The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn.

—Alvin Toffler
We are a digital, print, and live magazine in which the world’s most creative writers, designers, scientists, and entrepreneurs explore how we can create a sustainable human age we actually want to live in.
Nostalgia tugs hard at our narratives about nature. If we could just hold nature still, even for a human lifetime, then we could save it.

But we cannot. Long before humans emerged as a planetary force, we have had to negotiate and renegotiate our relationship with nature. At various times, it has been an evil presence to be beaten back, a resource to be mined, a treasure to be restored, a place of spiritual renewal, and a source for technological inspiration.

And now, here we are in the Anthropocene, face to face with an existential riddle. Oliver Morton captured it eloquently in *The Planet Remade*: “Humans have become so powerful that they have become a force of nature—and forces of nature are by definition those things beyond the power of humans to control.”

This is strange and difficult territory, just the sort of stuff that we created this magazine to cover. And in that spirit, we’ve assembled a cadre of premier writers to explore how our understanding of nature, and our connection to it, is shifting yet again—and how conservation might look very differently in the twenty-first century than it did in the twentieth.

David Quammen starts us out with an epochal idea. What if evolution isn’t linear, as Charles Darwin proposed when he first sketched the tree of life? What if, instead of species’ passing their DNA to their offspring from one generation to the next, they are exchanging genes throughout their lifetimes? Quammen deftly explains the concept of horizontal gene transfer—and then muses on how it could upend current thinking about everything from antibiotic resistance to cancerous tumors.

Next, Wayt Gibbs explores how satellite surveillance technology is reframing our connection with nature in some of the same exhilarating and profoundly disturbing ways that social media reframed our connections with each other. Seeing the world’s 3 trillion trees in real time allows environmental watchdogs to catch criminals. But it also means that the data riches of big tech’s unblinking eyes will go to whoever can pay top dollar.

When scouting the future, the technology trail is always the easiest to follow. But it’s far from the only one. The economics of nature conservation are also changing in surprising ways. Forty years ago, a group of conservationists embarked on a bold experiment. They sought to integrate conservation and development by fostering new industries—from finding new miracle drugs in nature to ecotourism—that could generate revenue for the people living near protected areas. Economist David Simpson asks, “So how did that go?” His observations are both jarring and instructive. What if the key to saving wild biodiversity isn’t to show that it’s useful—rather, it’s to make it “useless.”

As you peruse the issue, you may also notice the absence of some familiar nature themes. For example, habitat loss imperils more and more species, and we humans must rein in our voracious appetites for more resources. The urgency hasn’t gone away—but those sorts of warnings and admonitions alone seem increasingly insufficient in this new Human Age. The Anthropocene demands that all of us, conservationists included, loosen our grip on how we think the future will unfold—and get creative. Nostalgia serves a variety of purposes in our lives. But negotiating change and moving forward generally aren’t among them.

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1. Idea Watch

People and projects pushing the boundaries of sustainability
In the fall of 2011, my wife and I decided to sell our 900-square-foot Berkeley bungalow and look for more spacious digs. One year and ten failed offers later, we moved into a sprawling, redwood-paneled, mid-century modern in the Berkeley hills. The place needed work. But it was perched on a hillside amidst California oaks, its floor-to-ceiling windows boasting commanding views of San Francisco and the Golden Gate Bridge.

We hadn’t set out to live in a fire zone. But after living cheek by jowl with our neighbors in the Berkeley flats for 17 years, we found the views and the benefits of living a little closer to nature and a little farther from everyone else hard to resist. In this, we were not alone. Millions of Californians over the past five decades have moved up hillsides and into forested areas. And, like many of our fellow residents, we’ve begun to harbor second thoughts after two seasons of catastrophic wildfires.

Were a firestorm like the recent ones that swept through Paradise, Santa Rosa, and Redding to sweep through our neighborhood, our home, seemingly floating in the canopy of an oak forest, would be indefensible and our escape, down narrow and twisting roads to the concreted safety of the flatlands by San Francisco Bay, far from certain.

The situation seems bound to get worse. The degree to which the recent spate of intense wildfires can be attributed to global warming is disputed—and in some sense irresolvable. Disentangling decades of fire suppression and unplanned growth from the effects of a hotter and drier climate is well-nigh impossible. But what seems clear is that both these drivers of worsening wildfires are likely to continue. Global temperatures continue to rise. And Californians show no more sign of abandoning our suburban and exurban redoubts for fear of wildfires than we have shown willingness to abandon our fault-riddled cities for fear of earthquakes.

The same is true for the two of us. My wife has declared that if we get burned out, she doesn’t think she’ll want to return. But neither of us feels much urgency to leave preemptively. And we have greater resources and flexibility than most. For those struggling economically—tied to 9-to-5 jobs, dependent on caretakers, or caretakers themselves—the choices are harder still.

Oddly, the thing that we both acknowledge might prompt us to take action now is not the dreaded fear of fire apocalypse but more prosaic concerns about quality of life. For the third time in little more than a year, we spent a week or more sheltering indoors from the Beijing levels of air pollution that had drifted into the Bay Area from fires to our north. The prospect that fires of this sort might produce frequent air-quality crises almost year-round, more than the fear of losing our home or our lives to raging wildfire in the Berkeley hills, is what has given us pause.

While it might not seem entirely rational, our reaction and priorities are a much better reflection of how and why human societies have tended to deal with environmental challenges. For decades, prophets of environmental doom have been haranguing...
ing the public with threats of ecological apocalypse, to little effect. Yet during the same time, we’ve managed to pass laws that have dramatically reduced air and water pollution, protected coastlines and wetlands, and brought endangered species back from the brink. The dominant tenor of environmental communication during this period has been apocalyptic. And yet, the sorts of threats that people have generally responded to have been closer to home, and the actions to address them have brought near-term benefits.

Two recent government reports, the United Nations IPCC Special Report on Global Warming of 1.5°C and the United States National Climate Assessment, have stoked fears of economic, even societal, collapse. News reports have predictably emphasized the most sensational and unlikely scenarios while activists claim that without rapid and sweeping transformations of the global economy, social collapse and ecological genocide are virtually assured.

And yet it is worth considering whether we might be better served by focusing on the more prosaic impacts that climate change will almost certainly bring: a hotter and drier climate, worsening air quality, and more intense natural disasters that we may become increasingly adept at weathering but that will almost certainly create ample misery and discomfort.

Thinking about apocalypse, like thinking about one’s own death, is not something that most of us have much enthusiasm for. And so we don’t. We will all die sooner or later. In the meantime, there is a life to live, obligations to fulfill, friends and family to love, a future to plan. And so we get on with our lives, even with the knowledge that it will all, ultimately, come to an end.

To describe the impacts of climate change as a nuisance is the sort of thing that many environmentalists might dismissively. But a nuisance is something that, while it can be tolerated, we can also do something about. California policy makers, for instance, are now seriously considering whether it might be wise to pay to underground power lines in fire-prone areas, given that they have been the proximate cause of most of the state’s recent wildfires. A focus on this sort of adaptation might also motivate the state to invest in modernizing its crumbling water and transportation systems for a hotter and more variable climate.

That won’t stop global warming. But it is also the case that the benefits of cutting emissions today will not begin to have an impact on the climate for many decades. Meanwhile, the fires, the floods, and the water shortages will continue to worsen at the interface of a climate that is becoming more extreme and an economy and population that appear likely to continue expanding, even under the most extreme climate scenarios.

Doing something tangible today to address the impacts of climate change might even steel us to take more far-reaching action to reduce emissions over the long term. Investing in measures to better adapt to climate change means investing in the future, in the belief that humans can continue to thrive, even on a hotter planet.

Some suggest that doing so is a kind of folly, that focusing on short-term adaptation will inevitably be overwhelmed by increasingly extreme climate impacts and, worse, might undermine our determination to radically reduce emissions.

But there is little evidence that this is actually so. To date, despite decades of increasingly dire warnings about the consequences of continued carbon dioxide emissions, we have failed to take significant action to either adapt to a changing climate or to meaningfully cut our emissions.

Demands that people see the apocalyptic writing on the wall and undertake radical changes to their lifestyles or economy are likely to continue to fall on deaf ears. On our part, most especially, I have spent much of my career working on the fight against climate change. Investing in measures to better adapt to climate change means investing in the future, in the belief that humans can continue to thrive, even on a hotter planet.

I understand better than most the risks that we personally face given a changing climate as well as the unquantifiable risk that human societies must confront over the longer term. Yet, at least for now, my wife and I are staying put. Waking up early to the San Francisco skyline crisp and pink from the glow of the low winter sun, or coming home in the evening to the hooting from the redwood tree at the corner of our lot, is not the sort of thing that I’ll easily give up. It is literally and figuratively a privilege.

Most of us, even those living in far more difficult circumstances than we do, deeply love much about our lives, our communities, and the places where we live. For these reasons, it is worth considering whether foregrounding efforts to adapt to climate change—undergrounding power lines, developing drought-resistant crops, planning for rising sea levels and more frequent floods—might usefully shift the focus of climate discussions toward all that we have at stake in the here and now, and not toward a remote and abstracted future that is difficult to summon and unpleasant to think about.

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CONSTRUCTIVE DESIGN

These Buildings Generate More Energy Than They Use

Norway ushers in an era of energy-positive architecture

By Lucy Wang

In 2010, organizers of a climate conference in Norway issued a provocative challenge: Who will step up and curb the building industry’s worrisome carbon footprint? Buildings account for nearly 40 percent of global carbon emissions—almost twice as much as the transportation industry—yet the architecture and construction sectors had been slow to change.

Svein Richard Brandtzæg, CEO of the aluminum company Hydro, responded first. From the conference stage, he extended an open invitation to join an unprecedented initiative for energy-positive construction: buildings that generate more energy than they use.

A few months later, a “super team” was born. Hydro and the Zero Emission Resource Organisation (ZERO), the nonprofit behind the

HouseZero
Opened late last year, HouseZero is a retrofit of the Harvard Center for Green Buildings and Cities (CGBC) headquarters in a pre-1940s Cambridge building, converting it into an energy-positive prototype for ultra-efficiency. Hundreds of sensors will monitor HouseZero’s performance to help CGBC develop new systems and data-driven learning algorithms for improving energy efficiency and health in building behavior.

Svart
Expected to open in 2021, Svart will be the world’s first energy-positive hotel. Set at the foot of a glacier just above the Arctic Circle, the hotel building will be raised on poles to minimize site impact, while its circular form will take advantage of panoramic views in all directions.

Powerhouse Drøbak Montessori
A photovoltaic-clad "solar plate" inclined at 33 degrees intersects the school’s rectangular form, creating visual interest and a means of introducing fresh air into the interior while optimizing the tilt angle of the solar cells for energy production. The plus-energy school produces 30,500 kWh a year and uses less than a quarter of the energy that an average school of a similar size consumes.

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A few months later, a “super team” was born. Hydro and the Zero Emission Resource Organisation (ZERO), the nonprofit behind the
climate conference, joined the real-estate company Entra, the multinational construction group Skanska, and world-renowned architects Snøhetta to form an alliance—aptly named “Powerhouse.” Its ambitious mission: Create energy-positive buildings that, over a lifespan of 60 years, generate more energy than the total amount consumed for construction, daily operations, material production, and future demolition. Moreover, they proposed doing it in Norway—where long winters mean higher energy demands and reduced solar-cell efficiency. If it could be done there, alliance members surmised, it could be done anywhere.

“We wanted to be number one,” Snøhetta senior architect Tine Hegli explains of the driving motivation behind the alliance. “The [hires] to make an energy-positive building in the coldest part of Norway. We like to be pioneering. It’s not easy to get inspired by saving energy—not for architects, at least. But to be on a team, a super team, that will be the first . . . is really inspiring.”

Since then, Powerhouse has made international headlines for projects such as Svart, the world’s first energy-positive hotel, set to rise in the Arctic Circle by 2021. Meanwhile, the consultancy firm Agoplan Viak has joined the alliance, and Hydro has exited.

Powerhouse’s holistic energy approach is especially impressive because it includes embodied energy: the total energy associated with extracting, processing, manufacturing, and delivering building materials to the construction site. A piece of timber, for instance, has less embodied energy than concrete, whereas recycled on-site material has the lowest. Every project uses a site-specific approach, blending high-tech with low-tech solutions. Solar collectors, geothermal wells, and heat-recovery systems work in tandem with daylight maximization and natural ventilation, such as stack-effect cooling. Recycling, whether with the building structure or materials, is essential to minimizing the embodied-energy footprint. A Passive House—standard airtight building envelope is also standard for preventing energy loss.

So far, Powerhouse has completed two projects—Powerhouse Kjørbo and Powerhouse Drøbak Montessori School—with a third, Powerhouse Brattørkaia, soon to be finished. All buildings are equipped with real-time energy monitors, and Powerhouse will make follow-up visits to ensure efficient building operation. Although Powerhouse hasn’t yet built projects outside Norway, its influence has been far-reaching. In addition to feasibility studies made in other countries, Powerhouse directly inspired HouseZero, the recently completed positive-energy headquarters for the Harvard Center for Green Buildings and Cities (CGBC) in Cambridge, Massachusetts. Designed by Snøhetta in collaboration with Skanska, the project was commissioned by Harvard CGBC director Ali Malkawi after his visit to Powerhouse Kjørbo.

Until now we’ve designed projects to be energy-positive and [have] calculated embodied energy. In this new definition we will focus on carbon accounts instead.

“We hope for a project in the U.S. to come soon,” says Rune Stene, managing director of Powerhouse and director of Skanska Technology. With the Powerhouse name now trademarked in the U.S., the biggest barrier to Powerhouse’s adoption on American soil seems to boil down to a difference in mindset and to stringent requirements. At least two members of the alliance must be involved in a project, and the project must use strictly vetted supply partners. Powerhouse’s data-heavy “frontloading” approach may also be a turn-off in that it departs from normal practices, says Snøhetta senior architect Kristian Edwards. But he stresses the importance of the process for predicting building cost and energy performance.

“These days we are also investigating a new definition for Powerhouse, where we turn from energy to carbon,” adds Stene, referring to the shift in global attention from energy efficiency to carbon reduction. “Until now we’ve designed projects to be energy-positive and [have] calculated embodied energy. In this new definition we will focus on carbon accounts instead. Using the latest IPCC report, we’ll create maximum carbon budgets for each building covering everything from materials and operations across its lifespan.”

Lucy Wang is a freelance writer and design editor @Inhabitat. Her work has appeared in Time, Dwell, Architizer, and Chicago Reader.
We usually think of fossil fuels as coming from deep in the Earth, but actually they come from deep in the past. The fossil-fueled energy that powers the global economy originated as sunlight and carbon dioxide that plants, plankton, and algae converted into organic chemicals. Millions of years of heat and pressure transformed those buried chemicals into the oil, coal, and natural gas that we now burn to run our cars and power plants. The problem with fossil fuels is not that they are nonrenewable but rather that their cycle of renewal operates on geological time scales—and we are harvesting them far faster than natural systems can replenish them.

But over the past year, scientists in Sweden and elsewhere have made headway on artificial systems that are far faster at capturing the energy of sunshine in fluid form. Bottled in this way, solar energy could be stored, transported, and tapped on demand as conveniently as oil or natural gas—but without emitting fossilized carbon or gobbling up farmland. Though many technical hurdles remain, recent advances in solar thermal fuels and in hybrid devices that turn sunlight into both electricity and hydrogen are generating fresh excitement in fields that for years seemed to have stalled.

The progress is reviving hopes that smart chemistry and materials science can solve the “gigawatt-day” conundrum—otherwise known as how to keep the lights on and factories humming when the winds fail and clouds block the sun for days at a time. Researchers and entrepreneurs have tried to tackle the problem in other ways—for example, with electric batteries or by pumping water uphill when electricity is plentiful and later releasing it to fill in the calm, gray gaps. But none seems likely to scale sufficiently, due to geographic, economic, and environmental handicaps. The future for solar energy would undoubtedly be brighter if it could be drawn down 24/7 and used for more than just electricity.

