers share very little information about what goes into them, says emergency physician and epidemiologist Rohini Haar of the University of California, Berkeley. That means it's not always clear what's in the fumes that spew from a tear gas canister, and that can make it difficult to tie specific chemicals to specific health risks.

While it seems most probable that the tear gas used so far in Minneapolis and other cities contains CS, it's unclear whether law enforcement could be using even more painful but less studied versions, Haar says. "I know they exist, I know that they're manufactured, but there's no regulation on telling us what people are buying or what's in a canister."

Further muddying the picture are other

PREVIOUS PAGE: STEPHEN MATUREN/STRINGER/GETTY IMAGES NEWS

compounds that get mixed in to assist with dispersal or prolong exposure, and which can be toxic themselves. For instance, tear gas canisters may contain potassium perchlorate, a chemical that donates oxygen to the canister's explosion and which has also been linked to thyroid issues. And CS is sometimes mixed with silica gel to keep it from disintegrating quickly. These longer-lasting forms can linger on clothes and expose first responders, and they can affect an area for days.

First comes the pain

Tear gas and pepper spray activate pain-sensing nerves on the skin, on the surface of the eye and in airways, says Sven Jordt, a pain and sensation researcher at Duke University. That effect immediately triggers protective reflexes — coughing, tears, mucus secretion — that help wash away the chemicals. "But these agents are so potent that these reflexes become overwhelming and incapacitate you if you don't remove yourself from the situation," Jordt says.

There is no antidote for these agents, the U.S. Centers for Disease Control and Prevention says. If a person is exposed, they should move away from the exposure source, find fresh air, wash their skin with soap and water and rinse their eyes until they appear clear of chemicals, the CDC recommends. After following those steps, it typically takes about 30 minutes for symptoms to disappear, though more severe exposure may lead to long-lasting symptoms, especially if the individual was exposed indoors.

Children are among the most at risk from these chemicals, due to their small bodies and the vulnerability of their pain nerves. "Their tissues are more delicate, their skin is thinner, so it's easier for the agent to reach their nerve endings," Jordt says. "Their airways have a smaller diameter, so if there's any obstruction, swelling, mucus, they have more trouble breathing." Moreover, CS gas tends to accumulate near the ground, and children are shorter, which potentially increases their exposure, he says.

VINCENT ALBAN/THE *NEW YORK TIMES*/REDUX

A U.S. Border Patrol agent shoots orange pepper spray into the face of a pinned-down demonstrator in January in Minneapolis. Tear gas and pepper spray can overwhelm the eyes, mouth and skin with pain and cause severe complications at high levels of exposure. ↓

WHAT MAY BE INSIDE A TEAR GAS CANISTER

Canisters can contain a mix of hazardous chemicals in addition to the primary tear gas irritant. Most of the secondary ingredients play a role in the pyrotechnical reaction that disperses the irritant via smoke. Some, like charcoal and silicon, are relatively harmless. But others may carry concerning health risks for those exposed to them.

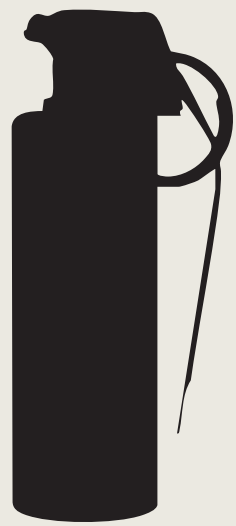
Lead dithiocyanate
A solid ingredient in the primer that ignites the pyrotechnical reaction. It is considered a carcinogen. Repeated inhalation can cause lead poisoning, potentially damaging the nervous system, kidneys and brain.

Potassium perchlorate
A white, odorless powder that acts as an oxidizer for the pyrotechnical charge. Exposure can irritate the eyes, skin and respiratory tract. High levels or repeated exposure may affect the thyroid, white blood cells and kidneys.

Barium chromate
A yellow agent that controls the burn rate of the pyrotechnical reaction. It can lead to blisters and ulcers on the skin, can cause cancer, may damage the liver and kidneys, and may also cause birth defects in humans.

Zinc metal
A lustrous metal used to generate smoke. Zinc is toxic if inhaled and can cause "metal fume fever," which can cause chest pain, cough and shortness of breath.

CS
The most common tear gas irritant. A white, solid powder at room temperature, CS particles are dispersed in smoke. Contact causes immediate irritation to the eyes, skin and respiratory tract, though more severe symptoms can arise from prolonged or repeated exposure.



Diphenylamine
A colorless material used to extend the shelf-life of explosives. It can cause skin and eye irritation, increased blood pressure and heart rate and bladder injury. It also may pose a reproductive hazard.

Longer-term respiratory risks

Acute symptoms have been well-documented. But the longer-term effects of crowd control agents remain poorly understood. Much of what's known is based on anecdotal evidence, such as reports from conflict zones, Hassan says. And many of the studies involved only healthy populations like military recruits, and aren't representative of the broader population, Jordt says.

But even studies on healthy groups have been concerning.

A 2014 study of more than 6,000 army recruits found the odds of being diagnosed with an acute respiratory illness — such as bronchitis, sinusitis and throat pain — more than doubled after they were exposed to tear gas in basic training. A total of 114 recruits were diagnosed with respiratory illness during the week following exposure to the CS agent, while 47 were diagnosed in the week before.

The study also found that higher amounts of exposure were associated with greater chances of illness, and subsequent research found that reducing exposure concentrations reduced the risks. That research showed that the effects of tear gas persisted in the days following exposure in healthy subjects, and it led the military to limit exposure concentrations and durations during training and improve decontamination procedures.

These chemicals can burn the surfaces of the eyes and the airways, damaging them for some time, Jordt says. That can lead to fluids leaking into the lungs, causing pulmonary edema, which can subsequently lead to infection and other respiratory issues. After high levels or repeated instances of exposure, that sort of damage may potentially cause lasting effects.

The elderly, smokers and people with asthma or other respiratory conditions should be especially wary about exposure, Jordt says,

T. TIBBITTS

SCOTT OLSON/STAFF/GETTY IMAGES NEWS

A demonstrator has their eyes flushed outside the Bishop Henry Whipple Federal Building in Minneapolis after being pepper-sprayed on January 9, 2026. ↑

as the chemicals could trigger or exacerbate preexisting respiratory issues, including infectious diseases. That has been a concern for the people in Minnesota because the protests mostly occurred in the middle of respiratory virus season, Szema points out.

