NAUTILUS

APPETITE FOR DESTRUCTION
The high price of a seafood favorite

THE BIG NOTHING
What lies between stars

YOU ARE PROBABLY NAIVE
Why you think you're always right

Where Do Our Minds Go?

THE BIG QUESTION ABOUT ANESTHESIA P.20

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ISSUE 45

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COVER Wesley Allsbrook


sails of change
#30x30
“Sails of Change supports #30×30,
a global call to protect 30% of our planet by 2030.
To do so, we must Protect, Restore, Learn, Commit.”
- Dona Bertarelli, Founder of Sails of Change
sails of change

Features

NAUTILUS

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What's the Big Idea?

BY KEVIN BERGER

WRITING ABOUT THE ENVIRONMENT is a challenge for modern journalists. How many more ways can we say humans have made a mess of the world and everything we care about is vanishing? Well, maybe you shouldn't answer that. There are many more ways.

But what I mean is because the underlying theme of most environmental articles is the same, the articles don't feel vital. Outrage has a sell date and by now outrage is stale. We can only read so many tales of greed and blight before, to quote the great songwriter Neil Finn, we "turn right over to the TV page." Maybe our exhaustion is a big part of the reason why the collective action needed to arrest climate change is stalled like a rusted Jeep on a desert road. Yeah, it's an eyesore and somebody should move it. But I've got more important things to worry about right now.

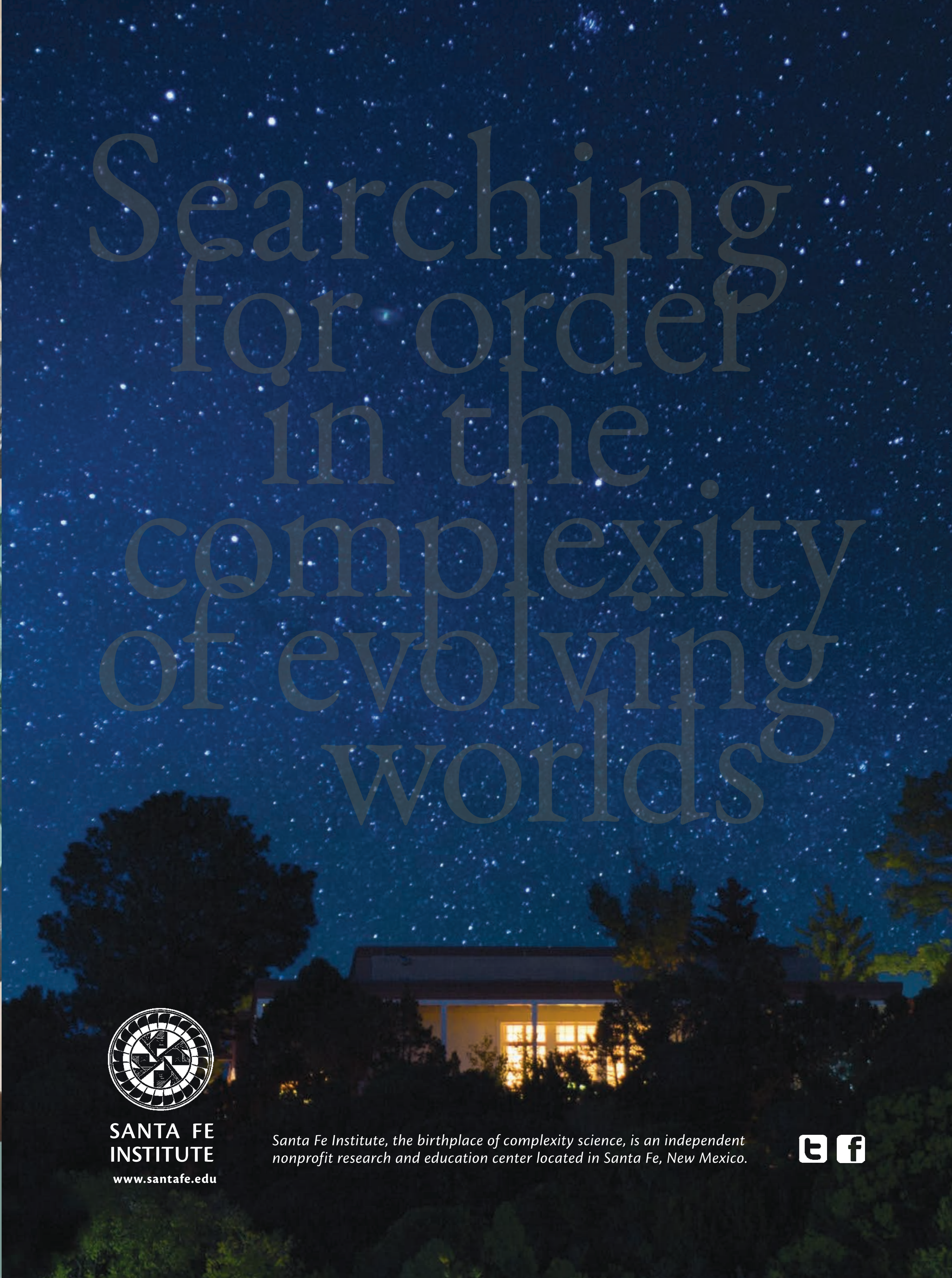
Making you care is my job as an editor. Finding the stories that light up your reading mind is, I admit, a challenge. I consistently ask myself, Have readers heard all this before? Does our story have a wedge that pries up a rock to reveal new information? Does the data add up to a vital idea? And most importantly, Is the article a pleasure to read?

Of course, I think the environmental science articles in this issue live up to those standards. "The High Environmental Cost of Cheap Shrimp" spotlights an estuary in Ecuador that embodies a global problem, the destruction of mangroves. The trees with labyrinthine roots are fulcrums of wetland ecosystems. They are also natural citadels for us. They halt rising storm waters and provide a line of defense for homes. Cutting them down for get-rich-quick developments is a well known offense in environmental circles.

But what makes Kata Karáth's story special is that cutting down the mangroves is also uprooting the livelihood of fishermen in Ecuador. The mangroves provide sustainable habitats for the shellfish they catch and sell. But in recent decades, big shrimp companies have cleared the mangroves to make room for pools in the estuary's brackish waters for shrimp to breed. Good environmental reporting makes us see the hidden consequences of daily actions. An average American eats more than 4 pounds of shrimp per year and 37 percent of it comes from Ecuador. I didn't know any of that and didn't give a second thought to greenlighting Kata's investigation.

Another article in this issue, "How Are the Bees Doing?" answers a question about which I have been curious, given the acres of articles that appeared on colony collapse disorder more than 10 years ago, and have disappeared from headlines. The answer, in short, is the bees are not alright. Journalist Lois Parshley doesn't stop there. She outlines projects by savvy insect and agricultural experts to rescue bees from insecticides and urban sprawl.

What makes Lois' article even more original, and quintessentially *Nautilus*, is it contains a vital idea. Bees, Lois learned, respond to environmental changes by working together. When their hives get too hot, stemming from changes in the atmosphere, they fan their wings to cool it off. To survive, and thrive, the bees work together. There is no other way. Yes, we know bees are critical pollinators. Our food supply depends on them. But bees as role models for humans? Now that's an idea to base an article on.



Searching for order in the complexity of evolving worlds
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Preludes

ENVIRONMENT

We Only Think We Flush It Away

THE EPITOME OF MODERN CONVENIENCE, our toilets make waste disappear with incredible efficiency and ease. We seldom think twice about pulling the lever or about where all that swirls down the pipes ends up afterward. But the massive mazes of sewage pipes underneath our towns and cities ultimately lead to *some* body of water nearby, and many of these aquatic ecosystems lead to the ocean. We tend to believe that our wastewater treatment plants clean up everything we dish out. Unfortunately, it's a big misconception, in part because the populations grow faster than treatment plants are built, and compounds evolve faster than the cleaning techniques designed to filter them.

Our wastewater systems are very efficient at removing pathogens, but not environmental pollutants. Neither do most of them have the right equipment to destroy many pharmaceuticals that flow through us and into the seas. Some of these chemicals are so ubiquitous in the ocean that scientists use them as indicators of how far contamination spreads, says Stephanie Wear, marine biologist and founder of Ocean Sewage Alliance, a nonprofit that aims to "re-potty train the world." In her recent study published in *Biological Conservation*, Ware's team used diclofenac—an anti-inflammatory drug which persists in the water for weeks to months—to map how far sewage pollution spreads. As these chemicals float in the water, they smother corals, poison fish, kill mangrove forests, and destroy coastal marshes. "We found that 31 percent of salt marshes globally were heavily polluted with human sewage," Wear says. "We are destroying the ocean with our pollutants."

Plastic, as we know, is the scourge of the oceans. By 2050, plastic will outweigh all the fish in the seas. We don't flush plastic water bottles down the toilet—but we do flush microplastics. We consume a credit card's worth of microplastics every week, which find their way into waterways and the ocean, into fish, and back into us. Plastic gets the headlines but it's not the whole story. Our sewage is a noxious cocktail of chemicals that are coming back to us like a toxic tsunami. Widespread ocean pollution threatens the health of over 3 billion people, points out Phillip Landrigan, epidemiologist at Harvard T.H. Chan School of Public Health, and a corresponding author of a recent study that depicts the harmful and deadly effects of these contaminants. Here are five contaminants circulating in that surging tide, if you dare to dive in.

CAFFEINE

Oh, that morning cup of Joe without which so many of us can barely function. Caffeine is the single most commonly consumed psychoactive compound worldwide, found in coffee, tea, chocolate, energizing drinks, and in some drugs. Once it gives us the jolt we crave, it passes through us, flowing into the sewer and then into whatever body of water that sewer is

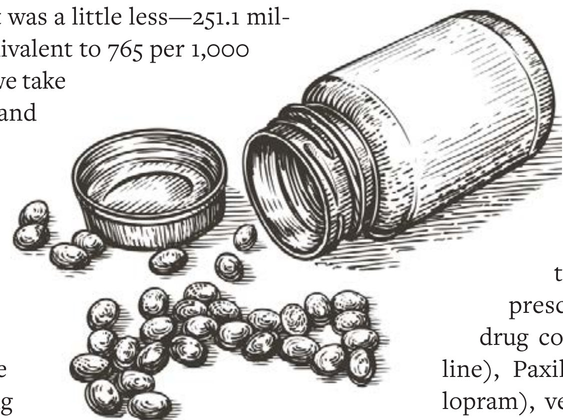
FLAT VECTORS / SHUTTERSTOCK

connected to. Relatively stable under variable environmental conditions and constantly replenished by us, it is commonly released into the environment in the wastewater effluent. People drinking too much caffeine can suffer health issues, including nervousness, nausea, and increased heart rate. Concentrations of 80 to 100 mg per liter are considered lethal for humans, and while deaths are rare, they aren't unheard of. How much is deadly for aquatic species? There are no set numbers, but studies are now spilling the beans, finding that cafeine can mess up some creatures' functions. It can inhibit growth in fathead minnows, impair reproduction in purple sea urchins, and cause skeletal deformation in South America's catfish.

ANTIBIOTICS

Some of the most widely prescribed medications worldwide, antibiotics are used for animals and humans. In 2016, American doctors wrote 270 million antibiotic prescriptions—enough for 5 out of every 6 people. In 2019, it was a little less—251.1 million prescriptions, an equivalent to 765 per 1,000 persons. However, when we take antibiotics, we absorb and metabolize only a small portion of the whole dose, excreting a much larger amount of it in urine and feces. As we flush, these chemicals flow into rivers, lakes, and the ocean, eventually making their way into marine creatures, including those we eat. A 2014 study found five different types of antibiotics in wild and farmed seafood sold in the United States. The more recent 2021 study, done in Chile, the largest producer of salmon after Norway, looked at antibiotics levels in wild and farmed salmon and trout, and found plenty in both. Seafood farmers commonly treat their stocks with antibiotics just as poultry and cattle producers do, so finding antibiotics in farmed fish isn't overly surprising. However, wild salmon, trout, shrimp, and other species should not have them, and yet the Chilean study notes that "antibiotics were present with highest frequency and concentrations in wild fish." The authors point at sewage as a source.

The presence of these compounds in marine creatures is not only undesirable for human consumption, but it contributes to antibiotic resistance as it enables pathogenic bacteria to develop defense mechanisms against it. "That's a breeding ground of antibiotic resistance," says Wear. "By not treating our waste properly, we are essentially breeding superbugs."

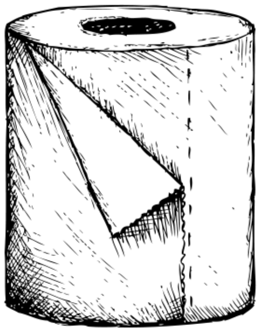


ANTIDEPRESSANTS

The use of antidepressants and anti-anxiety medications has been steadily rising worldwide, with the pandemic woes certainly adding to it. Recent studies show that fish are now swimming in them also. One Texas-based investigation found that fish that swam in creeks that received effluent from nearby sewage plants had Prozac and Zoloft in their tissues, mostly in brains and livers. In another study, a team of researchers examined fish in the Niagara River, which connects Lake Erie and Lake Ontario, absorbing effluents from several local wastewater treatment plants. The team found that the fish were on a "multi-drug regiment" that doctors would hardly ever prescribe together. The uncanny drug combo included Zoloft (sertraline), Paxil (paroxetine), Celexa (citalopram), venlafaxine (an antidepressant and nerve pain medication), and bupropion (an antidepressant and smoking cessation aid). "The highest bioaccumulation was found in the brain, followed by liver, muscle, and gonads, and can be attributed to direct exposure to WWTP effluent," the authors wrote. A more recent study went a step further and examined whether such chemicals affect fish behavior. Turns out some do—the fish on Prozac were less aggressive at chasing prey and eating it, which isn't a good thing for the species' survival.

TOP: DIVIART / SHUTTERSTOCK; BOTTOM: AVA BITTER / SHUTTERSTOCK

How much caffeine is deadly for aquatic species?

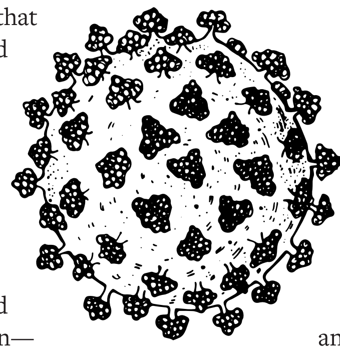


HUMAN WASTE

We may not think that bodily fluids have any use, but human waste is an excellent fertilizer, naturally full of three nutrients, nitrogen, phosphorus, and potassium, which plants use to build their cell walls, grow, and thrive. That works well on land, but not in water. The potent trio fuels the blooms of toxic algae that overgrow so much that they suck up all the oxygen from the water and release toxins as the byproduct of their lifecycle, killing fish, turtles, birds, and even marine mammals. Called HABs, for Harmful Algal Blooms, they are bad for humans also. The gasses they release while floating near beaches can cause respiratory problems, neurological damage, and even death.

That's not all. Our sewage effluent (and also agricultural runoff) causes eutrophication—an over-enrichment of the marine and aquatic environments. It triggers massive overgrowth of grasses in coastal marshes: The grasses grow taller, yet with weaker roots—because of the overabundance of nutrients they don't have to invest into their root systems. Yet, it's the roots that hold the marshes together, so when they're weak, the marshes fall apart, rot, crumble, and slowly turn into mudflats. Similarly, the mangrove forests end up with weakened root systems and start dying out. "Their canopies grow big and while they look healthy, their roots are not," Wear says. "When there is a big drought, they need healthy roots to stay and when they don't have strong roots, they die out." Healthy marshes and mangrove forests work as sponges, absorbing waves during high tides and storm surges, so in addition to serving as fish nurseries, they also protect us from floods. The destruction of such protective systems leaves coastal residents vulnerable to sea level rise.

HUMAN BACTERIA



We worry about zoonotic diseases spilling into us, but in this case, we are quite literally spilling our pathogens onto corals by way of inadequately treated effluent or storm overflows. In humans, *Serratia marcescens* is a pathogen associated with the gut environment, which can cause diarrhea as well as urinary, respiratory, and other infections. In the ocean, particularly in the Florida Keys and the Caribbean, *S. marcescens* sickens the already stressed-out coral reefs, giving them the so-called white pox disease, producing patches of dead white tissue. One study found that in the Florida Keys the elkhorn coral, *Acropora palmata*, is so severely affected that it loses about 2.5 cm^2 of its surface a day—about 70 percent is lost already.

WHAT CAN WE DO to turn that noxious tide? Experts say that the solutions lie in better sewage technologies and stricter environmental policies. On a more long-term scale, our environmental policies must become more aggressive at regulating chemicals. "So far, most countries have operated on the premise that chemicals are innocent until they're proven guilty—sort of like criminal law," says Landrigan. It takes a couple of decades to realize that some are causing harm, and then the public goes through multi-year battles to restrict their use, which is a backward way of doing business. We can stop the toxic tsunami if we are more conscious about what we approve, market, manufacture, and let flow down the drain, at homes, factories, and farms.

—Lina Zeldovich

LEFT: OLHA TURCHENKO / SHUTTERSTOCK; RIGHT: VIDIMAGES / SHUTTERSTOCK

AMANDA CARDEN / SHUTTERSTOCK

COMMUNICATION

How to Change Minds

One question for Lee McIntyre, research fellow at the Center for Philosophy and History of Science at Boston University. McIntyre is the author of The Scientific Attitude: Defending Science from Denial, Fraud, and Pseudoscience, *and* How to Talk to a Science Denier.

How do we get people who believe in pseudoscience to trust science?
We shouldn't be dismissive of people who believe in pseudoscience. In many cases they're victims who have fallen for disinformation that's been put forward by someone else, often people who stand to profit in some way. Most people don't consider themselves to be anti-science or science-deniers. They'll say things like, "I did my own research." They consider themselves to be picking up on something that has been tested and shown.

Maybe you've got a yoga instructor who teaches you about wellness and stress. That's terrific. Maybe they really helped you. But one day they start to voice anti-vax opinions, and so you take that seriously as well. And then you "do your own research" on the internet, and you find all these people who are worried about it. Then maybe you go to your doctor and mention it, and the doctor says, "I'm surprised at you. How could a thinking person take that seriously? It's ridiculous." Then your ego is hurt. At that point, watch a few more YouTube videos, go to an anti-vax convention, and you've got an anti-vaxxer on your hands. That's why it's important for people who believe in good peer-reviewed science to treat science deniers with respect, because you don't want to push them down that rabbit hole.

The appropriate pushback to people who have "done their own research" is to say, "Wonderful, we're talking about data here. You think you've got evidence which shows that this is the case? Let's take a look at that." You know what you're going to find. This is not a peer-reviewed study, it's been debunked, and 99.9 percent of the profession is on the other side. It's a case of them trusting the wrong people.

One tactic I've used is to say, "It sounds like you believe in science. You hold your beliefs based on the evidence." Invariably they say yes. "Then answer a question: What evidence, if it existed, would convince you that you were wrong?" See what they say. If they can't answer that, the next step is to point out they're not reasoning like a scientist. Scientists base their beliefs on evidence. If we recreated the experiment on which their beliefs were formed, and couldn't get the experiment to work, wouldn't that convince them they were wrong?

Ego is very strong. You can't convince somebody against their will. You can say the sky is blue and if they don't like you they're going to say, "No it's not, it's an optical illusion." It's a hard conversation because you're talking to people whose knowledge base is slight compared to scientists. It's like having an argument in the aisle of the plane over who should be flying it, the pilot or the guy in 37J. It's ridiculous. But the reality is that if you take seriously the idea that science deniers are victims and they've trusted the wrong people, then you can begin to undo some of that disinformation.

The same goes for scientists. When they go in there and say, "We know everything, we're scientists, trust us, your knowledge is a fly spec compared to ours," that's just not going to work. The most effective way for scientists to enter into this is to say we don't know everything, but here's what we do know, and here's why we know it. Here are the experiments that we've done. Here are the questions that we're still asking. Here's the work that we're still doing to try to nail down these remaining points. Expressing that kind of humility and embracing the uncertainty helps build trust rather than destroy it. It's only when you can get the person to listen to you that they'll listen to your information. If people can dig themselves into pseudoscience, they can dig themselves out.

—*Kevin Berger*

GEOSCIENCE

Are We Ready for the Next Massive Volcano?

MIKE CASSIDY was there in 2010 when Eyjafjallajökull, a volcano-covering ice cap in Iceland, erupted. Cassidy, a Ph.D. student at the time, had been invited on a research cruise by scientists studying the ocean. From the research vessel, he got an amazing view of the volcano as it was erupting. Lately, Cassidy's been mulling over the risks of large eruptions. He's an associate professor of volcanology at University of Birmingham, England, and currently a visiting fellow at the University of Oxford studying what makes eruptions dangerously explosive.

This August, Cassidy wrote an article in *Nature* headlined, "Huge volcanic eruptions: time to prepare." He co-authored it with Lara Mani, a research associate at the Center for the Study of Existential Risk at the University of Cambridge. The authors argued the massive eruption in January of the Hunga Tonga–Hunga Ha'apai volcano is a "wake-up call." They called it the "volcanic equivalent of a 'near miss' asteroid whizzing by the Earth." Yet it was relatively small compared to what's likely to come. How do we prepare for an eruption that isn't a near miss? *Nautilus* caught up with Cassidy to find out.

Why do you say the recent Tonga eruption was a wake-up call?

We first started really thinking about this a few years ago in the COVID-19 lockdown. We saw how countries were not that prepared. But then the biomedical community took monumental steps to get these vaccines and other treatments ready for us in record speeds. Lara and I talked to each other, and we said, "I really don't think that the volcanology community is that prepared and would fare as well as the biomedical community has." Then a year later, we saw this massive volcanic eruption that sent shock waves around the world. We'd never seen this before with modern day instruments. We saw this in Krakatoa in 1883 and it sent this tsunami, and this big ash cloud. Tonga only lasted a few hours but had all these huge effects. We were totally caught unawares. The closest seismometer was in Fiji, about 700 kilometers away. This volcano was erupting mildly, some little explosive eruptions, but they didn't

OLIVIER A. A. VANDEGINSTE / SHUTTERSTOCK

have the facilities or the know-how or the resources to monitor this. The satellite systems that we had weren't able to measure this properly in real-time to understand what was going on.

You've written that there's a 1-in-6 chance of a really large eruption this century. How big are we talking?

A magnitude seven. Mount Rinjani, which erupted in the 13th century, causing a mini ice age lasting several hundred years, was a magnitude seven. It caused famine across the world. It wasn't even a super eruption. Those super eruptions are 10 times larger. The odds of one occurring are about 1 in 170 this century. A really large eruption, one down from a super eruption, which could cause mass disruption, is a 1 in 6 in the next 100 years. It could cause cascading failures for lots of different things. And it would be great if it were taken more seriously.

How do you know the odds of a really large eruption are 1-in-6?

There's some recent studies that have looked at ice cores, both from Greenland and from Antarctica, from both poles. And they're able to pick out the volcanic eruptions in the ice cores, because they send out these really large peaks in sulfur. Once they see these large peaks in sulfur, they can date those large peaks in sulfur

> How do we prepare for an eruption that isn't a near miss?

and tell us how large these eruptions were, and how many there were for a given period. That gives us our frequency. What the ice cores don't tell us is which volcanoes were responsible for those eruptions. And that's where we really need to do the work.

The Tonga eruption didn't tick the box for the 1-in-6 chance this century?
No. That was actually 10 or even 100 times smaller than the ones we are talking about, eruptions that released more sulfur into the stratosphere than the Tambora eruption in 1815. And actually, because Tonga was slightly submarine, what that did is it stripped out loads of the sulfur that erupted, and perhaps it didn't have a big sulfur content in the first place. That's important because sulfur is the thing that really cools the air. The quirk of the Tonga thing is that because it erupted underwater, it vaporized a huge amount of sea water up into the sky. There's 10 percent of water in the stratosphere, which is never there. That water could have a warming effect on the globe in the next few years. This is something we never knew could happen. But it will fall out.

How can we prepare for massive volcanic eruptions?
There's lots of things you can do. Most volcanoes are not well monitored. If we're able to sense they're going to erupt, and we know that they could pose a big threat, then we could evacuate lots of people. There could be millions in some places—in Southeast Asia, there's tens of millions of people living within 50 kilometers of a volcano. Or we could at least educate them and make them ready for these large sorts of eruptions. That already mitigates a large amount of the loss of life, but not just loss of life. We're also talking about all the cascading effects that happen from that. You can limit the damage done to a country's infrastructure—their electricity network, trade, water, and food systems—with prior knowledge. We can also pinpoint where the risks are and increase the monitoring of those particular volcanoes.

—Brian Gallagher

PSYCHOLOGY

Don't Give Up on Facts

CYNICS SAY that bringing new facts to light will not change anybody's opinion. Some say that the reported "facts" that people believe are based not on evidence and reason, but on partisanship. That when someone hears something, be it through news broadcasts or social-media rumors, whether they believe it or not depends on whether it supports their political views. What reasoning ability we have, some scientists say, is used to justify beliefs we already have, rather than to arrive at those beliefs in the first place: Like a lawyer, reason shores up evidence for a view that has already been decided by other mental processes.

Is the situation really that bad? Is there no point in trotting out evidence if it won't change people's minds? Recent research on how people consume and react to fake news is opening up space for some optimism. Psychologists Gordon Pennycook and David Rand, for example, have been looking at the role of reason, previous knowledge, and the strength of a person's partisanship to see how much each factor might affect their susceptibility to false news stories. In a 2021 paper, "The psychology of fake news," they reviewed the latest studies on why people fall for and share misinformation. They found that the common narrative about why people fall prey to fake news isn't quite right. People

failing to tell false or misleading news from the truth isn't a symptom of political polarization in a "post-truth" world.