A Battery for Heat

“A solar thermal fuel is like a rechargeable battery,” explains Jeffrey Grossman, whose lab at MIT has long worked on these materials. “But instead of electricity, you put sunlight in and get heat out, triggered on demand.” Unlike ethanol or a fossil fuel, this bottled sunshine can release its energy without destroying itself. Instead, the molecules in the fuel toggle between two distinct shapes: a “charged” state that stores lots of chemical energy in the bonds among its atoms and a relaxed, “discharged” state.

To charge the fuel, you simply expose it to sunlight. Later, you can extract the energy by passing the charged fuel through a filter loaded with a catalyst. As the molecules toggle back to their relaxed state, they give off heat. “You could use that thermal energy for your water heater, your dishwasher, or your clothes dryer,” Grossman says. “There could be lots of industrial applications as well.”

The trouble, observes Wei Feng, who studies solar thermal fuels at Tianjin University in China, has been finding a commercially practical fuel. The ultimate goal is a clear, low-cost liquid that can grab a big chunk of the energy carried by sunlight (not just the slim ultraviolet portion), then hold that energy for days or weeks at room temperature or below, and finally release lots of heat quickly without gumming up or eroding the catalyst.

A Swedish research group led by Kasper Moth-Poulsen has been testing variants of a transparent liquid called norbornadiene that transforms into quadricyclane when illuminated by ordinary sunlight, in a setup they installed on the roof of the physics building at Chalmers University of Technology in Gothenburg. The material—which is easily made from carbon, hydrogen, and nitrogen—captures up to 30 percent of the incoming solar energy and, once charged, looks to
be stable for many years. When pumped through a carbon filter laced with a cobalt-based catalyst, the fluid rapidly heats up from room temperature to around 84°C (183°F)—not quite boiling, but plenty hot enough for a bath or radiator.

“There is still a lot to figure out,” Moth-Poulson acknowledges. Wei notes that the most efficient variants still need toxic solvents to function well in liquid form, for example. But with an energy density of about 250 watt-hours per kilogram—double that of the Powerwall batteries manufactured by Tesla—the new fuel is encouraging enough that companies have begun calling to discuss commercial applications, Moth-Poulson says.

**From Hydro to Hydrogen**

Solar thermal fuels may one day take over some of the work done today by natural gas, but they are unlikely to replace gasoline or diesel. Automakers have experimented for years with hydrogen-fueled vehicles, however, and clean-energy visionaries have long dreamed of producing that flammable gas—by sunlight, the same stuff that makes up the sun—by using sunlight to strip the H₂ from H₂O.

A group at Lawrence Berkeley National Lab reported a milestone of a different kind in December 2018: a design for a hybrid device that joins a hydrogen-producing photoelectrochemical cell back-to-back with an electricity-generating photovoltaic solar cell. Though challenging to fabricate, advanced HPEV cells (as they call them) could, they believe, convert solar energy with a total efficiency over 20 percent. Conveniently, the hybrid cells could shift energy output from electrical power to hydrogen and then back again as demand waxes and wanes.

Though solar hydrogen research is still very much in the bench-science stage, Stéphane Abanades of the French National Center for Scientific Research and colleagues in China recently published a design concept for a large-scale solar power tower that could reach efficiencies over 35 percent. The scheme exploits the fact that it’s far easier to split superheated steam than liquid water. In their plan, rays from sun-tracking mirrors would be concentrated and then split by optics so that shorter wavelengths illuminate PV cells to make electricity while longer-wavelength rays land on a receiving chamber to produce heat. Water, preheated by cooling the PV cells and then boiled into steam by the thermal receiver, would finally get split into hydrogen and oxygen by a solid-oxide electrolysis cell powered by the PV current. The engineers figure that a small 50-mirror plant with a 24-meter tower could generate nearly 10 kilograms of hydrogen a day, plus lots of oxygen. That’s enough to fuel a hybrid hydrogen metro bus for 120 kilometers. Abanades says that by using available components, the design could be scaled up by at least an order of magnitude.

Until someone constructs a functional prototype, it will be easy to dismiss such designs as wishful thinking. But at least this approach doesn’t require any breakthroughs in materials science. And after all, the idea of punching a metal straw through miles of bedrock to suck up the messy remains of ancient algae once seemed like a pipe dream, too.
more and more expensive for everybody left behind,” he explains.

The grid is an important economic asset, but it’s also a social asset. The interconnected network relies on people consuming power. As consumers defect from the grid, it creates a death spiral for the most vulnerable consumers. That’s because people who live in apartment buildings or run small businesses won’t be able to invest in solar cells or battery storage in the same way large companies or people who own their own homes can. In this respect, power grids are analogous to healthcare systems. If young and healthy people forgo insurance and leave the marketplace, sicker and poorer folks bear the burden of the system.

More recently, Martin has transformed his worry into a question: What if there were a way to turn the energy-distribution system into a trading platform? That question, of course, isn’t his alone. It is the driving idea behind several new companies, including Power Ledger, where Martin is now managing director. Through the company’s blockchain platform, consumers who have solar cells and storage can share their excess capacity by selling that energy across the grid to their neighbors.

When most people think about blockchain, they think about cryptocurrencies such as bitcoin. But blockchain technology has many potential uses, including healthcare, voting, and property records. Think of it as thousands of shared spreadsheets that are all connected to the same municipal power grid. That group includes a diverse range of buildings: an apartment building or the shopping mall. “If all four buildings have photovoltaic panels installed, nine apartment buildings will grow from 5 percent of the market to about 25 percent in 2025,” Martin explains. “But when they can sell extra energy to their neighbors, they can optimize the amount of solar they install, confidently knowing that they can sell any excess to the apartment building or the shopping mall.”

That apartment building (a tall, skinny tower) has little ability to install solar panels and would traditionally be locked out of renewable energy.

He adds that, even though four buildings have photovoltaic panels installed, nine buildings are involved in the energy-trading scheme. If all four buildings have extra energy, they can sell it to the local energy-storage system. In Japan, the company plans to install and provision solar panels on more than 55,000 rooftops by the end of 2020, allowing energy sharing and trading through their platform.

It’s all part of a broader idea to democratize energy production and distribution—and move it closer to consumers. The World Energy Council predicts that decentralized energy, which includes peer-to-peer systems, will grow from 5 percent of the market today to about 25 percent in 2025. Ultimately, the challenge is a mental one that mirrors other societal conundrums: to convince consumers that we’re all in this together. In this case, the goal is not to install batteries in home garages but rather in the grid, where this investment in renewables can be monetized by selling extra capacity to neighbors. In Australia, where one in four houses has solar panels already, the genie is out of the bottle. Martin says, “The old system of large power plants pushing energy through transmission and distribution systems to consumers who got only as much as they paid for—that’s going away.”

Katharine Gammon is a freelance science writer based in Santa Monica, California. She writes for a wide range of magazines covering technology, society, and animal science.
How will we feed a burgeoning world population without ruining our planetary resources? Robyn Metcalfe looks at global food-supply chains and finds some possible answers. We are in the midst of a whirlwind of technological changes that soon may deliver dinner plates, tailored to our health needs, directly to our doorsteps. Blockchain technology and the Internet of Things will mean less food waste. Despite fears of DNA-modified food and processed meals, Metcalfe makes the case that we should be cautiously optimistic and embrace these technologies.

The end is nigh for fossil fuels, but not due to wishful thinking from environmentalists. Instead, thank market forces and innovation. That is the theme of Dieter Helm’s Burn Out, in which he argues that new technologies, the Internet of Things, and falling demand for oil will reduce oil and gas dependency. Largely dismissive of United Nations efforts to regulate emissions, Helm contends that these changes may benefit the United States and Europe. Written by an industry expert, Burn Out offers a refreshing insider perspective on an energy transformation.

For many people, it’s a given that the world’s population is increasing unsustainably. That’s wrong, say Darrell Bricker and John Ibbitson. We are actually three decades away from a population bust, driven by shrinking family size and women’s empowerment. That may help the planet, but it will also challenge us to accept immigration if we want to keep workforces young. As the authors say: “Population decline isn’t a good thing or a bad thing. But it is a big thing.” A contrarian and sharply written read.

After analyzing our past in Sapiens and our future in Homo Deus, Harari turns to present, tackling issues from populism to artificial intelligence to our “post-truth” world. In 21 essays, Harari taps into nagging doubts about where the world is headed as liberal and democratic narratives are increasingly questioned. His sweeping generalizations may irk some readers, but his book is peppered with the kinds of observations you will unwittingly find yourself bringing up around the dinner table.

Animals also cry. In his latest book, Frans de Waal describes depressed fish, nerve-wracked dogs, and other animals that share emotional traits with humans—but that many behavioral scientists have long ignored. The book title refers to Mama, a chimpanzee whose video-recorded deathbed goodbye and hug to biologist Dr. Jan van Hooff went viral. Full of telling anecdotes, the book has a deeper purpose: nudging us to recognize that the evolutionary roots of emotions may be behind how we love, reach for power, or even murder.

Being in a hurry may be a defining feature of the Anthropocene, but this book urges us to think long-term—over billions of years. Marcia Bjornerud travels to places such as Norway’s Svalbard archipelago to analyze our relationship with time—or, as she says, “time denial.” Understanding Earth’s age-old rhythms, she argues, will help ensure planetary sustainability by forcing us to think across generations. Timefulness transforms geological phenomena, from atmospheric carbon molecules to ancient mountains, into a meditation on life itself.

The Anthropocene Nightstand
By Alistair Scrutton
How to Die in The Anthropocene

Death is inevitable, but its environmental toll may not have to be.

By Jennifer Monnier

In the spring of 2018, Katrina Spade took a short plane ride from Seattle, Washington, across the state to a town called Pullman. She met with Washington State University researchers with whom she had been working to create a unique soil. She scooped up a small mound of the soil and held it in her hand. It was the first proof that a human body could be safely turned into earth, like food scraps in a compost bin.

Spade first considered composting human bodies while studying architecture as a graduate student at the University of Massachusetts Amherst in 2011. She had been learning about the environmental toll of human death.

Each year in the United States, just over half of the nearly 3 million deceased are rapidly disintegrated into ash through cremation, each releasing about 100 kilograms of CO₂. About 43 percent of American deaths result in embalming and burial. The bodies are injected with a solution made up mostly of formaldehyde, a carcinogen, in what adds up to about 800,000 gallons of the solution per year. Then they are placed into thick caskets of wood, copper, bronze, steel, and/or concrete—all intended to slow their disintegration underground. The burials take up a lot of land, usually consisting of pristine lawns that require polluting fertilizers and hefty water use to maintain. Urban planning experts worry there’s not enough land available to support the upcoming burials of an aging baby-boomer population.

In the Anthropocene, composting has been shown to work, it remains a possibility not yet available to the public. Whether it can scale to meet the demands of a growing, and inevitably dying, population remains to be seen.

Yet, there’s precedent for a cultural shift toward environmentally friendly funerals. Though cremation is popular today, in 1990 it was the preference of only 15 percent of US citizens. According to a survey by the advocacy group Green Burial Council, many people began choosing cremation over burial because they considered it a greener option, since it uses less land. Natural burial has also risen in popularity in the past two decades, with a growing number of registered natural burial sites in the US, the UK, and Canada.

To compost anything, you need four basic ingredients: carbon, nitrogen, oxygen, and moisture. To compost a corpse, Spade’s design puts it all inside a hexagonal vessel.

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Spade and her colleagues at Recompose have heard from people around the world who are interested in leasing out their technology, she says. She and her coworkers are speaking to funeral homes in Brazil and the Netherlands and have heard from interested individuals in Australia and Europe.

The process is estimated to cost a consumer around $5,500. That buys friends and family time with the composting vessels, the actual transformation of human to soil, the body's transportation, and a death certificate. Compare that to the median cost of a funeral with a conventional burial, around $7,360, or a funeral with cremation, around $6,260.

Consumer choice is only one piece of the puzzle—recomposition isn’t yet legal anywhere. In other states and in countries around the world, the funeral industry has proven stubbornly resistant to innovation. The most recent example of this resistance has played out through efforts to legalize alkaline hydrolysis, another green alternative which cremates bodies using a mostly-water solution instead of heat. It’s currently legal in 16 US states but has faced contentious legal battles and religious criticisms in some states. New Hampshire legalized the technology for two years, then repealed it in 2009. During hearings on a 2015 bill to legalize the technology in Indiana, Representative Dick Hamm made an impassioned speech comparing it to letting bodies “run down the drain.” Hamm owns two casket companies. Recomposition could run into similar problems in states resistant to change.

But in Washington, where the funeral industry has relatively few barriers to entry, the state legislature passed a bill in April that would legalize both recomposition (which they’re calling natural organic reduction) and alkaline hydrolysis. “It’s a way for death care to be part of the climate drawdown puzzle,” Spade says, “and we’re excited to be part of that.”

Jennifer Monnier is a freelance science journalist in Seattle, Washington. She writes about energy, agriculture, environmental research, and how people are adapting to climate change. Her work has appeared in Crosscut, Spectrum News, and other publications.

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If I were asked to make even a conservative estimate of the number of chairs in the world, I'd find it hard to go lower than eight to ten per person. Applying that logic, there could be more than 60 billion of them on the planet. Surely chairs should be one of the universal signals of the arrival of the Anthropocene?

As to why there are suddenly so many chairs, there is no single clear reason. It is a confluence of fashion, politics, changing work habits, and the lust for comfort. The last of these requires no explanation in a culture in which ease and comfort are among the strongest drivers of consumer decision-making.

While chairs began to appear with a little more frequency in the early modern period, it seems that they became
much more widely popular in the eighteenth and nineteenth centuries during the Industrial Revolution.

Before the eighteenth century, a chair was relatively easy to come by, but the majority of the population had little use for them. Even today, it is not easy to sit in a hard wooden chair for sustained periods, and upholstered chairs were prohibitively expensive. But the fashion for a new reclining culture (imported from the French court of the eighteenth century) helped to popularize their early use.

For centuries before, chairs had persistently been associated with power, wealth, and high status. They were about as widely used by the peasantry as a crown. There is an instructive stage direction in the First Folio of King Lear in which the monarch enters while being carried by servants “in a chair.” The idea of chairs as a symbol of status still persists today. The highest attainment in my own profession, academia, is called “a chair.” The individual that runs a meeting is called “a chair.” The head of a company is also a chairman or chairwoman. And it is a truth, universally acknowledged, that the best chair in any office building always belongs to the boss.

Democratization of the use of chairs (particularly after the French Revolution and the 1832 Great Reform Act in the UK) coincided with a slow change in our working patterns. The majority of work done in the Victorian period would have been understood as manual labor or factory work.

But toward the end of the nineteenth century, as the second wave of a technological revolution gathered pace with inventions such as the typewriter, telegraphy, and the expanding uses and applications of electricity, the labor market also began to change. The new category of office clerks was the fastest-growing occupational group in the latter half of the period. In 1851, the census suggests, fewer than 44,000 people were performing administrative work. But in just two decades, sedentary workers had more than doubled to 91,000.

Today, sedentary workers: are in the majority. And, throughout the twentieth century, a forest of other sedentary activities have grown up around us to match our new working lives.

Novel-reading increased hugely in popularity throughout the nineteenth century—and further sedentary leisure activities followed in its wake: cinema, radio, and TV. More recently, gaming, streaming, and screen time generally are all activities that are hungry for us to sit still in contemplation. The Anthropocene human being needs chairs to fulfill all of these (I suppose we could call them) “activities.”

If modern life presents us with a bouquet of sedentary behaviors, then chairs are the stalks. They are so necessary to leading a modern life that most of what we do seems unimaginable without them. Research conducted by the British Heart Foundation suggests that we enjoy about 9.5 hours per day of sedentary time. There are a few problems with this.

Our bodies do their best to be the kinds of body that we need. Wolff’s Law and Davis’s Law can be boiled down to the adage “use it or lose it” for the body’s hard and soft tissues, respectively. In both cases they tell us that bone or muscle will respond either to increased load or the cessation of use. Bones become thinner or denser. Muscles, stronger or weaker. Seated so much, with most of the musculature in our backs disengaged as we recline in a chair, it is little wonder that with our weakened spines, back pain is now the number-one cause of disability globally.

