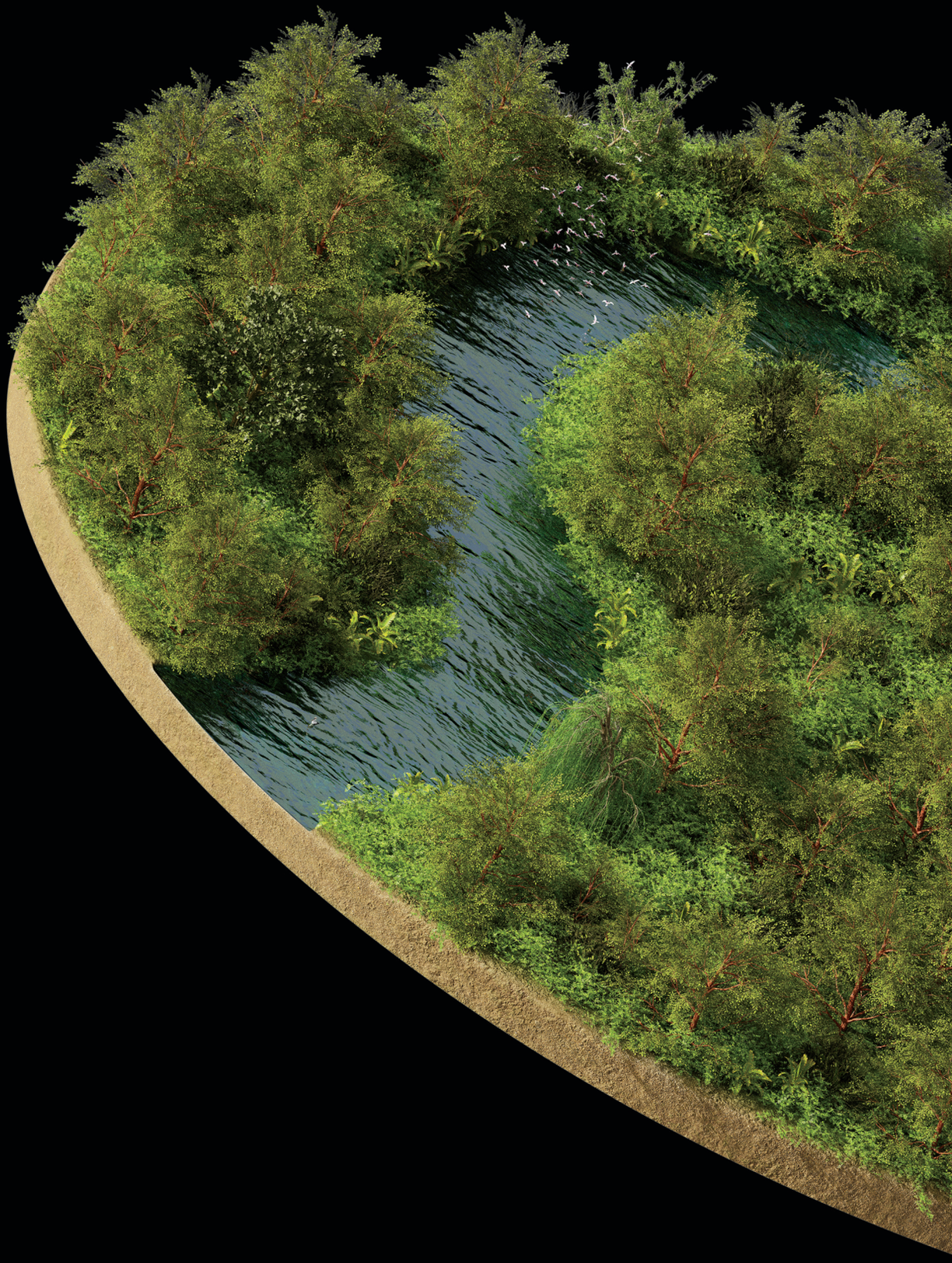

TIPPING AWAY

BRAZILIAN SCIENTISTS FEAR THAT THE AMAZON MAY HAVE REACHED A 'TIPPING POINT' TO BECOMING GRASSY SAVANNA — WITH PROFOUND EFFECTS ON THE CLIMATE WORLDWIDE.

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One of the first times Luciana Vanni Gatti tried to collect Amazonian air she got so woozy that she couldn't even operate the controls. An atmospheric chemist, she wanted to measure the concentration of carbon high above the rainforest. To obtain her samples she had to train bush pilots at obscure air-taxi businesses. The discomfort began as she waited on the tarmac, holding one door open against the wind to keep the tiny cockpit from turning into an oven in the equatorial sun. When at last they took off, they rose precipitously, and every time they plunged into a cloud, the plane seemed to be, in Gatti's words, *sambando* — dancing the samba. Then the air temperature dipped below freezing, and her sweat turned cold.

Not that it was all bad. As the frenetic port of Manaus receded, the canopy spread out below like a shaggy carpet, immaculate green except for the pink and yellow blooms of ipê trees, and it was one of those moments — increasingly rare in Gatti's experience — when you could pretend that nature had no final border, and the Amazon looked like what it somehow still was, the world's largest rainforest.

The Amazon has been called "the lungs of the earth" because of the amount of carbon dioxide it absorbs — according to most estimates, around half a billion tons per year. The problem, scientifically speaking, is that these estimates have always depended on a series of extrapolations. Some researchers use satellites to detect changes that indicate the presence of greenhouse gases. But the method is indirect, and clouds can contaminate the results. Others start with individual tree measurements in plots scattered across the region, which allows them to calculate the so-called biomass in each trunk, which, in turn, allows them to work out how much carbon is being stored by the ecosystem as a whole. But it's hard to know how representative small study areas are, because the Amazon is almost as large as the contiguous United States, with regional differences in rainfall, temperature, flora and the extent of logging and agriculture. (One study even warned of the risk of "majestic-forest selection bias.")