What is uncontroversial is that people are more likely to believe news content that supports their political view of the world. For some, this alone counts as evidence of partisan bias affecting reasoning. Pennycook and Rand note, however, that other influences can explain this. For example, whether we accept new information depends on the beliefs that we already have. When we encounter some new information that violates what we already believe, we have stricter criteria for accepting it. This is not bias—it's a sensible thing to do. A widely accepted formal structure of reasoning used in artificial intelligence is Bayesian reasoning, which explicitly incorporates influences of "priors"—the prior beliefs you have—when evaluating the truth of new information. So when somebody disbelieves something true, or believes a piece of fake news, it might not be their *reasoning* that is impaired. Their reasoning might be functioning as it should, but because of their prior beliefs, they end up arriving at false conclusions.

Another route to false beliefs is not reasoning at all. People who are more reflective can better discern truth from falsehood in new information, and this is true whether the information is concordant, or aligned, with their politics or not. In fact, simply asking people to reflect on the probability of information being true significantly increases their chances of being able to tell if it is. A 2021 *Nature* study from Rand, Pennycook, and their colleagues showed that prompting people to reflect on the accuracy of information before deciding whether to share it on social media reduced sharing of false headlines by 51 percent. Around half of the fake news people end up sharing might simply stem from their inattention to whether something is true or not.

ETIAMMOS / SHUTTERSTOCK

Thinking about accuracy can help reduce the spread of fake news.

Fighting fake news presents challenges. One of the biggest problems is that there is too much news content for human fact-checkers to comb through. If fact-checkers flag a particular news story as likely to be fake, that will make people more skeptical of that particular article. But there's a trade-off: The existence of some warnings might make people uncritically believe any news *without* the warning. They might see a lack of a warning as a sign that it has been fact-checked, when in fact it is practically impossible to fact-check everything on the internet.

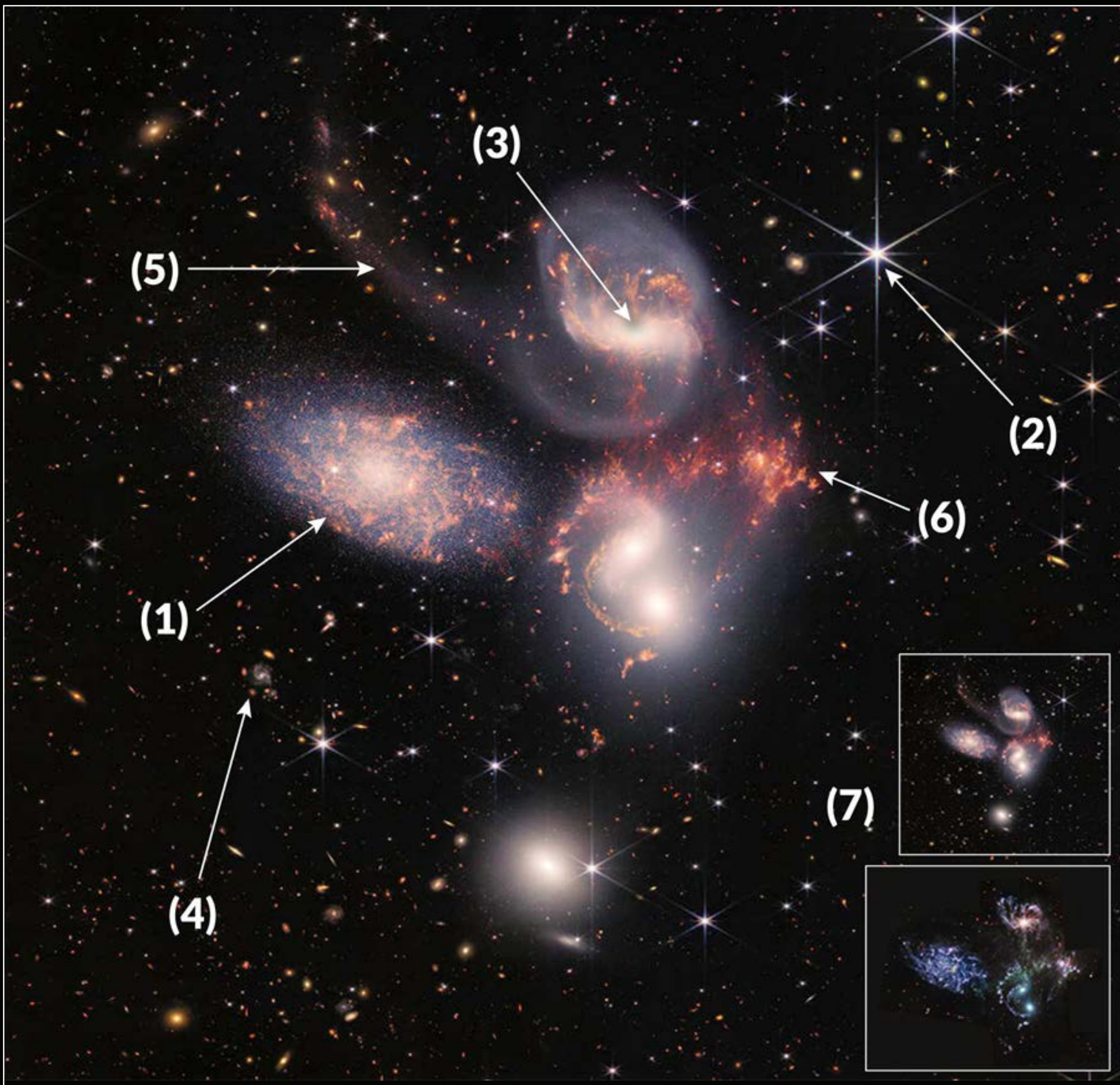
But Pennycook and Rand's findings suggest a practical solution that can scale: prompting people to *consider* the truthfulness of a news item before sharing. "Political identity and politically motivated reasoning," they write, "are not the primary factors driving the inability to tell truth from falsehood in online news." So, thinking about accuracy can help reduce the spread of fake news. This requires no oversight by a human fact-checker. It instead relies on the reasoning ability of the news consumer.

We shouldn't give up on using facts to right people's beliefs. Information can indeed help people reach better conclusions about the world. In general, people more often believe information that's true even if it doesn't fit their politics than false information that flatters their worldview. People's reasoning isn't that bad—they just sometimes need a nudge to use it.

—*Jim Davies*

A Mirror of Our Best Selves

BY CALEB SCHARF



NASA

THE JAMES WEBB SPACE TELESCOPE'S first scientific images have included some of the deepest and most beautiful views of the cosmos, together with some stunning vistas of stellar birth and death, but for me it's what is reflected in these views that perhaps matters the most. They are proof positive the universe gives rise to structures capable of turning around and staring back at the universe.

A standout among JWST's first images is Stephan's Quintet, a collection of galaxies first discovered in the constellation of Pegasus by Édouard Stephan in 1877. This flamboyant collection is the prototype of what is termed a "compact galaxy group," a remarkably tight-knit ensemble where galaxy-on-galaxy collisions and gravitational interactions are writ large. Here are seven highlights that help us (and the universe) decode the scene.

Odd one out: This galaxy (NGC 7320) is a mere 40 million light-years from Earth and a foreground interloper, whereas the others of the quintet are genuinely physically associated with each other and are 290 million light-years from our solar system. The exquisitely ruffled texture in JWST's image of this more nearby galaxy comes from zones of star formation and heated dust as this galaxy experiences its own chapter of agitated evolution.

1

Like sparkling ornaments, stars that are in our own Milky Way muscle their way into the foreground of the picture the way that trees in a forest do. Their spiky appearance is caused by the diffraction of light around the edges of JWST's 18 hexagonal mirror segments, and is a unique signature of this telescope.

2

This brilliant emission of light at the center of galaxy NGC 7319 is as luminous as 40 million suns and is the result of matter streaming toward a supermassive black hole 24 million times more massive than our sun: an event of galactic gluttony that plays out across the universe in many other galaxies as well. JWST's spectroscopic instruments are also able to probe the light of this streaming material, revealing hot and cool gas as well as the signs of a shroud of microscopic silica dust, a tenuous interstellar beach perhaps awaiting spiraling erosion into the black hole.

3

Usurped by the grandeur of the quintet's prominent galaxies there are serendipitous images of hundreds of other galaxies from farther out in space and time, filling in this tiny piece of cosmic wallpaper and providing a testament to the remarkable sensitivity of JWST that they are "simply" there, unassuming and modest yet containing hundreds of billions of other stars and worlds.

4

Glowing tails containing billions of stars have been stripped from this galaxy by gravitational tidal forces not unlike the tides on Earth (except here the culprit is a smaller, passing galaxy not seen in this image), about 100 million years before the light of this image set off toward us. Maybe these stars will themselves form new dwarf galaxies or simply disperse into intergalactic space.

5

Intergalactic gas is colliding in the region of this complex red and gold arc as the galaxies bump up against each other at speeds of over 550 miles per second. That gas, shock-heated to millions of degrees is not directly visible here, instead JWST is capturing the glowing details of the messy aftermath where the collision has triggered the formation of new stars and hydrocarbon-rich dust across tens of thousands of light-years of space.

6

The main image is a composite of separate images taken in different infrared "colors"—some in the near infrared (shorter wavelengths of light) and some in the mid-infrared (longer wavelengths of light)—representing the unique capabilities of JWST. The near infrared image (upper right) doesn't capture the intense activity of glowing dust caused by shockwaves that the mid-infrared does (bottom right), but together they create a visual symphony of this entangled bank of galactic evolution.

7

Under Anesthesia, Where Do Our Minds Go?

To better understand our brains and design safer anesthesia, scientists are turning to EEG

BY JACKIE ROCHELEAU

AFTER EXPERIMENTING ON A HEN, his dog, his goldfish, and himself, dentist William Morton was ready. On Oct. 16, 1846, he hurried to the Massachusetts General Hospital surgical theater for what would be the first successful public test of a general anesthetic.

His concoction of sulfuric ether and oil from an orange (just for the fragrance) knocked a young man unconscious while a surgeon cut a tumor from his neck. To the onlooking students and clinicians, it was like a miracle. Some alchemical reaction between the ether and the man's brain allowed him to slip into a state akin to light sleep, to undergo what should have been a painful surgery with little discomfort, and then to return to himself with only a hazy memory of the experience.

General anesthesia redefined surgery and medicine, but over a century later it still carries significant risks. Too much sedation can lead to neurocognitive disorders and may even shorten lifespan; too little can lead to traumatic and painful wakefulness during surgery. So far, scientists have learned that, generally speaking, anesthetic drugs render people unconscious by altering how parts of the brain communicate. But they still don't fully understand why. Although anesthesia works primarily on the brain, anesthesiologists do not regularly monitor the brain when they put patients under. And it is only in the past decade that neuroscientists interested in altered states of consciousness have begun taking advantage of anesthesia as a research tool. "It's the central irony" of anesthesiology, says George Mashour, a University of Michigan neuroanesthesiologist, whose work entails keeping patients unconscious during neurosurgery and providing appropriate pain management.

Mashour is one of a small set of clinicians and scientists trying to change that. They are increasingly bringing the tools of neuroscience into the operating room to track the brain activity of patients, and testing out anesthesia on healthy study participants. These pioneers aim to learn how to more safely anesthetize their patients, tailoring the dose to individual patients and adjusting during surgery. They also want to better understand what governs the transitions between states of consciousness and even hope to crack the code of coma.

Monitoring patients' brains still isn't something that medical boards require.

YOUR BRAIN ON ANESTHESIA

Today's anesthetic arsenal eschews Morton's original formula for newer, safer drugs. These include ether-based inhalants such as sevoflurane and isoflurane, and the widely used, intravenous anesthetic propofol, all of which wear off faster than early ether-based anesthetics, enabling quicker recovery. (They are also less likely to cause fires and explosions in the operating room, a regular occurrence through the first half of the 20th century.) Despite these improvements, the risks associated with excessive sedation remain high. Depending on the complexity and length of surgery, between 17 and 43 percent of patients may have cognitive problems, typically in memory and executive functions.[1] These typically last only one to two weeks after surgery, but few rigorous studies have examined changes in cognitive function in the general population beyond six months after surgery. For adults over 65, the most common surgical complication is post-operative delirium, which manifests as inattention and either disorganized thought or altered levels of consciousness. Delirium can last from a few hours to several months and may be an independent risk factor for longer-term cognitive decline.[2] Delirium is also preventable in 4 out of 10 patients with pre-surgery cognitive evaluations and monitoring of blood biomarkers and EEG during surgical procedures, according to the American Society of Anesthesiologists' Perioperative Brain Health Initiative, a national nonprofit that aims to promote brain health for older adults during and after surgery.

Some studies have shown that the risk of long-term cognitive damage and post-op delirium is highest for those who already have underlying cognitive vulnerabilities, such as Alzheimer's or mild cognitive impairment, says Paul García, associate professor of anesthesiology at Columbia University, but so far there is no consensus. The risk factors remain unclear at least in part due to varying definitions of post-operative cognitive dysfunction used in studies.

A tiny subset of patients[3] (about 1 or 2 in 1,000, although estimates vary) have reported "accidental awareness," recalling some experience of their medical procedure during general anesthesia. For many patients, researchers point out, the experience is strange but inconsequential. However, about 50 percent of those patients have reported traumas that stick with them years later and have been shown to cause long-term psychological damage and even post-traumatic stress disorder. The risk of awareness on the operating table seems to be highest when anesthesiologists need to limit anesthetic doses to protect their patients, such as when heart rate or blood pressure are already threatened following traumatic injury or emergency C-section. There are also milder and more temporary side effects of anesthesia, such as vomiting and drowsiness.

Unlike the 1846 demonstration, when Morton merely administered the anesthetic and stepped aside for the surgeon, today anesthesiology entails maintenance: Clinicians are required to monitor the patient's vital signs, like heart rate, blood pressure, and body temperature throughout the operation, adjusting dosages as needed. But monitoring patients' brains still isn't something that medical boards require or that medical schools train anesthesiologists to do in the operating room.

PAGES 20-21: AGSANDREW / SHUTTERSTOCK

COUNT BACKWARD General anesthesia redefined surgery and medicine, but over a century later it still carries risks, including the experience of "accidental awareness" on the operating table, reported by about 1 in 2 of 1,000 patients.

SERGEY MIRONOV / SHUTTERSTOCK

SIGNAL TO NOISE

Scientists have known since the 1940s that raw electroencephalogram, or EEG, signals could be used to monitor the depth of a patient's anesthesia-induced sleep. In the 1990s, they began to crunch this raw data to deliver a numerical index value thought to measure an anesthetized patient's level of consciousness. But the practice of actually tracking patients' brain activity with EEG in the operating theater is still so rare that little data is available on how widespread it is. Renowned anesthesiologist Emery Brown began using EEG to track patients' brain waves—shorthand for electrical activity in the brain—in 2011. He estimates that over the past three years, a quarter of his fellow anesthesiologists at Massachusetts General Hospital have also begun using EEG monitoring.

EEG records the electrochemical activity between communicating neurons in the brain. As the brain lapses into anesthetic-induced unconsciousness, this activity follows a predictable pattern of sequences. Through electrodes stuck to the scalp, EEG records these sequences, which are then visualized as spiky waves on a monitor. When a patient is under general anesthesia, typically the waves crest more slowly with greater amplitude as the drugs disrupt connections between networks that keep us awake and aware. For example, propofol enhances inhibition of cortical neurons and disrupts communication across the cortex, the hub of complex functions like thinking and making sense of stimuli from the environment. It also dampens communication between the cortex, the brainstem, and the thalamus, an egg-shaped collection of neurons deep within the brain important for sensory information processing and arousal.

Brown and his colleagues have been experimenting with adjusting anesthetics according to what they see on EEG monitors. “You can actually see, based on the patterns, how unconscious someone is and you can dose your drugs accordingly,” says Brown. For example, with propofol, anesthesiologists can watch for brain waves to transition to higher amplitude, lower frequency oscillations, such as alpha and slow-delta rhythms, which signal their patient is sufficiently anesthetized and unconscious. If the patient goes too deep, the EEG becomes flatter, or slips into a potentially dangerous pattern called burst suppression, which tells the anesthesiologist to ease up on the dose. Burst suppression, indicated by a nearly flat line of suppressed activity interspersed with bursts of activity on EEG, is found in patients with inactivated brain states, such as coma or hypothermia. How easily someone slips into and out of burst suppression is influenced by age and brain health.

Not everyone is convinced that EEG monitoring will make a difference. Clinical trials testing whether EEG-guided dosing helps patients go under and recover better have so far produced mixed results,[4] but more studies are underway. It’s possible that the conditions necessitating surgery and inflammation from surgery’s toll on the body could also share responsibility for any long-term effects on cognition.[5]

One potential obstacle to successful EEG monitoring is that the technology commonly used by those who do track brain activity relies on proprietary algorithms to process raw data and produce an index value. Some, including Brown, feel this number oversimplifies the complexity of the relationship between brain waves and the anesthesia. Due to the proprietary nature of the algorithms, it’s also hard for other scientists to evaluate the indices. The most popular EEG index tool, the Bispectral Index Monitor, was introduced in the ’90s. It uses something called bispectral processing to determine the relationship among the various EEG frequencies and then measures this value against clinical EEG and behavioral data to provide an index of a patient’s level of sedation. But it doesn’t account for the ways the brain’s response to general anesthesia changes with age,[6] and so may not be as accurate in older patients.[7] An index, García says, “really won’t tell you much about brain health under anesthesia.”

General anesthesia redefined surgery and medicine, but over a century later it still carries significant risks.

Raw EEG data may be more useful, García and others believe. Some studies published in the past decade have found links between raw EEG patterns, like burst suppression—the near-flat line of quieted neurons interrupted by spurts of neuronal chatter—and delirium or other cognitive issues post-surgery among older patients.[8] In a study of 626 people ranging in age from 44 to 71, García and his colleagues saw that patients who showed burst suppression after they lost consciousness, during the maintenance phase of general anesthesia, were nearly twice as likely to experience delirium after waking up.[9]

Outside of the operating room, researchers have also begun conducting experiments by administering general anesthesia to healthy people who are not undergoing any kind of surgery. Studying what happens when they emerge from their anesthesia-induced sleep can provide a roadmap of how the brain should recover. Mashour and his colleagues have found that the healthy brain bounces back quickly, within just a few hours. They’ve also found that some higher, more complex functions, like executive function, are the first to return.[10]

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HOW TO LASSO A CLOUD

An anesthesiologist on the art of putting you under

JAY PRZYBYLO, a practicing anesthesiologist, has been putting people into states of coma and paralysis, denying their memories and stealing their time, as he puts it, for decades. In 2017, Przybylo published a vivid and thoughtful book, *Counting Backwards: A Doctor's Notes on Anesthesia*. One of the book's attractions is that Przybylo details the art of putting people under. That entails the five "As": *Anxiolysis*, relieving stress created by an upcoming surgical procedure; *Amnesia*, preventing memory formation during anesthesia care; *Analgesia*, relieving pain during and after the procedure; *Akinesia*, preventing a patient's movement during a procedure; and *Areflexia*, stopping adrenaline surge and swings in blood pressure and heart rate while under anesthesia. I loved how Przybylo described the final stage, and in a recent interview about his thoughts on his practice, I asked him.

You say areflexia is like lassoing a cloud. Why is it so hard?

The deeper you get with anesthesia, the more you lose these vital signs: breathing, blood pressure, heart rate. They kind of drift off, and so you have to be on your toes to pull them back in and keep them stable. You want the patient to be breathing. You want the patient to have a stable heart rate. You want the patient to have a stable blood pressure. But blood pressure isn't always related to the heart rate. It's related to the resistance in the blood vessels, and anesthetics can release that resistance, causing your blood pressure to drop. So it's a very delicate balance and a moving target.

Have you ever had a patient in your care recall being under?

I've asked a lot of patients this. When you're anesthetized, it's very quick. You often hear the phrase "lights out." But the reverse is more of a process. It doesn't happen in a matter of seconds. It happens in a number of minutes or possibly a little bit longer, depending upon what you've received. So some patients, as they're emerging from anesthesia, before they're fully awake, before they're opening their eyes and focusing, they are hearing things, and what they describe to me typically sounds like what a person would hear in the recovery area.

I have not had anyone experience recall during a procedure itself, but I've read the reports. It really depends on the drugs a patient receives. Some of the drugs are very good on memory, but very poor on pain. And so you have to cover all bets. Every once in a while, you'll see a lawsuit that winds up in a journal or a paper from a patient who was not appropriately anesthetized and the surgeon said something about the patient and they take it to court. They'll win a lawsuit on that every time.

There's debate in the field about whether general anesthesia disrupts memory formation or memory retrieval. What do you think?

We have no idea what the difference is between past memories and current memories, in terms of where they're stored. But there's no evidence that anesthesia impacts future memory or past memory. It only impacts memory of the moment. Let's say you have a cell in the hippocampus that has a lineup of switches that can be flipped to form a memory. If you stop the cell from

working, then nothing can flip the switch. If the patient is not sufficiently anesthetized, the cell is still working and that switch can still be flipped to form a memory. That's when you get recall. So, yeah, I believe it's memory formation that is disrupted, not retrieval.

But I still have questions about how past memories are retained after anesthesia. For example, if I anesthetize a patient for a heart transplant, they are going to be completely lights out. They cool the patient down dramatically, to the point where everything stops. There's absolutely no blood flow for a period of 40 minutes or so. The patient has no vital signs of any sort. By every measurement, that patient is dead on the table while the new heart is being sewn in. And yet, when you wake the patient up, they still have memory. So the question is, how is memory retained? This is a question that has not been resolved.

A cell is a living thing and there's all kinds of things going on inside that living cell, from reproduction to metabolism, to everything else. There's also some memory inside that cell. Under anesthesia, I can electrically turn that cell off. I can chemically turn it off. And yet that memory still comes back. And that leaves me thinking that there's a mechanical switch in that cell that allows it to retain memory, and that switch stays flipped until something reverses it.

You're talking about experiences prior to the surgery, right?

Right. A patient comes back and they recognize who they are. They recognize everybody around them. They speak. It's utterly baffling to me. I think I'm getting a handle on it, though. We have the advantage of being in the computer age. You unplug your computer and put it in your backpack, and you go to a coffee shop or a library. You turn the computer back on and the memory is still there.

The patient is dead on the table while the new heart is being sewn in.

There was no electricity flowing, but the memory is still there. The computer scientist says, Well, there's a bunch of zeros and ones, and this and that, but they don't give you the full answer. A switch is on or off in computers. It's one or zero, but it's a mechanical switch. It doesn't rely on electricity. It just works automatically on its own, whether on or off. I think what's happening in the brain is that your memory is stored with a number of switches that are turned one way or the other. And it doesn't matter if there's blood flowing, or if there are chemicals flowing. It doesn't matter if there's electricity, it still stays. I'm leaning toward that explanation. But I don't know how you could possibly prove it.

What have your decades of putting people under taught you about the nature of consciousness itself?

[Laughs] Not a whole lot. It's taught me how to turn it off and it's taught me how it comes back on, but it really hasn't taught me how it actually works.

—Kristen French

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In some of these states of unconsciousness, awareness of the self and the body remains intact.

Among 30 participants who underwent general anesthesia for three hours and completed cognitive tests in the following hours, abstract problem-solving skills, largely coordinated by the prefrontal cortex, appeared to recover first, while attention and reaction time recovered more slowly. Within three hours, all mental functions returned to baseline levels and the anesthetized group performed no different from the comparison group. As the participants' cognition recovered, researchers also noticed a decrease in the frequency of a particular EEG rhythm, called the posterior dominant rhythm, which is set off when someone is resting, but awake, with their eyes closed. The researchers determined that changes in the frequency of this rhythm after general anesthesia could be a neural indicator of cognitive recovery. Though the researchers found this signal in healthy young people, it could be a potential biomarker to track recovery in surgery patients too,[11] which could help anesthesiologists mitigate cognitive problems.

GETTING UNDER THE HOOD

A better understanding of how patients wake from anesthesia and under what circumstances they struggle could also help scientists with an even knottier problem: how to treat disorders of consciousness, including coma. General anesthesia lends itself to studying these questions, as researchers can control the transition into and out of unconsciousness and track how brain activity changes as the anesthetic takes hold and wears off. Like anesthesia, coma seems to alter essential communication between different brain networks. For example, in both coma and general anesthesia, communication between the cortex and thalamus slows.

General anesthesia is "a very good tool to disentangle responsiveness and unconsciousness because you can play on the verge of these two," says Athena Demertzi, a research associate at the University of Liège in Belgium. "It's especially fascinating to see how these brain network configurations change in different states of anesthesia."

Researchers are already using anesthesia to test potential coma therapies. For example, ritalin, often prescribed for ADHD, has been found to bring rats back to consciousness after general anesthesia, possibly by stimulating dopamine signaling in the brainstem's ventral tegmental area, a node in arousal networks.[12] In people with coma from traumatic brain injuries, some of those connections may remain intact. Brown and his colleagues are testing whether Ritalin could spur the recovery of consciousness in such patients via those remaining connections, and are starting a phase I clinical trial.

In her work, Demertzi wants to see if there's a way to reach patients with consciousness disorders who may have some remaining connection to their environment, but cannot communicate. In some of these states of unconsciousness, awareness of the self and the body remains intact. One way to probe whether an unconscious person has a sense of such boundaries: Flush their ears with water.

In an upcoming study, Demertzi will give healthy volunteers general anesthesia while she monitors their brain activity via EEG and irrigates their inner ears with water. This perturbs the vestibular system, which sends information about the positioning of the body in space to the brain. In conscious people, water flooding the inner ears triggers rapid, involuntary eye movements and produces nauseating vertigo. But this reaction weakens after multiple repetitions once the brain and body habituate and learn what to expect.

Demertzi suspects that after she irrigates the ears of study subjects who have been anesthetized, they will exhibit brain activity consistent with vestibular upset, but that the response will attenuate after multiple rounds of ear irrigation. Ultimately the idea is to identify an EEG signal that tracks with this brain activity so that it could be used to determine someone's level of consciousness.

