SCIENTIFIC AMERICAN

SPECIAL REPORT

THE FUTURE OF MEDICINE

CLIMATE CHANGE AND A NEW ERA OF INFECTIOUS DISEASE

PAGE 42

HOW THE DINOSAURS GOT LUCKY

They were confined to a few corners of the world for millions of years—until they caught some breaks

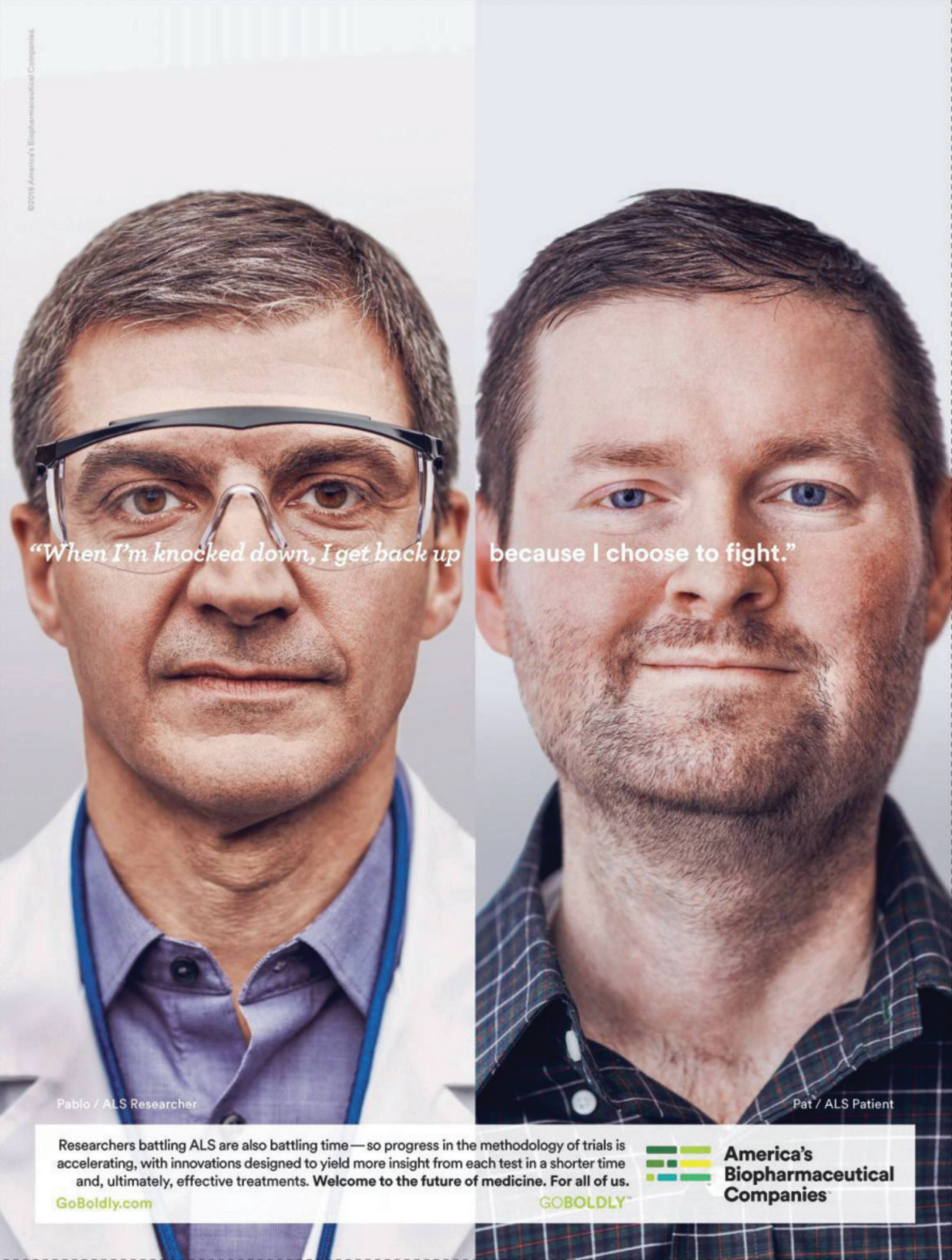
PLUS

DEEP-SEA MINING
Can we both exploit and protect the ocean floor? PAGE 72

MULTIMESSENGER ASTRONOMY
Light particles plus gravitational waves give a new view PAGE 36

OUR STUFF, OURSELVES
Why we get attached to possessions PAGE 66

MAY 2018
ScientificAmerican.com



Researchers battling ALS are also battling time — so progress in the methodology of trials is accelerating, with innovations designed to yield more insight from each test in a shorter time and, ultimately, effective treatments. **Welcome to the future of medicine. For all of us.**

GoBoldly.com

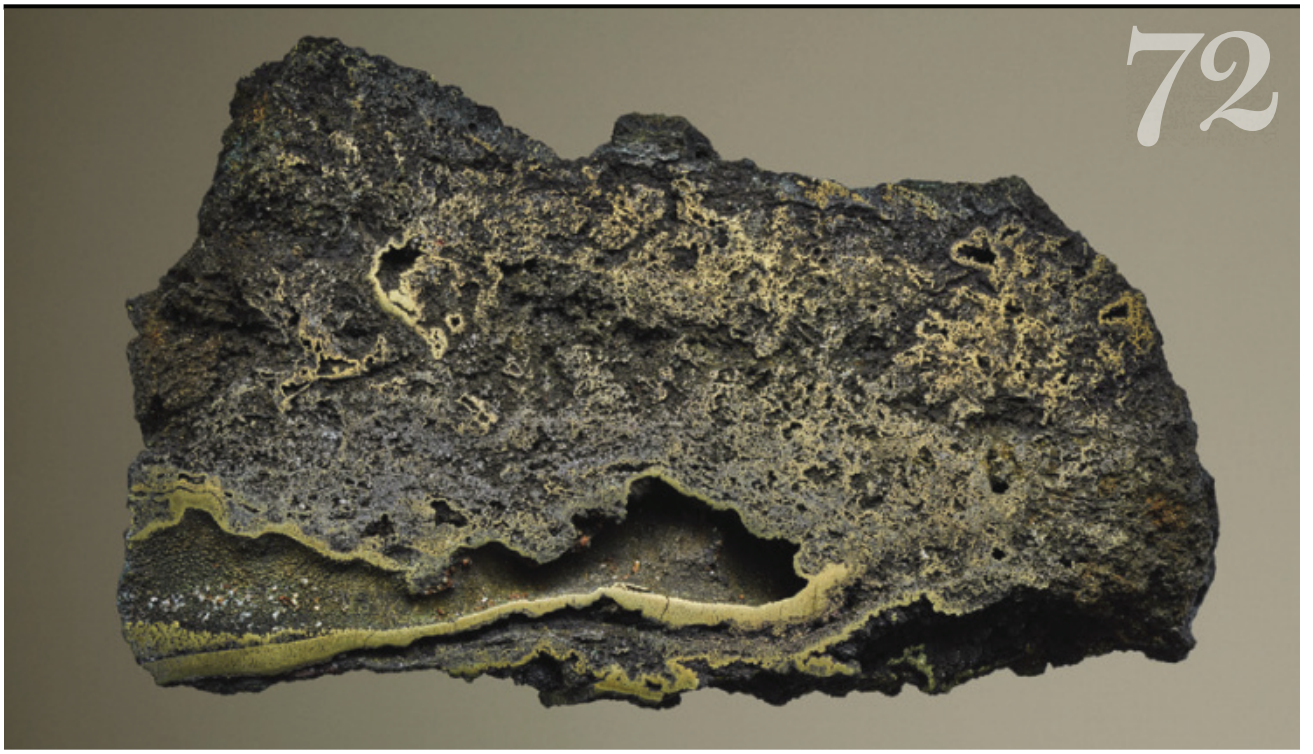
GOBOLDLY™

America's Biopharmaceutical Companies®

MAY 2018

VOLUME 318, NUMBER 5

SCIENTIFIC AMERICAN



ON THE COVER

Prorotodactylus, a protodinosaur that was about the size of a house cat, steps onto the world stage in this artist's conception. The animal is known from 250-million-year-old fossilized footprints found in the Holy Cross Mountains in Poland.
Illustration by James Gurney.