Gatti's solution was to measure the carbon in the air directly. Which led to the least pleasant part of the flight. The pilot had removed the plane's back seats to make up for the weight of a special silver "suitcase" donated by the U.S. National Oceanic and Atmospheric Administration. Inside, a thick layer of foam cradled 17 glass flasks with valves that opened and closed at the flick of a switch. Each one was supposed to capture a liter and a half of air from a different altitude, starting at 14,500 feet and going down to 1,000. To ensure that collection always took place above the same point on the map, the pilot had to descend in tight spirals, banking so hard that the horizon went near-vertical.

In a healthy rainforest, the concentration of carbon should decline as you approach the canopy from above, because trees are drawing the element out of the atmosphere and turning it into wood through photosynthesis. In 2010, when Gatti started running two flights a month at each of four different spots in the Brazilian Amazon, she expected to confirm this. But her samples showed the opposite: At lower altitudes, the ratio of carbon *increased*. This suggested that emissions from the slashing and burning of trees — the preferred method for clearing fields in the Amazon — were actually exceeding the forest's capacity to absorb carbon. At first Gatti was sure it was an anomaly caused by a passing drought. But the trend not only persisted into wetter years; it intensified.

For a while Gatti simply refused to believe her own data. She even became depressed. She had always felt a deep connection to nature. As a kid in a distant town called Cafelândia, she would climb a tree in front of her house, spending hours in a formation of branches that seemed custom-made to cradle her arms, legs and head. In later years, no matter how many times she flew over the Amazon, she never got used to the sight of freshly paved highways, new dirt roads always branching off them, forming a fish-bone pattern. Sometimes she soared past columns of beige smoke that rose all the way to the stratosphere.

Back at her laboratory, which is now housed at Brazil's National Institute for Space Research (INPE), Gatti ultimately spent two years refining her methodology. She wanted to know just how much carbon the rainforest was losing — and even more important, how representative these results were. The whole point of her project was that, by capturing air from such high altitudes, it could provide an empirical and comprehensive picture of the Amazon's so-called carbon budget. So she worked up seven different ways to calculate the effect of wind flows and the composition of air from over the Atlantic Ocean, gradually perfecting her method for subtracting the background noise. Finally she felt confident that her "regions of influence" captured what was happening across 80 percent of the Amazon. The net emissions averaged nearly 300 million tons of carbon per year — roughly the emissions of the entire nation of France.

When Gatti published her findings in Nature in 2021, it sparked panicked headlines across the world: The lungs of the earth are exhaling greenhouse gases. But her discovery was actually much more alarming than that. Because burning trees release a high proportion of carbon monoxide, she could separate these emissions from the total. And in the southeastern Amazon, air samples still showed net emissions, suggesting that the ecosystem itself could be releasing more carbon than it absorbed — or in Gatti's words, "effectively dying more than growing." The first time I spoke to Gatti, she repurposed a lyric by the Brazilian crooner Jorge Ben Jor. How could this be happening, she asked, in a "tropical country, blessed by God/and beautiful by nature"?

The Amazon is a labyrinth of a thousand rivers. They are born at 21,000 feet, with seasonal melts from the Sajama ice cap in Bolivia, and they are born in the dark rock of Peru's Apacheta cliff, as glacial seepage spraying white from its pores. They are born less than 100 miles from the Pacific Ocean; they are born in the middle of the South American continent, in Brazil's high plains, savannas and sandstone ridges. Most are just tributaries of tributaries, headwaters for much larger rivers — the Caquetá, the Madre de Dios, the Iriri, the Tapajós — any of which, on its own, would already be among the largest rivers in the world. Where these tributaries empty, just south of the Equator, they form the aorta of the Amazon proper, more than 10 miles wide at its widest point. From the Amazon's farthest source to its mouth in the Atlantic, water flows for 4,000 miles, almost as long as the Nile. Measured by the volume it releases into the ocean — the equivalent of a dozen Mississippis, one-fifth of all the fresh water that reaches the

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world's seas — the Amazon is the largest river in the world.

The consensus used to be that ecosystems are merely a product of prevailing weather patterns. But in the 1970s, the Brazilian researcher Eneas Salati proved that the Amazon, with its roughly 400 billion trees, also creates its own weather. On an average day, a single large tree releases more than 100 gallons of water as vapor. This not only lowers the air temperature through evaporative cooling; as Salati discovered by tracking oxygen isotopes in rainwater samples, it also gives rise to "flying rivers" — rain clouds that recycle the forest's own moisture five or six times, ultimately generating as much as 45 percent of its total precipitation. By creating the conditions for a continental swath of evergreens, this process is crucial to the Amazon's role as a global "sink" for carbon.

Many scientists now fear, however, that this virtuous cycle is breaking down. Just in the past half-century, 17 percent of the Amazon — an area larger than Texas — has been converted to croplands or cattle pasture. Less forest means less recycled rain, less vapor to cool the air, less of a canopy to shield against sunlight. Under drier, hotter conditions, even the lushest of Amazonian trees will shed leaves to save water, inhibiting photosynthesis — a feedback loop that is only exacerbated by global warming. According to the Brazilian Earth system scientist Carlos Nobre, if deforestation reaches 20 to 25 percent of the original area, the flying rivers will weaken enough that a rainforest simply will not be able to survive in most of the Amazon Basin. Instead it will collapse into scrubby savanna, possibly in a matter of decades.