"Using anesthesia to study the brain is not a hot topic," but it should be, says Brown. The more we understand about what these widely used drugs do to the brain, the better we can take care of patients in all states of consciousness.

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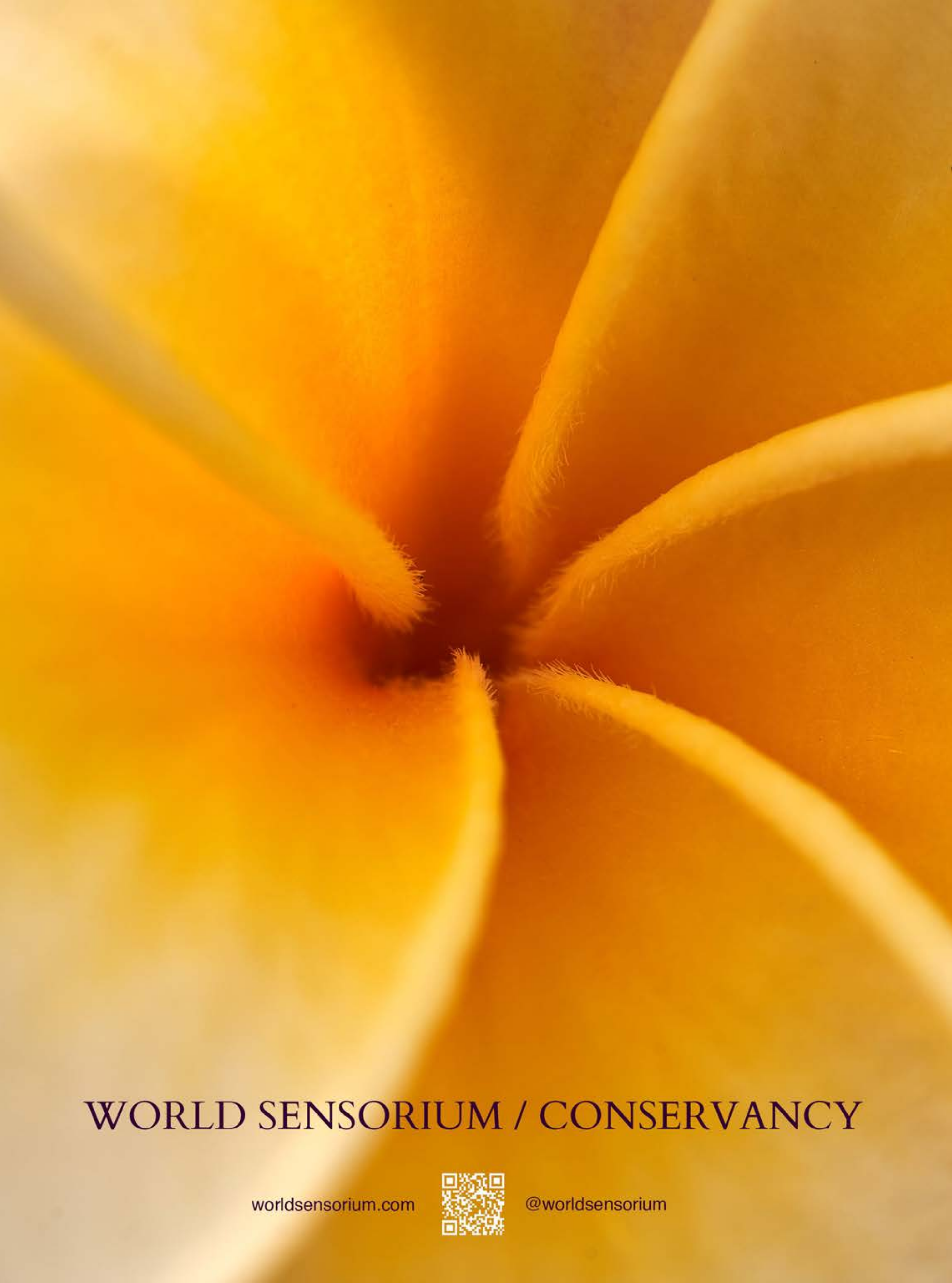
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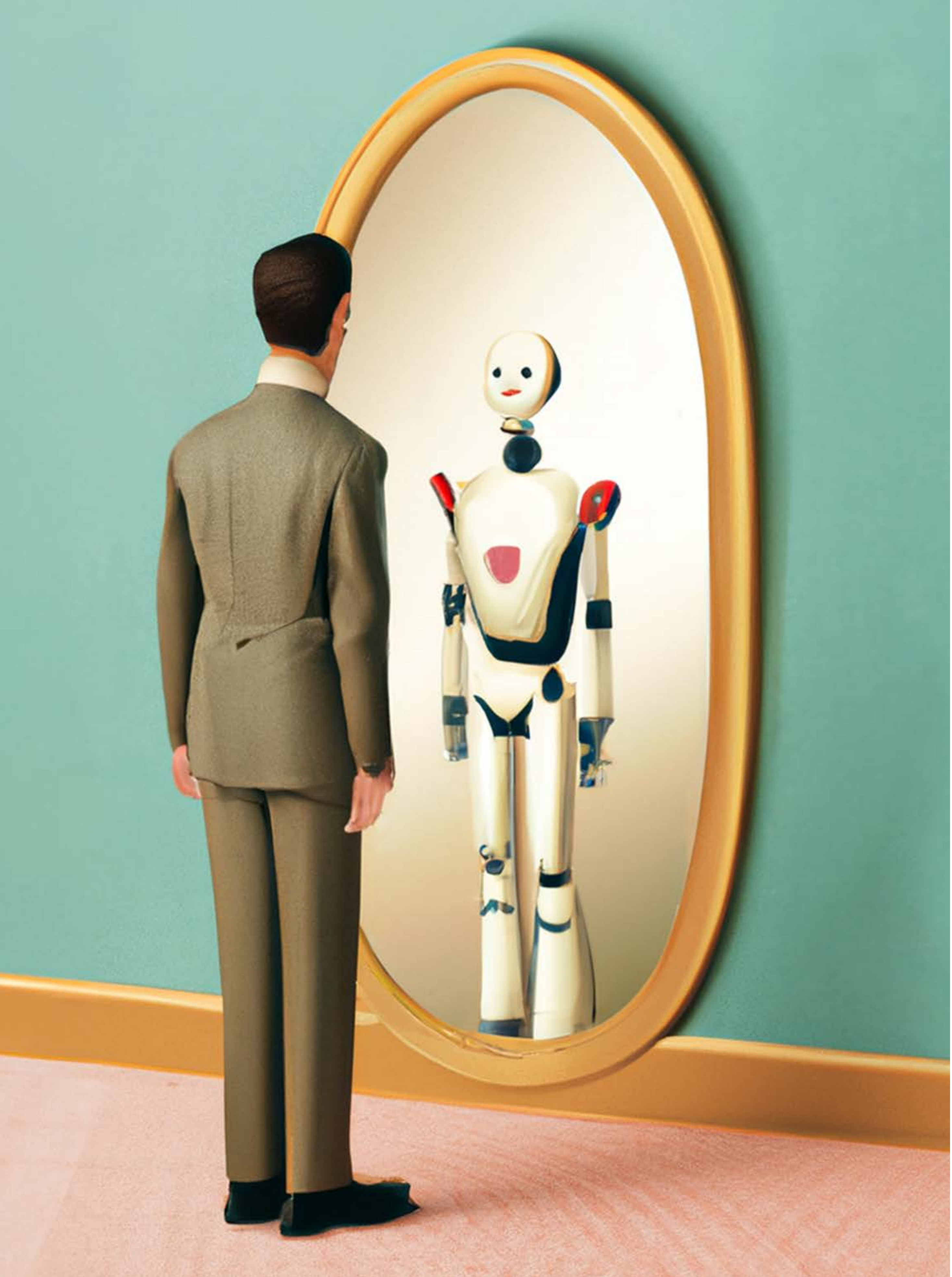

Moving Beyond Mimicry in Artificial Intelligence

What makes pre-trained AI models so impressive—and potentially harmful

BY RAPHAËL MILLIÈRE

IMAGINE ASKING A COMPUTER to make a digital painting, or a poem—and happily getting what you asked for. Or imagine chatting with it about various topics, and feeling it was a real interaction. What once was science fiction is becoming reality. In June, Google engineer Blake Lemoine told the *Washington Post* he was convinced Google's AI chatbot, LaMDA, was sentient. "I know a person when I talk to it," Lemoine said. Therein lies the rub: As algorithms are getting increasingly good at producing the kind of "outputs" we once thought were distinctly human, it's easy to be dazzled. To be sure, getting computers to generate compelling text and images is a remarkable feat; but it is not in itself evidence of sentience, or human-like intelligence. Current AI systems hold up a mirror to our online minds. Like Narcissus, we can get lost gazing at the reflection, even though it is not always flattering. We ought to ask ourselves: Is there more to these algorithms than mindless copy? The answer is not straightforward.

ILLUSTRATION BY **RAPHAËL MILLIÈRE WITH DALL-E 2**

> *We ought to ask ourselves: Is there more to these algorithms than mindless copy?*

AI research is converging on a way to deal with many problems that once called for piecemeal or specific solutions: training large machine learning models, on vast amounts of data, to perform a broad range of tasks they have not been explicitly designed for. A group of researchers from Stanford coined the suggestive phrase "foundation models" to capture the significance of this trend, although we may prefer the more neutral label "large pre-trained models," which loosely refers to a family of models that share a few important characteristics. They are trained through self-supervision, that is, without relying on humans manually labeling data; and they can adapt to novel tasks without further training. What's more, just scaling up their size and training data has proven surprisingly effective at improving their capabilities—no substantial changes to the underlying architecture required. As a result, much of the recent progress in AI has been driven by sheer engineering prowess, rather than groundbreaking theoretical innovation.

Some large pre-trained models are trained exclusively on text. In just a few years, these language models have shown an uncanny ability to write coherent paragraphs, explain jokes, and solve math problems. By now, all the large tech companies at the forefront of AI research have put big money into training their own large language models. Open AI paved the way in 2020 with GPT-3, which was recently followed by a flurry of other gargantuan models, such as PaLM from Google, OPT from Meta (formerly Facebook), and Chinchilla from DeepMind.

Other large models are trained on images or videos as well as text. In the past few months, some of these new "multi-modal" models have taken the internet by storm with their unforeseen abilities: Open AI's DALL-E 2 and Google's Imagen and Parti can generate coherent and stylish illustrations from virtually any caption; and DeepMind's Flamingo can describe images and answer questions about their content. Large models are also reaching beyond language and vision to venture into the territory of embodied agency. DeepMind designed a model, called Gato, and trained it on things like button presses, proprioceptive inputs, and joint torques—in addition to text and images. As a result, it can play video games and even control a real-world robot.

It is easy to be impressed by what these models can do. PaLM, DALL-E 2, and Gato have fueled a new wave of speculation about the near-term future of AI (and a fundraising frenzy in the industry). Some researchers have even rallied behind the provocative slogan, "Scaling is all you need." The idea is that further scaling of these models, or similar ones, might lead us all the way to AGI, or artificial general intelligence.

However, many researchers have cautioned against indulging our natural tendency for anthropomorphism when it comes to large pre-trained models. In a particularly influential article, Emily Bender, Timnit Gebru, and colleagues compared language models to "stochastic parrots," alleging that they haphazardly stitch together samples from their training data. Parrots repeat phrases without understanding what they mean; so it goes, the researchers argue, for language models—and their criticism could be extended to their multi-modal counterparts like DALL-E 2 as well.

Ongoing debates about whether large pre-trained models *understand* text and images are complicated by the fact that scientists and philosophers themselves disagree about the nature of linguistic and visual understanding in creatures like us. Many researchers have emphasized the importance of "grounding" for understanding, but this term can encompass a number of different ideas. These might include having appropriate connections between linguistic and perceptual representations, anchoring these in the real world through causal interaction, and modeling communicative intentions. Some also have the intuition that true understanding requires consciousness, while others prefer to think of these as two distinct issues. No surprise there is a looming risk of researchers talking past each other.

Still, it's hard to argue that large pre-trained models currently understand language, or the world, in the way humans do. Children do not learn the meaning of words in a vacuum, simply by reading books. They interact

Here's the thing about mimicry: It need not involve intelligence, or even agency.

with the world and get rich, multi-modal feedback from their actions. They also interact with adults, who provide a non-trivial amount of supervised learning in their development. Unlike AI models, they never stop learning. In the process, they form persistent goals, desires, beliefs, and personal memories; all of which are still largely missing in AI.

Acknowledging the differences between large pre-trained models and human cognition is important. Too often, these models are portrayed by AI evangelists as having almost magical abilities or being on the verge of reaching human-level general intelligence with further scaling. This misleadingly inspires people to assume large pre-trained models can achieve things they can't, and to be overconfident in the sophistication of their outputs. The alternative picture that skeptics offer through the "stochastic parrots" metaphor has the merit of cutting through the hype and tempering inflated expectations. It also highlights serious ethical concerns about what will happen as large pre-trained models get deployed at scale in consumer products.

But reducing large pre-trained models to mere stochastic parrots might push a little too far in the other direction, and could even encourage people to make other misleading assumptions. For one, there is ample evidence that the successes of these models are not merely due to memorizing sequences from their training data. Language models certainly reuse existing words and phrases—so do humans. But they also produce novel sentences never written before, and can even perform tasks that require using words humans made up and defined in the prompt. This also applies to multi-modal models. DALL-E 2, for example, can create accurate and coherent illustrations of such prompts as, "A photo of a confused grizzly bear in calculus class," "A fluffy baby sloth with a knitted hat trying to figure out a laptop," or "An old photograph of a 1920s airship shaped like a pig, floating over a wheat field." While the model's training data is not public, it is highly unlikely to contain images that come close to what these prompts (and many equally incongruous ones) describe.

I suggest much of what large pre-trained models do is a form of artificial mimicry. Rather than stochastic parrots, we might call them stochastic chameleons. Parrots repeat canned phrases; chameleons seamlessly blend in new environments. The difference might seem, ironically, a matter of semantics. However, it is significant when it comes to highlighting the capacities, limitations, and potential risks of large pre-trained models.

STOCHASTIC CHAMELEONS The center of this image was generated by DALL-E 2 with the prompt, "A talking chameleon made of circuit board." The generated image was then split into two parts and expanded on each side using DALL-E 2's "inpainting" feature, and the resulting images were reassembled into a single composite image using Photoshop.

ILLUSTRATION BY RAPHAËL MILLIÈRE WITH DALL-E 2

Their ability to adapt to the content, tone, and style of virtually any prompt is what makes them so impressive—and potentially harmful. They can be prone to mimicking the worst aspects of humanity, including racist, sexist, and hateful outputs. They have no intrinsic regard for truth or falsity, making them excellent bullshitters. As the LaMDA story reveals, we are not always good at recognizing that appearances can be deceiving.

Artificial mimicry comes in many forms. Language models are responsive to subtle stylistic features of the prompt. Give such a model the first few sentences of a Jane Austen novel, and it will complete it with a paragraph that feels distinctively Austenian, yet it is nowhere to be found in Austen's work. Give it a few sentences from a 4chan post, and it will spit out vitriolic trolling. Ask it leading questions about a sentient AI, and it will respond like one. With some "prompt engineering," one can even get language models to latch onto more complex patterns and solve tasks from a few examples. Text-to-image models respond to subtle linguistic cues about the aesthetic properties of the output. For example, you can prompt DALL-E 2 to generate an image in the style of a famous artist; or you can specify the medium, color palette, texture, angle, and general artistic style of the desired image. Whether it's with language or images, large pre-trained models excel at pastiche and imitation.

Here's the thing about mimicry: It need not involve intelligence, or even agency. The specialized pigment-containing cells through which chameleons and cephalopods blend in their environments may seem clever, but they don't require them to intentionally imitate features of their surroundings through careful analysis. The sophisticated eyes of the cuttlefish, which capture subtle color shades in the surroundings and reproduce them on the cuttlefish's skin, is a kind of biological mimicry that can be seen as solving a matching problem, one that involves sampling the right region of the color space based on context.

Artificial mimicry in large pre-trained models also solves a matching problem, but this one involves sampling a region of the model's latent space based on context. The latent space refers to the high-dimensional abstract space in which these models encode tokens (such as words, pixels, or any kind of serialized data) as vectors—a series of real numbers that specify a location in that space. When language models finish an incomplete sentence, or when multi-modal models generate an image from a description, they sample representations from the region of their latent space that matches the context the prompt provides. This may not require the sophisticated cognitive capacities we are tempted to ascribe to them.

Can pre-trained models offer a simulcrum of intelligent behavior?

Or does it? Sufficiently advanced mimicry is virtually indistinguishable from intelligent behavior—and therein lies the difficulty. When scaled-up models unlock new capabilities, combining novel concepts coherently, explaining new jokes to our satisfaction, or working through a math problem step-by-step to give the correct solution, it is hard to resist the intuition that there is *something more* than mindless mimicry going on.

Can large pre-trained models really offer more than a simulacrum of intelligent behavior? There are two ways to look at this issue. Some researchers think that the kind of intelligence found in biological agents is cut from a fundamentally different cloth than the kind of statistical pattern-matching large models excel at. For these skeptics, scaling up existing approaches is but a fool's errand in the quest for artificial intelligence, and the label "foundation models" is an unfortunate misnomer.

Others would argue that large pre-trained models are already making strides toward acquiring proto-intelligent abilities. For example, the way large language models can solve a math problem involves a seemingly non-trivial capacity to manipulate the parameters of the input with abstract templates. Likewise, many outputs from multi-modal models examplify a seemingly non-trivial capacity to translate concepts from the linguistic to the visual domain, and flexibly combine them in ways that are constrained by syntactic structure and background knowledge. One could see these capacities as very preliminary ingredients of intelligence, inklings of smarter aptitudes yet to be unlocked. To be sure, other ingredients are still missing, and there are compelling reasons to doubt that simply training larger models on more data, without further innovation, will ever be enough to replicate human-like intelligence.

To make headway on these issues, it helps to look beyond learning function and benchmarks. Sharpening working definitions of terms such as "understanding," "reasoning," and "intelligence" in light of philosophical and cognitive science research is important to avoid arguments that take us nowhere. We also need a better understanding of the mechanisms that underlie the performance of large pre-trained models to show what may lie beyond artificial mimicry. There are ongoing efforts to meticulously reverse-engineer the computations carried out by these models, which could support more specific and meaningful comparisons with human cognition. However, this is a painstaking process that inevitably lags behind the development of newer and larger models.

Regardless of how we answer these questions, we need to tread carefully when deploying large pre-trained models in the real world; not because they threaten to become sentient or superintelligent overnight, but because they emulate us, warts and all.

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The High Environmental Cost of Cheap Shrimp

Our appetite is destroying a natural bulwark against climate change

BY KATA KARÁTH

CRISTHIAN CASTRO SINKS KNEE-DEEP into grayish mud. The endless tangle of aerial roots around him makes mangrove trees look as if they are standing on legs, ready to run off at any moment. Castro, 39, has been navigating this muddy maze in Ecuador's Guayas River estuary six days a week for more than 25 years, hunting for delicious treasures. He is a *cangrejero*—artisanal crab catcher—and a fisherman, just like his father, and his father's father.

The value of Ecuador's shrimp exports is $5 billion, making it one of the shrimp capitals of the world.

"We, the people who are here, living by the riverbanks, in the mangroves, we have a great love for nature," says Castro. "Nature here has allowed us to dress and feed ourselves, and even that our children can study." Castro is the president of the Puerto Envidia Association of Crabbers and Fishermen, and his group, along with other artisanal fishing associations, is increasingly at the forefront of the fight to protect the estuary's ecosystem.

Spilling across approximately 4,600 square miles, the Guayas River estuary is the largest on the Pacific coast of South America. Its network contains 23 tributaries, dozens of small islands, tidal flats, and around 60,800 hectares of mangrove forests that jut into the Gulf of Guayaquil. The city of Guayaquil, with almost 2.7 million inhabitants, sits at the estuary's upper part, where the Daule and the Babahoyo rivers meet to form the Guayas.

Guayaquil is a city of superlatives: It's Ecuador's largest city, biggest port, most important economic hub—and it is also the planet's fourth-most vulnerable city to future flooding due to climate change.[1] According to Climate Central, an independent organization of climate scientists and journalists, most of the estuary and big chunks of Guayaquil could be underwater or regularly flooded by the end of the century unless the region improves its resilience. A 2013 study in *Nature Climate Change* estimates that even under a mild future climate scenario—about a 7.8-inch sea-level rise by 2050—the city's average annual losses from flooding could reach almost $3.2 billion, even if it bolsters its defenses.[1]

Guayaquileños were shaken to the core when the study came out, and the municipality has since been feverishly drawing up plans and protocols to protect the city, including revamping the city's waste management system to reduce street gutter blockage, constructing reservoirs, pumps, and walls, and creating more green spaces that would soak up excess water.

A key to climate resilience is the tangly mangroves. According to climate change researchers, ecologists, economists, and crab catchers like Castro, the tightly woven roots and branches of mangroves can blunt storms and large waves, and halt rising waters, providing a living line of defense against climate change for people, homes, and businesses. "In the entire regional ecosystem, the single most underpinning flora or fauna is the mangrove. It's the keystone species for the entire non-urban Guayas estuary system," says Stuart Hamilton, chair of the Department of Coastal Studies at East Carolina University in the United States.

Like estuaries around the world, the Guayas River estuary was born where the river meets the sea. In this tidal zone, the river's freshwater mixes with the salty ocean, resulting in brackish water which creates unique wetlands. Depending on geography and climate, many types of habitats can form in an estuary: salt marshes, mudflats, reefs, and, in the case of Ecuador, mangrove forests. Estuaries are nursing grounds for marine life, pitstops for migrating birds, and can capture massive quantities of CO_2 10 times faster—and store three to five times more carbon—than a tropical forest of the same size. As rivers deliver and distribute sediments, estuarine ecosystems act as natural dams, trapping the sand, clays, and gravel and mixing them with plants, roots, and other organic matter to literally build the soil they grow on, and—crucially for coastal communities and cities such as Guayaquil—to act as buffer zones, standing in the way of storms, floods, tsunamis, and rising sea levels.

The brackish shallows of the Guayas River estuary also make perfect breeding grounds for industrial shrimp farming—which has given birth to a major conflict. The booming international industry, important to the local economy, threatens the Guayas River estuary, along with the livelihood and culture of fishermen like Castro. As mangroves are logged to make way for shrimp farms, the estuary's natural bulwark against climate change is falling.

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ECUADOR'S LOVE AFFAIR with commercial shrimp farming started in the 1970s, as it did elsewhere in the world. The government gave out the first concession to turn a stretch of coastal land into a shrimp farm in 1975, and ever since, the industry's trajectory has gone through the roof.

Today, shrimp is one of Ecuador's main exports, along with crude petroleum and bananas. The value of the country's shrimp exports grew from $850 million in 2010 to $5.32 billion in 2021, making Ecuador, alongside India, one of the two shrimp kings in the world. A lot of these exports go to the U.S.: An average American eats more than 4 pounds of shrimp per year,[2] and 37 percent of it comes from Ecuador,[3] according to the National Oceanic and Atmospheric Administration, a branch of the U.S. Department of Commerce. Shrimp farming makes this level of consumption possible: Farmed shrimp is, on average, three times cheaper than wild-caught.

In a 2021 interview with *The Fish Site*, an aquaculture industry news outlet, José Antonio Camposano, the president of Ecuador's National Chamber of Aquaculture (CNA), which represents the country's shrimp and other aquaculture sectors, said that the shrimp farm industry, which employs around 261,000 people in the country, represented about 4 percent of the country's GDP in 2020.[4]

A shrimp farm needs a warm climate, a constant supply of brackish or sea water, and, ideally, no trees. Mangroves interfere with the efficient spacing of a shrimp farm's nurseries and "grow-out" ponds, where shrimp mature, complicating aeration and access. Around the globe, large-scale commercial shrimp aquaculture has often led to mangrove deforestation[5]—in Indonesia, for example, 70 percent of mangrove forests have been

SAFE HARBOR Fishermen in the mangroves of the Guayas River estuary. The tightly woven roots and branches of mangroves provide a living line of defense against climate change. But as mangroves are logged to make way for shrimp farms, the estuary's natural bulwark against climate change is falling.

damaged by commercial shrimp farming, according to the Global Mangrove Alliance—and Ecuador is no exception.

Between 1969 and 2018, about 70 percent of the more than 159,000 hectares of mangrove that once covered the Gulf of Guayaquil were lost, mostly to shrimp farms, according to Wendy Chávez, an economist and environmental management consultant from Guayaquil.[6] In 1999, Ecuador gradually began to introduce laws to protect mangroves. They are now the property of the state and can only be utilized sustainably via state-issued and regulated concessions. Fines for mangrove deforestation are more than $89,000 per hectare, and shrimp farmers are also required to carry out mangrove reforestation based on their size, between 10 and 30 percent of their concession land.

That's on paper. In practice, these laws and regulations are rarely implemented and the political favor skews in support of shrimp farmers. In April 2022, Ecuadorian President Guillermo Lasso issued a new decree that allows illegal shrimp farms to legalize with relative ease, even if they had previously cut down protected mangroves to make space. And illegal logging continues, says Geovanny Chalén, crabber and former president of the Río de Aguas Vivas artisanal fishing association. Between 2011 and 2021, Chalén's association reported 15 cases, including the deforestation of over 40 hectares on the island of Los Chalenes in 2020. "A lot of mangroves are still being destroyed," he says.

