

03.2020

NATIONAL GEOGRAPHIC

THE END OF TRASH

CAN WE SAVE THE PLANET BY
REUSING ALL THE STUFF WE MAKE?



ADVERTORIAL FOR DOW

TRAVELING A CIRCULAR ROAD TO A CLEANER ENVIRONMENT.

What if every piece of plastic became a new product, recycled and reused in a never-ending circle? Dow is catalyzing that "circular economy" with education and innovations that keep plastic waste out of the oceans and landfills. Here are a few examples of how Dow is advancing on the road to a circular economy for plastic.



To learn more about these initiatives, go to DONT-WASTE.DOW.com

ADVANCING ON THE ROAD TO A CIRCULAR ECONOMY FOR PLASTIC.

SUSTAINABLE PACKAGING

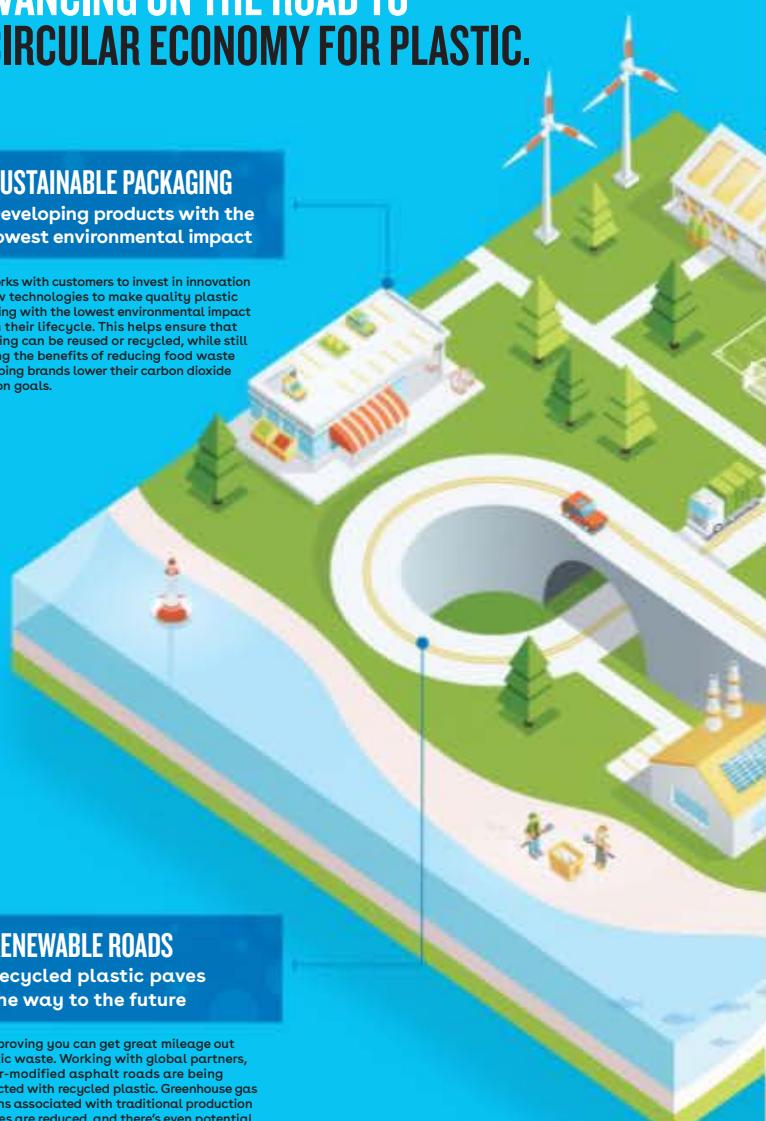
Developing products with the lowest environmental impact

Dow works with customers to invest in innovation and new technologies to make quality plastic packaging with the lowest environmental impact through their lifecycle. This helps ensure that packaging can be reused or recycled, while still providing the benefits of reducing food waste and helping brands lower their carbon dioxide reduction goals.

RENEWABLE ROADS

Recycled plastic paves the way to the future

Dow is proving you can get great mileage out of plastic waste. Working with global partners, polymer-modified asphalt roads are being constructed with recycled plastic. Greenhouse gas emissions associated with traditional production processes are reduced, and there's even potential for use in road improvements. So far, 60 miles are complete with more on the way.



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V
ADVERTORIAL FOR DOW

Inspiring and creating value with innovative solutions for responsible plastics use, reuse, repurposing and recycling.

PLASTIC CLASSROOMS

Building schools and futures with recycled plastic

Dow believes true innovation solves real life problems. It's happening today as one solution tackles two big challenges: Too much plastic waste and too few schools. Dow is collaborating with partners to build new classrooms and schools using self-assembling bricks made from recycled plastic.



EXPANDING RECYCLING

Advancing breakthroughs to give plastic many lives

Dow is investing in a number of innovations and partnerships to advance the production of circular polymers using feedstock recycling—the process of breaking down mixed waste plastics to manufacture new polymers.

Working to keep plastic waste out of the environment

Plastic waste doesn't belong in the environment, and all around the world, local efforts are making a huge difference in cleaning up trash-filled beaches, natural areas, and waterways. Last year, Dow hosted 175 cleanups, mobilizing more than 18,000 volunteers to remove over 175,000 pounds of waste.

Delivering circular economy solutions

Dow works closely with customers to ensure the plastics applications consumers use have the lowest environmental impact compared to alternative materials. This includes designing plastic products that can be easily recycled and/or can be made of recycled materials. Dow is driving innovation around advanced recycling processes, supporting reusability

and using fewer resources as part of its commitment to advancing end-of-life solutions for plastic.

Increasing impact through partnerships

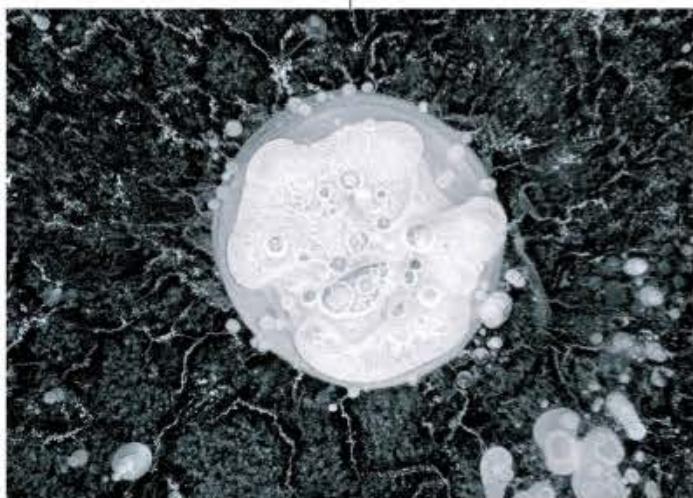
Dow is convening and driving a number of key partnerships throughout the globe—bringing together customers, brand owners, governments, waste management companies, and environmental organizations—to collaborate on solutions to this critical challenge. This includes being a founding member of the Alliance to End Plastic, a \$1.5 billion commitment from nearly 50 companies to develop and scale solutions that manage plastic waste and promote post-use solutions of plastic. Dow is also a founding investor in Circulate Capital's \$106 million Ocean Fund, which is the first fund and incubatory focused specifically on preventing ocean plastic, particularly in South Asia.



DOW

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FEATURES

The End of Trash

"To get along on this Earth," *National Geographic*'s senior environment editor writes, "we must do just one thing: Stop wasting so much of it." That's the goal of advocates of a circular economy—one that would extract value from most of the trash we now discard.

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NAT
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TV

Join the exploration of *Cosmos: Possible Worlds*

Television's most watched science show returns March 9. *Cosmos: Possible Worlds*, created and executive produced by Ann Druyan and hosted by astrophysicist Neil deGrasse Tyson, continues the legacy that Carl Sagan began more than 40 years ago. Episodes transport viewers across space and time with one-of-a-kind animations (above), holograms, and reenactments of world-altering discoveries.

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NAT GEO WILD

Enjoy the *Critter Fixers* TV debut

Veterinarians Vernard Hodges and Terrence Ferguson have been classmates, partners in an animal hospital—and now they're co-stars of a show about their work. *Critter Fixers: Country Vets* premieres February 23 at 10/9c on Nat Geo WILD.

NAT GEO LIVE

Experience an era *When Women Ruled the World*

A Nat Geo Live event may be coming to a venue near you. This month, learn about ancient queens with Egyptologist Kara Cooney, author of *When Women Ruled the World*. See schedules at nationalgeographic.com/events.

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IMAGINING
'THE END
OF TRASH'

The Promise of a Circular Economy

BY SUSAN GOLDBERG PHOTOGRAPH BY LUCA LOCATELLI



WE FEEL BAD when we throw out things that shouldn't have become trash (like uneaten, past-its-prime produce) or expend resources needlessly (like leaving lights on when we're away). This guilty feeling is deeply ingrained; the origins of the expression "waste not, want not" can be traced to the 1500s.

But we *do* waste, in ways big and small. The result is this shocking fact: Of the minerals, fossil fuels, foodstuffs, and other raw materials that we take from the Earth and turn into products, about two-thirds ends up as waste. And, more likely than not, that waste is part of a larger environmental problem.

"Plastic trash drifted into rivers and oceans; so did nitrates and phosphates leaching from fertilized fields. A third of all food rotted, even as the Amazon was deforested to produce more," writes senior environment editor Robert Kunzig in "The End of Trash," the cover story in this issue. And the biggest waste-caused problem? Climate change is what happens when "we burn fossil fuels and scatter the waste—carbon dioxide—into the atmosphere."

What if we could recapture waste and turn it into something else? This concept, called the circular economy,

is not entirely new. Environmentalists have espoused the reduce, reuse, recycle ethos since the 1970s. For generations, in Prato, Italy, old wool sweaters have been reduced to their yarn and rewoven into new clothes. And for decades, copper was extracted from church bells and statues; today it's more likely to come from iPhones and flat-screens.

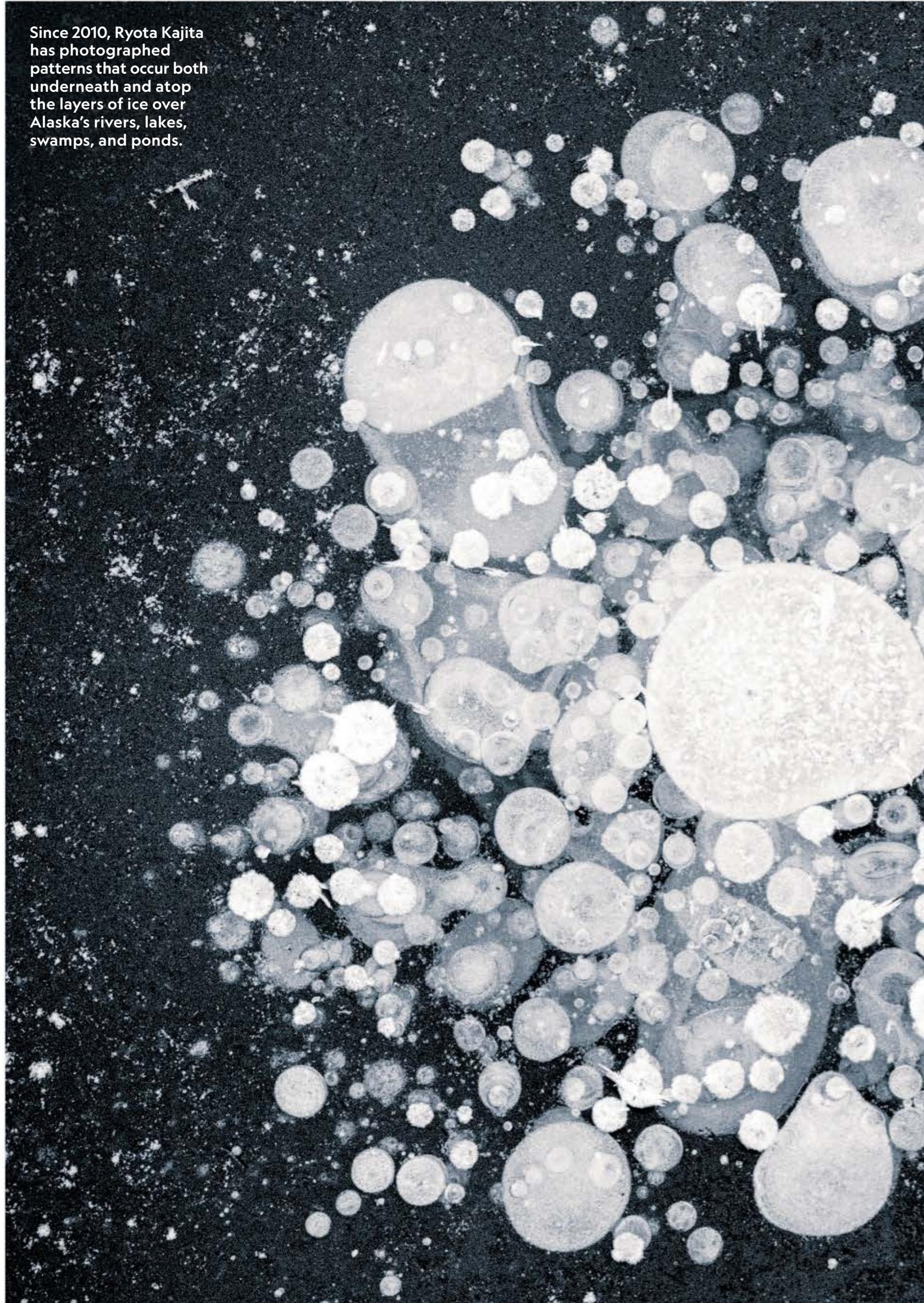
We sent Kunzig and photographer Luca Locatelli to document where the new circular economy is taking hold. They found a lot of examples. In New York, fungi filaments are used to create compostable packaging. In London, researchers are feeding beer waste to insects, which are made into animal feed. In hotel kitchens around the world, chefs are reducing food waste with AI garbage cans that measure it.

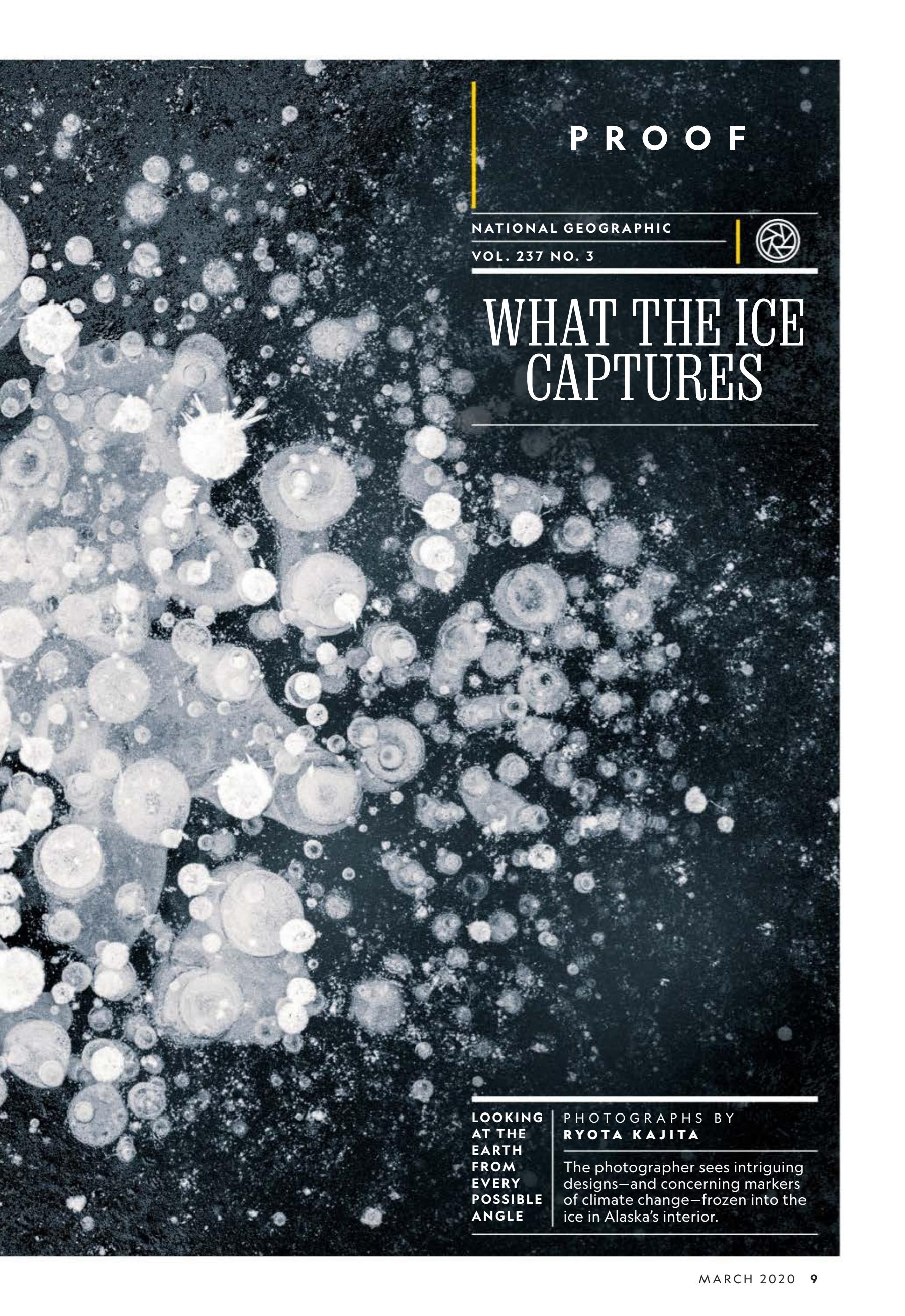
The idea that we might put an end to trash may seem far-fetched—and it is, but in a good way, Kunzig told me. "It reminds me of a line in *Diner*, a movie I love: 'If you don't have good dreams, you got nightmares.' The circular economy is like that—it's a dream we have to try to make real."

Thank you for reading *National Geographic*.

At this Prato, Italy, facility, bundles of discarded textiles will be processed and used to create new clothing—an example of the circular economy in action.

Since 2010, Ryota Kajita has photographed patterns that occur both underneath and atop the layers of ice over Alaska's rivers, lakes, swamps, and ponds.





PROOF

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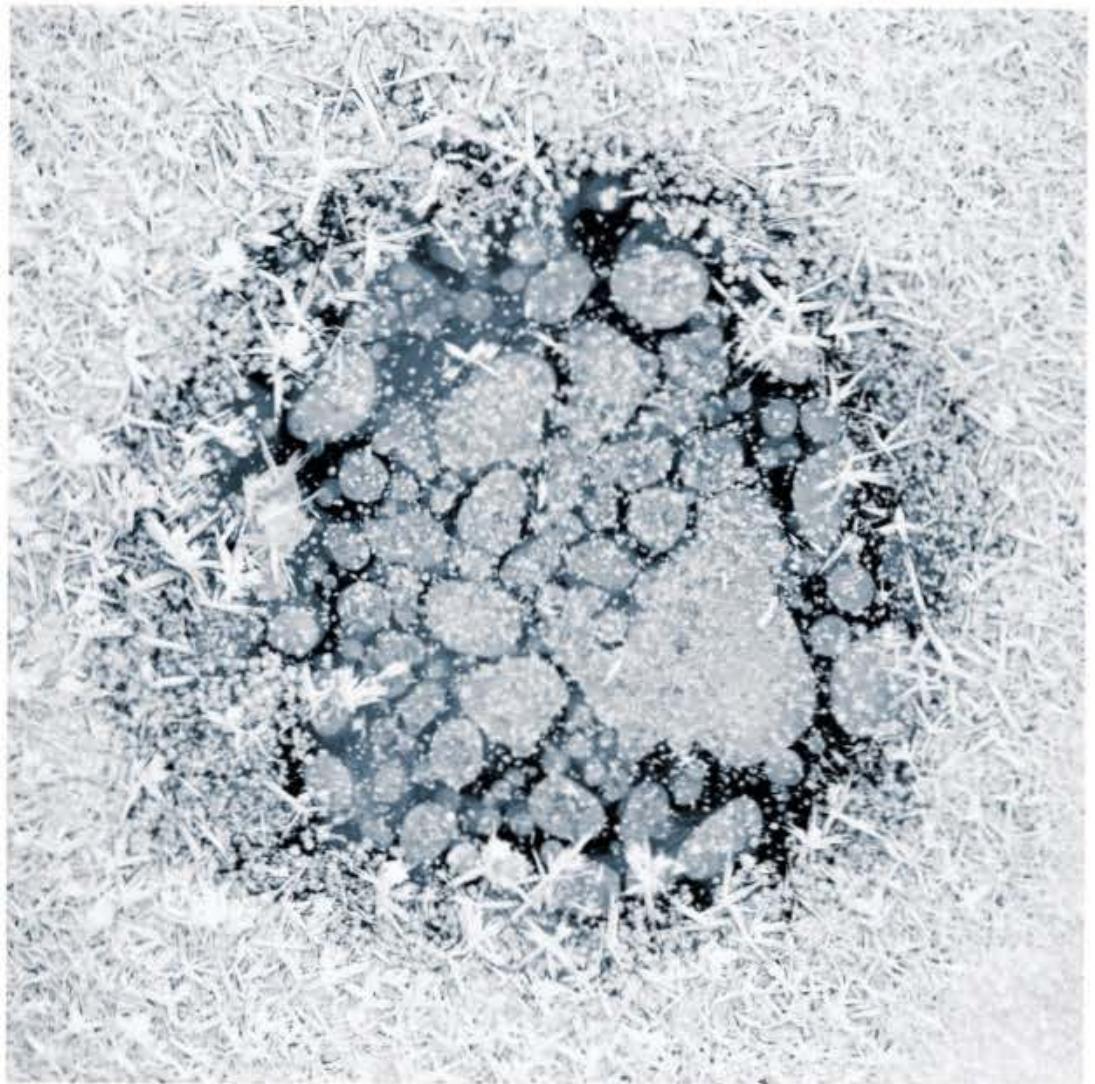
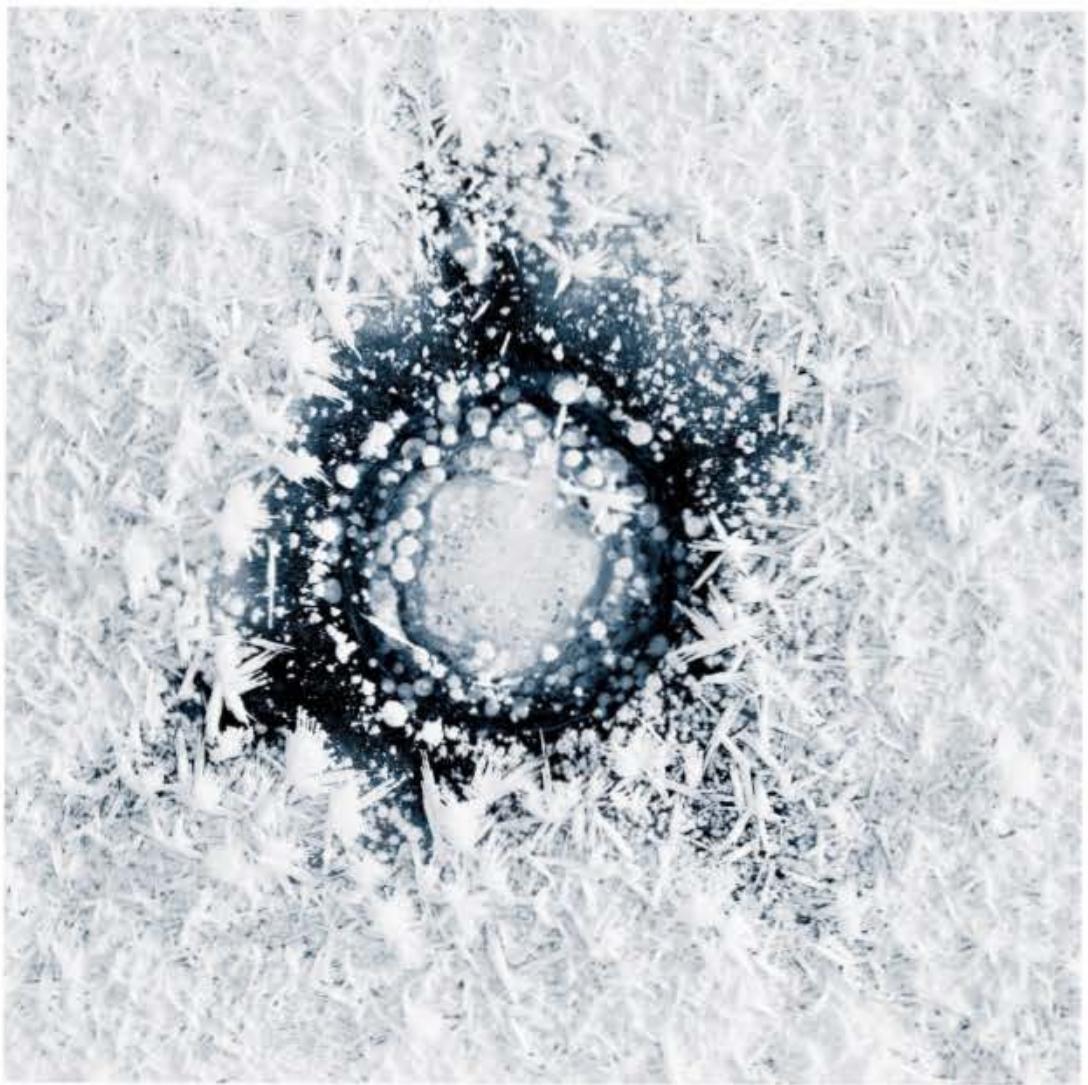