Much of the evidence for this theory — including Gatti's air-sample studies — emerged thanks to a groundbreaking initiative led by Nobre himself. When Nobre started trying to forecast the impact of deforestation back in 1988, he had to do it at the University of Maryland, because his home country lacked the computing power for serious climate modeling. Brazil was so strapped for resources that foreign researchers even dominated Amazon fieldwork. But Nobre spearheaded a program that, in the words of a Nature editorial, "revolutionized understanding of the Amazon rainforest and its role in the Earth system." Established in 1999 and known as the Large-Scale Biosphere-Atmosphere Experiment in Amazonia, or L.B.A., it united disciplines that usually did not collaborate, bringing together chemists like Gatti with biologists and meteorologists. While funding mostly came from the United States and Europe, Nobre insisted that South Americans play leading roles, thus giving rise to a whole new generation of Brazilian climate scientists.

Until recently, Nobre was working under the assumption that the Amazon would not become a net source of carbon for at least another few decades. But Gatti's research is not the only sign that, as he put it to me over Skype, "we are on the eve of this tipping point." The rain machine is slowing. Droughts used to come once every couple of decades, with a megadrought every century or two. But just since 1998 there have been five, two of them extreme. The effect is particularly acute in the eastern Amazon, which has already lost a staggering 30 percent of its forest. The dry season there used to be three months long; now it lasts more than four. During the driest months, rainfall has declined by as much as a third in four decades, while average temperatures have risen by as much as 3.1 degrees Celsius — triple the annual increase for the world as a whole in the fossil-fuel era. In some parts, jungles are already being colonized by grasses.

Losing the Amazon, one of the most biodiverse ecosystems on Earth, would be catastrophic for the tens of thousands of species that make their home there. Rising temperatures could also drive millions of people in the region to become climate refugees. And it would represent a more symbolic death, too, as "saving the rainforest" has long been a kind of synecdoche for modern environmentalism as a whole. What scientists are most concerned about, though, is the potential for this regional, ecological tipping point to produce knock-on effects in the global climate. Because the Amazon's flying rivers circulate back over the continent, the impact may already be reaching beyond the rainforest. In 2015, Brazil's populous southeast was hit by historic water shortages; in 2021, quasi-biblical sandstorms swept the region. If the flying rivers peter out entirely, it could affect atmospheric circulation even beyond South America, possibly influencing the weather as far away as the western United States.

But even these consequences pale next to the fallout from putting the Amazon's carbon back into the atmosphere. For all the slashing and burning of recent years, the ecosystem still stores about 120 billion tons of carbon in its

Illustration by Max Guther

trunks, branches, vines and soil — the equivalent of more than three years of human emissions. If all of that carbon is released, it could warm the planet by as much as 0.3 degrees Celsius. According to the Princeton ecologist Stephen Pacala, this alone would probably make the Paris Agreement — the international accord to limit warming since preindustrial times to 2 degrees — "impossible to achieve." Which, in turn, may mean that other climate tipping points are breached around the world. As the British scientist Tim Lenton put it to me, "The Amazon feeds back to everything."

In May I joined Gatti on a trip to the northeastern Amazon. Though it was not exactly part of her research, she wanted to visit the Tapajós National Forest, a 1.4-million-acre conservation area that held clues to the rainforest's mysterious emissions, and to the transformation predicted by Nobre. First she flew from São Paulo 1,500 miles north to Belém, at the Amazon's mouth in the Atlantic. From there she flew to Santarém, 400 miles upstream, where the Amazon's muddy brown waters are met by the dark blue Tapajós River. In the dry season, tourists come from across Brazil to the Tapajós's white-sand beaches. Now it was raining heavily, the beaches under water. The river lapped at Santarém's sidewalks.

Santarém is one of Brazil's oldest cities, founded by Jesuit missionaries at a time when the only local commodity was Indigenous souls. Its fortunes rose with the rubber boom of the 19th century, and fell with the bust of the 20th. More recently, it has been transformed by China's growing demand for soybeans, which are used as livestock feed and cooking oil. Gatti pointed out the long narrow barges docking at a terminal run by Cargill, the American commodities-trading giant. It began operating in 2003, the year before Gatti started running flights from Santarém's tiny airport. As we drove south on the BR-163, also known as Brazil's "grain corridor," Gatti recalled how, back then, so many of the fields were grass for grazing cattle. Of all the deforested land in the Amazon, more than two-thirds is pasture. Here, though, Gatti watched as the grass gave way to a "sea of soy."

Before our trip, Nobre had warned me to keep a low profile, because Gatti had become a public face amid the buzz around her discoveries. Just a few weeks later, the Indigenous-rights advocate Bruno Pereira and the environmental journalist Dom Phillips would be murdered. Profit makes its own law in the Amazon. In the Tapajós region, landowners must preserve 50 percent of their property as rainforest. But Gatti noticed how farmers and ranchers continued to expand their fields, ever so gradually, in long, thin strips meant to evade detection by the satellites of her own employer, INPE. In 2006 the soy industry agreed not to plant in newly deforested areas. But there are ways around this, too. Some farmers bribe local officials for falsified documents. Others transfer land to front men so that they can violate the moratorium without sullying their name. As we drove, Gatti noted violations to report, even though one of her own former colleagues once received death threats for this. She did not hide her affinities, favoring T-shirts with toucans and macaws on florid backgrounds.