Other sources have also linked respiratory illnesses and tear gas exposure. For instance, in a 2018 report reviewed and published by UC Berkeley's Human Rights Center, Haar and psychologist Jess Ghannam of the University of California, San Francisco described experiences of people exposed to tear gas almost daily in camps in the West Bank. The long-term impacts included lung problems, asthma, breathing issues and skin allergies, Haar says.

That level of daily exposure over years and in crowded conditions may be extreme, but it can provide insights into places where civilians have been repeatedly exposed to tear gas and pepper spray by law enforcement.

Lingering heart problems

While the risks of respiratory issues may seem obvious, evidence suggests that effects can cascade beyond the depths of one's breath. In 2025, a group of researchers led by pediatrician Konstantine Chakhunashvili of the Caucasus University in Tbilisi, Georgia, reported significant rates of heart issues in demonstrators who had been teargassed during the protests over Georgia's 2024 parliamentary election results.

Chakhunashvili and colleagues observed the hearts of 69 demonstrators who had been exposed to tear gas at the protests, where canisters containing the CS agent were found. Tests of the electrical activity of subjects' hearts — which were conducted at least five weeks after exposure — revealed delayed electrical impulses in about a third of the demonstrators and in 7 percent of nonexposed individuals. The researchers also detected a signal often associated with reduced blood flow in about 29 percent of the demonstrators, and in 3 percent of the unexposed people.

That suggests there's a link between tear gas and "possible issues with oxygenation of blood and possible oxygen deprivation of a heart muscle" that can linger for weeks, Chakhunashvili says. His team also surveyed over 300

↑ **Police release clouds of tear gas against a crowd of Vietnam War protesters in Washington, D.C., in November 1969.**

AP PHOTO

Chemicals born in battle

World War I, sometimes called the Chemist's War, is infamous for the widespread use of chemical weapons. Tear gas, introduced by French forces in 1914, was the first. Deadlier weapons followed, including the German army's use of lethal mustard gas starting in 1917. Still, tear gas remained widely used on the battlefield, in part because it was a cheap method for fatiguing enemy troops by forcing them to don hindersome gas masks.

After the war, the United States faced growing labor tensions, which sparked an eruption of riots across the country, including by soldiers angry that the government had not paid them. The U.S. Army, now experienced in producing chemical weapons, began developing a tear gas grenade for dispersing crowds of civilians.

Tear gas munitions were soon being sold to police departments, and in 1928, chemists Ben Corson and Roger Stoughton of Middlebury College in Vermont synthesized the most common tear gas irritant of the present day. Their surname initials formed the chemical's abbreviated name: CS.

Reports of U.S. troops using CS during the Vietnam War emerged in the 1960s, sparking an international outcry that eventually prompted the government in 1975 to prohibit the use of tear gas in war. Law enforcement, however, continued to use tear gas domestically, including on the war's protestors.

Also during the 1960s, a handheld spray containing aerosolized tear gas emerged on the domestic market. Called Mace, it was initially marketed for self-defense, but its point-and-spray design made it popular with police for use against individuals. Criticisms of Mace's health risks and abuse mounted, and by the 1980s, law enforcement adopted a faster acting, less toxic spray. It contained a chemical called oleoresin capsicum, or OC, which postal workers had been using since 1960 as a dog deterrent. Since then, OC-based pepper spray—alongside CS tear gas—has been widely used to suppress civilian demonstrations in the United States.

—*Nikk Ogasa*

demonstrators and found that more than a third reported experiencing fatigue, headaches, cough or psychological trauma more than a month after exposure. Others experienced eye problems, skin disorders or high blood pressure. More studies are needed to determine cause and effect.

Nonetheless, "the indiscriminate nature of tear gas should prompt at least the democratic world to implement stricter rules about its use," Chakhunashvili says.

Reproductive repercussions

Researchers in Minneapolis have raised concerns that tear gas might have lingering impacts on another part of the body. Hassan was living in southern Minneapolis in 2020 when protests erupted over the murder of George Floyd — an unarmed Black man — by a police officer. "I was hearing ... from my neighbors that they were experiencing unexpected changes in their bodies," she says.

Individuals who had not experienced menstruation in years, due to birth control or hormone use, told Hassan that they experienced spontaneous menstrual bleeding in the moments after being exposed to tear gas. "Hearing that like one time, I don't know, maybe sounds like a fluke," Hassan says. "I heard that several times from my neighbors and community members."

Hassan and colleagues analyzed survey responses from 1,276 people with uteri who were over 18 and had been exposed to chemical agents by law enforcement in 2020 and 2021. Eighty-three percent of the exposed individuals experienced uterine cramping, breast tenderness or early or late menstrual bleedings, the team reported in 2023 in *Frontiers in Epidemiology*. What's more, they found that individuals who had been exposed on more than two days were twice as likely to experience an adverse effect as those exposed on one day.

Notably, 10 of the 19 individuals who reported that they were pregnant when exposed reported a subsequent miscarriage — that's about twice the expected rate of miscarriage. Though the sample size is too small to conclusively associate exposure and miscarriage, the finding raises questions about both the short- and long-term fertility of those who are exposed to crowd control chemicals, Hassan and colleagues say.

It's not the first time such a link has been brought up. For instance, Haar's work in the West Bank and a 2012 report on teargassing of civilians in Bahrain both noted miscarriages following exposure. And in 2011, concerns about the link prompted the government of Chile to ban tear gas, though only temporarily.

83

percentage of 1,276 people with uteri over 18 who were exposed to chemical crowd control agents and experienced uterine cramping, breast tenderness or menstrual irregularities.

One hypothesis is that stress is at least partly to blame, Jordt says. Hassan, however, suspects a more physical explanation. "It would take a lot [of stress] for somebody to all of a sudden have a spontaneous bleed after years," she says. Another explanation is that these agents are disrupting hormonal systems in our bodies, both Hassan and Jordt say, similarly to how the plastics compound BPA does.