WHAT THE ICE CAPTURES

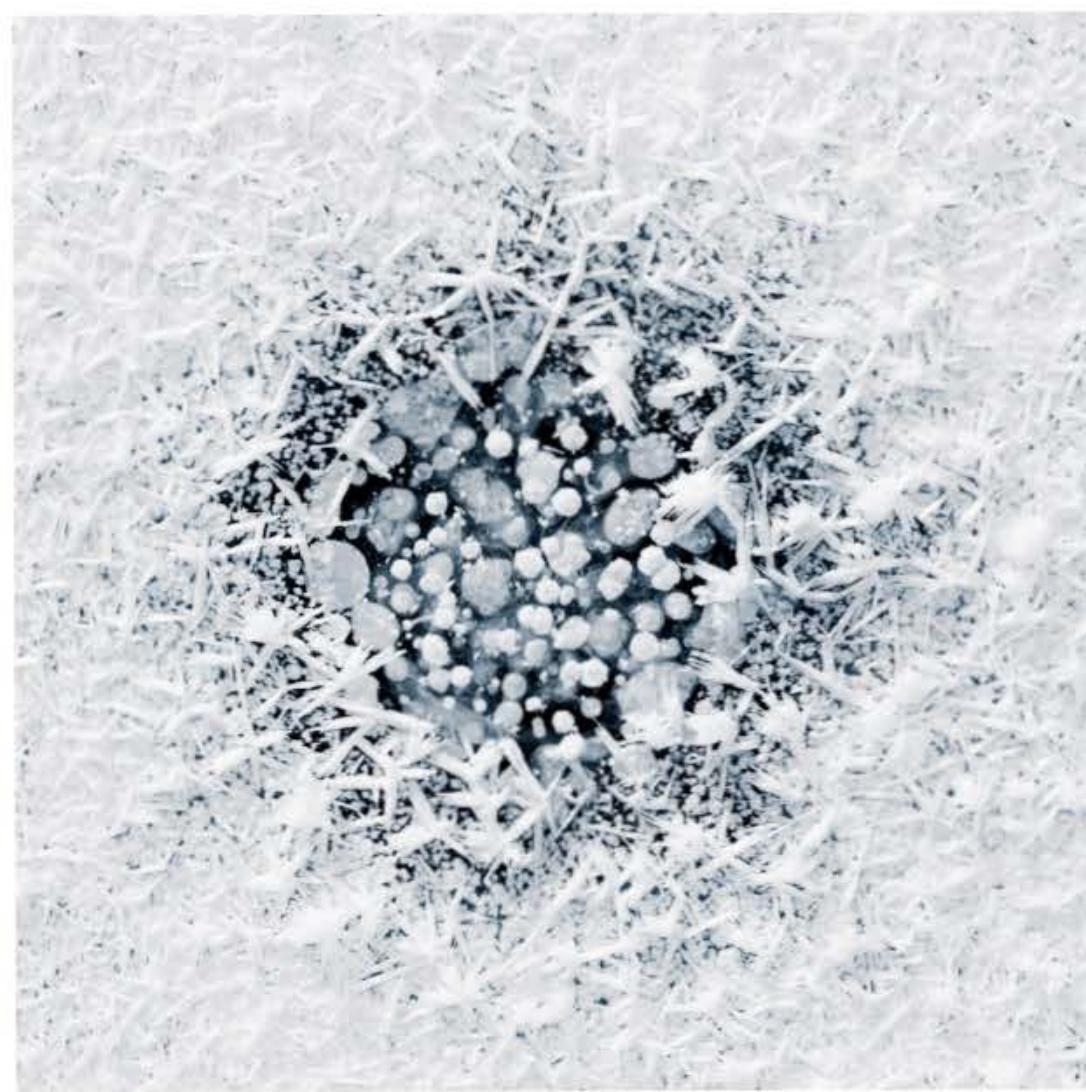
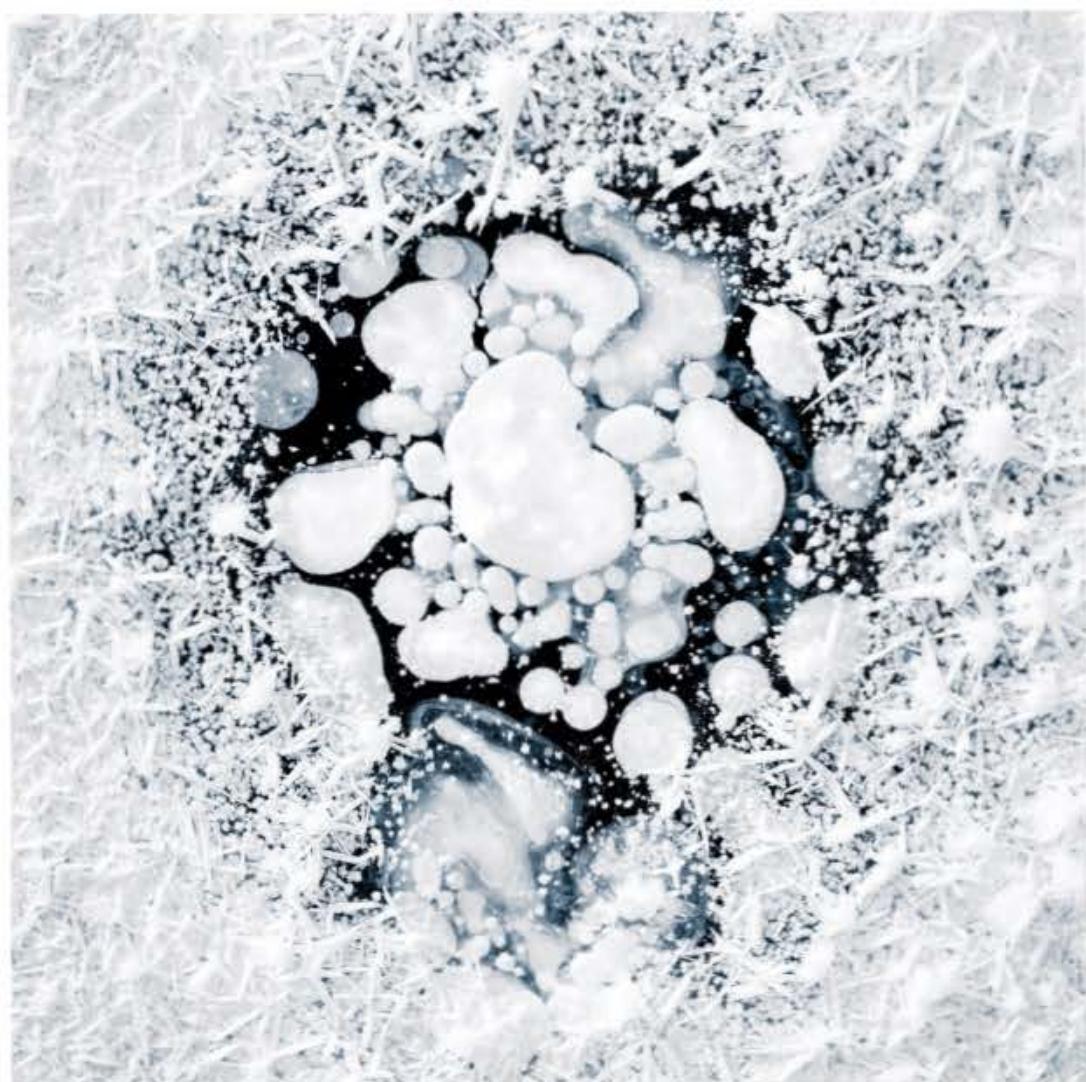
LOOKING
AT THE
EARTH
FROM
EVERY
POSSIBLE
ANGLE

PHOTOGRAPHS BY
RYOTA KAJITA

The photographer sees intriguing designs—and concerning markers of climate change—frozen into the ice in Alaska's interior.



Kajita described the science behind the images in his project, *Ice Formations*, for the digital gallery Life-Framer.com: "Many of the formations are frozen bubbles of gases such as methane and carbon



dioxide trapped under ice. When water freezes, it turns into ice slowly from the surface and traps the gases," creating unique geometric patterns. Frost and snow crystals on the ice add another dimension.



The under-ice formations he has photographed range from 10 to 30 inches in diameter, Kajita says. Though he likes how they look, he's concerned about what they signify. "Because methane gas is



considered one of the fundamental causes of greenhouse effects," he explains, "scientists in Alaska are researching these frozen bubbles in relation to the global climate change."

THE BACKSTORY

A PHOTOGRAPHER SEES BUBBLES UNDER THE ICE THAT ARE VISUALLY STRIKING—AND A MARKER OF CLIMATE CHANGE.

YEAR AFTER YEAR, as autumn in Alaska is ending, Ryota Kajita goes looking for winter's first ice. A Japanese-born photographer living in Fairbanks, Kajita believes that "everything—even if it appears to be insignificant—connects to larger aspects of our Earth." An example, he says, is the ice, after it has frozen over ponds and lakes but before it's been obscured by snow.

Kajita has been shooting photos through the ice since 2010 for his project, *Ice Formations*. He's captivated by the geometric patterns he sees: fizzy fields of bubbles under the

frozen surface, and snow and ice crystals dusted across it. Many photos are compositions of trapped, frozen bubbles of methane and carbon dioxide.

Though Kajita loves to photograph the formations, their existence worries him. As Earth's northern regions warm, the melting of permafrost accelerates. That releases more methane, a harmful greenhouse gas.

Kajita hopes people who see the photos will "feel connected to nature"—and that connection will help them "face bigger issues, like global climate change." —PATRICIA EDMONDS



"The window of time to find ice patterns is brief," says Kajita, "because all surfaces on the ground will be covered once snow falls."

EXPLORE

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- Mudskipper Parenting
- Arctic Racing



ILLUMINATING THE MYSTERIES—AND WONDERS—ALL AROUND US EVERY DAY

NATIONAL GEOGRAPHIC

VOL. 237 NO. 3

Finding Our Way to the Future

THE MOST AMBITIOUS SCIENTIFIC MISSION MAY BE TO INSPIRE HUMANITY TO ACT, SAYS THE AUTHOR, A CO-CREATOR OF *COSMOS*.

BY ANN DRUYAN

I

IT WAS A RAINY NIGHT when the future became a place, one you could visit. A downpour at sunset couldn't discourage the 200,000 people who had gathered for the opening ceremony of the 1939 New York World's Fair. "World of Tomorrow" was the theme of this art deco land of promise.

There were television sets, calculating machines, and a robot. For the first time, people saw these things that would change their lives. But on that night they had come to hear the greatest scientific genius since Isaac Newton. Albert Einstein was to give brief remarks and flip the switch that would illuminate the fair. The spectacle promised to be the largest flash of artificial light in technical history, visible for a radius of 40 miles. A wow—but not as mind-blowing as the source of this sudden, unprecedented brilliance. Scientists would capture cosmic rays and transmit them to Queens, where they would supply the energy that would turn night into day, flooding with blinding



light a new world made possible by science.

It fell to Einstein to explain cosmic rays. He was instructed to keep it to five minutes. Initially he refused. That wouldn't possibly be enough time to explain this mysterious phenomenon. But he was a true believer in the scientist's duty to communicate with the public. And so he agreed.

As the sun was setting, Einstein stepped to the microphone. He had just turned 60 and had enjoyed decades of the rarest form of iconic celebrity, a renown based on his discoveries of new physical realities on the grandest possible scale. Those who stood there in the rain to hear him were only a fraction of those who listened to the event on radio.

"If science, like art, is to perform its mission truly and fully," he began, "its achievements must enter not only superficially but with their inner meaning into the consciousness of people."

When I discovered Einstein's rarely quoted words, I found the credo for 40 years of my life's work. This always has been and always will be the dream of *Cosmos*. Einstein was urging us to tear down the walls around science that have excluded and intimidated so many of us—to translate scientific insights from the technical jargon of its priesthood into the spoken language shared by us all, so that we may take these insights to heart and be changed by a personal encounter with the wonders they reveal.

We didn't know that particular Einstein quote when Carl Sagan and I began writing the original *Cosmos* with astronomer Steve Soter. We just felt a kind of evangelical urgency to share the awesome power of science, to convey the spiritual uplift of the universe it reveals, and to amplify the alarms that Carl, Steve, and other scientists were sounding about our impact on the planet. *Cosmos* gave voice to those forebodings, but it was also suffused with hope, with a sense of human self-esteem derived, in part, from our successes in finding our way in the universe and from the courage of those scientists who dared to uncover and express forbidden truths.

The original award-winning television series and book of 1980 were embraced by hundreds of millions of people. The Library of Congress included the book as one of 88 in an exhibition called "Books That Shaped America." So it was with a fair degree of fear that I set out with Steve, a dozen years after Carl's death, to undertake *Cosmos: A SpaceTime Odyssey*. Now on my third series of voyages on the Ship of the Imagination, I once again have brilliant collaborators, and I am still worried about not measuring up. Despite this, the times impel me forward.

We all feel the chill our present casts on our future. Some part of us knows that we must awaken to action or doom our children to dangers and hardships we ourselves have never had to face. How do we rouse ourselves and keep from sleepwalking into a climate or nuclear catastrophe that may not be reversed before it has destroyed us and countless other species? How do we learn to value those things we cannot

Watch *Cosmos: Possible Worlds*

Created and executive produced by Ann Druyan and hosted by astrophysicist Neil deGrasse Tyson, the third season of the series *Cosmos: Possible Worlds* transports viewers across space and time with animations, holograms, and reenactments of world-altering discoveries. The series premieres March 9 on National Geographic.

live without—air, water, the sustaining fabric of life on Earth, the future—more than we prize money and short-term convenience? Nothing less than a global spiritual awakening can transform us.

Science, like love, is a means to that transcendence, to that soaring experience of the oneness of being fully alive. Love asks us to get beyond our personal hopes and fears, to embrace another's reality. This is precisely the way science loves nature. This lack of a final destination, an absolute truth, is what makes science such a worthy methodology for sacred searching. It is a never-ending lesson in humility. The vastness of the universe—and love, the thing that makes the vastness bearable—is out of reach to the arrogant. What's real must matter more to us than what we wish to believe. But how do we tell the difference?

I know a way to part the curtains of darkness that prevent us from having a complete experience of nature. Here it is, the basic rules of the road for science: Test ideas by experiment and observation. Build on those ideas that pass the test. Reject the ones that fail. Follow the evidence wherever it leads. And question everything, including authority.

If pilgrimages toward understanding our circumstances in the universe, the origin of life, and the laws of nature are not spiritual quests, then I don't know what could be. I'm not a scientist, just a hunter-gatherer of stories. The ones I treasure most are about the searchers who have helped us find our way in the great dark ocean and the islands of light they left to us.

The misuse of science endangers our civilization, but science also has redemptive powers. It can cleanse a planetary atmosphere overburdened with carbon dioxide. It can set life free to neutralize the toxins that we have scattered so carelessly. Its unrivaled powers of prophecy are demonstrated by our current predicament.

The words Einstein spoke on that rainy night might prove to be among his most important gifts to us. If we take what the scientists are telling us to heart, a conscious and motivated public can will this possible world into existence. □

Writer-director-producer **Ann Druyan** was creative director of NASA's Voyager message project that sent sounds and images into space on golden disks. This essay is drawn from her new book, *Cosmos: Possible Worlds*. Druyan has won Emmy and Peabody Awards for her contributions to National Geographic's renowned television series *Cosmos*.



If we lose our snowcapped mountains,

how will we shred?

A QUARTER CENTURY AFTER INVENTING RECYCLED FLEECE, POLARTEC CONTINUES TO LEAD THE OUTDOOR INDUSTRY WITH SUSTAINABLE INNOVATION AND CUTTING-EDGE MATERIAL SCIENCE.



THREE DAYS AFTER THE MILL BURNED DOWN,

Aaron Feuerstein, then 70 and white-haired, stood before his workers. It was just before Christmas, 1995, and Malden Mills employees were braced for the worst. With the insurance settlement, Feuerstein could presumably have closed the business and retired quite comfortably. But he announced that he would rebuild—and keep every worker on the payroll. It was reported that everyone wept, including the news crews.

Feuerstein had good reason to be confident, even standing in the ashes of his mill. In 1981, his team of engineers had developed a dense polyester fabric that stayed warm when wet and dried quickly. It was the first synthetic alternative to wool insulation. They called it *PolarFleece*. Years later, *Time* magazine would name fleece one of the 100 best inventions of the 20th century.

The brand that invented synthetic fleece is now called *Polartec*, and it has expanded the limits of outdoor exploration. "What people have accomplished wouldn't have been possible if we'd stopped innovating at wool," says David Karstad, creative director and vice president of marketing at *Polartec*, which has recently been acquired by *Milliken & Company*.

Polartec didn't stop innovating at fleece, either. In the mid-90s, **the company turned its attention to environmental sustainability, and pioneered the process to knit recycled polyester yarn made from plastic water bottles into performance fabrics.** In 1993, the brand collaborated with *Patagonia* to design and manufacture the first-ever recycled polyester fleece.

Since then, *Polartec* has diverted about 1.5 billion plastic bottles from landfills and manufactured more than 200 styles with a minimum of 50 percent recycled content. The goal is to reach 100 percent recycled content across all products.

But according to *Polartec* President Steve Layton, these days recycled content is table stakes.

The next level of sustainable manufacturing is circularity—polyester products made from recycled content that can themselves be recycled.

"That's going to be the key moving forward," says Layton. "To be able to take a *Polartec* sweatshirt at the end of its life and put it in the recycling bin, the same as a plastic bottle—that's the ultimate goal."

Now that *Milliken* has acquired *Polartec*, that level of innovation is even more promising. Layton, a longtime *Milliken* leader tapped to head the *Polartec* business in June, says the acquisition paves the way for scientific advancement in recycled performance textiles.

"I get excited when I think about how many material scientists and engineers we have in research and development within *Milliken*," he says. "Our plastics team has already made some important strides in [recycling] polypropylene. Hopefully we can apply it to polyesters and go from there."

He reveals that dedicated teams of material scientists and engineers at *Milliken* are working on different areas of sustainability for the *Polartec* brand. They're **developing fabric with recycled content, researching biodegradable fabrics, and looking into combining synthetic fibers and hemp.** "There's a lot of great energy behind it," says Layton.

A quarter century after the invention of recycled fleece, *Polartec* is well-positioned to keep leading on sustainable fabrics. "We can't solve the intractable problems created over the last hundred years of industrial apparel-making, but we can certainly change how it impacts the planet going forward," says Karstad. "If any industry can do it, it's the outdoor industry, because it's dependent on having an outdoors to explore." After a beat, he says: "If we lose our snowcapped mountains, how will we shred?"

Polartec has diverted about 1.5 billion plastic bottles from landfills and manufactured more than 200 styles with a minimum of 50 percent recycled content.



PHOTOS, TOP TO BOTTOM, LEFT TO RIGHT

Professional backcountry skier Baker Boyd tests the latest *Polartec* fabric prototypes.

Quality control is a hands-on process at *Polartec*'s finishing plant in Cleveland, Tenn.

Recycled fabrics begin as spools of yarn made from recycled plastic waste.

An employee takes a break at *Polartec*'s Raschel Knitting facility in Hudson, N.H.

Milliken.

LEARN MORE AT MILLIKEN.COM

**DISPATCHES
FROM THE FRONT LINES
OF SCIENCE
AND INNOVATION**

The grand master workout
Though chess is hardly a strenuous sport, its grand masters experience physical costs on a par with those faced by more active athletes. Because of the human body's response to the stress of elite play, chess professionals can burn up to 6,000 calories a day in tournaments, a Stanford University researcher says. —ANNIE ROTH



Geologist Milagros Carretero sits inside the Pulpí Geode, one of the world's largest geodes.

GEOLOGY

A GIANT AMONG GEODES

SCIENTISTS ARE WORKING ON THE RECIPE FOR THIS SPANISH SITE'S ENORMOUS GYPSUM CRYSTALS.

ANY GEODE MIGHT MAKE US WONDER: What geologic forces form these hollows lined with crystals? But the Pulpí Geode, discovered in an abandoned Spanish mine, takes wonder to a different scale. One of the world's largest geodes, it's an approximately 390-cubic-foot cavity whose walls bristle with imposing gypsum crystals, some nearly seven feet long. Now scientists are hoping to uncover how these colossal crystals developed.

They seem to have been made by a very specific recipe: a 250-million-year-old supply of the mineral anhydrite, a climate hospitable to crystal formation, and lots of water and time. In the resulting chemical soup, larger crystals may have cannibalized smaller ones to boost their own size, while swings in the local temperature could have accelerated the crystal growth even further.

Though key chapters remain incomplete, this otherworldly site now has a possible origin story. —ROBIN GEORGE ANDREWS

ETHNOBOTANY

Did this plant help Vikings lose control?

The English word "berserk" is derived from berserkers, violent Vikings said to consume something that induced rage before battle. Historians have long assumed that fly agaric, a hallucinogenic mushroom, was the berserkers' drug of choice. But now ethnobotanist Karsten Fatur says Vikings likely took henbane (below). The plant is more common in Scandinavia than fly agaric, he says, and has compounds with greater links to aggression. —A.R.



TURKISH CRAFTSMANSHIP

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İSTANBUL

ART AND CULTURES

Agar evolved from a kitchen ingredient to a lab medium for growing bacteria. Now it's the canvas for artworks made of microorganisms.

BY JENNIFER TSANG

ANGELINA HESSE, a Dutch-American lab assistant and cook, suggested in the 1880s that an ingredient in jellies and puddings could be used to grow bacteria. By finding that purpose for agar, Hesse revolutionized microbiology and set the stage for a new art form.

In the laboratory, agar—a gelatinous substance isolated from seaweed—is mixed with other nutrients and water, heated to sterilize, and poured into shallow dishes. When cooled, it thickens into a smooth, semisolid surface for bacteria to grow on—an upgrade from the potatoes, meat extract, and bread scientists were previously using.

More than a century after Hesse's work, agar is still at the center of bacterial cultivation. It has also become

an unconventional canvas for showcasing microscopic organisms in all their visual brilliance.

Some microbes create color naturally. Different species of *Streptomyces*, which produces many of our antibiotics, come in pigments ranging from reds and blues to black. *E. coli* is naturally a beige color, but introduced genes can make it or other microbes fluoresce in bright pinks, greens, and blues. Invisible when first applied to the agar, the microbes multiply over time to reveal patterns and colors.

Since 2015, the American Society for Microbiology (ASM) has held the annual Agar Art Contest to illuminate this intersection between science and art. Every year, says ASM's Katherine Lontok, contestants become "more and more intricate with it, incorporating things like 3D agar and using spores and all different kinds of organisms."

Microbes surround us all the time, but most are unseen. Agar art reveals that invisible world, limited only by the microbial palette and the creator's imagination. The contest is "a great public outreach tool," Lontok says, and shows the often overlooked "beauty and diversity of microbes."

STAPH COLORS
Kim found two of her pigments very close at hand: "The white bacteria, most likely *Staphylococcus epidermidis*, and the yellow bacteria, most likely *Staphylococcus aureus*, were sourced from my skin," she says.

AN UNDERSEA SCENE ON AGAR

This artwork, "Marine Universe," was a finalist in the professional category of the 2019 ASM contest. To compose it, Princeton University student Janie Kim used microorganisms from numerous places.

HIGHLIGHTS OF AGAR ART

The Agar Art Contest proves that "scientists absolutely can be creative," says Katherine Lontok of the American Society for Microbiology, the sponsor of the competition. Here, a sample of 2019 entries; see more at ngm.com/mar2020.



This scene of a koi and a lotus flower, which won first place in the professional category, took nine different organisms to make.



Supreme Court Justice Ruth Bader Ginsburg—aka RBG—was painted on an agar known as VRBG, the acronym for its chemical components.



This desert scene was made of pathogens that cause urinary tract infections in "water-stressed regions like the Middle East," the artist says.

GROWING GREEN

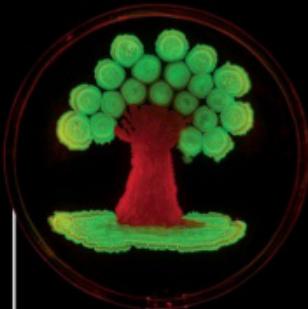
Yellow *S. aureus* bacteria and blue *E. coli* bacteria can be mixed to make green. Kim appreciates how they "exist together to create art, much like marine symbioses themselves."

E. COLI COLOR

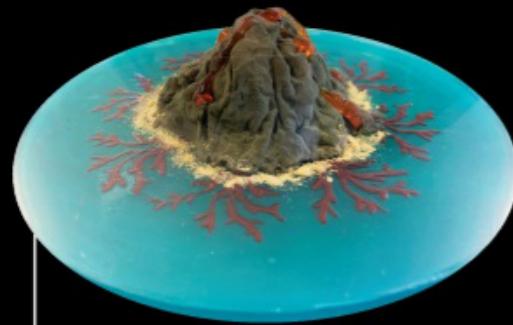
A gene-regulating sequence controls how blue these *E. coli* bacteria look. "Fittingly," Kim says, the sequence comes "from a marine bacterium associated with algae."



Spreading backyard soil on agar to see what would grow, one artist wound up with the purple and yellow shades to make this butterfly.



Luminous in green and red, *Bacillus subtilis* containing introduced fluorescent protein genes was used to make this tree.



The 3D volcano is a mound of agar inoculated with the mold *Cladosporium cladosporioides*, dripping with dyed-agar lava. The sand is mold spores, and the corals are microorganisms grown on a dyed-agar sea.

FOR HIS OFFSPRING, THIS DAD GIVES THE AIR HE BREATHES

PHOTOGRAPH BY
THOMAS P. PESCHAK

STUDYING ELUSIVE FISH that dwell in dark mud chambers is no easy feat. Thus the science of the many species of mudskippers is incomplete—and some of what's known is a bit odd. Example: Mudskippers of one sort keep their protruding eyes moist by retracting them deep into their sockets and then popping them out again—hence the genus name *Boleophthalmus*, or “ejected eye.”