Gatti, now 62, has always had a rebellious streak. When she was in college in the late 1970s, some fellow students were arrested for protesting the dictatorship. Outraged, she joined an underground political party and stopped attending classes for a while. Though she was scarcely aware of this at the time, it was the military regime that oversaw the first modern effort to colonize the rainforest. One of its most ambitious projects was the Trans-Amazonian Highway, which pierced 2,600 miles west from the coast and now forms the southern border of the Tapajós National Forest. The goal was partly to fill what the generals saw as a "demographic void," keeping foreign powers like the United States from moving in. They also hoped to relieve pressure on ballooning cities by uniting "men without land in the northeast and land without men in the Amazon." Never mind that the forest was already occupied by a multitude of Indigenous groups; they, too, would be made into productive citizens.

The military regime had also built the BR-163, which branches off from the Trans-Amazonian, forming the Tapajós's eastern border. As we sped along it, signs advertised land for sale, a store called House of Seeds, a World Church of the Power of God. To our right, the Tapajós was a looming wall of green. To our left were private lands where forests were interspersed with croplands. It was the tail end of the soy harvest now, when many landowners started a rotation of corn; tractors rolled through, long metal wings spraying pesticides. Gatti pointed out a freshly cleared area; the trunks lay scattered like a game of pickup sticks. Even when landowners followed the law, what was once a seamless ecosystem became an archipelago, fragments of forest hemmed in by flat expanses. At one point we passed a lone Brazil nut tree, inanely protected by Brazilian law even amid the monoculture. "Here lies the forest," Gatti declared.

As she spoke, Gatti gesticulated so vehemently that both hands sometimes came off the steering wheel. She betrayed no affection for Jair Bolsonaro, the former army officer who spent four years as president pushing to develop the Amazon. Claiming (baselessly) that his own government's deforestation numbers were a lie, he strangled INPE's funding to the point that it reportedly had to shut off its supercomputer. He also slashed budgets for protecting Indigenous people and the environment. Predictably, deforestation accelerated; in 2021, a thousand trees were cut down every minute. Gatti sometimes thought about quitting, moving with her German shepherd to an eco-villa in the countryside. With Luiz Inácio Lula da Silva returning to the presidency, though, she is feeling hopeful for the first time in years. The last time he was in office, from 2003 to 2011, deforestation fell by two-thirds — and he has promised to crack down on illegal cutting once again. The question is whether that will be enough to halt a process that may now have a momentum of its own.

Eventually Gatti pulled off to the right, through a tunnel of overhanging branches and into an open area where tall trees shaded a research base built as part of Nobre's L.B.A. The base resembled an eco-lodge, with low-slung wooden buildings topped by clay-tiled roofs. Night was falling, the roar of frogs competing with the distant howl of monkeys. We were met by a 39-year-old biologist, Erika Berenguer, who wore an old white T-shirt, overlarge and dirty. Her specialty, she said, was *desgraça* — calamity. It turns out that deforestation numbers actually understate the problem of the Amazon, because a fifth of the standing forest has been "degraded" by logging, burning and fragmentation. Now based in Oxford, Berenguer has spent the last 12 years studying how these ills affect the Amazon's ability to store carbon. As she would explain, though, even she

was shocked by what happened in 2015, a critical turning point in the health of the ecosystem.

At the time Berenguer's project was to measure every single tree in a few dozen plots in and around the Tapajós National Forest, at regular intervals, to calculate the weight of all the organic matter, or biomass, which serves as a proxy for carbon. At first, when she noticed flames inside the conservation area, she just kept doing her work — gathering up leaf litter, fixing tape around centuries-old trunks, tagging each one with numbered scraps of metal sliced from beer cans. Outside observers usually fail to distinguish between deforestation fires (intentionally set to clear freshly clear-cut areas) and wildfires (when the flames accidentally spread to standing forests). Now it was August, the height of the dry season, when ranchers and farmers in the Amazon clear fields with fire. Almost every year, embers floated across the BR-163 highway, igniting leaves on the forest floor. But the forest itself remained so damp that the flames could not spread far.

Berenguer, a native of cosmopolitan Rio de Janeiro, made a point of sweating alongside her assistants, local men with nicknames like Xarope (Syrup) and Graveto (Stick), whose families had settled by the BR-163 as part of the colonization push of the 1970s. They were not too concerned, either. As subsistence farmers, they also used fire to maintain their lands. It is a tradition that dates back to the region's oldest inhabitants, Indigenous people who discovered that ash fertilizes the nutrient-poor soils. Outside the rarest of megadroughts, they never had to worry about losing control of the flames. Researchers have found areas of the Amazon that, according to sediment core samples, went 4,000 years without a single burn.

As Berenguer worked through September, however, the smoke from disparate fires coagulated into a permanent, indistinguishable haze. It permeated everything — their truck, their clothes, even Berenguer's bra. When they kicked away dead leaves, they noticed that the soil beneath was cracking. The little plants of the understory wilted. Soon everyone was coughing; people took turns breathing mist from a nebulizer, and her own snot turned black. Each morning, she and her assistants had to clean a layer of fresh soot from the windshield of their truck. They turned the brights on, turned the emergency lights on and edged onto the highway. They drove slowly but couldn't see vehicles ahead until they were nearly colliding with them. The sky was hidden. The sun was a red suggestion. Ash fell like alien snow.

The fires were escaping to crop gardens, to pastureland where cattle grazed, to the thatched roofs of houses. And the fires were doing what they should not: spreading inside the rainforest. Splitting her time between Britain and the Amazon, Berenguer had come to know her research plots as intimately as her old neighborhood in Rio. She thought of her favorite places as rainforest versions of her local coffee shop, her local bakery. There were the fallen logs where she and her assistants returned day after day so they could sit and eat lunch. There were the tall, thin buttress roots that acted as a makeshift bathroom stall, hiding her from view when necessary. In one plot, a thick loop of liana hung from the canopy, making for the perfect swing. Now she wanted to save these places.