Just as we have an Anthropocene environment, we might equally class ourselves as Anthropocene humans. Paleolithic humans died most frequently in infancy. Violence and injury were also common causes of mortality in later life. Modern humans, though, overwhelmingly die as a result of metabolic disorders such as Type 2 diabetes, heart disease, and some cancers—all strongly linked with inactivity: namely, chair use.

A 2012 study investigating the effects of inactivity collated behavioral data from 7,813 women and found that those who sat for ten hours a day had shorter telomeres (an indicator of cellular aging). Their sedentary habits had aged them biologically by about eight years. Some studies even suggest that the effects of sitting for sustained periods cannot be offset by a little exercise.

These studies and many others attest to the fact that we should be thinking carefully about investing any further in our relatively newfound and passionate love affair with the chair.
Do we have a sense that things could go right? Even if it’s physically possible—is it politically possible, and is it humanly possible?

What do a policy report, a street demonstration, and a fictional story share in common? For science-fiction writer Kim Stanley Robinson, they could help our imagination picture a way forward to address climate change. In his novels, such as the acclaimed Mars trilogy or the aquatic New York 2140, Robinson invites his readers to challenge their own assumptions. If someone puts forward a seemingly wild yet necessary vision for a better future, why wouldn’t we believe that such a world is possible? I spoke with the 67-year-old American writer; this is a condensed version of that interview.

In 2019 we seem to have plenty of technological, fiscal, and legal instruments to deal with climate change, yet picturing a way forward is as challenging as ever. Are we facing a failure of imagination?

I would agree with that. I’ve been trying hard to imagine a plausible, positive scenario going forward, and I’m aware that it’s not easy. This is not because people haven’t been trying; it’s because the problem is big and intractable to a certain extent. We run the world economy by and large as a capitalist profit-making enterprise, and the mitigation of climate change is not a profit-making enterprise. It’s not the highest rate of return—and the market directs all capital to the highest rate of return.

And with this conundrum, what does science fiction provide?

You can’t talk about every possible future in one work of science fiction—that would be crazy. But what you could do is tell a bunch of stories that are relatively plausible, that are set in the near future, and that describe a course of action that readers can imagine in a kind of “thick” texture. Where you really feel like you’re there. There’ll be some contingent events and some characters that are representative, but they are also individual characters with their own quirks. There’ll be a story, and yet the reader will also say: “Well, yeah—this could be one way forward.” This way, you have the utopian strand of describing things going right. Do we have a sense that things could go right? Even if it’s physically possible, the question is: Is it politically possible, and is it humanly possible?

I guess your writing deals more with the politics of possibility more than the politics of probability?

Well, that’s for sure. I have a bad feeling—that I think is widely shared—that we are not responding fast enough. I think that the Paris Accords are real achievements in human history; nevertheless, we are not achieving what we set out to do. Everybody’s overshooting, and there’s more...
change. There are bottom-up changes, where individuals, small groups, and local collectives make changes at the individual, household, and local levels; and then there are the top-down ones, the stuff that happens in nation-states and in international treaties, often decided amongst the technocrats and diplomats and experts. There’s no reason to privilege one over the other—the important thing is to keep both of them in mind simultaneously.

Take a look at the Green New Deal. You can say it’s been demanded by the left wing of the Democratic Party in the United States. On the other hand, you could also say that it’s a top-down document that has been concocted by a committee of a few. Well, both are true—and that’s one of the reasons why the Green New Deal is important and significant and needs to be supported.

In a way, I guess, the Green New Deal shares a trait with science fiction in that it shows a way forward. It doesn’t put all the dots on the i’s, but it shows a way to actually reach 1.5 or 2 degrees and transform society into something that’s better.

I would invite everybody to think of the Green New Deal as it currently exists (a document which is quite impressive in its amount of detail and substance) as a science-fiction story. It’s a utopian science-fiction story written in the form of a proclamation or a blueprint for action. In my short-story collection, The Martians, I experimented with all kinds of formats, including a short story in the form of the Martian Constitution and a short story in the form of an abstract in a scientific journal. In the case of the Green New Deal, and in the best possible way, I want to suggest that seeing it as a kind of science-fiction story is what we need. We need that kind of vision.

There’s a line in New York 2140 that says, “People are scared for the kids. That’s a moment things can tip.” Now it seems as if it’s actually children themselves who are more worried and who are pushing things from the bottom up. Maybe I assumed that parents have enough control over their situation to worry about doing things for their kids politically. With the best will in the world, the generation that you might call parents is sort of swamped with their own problems—by debt, by job precariousness, and so on. It’s really been the teenagers and children who are speaking up and saying: “Wait—now that I’ve learned of this situation, this is bad. Something has to be done now.” And that has surprised me. Because of the science-fiction novel I’m writing right now, I’m very interested in the climate-change lawsuits being brought by children as well as in their legal standing in courts worldwide. You can extrapolate from there—of course, that’s what science fiction does—to questions about the rights of the unborn. What about someone who is going to be born in the year 2050? Can they sue us now for what we’re doing? And what’s their legal standing?

In the best possible way, I want to suggest that seeing the Green New Deal as a kind of science-fiction story is what we need. We need that kind of vision.
Saltwater Aquaculture Moves Inland

Improved technology could give fish farms a sustainable foothold far from the ocean

By Laura Poppick

On a narrow sand spit in northern California, a Norwegian company plans to build a massive fish farm that would be the largest of its kind on the West Coast. Located near the city of Eureka, the 30-acre farm proposed in February 2019 could ultimately produce 27,500 tons of fish per year—and would do so entirely on land and indoors. It’s the second such facility the company, Nordic Aquafarms, has proposed in the U.S. in less than two years—with an even larger indoor farm under way in Belfast, Maine, where they ultimately hope to produce 33,000 tons of fish per year.

The company is riding a wave of demand for farmed fish as aquaculture becomes the fastest-growing food sector in the world. It has also emerged as a leader among larger-scale fish farms heading indoors and inland—and even potentially to arid regions of the world. The industry hopes to confront head-on the environmental ills of outdoor aquaculture by designing sustainable closed-loop systems that can also turn a profit.

Traditional aquaculture operations, such as inland flow-through ponds and marine net pens, can pose serious environmental problems. Water from these farms flows freely into the environment, potentially carrying harmful nutrients, parasites, and pathogens that threaten wild fish populations and surrounding ecosystems. Salmon farmed in net pens along the coast of British Columbia and elsewhere around the world, for example, have infected wild salmon populations with parasitic sea lice. Inland flow-through systems also consume copious amounts of water, since they require a continuous influx of flowing water to operate.

Nordic and others have embraced a technology called Recirculating Aquaculture Systems (RAS) to diminish these problems by recycling water within a closed loop and thus significantly reducing a farm’s contact with the environment. With the familiar sounds of pumps humming and water bubbling vigorously through filters, RAS functions similarly to a home aquarium: water perpetually loops through a series of filters and treatments before recirculating back through a tank. A biofilter breaks down fish urine with the help of ammonia-consuming bacteria, and physical filters remove fecal material and leftover food. That solid waste gets disposed of elsewhere and can be repurposed as products (such as agricultural fertilizer) or for biotical production. A small amount of wastewater exits the system into the environment through tank.
A recirculating farm will use about one-five-thousandth of the volume of water required for a conventional production system.

RAS technology offers an appealing alternative to flow-through systems because it consumes significantly less water, says Timmons. “A recirculating farm will use about one-five-thousandth of the volume of water required for a conventional production system,” says Timmons—noting that this makes RAS an especially viable option in drier regions of the world.

On the prairie near Winnipeg, Canada, for example, biotechnology company Myera Group has launched a small-scale RAS facility that takes advantage of briny aquifer water unsuitable for drinking but ideal for growing saltwater fish, says Shirley Thompson of the University of Manitoba in Winnipeg. She studies sustainable food systems and points out that farms can also use the wastewater from these systems to irrigate and fertilize crops—adding to its viability in dry regions of the world.

With all of its potential benefits, RAS has started to replace outdoor ponds in China—the world’s largest producer of farmed fish—and has increasingly spread elsewhere around the world. The largest farm of its kind in East Africa opened in Kenya in 2015. Located in the city of Machakos, about 40 miles from Nairobi, Kamuthanga Fish Farm produces tilapia; it recently became the first aquaculture farm in Africa to receive the EcoMark Africa label—a certificate that recognizes sustainably produced products.

Still, some hurdles—including energy consumption and sourcing fish feed—do limit the long-term sustainability of RAS farms as they scale up. Compared to flow-through systems and net pens, RAS farms consume roughly two to six more kilowatt-hours of energy per kilogram of fish produced, according to Timmons. Most of this additional energy goes into powering pumps that keep water cycling, he says, and renewable energy such as solar panels can help offset these energy needs. But this still remains a stumbling block for larger-scale RAS.

Sustainably sourcing feed to support these farms also poses challenges, especially as they scale up. Researchers are working to pinpoint the nutrient and energy requirements of fish in order to find ways to meet those needs with plant-based material such as soy rather than with fishmeal. These efforts can improve the efficiency and sustainability of these feeds, Timmons says.

RAS technology also carries its own operational risks. If biofilters malfunction, for example, waste can quickly build up in recirculating water and harm fish, says Ingrid Bakke, a biotechnology researcher at the Norwegian University of Science and Technology who studies bacterial activity in aquaculture systems. “If they fail, it’s a big problem because ammonia is really toxic to fish,” she says.

Tank-monitoring technologies can help companies track malfunctions and catch problems before they escalate, but these systems are expensive and still remain susceptible to human error.

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Natural isn't what it used to be
Darwinian theory is based on the idea that heredity flows vertically, parent to offspring, and that life's history has branched like a tree. Now we know otherwise: that the 'tree' of life isn't that simple.

By David Quammen

Since the late 1970s, there have come three big surprises about what we humans are and about how life on our planet has evolved.

The first of those three surprises involves a whole category of life, previously unsuspected and now known as the archaea. (They look like bacteria through a microscope, but their DNA reveals they are shockingly different.) Another is a mode of hereditary change that was also unsuspected, now called horizontal gene transfer. (Heredity was supposed to move only vertically, from parents to offspring.) The third is a revelation, or anyway a strong likelihood, about our own deepest an-
This is an aspect of evolution that was unimagined by Charles Darwin. Evolution is trickier, far more intricate, than we had realized. The tree of life is more tangled.

Beginning in July 1837, Charles Darwin kept a small notebook, which he labeled “B,” devoted to the wildest idea he ever had. It wasn’t just a private thing but a secret thought. The notebook was bound in brown leather, with a tab and a clasp; 280 pages of cream-colored paper, compact enough to fit in his jacket pocket. The B notebook was first of a series on what, to himself only, he called “transmutation.” At that time, the stability of species represented the bedrock of natural history. It was taken for granted, and was important, not just among clergy and pious lay people but scientists too. Now home from his wildcat voyage on HMS Beagle, the 27-year-old Darwin intended to investigate a radical alternative to scientific orthodoxy: that the forms of living creatures weren’t eternally stable, as God had reputedly created them, but instead had changed over time, one into another—by some mechanism that Darwin didn’t yet understand.

Josette. (It seems now that our lineage traces to the archaea.) So we ourselves probably come from creatures that, as recently as forty years ago, were unknown to exist.

And the notion of species is especially insecure in the realm of bacteria and archaea. But the discovery that horizontal gene transfer (HGT) has occurred naturally, many times, even in the lineages of animals and plants, has brought the categorical reality of a species into greater question than ever. That’s even true for us humans—we are composite individuals, mosaics.

It’s not just that—as you may have read in magazine articles—your human body contains at least as many bacterial cells as it does human cells. (This doesn’t even count all the nonbacterial microbes—the virus particles, fungi, cells, archaea, and other teeny passengers inhabiting our guts, mouths, nostrils, and other bodily surfaces.) That’s the microbiome. Each of us is an ecosystem.

I’m talking about something else, a bigger and more shocking discovery that has come from the revolution in a field called molecular phylogenetics. (That phrase sounds fancy and technical, but it means merely the use of molecular information, such as DNA or RNA sequences, in discerning how one creature is related to another.) The discovery was that sizeable chunks of the genomes of all kinds of agents such as bacteria and viruses. Such horizontal gene transfer, like sex, has been a source of freshening innovation in otherwise discrete lineages, including ours—and it is still occurring.

This is an aspect of evolution that was unimagined by Charles Darwin. Evolution is trickier, far more intricate, than we had realized. The tree of life is more tangled.

He scribbled on. The tree is “irregularly branched,” he told the B notebook. Each branch diverges into smaller branches, he wrote, and then twigs, “Hence Genera,” the next higher category above species, which would be the twigslet or terminal buds. Some buds die away without yielding further growth, while new buds appear, somehow.

Fifteen pages along, after more ruminations, he drew a little sketch, in bold strokes, of a trunk rising into four major limbs and several minor ones. Each major limb diverged into clusters of branches, with certain branches labeled A, B, C, D. The letters were placeholders, meant to represent living species, or maybe genera. Felis, Canis, Vulpes, Gorilla.

This was a thunderous assertion, abstract but eloquent. You can look at the little sketch today, with its four labeled branches amid the limbs and the crown, and imagine the evolutionary divergence of all life from a common ancestor. Just above the sketch, as though gesturing toward it bashfully, Darwin wrote: “I think.”

It was an evolutionary tree of life. Darwin didn’t invent that phrase, “the tree of life,” nor originate its iconic use, though he put it to new purpose in his theory. Like so many other metaphors embedded deep in our thinking, it came down murkily, modified and reechoed, from early versions in Aristotle and the Bible. None represented the notion of change over time—of evolution—until Jean-Baptiste Lamarck’s 1809 book Philosophie Zoologique, which contained a vague evolutionary theory and depicted animal diversity in a branched diagram, descending down the page, with major animal groups connected by dotted lines.

Fifty years later, Darwin published On the Origin of Species. His book included just...
one illustration, a diagram of 11 hypothetical lineages proceeding upward through thousands of generations of inheritance—deep evolutionary time. Eight of those 11 lineages came to dead ends—meaning, they went extinct, like trilobites and ichthyosaurs. One rose through the eons without splitting—meaning, it persisted unchanged, much the way horseshoe crabs have survived relatively unchanged over 450 million years. The other two lineages, dominating the diagram, branched often, spread horizontally, and climbed vertically, representing the exploration of different niches by newly evolved forms. So there it all was: evolution and the origins of diversity.

Darwin had seen evolution as arboREAL. And the tree image would remain the best graphic representation of life’s history, evolution through time, the origins of diversity and adaptation, until the late twentieth century. Then rather suddenly a small group of scientists would discover: oops, no, it’s wrong.

Lynn Margulis was a forceful 29-year-old adjunct assistant professor from Chicago, divorced and raising two kids, when she brought new attention and credibility to a very strange old idea about the shape of the tree of life. She made her case, in March 1967, with a long paper published in the Journal of Theoretical Biology and titled “On the Origin of Mitosing Cells.” This radical, startling, and ambitious article—previously rejected by more than a dozen journals—proposed to rewrite two billion years of evolutionary history. It laid out an array of evidence supporting the odd conjecture that living ghosts of other life-forms exist and perform functions inside our very own cells. Adopting an earlier term, Margulis called that idea endosymbiosis.

“...This paper presents a theory,” she wrote—a theory proposing that “the eukaryotic cell is the result of the evolution of ancient symbioses.” Single-celled creatures had entered into other single-celled creatures, like food within stomachs, or like infections within hosts, and by happenstance and overlapping interests, at least a few such pairings had achieved lasting compatibility.

Eventually they became more than partners. The internalized microbes, she argued, had evolved into organelles—working components of a new, composite whole, like the liver or spleen inside a human—with fancy names and distinct functions: mitochondria, chloroplasts, centrioles. They were functional elements of a single new being. A new kind of cell.

The scientific consensus at first, and for some years afterward, was that this smart, knowledgeable, insistent, and charming young woman was in thrall of a loony idea. But eventually the emerging science of molecular phylogenetics confirmed most of her theory of endosymbiosis (mitochondria and chloroplasts as captured bacteria, yes). Margulis became eminent, though never conventional.

As new evidence of horizontal gene transfer continued to accumulate during the 1990s, she and other biologists started questioning the belief that the evolutionary pattern is a tree. “It’s not,” Margulis told a reporter in 2011. “The evolutionary pattern is a web—the branches fuse.”