Photograph by Brett Stevens

SCIENTIFIC AMERICAN


14


78

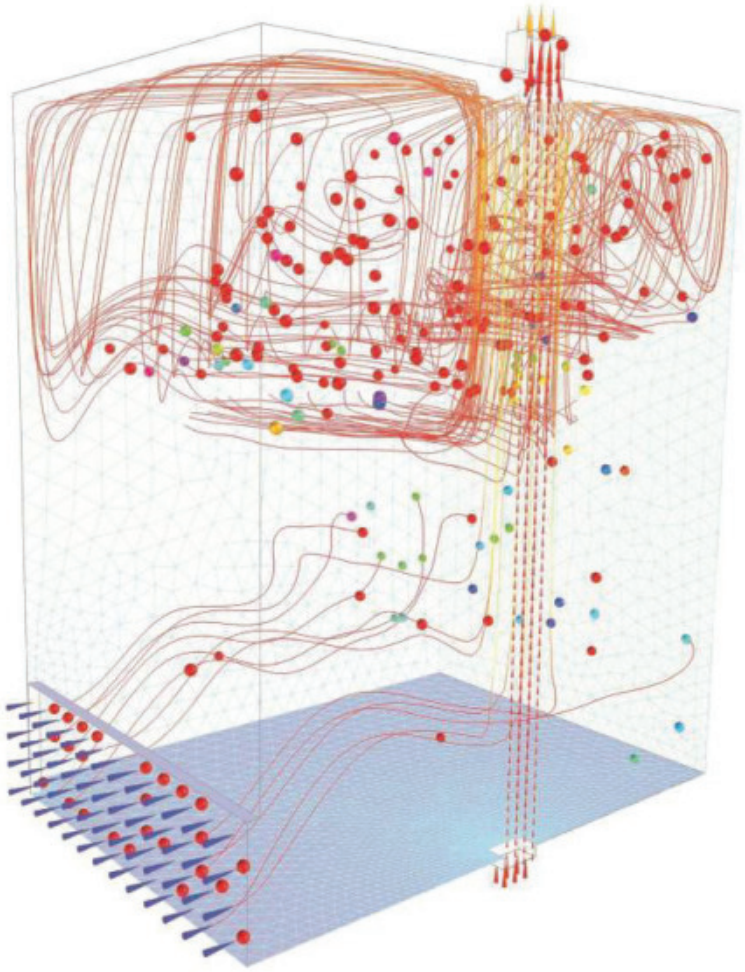

82

ON THE WEB

Earthquake Warnings
Scientific American explores how geologists track vibrations in the earth's crust to warn people seconds to minutes before tremors strike.
Go to www.ScientificAmerican.com/may2018/quakes

Scientific American (ISSN 0036-8733), Volume 318, Number 5, May 2018, published monthly by Scientific American, a division of Nature America, Inc., 1 New York Plaza, Suite 4500, New York, N.Y. 10004-1562. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; TVQ1218059275 TQ0001. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. **Individual Subscription rates:** 1 year $49.99 (USD), Canada $59.99 (USD), International $69.99 (USD). **Institutional Subscription rates:** Schools and Public Libraries: 1 year $84 (USD), Canada $89 (USD), International $96 (USD). Businesses and Colleges/Universities: 1 year $399 (USD), Canada $405 (USD), International $411 (USD). Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints available:** write Reprint Department, Scientific American, 1 New York Plaza, Suite 4500, New York, N.Y. 10004-1562; fax: 646-563-7138; reprints@SciAm.com. **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 248-7684. Send e-mail to scacustserv@cdsfulfillment.com.** Printed in U.S.A.

Prevent epidemic outbreaks with mathematical modeling and simulation.



Visualization of the motion of bacteria particles in a room with a displacement ventilation system.

Using math to analyze the spread of epidemic diseases is not a new concept. One of the first compartmental models of mathematical epidemiology dates back to 1760 and was presented by Daniel Bernoulli for studying the mortality rate of smallpox. Today, medical researchers and public health officials continue to use mathematical modeling and simulation to prevent and control epidemic outbreaks in the modern world.

The COMSOL Multiphysics® software is used for simulating designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. See how you can apply it to analyzing the spread of epidemic diseases.

comsol.blog/epidemiology-simulation

COMSOL

Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina

Our Planet, Ourselves

Mosquitoes—and the viruses that they carry—are pushing up the incidence of malaria globally and causing periodic explosive outbreaks of Rift Valley fever, which first brings on flulike symptoms but can turn into a severe hemorrhagic fever akin to Ebola. Bluetongue virus, a ruminant virus spread by midges that was once confined to tropical areas, has reached as far as Norway. Studies have shown shifts in cholera transmission with recent climate variability. As emerging diseases migrate to new areas, they encounter new species, making outbreaks even more difficult to manage.

Unfortunately, writes journalist Lois Parshley in her feature article "Catching Fever," the common enabler for the movement of each of these ailments is human-caused climate change. As weather patterns wreak more havoc, a Pandora's box of microbes enters new terrain, stressing global public health systems.

Parshley's article, starting on page 58, is part of an important special report on "The Future of Medicine." In the package, contributing editor Melinda Wenner Moyer describes the "American Epidemic" (*page 44*): a resurgence of infectious disease outbreaks that are sickening thousands. Before vaccines, better sanitation and indoor plumbing, the root causes of such waves of illness and death were mainly biological: viruses, bacteria and parasites. Now they are social as well: growing income inequality in the U.S. has led to rising rates of hepatitis A, Legionnaires' disease and other scourges. The problems are hardly confined to poor neighborhoods, although they may reemerge there. Once an outbreak occurs, it's not choosy about whom it infects. After a formidable flu season this year, associate editor Dina Fine Maron looks "Beyond the Flu Shot" (*page 55*).

Such alterations are happening whether we want to use the words "climate change" or not. Whether we acknowledge the scientific consensus, demonstrated in thousands of studies over decades, climate change is both real and promoted by human activities. Coastal communities are being affected by rising seas, drought-prone areas are arid for longer periods and, as our report shows, infectious agents are taking advantage of these more extreme weather patterns.

For more than 170 years *Scientific American* has ably chronicled how advances in science and technology have advanced discovery and shaped the world. But I think we all could do a better job communicating the value of an evidence-based view for addressing human problems. For this reason, I have agreed to join the Advisory Committee for the Climate Communications Initiative of the National Academies of Sciences, Engineering, and Medicine. You can learn more about it here: http://nas-sites.org/americasclimatechoices/cci. As always, I welcome your comments. SA

Illustration by Nick Higgins

January 2018

"Cryptocurrencies seem to approach some sort of computer game to be speculated on by the wealthy."

STANLEY HIRTLE *DAYTON, OHIO*

POLITICAL CURRENCY

In "Breaking the Bank" [The Future of Money], Alexander Lipton and Alex "Sandy" Pentland argue that a particular approach toward digital currency would make global financial systems more transparent, accountable and equitable. Their article and the others in this report somehow seemed to avoid the issues of the creation and distribution of real wealth: the production of goods and services that are valuable to people, of which currencies are only the medium of exchange.

Today much of corporate profit instead comes from finance. And cryptocurrencies seem to be detached from issues of real wealth and approach some sort of computer game to be speculated on by the wealthy. Currencies have the value that people give them, and when they are detached from the real economy, they encourage the kind of exploitation and corruption of those who are charged with preserving the integrity of the system that were front and center during the mortgage crisis.

It is hard to see why cryptocurrencies are going to make things more equal. What is needed is more social control of investment by all stakeholders and less imbalanced distribution of the proceeds.

STANLEY HIRTLE *Dayton, Ohio*

The authors clarify the workings of digital currency but make some distortions about the larger world. In describing the beginning of government-backed central banks in 17th-century Europe, they write that "the king typically repaid the loans [from merchants, in order to fight wars] with taxes imposed on profits." Such loans were also paid back by looting other nations when wars were won. The exploitation of a conquered country was, and still is, a source of income for imperialistic nations.

The article does mention the issue of the undesirable concentration of wealth but attributes it to "outdated paradigms," with the crash of 2008 described as caused by "not enough bureaucratic capacity to deal with the individual losses of tens of millions of citizens." Without strict regulations, I doubt that any financial system will stop the greed that is driving an increase in the wealth gap and global warming. And I think the focus on rescuing the financial industry alone in 2008 was linked to the enormous influence that it had on the Bush and Obama administrations. It will take laws prohibiting the revolving door between Wall Street and government administrative positions, a limit on executive bonuses and salaries, and an estate tax increase to fix this problem.

JULIAN WEISSGLASS *Emeritus professor, University of California, Santa Barbara*

CATCH AND DECREASE

In "The Messy Facts about Diet and Inflammation" [The Science of Health], Claudia Wallis reports yet another recommendation of the Mediterranean diet, which calls for plenty of fish. But this can only be a short-term solution. We are already taking unsustainable quantities of fish from the sea, and if people follow the advice to eat more, that will hasten the day when we have to cut down drastically because there are not enough fish left. This raises the question of whether physicians have a duty to consider only the immediate benefits to health when giving advice.

DUDLEY MILES *London*

TREASURE ISLANDS

In Michael Waldholz's "War against Ourselves," the immunosuppressant rapamycin is identified as an active component of the synthetic vaccine particles (SVPs) that are being developed to reduce immune system reactions to biologic drugs.

Rapamycin has a widening therapeutic role in inhibiting cellular proliferation, from suppressing tumors to preventing autoimmune rejections. But few may realize the origin of the drug, which was found in the 1970s in soil samples that had been extracted by scientists on Easter Island. ("Rapamycin" derives from Rapa Nui, the local name for the island.) In appreciating this discovery, let us consider how many other potentially beneficial medicines in remote natural environments may be challenged by climate change, land development and other threats.

ALAN L. KLEIN *Boca Raton, Fla.*

DENIAL IMBALANCE

In "For the Love of Science" [Skeptic], Michael Shermer first calls out conservatives for their rejection of evolution, global warming and stem cell research. He then demonstrates a classic false equivalence by criticizing liberals for their opposition to "GMOs, nuclear power, genetic engineering and evolutionary psychology."