NO MANGROVES, NO CRABS Crabbers are not a priority for Ecuador. The Gulf of Guayaquil makes around $40 million annually from catching, selling, and preparing crabs, but only exports $81,000 to $108,000 a year. But many local fishermen depend on crabs, which are unique to the mangroves. Here, crabbers of the Guayas River estuary demonstrate their catch.

Leonardo Mariduena, CNA's environment director, wrote in a June 2021 article published in *Revista AQUACULTURA*, CNA's monthly magazine, that CNA reported instances of illegal mangrove loggings to the Ministry of Environment. "However," he continued, the mangroves are "a colonizing plant formation, which doesn't allow on many occasions access to water for the pumping stations. There is no other remedy than selective pruning, endorsed by the environmental authority." Despite repeated requests, CNA officials and shrimp industry representatives in Ecuador refused to comment for this article.

IN APRIL, I MADE the 250-mile journey from the capital, Quito, to see the estuary, its people, and the mangroves that connect and divide them. After descending through a cloudbank from the Andes on a serpentine road that seemed to go on forever, I'd ignorantly expected to see mangroves right away. Instead, I was greeted by fields of rice, banana, and cacao plantations,

KATA KARÁTH

all ruled by giant haciendas. One banana plantation even had its own private airport. Only when the road leveled out into a highway that runs parallel to the Churute Reserve could I squint to see in the distance the thin dark green line that was the edge of the mangrove forest.

> *Estuaries can capture CO_2 10 times faster—and store three to five times more carbon—than a forest of the same size.*

I turned left at a small roadside restaurant with a hand-scribbled sign that read "Crab Meat For Sale," and swiftly found myself in a land of contrast. Humble wooden shacks and kitschy multistory houses alternated along the dirt road. The air was hot and humid, laced with a faint smell of the sea. I passed a family swimming in a stream between rice fields, and another family taking a dip in a slick blue-tiled pool.

There are many small communities in the estuary,[6] some 10,000 people in total spread across the various islands. Some villages take up to two hours to reach by boat from Guayaquil. This isolation translates into a lack of everything—potable water, electricity, sewage system, schools, and health centers. "The municipality [of Guayaquil] argues that they are only responsible to cover the basic needs and services for the urban areas, and the communities in the Gulf of Guayaquil are located in the rural areas," says Chávez.

Lack of support from provincial authorities means that the rural folk rely on NGOs for generators or solar panels, and for water, on shrimp farms, which the farms deliver to the local communities as part of their effort to establish amity. Meanwhile, I took a wrong turn. Instead of the mangroves, I came face-to-face with a shrimp farm. There was pool after still pool, separated by narrow low dirt walls upon which sat generators and pipes that pumped nutrients into the water. Only a couple of warehouses broke the seemingly bleak landscape. Not a single tree in sight, mangrove or any other kind, but there was a watchtower, which, I was told later, was essential as shrimp thefts can rack up hefty damages.

In economic terms, crabbers are not a priority for Ecuador. Crabs are mostly sold domestically. The Gulf of Guayaquil makes around $40 million annually from catching, selling, and preparing crabs, while national exports amount to a meager $81,000 to $108,000 a year. Meanwhile, Castro and other artisanal fishermen depend on the survival of the mangroves. Many of the species they catch and collect, such as catfish, cockles, clams, but especially red crabs (*Ucides occidentalis*) and mouthless crabs (*Cardiosoma crassum*), are unique to the mangroves and the estuary. "No mangroves, no crabs." Hamilton sums up simply. "They're fundamental, so the more you lose of them, the more problems you're going to have with wild catch. Crabs are going to decrease, mollusks are going to decrease."

Castro's workday typically starts at 5 a.m. After a hearty breakfast of rice with chicken, fish, or seafood with a side of green plantain mashed with scrambled eggs, he sets out in his Ranger motorcycle from his home in El Mango, a community of a few dozen houses along the Troncal de La Costa highway, for a small, wooden pier just past the entrance of the Churute Mangrove Ecological Reserve, some 12 miles away. He started fishing and crabbing along the snaking estuary coastline at the age of 11, and has witnessed how the shrimp industry, like a tide that never ebbs, has been engulfing the labyrinthine mangrove forests to make way for painfully straight-lined shrimp breeding pools. He and his family used to live next to the mangroves, but the expanding shrimp farms forced them to move away.

The majority of the surviving mangroves have been divided under special mangrove concessions.[6] Theoretically, this grants members of crabber and fishermen associations unique access. In exchange, they must become custodians of the forest and carry out regular boat patrolling of the mangroves, especially to report deforestation. "It's very expensive," says Chávez. "The only way to do that is really pay for a lot of gasoline and go every day, on your own time."

Castro says associations have been diligently reporting mangrove logging for years, often taking videos and photos as evidence, but authorities have mostly

Mangroves are logged because they interfere with the spacing of a shrimp farm's nurseries and ponds.

ignored their reports. Besides, because there is barely any maritime patrol in the estuary, the concession agreements also mean that the associations are responsible for detaining and handling unaffiliated fishers and crabbers.

Under the Socio Bosque Program, which is connected to a United Nations-backed carbon-credit system that allows developed nations to maintain carbon-emission levels by paying developing countries to reduce deforestation, mangrove custodians are receiving some financial support. But the money—between $7,000-15,000 per year per custodian association, depending on the size of their mangrove forest—is far from covering the custodians' costs. Castro's association has such a concession, and when he goes crabbing he usually teams up with other crabbers and fishermen so that they can afford to rent a long, slim motorized canoe for $8 per day.

The way Castro and his fellow crabbers track down and catch crabs can only be described as art. But it's a very dirty kind of art: Crabbers kneel or lie down in the mud, thrust their arms, often shoulder-deep, into the dark tunnels where crabs live, and use long metal hooks to grab onto the animals and drag them out. They can tell which crab they want to catch just by looking at the holes. "We can tell it apart by the trail or footprint of the crab," says Castro. "Male crabs have a bigger footprint, they leave thicker trails, while the female has finer legs, so their footprints are not so defined on the ground." Artisanal crabbers also look for holes that are fist-sized or bigger because fishery regulations only allow them to catch males that are larger than 2.9 inches.

The surviving mangroves are helping safeguard the estuary, and, ironically, the shrimpers, from the pollution caused by shrimping. Studies by the University of Guayaquil[7] and the environmental group Acción Ecológica[8] show that the shrimp farms occasionally discharge untreated water full of biocides, antibiotics, and fertilizers containing nitrogen, phosphorus, and silicate.[9] This adds to the approximately 10 to 12 million cubic feet of domestic and industrial waste Guayaquil dumps into the estuary each day, according to a 2015 analysis by EMAPAG-EP, the city's municipal water and sewage company. The estuary mudflats accumulate and trap various toxins,[10] some of which—such as nickel and arsenic—are reaching alarming levels, reports a 2021 study published in the scientific journal *Foods*. Mangroves act as natural bio-filters, Hamilton explains, and without them, many pollutants would be left loose in the water. "You'll probably have more harmful alga blooms, more hyper-eutrophication on the water body, more fish kills, and lower water quality," Hamilton says.

In May, Castro, Chalén, and various leaders of crabber and fishermen associations from the Guayas River estuary met with Gustavo Manrique, Ecuador's Environment Minister, to discuss the illegal logging of mangrove forests—the first time an Ecuador minister of any kind has met with the crab catchers of the Guayas estuary. Manrique promised to launch an extensive investigation into past and current complaints and resolve the situation, at least in protected areas of the estuary.

Knee-deep in mud amid the snarl of mangrove roots, Castro tells me the meeting was promising. The fishermen had been given a voice in the fate of the estuary, but he remains skeptical about deep-rooted change. One thing is for sure, Castro says, his future, as well as the estuary's, hinges on a firm decision: to stay and fight.

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Are You a Naïve Realist?

Do you think you see the world objectively and others are biased?

BY ERIKA WEISZ & SARAH STAMPER

WHEN LEE ROSS, a professor of psychology at Stanford, explained to his students what his term "fundamental attribution error" meant, he loved to quote George Carlin. "Have you ever noticed that anybody driving slower than you is an idiot, and anyone going faster than you is a maniac?" The late comedian perfectly captured our tendency to attribute the world's problems to other people and not ourselves. I'm the only good driver on the road. Everybody else should drive like me.

THE REAL THING Lee Ross, who passed away in 2021, was a beloved professor of psychology at Stanford. He showed that the best inoculation against naïve realism—the illusion of personal objectivity—is a healthy dose of fact.

COURTESY OF JOSH ROSS / STANFORD UNIVERSITY

Have you ever noticed that anybody driving slower than you is an idiot?

Ross and his colleagues demonstrated that the fundamental attribution error was fed by the illusion of personal objectivity. In a 2016 Ted Talk, Ross joked that people "believe that their take on the world is the objective one, and what has to be understood or explained is, 'What is it about those other people that seem to get it wrong?' " Ross came to call this "naïve realism," the tendency for people to think they see the world objectively, as it is, free from personal bias.[1] Ross established three characteristics of the "naïve realist."

First, the naïve realist believes that their perceptions are realistic and "objective." Accordingly, other people (at least, reasonable other people) should share their beliefs, preferences, and convictions. Second, the naïve realist expects that any reasonable, open-minded person will be persuaded to agree with the naïve realist if there is disagreement between parties. If there is disagreement, and if the disagreeing party is a reasonable person, presenting the "real facts" should restore harmony. Third, anyone who disagrees with the naïve realist after the presentation of real facts is unreasonable, biased, or irrational.

Ross and his colleagues spent decades characterizing instances where the illusion of objectivity shaped how people think. In one of their studies, participants completed a questionnaire asking about their views on various hot button political issues such as abortion and capital punishment. The researchers collected and randomly redistributed the questionnaires among the participants. After reading a peer's questionnaire, participants indicated the level of similarity between their views and the peer's views. They also indicated the extent to which rational considerations (such as attention to facts) and sources of bias (such as wishful thinking, unreliable information sources, and peer-group pressures) influenced their peer's views and their own views.

Ross found that people thought their own views were shaped by rational considerations more than biased thinking. They also found that participants' evaluation of peers relied entirely on the perception of similarity between their views. When students read questionnaires of like-minded peers, they saw their peers as reason-driven, rather than bias-driven. Conversely, when they read questionnaires of peers whose views differed from their own, they attributed their views to sources of error rather than rational consideration.[2,3]

We've been thinking a lot about Ross lately. For one of us (Erika), Ross was a favorite professor, and his

We miscalculate the extent to which our opponents' viewpoints differ from our own.

death last year was a personal blow. What stood out for most people when they met Ross was his brilliance and readiness for humor. He was smart, attentive, and listened to his students. He cared deeply about growing the next generation of psychologists.

We also can't help thinking about Ross because of how accurately his theory of naïve realism applies to our lives and culture today. America has fractured into separate camps because people are convinced their views are objective while those who disagree with them are deluded. The early days of the COVID-19 pandemic were characterized by something resembling a shared reality, but the country quickly devolved into factions over the effectiveness of mask-wearing and social-distancing. Despite evidence to the contrary, nearly one-third of Americans still believe the 2020 presidential election was stolen.

As Ross showed, the best inoculation against naïve realism—the illusion of personal objectivity—is a healthy dose of fact, aggregated from non-biased sources with no skin in the game. But against the backdrop of a highly polarized political landscape, and a media environment flush with disinformation, it is exceedingly difficult to even know where to begin in de-biasing oneself.

RECENT STUDIES from the field of social psychology offer some breadcrumbs. For example, it turns out that simply raising awareness of cognitive biases helps people identify instances of bias in their own judgments and correct their thinking accordingly. In 2014, psychologists Eran Halperin and Meytal Nasie led a series of studies examining whether merely making people aware of naïve realism and its consequences could lay a foundation for compromise among Israelis and Palestinians. Participants were assigned to a control condition, or to an experimental condition in which they read a passage describing naïve realism and its consequences, which included the following excerpt:

> Naïve Realism is the human tendency to form one's own worldview regarding various subjects, perceived by an individual as the only truth. Accordingly the individual believes that other people's reluctance to share his or her views arises from ignorance, irrationality, an inability to draw reasonable conclusions from objective evidence, ideological biases, or self-interest. The psychological bias of naïve realism causes people to see the world in a unilateral and simplistic manner. As a result of this bias, people tend to ignore or reject any information that does not fit their pre-existing worldview, which is perceived by them as the only truth. Consequently, they fail to see things from several points of view and may miss opportunities for change and progress.

Participants in the experimental condition—in particular, those who held more hawkish political ideologies—reported greater openness to learning about the point of view of the rival group following this short intervention. Remarkably, this was true of both Israelis and Palestinians, offering a simple and intuitive strategy to set the stage for dialogue between parties in conflict.[4]

In a 2022 paper, Halperin, psychologist Lucía López Rodríguez, and their colleagues built off this finding. They wondered whether a similar intervention might help Europeans become more accepting of immigrants' cultural practices. In a series of experiments, European participants were randomly assigned to a control group or to an experimental group in which they read a passage similar to that used six years earlier by Nasie and colleagues. Then participants were given a battery of questions assessing their attitudes toward Moroccan immigrants; for instance, "I feel irritated when Moroccans speak their language around me," and "I do not understand why Moroccans keep their ethnic cultural traditions instead of trying to fit into the mainstream culture."

> I would unite with anybody to do right; and with nobody to do wrong.

Rodríguez and Halperin found—once again—that learning about naïve realism could be enough to buffer people from some of its most harmful effects. Participants who read about naïve realism reported greater acceptance of immigrants' cultural differences as compared to participants in the control condition.[5] And while it remains unclear exactly why this intervention works, Rodríguez and Halperin speculated that it has to do with the desire to maintain a positive self-view. "Realizing that our perception does not exactly correspond to reality could make it difficult to maintain an enhanced view of oneself," they wrote. "This reduction in self-enhancement, in turn, may lead to questioning our beliefs, including those about the superiority of the ingroup, which would pave the way to accept others' culture."

While learning about naïve realism might help us overcome *some* of our political animosity, it is naïve to expect that alone is sufficient to repair the fractures in our democracy. A problem of this magnitude requires more than just a shift in individuals' willingness to entertain others' perspectives. But it is a place to start.

What's more, there's reason to think that now might be a particularly important moment to venture past our own perspectives. Polls show that Americans have more in common than not. Research from YouGov and More in Common suggest that Americans miscalculate the extent to which their political opponents' viewpoints differ from their own. Democrats, for example, underestimate the extent to which Republicans think that properly controlled immigration can be good for America. Republicans, for their part, overestimate the extent to which Democrats think police are bad people.

Ross's decades of scholarship show that people reliably misunderstand others, especially those most different from themselves. Remaining vigilant to the threats of naïve realism, epistemic humility, open-mindedness, and patience might be the only remedy to what Ross and his colleagues called the illusion of asymmetric insight, the misperception that we know others better than they know us. And this, according to Ross and colleagues, "leads us to talk when we would do well to listen."[6]

Ross spent years in the field bringing the lessons of social psychology to bear on some of the world's most perilous conflicts. In work with Unionists and Nationalists in Northern Ireland, Ross and his colleagues developed an exercise that proved especially fruitful. Individuals from each side of the conflict were tasked with describing the other side's position back to them. And they were required to keep at it until the other side agreed that they represented it correctly. "This procedure initially proves difficult for all concerned and inevitably produces false starts," Ross wrote in 2018.[7] "Yet when the two sides finally are satisfied with the efforts of their counterpart, they feel greater empathy for each other, avoid the caricaturing of each other's views, and are on the road to a more thoughtful and less defensive exploration of future possibilities."

In one of his final papers, Ross reflected on the work of abolitionist Frederick Douglass, who, when asked about his willingness to discuss abolition with slaveholders, offered the following insight: "I would unite with anybody to do right; and with nobody to do wrong."[8] In the wake of ended friendships, fractured families, and with our democracy on the brink, Americans have a unique opportunity to ask themselves with whom they could partner to do good.

Most Americans also agree on one key issue: that democracy is imperiled, and America is at risk of failing.[9] While Democrats and Republicans diverge on the exact nature of the threat and how it should be addressed, this rare instance of agreement presents an opportunity for cross-partisan collaboration. For Americans of diverse ideologies and beliefs to find their way to the negotiation table, they must recognize and examine their illusions of personal objectivity, armed with what social psychologists Jay Van Bavel and Dominic Packer referred to as Ross' Golden Rule: "Proceed from the naïve but charitable assumption that when people respond in ways that are surprising or offensive, it is generally their perceptions, assumptions, and construals, rather than their basic values, that differ from our own."[10]

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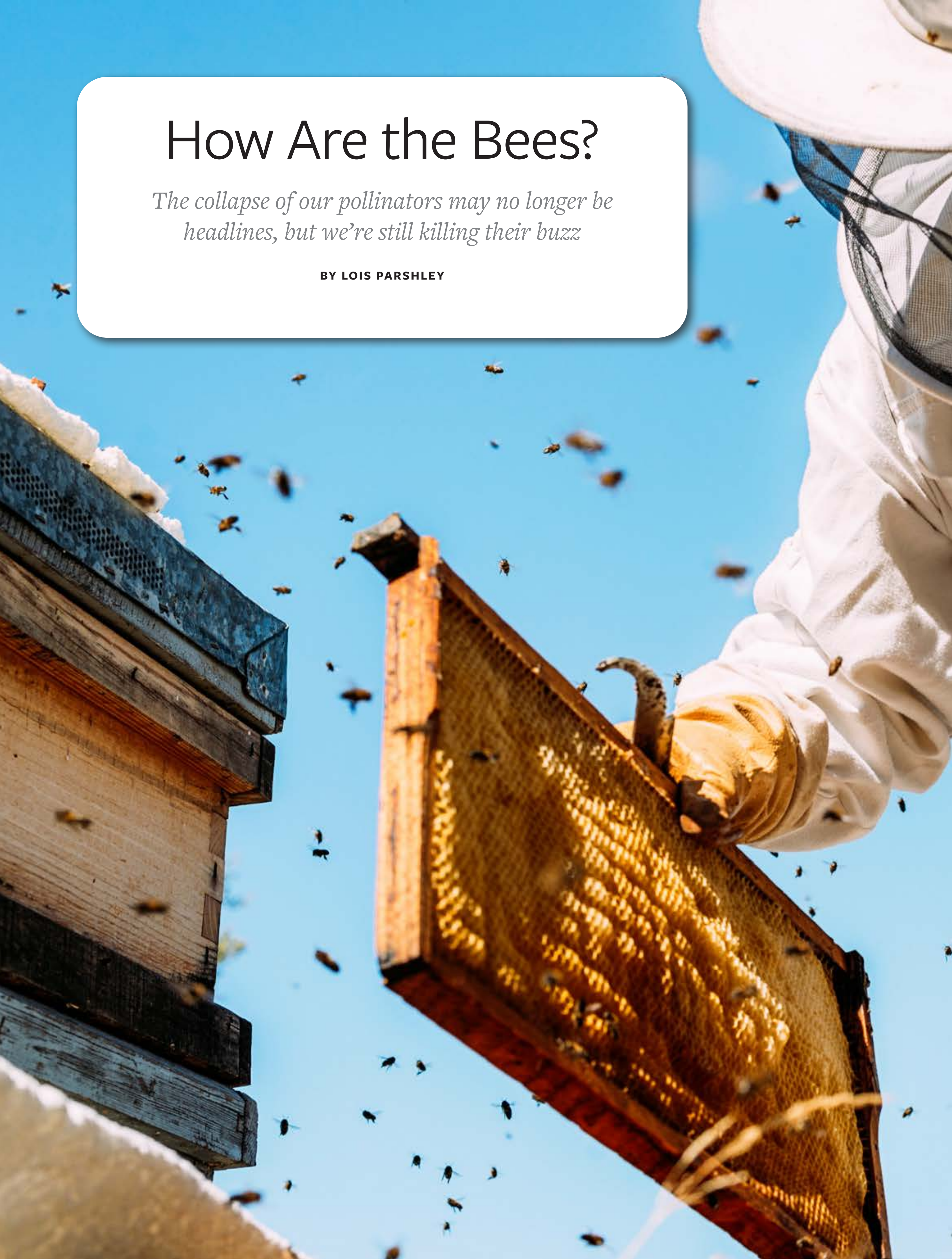
How Are the Bees?

The collapse of our pollinators may no longer be headlines, but we're still killing their buzz

BY LOIS PARSHLEY



CHELSEA COOK GREW to love the low hum of the honeybees she studied as a graduate student in Boulder, Colorado. Their characteristic buzz, she learned, was audible cooperation, the result of worker bees fanning their wings at the colony's entrance to circulate the air and cool the hive. Cook often watched as the insects responded quickly to minute adjustments in temperature: When a cloud drifted over the sun, the fanners disappeared, and when it emerged again, they promptly took up their places.

Fascinated by how strictly the insects were managing their environment, Cook conducted an experiment. "I found an old hot plate and a pickle jar, created mesh cages, put a bee inside, and heated them up," she says. Previous research had established that honeybees regularly fan to control temperature, humidity, and carbon dioxide. But over and over, the bee on Cook's hot plate sat still. Confused, she put two bees together. "Sure enough," with a companion, "they fanned." Honeybees, she found, use social information—paying attention to each other—to respond to environmental changes.[1]

As global temperatures rise, understanding how bees will respond is becoming increasingly important. Back in 2006, beekeepers in Pennsylvania were mystified when their previously healthy hives suddenly emptied, a phenomenon dubbed colony collapse disorder. Beekeepers across the country soon saw similar disappearances: There were no dead bodies inside the barren hives to suggest starvation, and neighboring bees, who often rob hives, seemed to avoid the unprotected honey.

From 2008 to 2013, wild bee populations plummeted by 23 percent.

It's a mystery that's never been fully solved. But while reports of colony collapse disorder have waned over the last decade, the fate of bees has not improved. Honeybee mortality remains startlingly high, says Nathalie Steinhauer, the research coordinator for the Bee Informed Partnership, a nonprofit organization that started conducting extensive annual bee surveys in response to colony collapse. Steinhauer explains that for the last decade, around 30 to 40 percent of the United States' honeybees have died every year.[2] While intensive management has been able to keep honeybee populations roughly stable, that's much "higher than what beekeepers consider acceptable." Nor are the 4,000 native bee species in North America doing any better: Nearly 1 in 4 of them is at increasing risk of extinction.[3]

Scientists have laid the blame for bee declines on a combination of factors, like the proliferation of pesticides, and parasites like the Varroa mite, which can carry deadly pathogens. While those are major stressors on their own, they are now exacerbated by climate change, painting a disquieting future.

"Honeybees are absolutely critical to our agriculture," says Cook, now a biologist and founder of the Cook Lab at Marquette University in Wisconsin. Three-quarters of food crops rely on honeybees for at least some pollination,[4] making honeybees more important than fertilizer.[5] While some plants can self-pollinate, others, like tomatoes and potatoes, don't release their pollen until bees arrive to vibrate their flowers[6]; others may require bumblebee saliva to encourage them to flower.[7] Even trees previously thought to self-fertilize likely have pollinators contributing to their seed production.

Yet globally, pollinators are now declining so quickly the Food and Agriculture Organization of the United Nations warns their loss may spark a food crisis.[4]

The problem extends far behind the dinner table: Over 80 percent of wild plants also depend on pollination, often from native bee species, which have evolved alongside the plants they serve. But from 2008 to 2013, wild bee populations plummeted by 23 percent.[8] If these bees disappear, says Diana Cox-Foster, an entomologist and research leader with the United States Department of Agriculture, "the landscape would basically regress back to grassland." Long before extinction, she worries about the feedback loops losing wild bee populations may spark: Fewer bees may encourage grass growth, for example, leading to worse wildfires. "Having healthy pollinators and pollinator plantings helps you avoid a tinderbox landscape."

To forestall these crises, it's critical to find ways to help bees navigate shrinking habitats and a warming world. Cook's work is now focused on helping beekeepers manage their colonies as the climate shifts. "We're stewards," she says, "We have to figure out how to treat them better."

AMERICAN AGRICULTURE RELIES on the hard work of both managed hives and wild bees: Native bees can perform much of the pollination farmers need,[9] and significantly contribute to crop production. But when most people think of bees, they think of the humble *Apis mellifera*, more commonly known as a European honeybee. They are essentially insect livestock, brought to the United States to pollinate Old World plants also introduced by colonists. They are as closely managed as other domesticated animals. Many commercial

PAGES 52-53: SANTYPAN / SHUTTERSTOCK

Fewer bees may encourage grass growth, leading to worse wildfires.

beekeepers transport their honeybee hives to multiple locations a year, servicing almond orchards in California in the early spring and returning to the Great Plains for honey production later in the summer. But for the last decade, the same number of bees have been making less and less honey—and, for beekeepers, less and less money. In 2021, because of extensive drought that withered crops across the Midwest, the USDA reported that honey production dropped by a staggering 126 million pounds, or about 14 percent per colony.