Among the great old trees of the Tapajós, the flames rose a mere foot from the ground. Berenguer and Xarope could stamp them out with their boots. But their efforts were in vain. The flames consolidated into a thin, uninterrupted arc that stretched for miles into the forest. It advanced slowly, a thousand feet per day; in its wake, the rich perennial green was left brown and gray and charcoal-black. Berenguer watched as animals fled from the fire line — butterflies, deer, thumbnail-size frogs. One day she surprised a snake. It leaped onto a smoldering trunk, accidentally immolating itself, and Berenguer heard a sizzling sound, like buttered bread hitting a griddle plate.

Across the Amazon, more forests ultimately burned than in the largest California wildfires in history, putting half a billion tons of carbon back into the atmosphere — the equivalent of more than one year of emissions by Mexico. It was the Amazon's worst wildfire season on record. Subsequent years have not been as dry, but wildfires have mostly remained well above the average of previous seasons — yet another sign that the ecosystem is losing its natural resilience, entering an alternate feedback loop. In Gatti's samples, the 2015-16 drought also marked the moment when, as she put it to me, "the southeastern Amazon went to pot," and the forest itself started consistently releasing more carbon than it absorbed. Fire does more than

Illustration by Max Guther

destroy trees. It also accelerates the transformations predicted by Nobre's tipping-point theory.

Just about every researcher I spoke to for this article was careful to emphasize their deep respect for Nobre, who has done so much to advance Amazon climate science. But some have reservations about his theory. Partly this is because his earliest simulations showed that, with less rain, the Amazon would give way to the Cerrado, a savanna that covers much of central Brazil. The Cerrado, though, is a carbon-rich patchwork of grasslands, marshes and forests that is itself endangered by global warming and expanding agriculture. How could such a vibrant ecosystem represent ecological collapse? Other researchers, having studied the Amazon up close in mucky fieldwork, object to the use of computer models that apply uniform assumptions to this multifarious biome. Still others express a more pragmatic concern — that the way Nobre communicates his theory is demobilizing. "Carlos gives the impression that the entire forest is going to collapse at the same time, water will stop circulating and it will all become a big savanna," Berenguer told me. Gatti's article, she added, actually led to some misunderstanding, too. Attending the United Nations Climate Change Conference in Glasgow in 2021, she even heard people say that if the Amazon was now a net emitter, why bother saving it?

Nobre himself is aware of these qualms. Now he hastens to clarify that the transformation will take different forms in different regions, and that any end state will be more of an impoverished scrubland than a Cerrado-style savanna. He also predicts that the Amazon's western forests, which are rainier throughout the year because of their proximity to the Andes Mountains, would survive a tipping point. His theory, though, is no longer confined to computer simulations; in the southeastern basin, it may already be playing out. In one study, a team led by the researcher Paulo Brando intentionally set a series of fires in swaths of forest abutted by an inactive soy plantation. After a second burn, coincidentally during a drought year, one plot lost nearly a third of its canopy cover, and African grasses — imported species commonly used in cattle pasture — moved in. Brando also participated in an observational study, led by his colleague Divino Silvério, of the region's enormous Xingu Indigenous Park. Indigenous lands are home to much of Brazil's best-preserved rainforest. But after repeated wildfires, the Xingu's grasslands — traditionally maintained as a source of thatch — nearly tripled in size in less than two decades, to 8 percent of the total area. In the central Amazon, meanwhile, naturally occurring white-sand savannas are taking over seasonally flooded forests — again, largely thanks to fire.

It is tempting to think of climate change as a process that, absent human emissions, would only happen gradually. But as Tim Lenton points out, our planet is naturally prone to "threshold behavior." In a widely cited 2008 paper, Lenton brought the catchy language of tipping points to the arcane revelations of Earth systems science and paleoclimatology. Throughout our planet's history, in individual ecosystems as well as the wider climate, small, incremental changes have started to reinforce one another until — sometimes suddenly — one feedback loop was replaced with a radically different one. What Lenton calls the most "iconic" examples are the Dansgaard-Oeschger events of the last glacial period, when temperatures in Greenland repeatedly shot up by as much as 15 degrees Celsius in the span of a few decades, before cooling again. The causes are intensely debated but most likely involved changes in ice-sheet coverage and the circulation of seawaters.

There is already evidence that our current era of global warming is shifting the borders of various biomes. In Alaska, for example, white spruce trees are moving into areas of tundra for the first time in thousands of years. But humans may have triggered ecological "regime shifts" even before the fossil-fuel era. The Australian Outback was probably lush and green until around 40,000 years ago, when people hunted grass-eating megafauna to extinction, leaving more fuel for fires, which apparently disrupted the continent's own "flying rivers." On Mexico's Yucatán Peninsula, deforestation is thought to have amplified the drought that toppled the Maya. Then there is the Sahara. Ten thousand years ago, the area resembled temperate South Africa, but livestock grazing may have helped turn it into a desert. As the NOAA scientist Elena Shevliakova,

Illustration by Max Guther

who has modeled the global impacts of Amazon deforestation, put it to me, "If a green Sahara is possible, why not a savanna in the Amazon?"

The Amazon has survived ice ages. It may not survive humans. By hastening the demise of its flying rivers, cattle ranchers and soy farmers may be endangering their own livelihoods too. But thanks to what climatologists call teleconnections — weather anomalies linked across thousands of miles — they also threaten agriculture much farther afield. In the El Niño teleconnection, an unusually warm Pacific Ocean pulls the jet stream south, bringing drier conditions to Canada and the northern United States (as well as to the Amazon region). According to a study led by the Notre Dame researcher David Medvigy, a similar pattern could emerge if the Amazon stops recycling its own moisture, as the dry air would travel north in winter. This could halve the snowpack in the Sierra Nevada, a crucial source of water for an already-drought-stricken California.