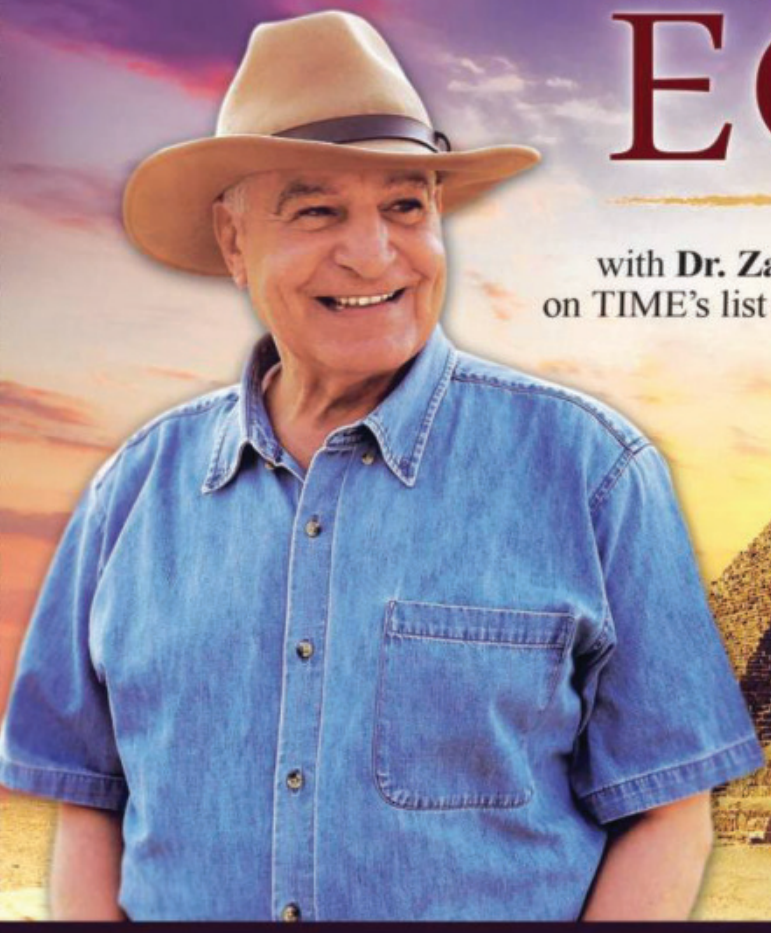
Many conservatives do deny that evolution and global warming exist, but liberals are not similarly nuclear power denialists. Anyone can see that fissioning uranium 235 or plutonium can be used to generate electricity. The problem with nuclear power is its potential for long-lasting negative effects. And safe storage of nuclear waste involves preparing for contingencies 10,000 years in the future.

Likewise, no one believes that ingesting foods containing genetically modified DNA is lethal, but there are concerns about, for instance, herbicide-resistant crops spawning herbicide-resistant weeds. To say that GMOs are completely harmless is to overlook the law of unintended consequences. Finally, I'm not sure that opposition to genetic engineering is a liberal stance.

ALBERT CINELLI *Sacramento, Calif.*

THE ROYAL TOUR TO EGYPT

with **Dr. Zahi Hawass**, the legendary archaeologist
on TIME's list of 100 Most Influential People in the world



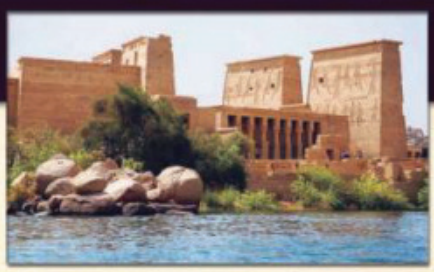
MULTIPLE TOUR DATES IN 2018 & 2019

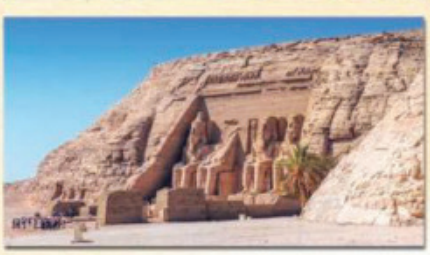
This is the most exciting tour to Egypt ever offered. Visit the Land of the Pharaohs with the most famous archaeologist in the world – Dr. Zahi Hawass, one of the TIME's 100 Most Influential People in 2006. For over 20 years he held all the keys to the Egyptian antiquities - first as a Secretary General of the Supreme Council of Antiquities, later as a Minister of State of Antiquities.

Explore the wonders of the ancient Egyptian civilization, including enormous Karnak and Abu Simbel temples, tombs in the Valley of the Kings and much more! You will stay in a 5-star hotel in the shadow of the pyramids and sail on a luxury cruise ship.

The Royal Tour offers private entrances to the entire Giza pyramid complex and the Luxor temple outside of opening hours. Only with us will you get an exclusive access between the paws of the Great Sphinx, the place closed to the public! Thanks to the special permission from the Minister of Antiquities, you will see the Tombs of the Pyramid Builders in Giza, the active excavation site.

Zahi Hawass: *No one can tour Egypt like this. Except for you - when you come and join me. I will tell you about the discoveries that I made in the last 20 years. You will visit many unique sites that very few people can see. You will be treated like royalty, this is why we call it the Royal Tour.*





For more information visit:
www.archaeologicalpaths.com

ARCHAEOLOGICAL PATHS

contact@archaeologicalpaths.com
US phone: 917-719-1974

SHERMER REPLIES: Science denial comes in many forms, but the underlying cause is group identity, in which scientific facts are autocorrected into ideologically charged claims that threaten tribal membership. When conservatives confront statements about climate change or gun control, for example, they hear big government intrusion into free markets and a slippery slope toward the abolishment of the Second Amendment, if not the entire U.S. Constitution. When liberals encounter statements about GMOs or genetic engineering, they hear corporate greed or Nazi eugenics. The motivating force behind the response is virtue signaling to one's ideological tribe. Scientific facts do not speak for themselves, so we must decouple them from such tribal identities.

CUT BACKSLIDE

"War on Science Agencies," by Andrew A. Rosenberg and Kathleen Rest [Forum], made good points regarding the debasement and politicization of science by the current presidential administration. But three major harmful effects were omitted.

The first is economic. Vibrant scientific research is a source of important discoveries that have enormous economic value. The second area is national security. It takes little imagination to recognize the wide applicability of scientific discoveries in maintaining the nation's defense. The third is U.S. global leadership. What happens to the nation's standing globally if it is reduced to a second-class scientific power?

James Heckman *Halifax, Pa.*

EDITORS' NOTE

Research projects can sometimes end—abruptly. Just after *Scientific American* published "Building a Backup Bee," by Paige Embry [March 2018], we learned the Wonderful Company decided to close the eight-year-long research project that the story describes. The goal was to develop a backup bee for the struggling honeybee. We think the science in the story remains intriguing, and the idea of having another commercial pollinator remains important.

ERRATUM

"War against Ourselves," by Michael Waldholz, incorrectly referred to inflammatory bowel disease as "irritable bowel disease."

SCIENTIFIC AMERICAN®
ESTABLISHED 1845

EDITOR IN CHIEF AND SENIOR VICE PRESIDENT
Mariette DiChristina

DIGITAL CONTENT MANAGER **Curtis Brainard** COPY DIRECTOR **Maria-Christina Keller** CREATIVE DIRECTOR **Michael Mrak**

EDITORIAL

CHIEF FEATURES EDITOR **Seth Fletcher** CHIEF NEWS EDITOR **Dean Visser** CHIEF OPINION EDITOR **Michael D. Lemonick**

FEATURES

SENIOR EDITOR, SUSTAINABILITY **Mark Fischetti**
SENIOR EDITOR, CHEMISTRY / POLICY / BIOLOGY **Josh Fischman**
SENIOR EDITOR, SPACE / PHYSICS **Clara Moskowitz**
SENIOR EDITOR, LIFE SCIENCES **Madhusree Mukerjee**
SENIOR EDITOR, TECHNOLOGY / MIND **Jen Schwartz**
SENIOR EDITOR, EVOLUTION / ECOLOGY **Kate Wong**

NEWS

SENIOR EDITOR, MIND / BRAIN **Gary Stix**
ASSOCIATE EDITOR, SPACE / PHYSICS **Lee Billings**
ASSOCIATE EDITOR, TECHNOLOGY **Larry Greenemeier**
ASSOCIATE EDITOR, BIOLOGY / MEDICINE **Dina Fine Maron**
ASSOCIATE EDITOR, SUSTAINABILITY **Andrea Thompson**
ASSISTANT EDITOR, NEWS **Tanya Lewis**

DIGITAL CONTENT

MANAGING MULTIMEDIA EDITOR **Eliene Augenbraun**
SENIOR EDITOR, MULTIMEDIA **Steve Mirsky**
ENGAGEMENT EDITOR **Sunya Bhutta**
COLLECTIONS EDITOR **Andrea Gawrylewski**

ART

ART DIRECTOR **Jason Mischka** SENIOR GRAPHICS EDITOR **Jen Christiansen** PHOTOGRAPHY EDITOR **Monica Bradley** ART DIRECTOR, ONLINE **Ryan Reid**
ASSISTANT PHOTO EDITOR **Liz Tormes** ASSISTANT GRAPHICS EDITOR **Amanda Montañez**

COPY AND PRODUCTION

SENIOR COPY EDITORS **Michael Battaglia, Daniel C. Schlenoff** COPY EDITOR **Aaron Shattuck**
MANAGING PRODUCTION EDITOR **Richard Hunt** PREPRESS AND QUALITY MANAGER **Silvia De Santis**

DIGITAL

SENIOR MANAGER, E-COMMERCE AND PRODUCT DEVELOPMENT **Angela Cesaro** TECHNICAL LEAD **Nicholas Sollecito**
SENIOR WEB PRODUCER **Ian Kelly** WEB PRODUCER **Jessica Ramirez**