She was right: the tree of life is not perfectly tree-shaped. There’s something...
Woese showed that humans, and all other animals, all plants, all fungi, all eukaryotes, have arisen from a lineage unknown to science before 1977. It was the last of the great classical trees: authoritative, profound, and correct to some degree. But it entirely missed what was coming next.

Methanogens were hard to grow in a laboratory, since oxygen poisoned them, but Woese’s collaborators managed it. Under a microscope, these methanogens looked like bacteria. For centuries, they had been considered bacteria. But as Woese examined the fingerprint, he found anomalies. A certain pair of small fragments, common to all bacteria, were missing. Other sequences looked eukaryotic, suggesting a completely distinct form of life: a yeast, a protozoan, what? And still others were just weird.

What was this RNA? Woese wondered, and what manner of organism did it represent? It couldn’t be from a prokaryote. It wasn’t eukaryotic. It wasn’t from Mars, because it contained too many familiar stretches of RNA code.

“What came next was...” Woese's RNA fingerprint data showed: that we humans, and all other animals, all plants, all fungi, all eukaryotes, have arisen from an ancestral lineage that was unknown to science before 1977. It was the last of the great classical trees: authoritative, profound, completely new to science, and correct to some degree. But it entirely missed what was coming next.

As a medical officer at the London Pathological Laboratory of Britain’s Ministry of Health, Griffith studied what’s now known as *Streptococcus pneumoniae*, a dangerous bug that could cause severe, often fatal, pneumonia. During the 1918–19 influenza pandemic, this kind of pneumonia took hold as a secondary infection in many patients and probably killed more millions of people than the flu virus itself.

Griffith’s work, which was pragmatically medical, involved identifying different types of the streptococcus—there were four—in different patients and parts of the country. He got his data by examining sputum coughed from the lungs of the ill. In 1923, he discovered something important: that each of the four types of the bacterium existed in two different forms—one that was ferociously virulent, one that was mild. Sometimes the virulent form might transmogrify into the mild form, he noticed. He didn’t know why.

His second discovery was far more puzzling: Under certain experimental circumstances, the mild form of, say, Type II bacteria could change into the virulent form of, say, Type I. What? It seemed as though the streptococcus had morphed into a different species.

The transformation Griffith witnessed was later shown to be one of three cardinal mechanisms of horizontal gene transfer, the most counterintuitive phenomenon discovered by biologists in the past century. Griffith’s experiments, and others like them, demonstrated that in its naked form—floating loose in the environment after having
Recent research has found evidence of bacterial DNA transferred horizontally into the genomes of human tumors. What that dizzying revelation means is still unclear, but there’s at least some chance that such insertions might play a role in causing cancer.

been liberated from a busted bacterial cell—DNA is capable of getting into another bacterium and causing heritable change. This sort of sideways passage can carry DNA not just across minor boundaries, type to type among Streptococcus pneumoniae, but also across huge gaps—from one bacterial species to another, from one genus to another, even from one domain of life to another. And the transformations that result from such horizontal transfer can be far more consequential than merely changing a pneumonia bug from mild to virulent.

Today we live with one of those consequences: bacterial resistance to multiple antibiotics, which spreads sideways among different kinds of bacteria. It can happen gradually or in a sudden leap, conveying multiresistant bacteria from harmless bacteria such as the common form of Escherichia coli into dangerous bacteria such as Streptococcus pneumoniae. Because of that sideways spread, fast and easy, bacterial resistance has become a dire problem. More than 23,000 deaths annually in the United States and seven hundred thousand deaths globally occur from infection by unstoppable strains of bacteria. This grim, costly trend has been driven not just by overuse of antibiotics, and by incremental adaptation—one strain of bacteria adapting to one antibiotic—but also by horizontal gene transfer, which spreads adaptations instantly.

The implications of horizontal gene transfer go far beyond the problem of antibiotic resistance. Those implications include the whole matter of how evolution works—by classical Darwinian mechanisms, or otherwise?—and how it has worked for much of the past four billion years.

HGT contradicts the conviction that bacterial species are fixed and discrete. If genes routinely cross the boundary between one species of bacteria and another, then in what sense is it really a boundary? New investigations, as time passed, showed that genes have even been transferred sideways between complex eukaryotic organisms. For instance: there’s a peculiar group of tiny animals known as rotifers, notable throughout molecular biology for their massive uploads of alien genes. A big rotifer might be a millimeter long, barely big enough to see, but small as they are, these are not single-celled creatures. They’re multicellular animals.

When Harvard researchers sequenced sections of genome in one rotifer species, they found at least 22 genes that must have arrived by horizontal transfer. Some of those were bacterial genes, some were fungal. One gene had come from a plant. Later work suggested that 8 percent of its genes had been acquired by horizontal transfer from bacteria or other dissimilar creatures.

That was definitely supposed to be impossible. It wasn’t.

HGT started showing up among insects as well. The most dramatic case was one species of fruit fly, which had accepted almost the entire genome of a bacterium known as Wolbachia—more than a million letters of genetic code—into its own nuclear genome. Again, this was supposed to be impossible.

By 1999, discoveries had progressed to a point such that Ford Doolittle, a highly respected researcher and theorist based in Halifax, Nova Scotia, published an overview paper in Science that put HGT at the center of a new discussion: whether it’s even possible to classify organisms into some “natural order” by placing them on a schematic tree of life. Doolittle illustrated—literally—the difficulties with his own hand-drawn figure of what he called “a reticulated tree.” To his surprise, the editors of Science published it along with his paper.

And more recent research has found evidence of bacterial DNA transferred horizontally into the genomes of human tumors. What that dizzying revelation means is still unclear, but there’s at least some chance that such insertions might play a role in causing cancer. Putting horizontal gene transfer on the list of suspected human carcinogens brings it out of the realm of microbial ancients.

The cumulative effect of these discoveries has been to challenge three concepts that we have long considered categorically solid: the concepts of species, of individual, and of the tree of life. Now we can understand better. The boundaries between one species and another are not nearly so clear and impervious as we thought. The living individual, including the human individual, is a singular thing, yes, but at the same time a mosaic of life forms and genes of varied origin. And the tree of life, as I’ve said earlier, is not a tree. That is, life’s history doesn’t conform to the pattern of any arboreal plant you’ll ever find in a forest. Again, it’s more tangled.

These discoveries should not merely complicate our magisterial human self-image, but also help lead us toward a wiser and humbler understanding of our place—collectively and as “individuals” within the “species” Homo sapiens—in the story of life on Earth.

It’s a story in which we humans are important protagonists but not the ultimate and predestined heroes. It’s a story in which heredity has moved sideways as well as vertically and all the conventional hierarchies and boundaries have proven more imperfect, transgressive, and leaky than we had supposed. But these revelations don’t diminish our responsibility, as humans, to respect and preserve the diversity of living creatures, with all their own mosaic genomes and tangled lineages, who cohabit the planet with us. On the contrary, I think. All this should make us only more amazed, respectful, and careful. Life on Earth is wondrous precisely because it’s so complicated.
Tech companies are rapidly networking the environment in ways that will transform our perception of nature—just as social media reshaped our relationships with each other. What could possibly go wrong?

By W. Wayt Gibbs
It was only on the fourth orbit, when the spacecraft’s orientation had changed, that they had the vision for which their mission will always be remembered. Shortly after they had swept from night to day, a bright, colourful complexity came past the limb of the Moon and into view.

—Oh my God! Look at that picture over there! Here’s the Earth coming up. Wow, that is pretty. and life returned to the world . . . It has been called

—Oh that’s a beautiful shot. the most important picture of the 20th century.

—Oliver Morton

The Moon: A History for the Future

“Earthrise,” that iconic photograph snapped from the Apollo 8 space capsule 50 years ago on a Christmas–eve orbit around the Moon, forced a self-absorbed species to reflect on its fragility. “Prior to that image, people had a perception of the planet being essentially infinite in its capacity to take all the damage we dish out,” recalls John Amos. A geoscientist who worked for years helping oil companies scout prospects from space, Amos was among a generation inspired by the “overview effect” to shift into activism. He left industry to launch an environmental-surveillance nonprofit called SkyTruth.

Half a century later, the arcs of fast-rising technologies—commercial rockets, cubesats, and drones, plus cloud computing, machine learning, and the Internet of Things—are now intersecting in ways that will again indubitably alter how we see the world and our place in it. It is no longer just advanced militaries and rich corporations who can keep tabs on what people are up to half a world away. Watchdogs such as Global Forest Watch, Global Fishing Watch, and SkyTruth are combing through satellite photos and radar scans to alert authorities to illegal clear-cutting, whaling, mountaintop removals, and other environmental misbehavior. Researchers at the Cornell Lab of Ornithology have exploited Amazon cloud servers to assemble millions of amateur birderwatcher reports into exquisite animated maps that plot the changing abundance of 122 bird species throughout North America. Ranchers are stapling health-monitoring microchips to their livestock. Beekeepers are sticking wireless sensors into their hives. Farmers are planting high-tech electronics into the soil along with their crops. Autonomous sailboats now ply the Southern Ocean to look for killer whales, and AI-enhanced drones patrol elephant habitats in southern Africa to spot poachers on the prowl.

“We are on the curling edge of the wave,” Amos says. The power of the “Earthrise” image came, in part, from the humbling invisibility of human existence in it. “This new instrumentation is more about seeing what people are up to in the environment,” he says. “The promise of this convergence in technology lies in imposing radical transparency on corporate activity and supply chains everywhere.” As SkyTruth’s motto goes, “If you can see it, you can change it.”

Or so one would hope. One lesson from past revolutions in social media and other technologies is that “Power always learns, and powerful tools always fall into its hands,” Ze尼ep Tufekci of the Berkman Klein Center for Internet and Society wrote recently in MIT Technology Review. In less than a decade, starry-eyed promises inspired by Internet-organized protests in Tahrir Square gave way to the grim realities of data trafficking, cyberbullying, election meddling, and surveillance states. Radical transparency in our online lives has frayed, not tightened, the fabric of societies. And now, in the unrelenting march of technological monitoring, things are getting real.

As sprawling webs of sensors, cameras, and satellites give some (but not others) a near-real-time view from everywhere, certain parallels to recent history are unmistakable—and unnerving. Data-gathering startups are popping up all over, but they are locked in earthshot races to monetize what they tout as “intelligence.” Tech giants are “indexing the Earth” by hoovering up satellite images the moment they are released to public access and then pouring the data into vast archives. Though today these companies often beneficiently grant free access to selected researchers and nonprofits, their long-term business strategies hinge on converting data into dollars. And those who are being observed and recorded are not the customers—they are the products. Does any of this sound familiar?

Yet history is not destiny. If we anticipate many of the ways that these new windows on the world might be misused, it should be possible to set up rules and agencies that will encourage the best uses while thwarting bad actors. Surprisingly, experts say that might not be as hard as it sounds.

The Unblinking Eye

Online instrumentation of the built and natural environment is extending our view of the real world in three dimensions at once: in extent, in detail, and in time. We are fast approaching a moment when, for a price, you can put eyes on any given spot on the planet on any given day, then scroll back through time to see how that place has changed. Advances in machine-learning algorithms have made it possible to train an unblinking AI gaze on a location of interest and get automated alerts when the software spots something amiss. One can now tag, say, a whaling ship and follow it from port to port. With each passing year, this tech makes it easier to conduct oversight—in the most literal sense—of those who exploit the land and sea.

What’s more, the number of eyes in orbit is skyrocketing, driven by launch costs that have plummeted 90 percent since the Space Shuttle era. Europe’s Copernicus program has fielded six Earth-observing satellites, called Sentinels, since 2014. It plans to expand the fleet to 30 within the next decade. Last year, China added six
A thickening flock of Earth-observing satellites blankets the planet. Over 700 were launched during the past 10 years, and more than 2,200 additional ones are scheduled to go up within the next 10 years. These scanners orbit among an increasingly crowded field of thousands of communications, navigation, and astronomical satellites as well as almost a million pieces of space debris bigger than one centimeter.

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Such surveillance works only when skies are sunny. But soon, constellations of very high-resolution satellites will use radar to peer through clouds and the dark of night as well. “That kicks open some doors,” Amos says. In particular, high-def radar can light up the vast “dark fleet” of fishing vessels that refuse to broadcast their positions via radio transponders.

Armed with new ways of seeing and with software that can merge surveillance quickly from multiple sources, watchdogs now have more opportunities to illuminate shady behavior while there is still time to do something about it. “We’re just now seeing the beginning of what is going to become possible,” he says.

In January, the Center for Strategic and International Studies reported that it had used returns from a space-based radar—along with tracking data from radio, visible, and infrared satellites—to monitor fishing activity among the disputed Spratly Islands in the South China Sea. The study revealed that the number of boats operating surreptitiously in the area is “exponentially higher” than those broadcasting as they should. A large fraction of the vessels that look like fishing boats, the investigators concluded, are actually militia patrolling the waters on behalf of China.

A different group of researchers working with Global Fishing Watch recently combined observations from multiple satellites to uncover illicit Chinese behavior of a different kind. In a study soon to be published, “We show that Chinese ships are fishing for squid in North Korean waters, almost certainly in violation of UN sanctions, while the North Koreans are fishing for squid in Russian waters,” says Paul Woods, the team’s chief technology officer. “There’s no way at this scale that there isn’t a financial transaction between the North Koreans and businesses in China,” he suspects, despite international accords prohibiting such trade.

In addition to getting clearer views of the present, activists are now able to exploit cloud computing to replay the past from extensive image archives maintained by Google, Amazon, and various government agencies. Amazon makes all data from Landsat 8 freely available on its cloud storage service. Websites such as EO Browser have taken advantage of the open-use policy to create services that let you zoom in to any location, enter a time range, pick the satellite sources you like, and then produce a time-lapse video of how the scene has evolved. Though the search engine and imagery are high-resolution optical and infrared imaging satellites to its fast-growing constellation.
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and the UN Environment Program. The viewer, developed over three years and 10 million hours of computing time, maps disappearing streams and dwindling lakes worldwide over the past 35 years. Scroll over northern California in the viewer, and the demise of Goose Lake is unmistakable. Click on the lake, and year-by-year measurements reveal that the 2008 drought sounded its death knell.

Access to space has become cheap enough that better-funded nonprofits can now put their own birds into the sky. The Environmental Defense Fund plans to launch by 2021 a satellite it is building to measure methane leaking from oil and gas production sites worldwide, revisiting each site at least once a week.

To keep tabs on things that can’t yet be seen from space—or to follow up on interesting sightings—some activist groups are deploying drones into the skies and oceans. Last winter, autonomous sailing robots built by Saildrone set off from South America to circumnavigate Antarctica. The months-long mission gathers data for scientists at NOAA and CNRSO on how fast the Southern Ocean is absorbing CO₂ from the atmosphere, a crucial variable in global climate models. The floating drones are also mapping the abundance of phytoplankton and krill, which form the base of the marine food web.

Global Fishing Watch, and a new surface-water viewer developed by the European Commission for environmental evidence of slave labor at brick kilns in India, in cotton fields in Turkmenistan, and in mangrove-displacing shrimp farms in Bangladesh. Google has lent its Earth Engine system to Global Forest Watch, Global Fishing Watch, and a new surface-water viewer developed by the European Commission for environmental evidence of slave labor at brick kilns in India, in cotton fields in Turkmenistan, and in mangrove-displacing shrimp farms in Bangladesh. Google has lent its Earth Engine system to Global Forest Watch.

When data that is too massive for nonprofits and individuals to download is generated by government, stored on private servers, and digested by profit-making companies, who controls it? And who pays?

Both poachers and wild animals in their recorded videos. Once they got the system working well in the lab, they tested it in the field in South Africa. It worked so well that they are now using it in national parks in Botswana and other African countries. Global Fishing Watch has used AI to distinguish fishing vessels from cargo and naval ships. A research team at Stanford reported in April that it had fed aerial photos of North Carolina farmland into a deep-learning system to find almost 600 industrial livestock farms that manual mapping had missed. Such concentrated feeding operations are a major source of freshwater pollution, in part because 60 percent of them operate without discharge permits, according to the EPA. In principle, regulators could use the AI to survey other states as well and to identify new operations as they pop up.