Now, Hassan is collecting data to investigate whether widespread tear gas use in Minneapolis affected preterm birth rates in 2020 and 2021. She may also include data from 2025 and 2026 as it becomes available. "I repeatedly was getting emails from health care providers who had noticed more preterm birth," Hassan says. "I'm hoping to be able to explore that a little bit and get an understanding if there are population level changes."

Research efforts like Hassan's are uncommon in the United States, due to a scarcity of federal research support — a drought that had set in long before DHS began its operation in Minnesota. There's basically no government funding for this sort of research, Haar and Jordt say.

"It seems to me that there is no real, serious intent to try and understand the health effects of these agents from the side of the government," Jordt says. ✖

← At the Prospect Hill field site in Harvard Forest, an experiment that imitates the effects of climate change on soil has been running for 35 years.

HOW WARMING IS SHIFTING MICROBIAL WORLDS

Climate change is affecting microbes, and that has implications for all life on Earth

By Erin Garcia de Jesús

At first glance, Harvard Forest seems like an ordinary woodland. Oak trees shade the terrain among small shrubs and other trees, mostly maple, birch and beech. Fallen leaves coat the ground below. What makes this 1,600-hectare patch of land in north central Massachusetts special is buried in the soil.

Some 10 centimeters below, scientists have installed a subterranean network of wires — some of which have been active for about 35 years — that warms the forest floor. By continuously heating the soil 5 degrees Celsius above ambient soil temperature, these wires imitate the warming effects of climate change for researchers who want to understand what a hotter world might mean for the surrounding ecosystem.

Ecologist Serita Frey of the University of New Hampshire in Durham has certainly noticed changes since she started working at Harvard Forest in 2003. These days, more rain and less snow falls in winter. Summers are drier than they used to be. More trees are falling victim to disease, and some invasive species are moving in. But what is less noticeable — and what she's keen to learn — is what's happening to the bacteria, fungi and other microbes that make their homes in the dirt below the forest floor.

Microbes, like all life on Earth, are facing a warming climate. With underground wires artificially warming the soil, Frey and her team can collect soil samples to monitor how microorganisms that make their homes in Harvard Forest's soil are faring. They've learned, for instance, that two decades of warming have altered populations of bacteria inhabiting the topsoil of heated plots, as well as the makeup of the microbial community found in clumps of soil.

Overall, human-driven climate change is "shifting the composition of the community in terms of who's there," Frey says. "But we're also shifting its function."

Scientists have long known that microbes play a crucial role in maintaining the levels of carbon and other nutrients in our environment. As microbes break down dead animal and plant matter, these organisms can both absorb and produce climate-altering gases, including carbon dioxide, methane and nitrous oxide. In a warming world, that cycle could start to look different, with serious consequences for other life on the planet. Frey is among many researchers working to understand how climate change will affect microbes — and if humans can harness them to reduce its impacts.

One of the Harvard Forest experiments aims to understand how global warming and nitrogen pollution affect the activity of soil microbes. ↙

Like with the soil work, research elsewhere is revealing that viruses and other microbes in thawing permafrost may add more carbon to the atmosphere as they break down previously frozen matter. But other microbial abilities might have the opposite effect and prove beneficial against climate change–induced consequences. For example, when paired with helpful soil fungi, plants at risk of losing their habitat could get a boost to endure environmental stress or disease.

Understanding how microbes respond to warming temperatures, drought, flooding and more is key for identifying strategies that might prevent additional carbon from seeping into the atmosphere or help manage transforming ecosystems, says microbial ecologist Jizhong "Joe" Zhou of the University of Oklahoma in Norman. Earth's microbes have weathered 3.5 billion years of oscillating climates. For them, change is the only constant.

CHANGING COMMUNITIES

Roughly 2,300 kilometers away from Harvard Forest's shaded terrain, tall prairie grasses and small trees cover a vast expanse of rolling hills south of Oklahoma City. Dotting the grassland are long, tubelike infrared lamps that hover 1.5 meters above the soil and are spread evenly across experimental plots, each a few meters wide.

Part of an experiment that Zhou leads at the University of Oklahoma's Kessler Atmospheric and Ecological Field Station, or KAEFS, the lamps heat the dirt and surrounding air to 3 or 4 degrees

PREVIOUS SPREAD: COURTESY OF AUDREY BARKER PLOTKIN; THIS PAGE: ADRIANA ROMERO OLIVARES

Celsius above ambient temperature. Like at Harvard Forest, the goal behind this experiment is to zoom in on soil's smallest life-forms to see if and how quickly new microbes might take over, in this case, warmer grassland soils.

Experiments in other research sites use outdoor chambers to create hotter experimental plots or, as Harvard Forest does, warm the soil directly. But heating air and soil together is a more realistic way of looking at how increasing temperatures impact subterranean ecosystems, Zhou says. In nature, "warming generally affects the air first."

Since the project began in 2009, Zhou and his team have collected a trove of data. Wires made of a mix of copper and nickel and placed as deep as 75 centimeters in the soil record the temperature every 15 minutes. The team also regularly measures the soil's water content and keeps tabs on which plants are growing and how much carbon is in the soil. Every year, when plant growth peaks in September or October, researchers pull a 15-centimeter-deep chunk of soil from three spots in each plot to assess the microbial makeup.

After roughly five years of artificial warming, many of the microbes inhabiting the grassland plots changed, Zhou and colleagues reported in 2018 in *Nature Climate Change*. These included bacteria such as Actinobacteria, which help maintain nutrient levels to keep soil fertile, and Ascomycota fungi, which also help stabilize soil. Such organisms either dominated other microbes or died out altogether under higher temperatures compared with control plots. Warming also pushed these microbial populations to change faster over time. Population shifts that might have happened naturally over the course of decades instead happened in just a few years.

↗ Infrared lamps heat both soil and air to mimic climate change at an Oklahoma field station.

COURTESTY OF J. ZHOU

As Zhou and colleagues continued to monitor changes for an additional two years, they found that the microbial diversity in the soil decreased. Fewer species of bacteria and fungi occupied grassland plots that experienced continuous warming and drought. When that happens, relationships between the species that remain can become increasingly complex, sometimes forcing them to battle one another to persist in a changing environment.

"If we look at the future, 15, 20 years, 50 years or 100 years later," Zhou says, "the whole community could be quite different from right now." And as microbial populations fluctuate, so can their roles in the ecosystem.