When it's time for these amphibious fish to breed in the tropical intertidal zones where some of them live, the male stages flamboyant courtship displays, flaring his fins and leaping high into the air. If a female's impressed, she follows the male to a burrow for procreation away from prying eyes. But thanks to an endoscope, excavation tools, and patient research, Atsushi Ishimatsu of Japan's Nagasaki University and his team have pieced together a vision of how mudskippers reproduce.

The male builds a burrow to serve as a nest. One or more shafts lead to a chamber that fills partly with water but has a domed ceiling to hold an air pocket. The female deposits eggs on the ceiling, and the male fertilizes them. Once she departs, he tends the eggs for their few days of gestation. To maintain the oxygen the eggs need, the male will swim to the surface, gulp air, bring it back, and exhale, over and over. Watching video that Ishimatsu made with the endoscope, his colleague Karen L. M. Martin deduced that a male might take “roughly 100 mouthfuls” to create the air bubble.

Then somehow, Martin says, the expectant male “keeps track of tide and time”—and at the right moment, he begins gulping the air in the burrow and blowing it out. Water pours in, triggering the larvae to hatch; they swim up from the burrow and away. The male, Martin says, is “really a very good papa.” —PATRICIA EDMONDS



A few dozen species of mudskippers live in mangrove and tidal-zone ecosystems around the world, including on Kuwait's coast, where it took veteran *National Geographic* photographer Thomas P. Peschak “many hours of lying motionless in the mud to photograph the courtship rituals” of the fish.

JEFF
GOLDBLUM

Finding the Surprises in Familiar Things



The World According to Jeff Goldblum premieres on Disney+ this spring. For an extended version of this interview, visit www.nationalgeographic.co.uk/jeffgoldblum.

JEFF GOLDBLUM crackles with curiosity. Eyes wide, posture keen, mouth agape, hand gestures expectant. It's a quality he's leased to an array of wide-eyed, reactor-brained characters in films such as *Jurassic Park*, *Independence Day*, and *The Fly*. Now the Pennsylvania-born actor and musician—a man of 67 who, by his own admission, is "still four years old in many respects"—is unleashing his eccentric brand of curiosity in a new show for National Geographic and Disney+. He explores a suite of subjects: Politics, disease, and crime are out; bikes, pools, and tattoos are in. It's *The World According to Jeff Goldblum*.

Your subjects—denim, gaming, ice cream, barbecue—seem quite disparate but universal. Why these?

They're eclectic, a mélange, a potpourri, a shepherd's pie, with many surprises. I'd recently hosted three episodes of a National Geographic show called *Explorer*—and really loved them. That's how this show came about. We thought

we'd do familiar subjects in which we might be able to find something unexpected: historic, scientific, and something of the human connection, our own story, triggered by these things.

Are you curious about why you're curious?

Having two kids, I am in a cycle of particularly appetized curiosity. My kids look around and they say, What is this, why is this? Maybe it's something you pass down. Or maybe our species has to be curious to be connected to the world. While making this show, I read these books by Yuval Noah Harari: *Sapiens*, *Homo Deus*, and *21 Lessons for the 21st Century*. As Harari says, larger issues like climate change, the dangers of nuclear proliferation, and technological disruption can be solved only with global cooperation. It was always true that the only reason the human species proliferated and flourished was that we cooperated in groups and therefore were curious about each other.

If you could time travel, who would you want to meet?

I just started reading *The Invention of Nature* about Alexander von Humboldt. They say more things are named after him than anybody else. He predicted climate change challenges, the unintended consequences of civilization, the industrial revolution. I bet his would be a good brain to pick. That's kind of the show in a nutshell: It's me, not pretending to know any more than I do, but getting interested, talking to interesting people who come from an unexpected place, and having a curious and fun encounter with them. And letting my mind, such as it is, roam free. □



The Race Goes On

TRAVELING NORTH TO COVER A GRUELING SLED DOG RACE, A PHOTOGRAPHER FINDS CLARITY IN THE ARCTIC AIR AND KINSHIP WITH THE DOGS THAT DIDN'T FINISH.

STORY AND
PHOTOGRAPHS
BY KATIE
ORLINSKY



SEVERAL YEARS AGO, I was offered a last-minute assignment to photograph the Yukon Quest, a thousand-mile sled dog race through the subarctic wilderness of Alaska and Canada. The race takes place in the dead of winter along a route that was used by sled dog teams during the gold rush to deliver mail and supplies. The Yukon Quest is considered one of the toughest sporting events on the planet: Temperatures frequently reach minus 50°F, winds can blow over 40 miles an hour, and the days are so short that most of the race happens in the dark.

I did not know any of this before the assignment. I'd never heard of the Yukon Quest or its more famous counterpart in the United States, the

Iditarod. When I thought of the Arctic—if I thought about it at all—I pictured exotic endangered animals and a distant, cold place out of reach to me as a photographer. It was a realm of rugged men with salt-and-pepper beards who owned bright orange camping gear and were raised by even more rugged fathers who taught their sons life lessons while hunting and fishing. My father was a theater producer from New York City. I learned life lessons backstage, not in the backcountry.

Even so, it's surprising that the Arctic intimidated me. I spent most of my 20s documenting conflict and social issues in the Middle East, Africa, and Latin America, focusing especially on Mexico and the drug war. I was committed to telling stories no matter the risk. Then in 2011 I became part of a story—a tragedy—in which the victims were my colleagues and I was a survivor. In the aftermath I had a hard time finding the inspiration I needed to love photography as I once did. I kept working—I needed the money—but often I was just going through the motions.

And so I took the assignment to photograph the 2014 Yukon Quest with no idea what to expect. A few days later I was on a plane to Canada. We landed in Whitehorse around midnight, the tarmac covered in snow. When I touched my airplane window, I could already feel the freezing cold air. I'd made it north; my luggage had not. In it was everything I thought I was going to need, including borrowed snow pants that were too big for me, long underwear I hadn't worn since a high school ski trip, and a brand-new, expensive puffy parka (I'd left the tag on so I could return it once I got home). I was supposed to fly from Whitehorse to Dawson City to photograph the race first thing in the morning, and all I had was a gray hoodie and a backpack full of camera equipment.

Inside the airport I explained my plight to the two women behind the Air Canada desk. One of them disappeared into the back office. She returned with a navy blue Air Canada wool cardigan. The other woman asked her husband to bring boots and a jacket. She gave me her own gray down jacket, the furry boots off her feet, and a pair of red fleece gloves.

It was still dark as I boarded the plane for Dawson City later that morning. When the sun finally began to rise, sweeping mountain ranges came into view. They went on and on—jagged peaks of hot pink and beige, mounds of gray and black, rolling hills of endless white. I had never dreamed of a landscape this magical and took pictures through the window until a dense fog settled in.

As I got off the plane, the snow crunching beneath my feet sparkled as if a million little children had sprinkled it with all the glitter in the world. I spent the ride to the hotel in silent awe as we drove by lavender-tinted mountain ranges and frozen rivers coated with a mosaic of blue and white ice. The entire boreal forest was layered in what looked to me like shimmering snow. I later learned that it's called hoarfrost—the most beautiful thing I had ever seen.



A day or two into her first trip north, Katie Orlinsky meets some of the contenders in the 2014 Yukon Quest sled dog race during their 36-hour mandatory stop in Dawson City, Canada.

It felt like another planet, a fairy tale. Some days I wish I could go back in time just to experience my first few hours in Dawson City again.

Meanwhile the cold was as brutal as the land was beautiful. When I stepped outside, the air was so dry I could barely breathe. But at that moment borrowed clothes and the kindness of strangers were all I needed for warmth. A feeling came over me that I hadn't experienced in a long time: As long as I had my camera, everything would be OK. I wanted to take pictures again.

I have been covering the Arctic, among other places, ever since. The following year I returned to the north to follow the Yukon Quest yet again, this time on assignment for *National Geographic*. I remember it was more than halfway through the race when I flew to a checkpoint in Eagle, Alaska. A pickup truck was waiting to take me and my fellow passengers, mostly from Alaska media or race volunteers, to our temporary sleeping quarters—the floor of the local school library.

Before we drove away, I noticed a pair of race veterinarians, identifiable by the medical patch on their giant red parkas, loading what looked like heavy potato sacks onto a small plane. Then I saw furry heads with pointy ears sticking out of the sacks.

Immediately I asked the driver if he could wait, and I rushed to photograph the scene. The vets told me that these dogs had been dropped from their team. The bags would keep them safe and calm while flying home.

Sled dogs, considered by some to be the world's greatest endurance athletes, are bred to thrive in the cold, snowy wilderness. Most mushers have trained their dogs since they were puppies. Even so, during such a long race, dropping dogs is a common occurrence. Sometimes a dog is tired or it's injured or it seems to have simply lost interest in running. (One year a dog got sick from eating the neon booties that protected its feet.)

When a dog team hits its stride, it is a beautiful sight to behold—paws tapping the snow like a soft chorus, legs swinging in quiet rhythm, hot breath leaving trails of billowing smoke that cluster like clouds in the cold air. It makes it easy to forget that every dog is different. Seeing the dropped dogs separated individually—into sacks, no less—was a stark reminder of this.

I spent the next few days focusing far more on the dogs that were leaving the race than those that might win it. The local media and race officials probably thought I was nuts. I thought my fascination with dogs in sacks flying in airplanes was pretty self-explanatory. Looking back, perhaps I also felt connected to the dropped dogs. I could relate to the idea of having a goal you'd worked toward your whole life, only to have something happen that changes your course.

Bad weather hit Eagle, and for days there were no commercial flights. I was close to missing the finish in Fairbanks on my first big *National Geographic* assignment. Fortunately I was able to join a late-night charter flight—in a tiny plane loaded with dropped dogs.

We took off, and I remember smiling as I looked out the window at the night sky opening up over a pitch-black Alaska wilderness. Buckled up in that plane, wearing the fancy parka I never ended up returning, surrounded by 16 dogs in sacks, I too felt safe and calm. □

Photographer **Katie Orlinsky**, based in New York City, has covered the Arctic for more than five years. Her latest feature, "The Carbon Threat," focused on permafrost thaw.



1,000

The estimated number of booties each musher carries during the Yukon Quest race to protect the feet of the dogs on his or her team.



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- Kokopelli: Epic Biking Trail



WHERE TO GO, WHAT TO KNOW, AND HOW TO SEE THE WORLD

NATIONAL GEOGRAPHIC

VOL. 237 NO. 3

BY THE NUMBERS

60

ESTIMATED AGE OF
ROCK FORMATIONS IN
MILLIONS OF YEARS

200

STEPS REQUIRED TO
REACH ROUSSANOU
MONASTERY

4

HOURS FROM
ATHENS BY CAR



BY DANIEL STONE PHOTOGRAPH BY VESELIN ATANASOV



'ROUSSANOU ... IS ROUGHLY GIRDED
BY THE TALLER SPIRES OF THE
METEORA, ON A SHARP LEANING
BLADE OF ROCK. IT IS AS COMPACT
AS A SWALLOW'S NEST.'

—Patrick Leigh Fermor, *Roumeli: Travels in Northern Greece*

GETTING THERE

SACRED HEIGHTS

THE MONASTERIES of Meteora, Greece, are marvels of engineering. Perched atop sandstone cliffs, with monastic cells hidden in crevices throughout, these Greek Orthodox sanctuaries reflect the contemplative solitude sought by the monks who built them between the 14th and 17th centuries. The most intimate, Roussanou Monastery (left), is now home to 16 nuns and holds relics of Saint Barbara, popular in medieval times.

HOW TO GET THERE

For centuries the only way to reach Roussanou and the other Meteora monasteries in central Greece was by climbing retractable ladders or being lifted up in a net basket. Restricted access kept the faithful in and the faithless out. Today new tunnels and steep roads and staircases open the churches to anyone willing to make a cliffside journey. Guided tours are recommended to better understand the sites' rich histories.

WHAT YOU'LL SEE

Inside: Sixteenth-century Byzantine frescoes fill Roussanou's chapel, from the walls to the domed ceiling, with illustrations of planets, peacocks, and seraphim. Ostrich eggs are displayed as symbols of kingship, resurrection, and safekeeping.

Outside: Look down when crossing the small bridge into Roussanou to see the monastery's private garden, says Greek travel expert George Kourelis. Look up to see eagles, falcons, and rare vultures.

EXPLORE NEARBY

Around Roussanou are 16 ancient hermetic caves (pack your climbing boots) and five other functioning clifftop monasteries (of the original 24). The Great Meteoron Monastery houses the skulls of monks who lived there, along with vibrant paintings and the church's 14th-century bread oven. Most of the churches were damaged by waves of pillaging and war in the 20th century, but they have since been restored.

MARCH

**1****LIGHT SCULPTURES****How Does Your Garden Glow?**

Find out at South Carolina's Brookgreen Gardens April 8 through September 12, when artist Bruce Munro's installations illuminate seven areas, including the arboretum. Munro also created California's recent "Field of Light at Sensorio," above.

3**AIRPORT**

THE JEWEL COMPLEX at Singapore's Changi Airport takes "green travel" literally. Inside the terrarium-like dome, find more than 2,000 trees and 100,000 shrubs, plus the world's tallest indoor waterfall.

**BLOSSOM WATCH****Lone Star State Flower**

Waves of wild bluebonnets turn the Texas Hill Country into a sea of cerulean and nourish several species of butterflies, typically from late March until mid to late April.

4**5**
NEW
BOOK

In Nature's Best Hope, author Douglas W. Tallamy gives homeowners tips on how to establish conservation corridors in their own backyards.

Here are five ways to celebrate flowers and gardens around the world this spring.

BY MARYELLEN KENNEDY DUCKETT

ART EXHIBITION

DIG INTO DETAILED DEPICTIONS OF PLANTS AT THE NATIONAL GALLERY OF IRELAND IN DUBLIN. THE EXHIBITION 'DRAWN FROM NATURE: IRISH BOTANICAL ART' RUNS MARCH 7 TO JUNE 21.

REEF REVIVAL

BY THERESA MACHEMER

BEAUTIFUL AND FRAGILE, coral reefs in tropical oceans worldwide are threatened by climate change, storms, and bleaching. Now travelers can help restore them by supporting coral replanting programs.

National Geographic Explorer Paola Rodríguez-Troncoso has worked on a Mexican program that sustainably replanted more than 6,000 coral fragments over six years. In this project, divers collect fragments from the ocean floor that have been knocked off reefs by storms or waves. Then they tether healthy pieces to the substrata of reefs at the same or nearby sites. It's a process that can vary by location.

For example, in some areas where reefs border lagoons, such as French Polynesia (below), the coral fragments are placed in underwater nurseries to recuperate before replanting.

Resorts and conservation groups are starting to educate and involve visitors in these efforts. To avoid programs that may do more harm than good, Rodríguez-Troncoso cautions against any that purposely break off fragments from healthy corals or fail to get the required permits. Though replanted fragments grow slowly, each one can be part of a reef's centuries-long life span. "That small seed," Rodríguez-Troncoso says, "that will really help."



In Moorea, French Polynesia, the nonprofit group Coral Gardeners tends broken pieces of coral on a nursery table for one month before reattaching them to reefs. Travelers there can adopt a coral piece and help the group plant it.



On the 142-mile Kokopelli's Trail, a group of bikepackers race against dusk on Porcupine Rim, a fast and scenic descent into Moab, Utah.

'BIKEPACKING' THE WEST

STRETCHING ALONG PUBLIC LANDS ON THE COLORADO PLATEAU,
KOKOPELLI'S TRAIL PIONEERED A NEW SPORT.

BY AARON GULLEY

THOUSANDS OF VISITORS speed daily along Interstate 70 between the soaring cliffs of Colorado National Monument and the fantastical sandstone of Utah's Arches and Canyonlands National Parks. Compared with those marquee destinations, the borderland between them—an open range of cinnamon-colored sand and scraggly juniper—seems barren and anonymous. But out of sight, a backcountry mountain bike path, Kokopelli's Trail, takes in 142 miles of slot canyons, bluffs, and desert mesas as formidable and astonishing as anything in the parks.

"It's big, wild country," says Chris Muhr, vice president of the Colorado Plateau Mountain Bike

Trail Association, the group that has stewarded the Kokopelli since its 1989 completion. "When the guys first talked about biking out there, it seemed crazy. But it's land that's hard to resist."

It's also land that's highly valuable. Every mile of the trail is on public property, a patchwork of Bureau of Land Management-administered rangelands, national forests, and the McInnis Canyons National Conservation Area. Linking so much public land is no small feat in Utah, a state with a vocal political movement for land transfers and privatization. In recent years the state's land conflicts bubbled onto the national stage with the fight over Bears Ears and

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Grand Staircase-Escalante National Monuments, both southwest of the Kokopelli. Those disputes, which pit preservation against development and extraction, are a microcosm of a larger struggle. According to a 2019 study in the journal *Science*, protected lands are increasingly in jeopardy worldwide, with 90 percent of reductions to public lands in the United States made since 2000.

"Vast expanses of undeveloped tracts of public lands like the Kokopelli are less and less common in the West," says Kurt Refsnider, executive director of the cycling advocacy group Bikepacking Roots. (Refsnider also holds the fastest known time for biking the Kokopelli: 11 hours and 52 minutes.) "The first step in preserving such lands is getting people out using them and engaged."

So when you get to ride across more than a hundred miles of unblemished land these days, it's not only a rare experience; it's also a ballot cast for land conservation. I got to do just that when I pedaled the Kokopelli in early November with my brother-in-law, Trevor Webb.

We rolled out of the Colorado border town of Fruita on a bracing Friday morning, alone on the rock benches above the Colorado River. Strictly speaking, the Kokopelli isn't just one trail but a stitched-together tapestry of single-track, back-country roads and even a bit of pavement that very roughly follows the river between Loma, Colorado, and Moab, Utah. After crossing Salt Creek a couple of hours into our ride, we cruised through a sea of grasslands turned flaxen with the gathering autumn and passed outcrops that were like battleships of

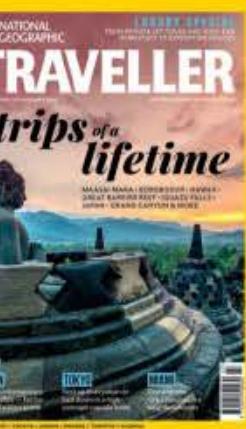
sandstone. Once we'd turned south, we rode through great basins where towers of rock balanced like outsize skeleton keys sunk in the sand. Over our entire three-day trip, we'd see only three 4x4s and a half dozen cyclists. Considering the throngs that visit the nearby parks and monuments (in 2018, more than a third of a million people entered Colorado National Monument while 2.4 million went to Arches and Canyonlands combined), the trail's solitude makes its vistas feel all the more exclusive.

The Kokopelli has always been about big ideas. When the concept of the trail was hatched in the late '80s, mountain biking was little more than a few eccentric cyclists modifying street bikes for off-road use. "It was taking off in Crested Butte and in Moab, and I just thought that if we could figure out a trail to link those two places through Grand Junction, maybe we'd have something positive instead of just oil shale," says Timms Fowler, whom Muhr describes as the visionary for the trail.

Though the project never grew beyond the initial Loma-to-Moab segment, it laid the groundwork for subsequent trails and systems that have turned the region into a riding hotbed, one of the first places to capitalize on the sport. Today the Kokopelli seems tailor-made for one of the industry's growing trends: bikepacking, in which cyclists ride with all their gear on multiday adventures. "I don't think they'd have anything to bikepack these days if we hadn't started putting in trails like the Kokopelli," says Muhr. "It was the first of its kind." □

Aaron Gulle is a Santa Fe, New Mexico-based journalist who has written for two decades on cycling, travel, sports, and fitness.





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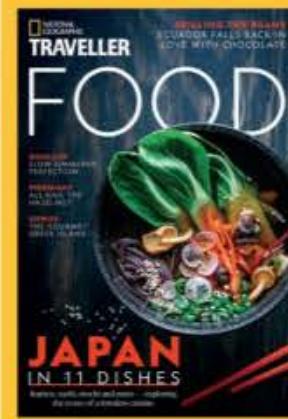
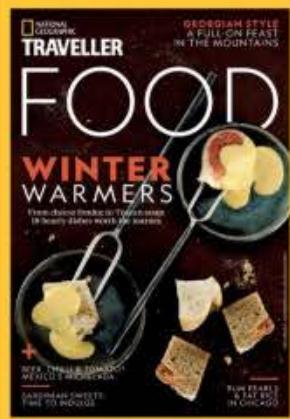
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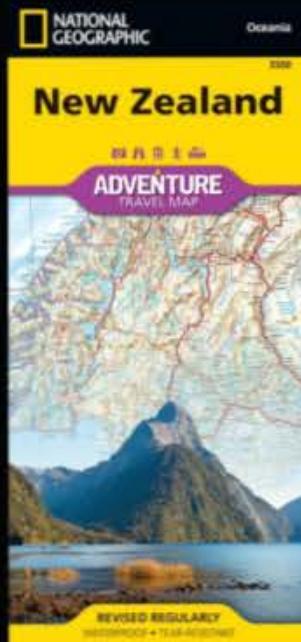
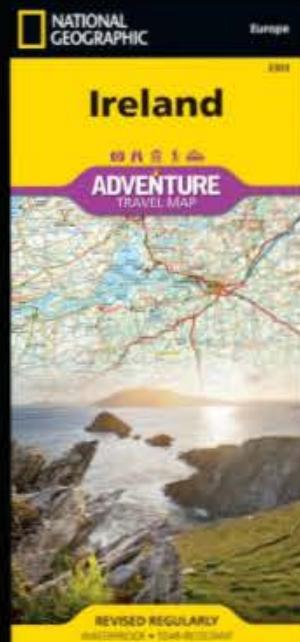
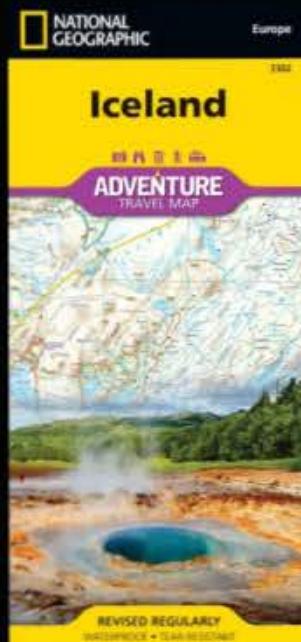
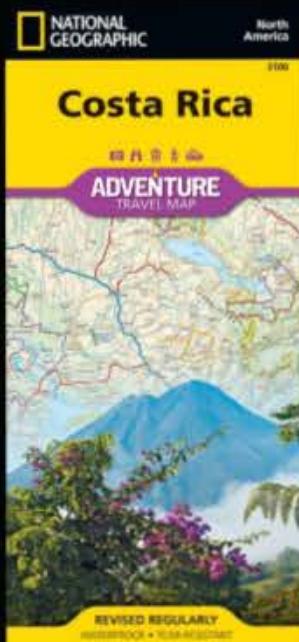
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FEATURES

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Yanke Shettima

The Lord is my helper

84

'THEY ARE
NOT REGULAR
STUDENTS.
BOKO HARAM
PLEDGED TO
KILL THEM
IF THEY
RETURNED
TO SCHOOL.
GUARDS
WATCH THEIR
BUILDING.'





A world without waste sounds impossible. But the vision of a circular economy—where we use resources sparingly and recycle materials endlessly—is inspiring businesses and environmentalists alike. Can we make it happen? Can we afford not to?

BY ROBERT KUNZIG
PHOTOGRAPHS BY LUCA LOCATELLI



A massive, sprawling mound of trash fills the lower half of the frame, composed of various discarded materials like plastic bags, paper, and debris. In the upper right corner, a mechanical arm with a large, metallic grapple hook is positioned, its hook partially submerged in the trash. The background is a plain, light-colored wall.