A growing number of scientists worry that one tipping point can trigger another. In some cases the influence is direct. If Greenland's ice sheet disappears, the circulation of Atlantic seawaters could be drastically altered, which would, in turn, wreak havoc on weather patterns across the globe, making Scandinavia uninhabitably cold, warming the Southern Hemisphere, drying out forests. The impact of Amazon dieback would be to release tens of billions of tons of carbon into the atmosphere — which is more diffuse, but no less dangerous. When Lenton and his colleague David Armstrong McKay recently compiled the latest evidence on an array of global climate thresholds, they found that even a very optimistic 1.5 degrees of warming since preindustrial times may be enough to trigger the gradual but irreversible melting of ice sheets in Greenland and West Antarctica, and to thaw methane-trapping permafrost.

It is difficult to predict how all these shifts might interact, as most models assume, for example, that Atlantic seawaters will always circulate according to known patterns. But in a 2018 paper, Lenton and the American Earth system scientist Will Steffen warned that a dominolike "tipping cascade" could push the global climate itself beyond a critical threshold, into an alternate feedback loop called "hothouse Earth," with hostile conditions not seen for millions of years. It can feel like doom-mongering to contemplate such a scenario. There is no way to put a number on it. Even if it is improbable, however, Lenton argues that the consequences would be so dire that it must be taken seriously. He sees it as a "profound risk-management problem": If we focus only on the most likely outcomes, we will never predict anomalies like 2021's unprecedented "heat dome" in the Pacific Northwest. Or last year's winter heat wave in Antarctica, when temperatures jumped 70 degrees Fahrenheit above the average. Or, for that matter, the proliferation of wildfires in the world's largest rainforest.

B

erenguer wanted to show Gatti how the 2015 megafires had altered forests in the northeastern Amazon. So Xarope picked us up from the research base in the morning, and we got back onto the BR-163. Here and there along the highway, Berenguer pointed out "tree skeletons" — dead trees whose sun-bleached branches poked from the otherwise lush green canopy of the Tapajós. Fire did not always kill them right away. When Berenguer was back in Britain, her assistants would send her updates by WhatsApp. *You know Tree 71?* one message might say, referring to a centuries-old specimen in one of her plots. *So, it just died.* It could take a few years more for it to fall to the ground. Some of the carbon in Gatti's air samples, then, could be a delayed consequence of past fires. But as we would see inside the living forest, something stranger was happening, too.

Eventually we exited the highway for an unmarked dirt track that ended in a wall of vegetation. Machete in hand, Berenguer led us onto a tight path. Just a few days earlier, she and her assistants spent hours clearing the way for us, but new vines were already reclaiming the space. "You can see it's a mess," Berenguer said. An impassable thicket of reedy bamboo hemmed us in on either side; the canopy was low above our heads. To me it looked normal enough, as far as jungle goes. In reality, though, a healthy rainforest should be easy to walk through, because the largest trees consume so much light and water that the understory lacks the resources to grow very dense.

We walked over fallen trunks. Unlike in the southeastern Amazon, Berenguer still saw no evidence of savannalike vegetation moving in. But the balance of native species was now out of whack, as opportunistic "pioneers" occupied the spaces left by dead giants. In some areas, fast-growing embaúba trees stood so uniformly that they resembled the stems of a wood-pulp plantation. In others, hundreds of newborn lianas formed a kind of snake nest. (Berenguer's team had to measure each one individually, a hellish task.) She pointed to a tall, proud tree that had somehow survived the blaze. Because all of the other nearby individuals of its species had been killed, it was unlikely to reproduce; Berenguer called it a "zombie."

A University of Birmingham researcher named Adriane Esquivel-Muelbert has found similar changes across the Amazon. Even in the absence of actual "savannization," trees that can withstand drier conditions are proliferating, while those that need more water are dying in greater numbers. The dominance of embaúba is particularly worrisome because the trees are hollow, storing far less carbon than a slower-growing species like mahogany. Their life cycle is also relatively short, leaving more frequent gaps in the canopy. The end result of this transformation is unclear, but Gatti's numbers have only continued to get worse. According to her latest five-year averages, the Brazilian Amazon is already giving off 50 percent more carbon than it was in the first five years of her project — and even the historically healthier western forests are sometimes emitting more than they absorb.

Eventually we came into a clearing. I began to sweat. The sun was searing hot; Berenguer said that unshaded ground can reach 176 degrees Fahrenheit here. Clearings are a natural part of the Amazonian cycle, as large trees inevitably die and other species gradually take their place. But even logging could not match the power of fire to turn the forest into "Swiss cheese." Berenguer never used to need sunscreen because the canopy was so thick; now she gets sunburned here. And the profusion of holes sets off a vicious cycle. The sun dries out the vegetation; trees shed leaves to preserve water; the litter becomes fuel for the next fire. The gaps also create a "wind corridor," allowing strong drafts to penetrate deep into the forest during storms. Perversely, with their heavy trunks, the largest, oldest trees are especially vulnerable to being knocked over.

"This used to be a beautiful forest," Xarope said.

"Some days it makes me sad," Berenguer said. "Other days it pisses me off. This is one of those days."