CONTRIBUTORS

EDITORIAL **David Biello, W. Wayt Gibbs, Ferris Jabr, Anna Kuchment, Robin Lloyd, Melinda Wenner Moyer, George Musser, Christie Nicholson, John Rennie, Ricki L. Rusting**
ART **Edward Bell, Bryan Christie, Lawrence R. Gendron, Nick Higgins**

EDITORIAL ADMINISTRATOR **Ericka Skirpan** SENIOR SECRETARY **Maya Harty**

PRESIDENT
Dean Sanderson

EXECUTIVE VICE PRESIDENT **Michael Florek** EXECUTIVE VICE PRESIDENT, GLOBAL ADVERTISING AND SPONSORSHIP **Jack Laschever**
PUBLISHER AND VICE PRESIDENT **Jeremy A. Abbate**

MARKETING AND BUSINESS DEVELOPMENT

HEAD, MARKETING AND PRODUCT MANAGEMENT **Richard Zinken**
MARKETING DIRECTOR, INSTITUTIONAL PARTNERSHIPS AND CUSTOMER DEVELOPMENT **Jessica Cole**
ONLINE MARKETING PRODUCT MANAGER **Zoya Lysak**

INTEGRATED MEDIA SALES

DIRECTOR, INTEGRATED MEDIA **Jay Berfas** DIRECTOR, INTEGRATED MEDIA **Matt Bondlow**
DIRECTOR, GLOBAL MEDIA ALLIANCES **Ted Macauley**
SENIOR ADMINISTRATOR, EXECUTIVE SERVICES **May Jung**

CONSUMER MARKETING

DIGITAL MARKETING MANAGER **Marie Cummings**
E-MAIL MARKETING MANAGER **Chris Monello**
MARKETING AND CUSTOMER SERVICE COORDINATOR **Christine Kaelin**

ANCILLARY PRODUCTS

ASSOCIATE VICE PRESIDENT, BUSINESS DEVELOPMENT **Diane McGarvey**
CUSTOM PUBLISHING EDITOR **Lisa Pallatroni**
RIGHTS AND PERMISSIONS MANAGER **Felicia Ruocco**

CORPORATE

HEAD, COMMUNICATIONS, USA **Rachel Scheer**
COMMUNICATIONS MANAGER **Lauren Kuhn**

PRINT PRODUCTION

ADVERTISING PRODUCTION CONTROLLER **Carl Cherebin** PRODUCTION CONTROLLER **Madelyn Keyes-Milch**

LETTERS TO THE EDITOR

Scientific American, 1 New York Plaza, Suite 4500, New York, NY 10004-1562 or editors@sciam.com
Letters may be edited for length and clarity. We regret that we cannot answer each one.
Join the conversation online—visit *Scientific American* on Facebook and Twitter.

HOW TO CONTACT US

Subscriptions
For new subscriptions, renewals, gifts, payments, and changes of address: U.S. and Canada, 800-333-1199; outside North America, 515-248-7684 or www.ScientificAmerican.com

Submissions
To submit article proposals, follow the guidelines at www.ScientificAmerican.com. Click on "Contact Us." We cannot return and are not responsible for materials delivered to our office.

Reprints
To order bulk reprints of articles (minimum of 1,000 copies): Reprint Department, Scientific American, 1 New York Plaza, Suite 4500, New York, NY 10004-1562; 212-451-8877; reprints@SciAm.com. For single copies of back issues: 800-333-1199.

Permissions
For permission to copy or reuse material: Permissions Department, Scientific American, 1 New York Plaza, Suite 4500, New York, NY 10004-1562; randp@SciAm.com; www.ScientificAmerican.com/permissions. Please allow three to six weeks for processing.

Advertising
www.ScientificAmerican.com has electronic contact information for sales representatives of Scientific American in all regions of the U.S. and in other countries.

IT'S ELECTRIC. IT'S GAS. IT'S BOTH WITH SUPER ALL-WHEEL CONTROL.

Introducing the all-new 2018 Mitsubishi Outlander PHEV. The only plug-in hybrid electric vehicle crossover with Super All-Wheel Control, for superior handling and response in all road conditions.

THE WORLD'S BEST-SELLING PLUG-IN HYBRID CROSSOVER* STARTING AT $34,595.**

Visit **MITSUBISHICARS.COM** to see how much you can save.

*JATO Dynamics global PHEV sales (September 2017). **Manufacturer's Suggested Retail Price (MSRP) for 2018 Outlander PHEV SEL model. GT model with accessories shown MSRP is $40,665. Excludes destination/handling, tax, title, license, etc. Retailer price, terms and vehicle availability may vary. See your Mitsubishi retailer for details.

MITSUBISHI MOTORS
Drive your Ambition

End the War on Weed

Federal marijuana laws are counterproductive and overly harsh

By the Editors

Cannabis—marijuana—is the world's most commonly used illicit drug. Polls suggest that one in eight U.S. adults smoke it, and more than 40 percent of them have tried the drug at some point in their lifetime. A majority of states allow some form of medical marijuana use, and nine states and Washington, D.C., have now legalized recreational use. Although the substance is illegal under U.S. federal law, in 2013 the Justice Department under President Barack Obama guided U.S. attorneys away from prosecuting personal marijuana use in states where it is legal. But in January, Attorney General Jeff Sessions reversed those guidelines, giving U.S. attorneys renewed authority to press criminal charges.

Like the failed Nixon-era War on Drugs, this resurgent war on marijuana is ill informed and misguided. Evidence suggests that cannabis—though not without its risks—is less harmful than legal substances such as alcohol and nicotine. And despite similar marijuana use among blacks and whites, a disproportionate number of blacks are arrested for it. By allowing states to regulate marijuana without federal interference, we can ensure better safety and control while allowing for greater research into its possible harms and benefits.

In 1970 the Controlled Substances Act established marijuana as a Schedule I drug, "with no currently accepted medical use and a high potential for abuse." This is the same category that includes heroin and MDMA (ecstasy). Yet marijuana is far less dangerous than many other drugs, and cannabis or its derivatives have been used to treat everything from chronic pain to post-traumatic stress disorder to childhood epilepsy. A 2015 study that compared the toxicological threshold of marijuana for risk to human health with that of other drugs found that alcohol posed the highest risk, followed by heroin, cocaine and nicotine. Marijuana was among the lowest. In addition, there is some evidence that pot may serve as a safe alternative to other drugs of abuse, including heroin and other opioids.

That does not mean that marijuana is entirely benign. Studies suggest it can impair driving, and a subset of users develops a form of dependence called marijuana use disorder. Other research indicates that teenage marijuana use may adversely impact the developing brain: it has been linked to changes in neural structure and function, including lower IQ, as well as an increased risk of psychosis in vulnerable individuals. But some of these findings have been challenged. A pair of longitudinal twin studies, for example, found no significant link between marijuana use and IQ. Moreover, people with these brain characteristics may simply be more likely to use marijuana in the first place.

We are not advocating for unfettered access to marijuana, especially by adolescents. More large-scale, randomized controlled studies are needed to tease out the risks and benefits. But to do these kinds of studies, scientists must have access to the drug, and until very recently, the federal government has had a monopoly on growing cannabis for research purposes. We also need more research on the various, often more potent, marijuana strains grown for recreational use. As long as the federal government continues to crack down on state-level legal marijuana, it will be difficult to carry out such studies.

Even those who oppose cannabis use should reconsider the efficacy of criminalizing it. One of the most compelling cases for easing restrictions comes from Portugal, which decriminalized all drugs in 2001. Drug usage has remained the same or decreased as a result, and drug-related deaths and sexually transmitted diseases have dropped significantly. Portugal's experience may not translate directly to the U.S., but its success is worth noting. A 2014 study found that medical marijuana legalization in the U.S. has not increased crime and may actually be linked to lower assault and homicide rates. Even a limited version of federal reform, such as downgrading cannabis to a Schedule II or III drug—categories considered less harmful—could prove beneficial.

It is time to stop treating marijuana like a deadly drug, when science and public opinion agree that it is relatively safe for adult recreational use. The last thing we need is another expensive and ineffective war on a substance like cannabis—especially when there are far more serious drug problems to tackle. SA

JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

Illustration by Tangmo Cecchini

The Suns in Our Daughters

Unleashing the energy trapped within undereducated girls

By Lisa Einstein

The question on the physics quiz seemed simple enough: "What is the smallest piece of matter that makes up everything in the universe?"

Binta's response: "Binta."

I laughed out loud. You would too if you saw tiny Binta, who is one of my smartest seventh graders. Surely she knew the correct answer is "atom." Yet, I mused, a famous equation governing atoms could also apply to her.

$E = mc^2$. The equation says that under the right conditions, mass can become energy, and vice versa. Because light moves so fast, an atom at rest—even with a small mass—contains a great deal of energy. A walnut has enough energy locked in it to power a small city. Mass from the sun radiates as light that warms the earth from 93 million miles away. Tiny masses hide astronomical energy. One look at Binta's effulgent smile proves that.

Reflecting on Binta's lesson as I walk home through the village, I am almost knocked over by Aissatou's exuberant tackle-hug. A magical six-year-old with a spirit too big to fit her child's body, Aissatou is further evidence of the small but powerful. A year into my Peace Corps service in Guinea, my young neighbor has become my local language teacher, running partner, closest friend and inspiration. I've watched her lead friends through dances she created, make bandages from spare fabric for her injured four-year-old sister and fashion a rope extension so our bucket can reach the bottom of our dried-up well. Aissatou is a designer: she builds, plays and imagines. I observe her ingenuity with awe.