All of these examples, and many others like them, are tremendously encouraging. They tempt us to envision a happier future in which the instrumentation of nature draws humans into a more synoptic, and yet more intimate, connection to our home planet—one where Gaia itself gains a voice and a Facebook account. These systems could help people routinely band together to watch over ecosystems and organisms they care about deeply, despite never having experienced them directly.

Yet Mariel Borowitz, a space-policy researcher at Georgia Tech and author of the book Open Space, sounds a note of caution. The corporations building these technologies “are creating new kinds of data, new use cases, new users. But they are companies, so they are selling that data to make a profit.” And the revenue gener-...
aspirational. “Although we’ve been effective at raising public awareness about certain issues,” Amos says, “we haven’t had a big impact in altering corporate behavior.” Environmental exploitation remains highly profitable, and profitable businesses find ways to protect themselves.

The same can be said of the technology industry. Among the tech giants, “everyone wants to be central, essential, and in control of your world,” security expert Bruce Schneier writes in his recent book *Click Here to Kill Everyone*, because “control equals profits.”

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That idea seems not to have escaped Amazon and Google—which, according to Borowitz and Woods, have been downloading essentially all the Earth observations that NASA, NOAA, the European Space Agency, and other agencies make available to the public. Amazon is even building a global network of 24 large antennas to download data directly from some of the satellites that gather it.

Planet Labs has been open about its long-term commercial strategy. CEO Will Marshall said last year that “Planet will index physical change on Earth the same way Google indexed the Internet.”

Not to be left out, Facebook’s AI team has been combining space imagery with public records to map the population of every community on Earth. That effort would seem to serve the company’s long-held goal to get the billions of people who currently lack Internet access online—and on Facebook.

The day may arrive when “going off the grid” is no longer possible.
None of this is necessarily a bad thing. Who could resist the convenience of Amazon’s Alexa observing from orbit that your roof needs replacing or your windows could use washing, and offering to schedule the work? If Google noticed you heading out on a backcountry hike and offered to automatically summon help if you appear to get lost or injured, would you refuse? There will be countless ways that the tech giants can use the view from everywhere to make our lives slightly safer, cheaper, or more convenient. Most have not yet been conceived.

But let us pause to remember that Amazon, Google, and Facebook grew to become the third-, fourth-, and fifth-most valuable companies in the world by pitching ads directly at the people most likely to act on them. Inference equals influence; the product that the tech companies sell to their customers is their ability to infer how we live, where we go, what we do. Imagine the value added to that product when what we do captures our interactions with the physical world.

A rush to exploit remote sensing for advertising may inevitably allow bad actors to target us in more harmful ways. Witness Facebook’s Cambridge Analytica fiasco and data breaches in September 2018, and again in April 2019, that exposed records—including location data—on hundreds of millions of its users. And recall how in 2017 Google tracked Android on millions of its users. And again in April 2019, that exposed records—including location data—on hundreds of millions of its users. And in September 2018, and again in April 2019, that exposed records—including location data—on hundreds of millions of its users. And in September 2018, and again in April 2019, that exposed records—including location data—

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The earliest satellites, from Sputnik on, were launched in a race to space, and a spirit of free competition has kept space open ever since. So far, 35 countries have lofted Earth-facing satellites. “Everyone with a reasonably legitimate need gets to access low-Earth orbit and put hardware in space,” Borowitz notes. “It’s just as important that there won’t be slant control imposed on [those] remote-sensing systems.”

The open-sky policy of space exploration could be extended to guarantee that no big player can exclude its competitors or critics from access to unfiltered observations—or to the computer storage and processing capacity needed to analyze them. There’s no avoiding the fact that we look at the world through a prism. But we should be free to switch prisms and compare different perspectives.

Scientific research has long embraced a similar principle—and it has been one of the greatest strengths of that enterprise. And financial regulators require public companies to be transparent about their performance, and the playing field is level for all investors. Similar rules could protect sensor data against undisclosed conflicts of interest and outright fraud.

“Space is a global public commons,” Amos points out. “It’s widely agreed that governments should demand license fees for the right to collect data from space or other public areas, much as broadcasters and wireless communications companies pay to use the electromagnetic spectrum. The fees could then help cover the costs of hosting the data for all to use.”

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The biggest customers for sensing data are governments and resource-extraction industries, and that is unlikely to change, Borowitz says. Sixty percent of DigitalGlobe’s business comes from the US military, she notes. Planet Labs has earned tens of millions of dollars selling imagery to the US National Geospatial-Intelligence Agency. Governments have often demanded exclusive access to the imagery they purchase. It stands to reason that as environmental sensing becomes commercially more valuable or politically more embarrassing, those who pay will want to keep it to themselves.

It doesn’t take much imagination to envision ways in which this technology could be used to monitor and control the earth’s environment. Considering the trend towards greater oil and gas exploration, and the desire to detect illegal deforestation, and the desire to detect illegal deforestation, and the desire to detect illegal deforestation, there will be pressure to monitor the global environment from space.

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“The environmental bad guys already have ways to do what they want,” Woods says. “As long as the information stays open, I believe these tools will benefit the small players more.”

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Hacking Nature

For decades, humans have modeled technology on observations of the natural world. But new discoveries about nature—and tools for manipulating it—have opened up novel approaches potentially more powerful than mere imitation to solving Human Age problems.

By Lindsey Doermann

Spinach that can detect explosives

Engineers have discovered how to transform spinach plants into environmental sensors that can alert us to the presence of explosives. The development is one in the nascent field of “cyborg botany,” a merging of nature and technology that draws upon plants’ remarkable sensory capabilities in order to drive robots, provide environmental data, and more.

In 2016, chemical engineer Min Hao Wong and his team at MIT transported carbon nanotubes into spinach leaves via their stomata. Traces of explosive material that the plant took in through the air or groundwater caused the nanotubes to emit a fluorescent signal. To get the message from the plant, Wong’s team focused a small infrared camera on the leaves and attached it to a Raspberry Pi, a cheap, miniature computer similar to what’s found in smartphones. When the camera detected a signal, it triggered an email alert.

Having worked out the spinach nanosensors, Wong has gone on to develop other applications of the technology—particularly in agriculture. Plants are extremely perceptive, so they may be able to warn of drought conditions or pest infestations before a farmer can detect them. Wong is exploring commercialization of the technology in his current role as deputy science director of Disruptive & Sustainable Technology for Agricultural Precision (DiSTAP), a research center in Singapore.

Plants may have a lot to tell us. We’re now just learning how to get the message.

photo ©Melanie Gonick/MIT

Lindsey Doermann is a science writer based in Seattle, Washington
Bioluminescence to light up the city

We terrestrial beings have long marveled at how some squid, jellyfish, and other sea creatures produce their own entrancing glows—a phenomenon known as bioluminescence. French designer Sandra Rey’s curiosity about that light inspired her to bring it up and out of the sea. She imagines bioluminescence as a natural resource on land for creating “living” lights: ones that emit a soothing glow without electricity.

Rey is the founder and CEO of Glowee, a company that merges biomimicry with synthetic biology to produce bioluminescent lights. She envisions that they could one day replace the ordinary electric streetlight and cut down on the CO2 emissions that lighting generates.

To create oceanic light on land, Glowee technicians insert the bioluminescence gene from the Hawaiian bobtail squid into E. coli bacteria, then cultivate those bacteria. What’s more, by programming the DNA, engineers can control the color of the light, when it turns off and on, and more.

The bacteria, of course, need care and feeding to keep glowing, so the company is working on ways to keep the lights on longer. At this point, says Rey, they have one system that lasts for six days and another that works like a fish tank: “As soon as you feed the system, the bacteria will produce light,” she says.

Glowee’s lights can take on any shape, from the standard streetlight to a window sticker, so the company has let its imagination run free with possible applications. The lights’ current limited lifespan makes them well suited for events or festivals.

In addition, some French shop owners, prohibited from illuminating signs or window displays in the middle of the night due to light pollution and energy-use concerns, are looking forward to applying bioluminescent stickers to their windows.

Ultimately, Rey has grander plans for bioluminescent lights. “For us, the biggest opportunity is to create networks of these living lights in the streets of tomorrow,” she says.

Sure, improvements in energy efficiency may help contain lighting’s environmental footprint. But to light up regions of the world that still lack access to electricity, we need big leaps forward in ecofriendly light. Rey may have just plucked one answer straight out of the ocean.
An Internet of bees

Bumblebees carrying location-tracking and sensor-laden “backpacks” might some-
day replace the drones that farmers use to
monitor their fields. Engineers at the Uni-
versity of Washington found that instead
of bulky equipment that needs frequent
recharging, they could equip insects with
tiny yet powerful devices to do the job.

Other researchers have tried to create
completely robotic insects, but those min-
iature robots struggle to fly in turbulent
conditions and are limited by power from
a tiny battery. The UW team has instead
harnessed the bees’ mechanics rather than
try to copy them. Thanks to evolution,
insects have already worked out how to
navigate in a range of conditions, and they
can power themselves.

To make bumblebees work as preci-
sion agricultural tools, the engineers were
able to load sensors, data storage, receivers
for location tracking, and a rechargeable
battery into a 102-milligram package. As
the bees go about their everyday activ-
ity, the sensors measure temperature and
humidity, and their position is tracked via
radio signal. When they go back to the
hive, the data are uploaded and the battery
recharges wirelessly.

The team refers to its technology as
Living IoT (for Internet of Things), and
it envisions a network of sensors that
leverages biology for new environmental
monitoring possibilities—letting nature
be the guide.
Sheep and goats that predict volcanic eruptions

The Roman author Aelian wrote of an amazing phenomenon in Greece that occurred five days before a large earthquake struck in 373 B.C. Mice, martens, snakes, and other creatures curiously fled town, he recorded.

As a high-school student, zoologist Martin Wikelski translated ancient Greek and Roman texts. This is how he first came across the idea that animals might have an innate ability to sense impending disaster.

Wikelski now directs the International Cooperation for Animal Research Using Space—the ICARUS initiative—out of the Max Planck Institute for Ornithology. He’s made a name for himself attaching GPS tags to animals large and small to see what their collective behavior might reveal. Among other phenomena, he’s shown that the presence of white storks can signify locust outbreaks and that the location and body temperature of mallards can portend the spread of avian influenza in humans.

Now he’s looking to goats to see if the ancients’ theory that animals “know” about imminent earthquakes and volcanic eruptions holds water. Sure, it’s still a controversial idea, but perhaps 24/7 data collection around big events could provide scientific credence one way or another.

Immediately after a powerful earthquake shook Norcia, Italy, in 2016, Wikelski outfitted farm animals near the epicenter with collars to see if they behaved differently in advance of aftershocks. Each collar housed both a GPS tracking device and an accelerometer. With this around-the-clock monitoring, he says, you can observe what “normal” behavior is and look for deviations from that.

In Italy, Wikelski and his team measured that the animals collectively increased their body accelerations over background levels hours before earthquakes struck. He observed “warning times” of between 2 and 18 hours, with longer times corresponding to more-distant epicenters. He is in the process of publishing more details on his findings.

Moving forward, he’s interested in better understanding the mechanism by which animals perceive these natural phenomena. It’s simply that animals are very sensitive to the earth’s shaking, he says, seismologists would have already solved earthquake prediction. Instead, rocks under high stress before a quake force charged particles out of the minerals. “There’s a charge in the air,” he says, “and that’s possibly what the animals are sensing.”

Further, Wikelski wants to tap into a larger network of tagged animals around the Ring of Fire. He wants to understand behavior patterns of different animals in the wild and see which “sensors” are better at predicting natural disasters. He’s applied for a patent for a disaster alert system based on animals’ collective aberrant behavior relative to a baseline.

As human activity impinges on animals around the world, Wikelski hopes that his emerging “Internet of animals” offers even more reason to care for them. The insights they can provide, he’s discovering, may prove more valuable than ever.
In the early 1990s, pharmaceutical giant Merck entered into a “bioprospecting” agreement with Costa Rica’s National Biodiversity Institute, known by its Spanish acronym INBio. Merck would receive exclusive access to test INBio’s extensive collections of indigenous organisms for their therapeutic potential in exchange for a million-dollar up-front payment, in-kind contributions to research, and a promise of royalties in the event that commercial products were identified.

The mood bordered on euphoria. Nature, the deal brokers promised, is a vast storehouse of chemical compounds that can fight off infections and cure diseases. Evolution, through eons of trial and error, has produced molecular compounds more ingenious than synthetic chemists could ever imagine. Indigenous organisms are genetically coded to metabolize miracle drugs.

By R. David Simpson

The Problem with Making Nature Pay for Itself

Illustrations by Daniel Horowitz

I don’t think ecosystem services are underappreciated. What is underappreciated is basic economics. This is the common thread running through all the disappointing experiences to date with finding ways to make nature pay for itself.
How much would you pay for something whose supply seems unlimited? Probably not much. Things that are in short supply command high prices; things that aren’t, don’t. This is a hard economic lesson, but a solid one.

The logical place to bioprospect is where biodiversity is most abundant. Tropical rainforests cover about six percent of the world’s land area, but they shelter more than half of its living species. While biological wealth is greatest in the tropics, material wealth isn’t. So bioprospecting might raise the standard of living for people in desperate need. These were the same desperately poor people who were diminishing biodiversity by carving farmland from forests. Bioprospecting seemed to hit the trifecta: life-saving drugs, new income sources, and a halt to deforestation.

INBio’s director predicted that research samples would soon displace coffee in Costa Rica’s export rankings. The nation began training teams of parataxonomists, rural workers who would continue the work of classifying Costa Rica’s biota. Other companies followed suit, expanding their natural-products research operations. United States government agencies combined to sponsor an International Cooperative Biodiversity Groups (ICBG) program under whose auspices pharmaceutical researchers were paired with source-country partners. Bioprospecting even inspired a movie. In the 1992 film Medicine Man, Sean Connery, then only three years removed from having been named People magazine’s “sexiest man alive,” played an ethnobotanist racing to find a cancer cure before the rainforest was felled around him.

As the enthusiasm for bioprospecting grew, so did tensions over splitting the spoils. Colonial powers have long exploited the Global South for its labor and raw materials. Now tropical nations faced a new form of expropriation, biopiracy. Google Scholar lists more than 150 works published before 2000 on “access and benefit sharing” for genetic resources. Such concerns might have been well founded had the case for bioprospecting stood on solid ground. Regrettably, however, bioprospecting didn’t make economic sense. David Kingston, a chemistry professor at Virginia Tech who participated in an ICBG in Suriname, characterized the repository of research leads in nature as “so vast as to seem unlimited.” This might seem to underscore how valuable biodiversity is to pharmaceutical researchers, but if you think about it, it really makes the opposite case. How much would you pay for something whose supply seems “unlimited”? Probably not much. Things that are in short supply command high prices; things that aren’t, don’t. This is a hard economic lesson, but a solid one.

Bioprospecting was an early example of an appeal to an “ecosystem service” in an effort to motivate conservation. The conservation community has since turned its energies to other ecosystem services that place more emphasis on the benefits that preserving relatively undeveloped habitats would bring to the communities living in or adjacent to them. These include services such as water purification, pollination, pest control, flood protection, global climate moderation, ecotourism, and a host of others. Considerable effort has gone into studying these services in hopes of finding some that will prove more effective in motivating conservation than did bioprospecting.

Bioprospecting disappointed because advocates hoping to align economic forces with conservation didn’t appreciate how economic forces work. This has been true of many other initiatives. When development pressures are high, it tends to be more cost-effective to rely on artificial substitutes for ecosystem services than to forgo converting land to agricultural or residential uses. Even when the argument can be made to retain some remnant areas of natural habitat to provide ecosystem services, it’s not clear that much meaningful conservation results. Trying to make nature valuable, it turns out, has had a disappointing track record.

**What went wrong?** Here we need a bit of history. And 1980 is a good place to begin. That was the year that the International Union for the Conservation of Nature (IUCN) issued its influential *World Conservation Strategy. “Too often,” it said, conservationists “had allowed themselves to be seen as resisting all development.” The self-criticism was well taken. Many of the world’s protected areas had been established by fiat and maintained by force. Perhaps desperately poor people threatened the biodiversity that parks were established to protect, but a solution that ignored their legitimate interests would prove self-defeating—as well as immoral.