Berenguer had hoped that the misfortune of the megafire would at least provide an opportunity to study how a rainforest recovers from such *desgraça*. But she worried that she would never find out, because it would never get the chance. Among scientists who study the Amazon, the notion of multiple tipping points, specific to each region's ecology, has increasingly taken hold. And some now speak of an even more urgent "flammability tipping point," past which an ecosystem that never evolved to burn starts burning regularly. During the drought of 2015, wildfires also ravaged another nearby conservation area, the Reserva Extrativista Tapajós-Arapiúns. Because it was left so degraded, with so much dried-out fuel on the floor, there was a much more intense conflagration in 2017, even though that was a

Answers to puzzles of 1.1.23

IN PLAY

T	R	E	E		J	A	P	A	N		S	P	A	M	S		A	C	T	S
Y	E	N	S		A	I	O	L	I		A	E	R	I	E		L	O	I	N
R	E	C	T	A	N	G	U	L	A	R	P	R	I	S	M		E	L	M	O
A	L	E	R	T			R	E	L	O				S	I	M	P	L	E	R
		L	O	V	E	W	I	L	L	T	E	A	R	U	S	A	P	A	R	T
D	R	A	G		N	O	T	E			D	O	E	S		C	O	B		
A	I	D	E		T	W	O		S	W	I	N	G	A	T			O	P	A
M	O	U	N	T	A	I	N	S	T	A	T	E	S		O	U	T	R	U	N
E	T	S		H	I	E		P	A	R				F	I	N	E	A	R	T
			T	E	L		D	O	C	T	O	R	D	O	L	I	T	T	L	E
A	X	I	O	M		T	O	O	K		Z	E	R	O		C	R	E	S	S
G	E	T	B	A	C	K	I	N	S	H	A	P	E		G	O	A			
I	N	S	I	G	H	T				E	R	R		S	U	R		P	A	T
L	O	N	N	I	E		B	R	E	A	K	O	U	T	I	N	S	O	N	G
E	N	O			M	A	N	U	A	L	S		N	A	N		A	S	T	I
		B	B	S		L	A	I	C			S	O	L	E		L	E	I	F
F	R	I	E	N	D	S	I	N	H	I	G	H	P	L	A	C	E	S		
L	E	G	R	O	O	M				S	U	R	E			D	I	N	A	R
U	R	G	E		P	I	C	T	U	R	E	I	N	P	I	C	T	U	R	E
B	A	I	T		E	T	H	O	S		S	N	E	E	R		E	D	E	N
S	N	E	S		S	H	I	N	E		S	E	D	G	E		M	E	A	T

KENKEN

2	1	3	5	4
5	3	4	1	2
4	5	1	2	3
1	4	2	3	5
3	2	5	4	1

3	2	1	5	7	4	6
1	4	6	2	5	3	7
7	1	2	3	6	5	4
2	6	4	7	3	1	5
5	7	3	1	4	6	2
4	5	7	6	1	2	3
6	3	5	4	2	7	1

ACROSTIC

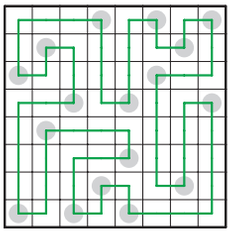
HOWARD BERGERSON, PALINDROMES (AND ANAGRAMS) — Sydney Yendys was born … to be a palindromist. … His first coherent utterance was "Dad-dad-dad … !" followed in due course by "Mam-mam-mam … !" Later in life he was to marry a girl called Edna, and to have a daughter, also named Edna.

A. Half-wit
B. Odds
C. Weird Al
D. About-face
E. Radar
F. Dahlias
G. Brahms
H. East Wind
I. Rostrum
J. Gyrating
K. Edda
L. Rom-com
M. Sheared
N. One-liner
O. Naïve
P. Paddle
Q. Amy Adams
R. Landlady
S. Indy
T. "Nanette"
U. Demonym
V. Rebound
W. Octet
X. Manual
Y. Eyes left
Z. Showcase

FOR STARTERS

	N	T	M	S	J
H	O	R	A	C	E
P	F	I	Z	E	R
C	A	P	O	N	E
W	I	L	L	E	M
G	R	E	A	S	Y

EVERY SECOND TURN



Answers to puzzle on Page 48

SPELLING BEE

Firepower (3 points). Also: Error, fireproof, offer, offerer (or offeror), poorer, popper, power, powwow, preop, prior, proffer, proof, proper, repro, reproof, riproff, roofer, roper, ropier, rower, wooer, woofer, worrier, wowie (or wowee). If you found other legitimate dictionary words in the beehive, feel free to include them in your score.

wet year. This time the flames were not the foot-tall ones that are usually seen in the Amazon but reached all the way to the canopy.

Though her mainstay was ecological calamity, Berenguer also wanted us to see what well-preserved old-growth forest looks like. In strictly scientific terms, it was a control, a necessary point of comparison with the messed-up forests, as she called them (though she used a more colorful word that cannot be printed here). She also let on that she welcomed the rare excuse to traipse around a more "David Attenborough" setting. So we drove south on the BR-163 until we hit the 117th kilometer marker, where we re-entered the Tapajós.

We were walking for only a few minutes before the difference became obvious. It was cooler and darker. The flora was far more varied, forming distinct layers as you lifted your eyes to the sky. The canopy was far more closed, the understory far more open; Berenguer and Xarope didn't even need to prune the trail for our visit. There were lianas here, too, but they were few and large. One was as thick as a tree; Berenguer said it was probably centuries old.

It's hard to shake a popular image of scientists as rigorously rational, unemotional about their work. But Berenguer was not embarrassed to admit that, as she put it, she and her colleagues have their own personal tipping points, too. For a while after the 2015 fires, she lost her sense of purpose, the hope that her work could make a difference. The flames had even ravaged the plot where she used to swing on that perfect loop of liana. "Your whole reference system is being destroyed, and you're powerless," she said. "It's hard to explain without sounding like a tree-hugger. Not to say I don't hug trees, because I do." Some trees were too big for that, though. Here was an urucurana, with its winglike buttress roots taller than my whole body. Here was a soaring strangler fig, which surrounds another tree's trunk as it grows, eventually killing its host. "What a dirty trick!" Gatti exclaimed.