I see Aissatou the way my parents saw me: filled with unlimited potential. My parents called their four kids "their greatest collaboration" and helped us grow into our fullest selves. Knowing the challenges facing young women in physics, Dad went out of his way to fuel my passion. Once he drove me six hours to a lecture by a female physicist. His encouragement emboldened me to dive into a challenging field dominated by men.

Aissatou, on the other hand, has been taught that she should be dominated by men. When male visitors arrive at her house, the jubilant builder I know transforms into a meek and submissive servant, bowing as she acquiesces to their every request.

The difference? I won the lottery at birth: time, place and parents who gave me the chance to develop my passions. I am on a mission to give Aissatou and Binta the chance to do the same.

I think about the untapped potential of millions of girls like Aissatou and Binta, who lack opportunities because of custom, poverty, laws or terrorist threats. The gifted young women I've taught as a Peace Corps volunteer implementing the Let Girls Learn program have strengthened my conviction that it is possible for them to fulfill their promise through education. And educating girls is not only morally right but also provides a cornerstone of achieving a peaceful and prosperous future.

I wonder if Binta intended to leave me the clue to a brighter world in her quiz. After all, I reflected on moral metaphors in science when I was her age.

"What exciting thing did you learn today?" my Dad would ask.

"We should all be like ideal gases," I responded one day after an exciting physics class. "They expand to fill whatever containers they occupy, so we can make the most of every situation too."

He smiled knowingly. "You know, gases with enough energy can even break open their containers."

When I see Aissatou squeal joyously on the improvised roller coaster she built from tree branches, I know that with the right support she could burst through her cultural container. If anyone has enough energy, she does.

Do you want to know something exciting I learned? Mass-energy equivalence means that the solar energy striking the earth each second equals only four pounds of mass. That means a small girl of 40 pounds could unleash the energy of 10 suns shining on the earth in a second. Take the 132 million girls who are not in school, and we have 1.32 billion suns in our daughters.

How will we help them rise?

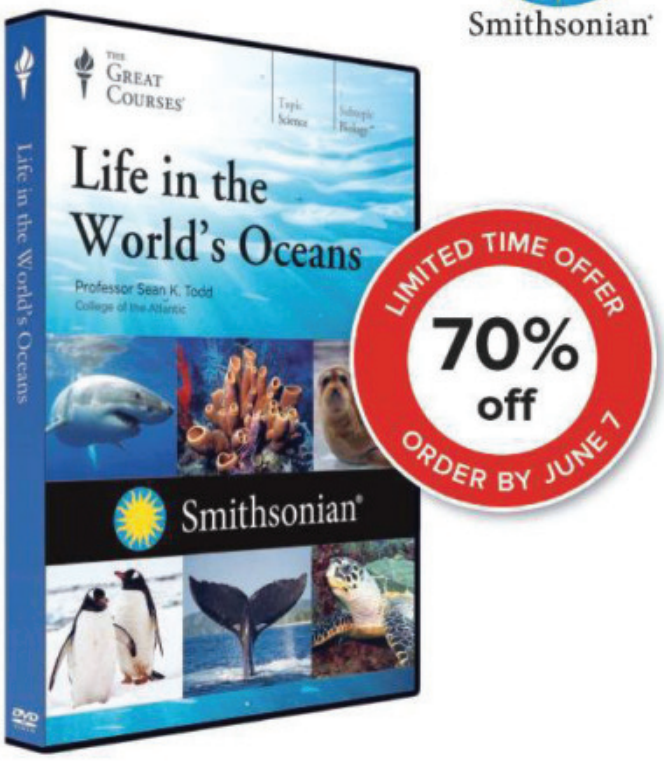
Lisa Einstein is a physics educator with the Peace Corps' Let Girls Learn program in Guinea, West Africa.

JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

Illustration by Cat O'Neil

THE GREAT COURSES®

Smithsonian®



Experience the Wonder of Ocean Life

The Great Courses has teamed with the Smithsonian to produce a vivid exploration of life in the world's oceans. In 30 lectures, Professor Sean K. Todd, of the College of the Atlantic and one of the world's leading marine biologists, takes you on a journey from the beginning of life four billion years ago to the state of our oceans today. He shares the latest research from the field's most fascinating areas of study, including marine-mammal intelligence and communication; bioluminescence; exploration of the ocean floor; and the Smithsonian's own cutting-edge research work around the world, including the Great Barrier Reef.

Swimming with dolphins, talking to whales, touring the barrier reef, plunging the depths of the seas—these are experiences that very few of us get to share. With **Life in the World's Oceans** and the Smithsonian, you get an unprecedented chance to get up close and personal with the underwater world, so you can better understand and appreciate the magnificence of ocean life.

Offer expires 06/07/18

THEGREATCOURSES.COM/9SA

1-800-832-2412

Life in the World's Oceans

Taught by Professor Sean K. Todd
COLLEGE OF THE ATLANTIC

LECTURE TITLES

1. Water: The Source of Life
2. Ocean Currents and Why They Matter
3. The Origin and Diversity of Ocean Life
4. Beaches, Estuaries, and Coral Reefs
5. Life in Polar and Deepwater Environments
6. Phytoplankton and Other Autotrophs
7. Invertebrate Life in the Ocean
8. An Overview of Marine Vertebrates
9. Fish: The First Vertebrates
10. Marine Megavertebrates and Their Fisheries
11. Sharks and Rays
12. Marine Reptiles and Birds
13. The Evolutionary History of Whales
14. The Taxonomy of Marine Mammals
15. How Animals Adapt to Ocean Temperatures
16. Mammalian Swimming and Buoyancy
17. Adaptations for Diving Deep in the Ocean
18. The Importance of Sound to Ocean Life
19. Food and Foraging among Marine Mammals
20. Marine Mammal Interactions with Fisheries
21. Breeding and Reproduction in a Large Ocean
22. Behavior and Sociality in Marine Mammals
23. Marine Mammal Distribution around the Globe
24. Intelligence in Marine Mammals
25. The Charismatic Megavertebrates
26. The Great Whale Hunt
27. The Evolution of Whale Research
28. Marine Mammal Strandings
29. The Urban Ocean: Human Impact on Marine Life
30. Our Role in the Ocean's Future

Life in the World's Oceans
Course no. 1725 | 30 lectures (30 minutes/lecture)

SAVE UP TO $285

DVD	~~$384.95~~	NOW $99.95
Video Download	~~$334.95~~	NOW $69.95

+$15 Shipping & Processing (DVD only)
and Lifetime Satisfaction Guarantee

Priority Code: 158601

For over 25 years, The Great Courses has brought the world's foremost educators to millions who want to go deeper into the subjects that matter most. No exams. No homework. Just a world of knowledge available anytime, anywhere. Download or stream to your laptop or PC, or use our free apps for iPad, iPhone, Android, Kindle Fire, or Roku. Over 600 courses available at www.TheGreatCourses.com.

ADVANCES

Mexican free-tailed bats have been migrating north earlier—possibly because of the warming climate.

INSIDE

JOEL SARTORE Getty Images

ECOLOGY

Batty Schedules

Earlier migrations could lead to major crop losses

Every year migratory bats travel from Mexico to Bracken Cave near San Antonio, Tex., where they spend the summer consuming insects that would otherwise devour common food crops. But the bats have been showing up far earlier than they did two decades ago, possibly because of a warming climate, new research suggests.

This trend creates a risky situation in which bats may not find enough food for themselves and their young, as the insects they prey on may not yet have arrived or hatched. If bat colonies shrink as a result of this schedule snafu, their pest control effect could fall out of sync with crop-growing seasons—potentially causing hefty losses, scientists say.

"If the whole system becomes unreliable, then it will be a big, big problem for agriculture," says Jennifer Krauel, a bat biologist at the University of Tennessee, Knoxville, who was not involved in the new research. "I don't think the bats will go away entirely, but even a reduced colony size will have an effect."

Mexican (also called Brazilian) free-tailed bats, the migratory species that inhabits Bracken Cave, feast on 20 different moth species and more than 40 other agricultural pests. One favorite is the corn earworm moth, which eats plants such as corn,

soybean, potato and pumpkin—costing U.S. farmers millions of dollars a year in ruined crops. A 2011 study estimated that bats indirectly contribute around $23 billion to the U.S. economy by keeping plant-eating insects in check and by hunting bugs that prey on pollinator insects.

In the new study, scientists at Rothamsted Research, an agricultural laboratory in England, used radar data from some 160 U.S. weather stations to analyze activity in the Texas bat colony (the largest in the world, with a peak population of around 40 million) from 1995 through 2017. Massive clouds of bats show up on radar images when these animals emerge for nighttime foraging. The researchers had set out to prove that radar could be used to accurately estimate the size of bat colonies. But over the course of the study, published online in February in *Global Change Biology*, they also discovered the creatures were leaving their winter quarters in Mexico earlier and reproducing sooner.

"This was very surprising," says Rothamsted meteorologist Phillip Stepanian, one of the study's co-authors. The bats' behavior appears to coincide with shifting seasonal temperatures. "We weren't out looking for climate change," he says, "but then it suddenly became very obvious."

Stepanian and his colleagues were also startled to find increasing numbers of bats overwintering at Bracken Cave instead of heading back to their cold weather quarters in Mexico—a behavior not reported at all during the first survey in 1957. Overwintering is another sign that warmer temperatures alter the bats' annual rhythms, Stepanian says.

