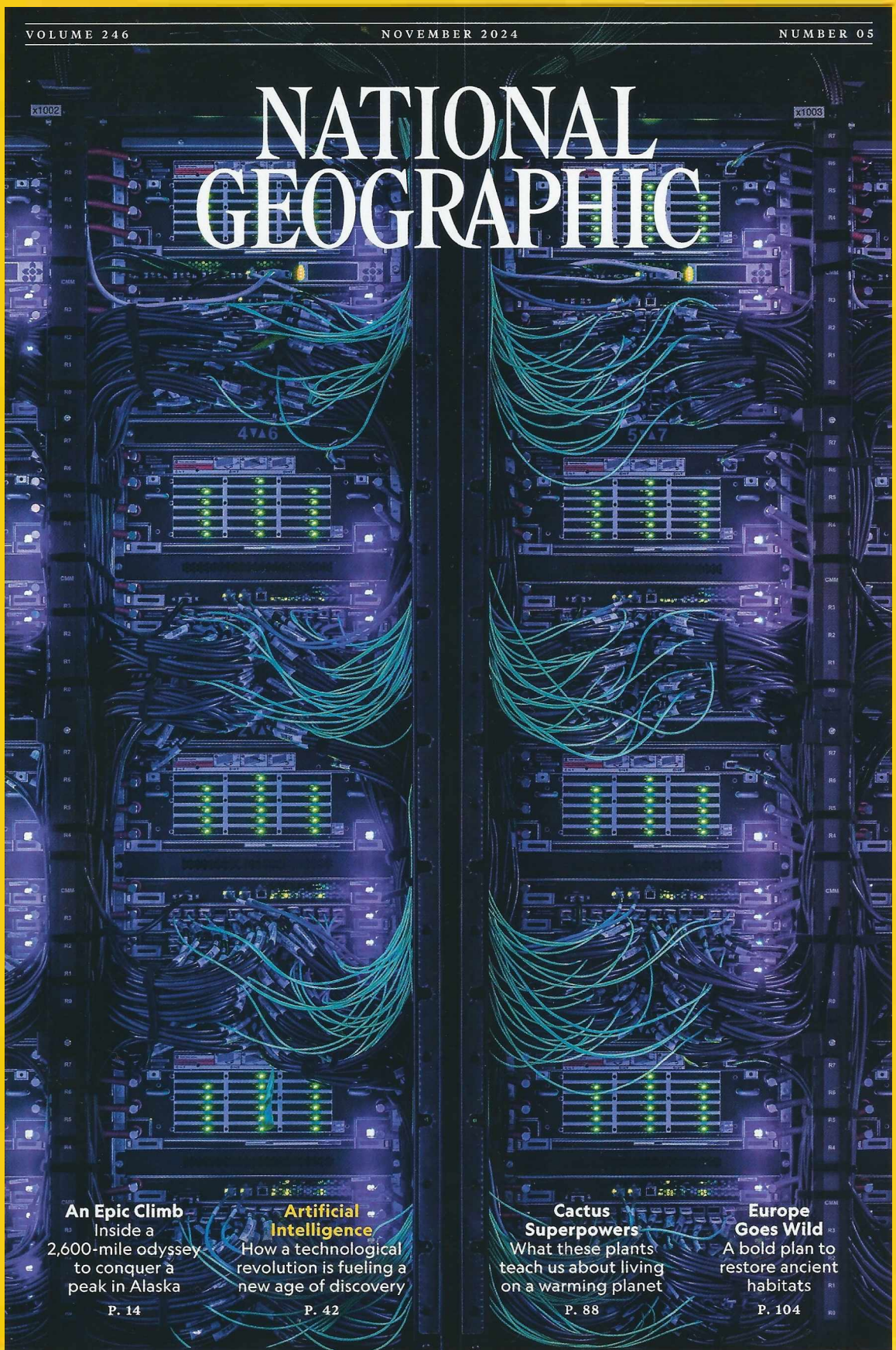
VOLUME 246 NOVEMBER 2024 NUMBER 05

NATIONAL GEOGRAPHIC



An Epic Climb
Inside a 2,600-mile odyssey to conquer a peak in Alaska
P. 14

Artificial Intelligence
How a technological revolution is fueling a new age of discovery
P. 42

Cactus Superpowers
What these plants teach us about living on a warming planet
P. 88