At one point we came upon a low tree bearing a yellow fruit that neither Berenguer nor Xarope could identify.

"Is it poisonous?" Gatti asked.

"I don't know," Xarope said. Then he plucked one from a branch and bit into it. We did the same. There was not much pulp around the stone but the flavor was sharp and rich.

Berenguer remembered a past research trip to track frugivores — fruit-eating creatures. She and her colleagues had to remain absolutely still and silent for hours to avoid spooking them. I suggested we try it out for a minute, just to hear what an old-growth forest sounds like without humans tramping around.

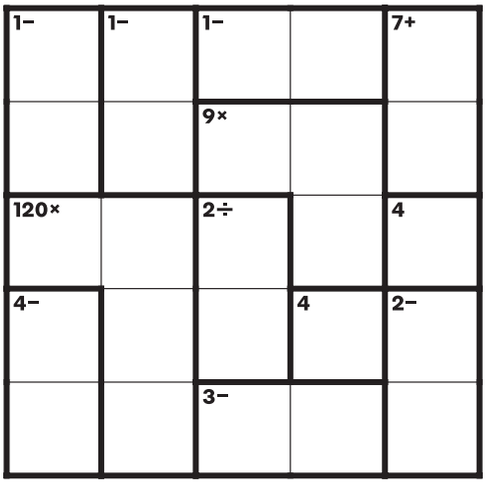
We stopped walking; Berenguer sat on a log. As our chitchat faded, the racket of birds swelled as if someone had suddenly turned the volume dial on a stereo. I closed my eyes for a moment. When I looked again, Berenguer's eyes had narrowed to slits, her lips curled into a faint smile. Earlier, describing what she felt in this place, Berenguer used the word *grandeza*, which literally means greatness, but also bigness. The rainforest made her feel small, and she liked this.

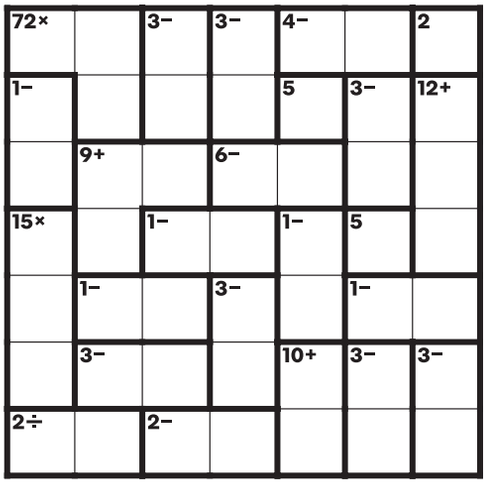
Gatti had spoken about feeling, at least temporarily, not so separate from the natural world — almost as if she were a kid again, ensconced in that tree in front of her house. Now she stood with her eyes shut, palms open at her sides as if she were at a religious revival, as if she were receiving something.

I glanced over at Xarope; he looked amused. Then the spell was broken by the more familiar sound, distant but unmistakable, of a semi truck shifting gears. ◆

KENKEN

Fill the grid with digits so as not to repeat a digit in any row or column, and so that the digits within each heavily outlined box will produce the target number shown, by using addition, subtraction, multiplication or division, as indicated in the box. A 5x5 grid will use the digits 1–5. A 7x7 grid will use 1–7.





Contributors

Tracy Kidder

"You Have to Learn to Listen to These Patients," Page 20

Tracy Kidder is the author of numerous books of narrative nonfiction, including "The Soul of a New Machine," "House" and "Mountains Beyond Mountains." He has won the Pulitzer Prize, a National Book Award, the Robert F. Kennedy Book Award, as well as a Bronze Star for his service in Vietnam — which he insists he didn't earn. His article in this issue is adapted from his latest book, "Rough Sleepers" (to be published this month), which is based on his time over more than five years with Dr. Jim O'Connell as he cared for the homeless in Boston. "Many of us awake most mornings to the news that chaos, violence and cruelty still rule the world," Kidder says. "But there are people putting up a fight against the darkness. Many are competent, determined and, in their spheres, effective. Dr. O'Connell is one of those."

Cole Barash

"You Have to Learn to Listen to These Patients," Page 20

Cole Barash is a visual artist whose current work focuses on the relationship between humans and nature. His monograph, "When the Wind Blows North," is scheduled to be published in 2023.

Alex Cuadros

"Tipping Away," Page 36

Alex Cuadros is the author of "Brazillionaires." He has been reporting from the Amazon since 2013 and is now working on a book about the Cinta Larga Indigenous group.

Iva Dixit

Screenland, Page 7

Iva Dixit is a staff editor for the magazine. She last wrote a Letter of Recommendation about raw onions.

Max Guther

"¡Chan-tatachan!" Page 30

Max Guther is a Berlin-based illustrator known for his work in a hyperreal isometric 3-D style, often with an unfamiliar perspective from above.

Shuja Haider

"¡Chan-tatachan!" Page 30

Shuja Haider is a senior editor at The Nation. He writes on left-wing politics, American music and contemporary subcultures.

Behind the Scenes

Kathy Ryan, director of photography: "For our profile of Juan Tamariz, we commissioned the photographer Ibai Acevedo because we knew he would bring some sleight of hand of his own to the challenge of photographing the famous magician. To create his spectral portrait of Tamariz, he brought along some colored lights, a fog machine and a vaping device to lend an ephemerally mischievous mood to the sitting."

Photograph of Tamariz and Acevedo by Marc Bordons