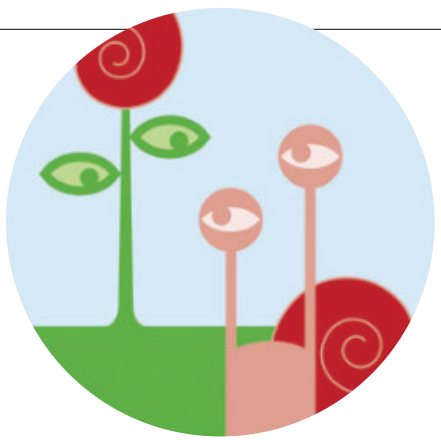
A separate study of migratory bats in Indiana, published last year, found that temperature variations affected arrival and departure times—likewise hinting at the potential influence of climate change. Joy O'Keefe, a biology professor at Indiana State University and co-author of that study, says early arrival at their summer roosts could expose these bats to cold snaps, and they could freeze to death.

Changing bat migration times can also clash with rainfall patterns. Many insects that bats eat breed in seasonal lakes and puddles. If the bats arrive too early to benefit from summer rainfall and the resulting abundance of bugs, they may struggle to

BOTANY

Watchful Plants

An animal's mere presence triggers broad-spectrum defense mechanisms



Plants cannot run or hide, so they need other strategies to avoid being eaten. Some curl up their leaves; others churn out chemicals to make themselves taste bad if they sense animals drooling on them, chewing them up or laying eggs on them—all surefire signals of an attack. New research now shows some flora can detect an herbivorous animal well before it launches an assault, letting a plant mount a preemptive defense that even works against other pest species.

When ecologist John Orrock of the University of Wisconsin–Madison squirted snail slime—a lubricating mucus the animals ooze as they slide along—into soil, nearby tomato plants appeared to notice. They increased their levels of an enzyme called lipoxygenase, which is known to deter herbivores. "None of the plants were ever actually attacked," Orrock says. "We just gave them cues that suggested an attack was coming, and that was enough to trigger big changes in their chemistry."

Initially Orrock found this defense worked against snails; in the latest study, his team measured the slimy warning's impact on another potential threat. The investigators found that hungry caterpil-

Illustration by Thomas Fuchs

feed their pups or skip reproduction altogether, O'Keefe says. She fears this shift could cause Midwestern bats to dwindle toward extinction, which would be bad news for humans. "Declines in bat populations could have severe implications for crop success," she says, adding that bats also "control significant disease vectors, such as mosquitoes."

Winifred Frick, chief scientist at the nonprofit Bat Conservation International, points to additional findings from Australia, where intense heat and resulting droughts have caused mass die-offs among fruit bats. Such events could become more likely in the U.S., Frick says.

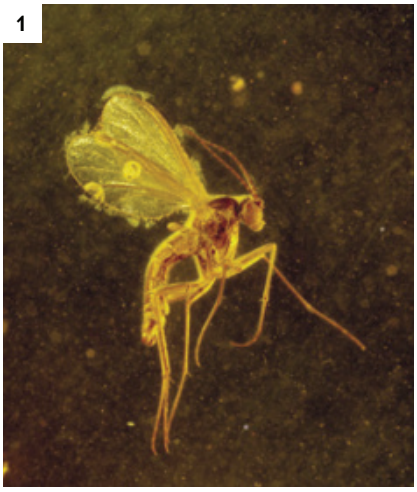
The Rothamsted researchers are not certain that climate change alone is prompting the Bracken Cave bat colony to migrate earlier. Scientists have found a direct link between seasonal temperatures and bird migration, but bats are also influenced by factors such as changes in wind speed and direction. And there are other complications. "Bats are mysterious little animals that move mostly at night and are difficult to observe and track," Stepanian says. "We have this conceptual picture of what might be happening, but really tying it to the cause is the next step." —*Inga Vesper*

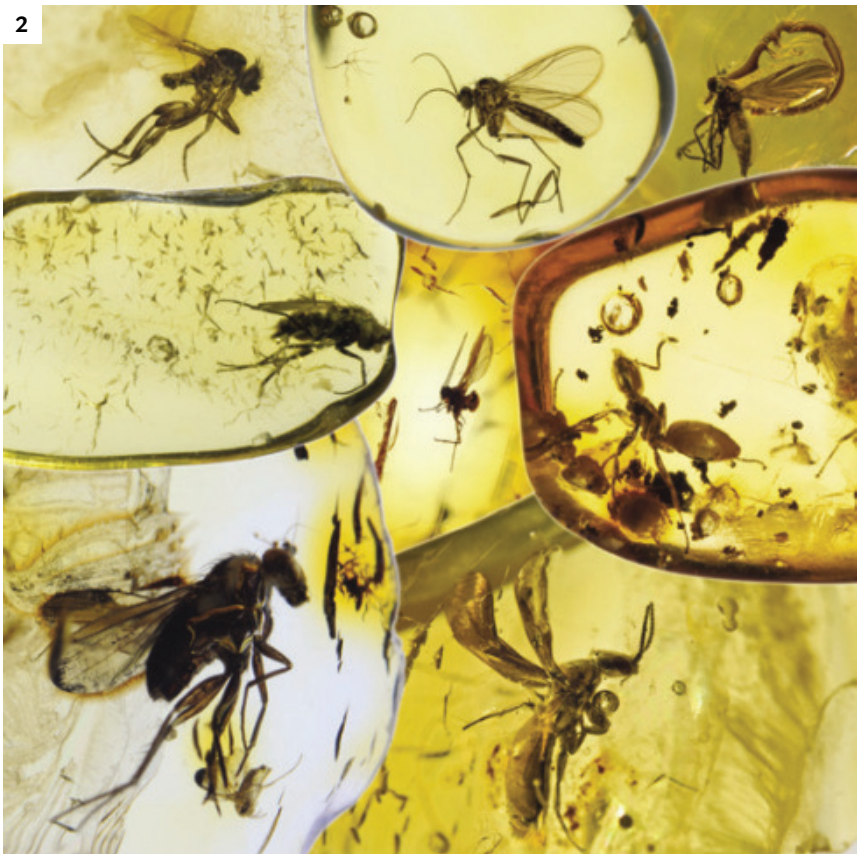
lars, which usually gorge on tomato leaves, had no appetite for them after the plants were exposed to snail slime and activated their chemical resistance. This nonspecific defense may be a strategy that gets the plants more bang for their buck by further improving their overall odds of survival, says Orrock, who reported the results with his colleagues in March in *Oecologia*.

The finding that a snail's approach can trigger a plant response that affects a different animal intrigued Richard Karban, a plant communications expert at the University of California, Davis, who was not involved in the study. "It is significant that the plants are responding before being damaged and that these cues are having such far-ranging effects," Karban says. The research was comprehensive, he adds, but he wonders how the tomato plants detected chemicals in snail slime that never actually touched them.

"That's the million-dollar question," Orrock says. He hopes future research will tease out the mechanisms that enable plants to perceive these relatively distant cues.

—*Erica Tennenhouse*





A fungus gnat in amber (*1*) and prehistoric insects in Lithuanian Baltic amber (*2*).

PALEONTOLOGY

Missing Bugs

A gap in the fossil record is key to unveiling insect origins

Insects are everywhere—in the air, on the ground, in the ground, and sometimes in your house and food. Yet there are none whatsoever in the known fossil record between 385 million and 325 million years ago. The earliest known insect fossil is a 385-million-year-old wingless creature that looks like a silverfish. But for the next 60 million years there is not so much as a single dragonfly, grasshopper or roach.

This so-called hexapod gap has long vexed paleontologists, given that insects today are found in almost every imaginable land habitat. One hypothesis suggests that chokingly low oxygen levels kept insect diversity from soaring during the gap and that these creatures proliferated only once the life-giving gas increased.

But advances in the understanding of atmospheric oxygen levels are challenging that idea, explains Sandra Schachat, a paleoentomologist at Stanford University, who led a recent study that modeled the gas's availability during the hexapod gap. Atmospheric oxygen at the time was much higher than once believed, according to the research, which was published in January in the *Proceedings of the Royal Society B*.

The disagreement between Schachat's findings and earlier research stems from the fact that her team used more recent atmospheric data that nowadays can be gathered cheaply and efficiently. "If these results are confirmed, we could dismiss low oxygen levels as a possibility" for explaining the gap, says Jesus Lozano Fernandez, a paleobiologist at the University of Bristol in England, who was not involved in the new work.

Schachat and her team combed through fossil information from a public paleontology database and realized there was something special about many of the insect fossils that came after the gap: they had wings. This was likely the trait that helped hexapod diversity take off; winged insects can zip away from predators and get at otherwise unreachable foods such as leaves and other insects. "The gap is simply the tail end of a larger interval in which insects are very rare on the landscape because wings had not yet originated," Schachat says.