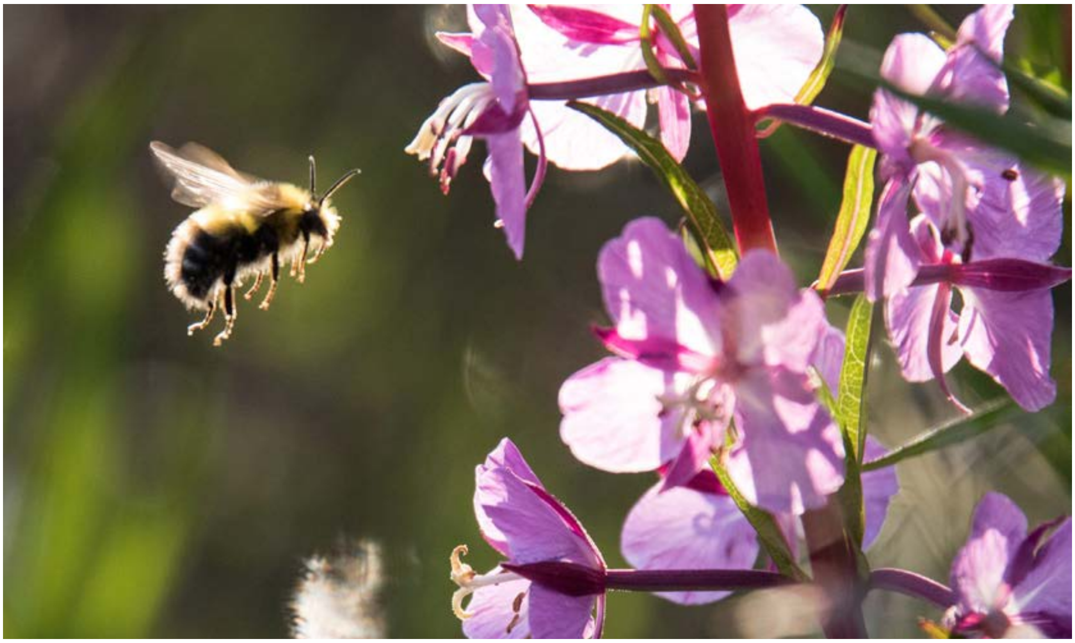
Bees' incredible ability to transform nectar into honey has long made them humanity's friend. But hives also rely on honey to survive long after summer blooms have faded. If flowers have died off but winter cold doesn't set in, bees may fruitlessly keep foraging, becoming nutritionally stressed. "If they used too many resources in the fall or emerge before flowers are available to feed on in the spring, there's phenology mismatches," a gap in the timing between bees and the flowers they depend on, says Christina Grozinger, the director of the Center for Pollinator Research at Penn State.

In the summer, honeybee workers transition through different states as they age, working as nurse bees when they are young, and foraging when they grow older. Winter bees, conversely, are physiologically different, and can survive for months. But if the colony is actively searching for nectar into the fall, they aren't producing winter bees, meaning they aren't as prepared to survive the winter.

"When spring comes, the older bees die at rates that exceed the replacement rate," says Gloria DeGrandi-Hoffman, research leader at the Carl Hayden Bee Research Center. Thirty years ago, she adds, "If you'd lose 10 percent of your colonies, that was a bad year for you." That's in part because, like humans, bees are more likely to get sick when they're mingling. Longer autumns and warmer winters are also extending bees' flying time—helping spread Varroa mites and their diseases and causing surging numbers of deaths.

These climate impacts are likely exaggerated by land use changes, which reduce bees' ability to adapt to new challenges. The increased use of herbicides and insecticides has reduced the diversity of plants bees used to depend on, while increasing their toxic load. Neonicotinoids, a class of insecticides that affect bees' central nervous system, are particularly harmful. Bees can be exposed simply by visiting a field where they have previously been sprayed, bringing the chemical back to the hive with them. These chemicals are now used on most corn and soybean fields in the U.S., and persist in soil for years, which is why the European Union has banned three of the most common neonics.

In the U.S., a 2020 study by Penn State researchers found that in the last two decades, the toxicity to which bees are exposed rose by 121 times in the Midwest, primarily because of neonicotinoid use.[10] While exposure may not immediately kill bees, even low doses of chemicals can exacerbate other stresses.[11] Glyphosate,



LOSS OF THE WILD A native bee feeds on fireweed in Alaska. Climate change is taking a toll on native bee populations and the plants they serve. Nearly 1 in 4 native bee species is at an increasing risk of extinction. The resultant rise in grassland could lead to worse wildfires.

SEAN MCDERMOTT

the active ingredient in Roundup, for example, severely impacts bumblebees' ability to control their temperature.[12]

While it may be hard to parse these various harms, DeGrandi-Hoffman uses a simple metric to understand how the beekeeping industry is doing. "If you look at companies that sell packages of bees or queens, they're sold out every year. They can't make enough to replace colonies that are lost."

HONEYBEES EVOLVED TO SURVIVE winter by huddling into a thermoregulated cluster, surrounding their queen. When anthers stop releasing pollen and petals begin to shrivel, worker bees drag the male drones out of the hive into the crisp fall air, a sacrifice completed by chewing off their wings. The test of the hive's endurance has begun. The bees' huddle expands and contracts. It is a dying time.

To help slow these crippling winter losses, beekeepers are increasingly turning to cold storage. When honeybees are kept artificially cold, they don't need to forage, be treated for mites, or be fed by their keepers, cutting down on costs and reducing mortality. As natural winters warm, states like Idaho and the Dakotas have been early adopters in adapting cold vegetable storage facilities for commercial beekeeping operations. Mike Lamoreaux, a business developer at Gellert, a climate control company that started out storing potatoes, says the practice has taken off over the last decade. Lamoreaux started overwintering bees in 2014. "We'd literally go to trade shows and people would stand in line, waiting to sign up," Lamoreaux says.

Cold storage isn't a catch-all solution. "It's not a hospital," Lamoreaux says. He warns people to

make sure their bees are as healthy as possible before bringing them in. Like so much in modern agriculture, there's also a question of scale: The costs and risks of these facilities work best for large-scale operations, who can afford to lose several hundred hives if something goes wrong.

To help slow crippling winter losses, beekeepers are turning to cold storage.

To make cold storage more accessible for hobbyists and smaller operations, Cook, along with her business partner Kimberly Drennan, an architect, recently designed a mobile climate-controlled apiary. The size of a horse trailer, it has insulated panels and smart sensors to control temperature, carbon dioxide, and humidity. After winning seed money from the USDA, along with a grant from the Advanced Industries Office of Economic Development in Colorado, their company HiveTech tested a prototype in apiaries this winter. Despite supply chain shortages, early results suggest the unit increased survival three times, compared to colonies that remained outside. Providing cold storage at home cuts down on the need to transport hives, reducing both costs and mortality, and helps beekeepers better manage mite populations and their hives' nutrition. "It puts the control in the hands of the beekeepers," Cook says.

These kinds of practical solutions are increasingly urgent. As honey yields drop, financial pressures on beekeepers are increasing. If apiaries can't stay in business, their efforts to keep bee populations stable will also vanish. "By adapting management—like cold storage—we can help bees make it," says DeGrandi-Hoffman.

Wild bees, meanwhile, have fewer ways to adapt. Grozinger's research suggests that across the country, many places that economically depend on wild pollinators will see their populations dwindle. Grozinger and her collaborators tracked wild bee abundance across the U.S., finding many of the places where bees are declining the fastest, like California's Central Valley, are also places that currently rely on pollinators. "This means growers will be more dependent on purchasing managed pollinators, like honeybees, to produce their crops," she says. This imbalance is already causing declining production: In another collaborative study, she found that poor seed generation in Pennsylvania black cherry trees may be due to the loss of wild andrenid bees, one of its most important pollinators.[13]

The urgency of understanding these relationships is heightened by how quickly some of these bees are vanishing from the landscape. The first bee added to the endangered species list was the rusty patched bumblebee, a wild bee which historically ranged from the upper Midwest to the East Coast, but others may soon join it. While honeybees are social animals, the majority of the United States' 4,000 types of native bees are solitary, meaning they don't have the help of a hive in sharing resources. "You can think about them like a single mom," Grozinger says, "whereas honeybees are like a village."

Adding to their vulnerability, many native bees also specialize on a small number of plants with a short blooming season, like the Mojave poppy bee, which U.S. Fish and Wildlife Service is currently considering listing as endangered. It is the only pollinator of the bearpoppy, a scrappy yellow flower that thrives in the harsh conditions of the desert, although mining, extreme heat, and drought have recently erased the wildflower from half its range.

The decline of wild bees will affect entire ecosystems, says Ellen Moss, a research associate at Newcastle University. Rising temperatures are increasingly disrupting the plants bees rely on, leading to food shortages. Moss recently conducted a study that simulated an increase in temperature of 1.5 degrees Celsius

The unit of importance for bees is its society, not the individual.

COLD SOLUTION When honeybees are kept artificially cold, they don't need to forage, be treated for mites, or be fed by their keepers. This cold storage unit at a shop in Fort Collins, Colorado, features insulated panels and smart sensors to control temperature, carbon dioxide, and humidity.

KIMBERLY DRENNAN

and a 40 percent increase in rainwater, over two growing seasons.[14] She found that floral abundance was reduced by almost half—causing the hard-working pollinators to visit each flower more frequently to collect the same amount of pollen or nectar, while the wildflowers themselves produced fewer seeds. "I was surprised by how strong the temperature effect on floral abundance was," Moss says.

Moss is concerned that writ large, each of these problems—climate change, habitat fragmentation, lower flower abundance—may compound. But so far, few researchers have looked outside of agriculture at the impact on non-crop plants, just as few studies have focused on wild bees and other pollinators. "No species exist in isolation," she says. If climate change tips the balance, "it could permanently change the composition of communities."

Still, bee experts say it's not too late to take steps to help wild bee populations. The silver lining is that bees reproduce quickly. "They can rebound from disaster surprisingly well," Grozinger says. She hopes to find ways to design climate resilient landscapes for bees. "If we provide a diversity of options and identify places that may provide shelter from extreme climate variation, they can find what they need in the environment," she says. In regions where increased rainfall is predicted, for instance, Grozinger is trying to determine where there might be natural rain shadows, preserving those key islands as habitat for pollinators. A recent study in *Science* suggests that conserving forage for wild bees could also minimize the toxicity of glyphosate—further highlighting the importance of wildflower plantings and conserving native habitat.[12]

Grozinger's lab has developed a public tool where you can get a bee's eye view of the landscape near you, gauging the quality of pollinator habitat across the U.S. and encouraging people to make bee-friendly gardens. Many efforts to increase "bee pasture," as Cox-Foster calls it, have added rippling benefits. For example, sowing cover crops—plants intended to cover the soil rather than be harvested—under almond trees not only doesn't compete with almond blossoms, but improves

the soil quality. Similarly, adding native plantings to solar and wind farms has been highly effective at alleviating their environmental impacts.[15] Even neighborhood projects to plant flowers for bees along curbs and roadways can help reduce habitat fragmentation.[16] Tucked into the recent infrastructure bill is a five-year program that provides $10 million in grants to replant roadsides for pollinators, and an additional $250 million will be distributed for invasive plant removal along transportation routes.[17]

Helping bees navigate a quickly shifting climate is a daunting task. But as a honeybee knows well, even minute actions add up. "The reason I study honeybees is their complex societies," Cook says. The monarchy metaphor—the queen rules the hive—is misleading. The hive's elegant division of labor is controlled by its thousands of workers, who make decisions at a local level that, when acted out, affect the entire colony. This wasn't inevitable; like many social insects, honeybees evolved from a solitary ancestor. To survive, they adapted to persist through difficult conditions communally. "Everyone is working toward the collective good," Cook says. "The unit of importance for bees is its society, not the individual." These are choices, she adds, "that change how we view solutions."

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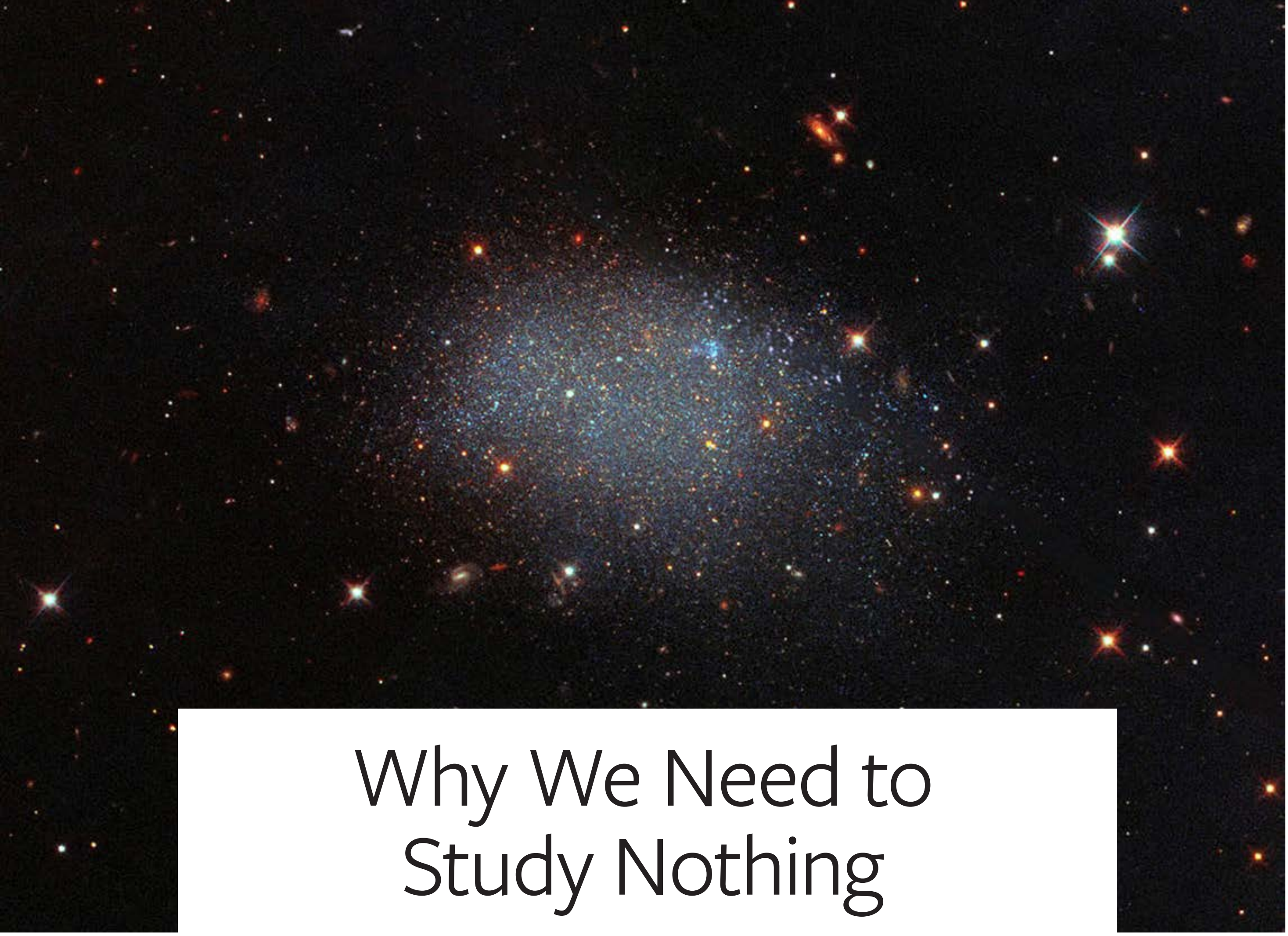


Why We Need to Study Nothing

The origins of the universe may be hidden in the voids of space

BY PAUL M. SUTTER

ESA / HUBBLE & NASA; E. SHAYA, L. RIZZI, B. TULLY, *ET AL.*

BEGINNING IN THE 1970S cosmologists started to uncover the structure of the universe writ large. They already knew that galaxies occasionally clump together into clusters, but over even larger distances, spanning 100 million light-years and more, they found superclusters. And in between those superclusters they saw something even more unexpected: vast regions devoid of galaxies, great and immense dark hollows. The first of these cosmic voids that cosmologists discovered was 65 million light-years across. No theoretical work had predicted their existence, and for years cosmologists thought they were creating patterns with their imaginations.

We now realize that the largest structures in the universe are not superclusters or any other agglomeration of matter. They are the voids: the negative spaces, the intergalactic Saharas.

I was introduced to voids by my mentor Ben Wandelt while I was in grad school. He was fascinated by them; they appeared too empty to be explained by standard cosmology. My graduate advisor, Paul Ricker, and I worked with Wandelt on this problem for a while. But like most cosmologists, even though I knew about the voids, I didn't think much of them. I favored galaxies and clusters. Voids were nothing, after all.

But after I got my Ph.D. I moved to Paris to join Wandelt for a postdoc position. Voids began to grow on me. I remember vividly the reactions we would get when we presented our preliminary work. Curiosity and interest, for sure, but also skepticism—not just the healthy skepticism needed for fruitful scientific progress, but the acidic scorn used to put junior scientists and their wayward ideas in their proper place. One time a prominent cosmologist—a senior, tenured professor—walked up to me in the hallway after I gave a talk at a conference, said simply "This will never work," and turned around and walked away.

You could stretch 25 Milky Ways side-by-side in the gap between us and the nearest galaxy.

I didn't mind the criticism because I knew something they didn't. Cosmic voids are cosmology at its purest. They are simple. The complications of star formation and black holes don't impact them because they don't have any stars or black holes. They are basically big fossils from the earliest days of the universe and their shapes encode the evolution of the universe as a whole. If you want to understand some of the biggest puzzles in physical science, such as dark energy, you don't want to look where the matter is, but where it isn't.

OUR MOST DISTANT SPACECRAFT, Voyager 1, has been traveling for over four decades and is now about 14.5 billion miles away from home. It is well and truly outside the boundaries of the solar system, and the average density within that space is a mere 10^{-15} grams per cubic centimeter. If that seems empty, just wait.

As we zoom out, we meet scattered stars, some of them associating with each other in clumps, others drifting alone. We see faint sketches of the great spiral arms of our galaxy, twisting pinwheels of gas and blue-bright stars, our own solar system tucked into a single spur of a much vaster arch. Our entire Milky Way galaxy is roughly 100,000 light-years across—a great, complicated metropolis of a few hundred billion stars. It has an average density of roughly 10^{-22} grams per cubic centimeter.

Beyond the warm confines of our galaxy sit the empty depths of intergalactic space, home to the occasional dwarf galaxy and the random flows of far-flung gas streams. The nearest major galaxy to our own, Andromeda, is 2.5 million light-years away. You could stretch 25 Milky Ways side-by-side in the gap between us.

Some galaxies lead solitary lives, and others assemble into groups and clusters of increasing size. As we continue to zoom out, entire galaxies, each one home to hundreds of billions of stars, appear as tiny motes of light adrift in an unlit ocean. The universe begins to look like a vast web, a network of long strings and tremendous walls, and between them the voids. We have a name for the nearby assortment of large-scale structures: Laniakea, the Hawaiian word for "bountiful heaven." A knotted, twisted tangle of vines made of galaxies stretches for over 100 million light-years. At these distances the average density of matter approaches 10^{-29} grams per cubic centimeter.

And in those cavernous gaps between the structures, we find: almost nothing. There the density plunges to perhaps 10^{-30} grams per cubic centimeter. That is, to be sure, not entirely empty. Voids do contain a few dim, dwarf galaxies. Molecules of cold hydrogen and helium float among them, some blown out of their home galaxies, the rest left over from the Big Bang.

The nearest void to our Milky Way galaxy is the appropriately named Local Void, bordering our section of the universe and continuing on for almost 200 million light-years. The aptly named Giant Void is eight times wider. Voids comprise a tiny fraction of the mass in the cosmos, yet completely dominate its volume.

A cosmos that generates large-scale structures must, by its very nature, also produce the voids. The culprit is gravity: simple, persistent gravity.

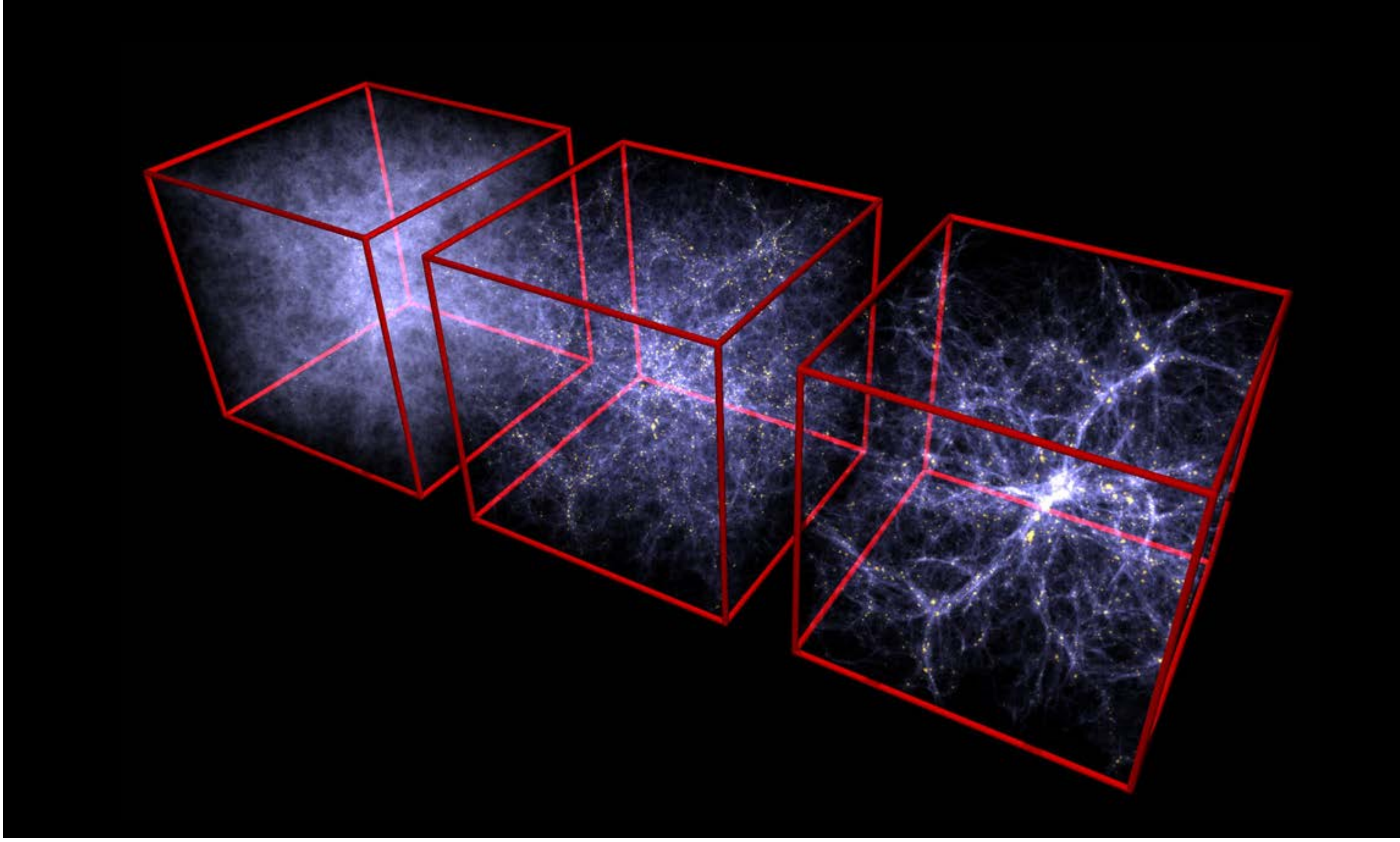
Billions of years ago, when the entire volume of our observable universe, 90 billion-plus light-years across, was crammed into a volume smaller than an atom, the exotic high-temperature plasma that filled our cosmos was relatively uniform. There were no significant density contrasts, and really nothing significant at all. Cosmologists believe that at this time, our universe underwent a sudden, rapid expansion known as inflation. It enlarged microscopic quantum fluctuations into the seeds of all we see today.

Once cosmologists realized this story of creation, they realized they must turn the tables.

From then, gravity worked in the shadows. Regions of ever-so-slightly higher density had a little more gravitational pull than their neighbors, which encouraged more material to flow into those dense pockets. With even more material, the gravitational pull grew stronger, building on itself in a feedback loop. Over hundreds of millions of years, it gave rise to stars, galaxies, clusters, and the majesty of the cosmic web.

But in a universe where the rich get richer, the poor must get poorer. As matter flowed into the dense regions that would light up with stars and activity, the cosmic voids, seeded in those very same humble epochs, grew to their present all-encompassing size.

Once cosmologists realized this story of creation and confirmed it with observations, they realized they must turn the tables. The large-scale structure was not a question, but an answer. By measuring it, they could solve some of their other puzzles. The shape of the cosmic web is sensitive to the amount of regular and dark matter, the abundance of neutrinos, the presence of dark energy, and so on. So cosmologists sampled hundreds of thousands, then millions, of galaxies throughout the universe to map the large-scale structure in an attempt to quantify the basic ingredients of the cosmos.



Those surveys focused on what astronomers knew best: the bright objects. The cosmic voids were forgotten.

Those galaxy surveys have revealed ever-more precise estimates of the amount of dark matter in the universe. They have also provided independent evidence for the existence of dark energy, the mysterious substance that is driving the accelerated expansion of the universe.

But it hasn't been easy. Galaxies and clusters are messy, complicated structures. The primordial density fluctuations have been swamped by generations of stars, supernovae, stellar winds, cosmic rays, magnetic fields, and all the wonderful astrophysics that makes life so interesting.

Teasing pristine, primordial cosmological information out of something as complicated as a galaxy or a cluster is next to impossible. Take a simple cosmological test developed by Charles Alcock and Bohdan Paczyński in 1979. If you scattered perfect spheres throughout the universe, from our point of view the spheres would appear to be elongated along our line of sight toward them—a slight stretch induced by the

COSMIC WEB As matter clumped into filaments and formed galaxies, it left vast empty regions: the voids. This sequence of three images shows structure in cosmic gas in a volume about 300 million light-years on a side, at 1 billion years after the Big Bang (left), 3 billion years (middle), and today (right). It was generated by the Millennium Simulation Project, a massive computer simulation in the mid-2000s.

VOLKER SPRINGEL / MAX PLANCK INSTITUTE FOR ASTROPHYSICS, GARCHING

Cosmic voids are the largest and most ancient time capsules known to science.

expansion of the universe. If you could measure that stretch as a function of distance, you could reconstruct the expansion history of the universe with incredible precision.

Clusters of galaxies are, for the most part, relatively spherical. They formed long ago and have since settled into equilibrium, balancing the motions of their own gas and galaxies against their gravitational pull. But trying to apply the Alcock-Paczyński test leads to failure. The motions of individual galaxies are hundreds of times larger than the effect of cosmological expansion, completely swamping it and rendering clusters useless.