Europe Goes Wild
A bold plan to restore ancient habitats
P. 104

CONTENTS

ON THE COVER El Capitan at California's Lawrence Livermore National Laboratory is expected to become the world's fastest supercomputer. Its mission: to ensure the safety and reliability of the U.S. nuclear weapons stockpile.
Photograph by SPENCER LOWELL

CORRECTION The cover image for the newsstand edition of the August 2024 issue was credited incorrectly. The photograph, which shows a reflection of the Eiffel Tower on the Seine, was taken by **William Daniels.**

NATIONAL GEOGRAPHIC EXPLORERS

These contributors have received funding from the National Geographic Society, which is committed to illuminating and protecting the wonder of our world.

Jasper Doest, p.104

An Explorer since 2022, Doest covers here the effort to expand wilderness in Romania. His interest in the rewilding movement began in 2009, when he photographed the reintroduction of bison in his native Netherlands for *National Geographic*'s Dutch edition. It's been "a focal point for me ever since," he says.

Mark Synnott, p.14

Before becoming an Explorer in 1999, he spent years honing his climbing skills on Yosemite's towering cliffs. Since then, he's embarked on and written about expeditions such as scaling Mount Everest and sailing the Northwest Passage. For this issue, he interviewed world-class climbers who ascended Devils Thumb in Alaska.

Christian Ziegler, p.88

The photojournalist, who splits his time between Germany and Panama, was named an Explorer in 2013. He has a specialty in tropical rainforest photography, documenting intricate ecosystems and rare species, and this month he turns his lens toward cactus in his 13th feature for the magazine.

Angela Posada-Swafford, p.88

A fellow of the Explorers Club, the Miami-based writer reports on scientific endeavors around the globe. She last wrote for *National Geographic* about see-through frogs in Ecuador and this month covers the resilience of cactus.

Neel Dhanesha, p.42

This writer and audio producer from Bangalore, India, tells stories about humans' changing relationship to the world around us. While reporting his first articles for the magazine, he spoke to artificial intelligence experts in Pittsburgh and Lesotho.