Going forward, the emphasis was to be on finding ways in which those poor populations themselves might benefit from conservation. The key was to demonstrate the myriad ways in which nature could benefit people. Conservation and development should be integrated. Rather than simply conserving resources for traditional uses, new industries based on natural assets were envisioned: collection, processing, and export of natural products; bioprospecting; ecotourism.

Like many other young researchers, I was motivated by the desire to help save nature in the fall of 1991 when I took a position at Resources for the Future, a nonprofit research institute dedicated to environmental and resource economics. The term “biodiversity” had been coined a few years earlier, and the idea of a sixth extinction crisis perpetrated by humans was entering the popular lexicon.

By then, the IUCN approach to conservation had also been picking up steam as more and more conservation advocates and scholars gravitated toward the idea. Since calls for altruism hadn’t worked, perhaps appeals to tangible self-interest would. Integrated conservation and development projects (or ICDPs) embodied these hopes. ICDPs often focused on schemes to market the products or services of tropical rainforests and other biodiversity hotspots to would-be consumers around the world. The most exciting ICDPs were the ones focused on mining genetic resources for pharmaceutical research. Cancer drugs had been developed from the rosy periwinkle and the Pacific yew, diabetes medication from Gila monster spit, heart drugs from foxglove, quinine from the bark of the cinchona tree. If pharmaceutical researchers could be compelled to pay for access to genetic resources, the argument went, the rainforests could be saved.

The problem of biopiracy remained, however. That was the question to which I turned at the start of my career. I tried to approach the question logically: if the difficulty lay in compensating providers for the value of the genetic resources they offered,
the first thing to think about was the value of genetic resources.

That led to my epiphany. Biodiversity wasn’t scarce—at least, not with respect to the needs of pharmaceutical researchers. Economists argue that value is determined by scarcity. If there isn’t much of something relative to the demand for it, people will pay a lot for more of it. If it’s relatively abundant, they won’t. So the argument I often heard as I began my work—that we should save the rainforests because they are home to millions of as-yet-undiscovered species, and each one of those species might be the source of the next miracle drug—actually cut the other way. If there were literally millions of undiscovered species, and each one of those species might be the source of the next miracle drug, we should save the rainforests because they are abundant, they won’t. So the argument I was trying to set me straight. Just that week, he spoke, a man in the audience sought me out to set me straight. Just that week, he informed me, the Washington Post had reported on a promising new compound that might meet the urgent need to treat antibiotic-resistant infections. What did I have to say about the fact that an immensely valuable new compound had just been isolated from a soil sample? I thought for a moment before responding. “Are you familiar with the phrase ‘cheap as dirt’?”

In the decades since I first wrote on bioprospecting, I have continued to study the broader and evolving field of ecosystem services. I’ve served as an author in the Millennium Ecosystem Assessment, a review editor for the United Nations-sponsored project on The Economics of Ecosystems and Biodiversity, and an advisor to the World Bank’s program on Wealth Accounting and the Valuation of Ecosystem Services. I’ve continued to research topics such as the pollination, storm protection, and pollution-treatment services of natural systems; and I served for several years as director of ecosystem economic studies in the US Environmental Protection Agency’s National Center for Environmental Economics.

The question that has dogged me is: Will the continuing search for instances in which economic forces are aligned with conservation identify more promising possibilities? Or did the bioprospecting experience reveal a more pervasive disconnect? I’m afraid the general answer may be that it did. There are certainly many instances in which preserving natural assets is economically justified. What I have much graver reservations about is whether there are enough such instances to motivate conservation on the scale that will be required to maintain anything like the diversity of nature the planet now supports. Bioprospecting fizzled spectacularly. Other forms of ICDPs have fared better. Take ecotourism. Gorilla-viewing excursions in Rwanda, cloud-forest tours in Costa Rica, and cruises retracing Darwin’s voyage in the Galápagos have, by and large, been win-win propositions for conservation and development. Some natural-product ventures have also prospered. Indigenous artisans have exported more than 6 million pounds of figurines and jewelry crafted from “vegetable ivory,” the seeds of tagua palms. Sustainably grown coffee, cocoa, and rattan also compete in world markets.

But the success comes with caveats. Too many ecotourists can “love an area to death,” and too much emphasis on harvesting tagua, coffee, cocoa, or rattan can transform natural habitats into de facto farms. A 2008 study of World Bank projects intended both to alleviate poverty and protect biodiversity found that fewer than one in six achieved both objectives. (2) I suspect, though, that the limitations of ICDPs as conservation vehicles all involve variants of the bioprospecting problem. When you try to scale them up, you bump up against the laws of supply and demand. Uniquely beautiful destinations attract visitors willing to pay a lot to see them; however, unique destinations...
The problem with bioprospecting and some other types of ICDPs was that the marginal value of the habitats it was hoped they would preserve was negligible. They remained so extensive globally that they were not scarce relative to demand. The opposite problem can beset ecosystems preserved to provide local services. Ecosystem services may be valuable, yes, but they may be most valuable when it would also be most expensive to set aside land to provide them. If ecosystem services are valuable enough to justify setting aside some land to provide them, then it may be because it’s not necessary to set aside much land to provide them.

Pollination, an ecosystem service that has been studied extensively, illustrates this point. Wild insects still pollinate crops in some areas, but many farmers whose crops require pollination rely on rented European honeybees (*Apis mellifera*). The rented bees are moved from farm to farm as crops flower and require their services. In the US, 1.7 million hives of honeybees—85 percent of all commercial bees in the country—are trucked to California every February to serve the state’s almond crop.

Some biologists and advocates have argued that those farmers should instead set aside land to support native insects that could pollinate almonds.

Whereas honeybees are currently trucked away to serve the next crop that comes into bloom, native pollinators need habitat maintained for them year-round. Land in California’s almond-growing areas can sell for $25,000 an acre or more, and almond farmers pay about $450 per acre to rent bees to pollinate their crop. In deciding whether to maintain remnant areas of natural habitat on her land or to instead rent honeybees, the almond farmer must ask herself, “How much $25,000-per-acre land am I willing to take out of almond production so I can save $450 per acre every year?” The economically rational answer is probably “not much.” Intuitively, farmers wouldn’t be willing to take much land out of almond production if their reason for doing so was to enhance almond production. In a recent paper published in *Environmental and Resource Economics*, I calculated that, under generous assumptions, an almond farmer who decided to rely on wild pollinators rather than honeybees would devote no more than about one-eighth of the area she might farm to sustaining them. (3)

In many instances, producers may find that employing substitutes such as European honeybees rather than native insects to pollinate crops, leeves rather than riparian vegetation to control floodwaters, and wastewater-treatment plants rather than wetlands to treat pollution is more cost-effective than setting aside extensive areas of expensive land to provide such services. When natural measures are cost-effective, on the other hand, it’s likely either because not much land is required to provide them, or because development pressures are low anyway.

**There are two conclusions** one might draw based on the history of ecosystem services thus far. The first is that ecosystem services are systematically underappreciated, and if we just keep looking, we’ll identify values that will convince decision-makers to save far more of the natural world.

I would offer an alternative conclusion. I don’t think ecosystem services are generally underappreciated. What is underappreciated is, rather, basic economics. This is the common thread running through all the disappointing experiences to date with finding ways to make nature pay for itself.

So what’s to be done?

I don’t want to have to confess to my grandchildren that my generation sat idly by while a sixth extinction crisis swept the planet. That means that our urgent task is to find ways of averting the crisis, ones that really work. Since the 1980s, we’ve been looking for ways to make nature valuable. What if we turned the problem on its head? Linus Blomqvist at the Breakthrough Institute, where I’ve done consulting work, has argued that the key to saving wild biodiversity isn’t by showing that it’s useful. Rather, it’s by making it useless. I suspect this formulation was chosen because it’s memorably provocative. The underlying argument, however, is worth considering.

Ecosystem services were intended to promote conservation by demonstrating that people would realize more value by retaining areas of natural habitat than they would from converting them to farms. If people realized less value from converting habitats to farms than they would from retaining them as forests, wouldn’t that also promote conservation?

In the 1980s, poor farmers in the developing world were clearing forests at rates that imperiled biodiversity. That motivated a transformation in conservation policy—Circumstances have changed dramatically since then. When the IUCN report was published in 1980, world population stood at a little less than 4.5 billion people. There are now more than 7.5 billion on the planet. If one looks into the figures more carefully, though, revealing details emerge. Urbanization is advancing much faster than population is growing. About 60 percent of
the people on Earth in 1980 lived in rural areas. About 45 percent of those who now share the planet live outside cities. While the earth’s population will likely continue to grow, the rate of growth is slowing. Urban families tend to be smaller than those reared to provide farm labor. The UN’s Revision of 2018 World Urbanization Prospects predicts that we’re now near peak rural population: the number of people living outside of cities will soon decline.

Wherever they live, people need to eat. And producing food requires land. Again, the trends offer grounds for optimism. The amount of agricultural land per person worldwide has declined by more than a third since 1980, even as population has grown by about two-thirds over the same period. The net result has been a modest increase in land devoted to agriculture across the globe. While Jesse Ausubel’s assertion (that the world is also near peak farmland) has not been universally accepted, a future decline in the area of crops and pasture is not out of the realm of possibility. If nothing else, it is clear that technological improvements in agriculture have allowed the Earth to support far more people by farming far less land than might have been predicted two generations ago.

In short, the data show that people are, by and large, moving away from marginal agricultural lands and into cities, a trend accompanied by intensification of agricultural production, greater crop yields, and—all in all—less human appropriation of the landscape per capita and, perhaps soon, in all—less human appropriation of the production, greater crop yields, and—all accompanied by intensification of agricultural mechanization. Perhaps it is time to ease up on the search for ways to make nature pay for itself and instead look for ways to let nature flourish . . . without us.  

If you’re thinking this all sounds too good to be true, you’re right. Much could go wrong without effective guardrails. Even if more crops can be grown on less land, additional quantities of food might be fed to meat and dairy animals rather than consumed directly. Farming might also shift. Perhaps increasing agricultural yields will mean that less land needs to be farmed overall, but we might be wary of farms shifting from biologically depauperate temperate zones to biodiverse tropical ones. Other consequences of agricultural intensification aren’t necessarily benign, either. Modern farming relies on synthetic fertilizers and pesticides, some of which end up in the air or water. It also employs machinery powered by fossil fuels. Selective breeding and, increasingly, trans-specific genetic transfer have expanded yields. While many scientists are not worried about novel crops, a portion of the consuming public is averse to such “unnatural” products.

This last observation underscores what may be the most important point. Nature might be rendered “useless” and left to go its own way in a world with fewer peasant farmers, more industrial agriculture, and larger and denser cities. But is that the world we want to live in? It’s a valid question, and one to which there’s no right answer.

If the world we want to live in is one that supports nearly its full complement of biodiversity, though, we need to think realistically about what it will take to sustain that endowment. A vision of the world’s hinterlands populated by farmers working in harmony with, and dependent on, nature and its services may not work on a planet of 10 billion. Moreover, Marx and Engels may have been on to something when they grudgingly credited the bourgeoisie with having “rescued a considerable part of the population from the idiocy of rural life.” No one should be forced to abandon a lifestyle she treasures. By the same token, though, no one should be trapped in a lifestyle she does not treasure to realize someone else’s preconception of what rural life should be. The less romantic alternative may be a world in which the rural poor transform into an urban underclass with less contact with nature but, one hopes, with the possibility of upward mobility.

For all these reasons, such a transformation should be managed. Environmental consequences call for mitigation. While more productive agriculture can be organized to reduce pressures for land conversion, landscape planning will be required to lay out reserves large enough to maintain complex ecosystems—as well as to map the corridors and connections required for seasonal migrations and adaptation to a changing climate. Finally, the teeming metropolises of the developing world are hardly workers’ paradises. The exodus from farms to cities won’t improve lives unless it’s accompanied by investments in sanitation and education.

This is a tough bill to fill. We won’t make progress, though, if we start from the wrong assumptions. Conservation advocates had the right idea 40 years ago when they recognized the need to unite conservation and development goals. They acted from the best of impulses in insisting that the most vulnerable populations not bear the burden of preserving nature. The prescription of relying on ecosystem services both to motivate the preservation of natural habitats and improve the lot of the poor has not worked out well, though. Too often the economics don’t make sense, and when they do, the conservation incentives may not amount to much. The world has changed markedly in four decades. The challenge we face now is not so much to find ways for the rural poor to live in harmony with nature. It is, rather, to manage the transition from a world of small farms to one of big cities in a way that realizes the conservation potential of that trend.

This transition is well under way. While we face a host of daunting social, political, economic, and environmental problems, we should not lose sight of an astounding fact. I think the single most remarkable contrast between the world of 1980 and today is the decline in extreme poverty. World Bank statistics show that only about 700 million people, fewer than ten percent of a much larger population, now try to subsist on less than US$1.90 per day. That’s still appalling, but it’s a huge improvement over the two billion plus in extremis 40 years ago.

If the objective of conservation in the Anthropocene is both to enhance human quality of life and save nature—and I believe it is—then it will be easier to swim with, rather than against, demographic or technological currents. Perhaps it is time to ease up on the search for ways to make nature pay for itself and instead look for ways to let nature flourish . . . without us.

R. David Simpson is a consultant on environmental and resource economics. He has served in government, taught at Johns Hopkins University’s School of Advanced International Studies and at University College London, and was a senior fellow at Resources for the Future. He was a coordinating lead author in the Millennium Ecosystem Assessment and has advised several other biodiversity conservation initiatives.

This article borrows from, and builds upon, ideas in an earlier article he wrote for The Breakthrough Journal.

First, the flying drones scout the landscape recording the swell of hills, the temperature and humidity of soils, the location of streams and rivers via radar and GPS data. This information feeds back into computers, which use machine learning—recording the information in photograph after photograph after photograph—to determine the best locations for planting a species, whether a mangrove in south Asia or a pine in western North America. Then the drones deploy to fire seed pods into the ground, planting more than 100,000 in a day.

Meanwhile, a swimming drone patrols the Great Barrier Reef, navigating by sonar and camera while scanning the area for destructive crown-of-thorns starfish. Using artificially intelligent software, the COTSbot spots the purple, thorny arms of the animal (even when wrapped around coral or partially hidden under it) and a pneumatic arm deploys...
to inject poison. The lethal drone can eliminate as many as 200 starfish in eight hours, helping preserve the reef from another echinoderm that can spawn millions of young.

And today, photo or audio files pour into a central location where computers that are set up as neural networks—a collection of programs training each other on a specific task, a crude imutation of the human brain—scan the collected works. The programs identify the whistle-sizzle of birds colliding with power lines, in hopes of developing better methods for avoiding such deadly strikes. Or they confirm sightings of an endangered plant or animal, such as a whale shark.

“We built an intelligent agent that replaces me,” explains Jason Holmberg, executive director and director of engineering for Wild Me, one of a slew of outfits employing artificial intelligence (perhaps better named “machine learning”) in pursuit of conservation goals. Holmberg spent two years data-mining YouTube vacation videos for encounters with whale sharks. He and his team then used that data to train the artificial intelligence program Wildbook to recognize whale shark sightings in order to enable scientists to gain a better understanding of populations, behavior, and other important information. “The users of our [machine learning] are overwhelmed with visual data,” he says. “Already, neural networks allow a learning from its environment through imitation of the human brain—scan the collected works. The programs identify the whistle-sizzle of birds colliding with power lines, in hopes of developing better methods for avoiding such deadly strikes. Or they confirm sightings of an endangered plant or animal, such as a whale shark.

Welcome to the brave new world of AI for conservation, which offers a new possibility for this increasingly unnatural world: automating wildness. We’re used to thinking about AI in manufacturing and self-driving cars, but the technology is finding new uses in agriculture, health care—and now environmental conservation.