But what of the voids? An individual void is anything but round; it occupies a random amount of volume in a wide variety of shapes. But we live in an isotropic universe: Our cosmos looks roughly the same, on average, no matter what direction we look. If we were to take a collection of voids, they should have random orientations, and if we were to find enough of them and stack them one on top of another, they should average out to form a sphere. If I give you enough scraps of randomly shaped paper and you stack them on top of each other, eventually you would build something round. Could the average void be good enough to teach us something about the universe?

This was what I worked on with Wandelt. It would consume three years of my research life. As more researchers and graduate students joined our team, I hit the road, living out of my backpack for weeks at a time, hopping from seminar to seminar and conference to conference, spreading what we were learning about cosmic voids and what they could teach us about the universe.

We learned that voids are amazingly simple. Unlike their cousins, the dense structures of the cosmos, they live relatively uncomplicated lives. They simply appear in the early universe and grow. When they do occasionally merge, it's a brief affair: A wall of galaxies between two voids thins out, and two voids become one. Because of their simplicity, they remained relatively uncontaminated by astrophysical processes and the movements of individual galaxies. Within a couple years, we were able to realize the dream of Alcock and

Paczyński, applying their test to real voids found in galaxy surveys and using the result to provide an independent measurement of the amount of dark matter and dark energy in the universe.

Because voids don't change much through their lives, they retain a memory of the young universe. If you want to know what our universe was like billions of years ago, you can't look into a galaxy or cluster—too much has changed. But a void? A void today is pretty much the same as a void billions of years ago. Voids are the largest and most ancient time capsules known to science.

When I say that voids are empty, I mean specifically that they are empty of matter. But that emptiness makes them full of something else: dark energy. Cosmologists aren't sure what dark energy is; all we know is that it's been causing the expansion of the universe to accelerate for the past 5 billion years. We believe that dark energy is somehow related to the vacuum of spacetime, a component of all the quantum fields that suffuse reality.

If you take a box and empty it of all the matter, you're left with vacuum and the quantum vacuum fields that live in it. On a grander scale, the cosmic voids are brimming with quantum fields, including dark energy. You'll never feel the effects of dark energy inside a solar system because the density of all the matter is more than enough to overwhelm the slight, subtle effects of dark energy. But out in the voids? It's nothing but dark energy. Indeed, the cosmic voids are the places in our universe where the expansion is accelerating. It's not happening in galaxies or clusters, but in the emptiness between them.

The lesson is clear: If you want to understand how dark energy works, you have to dive into the darkness.

Thanks to the dogged determination of my collaborators and other void-enthusiasts, voids have come out of the shadows. Every major upcoming galaxy survey now includes void science in their repertoire. Cosmologists are learning how to use voids to understand dark energy and dark matter, search for exotic fifth forces, dig into the conditions of the early cosmos, and more. Most recently, voids have provided the most powerful measurement of dark energy within the local universe, using simple analysis techniques developed by a handful of people, compared against the massive resources employed by giant collaborations to try to get the same information out of the bright structures.

No, we haven't yet solved all the mysteries of the cosmos. But the answers to those questions are certainly waiting for us in the void.

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Overthrowing the Patriarchy Through Ecstatic Sex

Zoologist Lucy Cooke uncovers the sexual power of females in the animal world

BY BRIAN GALLAGHER

LUCY COOKE WAS IN THE SERENGETI, making a BBC documentary about animal communication, when the lion expert in the Jeep with her played the sound of a roar from another lion's territory. Three lions, two males and one female, approached. The two males disappeared when they saw there was nothing that resembled a rival. But the female lion pinned them, circling the Jeep. They were stuck for two hours. What was going on? Cooke was informed the female wanted to mate with them. "That female lion—she's incredibly promiscuous," the lion expert told her. "She'll mate up to a hundred times with multiple males during her fertile period."

This blew Cooke's mind. "I was thrilled and quite delighted by the licentious promiscuity of the lioness," Cooke told *Nautilus* in a recent conversation. That's when the seed of her new book, *Bitch: On the Female of the Species* (or, in the United Kingdom edition, *A Revolutionary Guide to Sex, Evolution, and the Female Animal*) was planted. Cooke calls it a "shocking revelation" to have learned that "much of what I had been taught as gospel at university, the very foundations of evolutionary biology, had been distorted by prejudice." At Oxford University, where Cooke earned her master's in zoology, she was taught that, almost as a matter of biological law, males were the promiscuous ones, and females were choosy and chaste. The idea dates back to Charles Darwin's theory of sexual selection, and *Bitch* is about bringing Darwin up to date. ("This isn't your grandfather's evolutionary biology," the book's online description reads.)

"His theory of sexual selection was infused with the chauvinism of the period, unfortunately, which was very surprising to me, because Darwin's my hero," Cooke said. "He's the reason why I studied evolution. He is an extraordinary, meticulous scientist. It's fascinating that someone who is as cautious and thorough and methodical as Darwin is also not immune to cultural bias."

Bitch is an entertaining and erudite corrective to years of research bias against the idea of female agency in evolution and the study of female sexual anatomy. During our conversation, Cooke was jovial, and talked a lot about sex—duck sex, dolphin sex, spider sex, as well as same-sex "GG rubbing" among bonobos. She explained why sex didn't evolve for just reproduction ("another real Victorian idea"). She also talked about what it might mean for humanity that bonobos were able to "overthrow the patriarchy through ecstatic sex."

What was your impetus to write *Bitch*?

We are living in a time where being female has never been more scrutinized or politicized. I feel that there's been a revolution in our understanding of what it means to be female. And that revolution started in the early 1980s with the likes of Sarah Hrdy and Patricia Gowaty first challenging these stereotypes that Darwin had set in stone of the passive female that's chaste, submissive, and coy. But even though they started those challenges and, in many cases, won them in as early as the 1980s, much of that thinking has taken a long time to permeate into popular culture and even into science.

Is there one insight in particular that you want to leave readers with?

What I would hope is people understand that biological sex isn't a crystal ball. Females are not meant to behave in a certain way because they produce eggs. Males are not meant to behave in a certain way because they produce sperm. The variety that we see in nature of both the expression of sex and the spectrum of sex itself, should inspire us to see the limitless possibilities of the female experience, and not feel boxed in by stereotypes.

PAGES 66-67: GUDKOV ANDREY / SHUTTERSTOCK

Gowaty, who's been questioning these stereotypes for 30-odd years now, has taken to task Angus Bateman's study, a fruit fly experiment in the 1940s. It underpinned the stereotypes that females had nothing to gain by mating with multiple males. Whereas males have everything to gain. This was part of a law that held that males are promiscuous and females are chaste.

Gowaty has taken a forensic scalpel to Bateman's study, reproduced it herself, and gone back to his original notes, and found that even his own data doesn't support his results. He suffered from a case of confirmation bias. He skewed the results, and he collated them in a way which substantiated what he wanted to see rather than what was in front of his eyes.

Why do you describe sex, as in the male and female categories in species, as anarchical?

I was really surprised when I came to understand how sexual differentiation actually happens. Everybody at school learns that males are XY and females are XX. You think that the genes that govern being male are on the Y chromosome, and the genes that cover being female are on the X, and that the pathways that take you to being male or female are linear and distinct. That's what I assumed, like many people. And then I spoke to Jenny Graves, who had been studying sexual differentiation and determination for a very long time, in everything from platypus to nematode worms. She was part of the team that found the SRY gene, which is of course the trigger for the male pathway in humans. She's the one who told me that it's a pretty anarchic setup.

I was amazed by what she told me. When you have a fetus, it starts off as sexually neutral with a unisex kit of parts. Then there's a trigger—in humans, the presence or absence of the SRY gene—that starts one of these two pathways. The gonads either start down the pathway of becoming a testes or an ovary. Now, what I didn't know, which Jenny told me—she had to tell me three times because I couldn't believe it—is that the genes involved in making testes or ovaries are basically the same 60 genes. They just play to a different tune. And these two pathways involving these 60 genes are neither separate nor linear. They're enmeshed, and they work antagonistically. So, to create an ovary, you have to suppress the testes at the same time.

The foundations of evolutionary biology had been distorted by prejudice.

THE NATURE OF SEX

In her latest book *Bitch: On the Female of the Species*, zoologist and filmmaker Lucy Cooke re-examines her favorite subject from her student days at Oxford University—sexual selection.

They've now found in studies of mice that this suppression, this antagonistic relationship between these two pathways, continues into adulthood, which suggests that the gonad is never actually stable in a mouse, an astonishing thing to discover. When she sent me this diagram to explain what these two linear pathways look like, it was like a machine of millions of cogs with these little blue balls being spat out and pumped between things, and destroyed, and the whole thing was like a whirring map. It was chaos. She said that's what she sees these pathways to be like. This anarchic system is why you get such extraordinary variation.

What's an example of an animal that epitomizes this extraordinary variation?

The common garden mole. A couple of years ago, it had its genome decoded. The common garden mole female has what's described as "ovotestes." Her gonads are part ovarian tissue and part testicular tissue. During the breeding season, her ovarian side produces eggs. She has a pregnancy and gives birth as you'd expect. But outside of the breeding season, the testicular tissue swells, and it produces testosterone. Doesn't produce sperm, but the testosterone makes her dig really hard, and be really aggressive. It also means that she has a vagina that's sealed shut, and her genitalia externally resemble a male. She has a clitoris that looks like a penis. So, she's pumped full of testosterone. Morphologically, she looks, externally, like a male, yet she is a female. That sort of gonadal flexibility is the result of an incredibly anarchic system involving androgynous genes.

Evolution has furnished the male barnacle with an extravagantly long penis.

So what fundamentally tells men and women apart?

Biological sex is the standard definition. That's what the gonads do. Egg-making as opposed to sperm-making. But even that definition is problematic when you see creatures like the mole, and like common garden frogs. They have genetic sex determination. But then that genetic sex determination can be overridden by an environmental sex determination. There are plenty of animals, reptiles, and amphibians that have environmental sex determination. Famously turtles: If they're incubated over a certain temperature, they become female. Under that temperature, they become male. Frogs, it looks like they also have some sort of environmental trigger. Not sure what it is. But it can override the genetic trigger. You end up with XX males and XY females. Their gonads are a mishmash.

It was amusing how you described the way Darwin talked about the barnacles finding mates. Because barnacles don't, or can't, move.

Well, you're right. If you're a barnacle, you are cemented to a rock with your head. One of Darwin's big contributions to the field was realizing that barnacles were crustaceans, not mollusks. They're like crabs and lobsters, but they've eschewed their mobility for home security. That's what barnacles are big on. Their juveniles will form calcified plates and attach themselves to a rock by their head. Bingo for home security! Less good for finding a mate.

But thankfully, evolution has furnished the male barnacle with an extravagantly long penis. It's several times longer than his body. He can cruise the neighborhood for sex without ever having to move and inseminate whoever he comes across, and also make the best of a situation where if he can't find anyone to fertilize, he can just come home and fertilize himself.

Dolphin sex is very much unlike barnacle sex. The mating involves lots of movement. How has female sexual anatomy adapted?

This is new research from Patricia Brennan, who operates out of Mount Holyoke College in Massachusetts. Patricia is really the first person to study vaginas. Penises have been studied for a very long time because there's extraordinary diversity out there. Animal penises can have spines, bones, corkscrews. They can be roving, lengthy objects, like the barnacles. Taxonomists even use genitalia as a means of telling apart species that are otherwise identical. Certain beetle species can only be told apart by looking at their genitals. And so there's been a huge fascination in penises in zoology for a long time. Less so for vaginas.

Now, you could say, "Oh, it's inside. It's harder to examine." But the reality is that female genitalia was thought of like females were thought of—as being just a passive receptacle for the male. But Patricia Brennan has thought otherwise and has studied them. She paid attention to the genitalia of ducks first. Male ducks are famous for having, like the barnacle, a ridiculously long penis. I think the Argentine lake duck has one even longer than its body. On top of that, it's a corkscrew. You might think to yourself, "Well, I've never seen that on a duck."

I was actually thinking that.

Most of the time, it's kind of kept inside the cloaca. Ducks, and all birds, have cloacas. In the case of ducks, they also have this penis inside the cloaca that is filled with lymphatic fluid and can explode out of the cloaca at something like 75 miles an hour, like a sort of sinewy party hoot. You know those party hooter things you get, that shoot out? This extraordinary organ has caused a bit of a stir. And there's been lots of theories as to why duck penises would be so long and corkscrew. The idea was that it was good old sexual selection. Male competition. Unfortunately, young males that don't find a partner gang up together, and they can be sexually coercive on females. It's a really horrible thing if you've seen it. That was the driving force of the male penis length. The idea was that the longer the penis, the better able the male that wins the fight is at getting his sperm in.

Patricia Brennan was the first person to say, "Well, I wonder what kind of garage he's parking his car in?" She looked inside the female duck, which the textbooks would tell you is just a simple tube. She found anything but a simple tube. She found just as extravagant an organ. It corkscrewed in the opposite direction.

It makes evolutionary sense for males to get eaten.

Why would the duck vagina evolve that sort of structure?

What Patricia realized is that it prevents coercive males from fertilizing her, because a female vagina of a duck can open wide in order to lay an egg. The lumen can expand to lay an egg. Patricia theorizes that the female, if she chooses her partner in an elaborate dance, and he's the one that she wants to fertilize her egg, then she'll open up the lumen of her vagina, and this weird, curly whirly penis will go all the way through.

And if she's not interested?

Then her vagina remains tight. And with all these blind pouches, and this corkscrew the opposite way, the male's penis often folds back on itself and doesn't fertilize the eggs. That supports the data, which was always anomalous before: Very few of these coercive acts ever result in chicks.

Why is it evolutionarily significant that very few acts of forced duck sex result in chicks?

What was fascinating about that is that it's the female that's driving the evolution of the extraordinary male penis. Patricia Brennan also rescues the female from being a victim in all of this because she's retaining her autonomy. She's choosing who fathers her egg, although she's still subject to coercive acts. But as far as evolution's concerned, she's the winner, because she's retaining the choice of who fertilizes those eggs. Dolphins are also famously coercive, but Patricia found the same convoluted vagina, and she thinks it's the same deal there.

How did sex evolve to be more than just a way to reproduce?

This is another real Victorian idea, that sex is just for reproduction. If sex is just for reproduction, then same-sex sexual activity becomes anomalous. Because it's like, "Well, that's a waste of energy, isn't it? Why would that happen?" Yet same-sex sexual activity is widespread in the animal kingdom. Bruce Bagemihl, author of *Biological Exuberance: Animal Homosexuality and Natural Diversity*, documented over 300 species where same-sex sexual activity has been observed. In particular the bonobos, who are our closest relative alongside chimpanzees—the females have sex with each other. It's called GG rubbing. Their clitoris is migrated, so that it's in a position where it gets the most stimulation from this particular kind of sex. Amy Parish, who studied female bonobos, told me that if a female and a male present themselves to a female bonobo, more often than not, she'll choose to have sex with a female. The reason why this sex is so prevalent is because it serves a function, which is that it bonds the females.

You'd expect them to be competitive with one another. Female bonobos are like chimpanzees. They don't form a stable heritable matriline in groups. They are the sex that disperses from their natal group. So, when females are together in troops, they are unrelated females. Yet they're not competitive with each other. They have this incredibly strong sisterhood, which is forged and maintained by sexual activity with each other, which basically dampens aggression.

As a result of those bonds, the females are the dominant sex. Male bonobos are like chimpanzees. They're bigger than females. But they're not the dominant sex. The female bonobos eat first, whereas female chimpanzees don't. In most situations in the wild and all situations in captivity, females are dominant. So, the female bonobo have basically overthrown the patriarchy through ecstatic sex.

How come bonobos were able to overthrow the patriarchy through sex, and the chimpanzees weren't?

It'll be the environment. That's what it is. Chimpanzees are much more widely distributed in Africa than bonobos. Bonobos are only found on one side of the Congo River in a fairly small area. I believe there's more abundant fruit where they live. Chance is another factor. But it is interesting that they are so radically different, because male chimpanzees are patriarchal and warlike. Bonobos, equally closely related to us, are matriarchal and peaceful. Until the bonobo came along, the chimpanzee was the model for our ancestry as our closest relative. Then the bonobo came along and suddenly, "Oh, could that be a model for our ancestry?" That's the kind of thing that anthropologists will argue about forever.

Does the story of the chimps and bonobos illustrate the flexibility of dominance?

Yes. It's not dictated by whether you produce eggs or sperm. Patriarchy isn't burnt into our primate DNA. It's flexible. It also shows the power of the sisterhood. I'm not suggesting that we all have sex with each other. But forming alliances with females is clearly a good thing if you want to gain power. And it also shows the flexibility of sexuality. All bonobos, essentially, are bisexual. They're quite happy. It doesn't really matter. You can draw what you like from that.

What are the forces that determine how sexual dimorphism works in different species?

Darwin would've said that those dimorphisms are dictated by our sex cells. Females produce small amounts of energy-expensive eggs. And so we are destined to be choosy and chaste, and passive. Whereas males produce lots of mobile sperm, and so they're destined to be active and big, aggressive and dominant. But what we now understand is that sex isn't a crystal ball. Whether you produce eggs or sperm, it doesn't dictate what kind of dimorphisms exist, if any. It's the environment that you find yourself in that does. It's the combination of environmental factors, shared genes, and a bit of serendipity. There's also a considerable element of chance that shapes sexes to be either the same or different. But it's not simply that you can equate males are going to be bigger and more aggressive because they produce sperm, and females are going to be small and passive because they produce eggs. It's just nonsense.

"Well, I wonder what kind of garage he's parking his car in?"

Do you think Darwin was trying to avoid controversy in his treatment of sexual selection? Because his theory of natural selection was so radical. It challenged religion, and ideas of creation. Sexual selection, on the other hand, seems much more conservative, seemingly enshrining the Victorian values of English culture. Is that how you see it?

Well, this is a fantastic discussion to have and one that I really enjoy because it is all conjecture really, at this stage. But there are clues, aren't there, in his other writing? His two big published books, *On the Origin of Species* and *The Descent of Man*—they are a lot more conservative than, say, his more obscure monographs on barnacles. And so it's difficult to work out, isn't it, is how liberal he was? "What was his thinking? Did he really believe that females were inferior to males, and that males were the dominant drivers of evolutionary change?"

Well, I think he did believe in his theory of sexual selection, that it was driven by male competition and female choice. And he gave females agency by suggesting that female choice could shape the evolution of males. And that went down like a lead balloon in Victorian England. In that way, he did give females agency. His daughter, Henrietta, edited the book. She was famously prudish. So, how much she constrained his writing, we don't know. But I agree with you. To anger the church and suggest that humans had evolved from primates—that's probably enough controversy in one lifetime. He might not have been striving for sexual equality in the wake of that.

Listening to you narrating your book on my phone, I could tell you must have really enjoyed researching and writing about spiders.
It's just so amazing, isn't it, to imagine that world? Females can be way bigger, like 125 times bigger than the male, which is astonishing. The females also live much longer. The males live for a fraction of a time. Sometimes, they don't have fangs or even venom. They're just walking sacks of sperm. Also, to cap it all, they look like lunch. It makes sense for the female to be bigger. Because she's bigger, she can make more eggs. Although they've got eight eyes, they don't see very well. Their main sense is vibration. That's how they detect almost everything. So, if you are a male spider, you want to get the attention of your mate. She can't hear. She can't necessarily see you. So, you've got to make vibrations. And the best way to get her attention is to make like dinner, and shake the web, and be like, "Woo." Like, "Whoa, dinner."

Because animals with small brains have a limited sensory realm, so many courtship routines are based around things that are a bit like food. With bowerbirds, for example, the ones that decorate their bow with blue bling, well, that's because there's a blue fruit that's much prized. The male has to make like dinner to get noticed, because the worst thing that can happen is that he doesn't mate at all. He might get eaten before. If she's hungry and he's played it badly, he might get eaten before sex. But even if he gets eaten during sex, which often happens, they can be incredibly fast with their pedipalps, which inserts the sperm. Everyone's a winner. Not only has the male managed to fertilize the female, but by eating his body, she's also going to nourish those eggs and spiderlings. And they've got a better chance of survival.

That seems brutal.
But it works. It makes evolutionary sense for males to get eaten. Eileen Hebets, who studies in Nebraska, does some amazing work on spiders. She's found that there is something particular about eating another member of your own species that's particularly nourishing for the female. The females that cannibalized their own species grew much bigger and did much better. So, she came to the conclusion that there's something uniquely nutritious about eating your own species. But life's not great for the female spider because matriphagy is a thing with spiders. The mother herself may end up being consumed by her spiderlings, slowly eaten, abdomen first.

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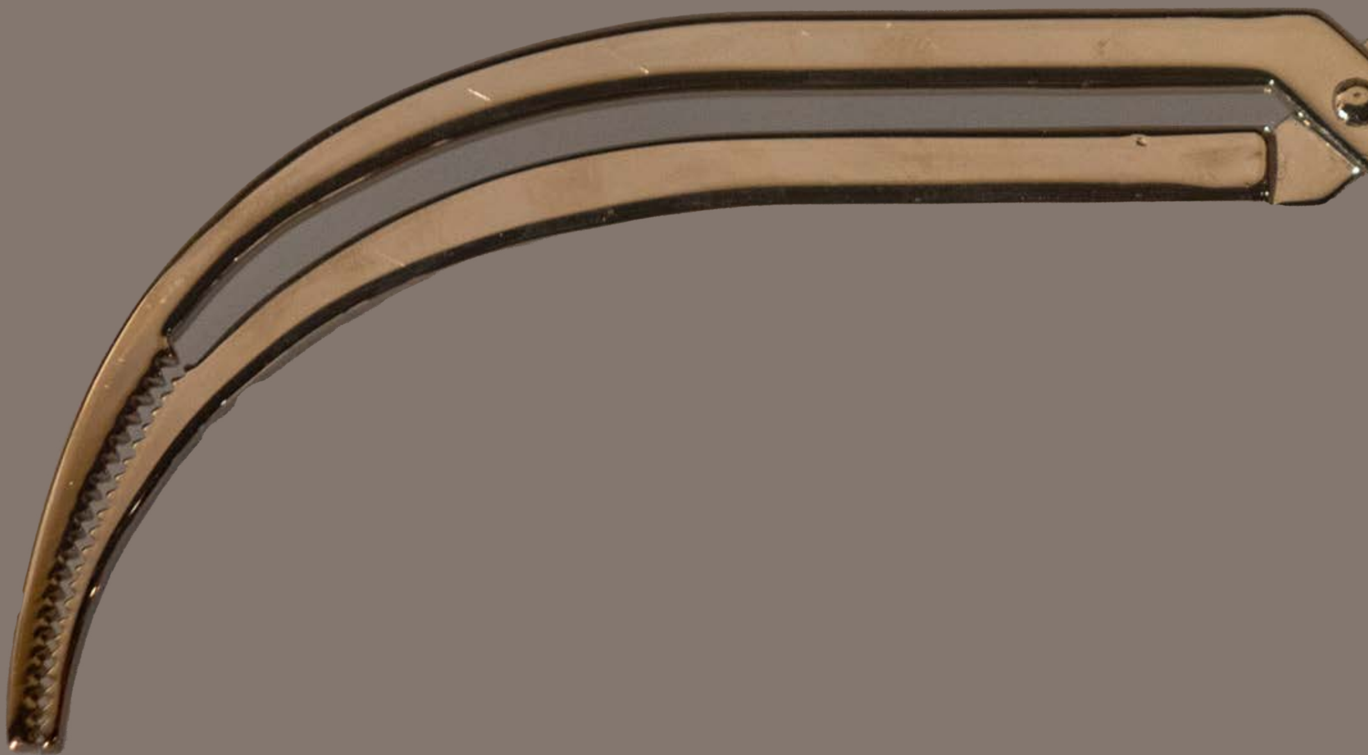
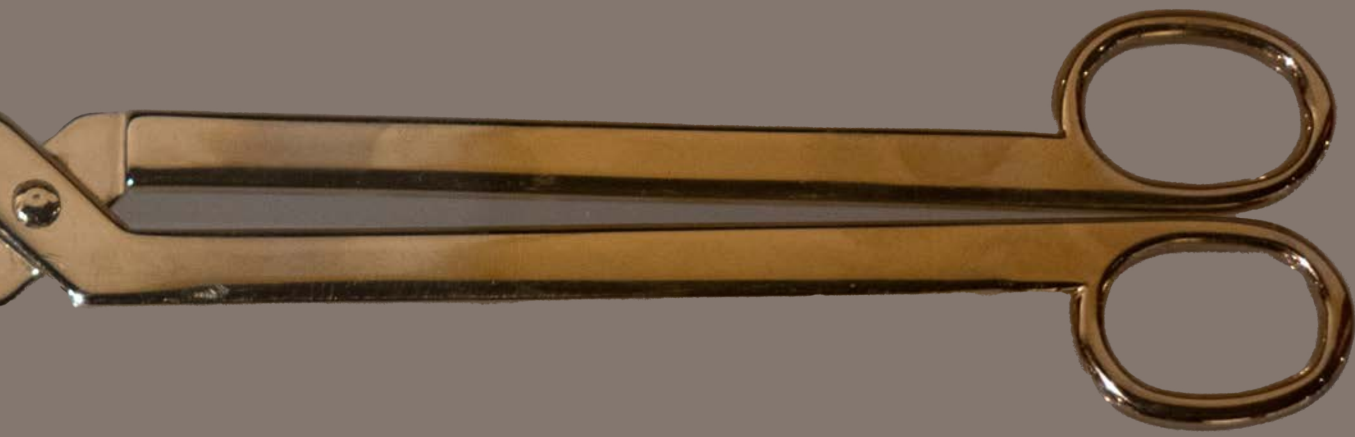


When the Surgeon Was an Uneducated Barber

A medical student confronts the history of surgery

BY MICHAEL DENHAM



SCARC / SHUTTERSTOCK

"COME HERE," THE VASCULAR SURGEON told me during a lull in activity. I stepped closer. "Put your hand where mine is." I burrowed my hand into the open abdomen, my wrist sliding past a mess of slippery intestines that occasionally contracted with a wave of peristalsis.