PARSING DIFFERENCES

For all that Zhou and others have learned about changing microbial communities, piecing together which organisms are doing what in their environment is tough. Scientists haven't historically had a solid grasp on which microbes live where. That may come as no surprise, because our planet may host as many as 1 trillion different species living across vastly different landscapes.

Because microbes are invisible to the unaided eye, scientists have to rely on indirect ways of studying them. DNA from the environment can provide a window into who's there, says Michael Van Nuland, a Portland, Ore.–based ecologist and evolutionary biologist with the Society for the Protection of Underground Networks. But it can be hard to know if that genetic material is coming from part of the microbial community as it is today, "or if you're capturing remnant pieces of DNA that had been floating around in the past."

It's also difficult to link the organism with its function. Scientists can find molecular signals in soil that suggest what some microbes do in an ecosystem, but such data don't readily specify how fast the organisms grow, how they draw carbon and other nutrients into soils or how they spread through the environment.

Over the last decade, projects to map microbes, from bacteria and fungi in soils to viruses that inhabit the oceans, have begun to help researchers fill some of these gaps. Such

baseline maps can help researchers document fluctuations in response to swings in temperature or storms in certain regions, Van Nuland says.

Van Nuland's project is creating an atlas of mycorrhizal fungi, which are in symbiotic relationships with a wide range of plants around the world, from crops such as corn, wheat and blueberries to common trees such as maple and pine. As temperatures rise, such fungi might adjust to the heat or shift their habitat to a more suitable location, even if the trees they exist in symbiosis with might not be able to follow, Van Nuland and colleagues reported in 2024 in the *Proceedings of the National Academy of Sciences*. Other fungi might persist in a stressed state, waiting for favorable conditions to return. Or they might simply die.

Fungi help most plants take in nutrients such as nitrogen and phosphorus and can provide a physical shield against pathogens. Losing such benefits could send destructive ripples through ecosystems. "It's not just understanding how climate change is affecting a single species," Van Nuland says. It's also "the network of interactions that these species have with other organisms in the environment that allow them to persist and thrive. We need to be taking that into account in order to understand how species respond to climate change."

DISRUPTED CYCLES

Warming is just one factor causing changes to microbial life. Other factors impacted by climate change, such as precipitation and pollution, can also have unpredictable ramifications.

Droughts, for instance, are becoming increasingly common. For the microbes occupying Zhou's experimental plots in Oklahoma's prairie landscape, a double punch of heat and drought is a push toward becoming more active and unleashing more carbon into the atmosphere, Zhou and colleagues report in a paper to appear in *Nature Climate Change*. But climate change can also lead to heavier, more unpredictable rainstorms. In wetter conditions, microbes seem to keep carbon in the soil, the team found.

Although impacts would probably vary dramatically across different ecosystems, the findings from Oklahoma suggest that carbon stocked away in soils might get released as droughts worsen around the world, the researchers say. Future warming might worsen as microbes' natural carbon cycling process gets disrupted. Drylands, which cover roughly 40 percent of Earth's surface, could be particularly vulnerable.

In Harvard Forest, Frey is interested in the dual influence of climate change and pollution. Like many forests across the northeastern United States, Harvard Forest's soil has historically been high in nitrogen from human-caused pollution such as car exhaust and power plant emissions (although atmospheric levels of nitrogen have improved over the last decade thanks to the Clean Air Act). But nitrogen is also essential for plant growth, allowing plants to make proteins and photosynthesize.

"MICROBES ARE SHAPING, AND HAVE BEEN SHAPING, OUR PLANET, OUR ATMOSPHERE, FOR ALL OF OUR EXISTENCE."

— Raquel Peixoto

Unlike warmer temperatures, which cause microbes to work overtime and release more carbon into the atmosphere, extra nitrogen puts the brakes on microbes, slowing decomposition and keeping organic compounds in the soil. Frey thought that adding extra nitrogen to Harvard Forest's soils would follow this principle and slow microbes down, offsetting the carbon that they would otherwise be emitting because of the artificial heat.

Instead, soil carbon dioxide emissions were actually higher in plots treated with both heat and nitrogen compared with just one of those factors, she and colleagues reported in 2024 in *Nature Ecology & Evolution*. The total amount of carbon in the soil, however, remained roughly the same.

"There's been this concern that with warming we're going to lose carbon from the system, and that's going to deplete soil nutrients," Frey says. However, it's possible that warming soils and extra nutrients boost plant growth in a way that pulls in more carbon from the atmosphere. "In systems that are more nutrient-rich to begin with, that have plenty of nitrogen around, maybe that loss of carbon will be lessened."

Because her team's experimental plots are small, predicting what the findings might mean for the

ecosystem's carbon balance writ large would require computational simulations, Frey says. At least for now, studies suggest that Harvard Forest is doing exactly what it is designed to do and is taking in more carbon than it is releasing.

THAWING PERMAFROST

Much of the work to dissect the influence of climate change on microbes focuses on fungi and bacteria because they do much of the work of moving nutrients through ecosystems. But viruses may also play a role, working behind the scenes to make sure that everything runs smoothly — or at least to their own advantage.

This dynamic is on display in the Arctic, a region warming almost four times as fast as other parts of the globe. To better understand the effect of climate change on viral communities, some researchers have turned to the permafrost — a layer of soil that remains frozen from year to year. As it thaws, revived bacteria, fungi and other microbes come to life, decomposing dead plant matter and adding carbon dioxide and methane to the atmosphere. Newly awakened viruses can then prey on these microorganisms.

As viruses infect, and sometimes kill, their hosts, they affect what microbes are living in a system, says Akbar Adjie Pratama, a viral ecologist at the Friedrich Schiller University Jena in Germany and Ohio State University in Columbus. As with other dead organisms, the hosts that viruses kill release carbon and other nutrients that get cycled back into the ecosystem. But this additional carbon could burden an already carbon-rich atmosphere.

In 2024, Pratama and colleagues reported in *Environmental Microbiology* that, over a span of seven years, a viral community in permafrost in Sweden remained surprisingly stable. Some of those viruses carried genes that, if the soil were to thaw, could help degrade carbon in the ecosystem. A few may infect *Methanoflorens* archaea, a group of microbes that emit methane into the atmosphere. Understanding the viral controls that naturally keep gas-leaking microbes in check, the team wrote, could help researchers find ways to do it artificially.