THE END OF TRASH

ENERGY

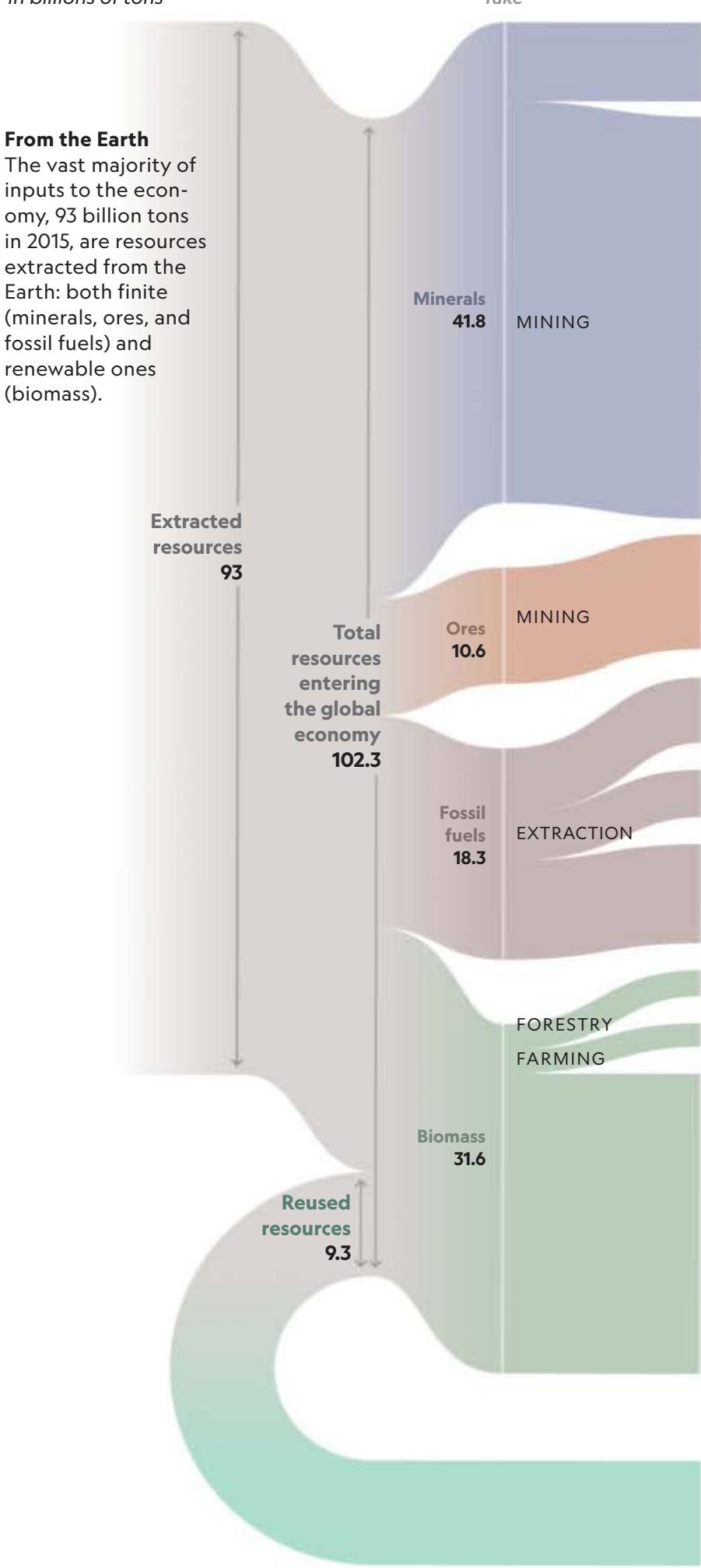
The trash silo at a new incinerator in Copenhagen holds more than 24,000 tons. Automatic cranes mix the waste to help it burn cleaner. Equipment to filter the smoke takes up much of the plant's interior. A clean-burning, energy-generating incinerator is a better end for trash than a dump—but the circular economy aims to end trash by not producing it at all.

PREVIOUS PHOTO
Dubbed Copenhill, the incinerator in Denmark's capital uses the latest technology to convert 534,600 tons of waste a year into energy to electrify 30,000 homes and heat 72,000. The plant doubles as a recreational destination, with an all-season ski slope, a tree-lined hiking and running trail, and a 280-foot climbing wall, the world's tallest.



AN X-RAY OF THE GLOBAL ECONOMY

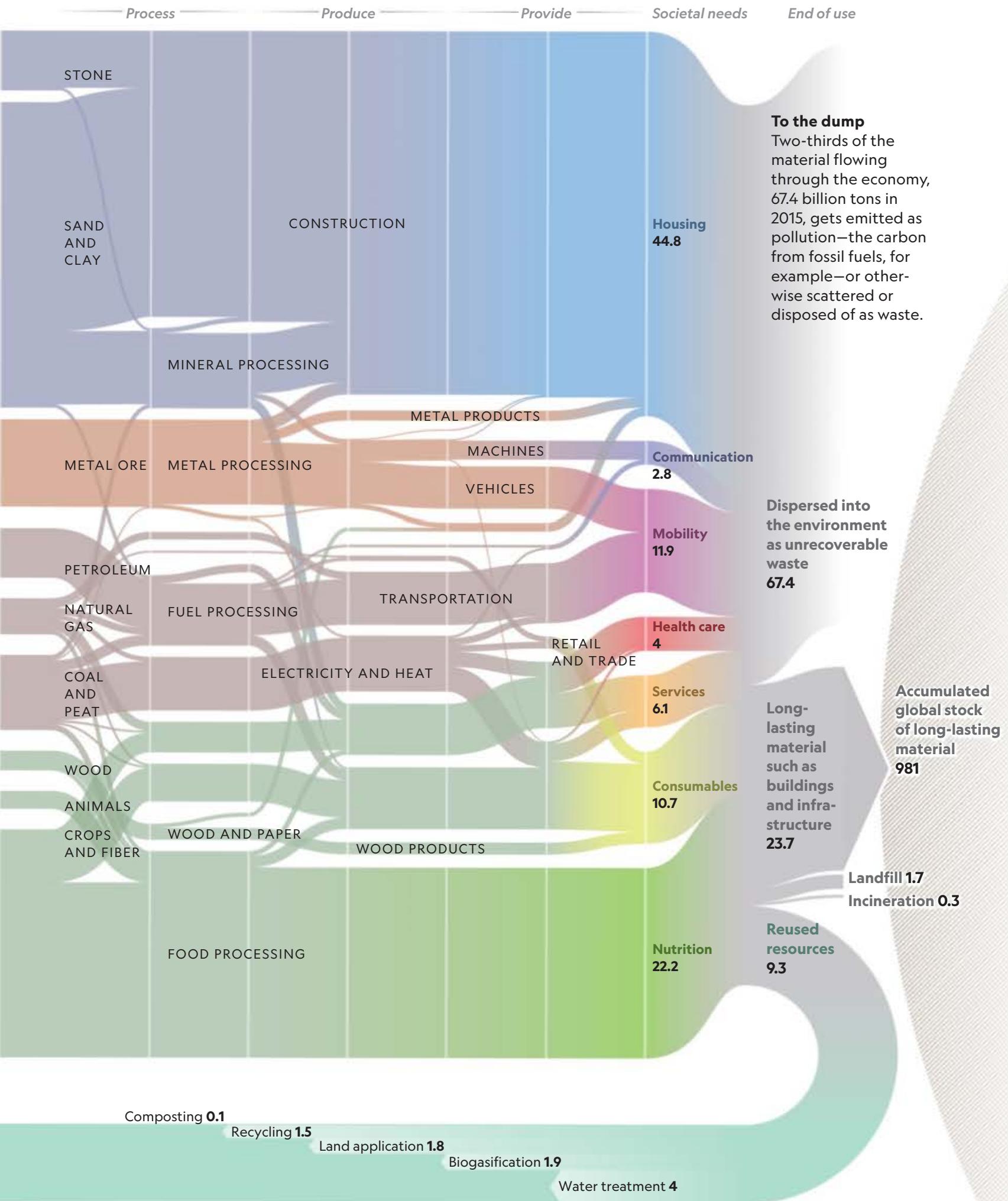
Global resources, 2015
in billions of tons



N AMSTERDAM I met a man who revealed to me the hidden currents of our lives—the massive flows of raw materials and products deployed, to such wonderful and damaging effect, by 7.7 billion humans. Our shared metabolism, you might say. It was a crisp fall morning, and I was sitting in a magnificent old brick pile on the Oosterpark, a palace of curved corridors and grand staircases and useless turrets. A century ago, when the Dutch were still extracting coffee, oil, and rubber from their colony in Indonesia, this building had been erected as a colonial research institute. Now it houses assorted do-gooder organizations. The one Marc de Wit works for is called Circle Economy, and it's part of a buzzing international movement that aims to reform how we've done just about everything for the past two centuries—since the rise of the steam engine, "if you need to pinpoint a time," de Wit said.

De Wit is 39, genial, bespectacled, a little disheveled, a chemist by training. He opened a pamphlet and spread out a diagram he called "an x-ray of our global economy." Unlike natural ecosystems, which operate in cycles—plants grow in soil, animals eat

Every year we transform more than 100 billion tons of raw material into products. Less than a quarter becomes buildings, cars, or other long-lasting things. Less than 10 percent cycles back into the economy. The circular economy movement aims to increase that number and reduce the enormous amount of waste.



plants, dung replenishes soil—the industrial economy is largely linear. On the diagram, fat, colored currents of the four types of raw material—minerals, ores, fossil fuels, and biomass—surged from left to right, splitting and braiding as they became products that met seven human needs. Sand went into concrete apartment towers on six continents. Metal ore became ships, cars, and also combine harvesters—in a single year we harvested 22.2 billion tons of biomass, just to feed us all. Fossil fuels powered those vehicles, kept us warm, became plastic, became all kinds of things. The total flow into the economy in 2015 was 102.3 billion tons.

All good so far; amazing even, if you’re the type to be amazed by human effort and ingenuity. It’s what happens next, after our needs are met, that’s the problem—the mother of all environmental problems, in fact. De Wit pointed to the gray fog on the right edge of the diagram. The gray fog is waste.

In 2015, he explained, about two-thirds of the material we scratched from the planet slipped through our fingers. More than 67 billion tons of hard-won stuff was lost, most of it scattered irretrievably. Plastic trash drifted into rivers and oceans; so did nitrates and phosphates leaching from fertilized fields. A third of all food rotted, even as the Amazon was deforested to produce more. Think of an environmental problem, and chances are it’s connected to waste. That includes climate change: It happens because we burn fossil fuels and scatter the waste—carbon dioxide—into the atmosphere.

This may sound ridiculous, but as de Wit walked me through the numbers that morning, it felt like an epiphany. There was a unifying, exhilarating clarity to that wonky diagram, to the way it defined the task. Sure, it said, the threats we face are multifarious and overwhelming. Sure, they’re planetary in scale. But really, to get along on this Earth, we must do just one thing: Stop wasting so much of it. De Wit pointed to a thin arrow that circled back, from right to left, along the bottom of the diagram, representing all the material we’d managed to capture through recycling, composting, and so on. It was only 9.3 billion tons: just 9 percent of the total.

The “circularity gap,” as de Wit and his colleagues dubbed it when they presented their report at the World Economic Forum in Davos in 2018, is relatively new in human history. It dates to our industrial use of fossil fuels in the

18th century. Until then, most of what humans did was done with muscle power, whether human or animal. Growing things, making things, shipping things took hard labor, which made them valuable. Our limited physical energy also restricted how big a dent we could put in the planet. It kept most of us very poor, however.

Cheap fossil energy, concentrated by geologic time and pressure in seams of coal or pools of oil, changed all that. It made it easier to extract raw materials anywhere, ship them to factories, and send the merchandise everywhere. Fossil fuels exploded our possibilities—and the process keeps intensifying. In the past half century, while the world’s population has more than doubled, the amount of material flowing through the economy has more than tripled.

“Now we’re reaching the limits,” de Wit said.

For that same half century, environmentalists have been warning of limits to growth. The new “circular economy” movement is different. It’s a collection of strategies—some old, such as reducing, reusing, and recycling, and some new, such as renting rather than owning things—that together are meant to reshape the global economy to eliminate waste. The circular economy doesn’t aim to end growth; it aims to bend how we do things back into harmony with nature, so that growth can continue. “Prosperity in a world of finite resources,” as European environment commissioner Janez Potočnik once put it, in the foreword to an Ellen MacArthur Foundation report. It said the circular economy could save European businesses up to \$630 billion a year.

The idea is catching on, particularly in Europe, that small, crowded, rich but resource-poor continent. The European Union is investing billions in the strategy. The Netherlands has pledged to go fully circular by 2050. Amsterdam, Paris, and London all have plans. “It must happen,” said Wayne Hubbard, head of the London Waste and Recycling Board, when I asked whether the circular economy could happen.

One man who definitely thinks it could happen, and whose work has proved revelatory to many others, is American architect William McDonough. With German chemist Michael Braungart, he wrote the visionary 2002 book *Cradle to Cradle*, which argues that products and economic processes could be designed such that all waste becomes fodder for something else. Before setting off for Europe, I made a pilgrimage to McDonough’s office in Charlottesville,

Virginia. Our conversation ricocheted from his childhood in Tokyo, through Plato, Aristotle, and Buckminster Fuller, to some new compostable blue jeans he was excited about, before I finally managed to ask him the nagging question: Is all this talk of an end to waste just pie in the sky?

"It's absolutely pie in the sky, no question about it," McDonough said. "You need pies in the sky to help us go forward. Because remember what Leibniz said."

I didn't remember much about that German philosopher.

"Leibniz said, 'If it is possible, therefore it exists.' And I'm saying, 'If we can make it exist, it's therefore possible.'"

Was that tautological? Was it wise? Did Leibniz really say that? It was intriguing, in any case. Not long after that, I took my busted old roller bag to be repaired (very circular, compared with buying a new one), packed the certified cradle-to-cradle jeans that McDonough had given me, and headed out to see what evidence of possible existence I could find for the circular economy.

Metals

THE FIRST SMALL BREAKS in our natural circularity actually predate the 18th-century industrial revolution. The Romans, besides tossing broken amphorae around in an uninhibited way, pioneered a fraught invention: sewers. That is, they channeled human waste into rivers, instead of returning it to fields where, as any circularity maven will tell you, those nutrients belong. As a young boy in Tokyo in the 1950s (his parents were in the occupying American Army), McDonough recalls waking at night to the sound of farmers collecting the family's night soil. His mother would soothe him with lullabies about poop, sometimes in Japanese with an Alabama accent. It made a permanent impression.

The Romans, like the Phoenicians before them, also mined copper from the rich deposits at Río Tinto in Spain. But they recycled too: They melted down bronze statues from conquered peoples to make weapons. Copper has always been a prime target for recyclers. Compared with sewage, it's scarce and valuable.

In the yard at the Aurubis copper smelter in Lünen, in the Ruhr region of western Germany, a large bust of Lenin stands in a flower bed—a

souvenir of the many bronze Lenins melted here, from towns around communist East Germany, after East and West were reunited in 1990. Aurubis, Europe's largest copper producer, is also the world's largest copper recycler. When the Lünen plant was built in 1916, at the height of World War I, copper for artillery shells was in short supply, and Germans were pulling bronze bells out of church towers. "Since that day, this plant has exclusively done recycling," said Detlev Laser, the deputy plant manager.

Copper, unlike plastic, say, can be recycled indefinitely without loss of quality—it's a perfect circular material. The Lünen plant still processes bulk copper, mostly pipes and cables, but it has had to adapt to waste with much lower concentrations. As Europe has replaced landfills with municipal incinerators, a lot of slag is showing up containing bits of metal—"because someone threw their cell phone in the trash" instead of the recycling bin, Laser said.

With Hendrik Roth, the plant's environmental manager, I watched an excavator drop bucket-loads of electronic debris, including laptops, onto a sloping conveyor that carried it toward a shredder—the first of more than a dozen steps in the bewildering and deafening sorting process. At one station, a conveyor raced by, carrying hand-size shards of circuit boards. Some fell into an abyss; others leaped as if by their own volition onto a belt above. A camera system, Roth explained, was deciding whether each shard contained metal—and if not, activating an air jet under it at just the right instant.

Aurubis sells the aluminum and plastic it recovers to those industries; copper and other nonferrous metals go into its own ovens. In the tidy yard, the dust is swept daily and fed to the smelter. "We have no waste here," Laser said.

Worldwide, only about a fifth of all electronic waste is recycled, according to a 2017 UN report. Aurubis even takes shipments from the United States. "But I do wonder sometimes why such a highly industrialized country would give up such resources," Roth said. "They're sitting on billions." That's starting to change. Apple, for example, encourages customers to trade in old iPhones; an intelligent robot in Texas dismantles them and extracts materials for new devices.

But copper exemplifies a general challenge: There's a limit to what even aggressive recycling can accomplish. At Aurubis, recycled copper accounts for only a third of production; the rest

MACHINES

Reusing machinery is a time-honored strategy for reducing waste. Nearly 3,300 decommissioned U.S. government planes and helicopters are stored at Davis-Monthan Air Force Base (right) in Tucson, Arizona, where dry air limits corrosion. The aircraft are scavenged for parts (next photo) or restored and returned to service. To preserve them, they are sprayed with a removable protective coating. The facility, often called the Boneyard, is the largest of its kind.



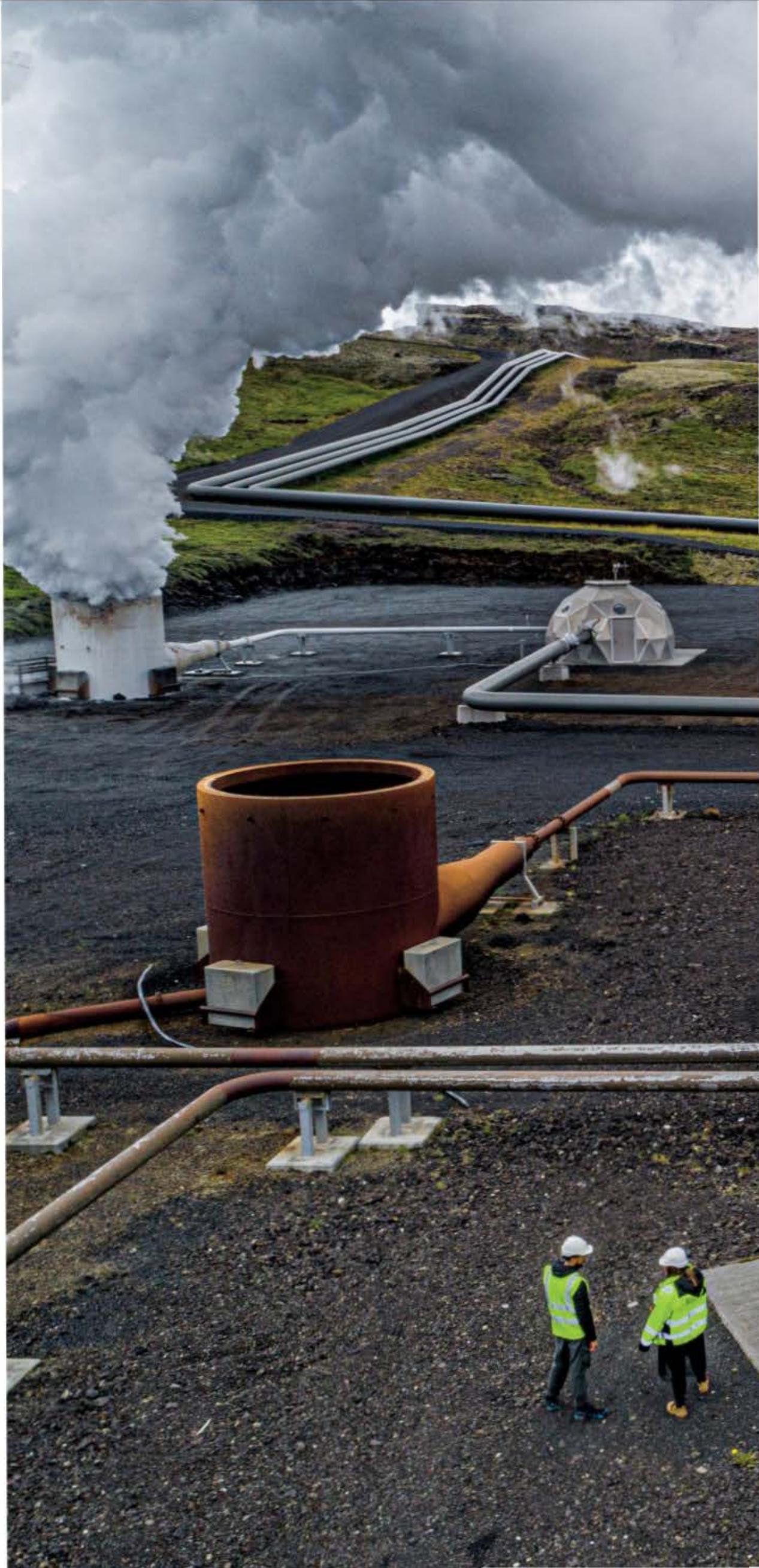






ENERGY

Switching from fossil fuels to renewable energy, like the heat generated by magma beneath Iceland's lava fields, is an essential step in creating a circular economy. The Hellisheiði Power Station (right), the country's largest geothermal plant and the world's third largest, produces electricity as well as heat for homes. Geodesic domes over each well help reduce the visual blot on the landscape. At the Blue Lagoon (next photo), geothermal water that has already generated electricity at the Svartsengi Power Station and is no longer scalding is used to create a popular tourist attraction. The water's high silica content keeps it from leaching into the lava field and gives it an appealing aqua tint.









still comes from mines. World copper production has quadrupled in the past half century and is still growing. The technologies we need to get off fossil fuels require a lot of copper; a single giant wind turbine uses about 33 tons.

"Demand is growing," Laser said. "You'll never cover that with recycling." The circular economy is going to require other strategies.

Clothes

THE EMBLEM OF the Ellen MacArthur Foundation, a set of nested circles, was on Dame Ellen's teal hoodie when we met in her headquarters, an old sailmaker's loft on the Isle of Wight. In 2005, at age 28, MacArthur finished sailing around the world on a 75-foot trimaran in a record time of just over 71 days—alone. She had packed 72 days' worth of food. She had raced storms off Antarctica and fixed a broken generator. She arrived home, having survived a microcosm of Spaceship Earth, with a visceral awareness of limited resources.

Why wasn't everyone talking about that? she wondered. She gave up competitive sailing and instead traded on her fame and access to corporate boardrooms—"it would be a waste not to use it," she told me—to establish an organization that has done more than any other to promote the circular economy, using a hierarchy of strategies (see diagram on page 69). The best is the simplest: Waste less stuff by keeping it in use.

That choice hits many people most acutely in their closets. From 2000 to 2015, while the world population grew by a fifth, clothing production doubled, according to an Ellen MacArthur Foundation report, thanks to the explosion of "fast fashion." With so many cheap clothes, the report estimated, the average item was worn a third fewer times by 2015. That year, the world threw away more than \$450 billion worth of clothes.

Jorik Boer makes a living rescuing some of them as head of the Boer Group, a Dutch family business that began a century ago on the streets of Rotterdam with his great-grandfather collecting rags, metal, and paper in a cart. Today, from his base in Dordrecht, Boer runs five plants in the Netherlands, Belgium, France, and Germany. Together they collect and sort—and resell for reuse or recycling—up to 460 tons of discarded clothing a day.

People have the wrong idea about what happens when they drop clothes into a donation bin, Boer said; they think the clothes are given directly to needy people. What usually happens instead is that companies like Boer buy donated clothing, sort it, and resell it—all over the world.

"You need a lot of experience to know where you can sell and reuse a piece of clothing," Boer said. Through the window behind him, I could see the rapid but practiced movements of women pulling clothes from conveyors, examining each item briefly, then pivoting and tossing it into one of 60 or so bags. Each woman sorts about three tons a day, Boer said. Sorters must have an eye for fashion—especially for the best stuff, just 5 or 10 percent of the total, which makes most of Boer's profit. In Russia and eastern Europe, prized items such as women's underwear can fetch up to five euros a kilogram (\$2.50 a pound). Most lower quality material gets shipped in 55-kilogram bales to Africa, where it's sold for as little as 50 cents a kilo.

At one point Boer eyeballed my gray sport coat, which I felt quite confident of; he couldn't see the ink stains on the inside pocket. "We cannot sell your jacket anywhere," he volunteered cheerfully. "No one in the world wants to buy it." Boer said he would actually have to pay someone to take my unfashionable garment away.

But they buy used underwear? I was miffed.

"That's clean, used underwear," Boer said. People normally don't donate dirty clothes.

He gets more clothing these days than he can handle, mostly from Germany, which collects 75 percent of its discards: Town governments have gotten into the act. He can't find enough skilled workers. At the T-shirt grading station, I noticed an older man. "That's my dad," Boer explained. Marinus, the retired CEO, still pitches in. He loves the work.

The Boers' biggest worry is how clothing is changing. Right now the company is able to resell 60 percent of what it collects. Clothes that are kept in service and worn again are better for the planet—the material and energy that went into making them don't have to be replaced—and also for Boer. "It's what's financing this whole business," he said.

The other 40 percent, the clothes no one wants, are recycled as wipe cloths or shredded for insulation or mattress stuffing. Some are incinerated. The recycled fraction increasingly includes cheaply made, worn-out items. Boer

loses money on almost all of it. Fast fashion, he said, could help put him out of business.

There's one form of recycling he makes a modest profit on. For decades Boer has shipped wool sweaters and other loose knits to companies in Prato, Italy, that mechanically tease the wool apart, recapturing long fibers that can become good-as-new garments. Woven cotton or polyester can't be recycled that way; the fibers end up too short. Half a dozen start-ups are working on technology to chemically recycle these fibers. To spur its development, Boer thinks the European Union should require new clothes to contain, say, 20 percent recycled fibers.

"In 10 years it will be there," Boer said. "It has to be there."

At Ellen MacArthur I heard enthusiasm for a different business model, one that might promote circularity in many economic sectors—a model based on renting rather than owning. Rent the Runway and other online clothes-rental companies make up less than a 10th of a percent of the global fashion market so far, but they're growing fast.

In theory, renting is more sustainable: If many people share the same item, fewer clothes might be needed overall. In practice, that's not certain; customers might just add luxury rentals to existing wardrobes. Renting will certainly add to the packaging, shipping, and dry-cleaning of clothes. Writing in *Elle* recently, journalist Elizabeth Cline, author of two books on fast fashion, tried to sort out the pros and cons. "Wearing what's already in your closet is the most sustainable way to get dressed," she concluded.

Food

PEOPLE CAN'T GO CIRCULAR on their own; the system has to change. But individual choices do matter. "It's about using less stuff in the first place," said Liz Goodwin of the World Resources Institute.

In 2008 the Waste and Resources Action Programme (WRAP), which Goodwin ran then, did one of the first major studies of food waste. The nonprofit surveyed more than 2,100 British families who had agreed to let inspectors paw through their garbage and weigh each food scrap. "Absolutely shocking," Goodwin recalled. "We found whole chickens in their wrappers." Nearly half of all salad and a quarter of all fruit

AN END TO PLASTIC TRASH

Plastic isn't the enemy, but plastic waste in the ocean and elsewhere is a global plague. Are biodegradables and recycling the cure? Staff writer Laura Parker considers what a circular economy for plastics might look like. For that article and other plastics coverage, go to natgeo.com/plastic.

was ending up in bins, as were nearly 400,000 tons of potatoes a year. In all, Britons were tossing one of every three bags of groceries.