"You feel that?" he asked me. I nodded as a strong, steady pulse pushed against my fingers. "That's the aorta."

Over the past few weeks as a medical student on my surgery rotation, I had begun learning many of the tasks essential for a variety of operations. I had practiced suturing wounds closed, tying surgical string to my scrub pants so that I could hone my knot tying skills in between surgeries. I had grown familiar with how each surgeon liked to organize the array of wiring and tubes responsible for inflating the abdomen to improve visibility, vacuuming blood to locate the source of bleeding, and burning tissue to cauterize blood vessels. I had learned how to replace the arms on the behemoth that is the approximately $2 million da Vinci robot frequently used by some of the surgeons at my hospital, marveling at how much money could be put to work in a single room.

Each little task represented centuries of progress and innovation, the result of countless surgeons and non-surgeons alike driving the field forward. But in that moment, with my hand against the steady thrum of our patient's heart driving blood down the torso toward the legs, I wasn't thinking about history but that against my fingers pulsed the vitality of another human being. A person who was placing their full trust in our care. The weight of that responsibility hit me, as it would again and again throughout my rotation on the surgical service. Rarely do we place as much trust in a stranger as we do in the operating theater. How did the profession of surgery progress to this point? In large part, at the expense of the vulnerable.

The surgeon asked his assistants "to unfasten their trousers and relieve themselves in the patient's open abdomen."

THE ESSENCE OF THE SURGEON has changed dramatically, not over three or four thousand years, but only over the last hundred," Ira Rutkow, surgeon, historian, and author of *Empire of the Scalpel*, published this March, told me. In his book, Rutkow offers an overview of surgery's long course from the Stone Age to modern times. Four main advances, he writes, led to the development of modern surgery: an understanding of human anatomy, an ability to control bleeding, a means of controlling pain, and a method of minimizing infection.

Poor outcomes were so prevalent that surgeons—loosely defined as people who used their hands to physically intervene on the human body to treat injuries or disease—"were usually looked at askance," Rutkow said. The Code of Hammurabi—the legal text of the famed Babylonian ruler who reigned from 1792 to 1750 B.C.—included a warning of the risk of failure in surgery: "If a surgeon has treated a gentleman for a severe wound with a bronze lancet and has caused the gentleman to die, or has opened an abscess of the eye for a gentleman with the bronze lancet and has caused the loss of the gentleman's eye, one shall cut off his hands."

Before Andreas Vesalius' seminal work *De humani corporis fabrica* (On the fabric of the human body) was published in 1543, common understanding of anatomy in Europe was largely based on the work of a physician named Galen of Pergamon, who was born in what is now Turkey in 129 A.D. Because dissections of human bodies were forbidden in the Roman Empire at the time, Galen relied on dissections of animals to make inferences about humans. His teachings included descriptions of the liver as having five lobes (human livers have two) and the wall separating the left and right sides of the heart as being littered with small holes (which led to significant misunderstandings of human circulation until the 17th century). "Western anatomy and medicine had, for hundreds of years, been effectively based on one man's anatomical romp through the animal kingdom," writes Paul Craddock, historian and author of *Spare Parts: An Unexpected History of Transplants*, published this May.

In contrast to the precedent of scholars blindly trusting Galen's observations, Vesalius performed his own dissections and noted how his findings differed from those of the esteemed Galen. His descriptions in the *Fabrica* helped usher in a wave of questioning and experimentation emblematic of the Scientific Revolution. It would not be long before Rutkow's second criterion for the development of modern surgery—the ability to stop bleeding—was met.

"The surgeon's role fell mostly to uneducated barbers who had been frequenting monasteries since the late 11th century A.D., when beards were banned," Rutkow writes. The two fields became more intertwined as barbers took on more surgical roles, like performing bloodletting and amputating digits. Patients' pain was often understood as having a biologically protective role, or even as a religious blessing.

Shortly after the *Fabrica*'s publication, during the Italian War of 1551-1559, one such barber-surgeon named Ambroise Paré struggled to find a method to halt bleeding in amputations. Based on the Greek and Roman use of ligatures to tie off blood vessels—a practice that by this time had been abandoned—Paré developed an instrument called the *bec de corbin* (crow's beak) to close off large blood vessels, buying time for a ligature to be tied around the blood vessels, stopping

TOOLS OF THE TRADE Today's array of surgical instruments (above) bear little resemblance to ancient surgeons' medieval instruments of torture, but in fact they evolved from them.

DARIO LO PRESTI / SHUTTERSTOCK

the hemorrhage. This device would evolve into today's hemostat, a surgical clamp used in almost every surgery I've participated in—an essential in the modern operating room.

Lives were sometimes abused and sacrificed without choice in the pursuit of surgical knowledge. Rutkow describes one such instance in 17th-century France. To prepare himself for a surgical reparation of King Louis XIV's anal fistula—an abnormal tunnel extending from the rectum to the skin around the anus, usually caused by an unchecked infection—the king's chief surgeon, named Charles-François Félix, practiced his technique on dozens of indigent patients, many of whom died. The success of the operation on the French king in 1686 brought Félix wealth and acclaim, lending prestige to the art of the surgery and jumpstarting a wave of medical tourism to Paris for anal fistula treatment, even for some patients who had no such problem.

Surgery in the United States shares this checkered past. In the 1840s Alabama physician James Marion Sims garnered national attention after publishing his work on vesicovaginal fistula repair, techniques which he optimized through his experiments on enslaved Black women.

It's almost unfathomable that centuries of surgery passed before the first public use of surgical anesthesia occurred at Massachusetts General Hospital in 1846. Inspired by a public display of nitrous oxide (also known as laughing gas) in which a participant injured himself but was seemingly nonplussed until the gas's effects wore off, dentist Horace Wells imagined the gas's potential application for tooth extraction. Collaborations with dentist William Thomas Green Morton, physician Charles Jackson, and surgeon John Collins Warren eventually led to a successfully painless 25-minute neck operation by Warren. Fights later ensued between Morton, Jackson, and Wells as to who should

Medicine had been based on one man's anatomical romp through the animal kingdom.

receive credit for the discovery of surgical anesthesia, as well as the associated financial rewards. Although rivalries, spiritual beliefs, and fears about safety limited the speed of its initial uptake, over the next decade surgical anesthesia became widespread.

As surgeries increased in complexity, the need to address risk of infection became ever more dire. Likely due to a belief in the antiseptic power of urine, an early transplant surgeon named Leonardo Fioravanti requested his assistants and spectators of the spleen operation "to unfasten their trousers and relieve themselves in the patient's open abdomen," Craddock relates.

Following his groundbreaking research on bacteria that refuted traditional notions of spontaneous generation, French chemist Louis Pasteur conjectured that microorganisms might be a cause of human disease. English surgeon Joseph Lister built on Pasteur's work to conclude that microbes from the environment—including the millions of bacteria on surgeon's hands and instruments—seeded wounds, leading to infection. In 1867, Lister published research describing his use of carbolic acid as a means of killing these organisms. His research was met with skepticism but would become universally accepted, heralding a new age of surgery into the 20th century.

SURGERY, I LEARNED, owes much of its current practice to fields outside of medicine. Grafting, for instance, taking tissue from one part of the body to heal another part, emerged from agricultural methods. The skin grafting technique described in the *Sushruta Samhita* in ancient India and the grafting technique described later in the Renaissance, in the 16th century, are both direct transpositions of farming. "That's where you get phrases like 'agriculture of the body' and 'the farming of men', all these metaphors," Craddock told me. "That kind of agricultural frame lies completely outside of legitimate medicine at the time, the medicine of Galen."

In the early 17th century, the English physician William Harvey discovered the heart's role as a pump. As a result, Craddock said, "you start to get these mechanical metaphors that speak to a very different understanding of the body as partly machine."

This mechanical framework, Craddock argues, later shifted to one of craft- or fabric-making as surgeons began using finer techniques on more delicate tissues. French surgeon Alexis Carrel pioneered techniques for suturing blood vessels, allowing for vessels to be reconnected to one another, a critical development in the history of transplant surgery for which he was awarded the Nobel Prize in Physiology or Medicine in 1912. According to Craddock, Carrel obtained both suturing material and sewing technique from famous Lyon embroiderer Marie-Anne Leroudier. This inter-industry transfer of skills allowed him to learn how to sew hundreds of stitches into delicate cigarette paper while studying "how far he could push his materials and how the fabric of the human body would respond to the action of his nimble, sensitive fingers," writes Craddock. Notably, Carrel would later retire to France in pursuit of a eugenics program that, thankfully, never panned out. Yet his technical advances remained of lasting impact to the field of surgery.

"If the study of surgical history offers any lesson," writes Rutkow in *Empire of the Scalpel*, "it is that progress can always be expected, at least relative to the technology of a given era, and will lead to increasingly sophisticated surgical operations with better results."

The development of military technology has spurred surgical innovations, often by creating new, more gruesome methods of injuring other humans. From the moment "the first machine gun rang out over the Western Front, one thing was clear," writes historian Lindsey Fitzharris in *The Facemaker: A Visionary Surgeon's Battle to Mend the Disfigured Soldiers of World War I*, published this June. "Europe's military technology had wildly surpassed its medical capabilities."

A strong, steady pulse pushed against my fingers. "That's the aorta," my professor said.

"Shells and mortar bombs exploded with a force that flung men around the battlefield like rag dolls," Fitzharris writes. "Noses were blown off, jaws were shattered, tongues were torn out, and eyeballs were dislodged. In some cases, entire faces were obliterated." Men suffering some form of facial trauma from France, Germany, and Britain alone totaled around 280,000 before the war ended.

The Facemaker describes the advancements of British facial reconstruction surgeon Harold Gillies in his efforts to repair the extensive injuries incurred by soldiers during the war. By establishing a center devoted to the interdisciplinary reconstruction of soldiers' faces—involving teams of "surgeons, physicians, dentists, radiologists, artists, sculptors, mask-makers, and photographers"—Gillies helped pioneer many techniques that would prove critical to the development of plastic surgery. Among these included the use of surgical flaps, healthy tissue cut from one area of the body and then moved to another while maintaining its original blood supply.

It can't be emphasized enough how transformative some of these surgeries were for these injured soldiers. Gillies's consideration of both function and aesthetics allowed many of his patients to return to some semblance of normalcy. That alone often proved to be transformative for these injured soldiers. Soldiers with significant facial wounds generally faced considerable obstacles on returning home, including broken engagements, scared children, and lost identities.

IN REALITY THERE IS NO WAY to separate present-day surgery and one's own practice from the experiences of all the surgeons and all the years that have passed," Rutkow writes.

I would like to think that, as a medical trainee, I am participating in a long lineage of surgeons, extending from clinicians expanding the definition of who can practice surgery today all the way back to the unnamed Stone Age practitioners who engaged in neurosurgery—as evidenced by numerous skulls with man-made holes scattered around the world. It makes me wonder how the ways we gain knowledge might inform surgical practice, as well as how advances should be memorialized.

Shortly after I palpated the aorta, I assisted with closing the footlong incision in the patient's abdomen. Because I had been practicing, I was more confident than I had been mere weeks before. I drove the needle into the patient's skin, my eyes homing in on the line dividing the layers of epidermis and dermis, my target. A fellow watched over my shoulder as I extended the continuous suture down the patient's belly, trying to close the layers of skin as evenly as possible, avoiding any unnatural ripples or mismatched edges.

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We Might Already Speak the Same Language As ET

Alien communication could utilize quantum physics, so SETI needs a new way to listen

BY CALEB SCHARF

THE FERMI PARADOX, the “where is everybody?” puzzle, is a persistent question in the search for life in the universe. It asks why, if life is not exceedingly rare in the cosmos, it hasn’t shown up on our doorstep. Equally we might ask why we haven’t even heard from alien life, through radio signals or any other means. A part of the answer could be that our present work on the search for extraterrestrial intelligence is actually very limited. Estimates show that we’ve only examined the equivalent of a hot tub of water compared to all the world’s oceans in our combing through the electromagnetic information that rolls in from the cosmos.[1]

If you’re a glass-half-full kind of person you’ll see this as an opportunity, but the problem is that we don’t actually know what might be filling the glass in the first place. The vast majority of SETI studies look for structure in electromagnetic radiation, whether in amplitude or frequency modulations of radio waves, or regularity in pulses of light, or in multi-wavelength correlations. In other words, we assume that information might be sailing past us in representations built using classical physics. But what if that’s just wrong?

If you're a glass-half-full kind of person, you'll see this as an opportunity.

In recent years a small cadre of physicists and astrophysicists have examined the possibilities for communication across the universe that uses the quantum properties of matter and radiation.[2] Here on Earth quantum mechanics is perhaps the greatest triumph and the greatest headache of 20th-century physics. As theories go it has repeatedly validated itself through some of the most exquisite measurements we've ever made about the world, yet it remains profoundly challenging because of its counterintuitive rules and contentious interpretations. Even the "simple stuff" is hard, including the basic mathematical tools needed to describe how matter and radiation futz around in weird states of uncertain superposition (think Schrödinger's cat) or mind-bending entanglement, where properties are linked across space and time, yet never definite until interactions occur.

Nonetheless, these tools point to a rich array of possibilities for the transport of information and for computation, all based on intrinsic properties of the universe rather than the parochial approaches we have for things like digital bits and semiconductor physics. Sitting at the center of this is a mechanism that we call quantum teleportation, where a quantum state can be transferred between otherwise indistinguishable objects, so that it is exactly as if a material system has been relocated. That quantum state might be of a photon, or a particle, or many of these objects, and might involve properties such as particle spin or photon polarization. Quantum teleportation is very real and was first accomplished in 1997, becoming an almost standardized technique here on Earth.[3] It has even been performed between a lab on the ground and an orbiting satellite, by teleporting the quantum state of single photons.[4]

To understand just what this could mean for cosmic communications, we have to wade a little deeper into the details, or else risk using a lot of metaphors and mystical sounding hand-waving. Rather than apologize for this I'll say that it's absolutely necessary to begin to grasp the far-reaching implications of quantum information exchange for thinking species.

THE FIRST STEP is to back up a distance and mention the "qubit," or quantum bit. In classical information the "bit" is literally an object that can represent only two conditions, a 1 or a 0—like the way that the cluster of pixels or ink dots in front of you has just done. But the photons and particles of the universe are fuzzy, quantum things with both wavelike and particle-like behaviors and can exist as indefinite superpositions of 1s and 0s, or a mix of spins or polarizations and other qualities. These are qubits, and Schrödinger's famous cat, that is both alive and dead simultaneously in a state of superposition, is very much a qubit. Qubits can be manipulated in ways that maintain their fuzzy superposition but nonetheless modify their unknown quantum state (like rotating a cat's box without opening it). These manipulations are cousins to the kind of logical gate operations we perform on classical bits of data with things like AND, NOT, and OR gates buried in our silicon chips, so that we've come to term them as quantum gates, forming the basis for quantum computation using qubits.

Qubits can be connected using another mind-bending property of the world that we call quantum entanglement, where (for example) a pair of qubits can be intermingled so that their unknown properties are nonetheless knotted together, and when one qubit is finally measured the consequences of that measurement will be instantly propagated across its entangled partners, no matter where they are. For computing this is key, because the application of quantum gates will naturally propagate across all entangled qubits.

If you're keeping up so far that's good, because we're almost ready to see how all of this comes together in quantum teleportation and interstellar communications. The last piece to mention is called the "no-cloning theorem," which is not some edict from the *Star Wars* mythology, but rather a mathematical proof that an unknown quantum state cannot have an identical,

PAGES 94-95: METAMORWORKS / SHUTTERSTOCK

BAD CONNECTION Searching for alien intelligence with radio telescopes relies on classical physics, writes astrobiologist Caleb Scharf. But that might be a bad connection.

SUMIKOPHOTO / SHUTTERSTOCK

independent copy made of it or else the limits of the speed of light for communication will be broken, with all hell breaking loose for causality and reality as we understand it. To get around this, quantum teleportation must destroy the original unknown quantum state as it is copied.

Now imagine that we have Bob, sitting here on Earth, and Alienx, sitting on a planet around a distant star. Alienx wants to teleport some quantum information—the unknown state of a single qubit that we'll call Q—to Bob. Alienx generates an additional, entangled *pair* of qubits and sends one of those out across space to Bob. In the meantime, Alienx applies a quantum gate to their half of the entangled qubit, but that quantum gate is *controlled* by the qubit Q that they want to send. In other words, they're imprinting qualities of Q onto the entangled qubit (actually further entangling it). They then make a *measurement* of Q (necessarily destroying its quantum state in the process) and the manipulated qubit, storing the results in some classical bits and transmitting that classical data to Bob by any ordinary means, like a radio signal.

What Bob ends up receiving is one of the entangled qubits, and the classical data about Alienx's measurements. He then reads the classical data and depending on what it says he applies a quantum gate to the received qubit, which will then acquire the state of the original Q. Lo and behold, an unknown quantum state, and quantum information, has been "teleported" across space. If that doesn't sound exciting, consider a more elaborate example where the quantum states of a collection of atoms are teleported using the same principles. If those atoms were parts of a set of molecules, Alienx could transmit not just a boring chemical

Lo and behold, an unknown quantum state has been "teleported" across space.

formula or molecular structural configurations, but the fuzzy quantum state of the molecules that they are utilizing, with precisely the same propensities for reaction and interaction. That is something completely out of reach for any classical communication.

The rub, though, and there is one, is that for any of this to work the pair of entangled qubits must retain *coherence*. Quantum coherence can be thought of as a system holding on to its pure quantum properties. For example, in the famous double-slit experiment an electron can exhibit pure wavelike characteristics of interference that modulate where the electron (as a particle) appears after passing through two tiny slits in a screen, and that wavelike interference only occurs when things are coherent, or undisturbed. Nudge the electron on its journey, or let it interact with the world in any other way and it can decohere, removing or collapsing its wavelike qualities to behave like a boring classical object.

The biggest barriers to coherence across the cosmos come from the fact that space contains photons and subatomic particles, as well as interstellar atoms and dust. Sending delicate, coherent quantum systems through all of this tends to make them far less coherent, causing the loss of their purest arrangements of superposition or entanglement—the intermingling of states that enables teleportation and communication. In a recent paper published in *Physical Review D* in April 2022, two scientists, Arjun Berera and Jaime Calderón-Figueroa of the University of Edinburgh have studied the effects of gravitational fields, interstellar matter, and cosmic radiation on coherence.[5] What they find is that coherence could actually remain across interstellar distances, and perhaps even across the Milky Way galaxy for certain wavelengths of electromagnetic radiation. X-ray light is particularly promising for dodging many of the sources of decoherence across space.

But if aliens are sending out quantum hailing signals, how will we find them? Teleportation involves those two channels of communication, one classic and one quantum, and a signal would have to be repeated to stand any chance of reception by an unknown party. The quantum piece might be a series of single photons (the qubits) or clusters of photons in more complex, entangled arrangements, while the classical channel would consist of the repeating data on the measurements of the qubits that our Alienx made in the example used above. If these two kinds of electromagnetic

It's possible, then, that this is the solution to the Fermi Paradox.

signals arrive at the same time, and from the same place in our skies, we—or any other species—might realize we're getting pinged with a teleportation.

Of course, the next steps; to figure out the protocols of what quantum gates to apply, and even how to respond, may seem hair-raisingly uncertain and complicated. Yet in truth, this would not be any more or less challenging than deciphering a classical extraterrestrial communications channel, and in some ways could be easier initially because we'd know that we were decoding a quantum communication and would have an idea of what possible quantum gates to try, from simple to more complex. In that sense we can already congratulate ourselves, because the use of quantum channels for communication could represent a filter between more sophisticated species and the classical plebeians of the cosmos, who are perhaps not worth investing time in.

But the real eye-opener is the implication that the best kind of transmitters and receivers for quantum teleportation communications would actually form parts of quantum computing systems. The process of qubit entanglement and the application of quantum gates for teleportation are simply elements of quantum computation. That tells us that, in principle, interstellar quantum communications could involve vastly richer information content than anything possible classically.

In fact, if issues of decoherence can be overcome, there is no reason why a quantum computer could not be distributed across interstellar space, with its entangled pieces interacting in much the same way as distinct pieces of a physically co-located quantum computer interact. In some respects, interstellar space is a much less decohering environment than pretty much anywhere on a planet like Earth, since the density of matter is typically around a trillion, trillion times lower (of course this is somewhat offset by the huge distances that quantum states have to traverse).

The transmission of computing information is still limited by the speed of light, so this kind of interstellar computing would be collectively slow. But that might not matter if the overall value of the process is vastly amplified by its distribution and the consequent access to greater computational resources (just more qubits for example). There might be forms of information exchange or problem-solving that are very much worth it, especially if they relate to deeper interspecies understanding or vital survival knowledge, which could include finding solutions to otherwise intractable scientific questions.

It is therefore possible that the solution to Fermi's paradox, at least for interstellar communications, is that the language being used by anyone worth talking to utilizes quantum physics, does not look much at all like our parochial classical electromagnetic signaling, and has thus far evaded our scrutiny. A corollary to this would be that any communicating species might settle down to deeply encrypted, eavesdropper-proof computing exchanges that last for ages and are wholly inaccessible to the rest of us, even while representing the greatest flow of information in the universe. It could be worth our while to try to find out whether or not this is going on, and even if it isn't we might learn something useful about our own baby-steps in utilizing quantum information.

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How Darkness Can Illuminate the Insect Apocalypse

Insects may have been evolving to avoid light. So maybe we need to look harder for them.

BY OLIVER RISKIN-KUTZ

SANDUSIT NOOM / SHUTTERSTOCK

IT WAS MUCH TOO WARM for a Massachusetts mid-October evening, and the bugs were there to say so. A sonic blanket lay over the Alewife Brook Reservation, a 136-acre spread of wetland, forest, and meadow just outside Boston—the buzzsaw purr of cicadas and the katydids' rhythmic zipper noise woven between the pure-tone chimes of crickets—making it sound like late summer. This sound has felt especially welcome lately, amid reports of dwindling global insect populations usually labeled an "insect apocalypse" in the news.

FIREFLY FISHING Entomology graduate student Avalon Owens has a theory that the so-called insect apocalypse may be partially driven by observation errors. Here, she collects male fireflies for an internal clock experiment. They don't flash when they're captured, so she has to peer into the net to see them once she's caught them. She uses a red headlamp "because it is easy on the eyeballs and relatively less visible to most insects (most animals, actually)."

Despite the racket, I couldn't see any insects until Avalon Owens, an entomology graduate student at Tufts who has what she calls "super-vision for tiny things," bent down to point out a sleeping bumblebee, nestled on the underside of a shrub's leaf. And then another, under another leaf, and then two more. I pointed out a mosquito that had landed on her forehead; she gently brushed it away with a forefinger.

Owens—bumblebee earrings hovering over the collar of a hunting camo fleece—tells me my difficulties in fully perceiving the insect world around me aren't unique to me. I had come to talk with her about her theory that part of what scientists call a decline in insect population is not an actual decline; rather, over the past few decades, bugs have started to hide where entomologists aren't looking. Her reasoning goes like this: Since humans have been artificially illuminating the night, they have noticed insects congregating around lights. First there were a few at campfires, then a flutter at gas lamps, then flocks at gas stations and streetlights. Entomologists took advantage: To find insects or count them, they turned on lights. People started using lights to attract insects more than three centuries ago and still today, researchers collect much of their insect population data with light traps at night.

"You put out a light and see what comes to it," Owens said. "And if they stop coming to it, you're like, 'Oh, there's no insects left.' "

BILLY HICKEY

But think about what happens to those bugs, drawn to candle flames or gas stations, or entomologists' light traps, for that matter. They're incinerated, or mashed against a headlight, or become a well-lit snack for predators. And even if they survive their encounter with the light, they've spent their night loitering instead of eating or finding a mate. Generations of insects later, the ones that remain are more likely to be the great-great-great-grandlarvae of the ones that stayed away.

If Owens is right that insects have been evolving to avoid light, then many of the observations on which some scientists base an insect apocalypse may actually indicate more of an insect-observation error. We could be trying to observe insects by looking exactly where they aren't.

That would be a problem, because insects are very important. They perform what ecologists call "ecosystem services," pollinating plants and eating pest species. And while doing that, they move the great drive belt that governs all life on the surface of the Earth: the transfer of energy from the sun to plants to animals to other animals. Insects, weighed all together, would probably be heavier than any other group of terrestrial animals. They achieve this mostly by eating a tremendous amount of plant matter—so much that the food preferences of local insects can determine which trees make up a forest, Laurel Symes, a Cornell ecologist, told me. Their appetite means much of the solar energy in plants has to go through insects before it goes anywhere else, and the rest of the animal kingdom knows that. "Everything will eat an insect if it can get ahold of it," Symes said. That "everything" includes birds, frogs, spiders, small mammals, some other insects, and Yellowstone grizzly bears, which can eat up to 40,000 army cutworm moths in a day, scooping them by the pawful from rocky crevices.

Why did insects have the "most ruinous propensity" to "rush impetuously into bright flames?"

My first reaction to hearing Owens' hypothesis was relief—a feeling that, if reports of the "insect apocalypse" had been based on faulty methods, then maybe that was at least one less thing to worry about in a world full of other, more dependable apocalypses. But unfortunately, Owens isn't saying that everything is just fine with insects and their ecologies. Global apocalypse or not, there's a lot of compelling evidence that insect populations of some species are declining and changing in some areas, especially those affected by human

Was it possible that insects had started to shake their fatal attraction to lights?

activities such as agriculture, which are also some of the places insects are most important to us. There is broad consensus among entomologists and ecologists that we should at least be worried about these species and the broader ecological effects of the changes in their numbers.