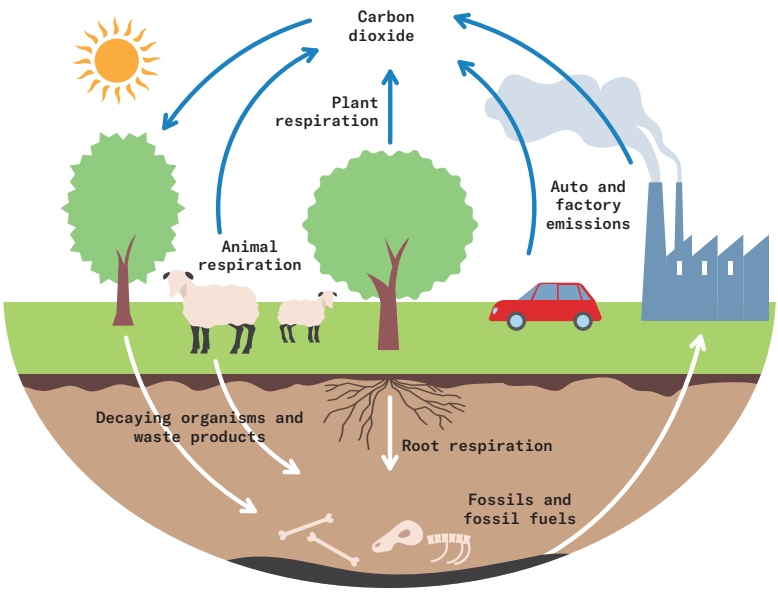
Uncovering the impact of viruses on ecosystems around the globe requires pinpointing which organisms viruses infect in permafrost, water and soil, Pratama says. But it's a tough task. He and colleagues have so far managed to link only a small fraction of permafrost viruses with their microbial hosts, and even fewer in groundwater. "How can we make a meaningful conclusion on the role of viruses when we can only link like 1 percent?" Pratama says.

CHANGE FOR THE BETTER

Understanding the roles that viruses and other microbes play in climate change — both the organisms themselves and the processes they contribute to — has the potential to identify allies that could help humans mitigate some of its effects.

For instance, viruses such as soil-dwelling phages that infect carbon- or nitrogen-emitting soil microbes could help curb greenhouse gas emissions, Pratama says. In places like the Netherlands, where the agricultural industry produces

CARBON ON THE MOVE



Carbon moves continuously through soils, waterways, organisms and the atmosphere in a process called the carbon cycle. As microbes break down dead organisms in soil or water, they push carbon into underground stores or the deep ocean. But, similar to animals and plants, microbes can also release carbon into the atmosphere as a by-product of making energy.

C. CHANG, RUDZHAN NAGIEV/ISTOCK/GETTY IMAGES PLUS

more nitrogen per hectare than most other countries in the European Union, adding such viruses to the soil could help cut down on nitrogen-fueled algal blooms that infiltrate waterways and degrade water quality.

Fungi could be collaborators, too. Planting trees to restore forests following a wildfire may have a better chance of succeeding if trees' fungal partners are also transplanted. "They are ecosystem engineers," Van Nuland says. "They work across kingdoms of life to get things done."

Beyond hypothetical uses, however, some scientists have already been applying what they know about microbes to aid stressed coral reefs during marine heat waves, which are coming on more frequently thanks to climate change.

Coral reefs host various algae that display a kaleidoscope of color and who in turn host myriad beneficial microbes. Heat waves push those algae to produce toxins that not only provoke corals to evict them — which we see as color-drained or bleached corals — but also kill off some of the good bacteria. In this environment, pathogens can start to grow. "An entire situation that is already bad is going to get worse," says marine ecologist Raquel Peixoto of King Abdullah University of Science and Technology in Thuwal, Saudi Arabia.

Peixoto has been experimenting with restoring healthy bacteria to bleached corals as a way to keep these marine animals alive. In 2021, she and her colleagues reported in *Science Advances* that using probiotics to restore the bacterial community was effective at protecting corals in an aquarium. The team has since tested their probiotic treatment in the wild. During a 2022 marine heat wave, treated corals were healthier than untreated organisms, the researchers reported last year in a paper posted to bioRxiv.org.

↑ **Marine ecologist Raquel Peixoto applies a probiotic to coral during a heat wave in the Red Sea. Beneficial bacteria may protect heat-stressed coral from disease.**

"We keep applying [the probiotic treatment] for the weeks where corals are in really bad shape," Peixoto says. Not only do corals benefit, but the microbiomes of fish, algae and sponges also improve. "We're seeing in the reef that that makes a difference," she says.

Such experiments with microbe-based solutions, however, are still few and small. Deploying such solutions to tackle climate change would require tremendously scaling up human attempts to engineer helpful microbes. And although it is clear that Earth's changing climate is altering microbes and their communities, the consequences remain murky. Regardless of what the future holds, what is certain is that microbes will play an essential part in what is to come.

"Microbes are shaping, and have been shaping, our planet, our atmosphere, for all of our existence," Peixoto says. Microbes as a whole are not going to go extinct. "They will evolve, they will be replaced, they will still be here," she says. But their role in keeping our planet functioning, "this is changing." ✖

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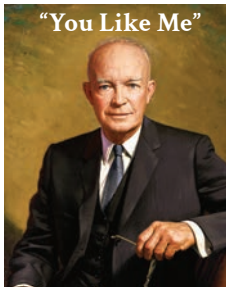

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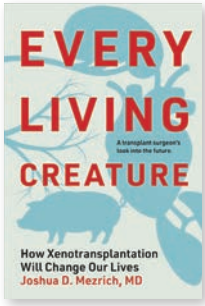
A GIANT LEAP FOR HUMANKIND?

● Earth peeks above the lunar horizon in this 1969 photo from Apollo 11, the first mission to put humans on the moon. Reactions to the historic feat reflected deep divisions within the United States at the time. While many people watched in awe, others expressed ambivalence or scorn given the ongoing fight against racial inequality and protests against the Vietnam War. Now, a new moonshot, also set against a backdrop of social unrest, is reminding us of space missions' power to unite humankind and bring our earthly problems into sharp relief (see Page 60). — *Cassie Martin*

ARE PIG ORGANS THE FUTURE OF TRANSPLANTATION?