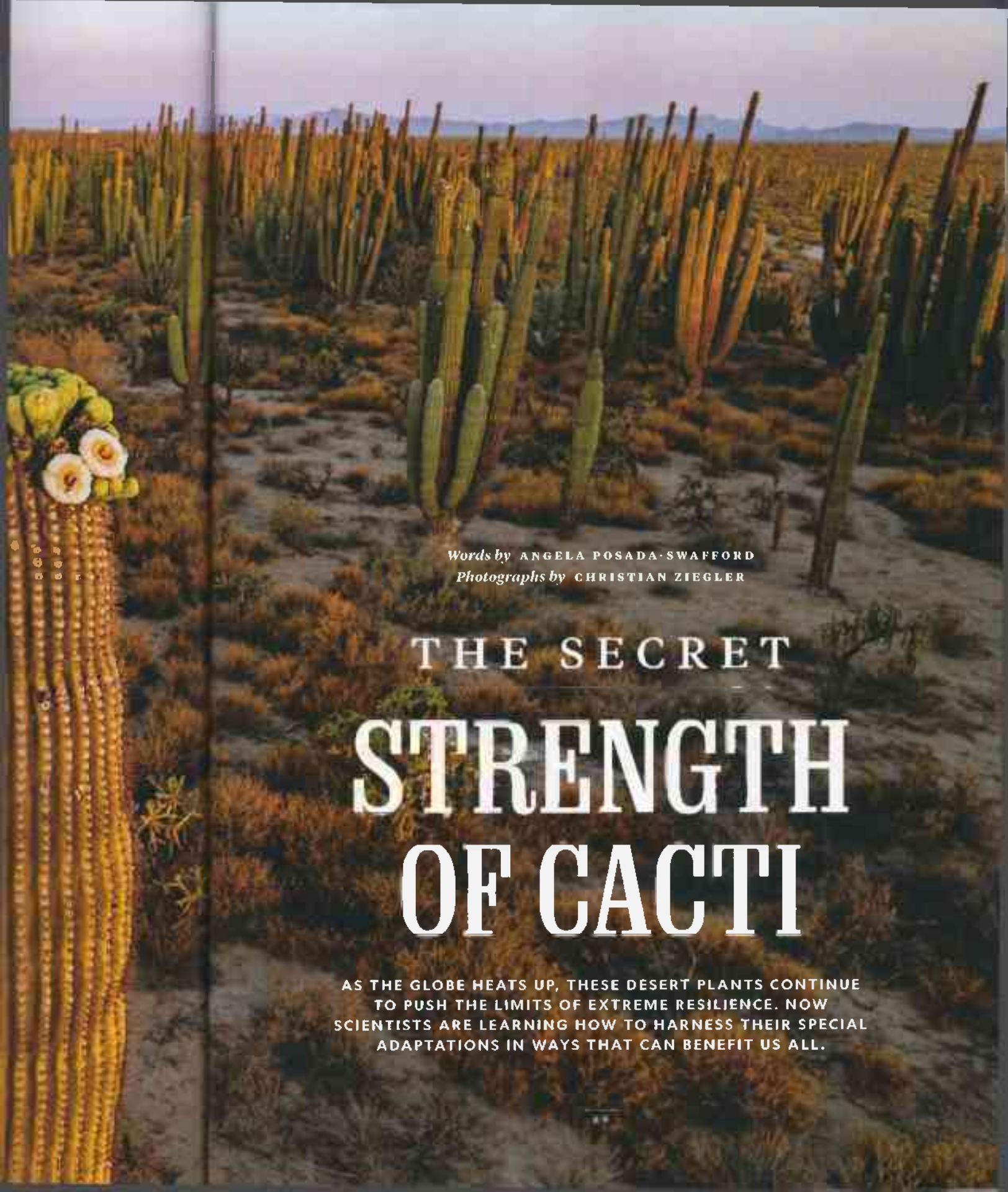
Chris Gayomali, p.42

Making his home in New York City, Gayomali is a former articles editor at GQ magazine and now writes the health and wellness newsletter *Heavies*. In this issue, he explores how AI is advancing our ability to detect neurological tumors.

Isabella Tree, p.104

After she and her husband, Charlie Burrell, shepherded their U.K. estate through a rewilding experiment, Tree found herself advising others. It led to a how-to guide—and a film, *Wilding*. Tree writes here about a bold effort to create a national park.

PHOTOGRAPHS BY JASPER DOEST (AVIAN); NEEL DHANESHA, OLIVIER HESS, CHRIS GAYOMALI, CHRISTIAN ZIEGLER



Words by ANGELA POSADA-SWAFFORD
Photographs by CHRISTIAN ZIEGLER

THE SECRET STRENGTH OF CACTI

AS THE GLOBE HEATS UP, THESE DESERT PLANTS CONTINUE TO PUSH THE LIMITS OF EXTREME RESILIENCE. NOW SCIENTISTS ARE LEARNING HOW TO HARNESS THEIR SPECIAL ADAPTATIONS IN WAYS THAT CAN BENEFIT US ALL.

The creamy white-and-yellow flowers of the saguaro open in sequence around the plant's crown.

AS THE G
TO PU
SCIENTIST
ADAP

ON A BRIGHT SPRING DAY, a lone 28-foot cactus towered above the dusty scrub within Saguaro National Park in Arizona. Despite the cloudless sky and oven-like heat, the spiky giant looked strong and healthy. Rain had recently fallen in the park, and the plant's pleated sidewalls were extended, retaining hundreds of gallons of water inside.

Such internal reservoirs help cacti thrive where other plants would instantly wilt. But the saguaro species *(Carnegiea gigantea)*, native to the Sonoran Desert in the United States and Mexico, hides another evolutionary trick. To capture it in action, a park biologist named Don Swann had arrived with an extra-long, custom-made telescoping pole and camera mount system that he extended toward the giant's crown. Then he snapped several digital photos, the latest in a set of images he'd been taking for several weeks. Later that afternoon, Swann reviewed the time-lapse series and pointed out that "something miraculous" was happening.

The photos highlighted an array of tightly shut white-and-yellow flowers that ringed the top of the plant. Saguaro flowers bloom only once and typically at night to protect their delicate internal anatomy from long hours of intense sun. But the photos, when viewed sequentially, revealed something else: The buds appeared to be moving. From mid-April through mid-June, the flowers were slowly migrating in a counterclockwise fashion, traveling radially from the plant's eastern face to its northern side, which offered more consistent shade.

"This could allow saguaros to take advantage of warmer temperatures, and more sun, during the cooler early spring, while minimizing the more deleterious heat effects later in the season," Swann suggested.