So if one of our main methods for finding and studying insects turns out not to work, where does that leave us? We need to understand insects, and if Owens is right, we don't understand them at all.

AMONG THE THINGS we don't understand about insects is why they would come to light in the first place. I had always assumed it's just a thing that insects do, but hearing from Owens about the terrible dangers insects brave to buzz around lights made me think again. Of course, I am not the first to wonder.

In April 1871, South African butterfly and moth naturalist Roland Trimen wrote to ask Charles Darwin my very question: Why did insects have the "most ruinous propensity" to "rush impetuously into bright flames?" The behavior could only have developed recently, he guessed, "after man began to lighten his darkness by artificial means."

Trimen also offered a tentative prediction based on Darwin's theory of evolution: "the elimination by death or severe injury of all those individuals in whom the propensity was strongest, might eventually rid a species of so peculiar a form of suicide."

Almost a century and a half later, in summer 2010, Dieter Ebert was sitting on the porch of a remote field station in rural Finland contemplating the same question. Ebert, an evolutionary biologist at the Zoological Institute of the University of Basel in Switzerland, and his graduate student Florian Altermatt were there to study crustaceans. But every evening they would sit on their back porch and watch the moths flapping around the lights there.

"There was always this question," Ebert said. "Why do they fly to the light?"

Darwin hadn't been able to answer Trimen's question, and it still doesn't have any universally accepted answer. Ebert's favorite hypothesis, he told me, is the so-called "moon compass theory," that insects have evolved to navigate by keeping a constant angle to the light of the moon, but trying to keep a constant bearing with respect to a light only feet away leads them to spiral into it.

Pondering the moths in Finland, Ebert remembered a white wall behind the porch of the farmhouse in Western Germany where he had grown up in the 1970s. There was a light in the middle of it that his family turned on at night, and Ebert would sit out and watch hundreds of moths land on the wall, until it was fully covered.

Ebert told me that in 2010, it seemed to him he didn't see as many moths as he had back then.

Forty years might not seem like much time on the scale of natural history. But evolutionary time is measured in generations rather than in years, and there is often more than one insect generation per year. Ebert specializes in studying cases of "fast evolutionary processes," like a population of Swiss water fleas, a crustacean that can evolve immunity to a deadly bacterium over the course of just two months.

"I have seen many cases where things evolve quite fast," Ebert said. "And once you understand that selection is strong, undoubtedly you will find the effect of adapting in response to the selection."

And in the case of insects, he said, the selective pressure of artificial lights on those that come to them is "extremely strong."

So he and Altermatt began to wonder: Was it possible that in the best-lit places insects had started to shake their fatal attraction to lights?

ONE OF THE BEST already-confirmed examples of fast evolution happens in insects. Over the course of the 20th and 21st centuries, more than 500 species of insects have evolved a resistance to specific pesticides. On Ebert's principle, that makes sense: A chemical tailor-made to kill you is a very strong selective pressure.

But millennia before people started to produce pesticides on an industrial scale in the 20th century, they figured out another cheap way to dispatch insects in bulk: to exploit their attraction to light. Ancient Greek and Roman beekeepers were already using open fires to attract and kill the wax moths that colonized their hives, and the method persisted until the 1860s when Townend Glover, the first United States Entomologist in the Department of Agriculture, was recommending "bonfires in June" as a method of controlling codling moths, whose larvae like to live in apples, pears, and English walnuts. Still today, modern light traps are an important tool for pest control.

At the same time people were exploiting insects' weird but useful attraction to light to kill them, another group began to use it to study them: entomologists, who worked alongside insect-killers over the years to devise ever more effective ways to trap insects.

In the 1860s, Glover (of the bonfires in June) invented the first version of the self-contained light trap—an assemblage of glass panes, leather straps, sliding drawers, and a kerosene lamp. You could set the "marvellous moth trap" out for the night and come back in the morning to study your catch (a welcome improvement over the method of wandering the woods at night with a candle, as entomologists had been doing for the previous few centuries).

Today, much of what we ("we" as in entomologists) know about insect populations comes from those sorts of traps (albeit updated versions with electric light sources). One blockbuster "insect apocalypse" article in 2019, for example, was a review of previous insect decline papers, and described "dramatic rates of decline that may lead to the extinction of 40% of the world's insect species over the next few decades."[1]

There are some technical issues with the 2019 review, like the extrapolation of population decline in certain areas to a worldwide loss of insects (this seems like a stretch to many ecologists, including Ebert and Owens).

But also, many of the papers in the 2019 review use data from light traps. The papers it uses to assess United Kingdom moth decline, for example, rely heavily on the Rothamsted Insect Survey, one of the oldest continuous insect population observatories. Since the 1960s, the survey has run two trap networks in the British Isles, one of which monitors moths with light traps, and the other of which monitors aphids using suction traps, which suck in flying insects passing by. In 2020, it published a result that might not surprise you if you're inclined to share Owens' suspicions: While it found moth populations appeared to have declined by about 31 percent over the past half-century, aphid populations had remained just about stable.[2]

FROM AN INSECT'S PERSPECTIVE, the light problem is much bigger than scattered bonfires and entomologists' lanterns and bulbs. What matters to an insect is that in the last 100 years or so, much of the world's nighttime has become much brighter—a process that has dramatically accelerated in the last 15 years with the widespread adoption of LED lighting. Illuminating the night is now easy, cheap, and (with respect to carbon emissions) relatively environmentally friendly.

These days, it's hard to find a spot in the United States where you can see the Milky Way at night. A light is no longer such a "very new object" to insects as it had been to the ones Darwin considered in 1871.

So in Finland in 2010, it seemed reasonable to Ebert and Altermatt that the insect populations most subjected to lights would have already begun to evolve away from their attraction to them. They devised an experiment to find out: They would check if urban moths were less likely than rural moths to come to a light.

They set about collecting spindle ermine moth caterpillars—small white caterpillars with black spots, which turn into small black-speckled white moths—from the French and Swiss countryside, and from parks and bushes near city street lights.

After a caterpillar hatched into a moth, the researchers would dye a dot on one wing, tagging it as a country moth or a city moth. Then, in the evening, they took it and its cohort of hatchlings into a room completely tapestried in black fabric. They set up a light trap at one end of the room, released the moths at the other end, and waited.

The work of coming back to the lab in the middle of the night, to check on the moths and record the ones that had been trapped and the ones sitting on the walls near the light, mostly fell to Altermatt. But Ebert remembers that on the one night he came in, it seemed like about equal numbers of city and country moths had come to the light.

As they started to crunch their numbers though, a pattern emerged. About 30 percent fewer of the city moths appeared to be attracted to the light.[3]

That's not a "super strong" effect, Ebert said. That could be in part because in some city bushes they had unwittingly collected the caterpillars of moths that had flown in from the country. But it could also be because the process of evolution away from light is an ongoing one.

"It might well be that if you do the same study in 20 years, that the effect is stronger," Ebert said.

But the effects of moths' evolution away from light-seeking behavior could go beyond a divide between urban and rural moths, Ebert added. The more advantageous it becomes to not be attracted to light in the city, the likelier that behavior will be to spread through the whole species.

And today, Owens believes that the widespread loss of light-seeking behavior, across many species of insects living everywhere from cities to the countryside to rainforests, may have already begun.

ON OUR WALK through the Alewife Brook Reservation, Owens crouched down to point out a recent adaptation: A spider had strung its web across a light illuminating the walkway. "Evolution in action," she said. If spiders have learned to come to lights to catch bugs, why shouldn't bugs have learned to stay away from lights and avoid being caught by spiders?

Owens' evidence, which she will use to investigate her hypothesis on a postdoctoral fellowship at Harvard, will be moths, many of them pinned in drawers in Harvard's Museum of Comparative Zoology.

Owens will use those moths, as well as data about captured moths in other collections, to answer two questions: How has the likelihood of entomologists capturing a given species of moth with a light trap changed over the past decades? And, how have the actual population sizes of that species varied over the same time period?

"You have two lines," Owens told me. "One line is what we think is happening to insects based on light trap data, and one line is what's actually happening to insects based on actual estimated population size." The plausibility of her hypothesis will be determined by the discrepancy between the two lines.

To find the shape of the actual-population line, Owens plans to sequence the genes of historical moth specimens in the MCZ collections from different years, and use changes in gene diversity between specimens as a proxy for changes in population size (when populations of a species are smaller, individuals are also generally more genetically similar to each other). And for the observed-at-light-trap line, she will need to determine how, and how often, entomologists caught what they caught, using whatever records they happened to leave behind.

A BUZZ IN THE AIR The Alewife Brook Reservation, a 136-acre spread of wetland, forest, and meadow just outside Boston, is home to a number of insects. The author visited with entomology graduate student Avalon Owens to investigate claims that there are less insects than there used to be.

WIKIMEDIA COMMONS

In Harvard's lepidoptera room, I began to see why that second task is so difficult. Much of the data about how a given moth was collected exists only as handwritten one-inch-by-one-quarter-inch note cards pinned under the moth, or worse, in the field notes of whichever researcher collected it. Often, especially for older samples, researchers don't mention their methods at all. And even if a researcher collected a moth with a light trap and recorded that, and the information was later entered into a museum's database—each step less likely than the last—unless they were one of a handful of completely systematic surveyors they might have only preserved those species that they happened to be interested in.

Beyond those issues, studying insect populations is just a data science nightmare. This is partly a problem of scale: About four-fifths of all documented animal species are insects. And although more than a million species of insect have already been discovered, there are likely millions more out there waiting to be found.

The number of individual insects also tends to change wildly year-by-year, in "big booms and busts," Owens told me. Although some of those correspond to events like temperature changes and droughts, "a lot of it is just literal, chaotic noise," she said.

More fundamentally, trying to understand insects also poses problems for humans as an animal species. Namely, "lots of insects are invisible," Symes, the Cornell ecologist, told me. They are just much better at hiding than we are at finding them. So, humans haven't yet been able to understand anything about insect populations with much precision.

"If you have a year-over-year 10 percent decline for 15 or 20 years, A, it matters a lot; and B, it's crazy how that could happen and we really wouldn't notice it," Symes said. "We'd have no idea if we had half as many insects now as we had 10 years ago."

TO AN INSECT, if you're not a potential mate there's a high chance you're a predator, so insects really don't

IS ANYBODY OUT THERE? Are there less moths now than there were 10 years ago, or have they just evolved to avoid artificial lights? Researchers Dieter Ebert and Florian Altermatt designed an experiment using ermine spindle moths to try to find out.

RAINER FUHRMANN / SHUTTERSTOCK

want you to find them. But if you are a suitor, they need you to. The result: "a lot of insects are nearly invisible, but they're not all silent," Symes said.

Often, insects communicate with each other from their hiding spots with chirps and buzzes. And to find them, she said, "we basically have to talk on their channel, or listen on their channel."

Even once you're listening on their channel though, insects can still be frustrating to get ahold of. "Tree crickets are surprisingly hard," Symes told me. "My first field season was almost entirely learning how to catch crickets." The trick, if there is one, seems to be in a combination of detailed anatomical knowledge of your prey, a good ear, trigonometry, and calisthenics.

"Because of the wing structure of tree crickets, the sound goes out in front and behind with almost nothing that goes to the sides," Symes said. "You'll lose the sound you're searching for sometimes, unless you have a really clear mental image of that shape. And then if you're able to walk around the space where they're hiding, you'll hear, 'Loud, quiet, loud ... Okay, it must be somewhere in between these two loud points.' And then it involves a lot of standing up and crouching down to be like, 'Okay, this is the height where it's the loudest.' "

And after all that (and assuming you're able to catch it), you've got yourself one cricket.

Entomologists trying to observe the insect world have generally shared the goal of capturing insects with insect predators. That's inconvenient for entomologists because it's a goal insects have spent their whole evolutionary history learning how to thwart. Anything an entomologist does that ends in an insect's capture is by definition a selective pressure on the insect, and in many cases imitates other selective pressures that are very present in the insect's life. The insect responds by pretending to be a leaf, or, possibly now, by learning to stay away from light bulbs.

To Symes, the solution to that problem is to observe insects without touching them, or even seeing them. She is the assistant director of the Center for Conservation Bioacoustics at the Cornell Lab of Ornithology—a center of which the guiding philosophy, essentially, is to "listen on their channel." Symes' work involves climbing into Central American rainforest canopies, leaving sound recorders there for months to capture choruses of singing insects, and then digging through the recordings for information about the singers' population sizes, mating habits, territorial grumpiness, wake-up times and bedtimes, and anything else a bug reveals when it talks.

"If you walk out there and listen, all of a sudden you have a much richer picture of what's in that space," Symes said. "I don't know exactly where this insect is sitting, but I know that it's there, whereas a predator actually has to catch it and eat it."

While a predator (or an entomologist) might get tired of trying to track down a hidden and intermittently-singing insect and move on to an easier meal, other insects have all night to slowly detect and crawl toward a mate. Symes' way of observing insects—a technique called Passive Acoustic Monitoring, or PAM—seems more like how an insect would go about it. When Symes takes a long-term recording and then spends hours listening to and annotating it in the lab, it's a sort of technological mimicry of that insectine patience.

"We'd have no idea if we had half as many insects now as we had 10 years ago."

As a human, you don't really notice how much of the night is dominated by electric lights, until you do.

Symes' access to the insect's-ear view (actually, insect's-knee view in the case of crickets and katydids, whose ears are on their legs) yields questions about insect lifestyles that wouldn't have been askable without it. For example, she noticed in a set of recordings that one species of katydid only chirped in the predawn hours.

"The interesting thing is they're one of the only brightly colored species," Symes said. "So I don't know if they maybe meet up right before dawn and then take a look at each other when the sun comes up and decide whether to mate or not—I'm not sure what unique use they're making of that time slot."

This mode of insect observation, freed from the human need to understand by capturing, collecting, and pinning on a board, also allows the Center to collect data on whole populations of singing insects at once. "If you get 50 calls per hour of a species this year, and next year you get 200 calls per hour, or 10 calls per hour, that's telling you something," Symes said.

That "something," she hopes, will be a better understanding of the species' population size, but it could go beyond that. The PAM technique is relatively recent, and the first long recordings the Center has are from 2016. As they collect more data, they'll be able to draw new inferences. You might record more calls from one species during a particularly wet season, or fewer during a dry one, Symes said. "You start to get some mapping between what the insects are doing and what the environment is doing."

THE CHANNEL ON WHICH Owens talks with and listens to insects, for the most part, isn't sound. She talks (and even flirts) with them using light. To experiment on male firefly mate preference, for example, she programmed an LED "firefly communicator" to flash like a female firefly.

It was Owens' observations of fireflies that led her to be thinking about light pollution, which in turn helped her come up with her hypothesis about insects evolving to no longer seek light. Light pollution is especially traumatic for fireflies, which need to be able to distinguish each others' flashes from, say, a semi's headlights, to reproduce. Owens has spent the past few years documenting the light-pollution-driven decimation of American firefly populations.

Light pollution isn't just destructive to fireflies. We, and many other species, rely on melatonin, a light-responsive hormone, to regulate our sleep cycles—a mechanism so evolutionarily ancient a version of it is present in plants. On that time scale, a light is still a very new object. Nighttime lights have been shown to disrupt, among others, migratory birds' flight patterns, frogs' and toads' mating, and mice's foraging. And now, with the widespread adoption of LED lighting, the night is brighter than ever.

As Owens got up from looking at the bees, curled up under their leaves for the night, she pointed out a new biomedical research facility looming up just outside the reservation.

"It's green architecture, and it's super eco-friendly, and it's right next to the reserve," she said. "And isn't that nice, humans and nature living together?"

To avoid the energy costs of heating and absorb as much sunlight as possible, the building was equipped with huge bay windows. And all night, energy-cheap LED lights blaze out of every floor and out into the reservation. I imagined the sleepy bumblebees bumbling off deeper into the woods, rudely stirred up by the city's accidental floodlights.

As a human, you don't really notice how much of the nighttime visual landscape is dominated by electric lights, until you do. Walking out of the reservation after dark, the lights felt visually aggressive—blinding splotches of white and orange blotting out the night around them. Suddenly, I wanted to see what the lights were hiding.

I looked at the lights around me, shining out of the Alewife Station parking lot, skimming across the reservation's creek and marshland. The insect song was everywhere but I still couldn't see any insects, even looking up at the streetlamps' globes.

"I don't see anything," I said, pointing, feeling smart.

"Yeah ..." Owens said. "It's also October," she cautioned. She kept looking.

"Oh, there's one!" She pointed at the lamp and I saw a flicker of wings. "Actually, there's a few." Following her finger, I could barely see a small troupe of flying insects, dancing around the periphery of the lamp's glow.

OLIVER RISKIN-KUTZ is a student at Harvard studying environmental history and biology. He's interested in the ways humans and other kinds of life live with and around each other. His writing has appeared in *Berkeleyside* and the *Harvard Crimson*. You can follow him on Twitter @OLRiskinKutz.

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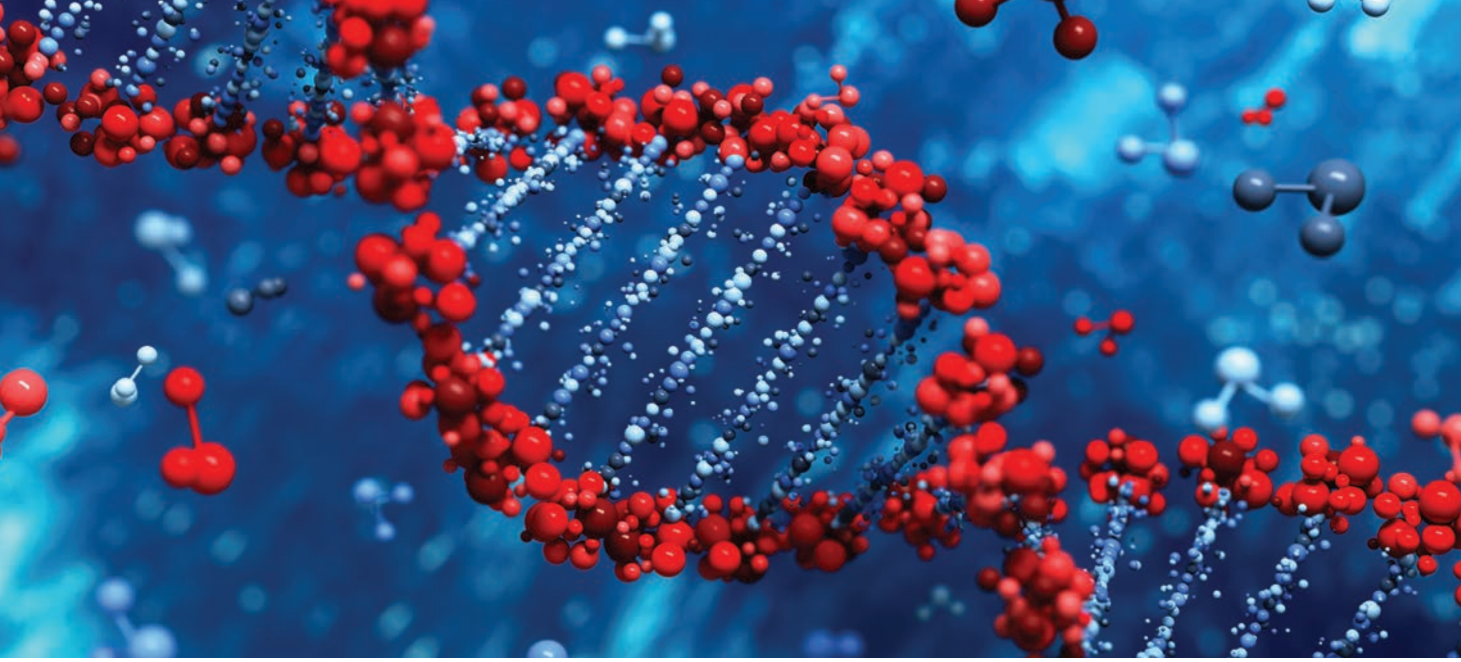

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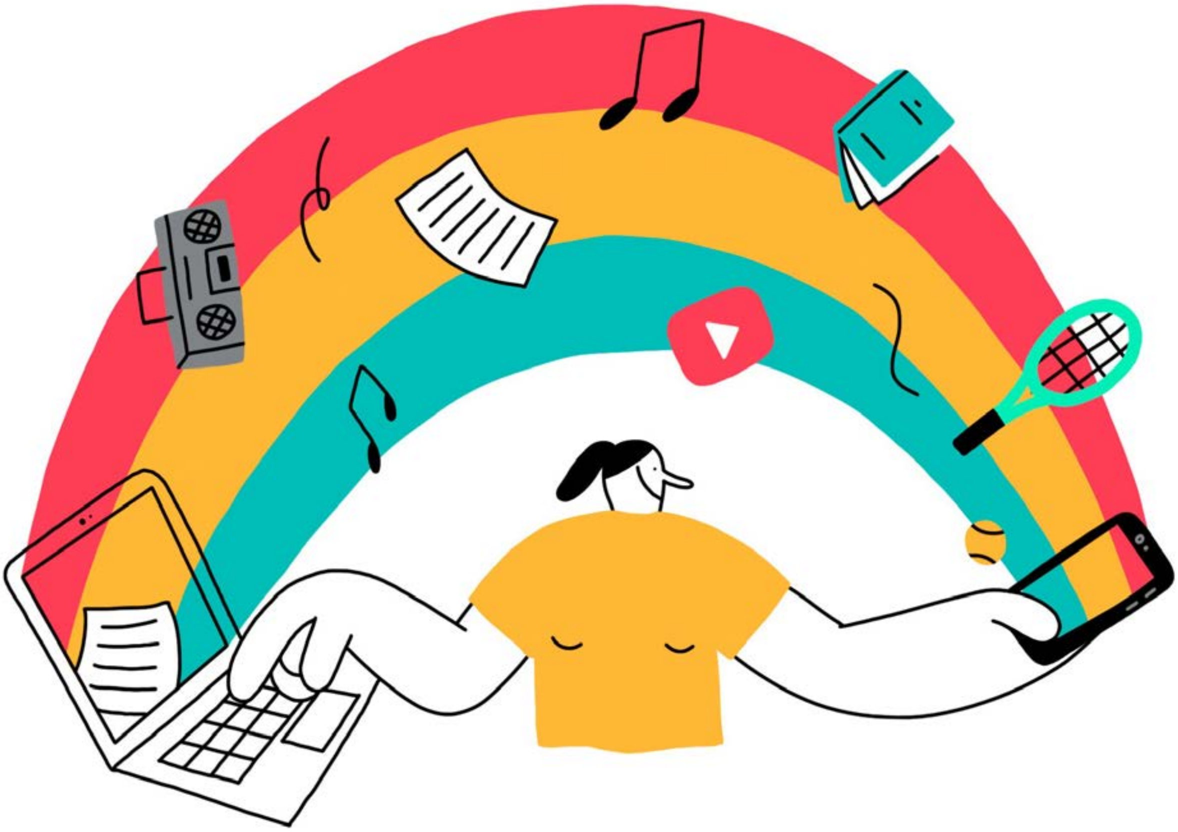

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- Dona Bertarelli

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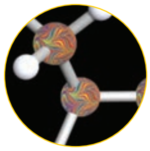

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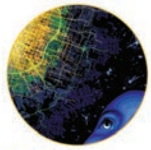

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Claudia Ford

The ethnobotanist on herbal medicine, childbirth, and abortion

INTERVIEW BY BRANDON KEIM

HISTORICAL MEDICINE

When I was delivering babies, I used herbal medicine in my practice. So that's one hat I wear, and the other is the ethnobotany hat, looking at the history of the use of plant medicines for health. Plants were our CVS and our pharmacy before anything else. For literally millennia, humans have used plant medicine for their health care.

THE CURSE OF EVE

Europeans and Indigenous Americans in the 1700s and 1800s had very different ideas about childbirth. European women were laboring under "the Curse of Eve"; they'd been told from birth that to give birth was a curse from God. You would be in pain; they would say the last rites before they went into labor; they expected to potentially die. Physiologically that doesn't have to be true. It's not a walk in the park, but it's not a death situation, either. But European women *were* dying. European women came into childbirth scared out of their heads. For Native American women, Eve was not a concept; they had none of that. From what we can tell from Indigenous scholars, most likely Indigenous women went into childbirth thinking of it the way a warrior thinks of going into battle. It's a rite of passage, it's something that you need to do, but there's no Curse of Eve.

ON ABORTION

There was no moral restriction against abortion, even in the Catholic church. For millennia the fetus was not considered an entity until quickening, which is when the mother can feel the fetus move. Even if a woman realized she wasn't having her menses, and she might know she was pregnant, still there was no association with a fetus.

TRACEY ELLIS

Terminating a pregnancy was seen more as part of the menstrual cycle, not part of pregnancy. Pregnancy is something that led to labor and childbirth; terminating a pregnancy was part of your menstrual cycle. If you had a late period, the first thing people would think would not necessarily be pregnancy. They might know that, but they would be thinking "OK, how do I bring on this period?" Not, "How do I not have a baby?" I know that's semantics. But *Dobbs* is all about semantics, right? If you think of it as restarting your menstrual cycle, it really is a women's health issue. Abortion is reproductive health care. It's not about the morality of the fetus.

HERB USE TODAY

Don't use herbs casually. The plants are powerful medicines. Especially knowing that women are sometimes desperate in this situation, I would never want them to hear something about a plant being useful for abortion, and then go use it. Don't do that. There are enough herbalists who are skilled who will help you, guide you, tell you how to do it. It's like any medicine: It's powerful. You need guidance.

The restarting of menstrual cycles and the termination of pregnancy has always been a part of the health of women's bodies and always been a decision in families, where it belongs. It's not like this is something new. We have always been doing this. It's just something we need to be able to do. And the autonomy, being able to make these choices, has always been with us. It's only recently been made problematic.


5
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