As it turned out, they're not exceptional. Roughly a third of all food is wasted globally, at an annual cost of nearly a trillion dollars, WRAP's global director, Richard Swannell, told me. Over dinner at a restaurant in Oxford, at which we both took care to clean our plates, Swannell explained that before the WRAP study, no one was aware of just how much food—and money—was going to waste in Britain.

WRAP launched a chipper PR campaign ("Love Food Hate Waste"). It worked with women's groups to disseminate food-rescue tips. (A favorite was ways to dress up toast to save stale bread.) It also persuaded grocery chains to adopt some simple measures: Clearer, extended "use by" dates; smaller, resealable packages; an end to "buy one, get one free" sales on perishables. It was boring stuff, forgotten common sense, but it worked. By 2012 the amount of edible food wasted in Britain had fallen by a fifth. "We've had massive progress," Swannell said.

The progress has stalled lately, but no one ever thought common sense alone would end food waste. Artificial intelligence may be required. From a remodeled Victorian furniture factory in the Shoreditch section of London, Marc Zornes, CEO of Winnow, is pitching a high-tech solution that his start-up already has placed into 1,300 restaurant kitchens: smart garbage cans.

Zornes demonstrated one in his conference room, using a plastic chicken leg. Each time a cook or waiter dumps a pot or platter of something into a Winnow can, a scale measures the added weight and a camera snaps a picture. The AI software identifies the new garbage—at Ikea it has learned to distinguish three kinds of meatballs—and displays its cost.

Zornes claimed his clients—AccorHotels, the French multinational, is another big one—routinely cut food waste in half by listening to their

AGRICULTURE

The world's largest indoor vertical farm, operated by AeroFarms at its headquarters in Newark, New Jersey, aims to raise vegetables sustainably year-round in the heart of cities. Baby leafy greens are grown on a reusable substrate made from recycled plastic bottles. Water is misted on the roots from below, saving 95 percent of what would be needed outdoors. No pesticides are used. Nutrients and fertilizers are applied only as needed. And the lighting provides the specific wavelength that the vegetables require. The company says its yields are 390 times as high as farming in fields.







FOOD

Black soldier flies raised on food waste might replace soy as a protein in animal feed, saving land. Entocycle, a British start-up, tests breeding conditions at its London lab (above) and feeds brewery and coffee waste to the larvae. They're harvested (below) after just two weeks.



CLOTHES

In Prato, Italy, where wool cloth has been produced for centuries, 99 percent of textile waste ends up in landfills. In the past year, 3,500 companies employing 40,000 workers produced a new textile waste recycling plant. The wool is sorted by color, washed, and shredded. Only one percent of textile waste is currently recycled.





Recycled since the 12th century, some companies process discarded textiles (above). After being cleaned (below), it's spun back into yarn, which can then be cycled into new clothing.



BY-PRODUCTS

In Kalundborg, Denmark, 11 companies cooperate to convert waste into resources. Novo Nordisk, which makes insulin, uses steam from a nearby power plant to sterilize its equipment (above). It sends massive amounts of yeast slurry to a bioenergy plant, where a technician tests a spoonful (below), and microbes process it into natural gas.



garbage cans. Breakfast buffets are notorious, he said; most leftovers are discarded. “When you start measuring the problem, you start managing it,” Zornes said. You make less of what you’re throwing out. I had walked through Winnow’s graffiti-decorated carriage doors expecting grooviness and hype; I walked out wanting to tell my nephew, a Ritz-Carlton chef, about Winnow.

A few days later I had a similar experience in Amsterdam at InStock, a restaurant that makes ambitious cuisine from surplus food. In a spare but cozily lit room, I sat down under a wooden sign that tallied the “rescued food”—780,054 kilograms, or more than 850 tons. One of the founders, Freke van Nimwegen, was at the bar checking the books. She joined me and told me her story as my prix fixe menu ran its courses.

Van Nimwegen was two years out of business school and working for Albert Heijn, the largest Dutch grocery chain, when she discovered the food waste problem. As an assistant store manager she wanted to do something about it, and she couldn’t—food banks might take some bread but not all the produce. She and two co-workers came up with the idea for InStock in 2014 and persuaded the company to support it. It has gone from a pop-up to this restaurant to two others in Utrecht and The Hague, and for van Nimwegen, it was just getting really interesting.

“It’s not that we had a dream to start a restaurant chain,” she said. “Not at all. We wanted to do something about food waste.”

My main course arrived: nuggets of “Kentucky Fried Goose.” “Watch out, there can be bullets in the meat,” said the waitress. Schiphol Airport, van Nimwegen explained, employs hunters to dispatch wild geese that might otherwise foul jet engines. The dead birds used to be incinerated; now they come here. The nuggets were chewy but tasty and bullet free. With eggplant chutney and red pepper coulis they went down nicely.

The chefs at InStock improvise with whatever they get. The food comes from Albert Heijn but also from producers, including farmers. “It’s easy to point fingers at the supermarket,” van Nimwegen said. “The whole supply chain, including the customer—everybody wants everything in stock. We’re just spoiled, basically. The companies don’t want to sell ‘no.’ So they’ll always have a little bit too much.”

In 2018 InStock started delivering surplus food to other restaurants. Van Nimwegen’s priority now is to get contracts to supply corporate

cafeterias. “The most important thing for us is to make volume,” she said. “These kinds of places have a thousand people that need lunch.” The Dutch have managed to decrease food waste by 29 percent since 2010, according to a government report, even more than the British.

Dessert was a fabulous foam of berries and cherries poached in red wine, from bottles open too long at the bar. The bill came in a toy shopping cart filled with misshapen fruit: a flat peach and a very skinny pear. I pocketed them to supplement the lunches I’d be rescuing from the breakfast buffet and, feeling a pleasant combination of woke and well-fed, cycled back to my hotel through the misty Amsterdam night.

In my room I found a bat flying in frantic circles. Watching the poor beast search for the open window, I sensed another gift, a metaphor this time. But at first I didn’t know what to do with it.

Openings

GETTING OUT OF THE TRAP we’ve entered with the linear economy, and back to an economy modeled on nature’s, is going to take a lot of “divergent thinking,” as psychologists call it. In Copenhagen I paused to admire the new municipal incinerator, which burns trash for energy and definitely diverges from the norm: There’s an all-season ski slope on its roof. But my real destination was the nearby port of Kalundborg, something of a circular economy icon.

There I sat in a cramped conference room with the managers of 11 industrial plants, separate companies all, who have formed an unusual bond: They use each other’s waste. The chairman of the group, Michael Hallgren, manages a Novo Nordisk plant that makes half the world’s supply of insulin—and along with its sister company, Novozymes, 330,000 tons of spent yeast. That slurry is trucked to a bioenergy plant, where microbes convert it to enough biogas for 6,000 homes and enough fertilizer for nearly 50,000 acres. That’s just the latest of 22 exchanges of waste—water, energy, or materials—that make up the Kalundborg Symbiosis.

It wasn’t planned, said Lisbeth Randers, the town’s symbiosis coordinator; it grew up over four decades, one bilateral deal at a time. A wallboard company came to Kalundborg in part because waste gas from the oil refinery was available as a

CLOSING THE CIRCLE

Use less, keep things in use longer, recycle endlessly—a circular economy will take a range of strategies. In the cradle-to-cradle vision, all products are ultimately broken down either to “technical nutrients,” which are made into new products, or biological ones, which return to the soil. Waste is a design flaw. As in nature, it doesn’t exist.

Use less

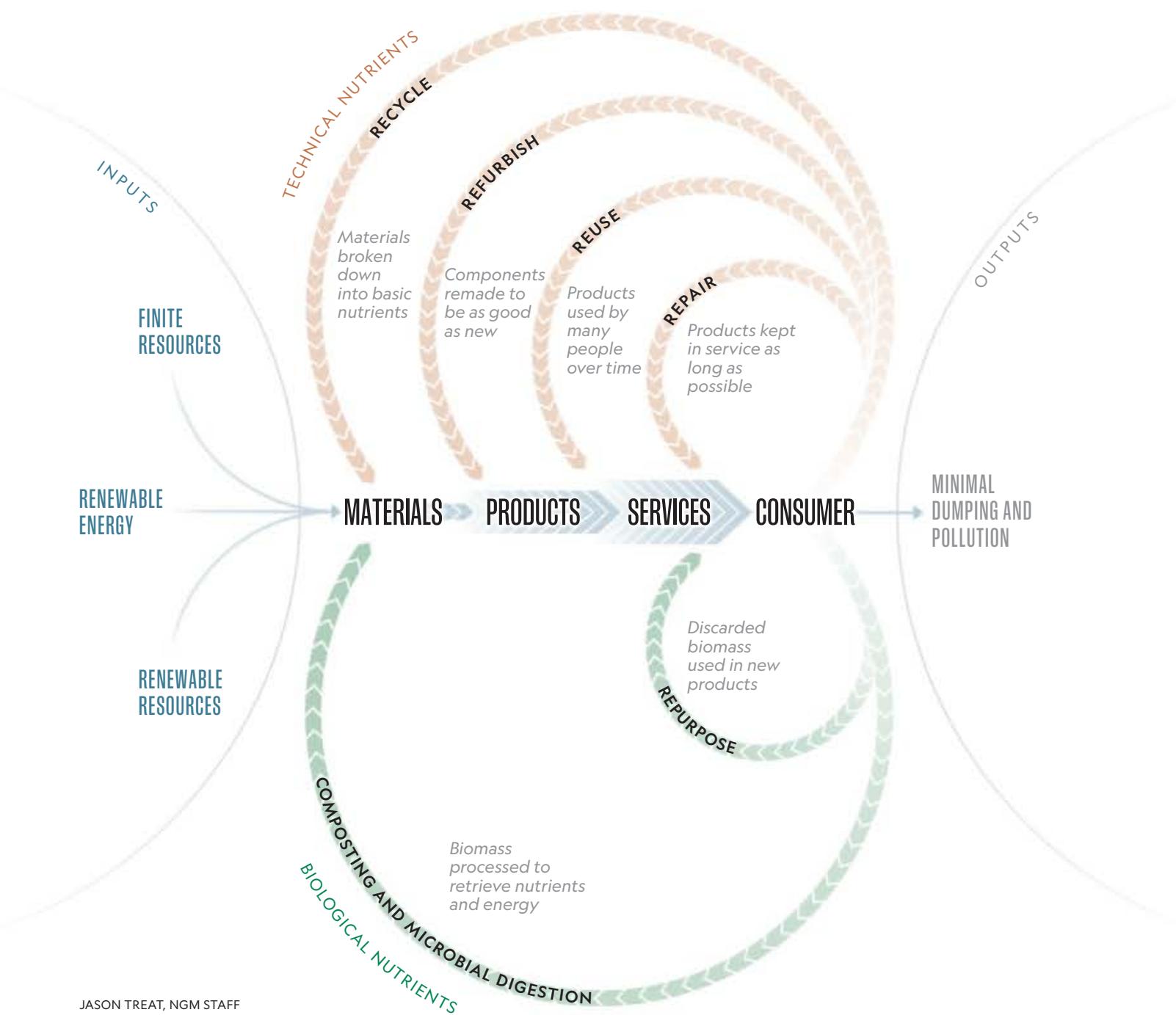
Renewable energy replaces fossil fuels; rental or sharing businesses serve more people with fewer products.

Design wisely

Machines and other products are designed to be long-lasting and easy to repair—or ephemeral and easy to break down into basic components.

No waste

All nutrients flow in cycles. Almost nothing is released as a pollutant or dumped in a landfill.



WHAT YOU CAN DO

Restrain yourself

Fly and drive less.
Eat all the food you buy.
Wear the clothes you already have. Avoid single-use plastics.

Repair and reuse

Buy fewer, higher quality products and repair them when they break. Donate the clothes you don't wear.

Recycle everything

Compost food waste (or feed it to your pig). Recycle everything you can—and lobby for more recycling.

cheap energy source; it later sourced gypsum from the nearby coal-fired power plant, which made it by scrubbing sulfur dioxide out of its smoke. None of this happened primarily for environmental reasons—but the Kalundborg Symbiosis, Randers said, reduces carbon dioxide emissions by 635,000 metric tons a year, while saving the participants \$27 million. Hallgren is now overseeing the construction of an insulin plant in Clayton, North Carolina. “I have a dream that I can make a symbiosis work in Clayton,” he said.

In the rolling fields of Westphalia in Germany, home to a famous kind of ham and, not incidentally, many pigs, I met a woman who, with no engineering education, has designed an industrial-scale solution to one of the region’s major problems: too much pig manure. Nitrates leaching from overfertilized fields have polluted groundwater in about a quarter of Germany. A typical farmer around the town of Velen, where I met Doris Nienhaus, might spend \$40,000 a year to truck nearly 2,000 tons of liquid manure more than a hundred miles away to a field that’s not already manured up. “At some point it won’t be economically viable,” Nienhaus said.

Her solution is a plant that extracts the basic nutrients—phosphorus, nitrogen, and potassium—from manure. Nienhaus, who used to work for the regional agricultural federation and has raised pigs, persuaded 90 farmers to invest \$8.4 million. Their farms’ manure is digested by microbes, and the resulting biogas fuels a generator that powers the plant, with electricity left over to sell to the grid. Fast centrifuges, a proprietary polymer, and hot ovens separate the digester glop into a brown liquid, rich in nitrogen and potassium, and a brown ash that is 35 percent phosphorus. All that will be sold; the plant will produce no waste, Nienhaus said. When I visited, it was in its test phase. Nienhaus displayed her first batch of potassium in a small white dish, like granules from a gold strike.

Once upon a time, every farmer ran a circular economy, keeping only as much livestock as his or her land could feed, and those animals pooped no more than the land could take. Industrial livestock operations broke that circle. A few years ago, I spent some time on a cattle feedlot in Texas; that’s when I started thinking about the circular economy. I watched 110-car trains full of Iowa corn rumble into Hereford, Texas, and I saw hills of manure at the feedlot, waiting to be sent to local farms. Shouldn’t that be going back to Iowa to

fertilize the corn, I asked? Too expensive, was the answer—but if a plant like Nienhaus’s were there, only the nutrients would need to be shipped. Maybe the circle could be unbroken again.

When Eben Bayer invented his new thing in 2006, he was an engineering student at Rensselaer Polytechnic Institute in Troy, New York. He was taking a class in invention, learning to think divergently, and the problem he was pondering—he’d read *Cradle to Cradle*—was the toxic glues in particleboard or fiberglass. Growing up on a Vermont farm, Bayer had spent hours shoveling wood chips into a furnace to make maple syrup. The wood chips often stuck together—because they’d been colonized by mycelium, the dense mesh of microscopic fibers that make up the roots of mushrooms. Bayer wondered: Could mushrooms grow a harmless glue?

The first product he and his partner Gavin McIntyre made at Ecovative Design, the company they founded, was packaging. They inoculated ground hemp fibers or wood chips with small amounts of mycelium, and the tiny white roots filled the spaces between the particles, enmeshing and gluing them. They found the stuff could be grown in molds of any shape. It stops growing when you dehydrate it—and when you’re done with it, you can compost it. In the past decade, Ecovative has made more than a million pounds of packaging—packing corners, display molds for cosmetics—for customers willing to pay a little extra to be sustainable.

Lately they’ve moved on to bigger things—things that are 100 percent mushroom. In soil mycelium grows in layers of mesh, but when it hits the air, it starts forming mushrooms. Ecovative has figured out how to trick mycelium into a hybrid growth pattern, in which it lays down solid microlayers one after another. “It’s like a biological 3-D printer,” Bayer said. With investment funding and \$9.2 million from DARPA, the Defense Advanced Research Projects Agency, Ecovative is expanding a lab to figure out how to grow all manner of things—shoe soles, vegan leather, edible scaffolding for artificial steaks—from mycelium. In 2018 designer Stella McCartney made a handbag out of the stuff and showed it at the Victoria and Albert Museum.

In the cradle-to-cradle vision of McDonough and Braungart, waste doesn’t exist even as a concept. Every material is either a well-designed “technical nutrient,” capable of being endlessly recycled, or a biological one, safe to

eat or compost. Bayer shares that view—but he's betting most things will be biological in the future. "Biologically derived materials already fit into how Earth works," he said. "Spaceship Earth can digest this stuff."

Beyond good and evil

ALL THE TRASH WE MAKE is not a sign that we're evil. It's a sign we're a little dumb. When I met Michael Braungart in Hamburg, Germany, he could barely wait for me to open my notebook before making this most essential point. He started his career as a Greenpeace activist, orchestrating protests at chemical companies, and has since consulted for many corporations. "We're fighting with cradle-to-cradle against a cultural heritage that comes out of religious beliefs," he said, meaning monotheistic ones. The legacy they've bequeathed to environmentalism, said Braungart, is the idea that nature is good and humans, in our effect on it, basically evil—the best we can do is limit the damage. To Braungart that's misguided and unambitious. He's an environmentalist who, like chemists and engineers, believes we can improve on nature. He once designed a biodegradable ice-cream wrapper implanted with wildflower seeds; you could litter it, and it would propagate beauty.

Outside Amsterdam I visited a 23-acre office park that McDonough's firm designed and Braungart helped select materials for, called Park 20/20. When the developer, Coert Zachariasse, made his own pilgrimage to Charlottesville a decade ago, he was hoping the guru would reveal exactly how to build a cradle-to-cradle office park. But McDonough demurred. "He said, 'We don't know yet, but we're going to figure it out,'" Zachariasse recalled. The developer felt disappointed at first—then liberated, empowered.

Park 20/20 is about three-quarters built, and it's already a green and pleasant office park. The facades are varied and imaginative, the spaces sunlit and inviting, the energy all renewable, the wastewater treated and recycled on-site. One of its coolest features is less apparent: Instead of the usual concrete-slab floors, the buildings have thinner, hollow, steel-beamed ones. They allow seven stories to fit in the usual height of six, using 30 percent less material overall.

In winter, warm water from the neighboring

canal, stored underground since the previous summer, flows through pipes in each subfloor, heating the space above; in summer, cool canal water from the previous winter flows through pipes in each ceiling, cooling the space below. And unlike concrete slabs, the prefabricated floor-ceiling sections are designed to be disassembled and reused, should the building need to be reconfigured or demolished. The Park 20/20 buildings are "material banks"—whereas elsewhere, building materials make up the largest waste stream flowing into landfills.

In McDonough's office I sat on an old Herman Miller chair upholstered with the first product he and Braungart ever designed, a fabric made of wool and ramie, which is made from nettles. Both men insisted it was edible, and had I been a goat, I might have tested that assertion. As McDonough was talking to me about Leibniz and a world of possibilities, I found my mind drifting to an old movie called *Diner*, which I'm more familiar with. "If you don't have good dreams...you got nightmares," Mickey Rourke's character says toward the end, as he and his young buddies are heading off into uncertainty. Maybe they'll grow up successfully, maybe not. And maybe, I thought, our whole species is in that situation—needing a dream to steer toward, in order to avoid the nightmare.

The circular economy is a dream that's inspiring a lot of people to do cool stuff. But—if I may close this journey with a thud—here's the thing: It's not happening. If you look away from the bright lights and at the dull numbers, the ones de Wit showed me, the "circularity gap" is growing, not shrinking. Our use of natural resources could double by 2050. Our carbon emissions are still increasing.

"Is it moving fast enough? Not really," de Wit said. "All indicators are in the red."

Like the other optimists I met, de Wit is counting on time. Building a circular economy will require an enormous cultural shift, on the scale of the industrial revolution. "You need stamina," de Wit said. "My sense is we can't do it with the generation in power. It will require a generation to take off." That was my generation he was hustling offstage; I didn't take it personally, though. Sure, we'll be pushing up daisies long before the circular economy arrives. But we'll be doing our bit for it that way. □

Luca Locatelli's photos of Dutch agriculture in the September 2017 issue are on exhibit at the Guggenheim Museum in New York. Senior editor **Robert Kunzig** wrote about cities in April 2019.

THE SECRETS

A PHOTOGRAPHER'S EXPERIMENT WITH A WILD NEST YIELDS
UNPRECEDENTED IMAGES SHOWING HOW THE INSECTS
DEFEND THEMSELVES, STAY WARM OR COOL, AND SOCALIZE.

BY JASON BITTEL | PHOTOGRAPHS BY INGO ARNDT



SEE JO





PREVIOUS PHOTO

With tubular tongues, western honeybees in Langen, Germany, slurp up water to carry back to their nest, where it will be used for climate control.

ABOVE

Bees arrive at their nest in a tree cavity created and long since abandoned by a black woodpecker.

Almost as soon
as the honeybee
colony was
installed, it came
under attack.



Not from varroa mites, pesticides, colony collapse disorder, or any of the many other perils now facing honeybee populations across the world, but from hornets—each one a red-eyed giant next to the hairy little bees. Each strike took just an instant, the predators snatching bees out of the air and then flying away with their victims, which would be carved up later and fed to the hornets' own ravenous larvae.

One-on-one, a western honeybee is no match for a European hornet. Up to an inch and a half long, the hornet is equipped with powerful mandibles capable of shearing smaller insects to pieces.

For those first few days of the siege, the

honeybees appeared helpless in the face of the hornet onslaught.

"I thought, Oh God, if this keeps happening, they will kill my whole colony," says photographer Ingo Arndt, whose yard in Langen, Germany, hosts the honeybees.

But as the week wore on, the bees began gaining ground. They started to swarm near the entrance of the nest, creating a living carpet of guards. Each time a hornet flew too close, some of the defenders would leap onto the invader and tackle it. In an instant, more honeybees would pile on and pin the hornet down.

Inside this bee ball, something even more bizarre was taking place. Western honeybees have a trick in which they can activate their



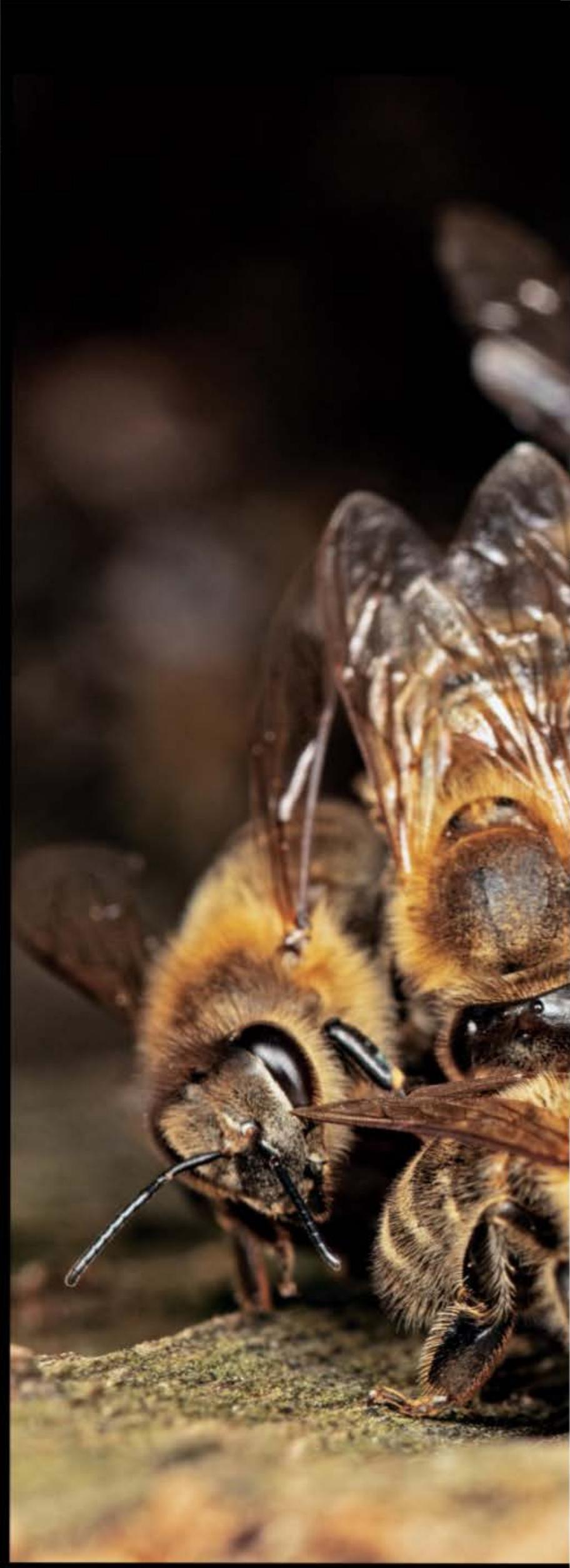


At work

These photos, which show a natural honeybee nest, add clarity to the way honeybees live in the wild. Here, worker bees construct new comb out of beeswax as others zoom into the woodpecker cavity carrying pollen and nectar. Unlike ants, which have specialized roles, every worker bee is capable of doing every job necessary for maintaining the nest.

Heated defense

To guard their nest from predatory hornets, the bees go into a defensive stance at the entrance to the cavity. They raise their front legs and open their mandibles (top). When a hornet gets close, they tackle it (middle) and pile on to prevent escape (bottom). Then the bees rapidly work their flight muscles to generate heat (right). The hornet's body temperature rises until it succumbs to the heat.









Growing up

Newly formed bees chew their way out of wax-covered cells. Like butterflies, bees go through several life stages. From eggs, they hatch into squirming, voracious larvae, which must be fed constantly by attentive worker bees. After several days, the workers cap the cells with wax, signaling the larvae to spin a cocoon to pupate, or finish metamorphosis. A week or two later, the fully formed bees emerge.

flight muscles so rapidly that their thoraxes, or midsections, radiate small amounts of heat. When a dozen or more bees rev their engines at the same time, the cluster can significantly raise the ambient temperature.

The bees were cooking the hornets alive.

"I find this ingenious," says Jürgen Tautz, a recently retired biologist who specialized in honeybees for about 25 years at the Julius Maximilian University of Würzburg, in Germany.