By Meghan Rosen



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Joshua D. Mezrich
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Today, more than 100,000 people in the United States are waiting for an organ transplant. They're seeking kidneys, livers, hearts and lungs — organs from human donors that could give these patients a second chance at life. But every year, roughly 5,000 people on the national transplant list die waiting.

There's a future, though, in which no one needs to wait — when doctors have enough organs for every patient who needs one. These organs will come from genetically engineered pigs, and they could be even better than the ones we're born with: resistant to cancer and infection and able to tolerate extreme temperatures and pressures. In this future, drones might zip through the sky ferrying bespoke pig organs directly to surgeons waiting to plug them into patients' bodies.

"This may sound far-fetched and futuristic, but it really isn't," writes transplant surgeon Joshua Mezrich. His new book, *Every Living Creature*, chronicles the history of xenotransplantation, the practice of moving organs or tissues from one species into the body of another. If doctors can get it to work, xenotransplantation could one day help meet a critical need, increasing the number of organs available for transplant.

That's the case Mezrich makes, anyway. Amidst the rosy view of xenotransplantation's future, he gets serious with the science. This is a book that plunges readers into the vast sea of transplant-related immunology. It offers crash courses in genetics and history and the ethics of using animals to grow organs for humans. It introduces a wide and revolving cast of characters in the field: surgeons and scientists, patients and funders. At times, the story can feel like a whirlwind, whisking readers across decades and from lab to lab and surgery to surgery. But at its core, *Every Living Creature* is a book about hope.

It's about doctors with the single-mindedness and perseverance to keep going when the idea of putting pig organs inside living humans seemed impossible. It's about patients who endure years of daily dialysis waiting for a kidney. It's about people who desperately need a new heart but are too sick to be put on the list and people whose organs are persistently problematic but not problematic enough to qualify for a new one.

This is also a story about the courageous people who volunteer for experimental surgeries. People like David Bennett, the 57-year-old Maryland man who received a pig heart in 2022. Or 58-year-old Lawrence Faucette, also from Maryland, who underwent a similar operation in 2023. These men were the first to have genetically engineered pig hearts transplanted into their bodies. Bennett survived for two months after surgery, Faucette for nearly six weeks. Both knew their xenotransplants wouldn't extend their lives significantly, but they signed up anyway because they hoped their cases could help future patients. Such stories lend the book emotional heft and root high-flying scientific aspirations to reality.

Mezrich acknowledges that the field is prone to hype. Great leaps in technology that are needed to integrate a pig's organ into a human have been just around the corner for decades. But that doesn't mean science hasn't already made advances, or that the goalposts will always be just out of reach. Already, we've seen progress beyond what doctors achieved with Bennett and Faucette. For example, 66-year-old Tim Andrews received a genetically modified pig kidney in 2025 that helped serve as a bridge until a human kidney became available.

The path ahead is full of hurdles. Scientists need to improve genetically modified organs so the human body can better tolerate them. And biotech companies specializing in pig organs need to scale up their farming facilities. But Mezrich predicts more xenotransplants like Andrews' in the coming years. He envisions a day — perhaps not too long from now — when life-saving pig organ transplants have become the norm. "Welcome to the future," he says. ✖

Why I Volunteer at Regeneron ISEF

Society for Science, publisher of Science News, founded and produces the Regeneron International Science and Engineering Fair (ISEF), the largest STEM competition for high school students in the world. The competition, which launched in 1950, brings together about 2,000 students from more than 60 countries, regions and territories to compete for over $9 million in scholarships and awards. Students compete in the Society for Science's global affiliated fair network to earn an opportunity to compete at ISEF. Each year, volunteers take on roles from judging to interpreting to registering attendees. Here's what Jen Gutierrez, a longtime volunteer, has to say:

I first became involved with ISEF when the fair came to Phoenix in 2013. I had recently left the classroom to become the K–12 science specialist for my district. Our local science fair fed into ISEF, and I was invited to attend an early planning meeting. Somehow by the next meeting I became chair of the Local Arrangements Committee, which helps the Society organize elements of ISEF, including recruit local volunteers. I didn't fully know what I was getting into at the time, but I've been involved ever since.

What keeps me coming back, year after year, is the students. I love those kids. Getting to meet them during project check-in, seeing how excited and happy they are and learning directly from their work never gets old. When the world feels uncertain, ISEF is a reminder that there are young people out there who are going to take care of us. Watching students succeed, whether earning a special award or simply realizing the value of their ideas, is incredibly meaningful.

As Phoenix prepares to host Regeneron ISEF again this coming May, I'm especially proud of the STEM community here in Arizona. It is a mecca of technology and science, and we're deeply connected throughout the state. Between the universities, science organizations and business community, there's a real eagerness to support ISEF. We always have a lot of support, and who wouldn't want to come here and enjoy the sunshine?

It's always special coming back to volunteer. You pick up right where you left off, hugging people. Everybody remembers everybody. People return because they feel needed, valued and connected to something bigger than themselves.

If I could give advice to someone thinking about volunteering for the first time, it would be simple: Come try it. It's rewarding, it's fun and you'll be surrounded by some of the most curious and creative minds you'll ever meet. Chances are, once you do it, you'll be back.

SOCIETY FOR SCIENCE

VOLUNTEER AT REGENERON ISEF IN PHOENIX THIS MAY!
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Society for Science is a nonprofit organization best known for our award-winning journalism, world-class STEM competitions and STEM outreach programming. For more than a century, our mission has been to promote the understanding and appreciation of science and the vital role it plays in human advancement: to inform, educate, and inspire.

ON MOONSHOTS AND MINNEAPOLIS

BY LISA GROSSMAN

Since the beginning of the year, I've been gearing up to cover the launch of NASA's Artemis II mission. This launch aims to bring humans back to the vicinity of the moon for the first time in more than 50 years, with an eventual eye toward landing humans on the moon and learning how to live there long-term.

I expected to feel unalloyed excitement for this moment. I've been enraptured with space since I was 8 years old. I dreamed of being the first woman to land on Mars and search for alien microbes. I followed that passion to an astronomy degree and a career writing about space, for the joy of sharing my cosmological enthusiasm.