This automated future raises some very old questions, with some decidedly new twists—starting with, What is wild, anyway? “We tend to think of a species as ‘wild’ if it does not exhibit evidence that it is controlled or shaped by humans,” argues Laura J. Martin, an environmental historian at Williams College. But there are few, if any, organisms or ecosystems which fit that definition in the world today, whether the human-shaping is direct or indirect. In fact, the Anthropocene is a world of novel ecosystems, a mix of animals, plants, and other organisms living under rapidly changing environmental conditions. These novel assemblages of plants and animals sometimes thrive so much that it may be impossible for them to tolerate a return to some original condition. And even if the original condition could be restored, how could it endure the shift in climate that is upon us? The Arctic of today is different from the Arctic of yesteryear or the Arctic of the next century. The only constant is change.

Consider the Amazon rainforest, sometimes known as the lungs of the world. Will the Amazon as we know it today persist, or will it be cleared for farms and ranches? Will it be cleared anew, only to grow back—as the eastern forests of the U.S. have? In fact, the regrowth of the Amazon seems to have happened before—just a few hundred years ago, when Europeans reached the so-called New World and killed off their fellow humans largely through diseases such as smallpox. The overgrown urban outposts of the Amazon suggest that the rainforest has not been left to its own will for millennia.

In 1851, writer and naturalist Henry David Thoreau penned the now famous assertion, “In wildness is the preservation of the world.” That line has become an inspiration to the modern environmental movement. But Thoreau himself struggled to define the wild, ultimately coming to the conclusion that wildness is more of an attitude or idea than a reality. A century after Thoreau’s death, the poet Wendell Berry added an inventive corollary to the famous quote, one that seems befitting of the Anthropocene: “In human culture is the preservation of wildness.”

The wild, in other words, requires human imagination and human choice. But it also requires human forbearance and—maybe—technology unleashed by humans. Imagine, for example, a robot capable of learning from its environment through images and other data. Imagine people giving this robot the task of a conservationist, to preserve and protect a particular ecosystem or ecology. Imagine this robot freed to pursue its task as it deems best, removing signs of human intrusion and impact.

For example, this “Wilderdrone” might be asked to create buffer strips of particular plants to consume the nitrogen and shield the core from too much fertilizer. Or it might reshape the land itself, either to better retain nitrogen or to promote ever faster flow through the protected area. It would learn from each action and implement better strategies based on the results, constantly improving its ability to remove, reduce, or replace human influences. Would the resulting creation—free from human interference and control, even human conception—be wild? “Can humans design technologies to curate ecosystems?” Martin asks. “And would these ecosystems be more, or less, wild than human-curated ones?”

After all, human conservationists already do all the above, but with the stigma of human interference in what ultimately is only a philosophical conception of the wild—whether that be a national park removed from historical context or a novel ecosystem growing on the margins of human activity.
Can artificial intelligence ever be autonomous? Can AI be used to promote the autonomy of nonhuman species?

There is a computer game called Universal Paperclips. The game asks players to adopt the role of an artificial intelligence programmed to make paper clips. At first, players simply make paper clips, sell them, invest in paper-clip-making machines, and make ever more paper clips. Over time, however, the game incrementally and insidiously reveals that the AI’s single paper clip—making goal brings to an end the reign of humans, as it stops at nothing in its quest to make everything into a paper clip. The game—and the thought experiment behind it—illustrates the unintended consequences of too much autonomy for a capably intelligent but narrowly focused agent.

Similarly, an artificially intelligent and autonomous “Wilderdrone” tasked with conservation—or even with simply managing human interference—might rapidly come to the conclusion that eliminating humans is the key step to preserving an endangered species or stop light pollution.

Even short of that twin AI-environmental apocalypse, AI for conservation could privilege an endangered animal over the people with whom the animal co-exists, a repeat of the many people-versus-parks conflicts from around the globe that have turned settled peoples into conservation refugees or misidentified a local community as a group of poachers. And it is not clear whose vision of the world has been, or will be, programmed into any such software nor who gets to choose what the right state for a given ecosystem should be. “Ultimately, humans need to make decisions among each other about what world to live in,” Martin notes.

If there’s one thing wildness is not, it’s static. And yet a kind of artificial stasis—an ecosystem artificially protected from the vagaries of nature itself—is what AI can promise, and that may prove an all too seductive offer for nostalgic humans.

If we use AI to try to create and enforce a kind of artificial stasis—inhuman gardeners on the most massive scale and ecosystems insulated from the vagaries of nature—won’t we be disappointed by the results?

Alternatively, AI could become a way to further blend the wild and the tame. If any of the world’s woodlands, fields, and wetlands end up conserved, the first thing required will be keeping a better eye on them. And satellite monitoring or drones paired with artificially intelligent computer systems suggest a cheap, easy, and potentially accurate way to do so. What a drone and a computer program can do in minutes takes hours, days, or even months for a person or team exposed to the elements and the attentions of biting insects, among other hindrances, as they attempt to survey a plot or plant a new forest. Once ground-truthed, artificial intelligence promises an end to this kind of work. Drones can now sense air pollution, monitor animals, and stop poaching, among other conservation pursuits.

And AI could go even further. It “has the potential to profoundly shape other species,” Martin says. AI “is changing how we collect data on ecosystems, and therefore how we view and understand ecosystems.” AI, however, may remain forever constrained by its human trainers.

The strategies of conservation are, in the end, simple: management through technology and surveillance. “Imagine a world where a cloud of hundreds of thousands of photos from tens of thousands of researchers and citizen scientists could accurately predict population sizes and even individual animal life histories quickly and with high accuracy, iterating population estimates weekly and allowing wildlife-conservation authorities to constantly monitor and protect populations,” Holmberg says. “Now imagine those photos largely collected by remote drones, reversing human encroachment and instead promoting larger wildlife refuges in which wildlife populations exist in a very natural state while still being carefully monitored and protected.”

In such a near-future world, will we reserve half for nature and simply do nothing to the land and sea? Or will we simply outsource to our technology decisions between competing visions for how a place should be used, adding a veneer that may obscure the very human power struggles and politics? If so, the Anthropocene might rapidly become the Robotocene. This is a common story when it comes to people outsourcing decisions to AI: just think of how we wrestle with whether to program an autonomous vehicle to run over a grandmother to save a baby, or not. These will be hard decisions and must be made with wide participation and democratically. The decisions must also be subject to change in response to the needs of humans or animals, circumstances or goals, clear mistakes or clear victories.

“Conservation is a form of care,” says Martin. “Can we design AI that care? That love? That cherish other species?” For the moment, a love of the wild is found only in human minds.
How different are we after all?

By Brandon Keim

In early February 2019, researchers from the Max Planck Institute and Osaka University reported that bluestreak cleaner wrasses—finger-length tropical fish renowned for their endearing practice of nibbling dead skin from the mouths of larger, scary-looking fish—appeared to recognize themselves in a mirror. (1)

Humans usually do this early in childhood. It’s considered a key developmental milestone, signifying a heightened sense of oneself as oneself, separate from others and from one’s environment. In fact, this sense of self-awareness is a condition so integral to human experience that it’s head-spinningly difficult to imagine its absence. Yet only a handful of nonhuman species, including several great apes, Asian elephants, bottlenose dolphins, magpies, and manta rays have passed the so-called mirror test; so the cleaner wrasses’ success was met with surprise—and some skepticism.

Fish, after all, are not typically recognized as intelligent. Conventional scientific wisdom holds that self-awareness involves a cognitive sophistication beyond the tiny-brained wrasses’ ken. Yet they met the test’s requirements. The wrasses swam upside-down in front of the mirror, a behavior not performed elsewhere, and they tried to remove marks the researchers had made beneath their throats, about which they could have learned only by using the mirror to inspect themselves. Nevertheless, the researchers disavowed the implications. Granting wrasses self-awareness, they noted, “would require a seismic readjustment of our cognitive scala naturae”—the Latin term for “ladder of being,” a conception of the animal kingdom as a hierarchy with Homo sapiens (“wise man”) perched on top.

A tenet of canonical Greek philosophy, the notion of scala naturae eventually dovetailed with Christian ideas of mankind (not animals) fashioned in God’s image, and later with colonial efforts to erase indigenous cultures that regarded animals as possessing intelligences comparable to our own. Such were the foundations of Enlightenment science. A few scientists, most prominently Charles Darwin, pushed back; but on this subject, they were pushed aside.

By the mid-twentieth century, scientific dogma treated animals as mindless stimulus-response machines. If people outside science were not always so reductionist, those views still shaped culture and species-level self-understanding. Consider the question “What makes us human?” It is typically answered in terms of differences. The myriad traits proposed to define us—tool use, language, empathy, and on and on—assume that humanity’s essence resides in what sets us apart from other beings.

The question “What makes us human?” is typically answered in terms of differences. The traits proposed to define us—tool use, language, empathy, and so on—assume that humanity’s essence resides in what sets us apart from other beings.
Predator, and they no longer elicit the same companions in response to an approaching referential, signifying some external object communication. This has obscured the richness of animal communication. Yet as with self-awareness, they also live in the past and in the future.

Communication is foundational to community, and social life is an especially powerful evolutionary driver of intelligence. Crows recognize the faces of people who bothered them years before, and they also inform another about them. This should not come as a surprise. Group life requires remembering identities, assessing abilities and intentions, and making judgments based on past experience. And then there’s the tangled topic of emotions—the positive or negative valences that shape all behavior but are most clearly related to others. Many researchers still regard animal emotions as baser than our own. Yet that assumption, too, has been shaken. Researchers use rats to study the neurobiological foundations of empathy—the ability to feel another’s feelings—and veterinary scientists recognize the suffering caused by separating dairy calves from their mothers. When an orca mother off the coast of Washington carried her dead baby’s body for weeks, as dolphins are known to do, many observers considered the most likely explanation to be grief. Animal communities are not just social and emotional. They’re also political. Many animals live in groups that make decisions collectively, even democratically.

Japanese great tits, a relative of the aforementioned chickadees, are among the species whose vocalizations are syntactical—that is, order determines meaning—and referential, signifying some external object rather than internal states of arousal. Change the order of calls used to summon companions in response to an approaching predator, and they no longer elicit the same response. It might not be “language,” but it’s certainly language-like, and much can be accomplished with just a few signals and pragmatic inference. And a great deal of meaning requires nothing language-like at all: consider the importance of a grimace or a smile or a hug.

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Another capacity invoked as uniquely human is that of language. Indeed, there’s no evidence of other species possessing our proficiency in coinining words and arranging them in nested, recursive forms, such as this very sentence. Yet as with self-awareness, the emphasis on human language as exceptional has obscured the richness of animal communication. Many animals recognize the faces of people who troubled them years before, and they may also inform another about them. This should not come as a surprise. Group life requires remembering identities, assessing abilities and intentions, and making judgments based on past experience.

And then there’s the tangled topic of emotions—the positive or negative valences that shape all behavior but are most clearly related to others. Many researchers still regard animal emotions as baser than our own. Yet that assumption, too, has been shaken. Researchers use rats to study the neurobiological foundations of empathy—the ability to feel another’s feelings—and veterinary scientists recognize the suffering caused by separating dairy calves from their mothers. When an orca mother off the coast of Washington carried her dead baby’s body for weeks, as dolphins are known to do, many observers considered the most likely explanation to be grief. Animal communities are not just social and emotional. They’re also political. Many animals live in groups that make decisions collectively, even democratically.

(9) African wild dogs, for example, appear to indicate their “vote” by sneezing, with packs moving only after a quorum of members—three if movement is initiated by a dominant pack member, ten if a lower-ranking dog takes the initiative—has argued. (10) Some questions remain about whether the sneezes are actually votes. Or do they simply happen to correlate with preferences expressed in some other, as-yet-unknown way, such as body posture? Nevertheless, it is evident that packs have mechanisms of participatory group decision-making.

Their relations might not be governed by human-style morality, another ostensibly defining human trait, with its abstractions and codifications—yet our morality may be grounded in biologically widespread predispositions. To watch two dogs playing is to observe a choreography of fairness and sharing. (11) Some creatures, such as the humbleback whales who defend seals from orca attacks, may well be motivated by explicit morality. (12)

All this research suggests that human intelligence is not a pinnacle of evolution but embodies one point in a radiation. Some scientists do worry that over-aggregation of commonalities will obscure experiences outside our own (what does it feel like to be a cuttlefish whose language ripples across his skin?), but the overall effect is a much-needed correction.

Does this mean that humans are not at all unique? It does not. Our technologically mediated hyperconnectivity and our collectively conceived fictions are certainly exceptional. (13) Yet it’s hard to enter into such claims without interrogating the underlying impulse to set ourselves apart, to set ourselves above. It’s this very sense of Homo sapiens being intrinsically more worthy than other animals, whose lives and interests can’t possibly be so important as our own, that’s pushed Earth to the brink of another mass extinction. (14) The very premise of human uniqueness begins to feel like a self-serving fetish. What if that which “makes us human” were instead conceived as what’s important to us—as such affection, or health, or the ability to make choices?

We might recognize that, rather than separating us, “humanity” is something we share with many other creatures—and consider what it means to live that way.
Humanity will be remembered for its chickens

University of Leicester researchers were curious about how our global appetite for chicken (there are over 22 billion of them with us at any given time) is shaping the planet and what clues the mounds of chicken bones might leave behind for future archaeologists.

The birds were domesticated from the wild red jungle fowl as far back as the sixteenth century. But in the 1950s, real changes began. Since 1957, chickens have grown up to five times heavier than their ancestors of 60 years ago. An analysis of isotopes in chicken bones also revealed that from mid-century onward, chickens were fed a diet that made them produce more meat—clear evidence of humanity’s ability to manipulate a species at a grand scale. Today, the production of feed for these ubiquitous birds produces more polluting nitrogen than the amount used to grow staple crops such as rice and wheat, the researchers found. And in Europe, for instance, it’s estimated that farming broiler chickens uses up more electricity and natural gas than the production of either beef or pork.

“Future foods could make diets more nutritious and sustainable.”

According to a new study, eating an array of rapidly emerging, alternative future food—including lab-grown meat, seaweed, and insect protein—would not only do more to protect the planet, but would actually provide us with more and better nutrients than would switching to an exclusively plant-based diet.

Researchers measured the nutritional and environmental profiles of nine future food products and found that all, with the exception of kelp, produced the same or more protein than either animal-based foods or plant-based diets. Most also provided more of several crucial nutrients such as vitamin B₁₂, zinc, and vitamin A. Some types of algae had 20 times more vitamin A than eggs, which is the richest animal-derived source of this nutrient. Compared to this, plant-only diets tended to be deficient in nutrients such as vitamin B₁₂ and omega fatty acids, among other things.

Future foods also scored high on environmental savings, requiring roughly the same amount (or less) land than do plant-based diets—and signifi-

Tweaking photosynthesis

Photosynthesis occurs inside plants with the help of an enzyme called RuBisCO, which latches onto molecules of carbon dioxide to convert them into energy-rich sugars for growth. But about a fifth of the time, RuBisCO grabs onto molecules of oxygen instead.

This presents a major lost opportunity for photosynthesis. That’s because oxygen molecules inside plants go on to create waste products such as glycolate and ammonia. These have to be recycled through photorespiration, a process that “costs the plant
precious energy and resources that it could have invested in photosynthesis to produce more growth and yield.* researchers explain. In some crops, photorespiration is estimated to cause a 50 percent loss in photosynthetic efficiency.

But now researchers have engineered tobacco plants—useful research subjects because they’re easy to genetically modify—to contain a much shorter photorespiration pathway with fewer steps. This saves on energy and, crucially, increases the efficiency of photosynthesis, therefore boosting plant growth. In tests that ran for two years, researchers showed that tobacco plants grown both in the laboratory and under real-world farming conditions consistently grew faster, taller, and with more biomass than their non-engineered counterparts.