The heat trap is a powerful weapon, but it can also lead to friendly fire. Sometimes the innermost bees in the ball die alongside the hornet, sacrificing themselves for the colony's defense.

This is just one facet of western honeybee behavior that Arndt has captured in new detail over the past two years. He has been photographing wildlife for 30 years, but he's no insect expert, so he partnered with Tautz.

The bee-versus-hornet behavior has been documented in related species in Asia and has been seen by western honeybee keepers in Israel and Egypt, but no one had ever captured the insect duel quite as Arndt had. "It's the best photo of it I've ever seen," says Thomas D. Seeley, a Cornell University professor who has been studying honeybee behavior and social interactions for half a century.

After the first few battles, Arndt says, he saw hornets and honeybees locked in combat as many as 10 times a day. If a honeybee colony is weak, hornets can annihilate it, but for now, the fight in Arndt's yard continues as a war of insect attrition.

There are other factors in this saga as well. Arndt says honeybees from nearby colonies often raid the nest in his backyard in an attempt to steal its honey, especially toward the end of summer when flowers become less available.

AFTER ACCOMPANYING scientists

through the forests of Germany's Hainich National Park as they studied bees in the wild, Arndt got hooked. But he realized that he'd never truly unlock the insects' secrets while watching them in an artificial box engineered by humans for the purpose of extracting honey. What he really wanted was to photograph a natural nest.

This is no small feat. Even if you put on a

beekeeping suit and climb 60 feet up into the forest canopy where bees like to nest, as Arndt did in 2018, "the most exciting stuff is happening inside the tree," he says.

So in February 2019, Arndt received permission from the German forest authorities to go into a local forest and remove a fallen beech tree with an abandoned black woodpecker cavity in its trunk—a treasured home for western honeybees. He cut out a piece of the log and arranged for it to be sent to his garden.

Arndt set to work building a four-walled, plywood photographer's blind up against the 200-pound hunk of wood, complete with lighting and a tiny window, which allowed him to sneak his macro lens through the back of the cavity. He then extracted the queen from a nearby colony of western honeybees and placed her inside the woodpecker burrow. All he had to do was wait in the blind with his finger on the shutter button.

Within moments, scout bees from the queen's original colony lit on the rim of the woodpecker burrow. More bees landed and then more, until the log hummed with tens of thousands of the wild, social insects. The entire colony soon moved

itself into the woodpecker cavity.

Over six months, Arndt shot more than 60,000 pictures, creating a portrait of wild honeybees unlike anything seen before.

"That is what makes this very special," Seeley says. Ornithologists have used similar techniques to study birds, but no one studying bees in the wild had done this.

Hundreds of hours in the blind paid off. When it was warm out, Arndt watched as bees made repeated trips to a nearby water source that he provided, where they would suck up the liquid with strawlike tongues and then fly back to the nest. Inside, they passed the water to another group

of bees, known as water spreaders, whose job is to regurgitate the liquid onto the combs, where it evaporates and creates a cooling effect. The process can be accelerated when other bees fan their wings to increase airflow to make the water evaporate faster. Called evaporative cooling, it's essentially what happens when you sweat and then sit in front of a fan.

55%

Americans who rank bees as first among a list of species they most want to save, according to a National Geographic and Morning Consult Poll. The least likely to be ranked at the top? Sharks, with zero first-place votes.

Over six months, Arndt shot more than 60,000 pictures, creating a portrait of wild honeybees unlike anything seen before.



Honeybees often lock legs with each other when working in their nest. The living chains are especially important while building combs because the temperature must be at least 95 degrees Fahrenheit to keep the beeswax soft and workable.

When the temperatures outside dipped, the honeybees grabbed hold of each other's legs to form a living quilt along the surface of the combs. Tautz likens the structure to a sleeping bag, but one in which the fabric's weave—made of interlocked bees—can be loosened or tightened to adjust the temperature.

IN SOME CASES, Arndt and Tautz were able to explain behaviors that beekeepers have long puzzled over. One mystery was why the insects would gnaw at the wood of their boxes without any appreciable effect. Inside the tree, they found, the behavior makes more sense.

"They scratch all the loose particles from inside the surface of the hollow," Tautz says.

Not only might this behavior remove potential pathogens, such as fungal buildups, but it also

creates a smooth surface onto which other bees can apply a shellac known as propolis.

"Propolis is a secretion produced by the buds of trees in spring," Tautz says. "It's very sticky, but bees collect it because it is antifungal and antibacterial. It's part of the pharmacy of the forest."

Other moments were captured for the first time, such as when Arndt photographed a honeybee opening a pheromone-emitting gland in midflight.

"Nobody has ever shown that before," Seeley says. He hopes these intimate photos will open people's eyes to the mostly hidden beauty of wild bees.

"We're so used to seeing bees or thinking of bees living in a square white box," Seeley says. "And that's how they live for beekeepers. But it's not how they lived for millions of years on their own." □

Jason Bittel writes frequently for *natgeo.com*; this is his first story in the magazine. **Ingo Arndt**'s book with Jürgen Tautz, *Honey Bees: Mysterious Forest Dwellers*, publishes this spring.





THE ABDUCTION OF 276 NIGERIAN SCHOOLGIRLS OUTRAGED THE WORLD. 112 ARE STILL MISSING. THE SURVIVORS ARE RECLAIMING THEIR FUTURE.

BY **NINA STROCHLIC**
PHOTOGRAPHS BY **BÉNÉDICTE KURZEN**

Esther Usman stands behind the dormitory in northeastern Nigeria where she and more than a hundred other students from Chibok live and study.

The young women are preparing for admission to university and are planning careers in business, medicine, and human rights law.



On April 14, 2014, a total of 276 schoolgirls were kidnapped from their dorms in Chibok, a city in north-eastern Nigeria, by the militant group Boko Haram. The girls' plight drew worldwide attention. Today, 112 of the young women remain missing. Most of the survivors are studying at the New Foundation



School (NFS), a college-preparatory program at the American University of Nigeria (AUN) in Yola. Among them are (clockwise from top left): Awa Abuga, Glori Aji, Mwada Baba, Yana Joshua, Kume Ishaku, and Grace Paul. They posed for portraits in a makeshift studio in their dorm's recreation room.

PATIENCE BULUS AND ESTHER JOSHUA HELD HANDS AS THEY WERE MARCHED OUT OF THEIR DORM ROOM AT GUNPOINT THAT APRIL NIGHT.

Hherded into the back of an open-bed truck, they lost their grip on each other. Amid the mass of frightened students, Patience heard Esther's soft voice ask, "What will happen?"

Then someone jumped off the side. Suddenly other girls were tumbling into the darkness, willing to risk being shot or lost in the unknown forest to flee their captors. Patience looked next to her, but Esther had been pulled deeper into the truck. Patience pushed her way to the edge and jumped without Esther.

For five years a rebel insurgency in northeastern Nigeria had terrorized the region and shut down schools. The Government Secondary School for girls in Chibok had reopened in April 2014 for students to take their final exams. In a region where less than half of all girls attend primary school, these students had defied the odds they were born into long before the war reached them. But around 11 p.m. on April 14, trucks of militants from Boko Haram, whose name roughly translates to "Western education is forbidden," forced 276 girls from their dorms onto trucks and drove toward the lawless cover of the Sambisa forest, a nature reserve the jihadist group had taken over to wage a bloody war against the government.

The attack sparked #BringBackOurGirls, an international campaign embraced by then U.S. First Lady Michelle Obama. Chibok, a remote, little-known town before the kidnappings, came to represent some of Nigeria's most crucial issues—corruption, insecurity, the invisibility of the poor. Media covered every development: The 57 girls who escaped early on; the ordeal of 10 of the girls who wound up in multiple American schools; videos released by Boko Haram showing sullen captives; two emotional releases of a total of 103 girls, reportedly in exchange for money and prisoners; four girls who are said to have fled later on their own.



Civilian patrols found Amina Ali, who decorated this photo, wandering in the Sambisa Forest Reserve in 2016. She was the first of the missing schoolgirls to be rescued. Later that year the government negotiated for the release of 21 girls, and then 82 more in 2017.



Amina Ali'

I will never give up





Students from Chibok take pictures on the last day of class before final exams and then summer recess. The rigorous academic schedule prepares them

for university entrance exams. Fifteen students have graduated from the NFS program and are studying at AUN. Some return to NFS weekly as mentors.

Of the 276 Chibok students kidnapped, 112 are still missing. Some are believed to be dead. Two and a half years ago, the government arranged for more than a hundred survivors to study at a tightly controlled campus in northeastern Nigeria. Since then, there's been relative silence.

PATIENCE SPENT THE SUMMER after the abduction in her village of Askira, listening to gospel music and coming to terms, she says, with the idea that the attack had ended her education. Esther's mother came to visit once, but Patience wasn't at home. Journalists wanted to know what happened that night; parents asked if she'd seen their missing daughters. Repeating the story of April 14 had become exhausting.

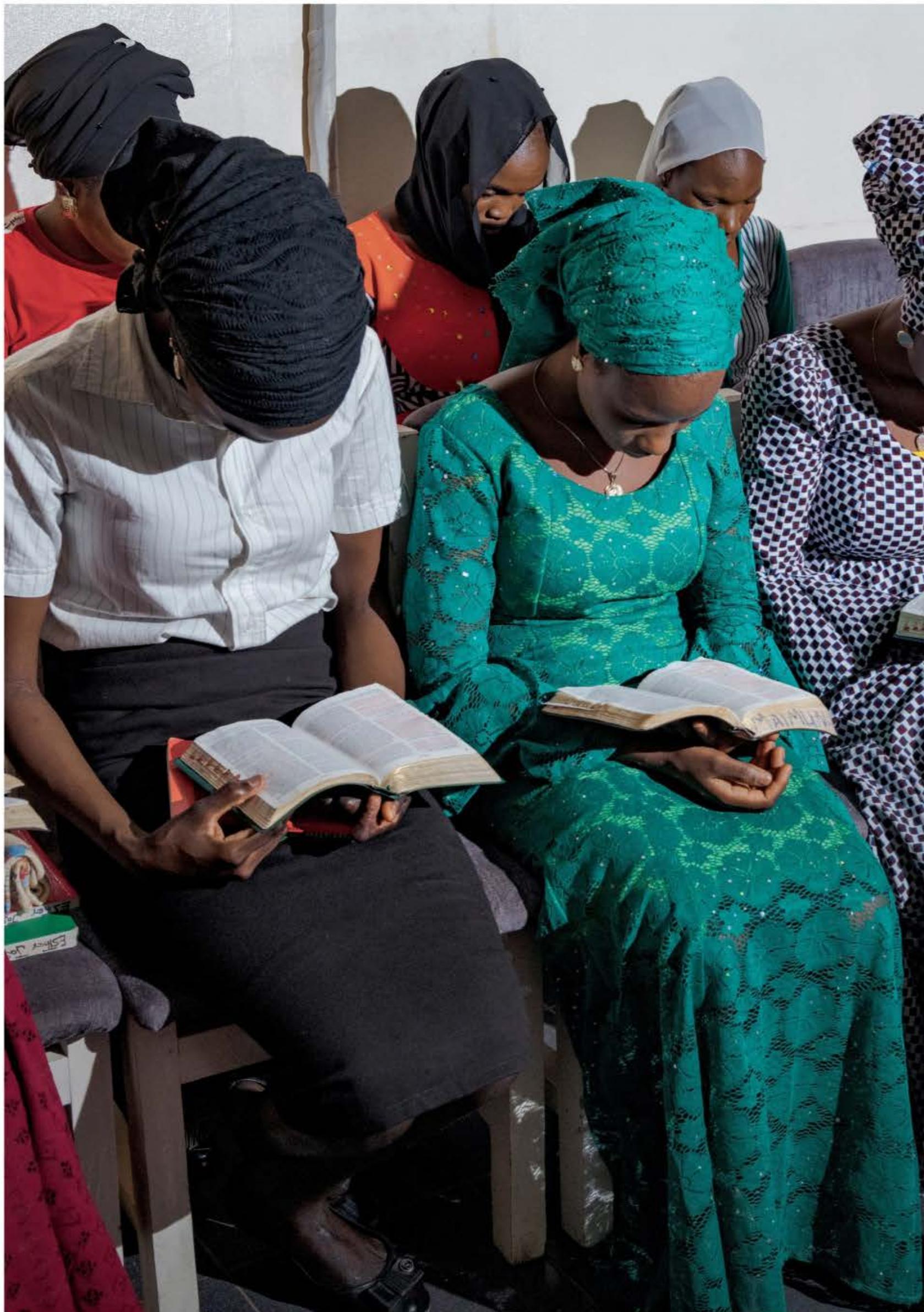
Patience and nine other survivors accepted an offer to study in the United States. She embraced the opportunity, even though neighbors in her village warned her parents that young women get into trouble far from home.

Around the same time Patience was preparing to move abroad, a school security guard visited Margee Ensign, president of the American University of Nigeria (AUN) campus in Yola, a city of several hundred thousand people. She told Ensign that her sister and 56 other girls had escaped shortly after the attack.

Some had jumped from the trucks, grabbed tree branches, twisted their ankles, and then run until they found help. Others, such as Mary K. (who asked that only her last initial be used), had ridden with the kidnappers for hours. When the truck stopped, Mary conspired with her classmates in their local dialect: They'd split into groups of two, ask to use the bathroom, and then run. The kidnappers, arguing among themselves, failed to find them. It took Mary 24 hours to get home, and when she finally did, she found her village engulfed in fighting.

Ensign and her staff drove to Chibok and returned with two vans of survivors who wanted to continue their education at AUN.

"We weren't ready," Ensign recalls. "Boko Haram was still in the area. But it wasn't a hard





On Sundays, the young women attend a service at AUN. At the end of the academic year, Pastor Raymond Obindu urged them to return and resume

their studies in the fall. In this region, less than half of all girls attend primary school. It's not uncommon for students to leave school to get married.

decision.” Two dozen students settled into the university’s campus, encircled by a high wall and secured by guards in crisp, red uniforms. They attended the New Foundation School (NFS), a tailor-made program to prepare the young women from Chibok for college.

OVER THE NEXT TWO YEARS, none of the missing students were released. Rumors of nightmare conditions in captivity—forced marriages, enslavement, starvation—were omnipresent. Then, in May 2016, Chibok student Amina Ali escaped from the forest with her baby. Five months later, Nigeria’s government reportedly offered Boko Haram cash and prisoners for the release of 21 girls. Severely malnourished, they were taken to a hospital in Abuja, the capital, to be assessed by a psychiatrist, physician, sports therapist, imam, and social worker. They said the militants had given them a choice: Convert to Islam and marry, or become slaves. Most chose slavery, the media reported.

In May 2017, 82 more girls were released. Their tearful reunion with their parents was broadcast around the world. In the U.S., Patience Bulus watched news footage, scanning the names of those rescued. Her heart leaped when she landed on Esther Joshua.

Patience recalled the day Esther transferred to Chibok from another school. Patience had sized her up and decided she’d make a perfect sidekick: They were from the same tribe and in their next-to-last year in school. Soon they were inseparable and planned to spend part of the summer of 2014 together at Esther’s house.

When Patience learned that her 103 recently freed classmates would join those studying at AUN, she texted a friend: When Esther arrives in Yola, tell her to call me.

In September 2017, AUN went from housing and educating 24 Chibok students to 130. The young women settled into a quiet existence of studying and praying. Esther was intimidated by the busy campus. In Chibok, there had been no laptops or yoga or karaoke nights. In Yola,



recreation rooms were outfitted with televisions, plush couches, and motivational sayings painted on the walls. The dorm was divided into four “houses,” each named for a famous woman.

Soon after Esther arrived, another student passed on Patience’s message. On the phone, Esther told Patience everything that had happened in the forest and swore her to secrecy. “Don’t let it stop you,” Patience advised. “This is our best opportunity to make something good.”

IN A FOUR-BED DORM ROOM, Esther stacked her new books onto shelves and emptied her suitcase into the wardrobe. Her new computer quickly filled up with selfies and pictures that

Patience sent over WhatsApp.

At first the new students kept to themselves, eating in their own building and going to the gym early on Saturdays. Before long, they began dining in the main cafeteria, and some attended classes in the library.

But they are not regular students. Boko Haram pledged to kill them if they returned to school. Guards watch their building and follow them whenever they leave. On campus they have a 24/7 support system: 11 student affairs “aunties” who live in the dorms, a nurse, and a walk-in psychologist’s office. Some have bullets and shrapnel still lodged in their bodies. One has a prosthetic leg. Another walks with a cane. Most

After Esther Joshua (at left) was released from captivity, she received a call from her friend Patience Bulus, who escaped during the abduction and is now

studying in the U.S. Patience urged Esther to seize her second chance at life. "This is our best opportunity to make something good," she said.

spent nearly three years in captivity and wrestle with lingering trauma.

AUN officials say the protection is necessary. But some see it as sheltering them. "After they were first released, they were kept together by the government in some facility in Abuja. After that they were shipped off to AUN," said Anietie Ewang, the Nigeria researcher at Human Rights Watch who has closely followed the case. "It feels like at every stage they've been secluded."

The Nigerian government and private donors are covering the costs of at least six years of education for each of them. Some are eyeing law school. Others plan to become actresses, writers, accountants. Fifteen students have graduated from the NFS high school program and are studying at the university. Mary K., who escaped on the day after the kidnapping, arrived on campus in 2014, unable to speak English. After two years, she was accepted to AUN. The transition wasn't easy. She knew other students gossiped about her, and thought about transferring to another school. Now she roams campus and seems to know everyone. Once a week she mentors a group of NFS students on how to manage their time, perfect their English, and pass the three standardized tests they need for AUN admission. This year she's spending a semester abroad, in Rome.

Not all the survivors of Boko Haram's war have such opportunities. In Borno State, the epicenter of the crisis, classes were canceled for two years. There and in two neighboring states, roughly 500 schools have been destroyed, 800 are closed, and more than 2,000 teachers have been killed.

Fifteen miles from AUN's campus, Gloria Abuya gets up at 5 a.m. and walks two hours to school from the 2,100-person camp for displaced people where she lives. When Boko Haram militants first arrived in Gloria's hometown of Gwoza in 2014, they killed the men and ordered their wives to bury the bodies. Later, they took the girls. Gloria spent two months in captivity before escaping one night as her captors prayed.

Many women held prisoner by Boko Haram return to communities that fear them and families that shun them. Gloria doesn't know when, if ever, she can resume her old life. "There's nothing left at home to go back to," she said.

In May 2019, a week before the start of their summer vacation, the Chibok students prepared to mark the anniversary of their release from captivity. "It's very sad because we remember our sisters in the forest," said Amina Ali, as she dressed for dinner after a day of rehearsals for the day's events. "And here we are, happy."

The next day the drama club performed a play in which two girls were kidnapped for ransom and their families fought to bring them back. The script poked fun at ineffective police, lazy elected officials, and greedy kidnappers. When the captives were freed and reunited with their families, the audience burst into applause. At the end, a row of students read messages for their missing classmates before a balloon release.

"Dear sister, I know the angels are watching over you."

"Dear sister, I feel you walk beside me."

"Dear sister, I can't wait to see you again."

Three families of missing girls who live in Abuja say they have no number to call for updates, have no warning before news comes out, and have had no contact with the government since a tense meeting with President Muhammadu Buhari in 2016. The government now rarely comments. Last April, the fifth anniversary of the abduction, Buhari released a message assuring Nigerians that "diverse efforts are being intensified to secure the release of the Chibok girls."

On a small hill behind a neighborhood of embassies and mansions in Abuja, Rebecca Samuel lives in a crammed cinder block home. Her daughter Sarah is among the students still missing. Three pictures she keeps in her purse show Sarah as a five-year-old graduating kindergarten, a sassy 14-year-old, and a serious teen dressed in white. When 82 girls were released in 2017, Samuel rushed to the hospital where they were held. Security wouldn't let her in.

AS SUMMER 2019 APPROACHED, AUN got word that militants had burned down the houses of several Chibok students' families. The head of security, Lionel Rawlins, discouraged the young women from returning home, but 90 or so decided to go anyway. For some, it was only the second summer since their release, and they





Last May, students and faculty gathered to celebrate the anniversary of the students' release from Boko Haram. The event included poems, speeches, and a play

about a fictitious kidnapping. At the end, the girls let go of balloons, including 112 black balloons—one for each of their missing classmates.

were desperate to see their families.

AUN worries about more than security: Most of these women are in their 20s, and in this region it's unusual for them to still be in school. If they hadn't spent years in captivity, many would be starting families. The previous fall, eight students didn't return to school, and half of those were said to have gotten married.

On the Sunday before they left for home, a pastor joined them for a sermon. "Some of you have passed through terrible things, through the shadow of death," he preached.

"AMEN!" they replied.

"Some of you are about to travel. Some of you are afraid." His pitch climbed. "Do not be afraid! If you live in fear, you are attracting danger."

Grace Dodo, a statuesque student who walks with a cane, tilted her head and joined in: "Yes!"

"I want you to go and come back and finish your education," the pastor said.

While Esther Joshua packed for a trip to see her family, Patience Bulus spent the summer far from home, on the idyllic campus of Dickinson College in Carlisle, Pennsylvania. In 2018 former AUN president Margee Ensign opened a college-prep program at Dickinson, where she's now president. She enrolled four Chibok survivors.

Patience studied quietly, blending in among the international students. Then in April 2019 she spoke on a panel at the U.S. Capitol about the crisis in Nigeria. Soon, Dickinson students began to recognize her broad smile and colorful hair wraps on campus. They'd approach and ask to hear her story. She'll tell it now. Why not? She plans to study psychology and become a therapist or work with refugees. She's stopped going to therapy sessions herself and has started seeing a career counselor.

"I'll never forget," Patience said, "but I've started to pretend like I forgot. I have to move on with my life." □

Nina Strochlic is a National Geographic staff writer. **Bénédicte Kurzen** is a French photographer who focuses on West Africa and the Middle East.



CULTURE,

BY RENE EBERSOLE
PHOTOGRAPHS BY JASPER DOEST



Japanese macaques have a long history as entertainers and cultural symbols. But in today's Japan, their use in circus-like acts is drawing increased scrutiny.

OR ABUSE?



寄贈
高彰



PREVIOUS PHOTO

Trainers with the Sen-zu No Sarumawashi performance group in Kawasaki take their diapered charges on daily walks in the streets. In the earliest stage of *sarumawashi* (monkey performance) training, baby monkeys are taught to sit on tiny stools. Gradually they learn to walk on stilts and vault over hurdles.

THIS PHOTO

After patrons in Kayabuki Tavern, in Utsonomiya, have finished eating, the owners' pet monkeys climb onto a make-shift stage at the back of the restaurant and obediently model a collection of papier-mâché masks.

The monkeys wore soccer uniforms.

Six Japanese macaques standing erect on leashes obediently kicked the ball up and down the turf as their human trainers and a crowd of spectators cheered them on in a mock Japan-versus-Brazil match.

The monkeys in blue jerseys (Japan) looked sturdier, with fat tails sticking through the holes cut in their pants, but Brazil's yellow lineup was quick—especially when player 10 stopped licking its hands. Suddenly, 10 got the ball, kicked, and scored. Victory! Japan's team bowed. And the crowd exploded in laughter.

This was just one of the warm-up acts to the main event in the indoor amphitheater at Japan's Nikko Saru Gundan, a roadside attraction off Route 121 in Nikko City. Wandering around the courtyard, I saw a macaque in diapers and an orange leisure suit trounce a five-year-old visitor in a game of air hockey. Every time the puck came its way, the monkey smacked it back toward the challenger's goal. Another monkey doled out fortunes. On the main outdoor stage, a



At Joshin'etsukogen National Park, in a volcanic region on the island of Honshu, "snow monkeys" lounge in hot springs. Years ago, after people began feeding the monkeys to draw them away from their farms and houses, the animals became a popular tourist attraction. Park staff feed them today.



male macaque in a kimono struck macho poses and leaped over high hurdles.

Soon it was time to line up at the amphitheater, where a woman named Yuria Suzuki and her faithful primate, Riku, were headlining a parody of a popular Japanese police show and a circus act. When Sergeant Suzuki pretended to dispatch Captain Riku to a reported crime scene, he ducked behind the curtain and returned with a butcher knife—a rubber prop—in his head. In the circus finale, Riku, in blue polka-dot pants and a pink satin vest, vaulted across a chasm between staircases and executed a one-armed handstand on a tall, swaying pole.

The presentation at Nikko Saru Gundan has roots in traditional Japanese culture. The acts evolved from a form of entertainment known as *sarumawashi*, monkey performance, based on

the belief that the saru (monkey) is the protector of horses and the mediator between gods and humans, capable of dispelling evil spirits and clearing the path for good fortune. Like Kabuki, *sarumawashi* was performed in public theaters as long as a thousand years ago.