One of the things I love most about space exploration is its inspirational power and its potential as a unifying force. The first moon landing is remembered as a moment when the world looked up in simultaneous amazement.

"For one priceless moment in the whole history of man, all the people on this Earth are truly one," President Richard Nixon said in his July 1969 phone call to Neil Armstrong and Buzz Aldrin after they landed on the moon.

So in January, as I attended lunar science talks at an astronomy meeting in Arizona, I wondered: Would Artemis II evoke the same feeling? We could certainly use it in 2026.

Two days later, a U.S. Immigration and Customs Enforcement agent shot and killed a woman about a mile from my house in Minneapolis.

The woman, Renée Good, was demographically identical to me. We both moved to Minneapolis less than a year ago and had children the same age. She had been observing several of the thousands of ICE agents who had inundated the city under Operation Metro Surge. The largest immigration enforcement deployment in U.S. history, it was met with intense resistance from many Minnesotans.

I came home from the conference to find masked agents in military vests driving around my neighborhood. I witnessed them arrest someone across the street from my house while people blew whistles and cried, "You can't do this!"

Thousands of protestors filled the streets, enduring frigid weather and chemical weapons deployed by federal agents (see Page 40). Protests intensified when agents shot and killed Alex Pretti, a 37-year-old intensive care nurse and observer.

← Civil rights leader Ralph Abernathy protests the Apollo 11 launch. He objected to the U.S. government prioritizing the space program over solving poverty.

BETTMANN/GETTY IMAGES

My immigrant neighbors hid in their homes with sheets over the windows in a way that reminded me of my Jewish relatives hiding during the Holocaust. My kids were scared. I was scared. It was hard to think about anything else.

Meanwhile, NASA prepared to launch Artemis II. I sat staring at the draft of my preview story with a hollow feeling in my chest: *Who cares about people going to the moon?*

This feeling was a departure from myself and from history. Or so I thought. I had bought into the popular image of the Apollo missions as a symbol of the astonishing things people are capable of when they work together. But that image is incomplete. It turns out plenty of people felt profoundly *who cares* about the Apollo moon landing—or worse, that it was a shameful waste of money and effort.

The 1960s, like now, were marked by deep political division and social unrest. The civil rights movement, the burgeoning gay rights movement and the Vietnam War were just some of the things that brought people out into the streets.

It's a coincidence that both of NASA's moonshots came at a time of mass protests, says historian Neil Maher of the New Jersey Institute of Technology in Newark. But in the '60s, some of the protests were aimed at the Apollo program itself.

Many of these movements were critical of the U.S. government investing resources into putting men on the moon rather than helping people on Earth, Maher says. Civil rights activists held a sit-in under a mockup of the Apollo 11 landing module in Houston and organized a "March Against Moon Rocks."

On the eve of the launch, Ralph Abernathy, the president of the Southern Christian Leadership Conference and an adviser to Martin Luther King Jr., led a peaceful march to the gate of the Kennedy Space Center in Florida. Abernathy brought 25 poor African-American families and four mules pulling two wagons to illustrate the contrast between "the perceived backwardness of African-American agriculture and the technological wonders of the space race," Maher says.

While Apollo 11's landing was televised around the world, African-Americans in a Chicago bar pointedly watched baseball instead, Maher says. In Harlem, some 50,000 people attending a cultural festival booed the news. After the astronauts returned to Earth, activists interrupted parades and dinners held in their honor.

Science News' coverage of Apollo was ambivalent, too. "It is impossible to minimize the astronauts' accomplishment," editor Warren Kornberg wrote in the July 26, 1969 issue (cover, below). "But the verdict of history may well be that, while the world erupted, we ignored the real challenge and chased a rocket trail to the moon."

Some letters from *Science News* readers called that view "naïve," arguing that the moon program wasn't all that expensive. Others were even more critical: "[Many suffering people] were NOT proud.

July 26, 1969

We are frustrated and ashamed."

Even wonder at the feat itself wasn't a given. "What has happened to awe?" lamented space sciences editor Jonathan Eberhart. "Perhaps it has simply become unfashionable, uncool." He implored readers to "try, briefly, to ignore the flashy rockets and the heroic astronauts. Try to feel the smallness of man and the vastness of what he is doing."

I feel weirdly reassured that not everyone was thrilled about Apollo. Maybe that means it's OK for me to be less than thrilled about Artemis.

Still, I grieve for that feeling of unity and common purpose in exploring space. NASA certainly wants Artemis II to evoke that sentiment. But I am having a hard time accessing it, with the government behind Artemis slashing scientific infrastructure, denying basic science in dangerous ways and defending its agents shooting civilians.

Maybe both things can be true. Space exploration "can be this incredibly powerful thing that can bring us together," Maher says. "It can also be this thing, like a mirror, that illustrates that we have a lot of divisions and problems. That's the beauty of it, that it can do both."

I still believe in the power of space exploration to give us perspective on earthly problems. I don't want to grow cynical about the moon. I hope my sense of transcendence in space comes back.

For now, I'm finding that feeling of unity in my Minneapolis neighbors: The protests centered on communal singing. The ubiquitous 3-D printed whistles. The networks of people making school and grocery runs for families afraid to leave their homes. The courage and tenacity on display every day. People are capable of astonishing things when they work together. ✖

SOME SAY THE WORLD WILL END IN ICE. COULD IT?

BY CAROLYN GRAMLING

Here are some ways the world might end in ice, according to science fiction. Earth freezes. Humankind's remnants huddle in ice caves, fending off giant alien monsters (*Snowball Earth*). Or people shelter in the New York Public Library as ice encases the Empire State Building (*The Day After Tomorrow*). Or a train hurtles in an endless loop, both protection and prison for Earth's scant survivors (*Snowpiercer*).

These stories are all set in Earth's near future, within a decade from now. And what makes the visions so chilling is that there's a snowflake of truth in them. Well, space monsters haven't invaded Earth — yet. And a lot of ink has been spilled describing the scientific fallacies of the movie *The Day After Tomorrow*.

But there have been at least five ice ages in Earth's history, the most severe one during the aptly named Cryogenian Period, between 720 million and 635 million years ago. At least twice during this period, glaciers extended from pole to pole, creating a "Snowball Earth."