Over the past half decade, Swann and other park scientists have teamed up with a group of citizen scientists to photograph 55 saguaros, becoming the first researchers to confirm with visual evidence that this floral migration happens annually. This is just one trait associated with just one species: All told, there are more than 1,500 known species of cacti, which, while still threatened by the unpredictability of climate change and human encroachment, continue to live in some of the harshest climates on Earth.

"A lot of the stories that have come out about cacti are fearful and negative," says desert plant ecologist Ben Wilder, director of the Next Generation Sonoran Desert Researchers, an organization that connects experts across the border between Mexico and the U.S. "To me,

The Sonoran Desert lies in both the United States and Mexico; its estimated 140 cactus species are being tested by increasingly hot and dry conditions.

de. Swann and other
ned up with a group
notograph 55 sagua-
searchers to confirm
this floral migration
just one trait asso-
cies: All told, there
n species of cacti,
ened by the unpre-
hange and human
e to live in some of
Earth.
have come out about
gative," says desert
director of the Next
ert Researchers, an
ts experts across the
nd the U.S. "To me,

cacti are such a beautiful story of adaptation to arid environments and all these different strategies of resilience and prosperity."

For researchers, cacti now represent a new frontier of survival, one offering surprising lessons that, if harnessed correctly, could be applied to a world far beyond them.

The family Cactaceae, which evolved 35 million years ago in the Americas, is one of the most diverse and outlandish assemblages of plants on the planet. They can branch out as massive trees, rise as 60-foot-tall columns, grow as thick balloons, or fit on a one-cent coin. Some are "living rocks" able to handle soils that would desiccate any other plant, while others grow furry white coats to keep them from the elements in the cold Andean altitudes.

Scientists are discovering that saguaro cactus spines contain information on past climate conditions, similar to tree rings.

Top: A native b
honeybees e

Bottom: A sing
columnar cactus
into a t

Top: A native bee pollinates a cactus flower. Native bees are more successful than European honeybees at pollinating desert cacti. In return, the plants provide the specific type of pollen the bees need to feed their young.

Bottom: A single cactus can have a diversity of features. These emerging spines of the Senita columnar cactus remain short on the lower part of the plant. Higher up, other spines will erupt into a thick mass of bristle-like spikes, each growing up to four inches long.

A lesser long-nosed bat drinks sweet nectar from a saguaro flower, which blooms only once, at night, and closes the next day.

None of those forms would exist if it weren't for a fundamental advancement: Cacti and other succulents have developed a unique approach to photosynthesis. Each time a plant opens its pores to take up the carbon dioxide necessary for energy conversion, some water is lost. If this happens frequently during daytime, high temperatures will cause the water to evaporate quickly.

To prevent that, the desert plants don't open their pores until the sun goes down. Then they absorb atmospheric gas and convert it into malic acid, which is stored in large sacs inside their cells for use the next day. It's a process called crassulacean acid metabolism, or CAM.

John Cushman, a professor of biochemistry and molecular biology at the University of Nevada in Reno, dreams of cultivating this genetic trait in more plants. On the agricultural front, this could lead to more efficient crops that lose less water under drought conditions. While that breakthrough may be years or even decades away, researchers have still found one way to make non-cactus plants be at least a little more cactus-like.

Before cultivating CAM in new plants, scientists need to alter their leaf anatomy to store malic acid and accommodate larger cells, the processing warehouses for this interaction. One by-product is that plants with larger cells can also hold more water, encouraging succulence, or the ability for their tissues to grow bigger and retain more available moisture. In a 2018 paper, Cushman demonstrated engineering tissue succulence in a small, white-flowered weed called mouse-ear cress *(Arabidopsis thaliana)*. A follow-up study, published in 2020, shows that the leaves of an experimental plant grew 40 percent thicker.

"It's an exciting adaptation that we still have a lot to learn from," says Cushman. For one thing, if a plant can expand the amount of water that it carries within its tissues, it can likely dilute the excessive salts that tend to concentrate in the soil during drought periods. Cushman is applying this science to soybeans,

the second largest commodity crop in the U.S., in hopes of radically improving food security.