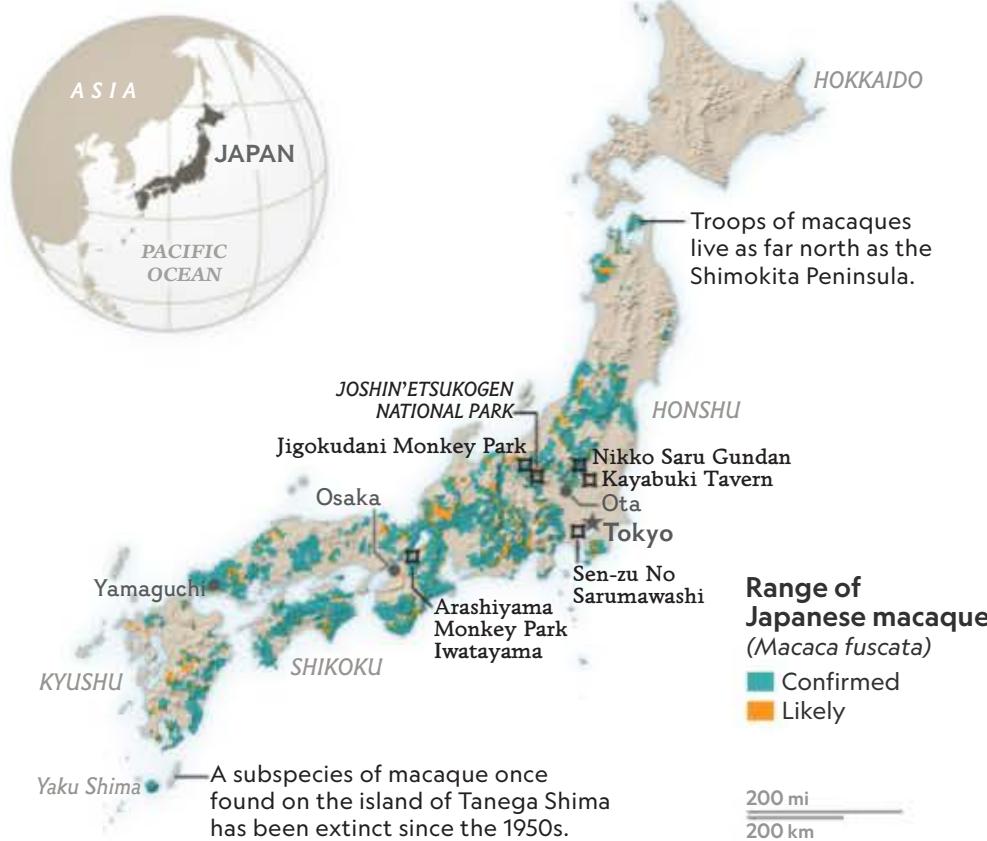
But in a modernizing Japan, the spiritual significance has faded.

Today's monkey performances resemble circus acts. Many animals are schooled using positive reinforcement and affection, but some are harshly disciplined and physically abused by their trainers, said Keiko Yamazaki, executive director of the Animal Literacy Research Institute and a board member of the Japanese Coalition for Animal Welfare. Yet diapered monkeys waddling across stages in Japan have not gotten the same attention as, say, bears that ride



Tourists watch the staff at Arashiyama Monkey Park Iwatayama, outside Kyoto, feed wild Japanese macaques. Such provisioning has helped boost monkey numbers. They're so abundant now that more than 19,000 are killed in the wild each year to prevent the animals from raiding farmers' crops.





motorbikes in high-wire acts in China. Captive monkeys are protected under Japan's animal welfare law, but the legislation emphasizes the treatment of common domestic pets.

"A lot of the welfare groups lobby for the kittens and the puppies—they want no-kill shelters. The cat ladies get a bigger following," Yamazaki said. "Our goal is to make Japan's animal welfare law applicable to all animals—farm animals, zoo animals, lab animals."

Japan has a long history of using animals for entertainment, but sensitivities toward a cultural tradition shouldn't prevent performing monkeys from being protected from abuse, she said. "It's like the circus. When you go back in history, you see animals have been trained using extremely abusive methods, and the monkey business is no exception. But culture evolves—it's not set in stone."

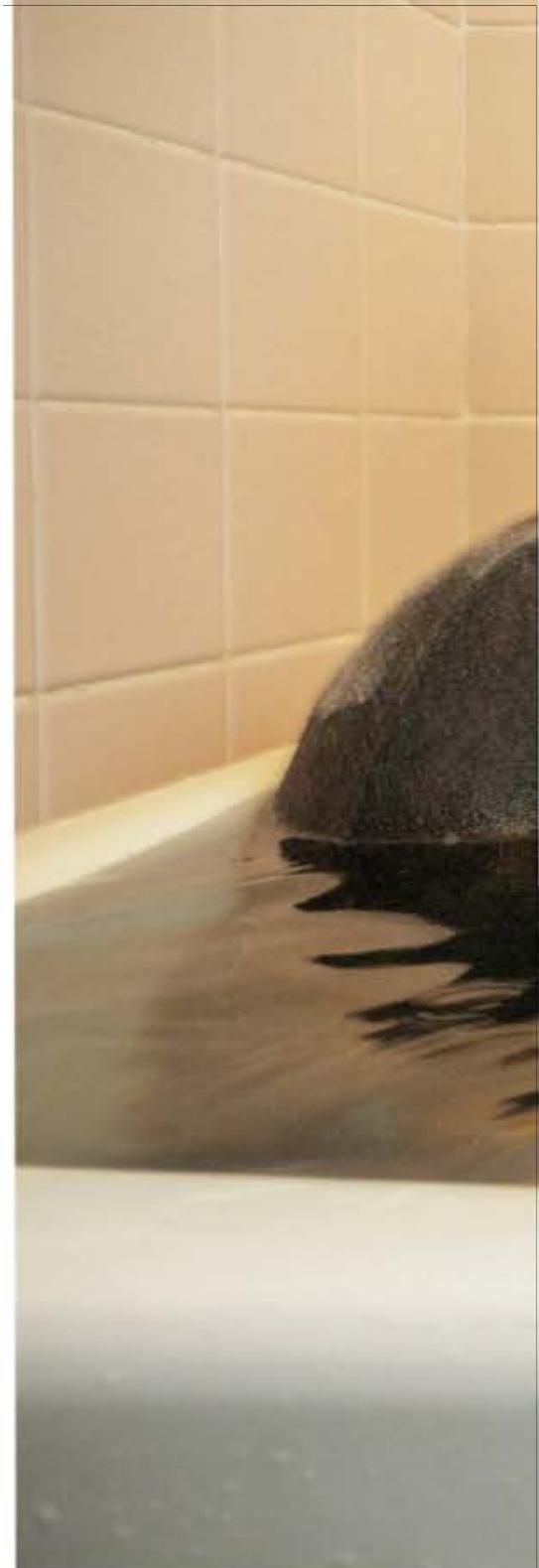
The 21st-century versions of sarumawashi range from monkeys turning backflips in frilly dresses at street festivals to Nikko Saru Gundan's primate pupils pretending to do math calculations and playing the piano in videos posted to YouTube. On a nine-day tour of sarumawashi culture, I saw a range of productions and visited a bar in Utsunomiya, nearly two hours north of Tokyo, where monkeys serve cold beers and warm hand towels and wear papier-mâché masks, including one that resembled U.S. president Donald Trump.

Chiemi Shiina, a sarumawashi monkey trainer, takes a bath with three baby macaques, the newest members of her Sen-zu No Sarumawashi entertainment group. Sen-zu trainers often sleep with the babies, building bonds with the animals as they grow into performers.

IN NATURE, Japanese macaques, also known as snow monkeys, are hardy creatures. No other nonhuman primate lives at such northern latitudes. At Jigokudani Monkey Park, roughly 2,800 feet above sea level and a three-and-a-half-hour drive northwest of Tokyo, all those familiar images in magazines and nature documentaries of frosted snow monkeys lounging in hot springs come to life before throngs of tourists snapping wildlife photos and selfies.

Despite their nickname, Japanese macaques are found throughout most of the country, including subtropical forests in the southern part of their range. They're true omnivores, eating everything from plants and fruits to insects, bark, and dirt. That varied diet has put them in some farmers' crosshairs.

Every year, *engai*, monkey damage, costs





millions of dollars in lost crops—mostly fruits and vegetables. Growers use fencing, scarecrows, and pyrotechnics to deter monkeys. In some municipalities, farmers can file complaints with agencies that manage programs to trap and kill nuisance animals. As a result, more than 19,000 monkeys are killed in Japan annually, according to the Ministry of the Environment. A byproduct of those eradication programs can be orphaned young monkeys, sometimes collected by concerned citizens and passed along to entertainment groups.

One afternoon near Yamaguchi, on a sloping hillside where a man was tending his koi pond, I took a short walk on a country path with Shuji Murasaki, 72. He stopped and motioned toward a large empty metal cage about the size of four school buses, in a field. It was a trap designed to

lure crop-raiding monkeys with food.

The village had captured about 10 monkeys the previous week, Murasaki said. He didn't know what happened to them—they probably were shot, though he wished they'd been sent to a zoo. Two tiny rescued monkeys found a home with his son, Kohei, who would train them to be performers, he said.

Murasaki, a human rights activist and former actor, was among a small group of people who revived traditional sarumawashi when it had virtually disappeared in the 1960s. Now he's retired and has passed his practice of staying true to sarumawashi's spiritual roots to Kohei. The performances they offer embrace the original Eastern ideas, Murasaki explained. "The animals are mediators between the audience and God—it's not just a monkey show, it's a ceremony."

野のとふ猿が
おぼくらが
かくへ

寄贈
高影





At Kayabuki Tavern, diners laugh while clapping for masked monkeys. When the performance is over, customers ask to have their photographs taken with the animals. The tavern owners say that sharing of photos on social media has been good for business. Some online reviewers, however, question the practice of making monkeys perform.





Kaoru Amagai lives in a traditional Japanese home in Ota, Gunma, with three pet macaques. He says he treats the monkeys as he would children, dressing them (he has a hundred pieces of clothing), bathing them, and feeding them daily yogurt snacks. He also says the chain in the foreground is to hold the monkeys' diapers in place.

In Japanese beliefs, every animal has a route to provide good fortune, he continued, and in the traditional sarumawashi act, each monkey trick has meaning. When the trainer spins the animal by the arms, the performance area is purified. When a monkey leaps through two hoops, it is spreading health and long life. Having monkeys walk on stilts extends wishes to children for wellness and happiness.

It's not easy training the animals to do such complicated stunts, Murasaki said. Even basic sarumawashi tricks can take more than a year to learn. The first step is teaching the monkey to sit on a small stool, he said. The trainer presents the stool and taps for the monkey to take a seat. If the monkey obliges, the trainer showers it with praise and affection. Next comes bipedal walking. "Very unnatural for monkeys," Murasaki emphasized, which is why it can take months of leading the monkey by its hands until the animal starts doing this on command.

Gradually, trainer and monkey work toward more elaborate moves and gymnastics. Tiny stilts are mastered, then replaced with taller ones. Murasaki and his son allow the monkeys to take the lead, he said, because the alternative—screaming or hitting—would discourage trust.

Training methods vary, however. On my visit to Nikko Saru Gundan, Tsuyoshi Oikawa, a trainer there for 20 years, told me that traditionally animal handlers used dominance to teach the monkeys that humans outranked them. To establish a pecking order, they'd yell and sometimes even bite the monkeys. He said he uses positive reinforcement through play combined with oral discipline. "We treat them like our kids. If they do good performances, we say well done. But if they don't, we scold them."

Around the world, attractions such as Nikko Saru Gundan face an increasing backlash from those morally opposed to keeping wild animals in captivity and exploiting them for entertainment. "The world is outraged by gimmicky animal acts, which is why so many animal circuses are closing their doors and countries are banning them," said Jason Baker, senior vice president of international campaigns with People for the Ethical Treatment of Animals. "Sadly, history has shown us that we can't rely on governments to protect animals, especially in countries like Japan, where animal welfare laws are weak. No one monitors living conditions, preproduction training sessions, maternal separation, or what

Traditional sarumawashi performances feature a trainer coaching a monkey through acrobatic stunts. The main stage at Nikko Saru Gundan specializes in glitzier, scripted productions with up to six monkeys, elaborate sets, and multiple costume changes. Globally, such attractions are increasingly controversial because of concern for the animals' welfare.



happens to animals when they're no longer used by the entertainment industry."

But Oikawa said that people critical of the attraction's animal ethics don't understand Japan's sarumawashi culture. "We love monkeys—we're on their side," he said. "We don't use abusive training methods."

SATOSHI HARADA was a trainer who used to work in monkey shows before becoming director and head animal coach of a monkey act company called Sen-zu No Sarumawashi, which stages shows at street festivals, schools, and parties. When I met him at the company's office in Kawasaki, he said he wanted to avoid stressful training methods by focusing more on positive reinforcement and affection, including even sleeping with the animals when they're very young.



We stepped into his troupe's practice room, where Harada introduced me to his colleagues and their furry collaborators dressed in diapers, including four new babies. He explained that the group keeps a rigorous training schedule—two hours in the morning and two hours in the afternoon, except on days when the monkeys are performing.

Earlier that morning, I'd marveled at the animals' acrobatics during a show for 300 toddlers who were sitting with their legs crisscross in a preschool gymnasium. The star of the show was Ponzo, wearing a bright yellow vest and a black jumpsuit. The children squealed with delight as the monkey nailed his tricks, striding across the auditorium on stilts that towered above Harada and even catapulting over a boy who had volunteered to sit in a chair. "Ankoru! Ankoru!" the

children yelled. "Encore! Encore!"

Now back at the Sen-zu office, the trainers stripped off the monkeys' diapers and shut them into red metal cages, where they live when not performing. Then the trainers set about their end-of-day routines: scrubbing foul-smelling feces off the metal drip trays beneath the cages and preparing bowls of oranges, apples, and bananas for the monkeys' dinner. They placed the bowls in a row on the floor and in unison presented the food to their performers. It was five o'clock, time to go home. They'd be back before breakfast to prepare for the next show. □

Rene Ebersole writes about animals and wildlife crime for *National Geographic*. **Jasper Doest** won the 2019 Wildlife Photographer of the Year Photo-journalist story award for this project.

These women have helped pave the way for new generations of National Geographic explorers.

(From left to right, top to bottom)

Asha de Vos

BIOLOGIST

Maria Mitchell

ASTRONOMER

Electa 'Exy' Johnson

SAILOR

Ella Al-Shamahi

PALEOANTHROPOLOGIST

Anne Morrow Lindbergh

AVIATOR

Marion Stirling Pugh

ARCHAEOLOGIST

Jocelyn Crane Griffin

CARCINOLOGIST

Gloria Hollister Anable

ICHTHYOLOGIST

Else Bostelmann

ARTIST

Dickey Chapelle

PHOTOGRAPHER

Evgenia Arbugaeva

PHOTOGRAPHER

Barbara Washburn

CARTOGRAPHER

Reina Torres de Araúz

ANTHROPOLOGIST

Marie Tharp

GEOLOGIST

Munazza Alam

ASTROPHYSICIST

Rae Wynn-Grant

ECOLOGIST

Jess Cramp

CONSERVATIONIST

Biruté Galdikas

PRIMATOLOGIST

Harriet Chalmers Adams

EXPLORER

Liliana Gutiérrez Mariscal

BIOLOGIST





TRAILBLAZERS ▶

BY NINA STROCHLIC | ARCHIVAL RESEARCH BY SARA MANCO

B

E SURE YOU'RE THE FIRST woman somewhere," an editor advised budding photographer Dickey Chapelle as World War II escalated. Chapelle took the advice and sneaked ashore with a Marine unit

during the Battle of Okinawa in 1945, flouting a ban on female journalists in combat zones. She temporarily lost her military press accreditation but went on to earn a reputation as a fearless war correspondent.

Since National Geographic's founding in 1888, women have churned out achievements in science and exploration, often with only fleeting recognition. They mapped the ocean floor, conquered the highest peaks, unearthed ancient civilizations, set deep-sea diving records, and flew around the world. They talked their way onto wars' front lines and traveled across continents.

"There is no reason why a woman cannot go wherever a man goes, and further," explorer Harriet Chalmers Adams said in 1920. "If a woman be fond of travel, if she has love of the strange, the mysterious, and the lost, there is nothing that will keep her at home."

Yet in the magazine women were often a side note, overshadowed by famous husbands. Matthew Stirling's byline was on more than a dozen articles detailing his discoveries in Mesoamerican archaeology, but his wife, Marion, who helped run the expeditions, had only one story published under her own byline: on keeping house in the field. "Damn, damn, damn!" a frustrated Anne Morrow Lindbergh wrote in her diary in 1933, about life with her famous aviator husband, Charles. She was the first American woman to earn a glider pilot's license, and she won awards for her navigation skills. "I am sick of being this 'handmaiden to the Lord.'"

Others were ignored by contemporaries. When geographer Marie Tharp offered proof of the theory of tectonic plate shift in the early 1950s, a colleague dismissed it as "girl talk." At least one, 1920s-era journalist Juliet Bredon, found it easier to publish in *National Geographic* under a man's name. Even world-renowned women of their time, such as 19th-century astronomer Maria Mitchell, struggled to get fair pay.

National Geographic's archive holds millions of photographs and documents from stories, research grants, and films since the Society's start. Stacks of microfiche filled with faded manuscripts and folders of typewritten correspondence reveal the stories of National Geographic's trailblazing women. From the past to the present, we salute some of them here.

Maria Mitchell

1818-1889

First person to discover a comet by telescope; first woman to work as a professional astronomer in the U.S.

In the 1800s, residents of Nantucket, Massachusetts, famously kept their telescopes trained on the sea, awaiting the return of local whaling and fishing boats. Maria Mitchell turned hers to the stars. Mitchell grew up helping her father, an amateur astronomer, make complex navigational calculations for whaling captains, determine eclipse times, and record movements of astral features.

At 10:30 p.m. on October 1, 1847, the 29-year-old was on the roof of the Pacific Bank, where her father had built a simple observatory. Wielding her telescope, she spotted something that wasn't on her astronomical charts: a comet.

Sixteen years earlier, King Frederick VI of Denmark had offered a gold medal to the first person to discover a comet by telescope. Mitchell claimed the prize. Her discovery and ensuing career made her the first professional female astronomer in the U.S. Within the year, she was elected to the American Academy of Arts and Sciences—the first woman invited to join. She visited observatories around the world and became an outspoken advocate for women in science, as well as an abolitionist and a suffragist.

Mitchell taught astronomy at the newly opened Vassar College, where she studied planets, stars, comets, and eclipses—and fought to be paid the same as her male colleagues. Comet 1847-VI, which she'd discovered, became known as Miss Mitchell's comet. A crater on the moon was named for her, as was a World War II cargo ship, the S.S. *Maria Mitchell*. In 1888, a year before Mitchell died, her brother, oceanographer Henry Mitchell, helped found the National Geographic Society.

PREVIOUS PHOTOS: BETTMANN/GETTY IMAGES (MITCHELL, LINDBERGH, ANABLE); THOMAS J. ABERCROMBIE (JOHNSON); RICHARD H. STEWART (PUGH); MILO WOODBRIDGE WILLIAMS (GRIFFIN); AMADO ARAÚZ, COURTESY THE ARAÚZ COLLECTION (TORRES DE ARAÚZ); JOHN TEE-VAN (BOSTELMANN); JOSEPH H. BAILEY (THARP)



The discovery of a comet propelled astronomer Maria Mitchell (seen at left, about 1880) to celebrity status in the mid-1800s. She was an advocate for suffrage and gender equality in science.

SCIENCE HISTORY IMAGES/ALAMY STOCK PHOTO





HARRIET CHALMERS ADAMS

1875-1937

First female journalist allowed to visit the French trenches during WWI; inaugural president of the Society of Woman Geographers

'I'VE NEVER FOUND MY SEX
A HINDERMENT; NEVER FACED A
DIFFICULTY WHICH A WOMAN, AS
WELL AS A MAN, COULD NOT
SURMOUNT; NEVER FELT A FEAR
OF DANGER; NEVER LACKED
COURAGE TO PROTECT MYSELF.
I'VE BEEN IN TIGHT PLACES, HAVE
SEEN HARROWING THINGS.'

A close-up of the French front line shows the rare access that photographer and writer Harriet Chalmers Adams had during World War I. Adams, who spent decades exploring the world, was the most prolific female contributor to *National Geographic* during its first 50 years.

ALAMY STOCK PHOTO (TOP);
HARRIET CHALMERS ADAMS

In the 1880s, long before she became her era's greatest female explorer, eight-year-old Harriet Chalmers traveled through the Sierra Nevada on horseback with her father. When she was 24, Chalmers married Franklin Pierce Adams, and they set off for Latin America, where they covered 40,000 miles by horse, canoe, foot, and train. When they returned nearly three years later, she gave a lecture at National Geographic and launched a 30-year career as a contributor.

Adams made it her mission to visit every country that was or had been a Spanish colony, and retraced the trail of Christopher Columbus from Europe to the Americas. She traversed Asia and attended Haile Selassie's coronation as emperor of Ethiopia. During World War I, she was the first female journalist allowed to photograph the French trenches, where she stayed for months.

She wrote 21 articles detailing her exploits for *National Geographic*, more than any other woman published in the magazine's first half century. In those pieces, she criticized the injustices that she'd observed. "What blessing has European civilization brought to them, which they did not already enjoy?" she wrote after a visit to Peru. "What have they not suffered in the name of the cross which surmounts the hill?"

Adams had no professional training as a geographer and had never been to college, but her color photo slides and adventurous travel style garnered her invitations to speak around the world, often from organizations that had never invited a woman in before. She was the third American woman asked to join the Royal Geographical Society in England. However, the New York-based Explorers Club gave her and other prominent female adventurers the cold shoulder.

Men "have always been so afraid that some mere woman might penetrate their sanctums of discussion that they don't even permit women in their clubhouses," Adams once said, "much less allow them to attend any meetings for discussions that might be mutually helpful."

Several female explorers decided to form their own club. In 1925 the Society of Woman Geographers launched with Adams as president. She served until moving to France in 1933, where she died four years later at 61.

REINA TORRES DE ARAÚZ

1932-1982

First female Latin American grantee of the National Geographic Society; helped preserve Panama's history

In 1961 an American-owned company demolished a colonial building called La Pólvora in a coastal city in Panama to make room for a highway. Reina Torres de Araúz, a 29-year-old anthropologist, was outraged and complained to Panama's president, Roberto Chiari. He listened: Panama created the National Commission of Archaeology and Historical Monuments and put Torres de Araúz in charge of ensuring that important sites were preserved.

Torres de Araúz was already a well-known anthropologist and cultural heritage defender by then. She'd been tapped to take part in the expedition to identify the best route through Panama for the construction of the Pan-American Highway, which eventually would stretch, unofficially in parts, from Alaska to Chile.

She spent her honeymoon scouting the road's path on the Trans-Darien Expedition, which was documented by *National Geographic*. The team left Panama in a Jeep and a Land Rover

and ended up in Colombia four months later, having completed the first motorized crossing from North to South America.

Her influence on Panama is deeply ingrained. She founded the archaeological research center at the University of Panama, set up scholarships to encourage students to embark on field research, and created departments for Panamanian prehistory, ethnography, and cultural anthropology. After serving as the director of the National Museum of Panama, she helped open six museums and an archaeology park.

In 1971 Torres de Araúz became National Geographic's first female Latin American grantee, which gave her the funding to catalog pre-Columbian gold artifacts. She successfully pushed for a law that halted the flow of such artifacts abroad.

Torres de Araúz died at 49, in 1982, but her legacy lives on in Panama City, where a sprawling museum named in her honor holds 15,000 priceless relics of Panama's past.



In 1960 Panamanian anthropologist Reina Torres de Araúz (below) was part of the first team to drive between North and South America via the Darién Gap, which connects Panama and Colombia.

AMADO ARAÚZ, COURTESY THE ARAÚZ COLLECTION

A lifetime of sailing around the world added up to a trip to the moon and back for Electa Johnson (right), on the Nile River in the early 1960s.

WINFIELD PARKS



Electa 'Exy' Johnson

1909-2004

Circled the globe seven times with her husband, Irving

"I don't suppose many mothers have a chance like this!" Exy said. She was cooking sperm whale harpooned by our 18-year-old son, Arthur. We were cruising among the Galápagos Islands for the sixth time in twenty years of voyaging around the world in the brigantine Yankee.

This moment, included in a draft of a story Irving and Electa, or Exy, Johnson co-authored for *National Geographic* in 1959, was just an average day on the water for the seafaring family. By the time they furled their sails permanently, the couple had made seven circumnavigations of the world in two ships named *Yankee*.

For their circumnavigations, they had a routine: They'd sail the world for 18 months and then spend 18 months in the U.S. Other trips brought them to the Baltics, down the Nile, and through Europe's canals, where Exy used some of the several

languages she spoke. They even participated in the search for missing aviator Amelia Earhart in the South Pacific. The couple wrote nine stories and numerous books together, and made three films for *National Geographic* during more than 40 years at sea.

Irving passed away in 1991, and when Exy died in 2004 at age 95, she had sailed the distance between the Earth and the moon and back. Their legacy continues in Los Angeles, where kids learn about teamwork and problem-solving aboard two brigantines: the *Irving Johnson* and the *Exy Johnson*.

JOCELYN CRANE GRIFFIN

1909-1998

Assisted on bathysphere expedition; researched fiddler crabs

ELSE BOSTELMANN

1882-1961

Painted marine life discovered in the deep sea

GLORIA HOLLISTER ANABLE

1900-1988

Set world record for deepest dive by a woman

In 1930 underwater explorers William Beebe and Otis Barton were lowered into the Atlantic Ocean near Bermuda in a tiny steel orb. Above the water, a group of female scientists ensured that this bold new contraption—called the bathysphere—operated without a hitch. It was the first serious foray into crewed deep-sea exploration, and soon it would be international news.

From the boat deck, laboratory assistant Jocelyn Crane Griffin helped identify the marine life. At the phone was Gloria Hollister Anable, the chief technical associate for the Department of Tropical Research at what is now the Wildlife Conservation Society, which supported the mission. This phone connection, via a cable that ran from the vessel to the ship, was Beebe's only lifeline to the outside world, and it was never supposed to go silent. Anable transcribed Beebe's observations as he watched the deep-sea life swim by and relayed information to him on depth, time, and weather. They bantered throughout. She and Griffin took turns in the bathysphere as well. Descending 1,208 feet on one of those dives, Anable set a record for the greatest depth reached by a woman.