The mystery now bugging Schachat is how insect wings evolved at all; the earliest flying insects found after the gap seem to have already been very diverse. "The two very first winged insects that we have in the fossil record—they're about as different from each other as you could imagine," she says. The origins of wings, then, must lie within the gap itself. Lurking somewhere in it, there may be undiscovered fossils that could reveal how insects became the first animals to take to the skies. —*Lucas Joel*

> "Insects [were] very rare on the landscape because wings had not yet originated."
> —SANDRA SCHACHAT, *STANFORD UNIVERSITY*

NATURAL HISTORY MUSEUM, LONDON *Alamy (1)*; PIR STUDIO *Alamy (2)*

IN THE NEWS

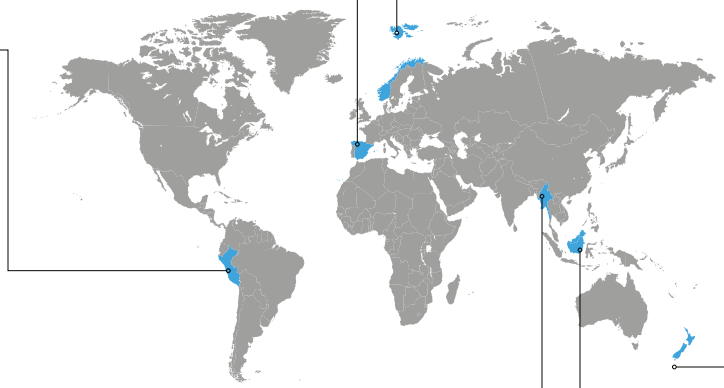
Quick Hits

SPAIN

Wall paintings previously discovered in three Spanish caves have now been dated to 65,000 years ago—some 20,000 years before *Homo sapiens* is thought to have arrived in Europe. Researchers say this find is the first clear evidence that Neandertals created art.

NORWAY

More than 70,000 new crops were added to the Svalbard Global Seed Vault, which brings the total number of crop varieties in the world's largest seed collection—an international effort to guard against the worldwide loss of plant diversity—to more than a million.



PERU

Ecologists analyzed 142 hydropower dams in the western Amazon basin and concluded that they are interfering with fish migration and sediment flow. If a proposed 160 more dams are built, they could cause similar cascading problems for the ecosystem.

NEW ZEALAND

Growth rings in "the loneliest tree on the planet," an isolated Sitka spruce on Campbell Island, still bear traces of radioactivity from atomic bomb testing in the 1950s and 1960s. Climatologists suggest the traces could define the start of a proposed age of accelerated human impact on the planet.

MYANMAR (FORMERLY BURMA)

Paleontologists found a 100-million-year-old spider trapped in amber in northern Myanmar. They think the ancient species, *Chimerarachne yingi,* lived in tropical forests and had a long tail that it may have used to sense prey and predators.

BORNEO

Half of the orangutans on the vast Southeast Asian island died between 1999 and 2015 as a result of hunting or habitat destruction by oil palm and other industries, a new study found. Another 45,000 of the great apes are predicted to die by 2050.

—Yasemin Saplakoglu

For more details, visit www.ScientificAmerican.com/may2018/advances

Scientists may someday be able to detect planets that have mountains like the Himalayas (*shown here*).

SPACE

Exoplanet Everests

Giant telescopes may be able to detect detailed features on distant worlds

The Himalayas distort Earth's contour only about as much as a human hair would that of a billiard ball. Discerning such a minuscule bump on a planet orbiting a distant star might seem laughably impossible, but two astronomers have proposed a way to detect mountains and other surface features on exoplanets.

Finding mountains could help address another key question: Can these planets hold life? So says astronomy graduate student Moiya McTier of Columbia University, one of the co-authors of the proposal, which was published in April in *Monthly Notices of the Royal Astronomical Society.*

Life on Earth is apparently dependent on the inner life of the planet itself. Plate tectonics recycles carbon and regulates temperatures, and Earth's magnetic field provides a shield from dangerous solar winds. Mountains and volcanoes are signs that a planet has, or at least at one point had, such an inner life.

Astronomers have now identified some 3,700 planets, but little is known about most of them besides their size and mass. Most were detected by the so-called transit method, in which astronomers measure a slight dimming of the light from a distant star when a planet orbits in front of it. The strategy proposed by McTier and her Columbia colleague David Kipping builds on that method but will likely require huge telescopes that may not be completed for decades.

The astronomers' insight is that a rotating, mountainous planet presents a changing silhouette during transit, causing measurements of the dip in light to fluctuate. Based on conservative estimates, the scientists believe the "bumpiness" of planets as mountainous as Mars could be measured accurately by a 74-meter telescope observing transits for about 20 hours, spread out over roughly six months. That is still a tall order for today's telescopes, but larger ones are on the horizon.

One of Kipping's biggest concerns with this approach is mountain-cloaking clouds. Nicolas Cowan, an astronomer at McGill University who was not involved in the research, agrees. But even without clouds, he worries that atmospheric absorption, scattering and refraction of light could spoil the view. "I suspect that for that method to work for a planet, it'll probably need to be airless," Cowan says. The Columbia researchers, though, think they can mitigate these effects by observing different wavelengths of light.

Even if astronomers manage to confirm a planet's bumpiness, they will need additional information—such as the presence of liquid water, tolerable temperatures and an atmosphere—to interpret the implications for habitability. "No single piece of information is going to solve it," Kipping notes.

—Bob Henderson

GETTY IMAGES

Parramatta red gum trees growing in climate-controlled pods.

MARK G. TJOELKER *Western Sydney University*

CLIMATE CHANGE

Sweaty Trees

How one species of eucalyptus keeps its cool

Recent summer temperatures in parts of Australia were high enough to melt asphalt. As global warming cranks up the heat and climatic events intensify, many plants may be unable to cope. But at least one species of eucalyptus tree can withstand extreme heat by continuing to "sweat" when other essential processes taper off, a new study finds.

As plants convert sunlight into food, or photosynthesize, they absorb carbon dioxide through pores on their leaves. These pores also release water via transpiration, which circulates nutrients through the plant and helps cool it by evaporation. But exceptionally high temperatures are known to greatly reduce photosynthesis—and most existing plant models suggest this should also decrease transpiration, leaving trees in danger of fatally overheating. Because it is difficult for scientists to control and vary trees' conditions in their natural environment, little is known about how individual species handle this situation.

Ecologist John Drake of the S.U.N.Y. College of Environmental Science and Forestry and his colleagues grew a dozen Parramatta red gum (*Eucalyptus parramattensis*) trees in large, climate-controlled plastic pods that isolated the trees from the surrounding forest for a year in Richmond, Australia. Six of the trees were grown at ambient air temperatures and six at temperatures three degrees Celsius higher. The researchers withheld water from the surface soil of all 12 trees for a month to simulate a mild dry spell, then induced a four-day "extreme" heat wave: They raised the maximum temperatures in half of the pods (three with ambient temperatures and three of the warmer ones)—to 44 degrees C.

Photosynthesis ground to a near halt in the trees facing the artificial heat wave. But to the researchers' surprise, these trees continued to transpire at close-to-normal levels, effectively cooling themselves and their surroundings. The trees grown in warmer conditions coped just as well as the others, and photosynthesis rates bounced back to normal after the heat wave passed, Drake and his colleagues reported online in February in *Global Change Biology*.

The researchers think the Parramatta red gums were able to effectively sweat—even without photosynthesis—because they are particularly good at tapping into water deep in the soil. But if a heat wave and a severe drought were to hit at the same time and the groundwater was depleted, the trees may not be so lucky, Drake says.

Other scientists call the finding encouraging. "It's definitely good news," says Trevor Keenan, an ecologist at Lawrence Berkeley National Laboratory, who was not part of the study. "It would be very interesting to know how this translates to other species," he adds. Drake hopes to conduct similar experiments with trees common in North America.

—*Yasemin Saplakoglu*

ANIMAL BEHAVIOR

Orangutan Medicine

The great apes use plant extracts to soothe achy limbs

BORNEO NATURE FOUNDATION

Medicine is not exclusively a human invention. Many other animals, from insects to birds to nonhuman primates, have been known to self-medicate with plants and minerals for infections and other conditions. Behavioral ecologist Helen Morrogh-Bernard of the Borneo Nature Foundation has spent decades studying the island's orangutans and says she has now found evidence they use plants in a previously unseen medicinal way.

During more than 20,000 hours of formal observation, Morrogh-Bernard and her colleagues watched 10 orangutans occasionally chew a particular plant (which is not part of their diet) into a foamy lather and then rub it into their fur. The apes spent up to 45 minutes at a time massaging the concoction onto their upper arms or legs. The researchers believe this behavior is the first known example of a nonhuman animal using a topical analgesic.

Local people use the same plant—*Dracaena cantleyi,* an unremarkable-looking shrub with stalked leaves—to treat aches and pains. Morrogh-Bernard's coauthors at the Czech Academy of Sciences, Palacký University Olomouc and the Medical University of Vienna studied its chemistry. They added extracts from it to human cells that had been grown in a dish and had been artificially stimulated to produce cytokines, an immune system response that causes inflammation and discomfort. The plant extract reduced the production of several types of cytokines, the scientists reported in a study published last November in *Scientific Reports.*

The results suggest that orangutans use the plant to reduce inflammation and treat pain, says Jacobus de Roode, a biologist at Emory University, who was not involved in the study. Such findings could help identify

SUSTAINABILITY

Timber Trafficking

Cutting to the core of Thailand's illegal rosewood trade

Poaching of elephants, rhinoceroses and pangolins makes headlines almost every day. But tree trafficking? Not so much. Nevertheless, illegal logging is a major market; the United Nations estimates its value in the tens of billions of dollars.

Rosewood—a category that includes 33 commercial species of long-lived hardwoods that share a sweet, floral smell—is a particularly lucrative target. These trees are being poached at breathtaking rates: authorities in Thailand alone seize more than one haul of rosewood a day on average, according to research published online in March in *Environmental Conservation*.