Or "maybe it was more of a 'Slushball Earth,'" says geoscientist Thomas Algeo of the University of Cincinnati. Fossils of seafloor-dwelling algae, which would have needed sunlight to survive, suggest that even in the coldest times, there were patches of open water near the equator that may have harbored life.

Earth's past deep freezes came from a combination of geologic processes. The Cryogenian followed after shifting tectonic plates caused a supercontinent to split apart. That increased rainfall and weathering, which dramatically reduced atmospheric carbon dioxide, causing runaway cooling. Widespread ice exacerbated the cooling, reflecting sunlight back to space rather than the ground absorbing the heat.

These processes are slow, which is not ideal for dramatic storytelling. However, sci-fi has the advantage of playing with time, taking known natural — or human-caused — climate interactions and feedback effects and accelerating them or amping them up for drama.

The Day After Tomorrow, for example, is based on a real-world scenario: the potential shutdown of the Atlantic Meridional

TUNG NAM

Overturning Circulation, a part of a global system of ocean currents that transports heat around the world, keeping regions that might otherwise be frigid relatively warm.

Geochemist Wallace Broecker suggested in the mid-1980s that large fluxes of freshwater to the North Atlantic Ocean could halt this circulation. Ocean current slowdowns or shutdowns have contributed to past ice ages, he said. Scientists fear it could happen again, and soon. But soon, geologically, means decades to a century. In *The Day After Tomorrow*, a new ice age arrives in weeks.

Snowpiercer, a graphic novel, movie and TV series, imagines a different deep-freeze scenario: Geoengineering gone haywire. To mitigate global warming, scientists released aerosols into the atmosphere to reflect sunlight to space. The idea is based on an actual type of geoengineering known as solar radiation management.

But the aerosols plunged the planet into a deep freeze within weeks (or hours, in the novel). Geoengineering strategies could cool Earth, but not *that* quickly (more like within a few years). And not by that much, or by accident. To bring on an ice age, aerosols would have to be deliberately and repeatedly injected over generations, says climate engineer Douglas MacMartin of Cornell University.

How Earth freezes in *Snowball Earth* is still something of a mystery, as the manga is still in progress (and an animated version of it is slated to debut in April). What is known is that the transition to an ice world takes about a decade. And — spoiler alert — the giant alien monsters might have something to do with it. For that, scientists don't really have an answer. ✖

FRESH GRIDFLOWERS

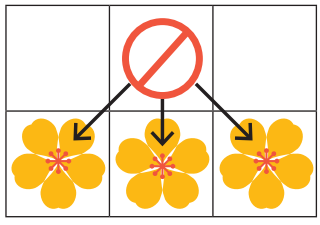
BY BEN ORLIN

You're hosting a wedding at your home next summer, and the happy couple asked you to decorate the four gardens on the grounds with — let me check my notes — ah, fresh gridflowers. Gridflowers are planted in square plots. Each autumn, they cast seeds to all neighboring squares, including diagonals. The next spring, the old flowers are gone. A fresh flower will grow only in the spots that had exactly two neighboring flowers the year before (see examples below). And true to its name, a gridflower won't grow beyond a given grid plot.

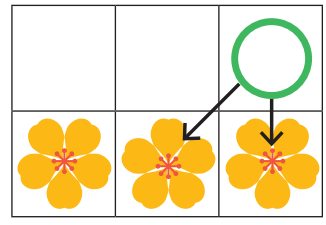
But the couple doesn't want hand-planted gridflowers. They want flowers that grew naturally from the spread of the previous year's flowers.

Therefore, you must plant your four gardens by hand this summer, so that next summer, each one contains a desired number of gridflowers.

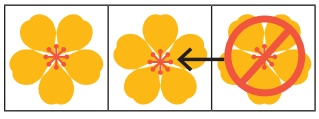
No flower next year
(Too many neighbors)



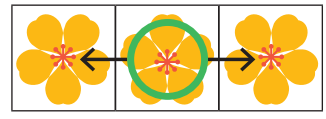
Flower next year
(Two neighbors)



No flower next year
(Too few neighbors)

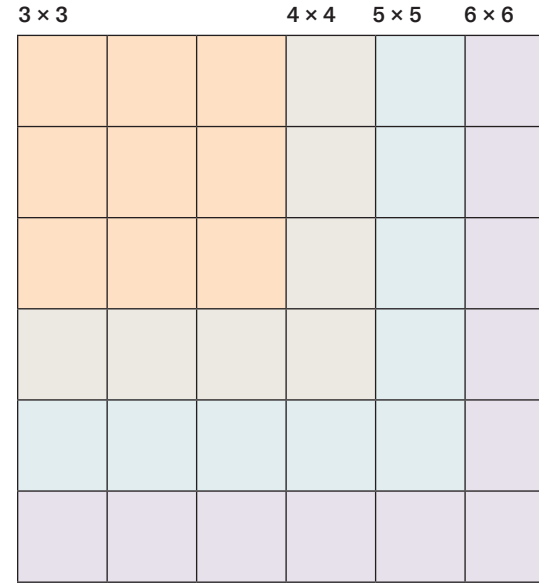


Flower next year
(Flower does not count
as a neighbor to itself)

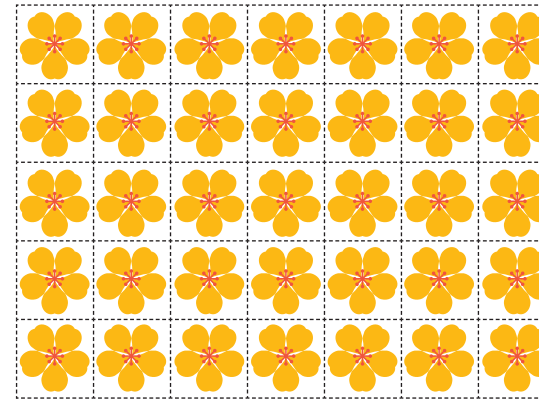


How can you achieve the following number of flowers for each garden next year?

- Exactly eight flowers for a 3 × 3 grid
- Exactly 12 flowers for a 4 × 4 grid
- At least 17 flowers for a 5 × 5 grid
- At least 24 flowers for a 6 × 6 grid



Cut out the blooms and use them on the grids above



C. CHANG

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