After each dive, Beebe's sketches and transcribed descriptions would be delivered to Else Bostelmann back at the lab in Bermuda, where she transformed them into dramatic paintings. Though she didn't watch from inside the bathysphere, she often would put on a diving helmet, tie her brushes to a palette of oil paints, and drag her canvas underwater to paint and find inspiration. Her drawings of fantastical marine life—fish with



From thousands of feet under the sea, William Beebe described what he saw via telephone to Gloria Hollister Anable (seen above at right, in bathysphere headquarters in Bermuda). On the ship, Jocelyn Crane Griffin (at center) helped identify the marine life. Later, Else Bostelmann (closest to the door) made fantastical drawings (left) of the creatures.

JOHN TEE-VAN (ABOVE); ELSE BOSTELMANN (LEFT, BOTH)



giant fangs, psychedelic crustaceans, a never-before-seen black-skinned fish—made the expedition come alive in *National Geographic*.

Beebe was mocked for hiring women, but he stuck by his team. After the mission ended, Bostelmann continued to illustrate for *National Geographic*, and Anable led a scientific expedition to what is now Guyana. Griffin went on to manage field stations in the Caribbean and took Beebe's job

as director of the Department of Tropical Research after his death in 1962.

In an interview in 1991, underwater explorer Sylvia Earle was asked what inspired her to get into oceanography. She cited Beebe's tales. "The aquariums of the world, as wonderful and diverse as they are... do not have the sort of creatures that Beebe described from his exploration back in the 1930s," she said. "And that certainly I found utterly inspiring."



In the 1930s the boldest attempt at crewed deep-sea exploration was conducted in the steel contraption called the bathysphere. This series of record-breaking expeditions to study marine life was staffed by Jocelyn Crane Griffin, Else Bostelmann, and Gloria Hollister Anable (shown here).

JOHN TEE-VAN







BARBARA WASHBURN

1914-2014

First woman to summit Denali; with husband Bradford Washburn, mapped the Grand Canyon

'I HAD NO REAL FEELING
ABOUT BEING A PIONEERING
WOMAN ON A SERIOUS
ALASKAN EXPEDITION.
I ONLY KNEW THAT AS
THE ONLY WOMAN, I HAD
TO MEASURE UP.'

Barbara Washburn's second ever hike was up the 13,628-foot Mount Hayes, in 1941. Six years later she gazed over the Denali Pass (left), near North America's highest peak.

BRADFORD WASHBURN (BOTH)

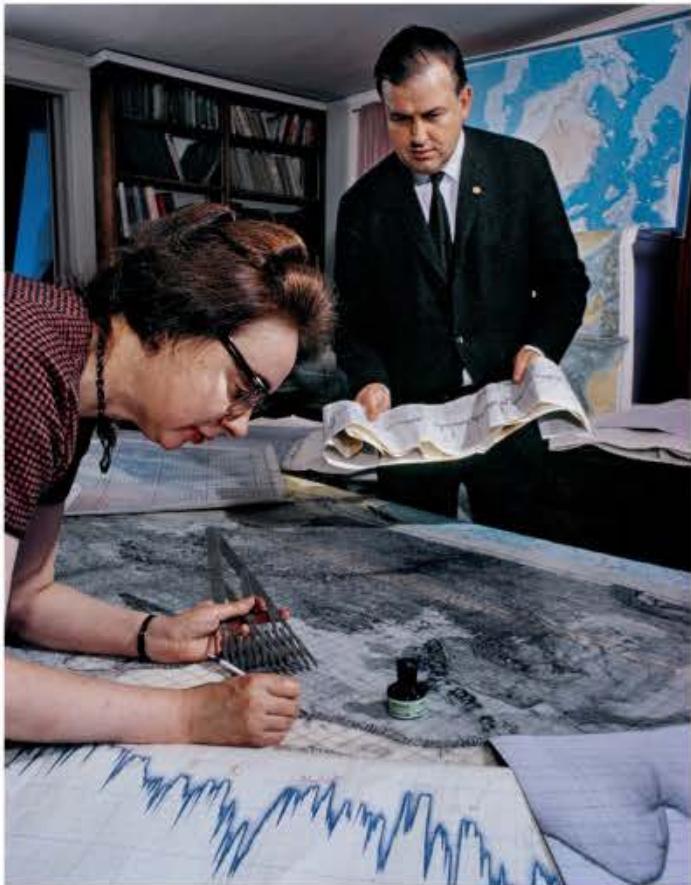
Barbara Washburn's life atop the world's highest peaks began with a job tip from her mail carrier in 1939. The position he recommended—as a secretary for Bradford Washburn, the director of the New England Museum of Natural History—did not appeal to her. "I don't want to work in that stuffy old museum," she recalled thinking, "and I certainly wouldn't want to work for a crazy mountain climber."

A year later, the young woman who'd never been camping was standing atop 10,151-foot Mount Bertha in Alaska. She had married that mountain climber.

One year after that, the couple, along with their team, became the first to successfully summit 13,628-foot Mount Hayes. She wore men's cold-weather gear because none was made for women then. Along a particularly treacherous ridge, Barbara took the lead because the team felt she'd be light enough to haul up if the ground crumbled beneath her. In 1947, Barbara and Bradford left their three children at home to climb Mount McKinley (now called Denali). After nearly two months of trekking, Barbara stood on the summit as the first woman to look out from North America's highest point.

Bradford was a trained cartographer, and the pair took on ambitious mapping projects. Starting in 1970, they used aerial photography, laser measurement tools, and a wheel-mounted odometer to fully map the Grand Canyon for National Geographic. The project took seven years and nearly 700 helicopter trips. They also mapped the White Mountains in New Hampshire and Mount Denali. In 1988, the couple were among 15 explorers—including Edmund Hillary, Jacques-Yves Cousteau, and Mary and Richard Leakey—to receive the National Geographic Centennial Award. Into their later years, the Washburns still applied for grants from National Geographic for projects such as a snow-depth survey on Mount Everest.

Barbara died in 2014, seven years after her husband and just two months shy of her 100th birthday. She said she never understood the fuss about her gender, describing herself instead as "an accidental mountaineer."



Painstakingly charted sonar data of the ocean floor helped geologists Marie Tharp and Bruce Heezen prove the then fringe theory of plate tectonics.

JOE COVELLO

Marie Tharp

1920-2006

Mapped the ocean floor and advanced the theory of continental drift

World War II gave Marie Tharp the chance to make an earthshaking discovery. Male students were off fighting, and universities had desks to fill. Tharp, who already had degrees in English and music, seized the opportunity to study geology, a field that had been hostile to women. After a stint as a field geologist for an oil company, she was hired as a technical assistant at Columbia University's Lamont Geological Observatory, where she met a graduate student named Bruce Heezen. Together Tharp and Heezen embarked on a bold project: to map the ocean floor.

Women were barred from working aboard

scientific research ships then, so Heezen used sonar measurements he collected on ocean expeditions, including some funded by National Geographic. In a basement office at Columbia, Tharp transformed the data and measurements from hundreds of other expeditions into maps.

As Tharp worked on the first map of the Atlantic Ocean, she noticed a valley running across the ocean floor and concluded that pieces of the Earth's crust were shifting. Her theory of continental drift was "almost a form of scientific heresy," Tharp would say later.

At first Heezen didn't accept her theory, mocking her evidence as "girl talk." But her conclusion was bolstered by sonar readings. This crack in the Earth convinced the scientific community that the continents had been one landmass, later separated by tectonic movement.

Backed by the U.S. Navy and National

Geographic, the project spread from Columbia to Tharp's home in South Nyack, New York. It was published in 1977 as the "World Ocean Floor" map, the first global depiction of the bottom of the oceans. It revealed a landscape covered in volcanic ranges and Everest-high peaks, split by a 40,390-mile seam running along the Earth's surface.

"It was a once-in-a-lifetime—a once-in-the-history-of-the-world—opportunity for anyone, but especially for a woman in the 1940s," she wrote.

The year after the map was published, Tharp and Heezen won the Hubbard Medal, National Geographic's highest honor, which recognizes lifetime achievement in research, discovery, and exploration. Tharp opened a map-distribution business after she retired from Columbia. By then, she finally had made it aboard a research vessel. She died in 2006.





BIRUTÉ GALDIKAS

Born 1946

One of the female scientists dubbed Trimates mentored by anthropologist Louis Leakey; has researched orangutans since the 1970s

Believing women to possess more patience and perception than men, paleoanthropologist Louis Leakey supported three young female scientists to live among the great apes. With funding from National Geographic, he helped set up field stations for Jane Goodall to study chimpanzees in Tanzania, Dian Fossey to live with mountain gorillas in Rwanda, and Biruté Galdikas to observe orangutans in Indonesian Borneo. The three women, who became known as the Trimates, went on to complete groundbreaking research.

When Galdikas first entered Tanjung Puting National Reserve in 1971, orangutans were thought to be difficult—if not impossible—to study. More solitary than other primates, they roamed over large areas of dense tree canopy. But before long, Galdikas could spot them in the wild and even get close enough to interact with them. She transformed her home into a “half-way house” for animals transitioning out of captivity and raised the orphans almost as her own children, according to a 1975 cover story that she wrote for *National Geographic*.

During the first four years of research and nearly 7,000 hours of observation, Galdikas made major discoveries about orangutans in the wild—gathering details about their diets, travel patterns, and relationships. Crucially, she raised an alarm over the deforestation that was fueling the rapid loss of their habitats.

Nearly 50 years later Galdikas is still in the field, making her work one of the longest continuous studies of a single species ever conducted.

Biruté Galdikas's almost 50-year study of wild orangutans in Indonesia revealed their social lives and habits.

RODNEY BRINDAMOUR

Marion Stirling Pugh

1911-2001

Helped conduct expeditions that reshaped understanding of Mesoamerican history

In a photograph taken during an expedition to Panama in 1948, Marion Stirling gazes at a recently discovered necklace made of some 800 human teeth. Her life had certainly changed since 1931, when she took a job in Washington, D.C., as secretary for Matthew Stirling, director of the Smithsonian's Bureau of American Ethnology.

Marion and Matthew were married a few

years later, and Marion began taking night classes in anthropology and geology. In 1938, while on a family trip to Mexico, Matthew, who would come to be known in the industry as "the golden shovel," went to see a giant stone sculpture that explorers had found decades earlier. It was a colossal Olmec head.

Matthew obtained funding from the Smithsonian Institution and National Geographic to excavate the area. On more than a dozen expeditions to southern Mexico (Marion missed one to give birth to their daughter), the pair essentially rewrote Mesoamerican history. They unearthed stone heads and other remnants of the ancient Olmec Empire, determining it was likely the region's first great civilization.

Marion supervised the scorpion-infested camp, and she cleaned and cataloged their findings. She co-authored many papers with Matthew and, in 1939, calculated that a calendar carved into an Olmec monument referred to the year 31 B.C., making it the oldest date recorded in the New World at the time.

The Stirlings later discovered pre-Columbian jade in Mexico, granite spheres in Costa Rica, and mounds built at Panamanian village sites.

Marion, who married again after Matthew's death, served twice as the president of the Society of Woman Geographers. In 1975 she was awarded its gold medal for pioneering contributions to archaeology in Mexico and Central America.



Marion Stirling (left) and her husband, Matthew, excavated pieces that rewrote Mesoamerican history during their expeditions to Mexico in the 1930s and '40s. Here she applies a coat of varnish to protect an ancient skull from crumbling.

RICHARD H. STEWART

On their way to break the record for transcontinental flight, Anne Morrow Lindbergh and her husband, Charles (above), pose at a California airfield in 1930. The newlyweds took off and landed in New York 14 hours, 23 minutes, 32 seconds later.

BETTMANN/GETTY IMAGES



ANNE MORROW LINDBERGH

1906-2001

First woman in the U.S. to earn a glider pilot license; first woman to receive a National Geographic Hubbard Medal

Anne Morrow's first date with Charles Lindbergh was in an airplane over Long Island in 1928. Her suitor had just made the first nonstop transatlantic flight and was arguably the most famous man in the world. Three months after their wedding, Anne made her first solo flight. In 1930 she was the first woman in the U.S. to earn a first-class glider pilot's license.

That year Charles and Anne flew from Los Angeles to New York in 14 hours and 23 minutes, breaking the transcontinental speed record. Anne was co-pilot, radio operator, navigator—and seven months pregnant. Then they flew to Japan, where Anne set a record for long-distance radio communication. She gained recognition as an aviator and author, and in 1934 she was the first woman awarded National Geographic's Hubbard Medal, for flights totaling 40,000 miles.

By then, the couple's lives had darkened. In 1932 their infant son had been kidnapped and murdered.

Then Charles became enamored of Germany's technological advances. He accepted a medal from the Nazi regime and became a vocal opponent of the U.S. entering World War II. Anne wrote a book in support of isolationism and called fascism the "wave of the future."

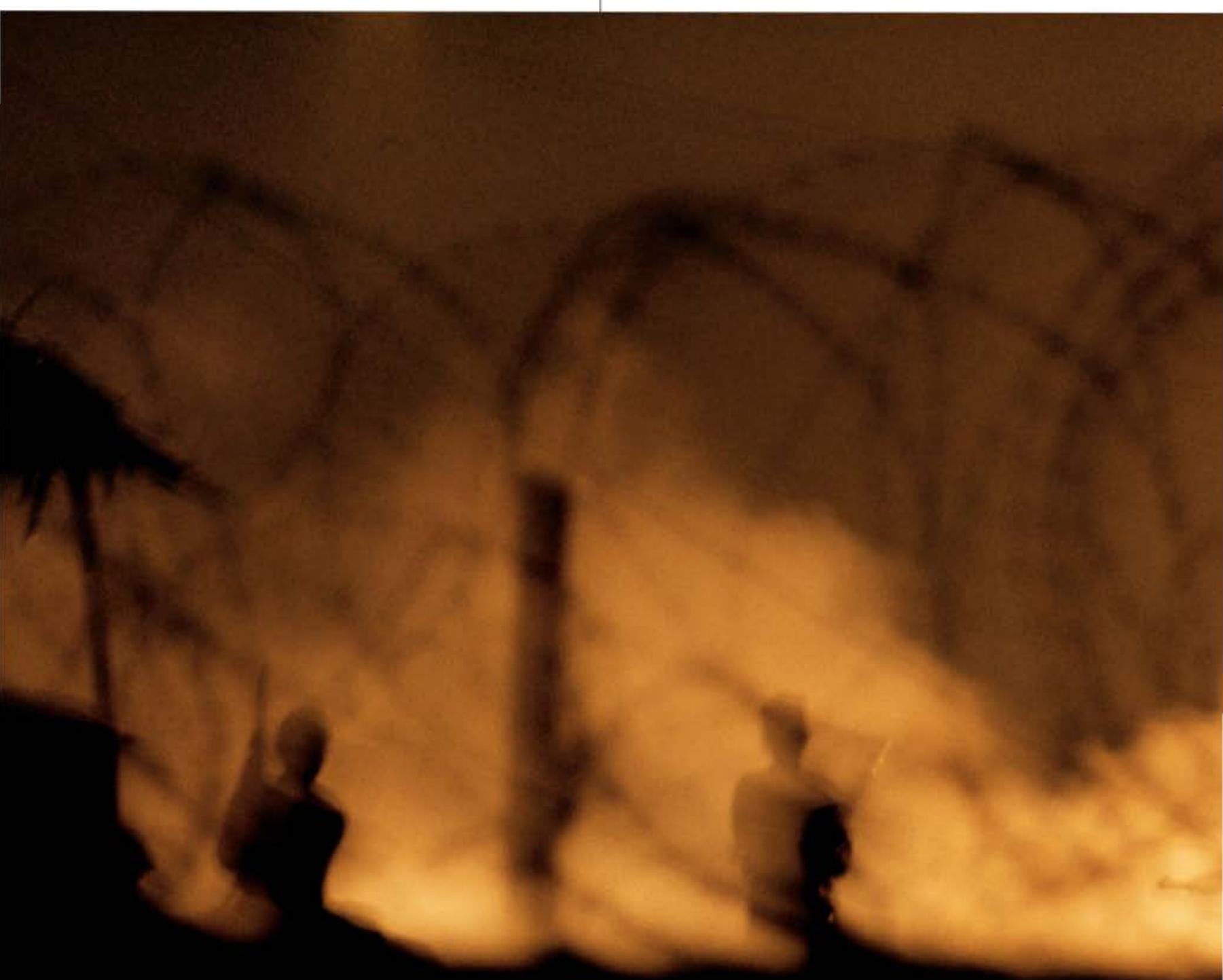
The once adoring public—and Anne's own mother—turned against the couple. In later interviews and published diaries, Anne regretted their stance, which she described as being mostly her husband's. "My marriage has stretched me out of my world, changed me so it is no longer possible to change back," she wrote. She found redemption through writing. In 1955 she released *Gift From the Sea*, a reflection on women's lives that was lauded as a feminist manifesto and topped best-seller lists.

In 1979, five years after Charles's death, Anne was inducted into the National Aviation Hall of Fame. She lived another 22 years, editing and writing in seclusion in Connecticut.

DICKEY CHAPELLE

1919-1965

**Fearless National Geographic
photojournalist who covered
WWII through the Vietnam
War; first female American war
correspondent killed in combat**





No amount of firepower could keep Dickey Chapelle away from war. In her photo (below) from the Vietnam War, an inferno flushes Vietcong soldiers from a hut in the Mekong Delta. Chapelle covered dozens of conflicts. She died from wounds suffered when she was with marines on patrol in Vietnam.

GEORGE F. MOBLEY (TOP);
DICKEY CHAPELLE



In 1959 Dickey Chapelle prepared to leap off a tower. The pioneering war correspondent was accompanying the U.S. Army's 101st Airborne Division in Kentucky and, at 41 years old, was parachuting for the first time. She was terrified. But fear never lasted long for Chapelle. She proclaimed parachuting as among "the greatest experiences one can have."

By then, Chapelle had reported on dozens of conflicts, including World War II. She'd been held in solitary confinement during the Hungarian uprising and was the first journalist accredited by the Algerian rebels. Fidel Castro called her "the polite little American with all that tiger blood in her veins." After training with the Screaming Eagles, she became the only woman at the time authorized to jump with combat paratroopers in Vietnam.

Born Georgette Meyer, Chapelle took the nickname Dickey from her hero, Arctic explorer Adm. Richard Byrd. She dreamed of being a pilot or aerospace engineer. At 14, she sold her first article to *U.S. Air Services* magazine; at 16, she enrolled at MIT. She married Tony Chapelle in 1940.

The couple began writing and photographing stories for *National Geographic* in the 1950s, but after they separated, Dickey took on both roles. Pinning Vietnamese paratrooper and U.S. Army parachutist badges to her bush hat, she ventured where other

reporters didn't dare go. If her presence was a novelty, it didn't grant her special treatment. "Not once has a general ever offered to trade me a SECRET operations order for my fair white virtue," she wrote to her publisher. She named her autobiography *What's a Woman Doing Here?* after a refrain she often heard on the battlefield.

"There's no question" that war is no place for a woman, Chapelle once told an interviewer. "There's only one other species on Earth for whom a war zone is no place, and that's men."

In 1962 Chapelle became the second woman to receive the George Polk Memorial Award, the highest citation for bravery from the Overseas Press Club of America. She'd seen more fighting in Vietnam than any other American—17 operations in all. But her conflict tally would end there.

On November 4, 1965, Chapelle was on a Marine mission near the coastal city of Chu Lai. About 8 a.m. the patrol unit walked into trip wire, which triggered a grenade that was wired to a mortar. Chapelle was hit in the neck by shrapnel. She died on the floor of a helicopter—the first female American correspondent to die in combat. Years later, other journalists reported that Vietnamese Airborne troops still reminisced about the small, foul-mouthed woman who'd once jumped with them.

For the first century of *National Geographic*, the few female explorers, photographers, and scientists in its pages were almost always white and American or European. Today's community of explorers and contributors is as diverse as the places, people, and species they study. But even in 2020, many of them—Asha de Vos, for example, the only Sri Lankan marine mammal biologist with a Ph.D.—are a rarity in their chosen profession. Here are some of the explorers representing *National Geographic* and clearing the path for another generation of adventurous women.



Jess Cramp

Born 1979

Marine biologist who helped create one of the world's largest shark sanctuaries

In the Cook Islands, where she lives, Jess Cramp is often the only woman aboard when she does research from commercial fishing boats. As a marine biologist focused on sharks, earning the respect of the crew is crucial to her scientific success. Long before Cramp made it onto a boat, she struggled to find female mentors in the competitive field. She helped create one of the world's largest shark sanctuaries, in the South Pacific, but says she still hears the words "You don't look like a scientist" far too often. "We can't answer the world's toughest questions with the status quo," Cramp says.



RAE WYNN-GRANT

Born 1985

Ecologist studying conflict between people and large carnivores



Asha de Vos

Born 1978

Pioneer of whale research in the North Indian Ocean

Before becoming the first Sri Lankan Ph.D. marine mammal biologist, Asha de Vos imagined "seeing things no one else would ever see and going where no one else would ever go." Years later that dream put her on a ship in the North Indian

Ocean, where she began to study blue whales. "As women, we have to work harder than men," she says. "Work so hard that people stop seeing you for your gender or background, but instead they see you for your capacity to do what you do."

"Often I show up to places, and people don't believe me when I say I'm Dr. Wynn-Grant," says Rae Wynn-Grant, who is the only African-American large-carnivore ecologist with a Ph.D. in the United States.

Nature programs on TV were her gateway into conservation, even though the hosts were "very different from me—often older, white, British or Australian men who seemed to have grown up in the outdoors." Wynn-Grant didn't go on her first hike until age 20, but since then she has honed her outdoor survival skills in fieldwork around the world. She studies human-carnivore conflict with grizzly bears in Yellowstone National Park, lions in Kenya and Tanzania, and black bears in the American Great Basin. She does it, she says, to build a world that's "thriving, healthy, and balanced."



Ella Al-Shamahi

Born 1983

Anthropologist researching Neanderthals in unstable and disputed territories

Ella Al-Shamahi digs for Neanderthal fossils in Iraq, Yemen, and other countries. The paleoanthropologist-stand-up comic can laugh off reactions from those surprised by a female scientist working in conflict zones, but she worries that a gender imbalance in her field dissuades young girls from entering it. So she has been on a mission to highlight accomplished women both on social media and in academia. "I'm aware I'm a minority. I'm aware that I need to represent," she says. "At times that feels like a burden but one I feel honored to be burdened with."



Evgenia Arbugaeva

Born 1985

Photographer exploring life in the Russian Arctic

To fully understand her isolated subjects, Arbugaeva spends months or years absorbed in life on the tundra. Her projects include a look at her Arctic hometown.

"In the field I ask myself: Have I given the maximum of myself to it?" she says. "I try to reach a point of a clean conscience about this."

One roll of film in a high school class hooked Evgenia Arbugaeva, now an acclaimed documentarian of the Russian Arctic. "In photography I instantly saw an endless potential in capturing and telling stories, the beauty of total immersion in the moment and at the same time creative control of it," she says.



Liliana Gutiérrez Mariscal

Born 1976

Biologist empowering women in coastal Mexico

If one of us makes it, we all will. This is a common saying among women in El Manglito, a Mexican fishing village where biologist Liliana Gutiérrez works. "Inside their communities," says Gutiérrez, women "see the whole picture." She helped found an organization

that invests in fishery restoration in Mexico and now works with female leaders to protect the ocean and uplift their coastal towns. "They truly and deeply understand the connection between children, education, and the health of oceans."



MUNAZZA ALAM

Born 1994

Astrophysicist seeking Earthlike planets

Munazza Alam is searching for the Earth's twin. This planet, which would be cool enough to have liquid water, is theoretical, but Alam, a graduate student at the Harvard-Smithsonian Center for Astrophysics, pores over telescopic data in hopes of finding it.

Growing up in New York City, Alam didn't pay much attention to space. Then, as a teenager, she saw the Milky Way for the first time on a trip to the Kitt Peak National Observatory in Arizona. Now the atmospheres of exoplanets are the subject of her academic fascination.

Entering the field wasn't easy. "I am usually the only person who looks like me in a room full of astronomers," she says. "Since I am sometimes my own worst critic, I have had to work extra hard to show myself that I am capable and that I belong in astronomy."



INSTAGRAM

MICHAELA SKOVRANOVA

IMAGES FROM OUR PHOTOGRAPHERS

WHO

A photojournalist based in Australia, Skovranova specializes in stories of humans and the environment.

WHERE

Cabbage Tree Bay Aquatic Reserve near Sydney, Australia

WHAT

Taken with an Olympus E-M5 Mark II and 9-18mm lens in an underwater housing

There can be magic in photographing women. Skovranova, who contributes to the @natgeo Instagram account, says she is enchanted by the combination of strength, playfulness, and camaraderie she sees in women; it's a chemistry that often yields warm and inspiring photos. An environmental photographer specializing in underwater scenes who likes to free dive—that is, hold her breath rather than use a breathing apparatus—Skovranova was swimming one day off Sydney's Shelly Beach. She watched a group of young women dive gleefully under the waves, laughing and cavorting together. "I feel like this gentle encouragement and playfulness is a beautiful part of womanhood," she says.

This page showcases images from National Geographic's Instagram accounts. We're the most popular brand on Instagram, with more than 127 million followers; join them at instagram.com/natgeo.

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Blanding's Turtle (*Emydoidea blandingii*)

Size: Carapace length, 15 - 28 cm **Weight:** 750 - 1,400 g **Habitat:** Swamps, marshes, ponds and slow-moving streams **Surviving number:** Unknown



Photographed by Alan Bartels

WILDLIFE AS CANON SEES IT

Built to last. Living to the venerable age of 77 or more in the wild, Blanding's turtle is armored from life's blows by a sturdy carapace. When the weather is warm, it lies on a log to soak up the sun; when the mercury drops, it can endure up to three months submerged under ice. But future generations have the odds stacked against them since nearly 80% of

nests are depredated, mainly by raccoons. Habitat is being lost and degraded as human settlements – and with them, more ravening raccoons – draw nearer.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.



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