In hot, dry regions of the world, this discovery would be especially valuable. Under high heat, RuBisCO struggles even more to differentiate between carbon dioxide and oxygen, leading to even more inefficient photosynthesis. The researchers are careful to caution that their discovery isn’t a quick fix. It will take several years to engineer crops with these energy-saving traits and to ensure that they are safe to eat. But with the rising twin challenges of increasing food production while doing so on less land to conserve biodiversity, the researchers believe this could be one powerful way of producing food more efficiently and sustainably. **—Emma Bryce**

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**Humanity’s changing body shape**

<table>
<thead>
<tr>
<th>Year</th>
<th>Height</th>
<th>Weight</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>161 cm</td>
<td>56.7 kg</td>
<td>39.7 years old</td>
</tr>
<tr>
<td>2014</td>
<td>163.1 cm</td>
<td>64.7 kg</td>
<td>42.2 years old</td>
</tr>
</tbody>
</table>

**It’s not enough to** consider the planetary impact of a numerically growing population. Increases in humanity’s height and weight are directly correlated with increases in the amount of food we consume—and thus global food security. Between 1975 and 2014, human mass across the planet increased by 146 percent. On average, individual humans grew 14 percent heavier and 1.3 percent taller. When researchers isolated the impact of these physical traits, they found that this accounted for a striking 15 percent of the surge in food demand since 1975. This was offset slightly by a globally aging population (older people tend to consume less food), but only by 2 percent. So ultimately, 13 percent of the increase in food demand over the past four decades is attributable solely to humanity’s increasing height and weight. **—Emma Bryce**

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**Life-Cycle Analysis**

**If you were looking for** a straight-up, yes-or-no answer to the title question, go ahead and turn the page now. Like so many life-cycle assessments, it’s never that simple. The environmental impact of plastic-bag bans is a good news–bad news story.

**First, the Good News**

Cities that have banned consumer plastic bags have seen a decrease in the number of bags found in nature. Abandoned bags are not only an eyesore, they are also detrimental to birds, fish, and other fauna as the bags make their way from cities to oceans—and we definitely don’t need to add to the Great Pacific Garbage Patch.
Now the Bad News

Despite the local clean-up factor, the environmental benefits of banning plastic bags remain to be seen. A recent life-cycle study from CIRAIG looked at the consequences of banning conventional, single-use, consumer plastic bags (made of high-density polyethylene) from the city of Montreal. The results challenged the conventional understanding of banning these bags.

A key question is what type of bag buyers and sellers use to replace the banned ones. The CIRAIG study looked at the environmental impacts of seven alternatives:

• Single-use bags
• Oxo-biodegradable bags
• Compostable bioplastic bags
• Low-density polyethylene bags
• Paper bags
• Reusable bags
• Woven polypropylene bags
• Unwoven polypropylene bags
• Cotton bags

Results showed that all replacement bags had higher indicator scores for impacts on human health, ecosystem quality, and fossil-fuel depletion. Therefore, by definition, only reusable bags have the potential to be an advantageous switch from single-use consumer plastic bags—and that potential is realized only by reusing the bags many times: as frequently as 9,400 times for cotton bags or a more reasonable 102 times for unwoven polypropylene bags.

The Unintended Consequences

It turns out that those much-maligned conventional plastic bags have very high reuse rates (as much as 77.7 percent), mostly as garbage-bin liners. When they are banned, people buy more conventional, polyethylene garbage bags. And there’s the kicker. While it was already difficult for reusable bags to be advantageous over the banned plastic bags, in this scenario, even if you reuse your reusable bags an infinite number of times, the impacts of using more garbage bags drown out the advantageous environmental effects.

—Pierre-Olivier Roy

The human health indicator considers effects such as climate change, human toxicity, respiratory effects due to the inhalation of particles, smog formation, water scarcity, ozone layer depletion, and others. The ecosystem quality indicator theoretically represents the number of species that disappear within a specified area over a year due to different effects such as climate change; land occupation and transformation; ecotoxicity; eutrophication; acidification of terrestrial, aquatic, and marine environments; water scarcity; and others. The fossil fuel depletion indicator represents the quantity of fossil fuels (crude oil, natural gas, coal) that were extracted in order to fulfill life-cycle material and energy requirements of a product, process, or service.

How many times would you have to use each bag to equal the fossil-fuel footprint of a single conventional plastic bag?

<table>
<thead>
<tr>
<th>Bag Type</th>
<th>Human Health</th>
<th>Ecosystem Quality</th>
<th>Fossil Fuel Depletion</th>
<th>Abandonment in the Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Plastics</td>
<td>32</td>
<td>195</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Oxo-biodegradable</td>
<td>19</td>
<td>164</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Bioplastics</td>
<td>16</td>
<td>148</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Thick Plastics</td>
<td>5</td>
<td>141</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Paper</td>
<td>5</td>
<td>139</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Woven polypropylene</td>
<td>4</td>
<td>137</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Unwoven polypropylene</td>
<td>3</td>
<td>135</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Cotton</td>
<td>2</td>
<td>133</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Why? The conventional plastic bag was designed for a single use—it is thin and light, and its life cycle requires little material and energy. Moreover, its reuse as a garbage bag at the end of its life significantly reduces its potential impacts in comparison to the other types of bag, whose material and energy requirements are much higher.
Eco-bricks made from sewage

The third little pig’s house, made of bricks, saved him from the wolf—but not global warming. Manufacturing bricks is carbon-intensive and creates toxic air pollution. So engineers at RMIT University in Australia have developed bricks made partly with treated sewage waste. To make traditional bricks, a mix of clay and concrete materials is heated at temperatures between 900 and 1,200 degrees Celsius. This requires a lot of fuel. In South Asian countries, where brickmakers burn coal, biomass, and trash, brick kilns have a global-warming impact equivalent to that of all passenger cars in the US. About eight percent of global carbon emissions comes from brick manufacturing, according to some estimates.

The researchers collected three different biosolid waste samples from two treatment plants and used them to make bricks containing 10, 15, 20, and 25 percent biowaste. They report that bricks containing 25 percent sewage solids required about half the energy to manufacture as regular bricks.

The biobricks could also reduce the need for massive excavation. More than 3 billion cubic meters of clay soil are dug up around the world every year to produce about 1.5 trillion bricks. That is “equivalent to over 1,000 soccer fields dug 440 meters deep or to a depth greater than three times the height of the Sydney Harbour Bridge,” the researchers write. Plus, 43 to 99 percent of heavy metals present in the biosolids remained trapped in the bricks, keeping them from leaching into the environment, the researchers found.

The bricks passed compressive-strength tests and were more porous than their conventional cousins, which made them more insulating. As an added bonus they were also cheaper to produce.

Further tests are needed before biobricks are produced on a larger scale because sewage waste in different parts of the world can have different compositions and chemical traits. But based on their study results, the researchers propose that including a minimum of 15 percent biosolids content into 15 percent of brick production could “completely recycle all the approximately 5 million tonnes of annual leftover biosolids production in Australia, New Zealand, the EU, the US, and Canada.”

—Prachi Patel

Old clothes turn into fire- and waterproof building materials

In today’s age of fast fashion, most clothes are thrown out after a few seasons, and most garments, including those that are donated, end up in landfills. The textile industry is the second-most polluting sector in the world, accounting for 10 percent of the world’s total carbon emissions. And synthetic fabrics are one of the biggest sources of plastic pollution in the oceans. No effective recycling technologies for cotton fabrics or blends exist yet. So Veena Sahajwalla and her colleagues at the University of New South Wales in Australia came up with a different use for old textiles. They collected clothing from municipal and textile-industry waste streams and removed zippers and buttons. Next they passed the leftover mix of cotton, wool, polyester, nylon, and other fabrics through a shredder and added a chemical to the resulting fluff to help the different fibers


stick together. Finally, they compressed the fibers under heat to form solid panels. The panels are moisture-resistant and as strong as wood-based particleboards so that they can be used for load-bearing applications. Panels made with added fine sawdust are flame-retardant. Plus, depending on their components, they have different textures and colors resembling wood, ceramic, or stone—so they can be used for various interior finishes such as floor tiles, wall panels, or ceilings. —Prachi Patel

How a seaweed-eating microbe could fight plastic pollution

Scientists at Tel Aviv University report that certain salt-loving microorganisms could eat seaweed and produce biodegradable plastics in a sustainable fashion.

Commercially available bioplastics are made of a fully degradable polymer called polyhydroxyalkanoate (PHA) that is naturally produced by bacteria or other microorganisms by fermenting sugars or fats. The microbes are usually fed vegetable oil or pure carbon sources such as glucose, which is derived from corn or sugar cane.

The Israeli team used single-celled microbes called Haloferax mediterranei instead. These have been shown to produce PHA in salty water; however, researchers have previously cultivated the microbes on traditional biomass sources. As an alternative, the Israeli team fed seven different species of seaweed to the microbes. The microbes produced the most PHA when fed Ulva lactuca, also known as sea lettuce, the researchers found. The results could lead to a sustainable and environmentally friendly method to produce bioplastics and bioenergy from offshore-grown biomass, the researchers write. —Prachi Patel

A new and inexpensive way to convert CO₂ into drugs, furniture, and more

Researchers have developed a form of artificial photosynthesis that converts carbon dioxide into plastics, fabrics, and other useful products more efficiently and cheaply than ever before.

To date, scientists have had some success mimicking photosynthesis to produce fuels such as ethanol, methane, and hydrogen at relatively high yields. But the processes have been too inefficient, energy-intensive, and expensive to be feasible on a commercial scale—mainly due to the catalyst that is needed to trigger the chemical reactions.

So a team from Rutgers University came up with a group of five different catalysts that are made with abundant, low-cost nickel and phosphorus. These catalysts turn carbon dioxide and water into chemical compounds containing one, two, three, or four carbon atoms with more than 99 percent efficiency. The process is highly energy-efficient and does not require much electricity. The number of carbon atoms in the end product depends on the catalyst used and the reaction conditions. The longer carbon chains are more valuable and could serve as the building blocks of plastics. Two of the products they have produced could be used as precursors for plastics, adhesives, and pharmaceuticals, the researchers say, and one of them can be a safer substitute for toxic formaldehyde.

The researchers now have patents on the process and have founded a start-up company to commercialize the technology. They plan to tweak the chemical reactions to create other products such as hydrocarbons and are working on scaling up the technology to produce larger quantities of end products. —Prachi Patel


make the best of a tragic situation. We might even find something to treasure. Several years ago, James Bell, an ecologist at New Zealand’s Victoria University of Wellington, and colleagues suggested that post-coral reefs might not, as conventional wisdom held, become underwater barrens dominated by algae. Though that’s happened in some places, particularly the Caribbean, reefs elsewhere sometimes follow a different trajectory. Even as corals die, sponges proliferate. Coral reefs become sponge reefs. Though most people know sponges from their kitchen sinks, phylum Porifera in fact contains between 5,000 and 10,000 species. Like corals, they’re technically animals, descended from an ancient trunk of life’s evolutionary tree—and the fossil record suggests that, when Earth’s oceans warmed and acidified 200 million years ago, sponge reefs indeed replaced coral reefs.

Present-day warming is a far more rapid affair, but something similar has happened off the coast of Brazil and the Indonesian island of Sulawesi. Sponges are surprisingly resilient—thanks in part to lipids and fatty acids that counteract the effects of heat stress on cell walls.

In a second study, Bell’s team moves from physiology to interactions. Sponge reefs don’t support the abundance and richness of organisms that coral reefs do, but there’s still much life to be found in them, albeit only hazily understood. If not quite rainforests, they might at least be forests. For example, seaweed can thrive among sponges and slow down the erosion of dead corals on which sponges form. But eventually, decades or centuries hence, those skeletons will crumble. Sponges will continue to grow, but the structural complexity provided by corals, the nooks and crannies that are niches for yet more creatures, will vanish. What sort of life will those reefs support? And how much? These are open questions. **—Brandon Keim**

**As corals decline, a new kind of reef emerges**

*When coral reefs die, what will replace them? It’s a question that feels almost inappropriate. It risks resignation, even acceptance of habitat degradation and climate change— and, make no mistake, much can still be done to protect corals. But nothing can change the fact that many reefs have been destroyed; barring a miracle, many more will yet be lost. And confronting the aftermath may help people*

**What counts as extreme temperature is a moving target**

*With climate change, weather patterns that were unusual in the past (ahem, February heat waves in London) are becoming more common. But how exactly do people recognize unusual weather conditions? Scientists use various benchmarks (1850, the past 30 years, and so on) when quantifying climate change, but there’s been little research on how the general public develops a baseline sense of “normal” climate or how that sense changes over time.

The first large-scale study to tackle this problem suggests that the public’s climatic baseline tends to be a very recent one, reflecting weather experienced roughly two to eight years ago. Researchers analyzed 2.18 billion tweets posted from the continental United States by 12.8 million users from March 2014 through November 2016. They used software to analyze the content of the tweets, picking out the ones that commented on the weather. Then they cross-referenced the social media data with local temperature, precipitation, and cloud cover data—controlling for variables such as month, year, and location to identify how temperature fluctuations drive social media posts about the weather.

Not surprisingly, the coldest cold and the hottest hot temperatures garner the most social media chatter. But people in counties that have experienced unusual cold snaps or heat waves for several years running become less likely
to tweet about such temperature extremes. “Temperatures initially considered remarkable rapidly become unremarkable with repeated exposure over a roughly five-year timescale,” the researchers write.

In a warming world, what “counts” as cold weather is also a moving target. “Gradual warming makes all cold temperatures more remarkable, so that mild winter temperatures, which previously would be unremarkable, become noteworthy as people’s expectations shift over time,” says lead author Frances Moore, assistant professor of environmental science and policy at the University of California, Davis. That’s how in 2019, during one of the warmest Januarys on record, everyone wound up talking about how cold it was.

How bringing back lost animals prevents big wildfires

About 15,000 years ago, as Earth warmed and humans proliferated, a wave of extinctions occurred: sloths the size of moving trucks, giant kangaroos, mammoths, bison, and deer who dwarfed their modern counterparts. On and on the list goes, a menagerie of fantastic creatures now known only from the fossil record.

In that fossil record, scientists have also noticed something else fantastical—or at least unusual. Charcoal. Lots of it, a fine layer that accumulated across many landscapes after the big animals vanished. This may not have been a coincidence.

The absence of those animals appears to have made ecosystems more prone to fire—a possibility with implications both disturbing and hopeful. “Rewilding potentially offers a powerful tool for managing the risks of wildfire,” write researchers led by ecologist Chris Johnson.

Their paper is part of a series examining how rewinding—reintroducing animals, particularly big animals, to landscapes that once hosted them or their extinct relatives—can have profound environmental benefits. Adding lost animals might help ecosystems sequester more carbon, reduce the impact of invasive species, fertilize streamside forests, and even regulate unpredictable ecological responses to climate change.

That they might also fight fire is perhaps the most surprising possibility. Yet as Johnson and colleagues review, there are plenty of reasons to think animals could be helpful. Small fires consume woody debris; so do big plant-eaters, quite literally. Because their feeding patterns are varied rather than uniform, with some areas heavily grazed or browsed and others ignored, they produce patches of low- and high-flammability vegetation “interspersed in arrangements that could impede the spread of landscape fire,” write Johnson and colleagues. By digging through soil litter and turning it over, big plant-eaters can also bury material that would otherwise become fuel. Barren passages created by the heavy, ceaseless steps of migrating herds serve not only as trails but also as potential firebreaks.

Much does remain to be learned, and the use of animals to fight fire is sure to be complicated. In certain instances, browsers—animals who feed on tall growth such as shrubs and small trees—could promote the spread of grasses, in turn making fires more likely. “There is some evidence that elephants can sometimes have that sort of effect in Africa,” says Johnson.

There’s a role for predators, too, in preventing potentially troublesome over-populations—such as deer whose munching prevents saplings from maturing, which turns forests into fire-prone thickets. That’s a problem now in New Zealand, says Johnson, where vegetation didn’t evolve to withstand the pressure of deer introduced to the island from elsewhere. Yet that doesn’t mean nonnative animals are intrinsically fire-prone: in Australia, nonnative swamp buffalo seem to reduce fire intensity and may actually play wetlands-enhancing roles formerly performed by now-extinct species.

The dynamics vary from place to place. Historical evidence of animal-induced fire control is strongest in warm environments with moderate rainfall and grass-dominated vegetation. Extinctions didn’t seem to have much effect on fire patterns in shrublands and arid grasslands. Nevertheless, the possibilities are tantalizing. Researchers have described how grazing reduces fire frequencies in the Kansas tallgrass prairie, the Kenyan savannah, and tropical Australian forests.

—Brandon Keim

Johnson, CN et al. Philosophical Transactions of the Royal Society B. 2018
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waterfutureconference.org

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worldbiodiversityforum.org

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