Designing smarter crops and botany with cactus-inspired attributes is a pretty big leap. But researchers are now identifying other superpowers that can be applied in dramatic ways to innovations that don't require plants at all—for instance, new building materials. One of the most exciting advancements involves *Copiapoa*, a genus that comprises at least 32 species, mostly exclusive to the coastal Atacama region in northern Chile, the driest nonpolar desert on Earth. For scientists, unlocking the mystery of how they endure starts with their unique shape. Most plants are five to six inches in diameter and can form into gray-greenish cushions that dot an eerie landscape otherwise devoid of vegetation.

"Very little is known about the biology of these plants," says Carol Peña, a botanist from the University of Concepción in Chile who regularly treks into the barren hills of the backcountry to explore how they sustain themselves. She often finds them tucked between folds of rock in a gully or set on steep cliffs facing the coast.

As Peña explains it, copiapoas probably survive by "drinking" the salty camanchaca fog that sweeps in from the sea every morning, as well as the dew that condenses on their spines and skin. That revelation, documented by many scientists, has inspired biomimicry researcher Tegwen Malik, from Swansea University in the United Kingdom, to think about whether the dew-collecting process might be replicated in metal structures.

Specifically, Malik took a close look at the conical, one-and-a-quarter-inch spines of the green and amber globular species *C. cinerea* var. *haseltoniana* and found that their surface has a series of tiny grooves that broaden at the base. "This creates a surface roughness gradient that enables dew droplets to be channeled along them even against gravity," she says.

Starting in 2013, she set out to re-create that structure by engineering a flat steel and aluminum replica of the stem and spines of the cactus, which she began testing under a series of different temperatures and humidities. After several years of experiments—testing indoor and outdoor conditions, and with various cooling methods—she finally got it to work. In 2023, Malik published a study showing that the prickly, contoured surface was 8 percent more efficient at harvesting dew than a flat sheet used as a baseline.

CACTI CAN BRANCH OUT AS MASSIVE TREES, RISE AS 60-FOOT-TALL COLUMNS, GROW AS THICK BALLOONS, OR FIT ON A ONE-CENT COIN.

To optimize her design, she imagines desert homes with these water-collecting features. The innovation could even be adopted more widely as a humanitarian measure to secure clean drinking water in arid regions that lack life-saving resources. "The easiest way could be to place the dew-harvesting surfaces on roof tiles, but you could also have these structures in tents in the desert, for example," she says. "We truly have a hidden gem in the *Copiapoa*, and we are only just learning some of their secrets."

At a moment when the long-kept secrets of the cacti are closer than ever to being revealed, the plant itself is facing a difficult future. Around 60 to 90 percent of cactus species will be negatively affected by climate change or human activity, according to a study co-authored by Bárbara Goettsch, co-chair of the International Union for

A hummingbird surveys the flowers of an octopus cactus, native to Mexico. The plant grows a thicket of thorny stems that can spread up to 30 feet.

Even the emblematic saguaro faces an uncertain future. Its survival is challenged by extreme heat, drought, and wildfire.

PHOTO: VICTOR AMMANN

Conservation of Nature's Cactus and Succulent Plants Specialist Group. "Cacti are among the most threatened taxonomic groups assessed to date," says Goettsch.

Case in point: March 2021 marked the end of the driest year in the past seven decades for the southern Baja California peninsula in Mexico. In response, large tracts of the famous columnar organ pipe *(Stenocereus thurberi)* are showing a yellowing of their stems.

Wilder, the director of the Sonoran research group, calls this a "cactus scorching event," the long-term effects of which are still largely unknown. What is clear is that some plants' photosynthetic systems appear to be breaking down because of the stress from intense heat and lack of moisture. "What we are seeing is that these extreme heat and drought events are having a landscape-level impact on the cactus population," he says.

Back in Tucson, Swann remained skeptically optimistic about the species he's been carefully photographing. He recently joined the Saguaro Arms Citizen Science Project, which began in the spring of 2023, and is discovering that saguaros appear to grow their first arm on the southeastern-facing side to receive more energy from the sun. At the same time, he's collaborating in the Future of the Saguaro research project, a partnership that aims to learn more about saguaro responses to climate change, including by planting test beds to study the genetics associated with heat resistance.

As the sun beat down, Swann gestured toward a slope covered in the iconic cacti, whose twisting arms make it nearly impossible to ignore their humanlike appearance. "These saguaros are going to live for a long time," he said. Some specimens may live more than 200 years. The opportunity for discovery is just heating up. □