"I was completely unaware of the scale of this illegal trade in Thailand," says co-author Vincent Nijman, an anthropologist at Oxford Brookes University in England. "More than a dozen species of rosewood run a high risk of becoming extinct in our lifetime."

Map by Mapping Specialists

This wood has long been prized for making instruments and furniture, but China's increasing spending power has triggered escalating demand. Many of the impacted species—found in South America, Africa and Southeast Asia—are protected by law, but such measures have not stopped a growing illegal timber trade. The illicit practice affects not only centuries-old rosewood trees but also swaths of rain forest that poachers clear to access them.

Monitoring the trade internationally is a challenge; no reliable databases exist, and related news stories and government reports are often in local languages. The latter is particularly relevant in Southeast Asia given that relatively few people outside the region speak Thai, Khmer, Vietnamese or Indonesian. "This has allowed certain countries to remain under the international conservation community's radar," Nijman says.

Nijman's doctoral student Penthai Siriwat scoured Thai news reports for rosewood seizures and uncovered a whopping 835 separate instances from January 2014 to April 2016. Siriwat and Nijman discovered

SOURCE: "USING ONLINE MEDIA-SOURCED SEIZURE DATA TO ASSESS THE ILLEGAL WILDLIFE TRADE IN SIAMESE ROSEWOOD," BY PENTHAI SIRIWAT AND VINCENT NIJMAN, IN *ENVIRONMENTAL CONSERVATION.* PUBLISHED ONLINE MARCH 15, 2018

The apes chew a plant (that is not part of their diet) into a foamy lather, which they rub into their fur to relieve pain.

plants and chemicals that might be useful for human medications, de Roode says.

In creatures such as insects, the ability to self-medicate is almost certainly innate; woolly bear caterpillars infected with parasitic flies seek out and eat plant substances that are toxic to the flies. But more complex animals may learn such tricks after an initial discovery by one member of their group. For example, an orangutan may have rubbed the plant on its skin to try to treat parasites and realized that it also had a pleasant pain-killing effect, says Michael Huffman, a primatologist at Kyoto University, who was not involved in the new research. That behavior may then have been passed on to other orangutans. Because this type of self-medication is seen only in south-central Borneo, Morrogh-Bernard says, it was probably learned locally. —*Doug Main*

that the most significant predictor of seizures was not the number of trees in an area but proximity to an international border or port.

The findings suggest that most of Thailand's rosewood likely is destined for China. Perhaps more important, they also highlight places where authorities could most effectively curb smuggling. Tracking seizures in a real-time database would provide even more valuable information, Nijman says.

But even if such data were available, Siriwat notes that the magnitude of the illicit rosewood trade now vastly overwhelms the resources allocated to stopping it. "When groups of five rangers have to confront illegal logging groups of 40 or more, it's incredibly challenging and dangerous," she says. "The Thai word for 'rosewood' is *mai phayung,* which sounds like the Thai word for 'to support.' But ironically, rosewood hasn't been receiving adequate support at all." —*Rachel Nuwer*

SCIENCE LITERACY

Views of Evolution Shaped by Knowledge

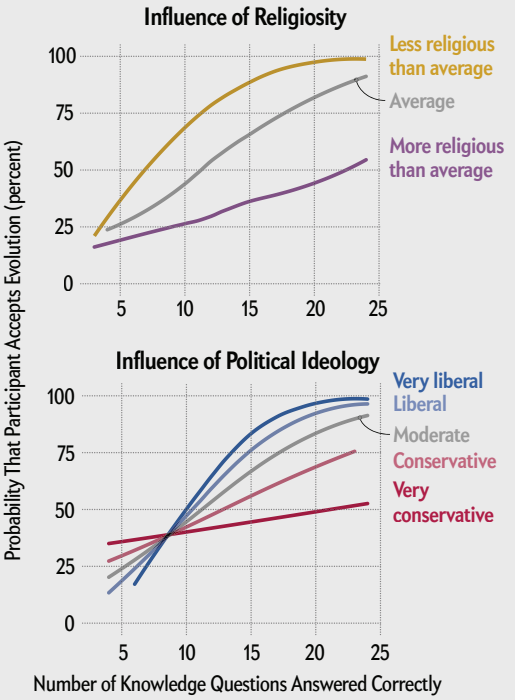
Greater understanding of the theory supersedes religion or politics

Science denialism can seem intractable, and studies on the topic are seldom encouraging. For example, research out of Yale Law School suggests that when people form their opinions on contentious topics such as climate change or evolution, political or religious values trump knowledge of the concept.

A study published in March in *BioScience* begs to differ, at least when it comes to evolution. Researchers at the University of Pennsylvania and their colleagues measured participants' knowledge of evolutionary theory, as well as their acceptance of evolution as fact. They found a significant link between understanding the fine points of the theory and believing in it, regardless of religious or political identity.

Unlike earlier research that involved only high school or college students, the demographics of the 1,100 subjects in the new study better approximated those of the overall U.S. population. The researchers also used more nuanced language in their questions to distinguish between subjects' intellectual grasp of evolution and their personal feelings toward it. It remains unclear whether science education leads directly to increased acceptance of evolution, but the Penn study supports this possibility. —*Amanda Montañez*

Graphic by Amanda Montañez



Study participants had previously submitted information on their political ideology and degree of religiosity. Although both factors influenced acceptance of evolution, scientific knowledge still appeared to play a significant role. The data shown here do not distinguish among different religions.

SOURCE: "NO MISSING LINK: KNOWLEDGE PREDICTS ACCEPTANCE OF EVOLUTION IN THE UNITED STATES," BY DEENA SKOLNICK WEISBERG ET AL., IN *BIOSCIENCE*, VOL. 68, NO. 3; MARCH 1, 2018

Claudia Wallis is an award-winning science journalist whose work has appeared in the *New York Times*, *Time*, *Fortune* and the *New Republic*. She was science editor at *Time* and managing editor of *Scientific American Mind*.

The Battle of the Belt

Gaining belly fat is dangerous for reasons we don't fully grasp

By Claudia Wallis

Among the indignities of aging is a creeping tendency to put on weight, as our resting metabolism slows down—by roughly 1 to 2 percent every decade. But what's worse, at least for women, is a shift, around menopause, in where this excess flab accumulates. Instead of thickening the hips and thighs, it starts to add rolls around the belly—a pattern more typical of men—which notoriously reshapes older women from pears into apples.

The change is not just cosmetic. A high waist-to-hip ratio portends a greater risk of heart disease, stroke, diabetes, metabolic syndrome and even certain cancers—for both men and women. The shift helps to explain why, after menopause, women begin to catch up to men in their rates of cardiovascular disease. And those potbellies are costly. A 2008 Danish study found that for every inch added to a healthy waistline, annual health care costs rose by about 3 percent for women and 5 percent for men.

Researchers have been investigating "middle-aged spread" for decades, but there is still debate about why it happens, whether it is a cause or merely an indicator of health risks, and what can be done to avoid it. As we grow older, we deposit relatively more excess fat around our abdominal organs as opposed to under the skin—where most of our body fat sits. There are some ethnic and racial differences, however, notes endocrinologist Robert Eckel, director of the Lipid Clinic at the University of Colorado Hospital. For a given waist circumference, African-Americans tend to have less of this "visceral fat," and Asians tend to have more. Visceral fat differs from subcutaneous fat in that it releases fatty acids and inflammatory substances directly into the liver rather than into the general circulation. Some experts believe this may play a direct role in causing the diseases linked to abdominal obesity.

But not everyone agrees. Samuel Klein, who heads the Center for Human Nutrition at the Washington University School of Medicine in St. Louis, has published data showing that key factors in those diseases—such as insulin sensitivity and triglyceride levels—are more tightly linked to the amount of fat inside the liver rather than outside it, although the two tend to track one another. Belly fat, he believes, is a marker of risk, not a cause, but it is an important indicator and a whole lot easier to size up than liver fat. Just use a tape measure.

Another area of uncertainty is why we pack on visceral fat with aging. Clearly, sex hormones are involved, given that the change occurs in women around menopause. But it is more complicated than just a drop in estrogen. Consider, for instance, that young women with polycystic ovary syndrome tend to have the apple shape and insulin resistance, although their bodies produce plenty of estrogen. Such women do, however, have high levels of androgens. Or consider that when transgender males—who are biologically female—take androgens to masculinize their body, they, too, develop more visceral fat and glucose intolerance. Both examples suggest that "a relative imbalance" of male and female hormones may be at work, says endocrinologist Margaret Wierman of the University of Colorado Denver. The same might also be true of healthy women at menopause.

But this isn't settled science. A newer theory made a splash last year after researchers reported in *Nature* that they could radically reduce body fat—including visceral fat—and raise metabolic rates in mice by blocking the action of follicle-stimulating hormone (FSH), a substance better known for its role in reproduction. Could FSH be the key to the midlife weight puzzle? The researchers had previously shown that blocking FSH could halt bone loss, raising the intriguing prospect of a medical twofer: one drug to combat obesity and osteoporosis. "The next step is to take this to humans," says senior author Mone Zaidi of the Icahn School of Medicine at Mount Sinai.

Of course, many a thrilling discovery in mice has fizzled in humans, and combating the evolutionary programming for storing fat is particularly difficult. Klein, for instance, has tested whether removing body fat with liposuction or surgically excising visceral fat in obese patients would reduce risk factors for diabetes and heart disease. No dice. "They looked better," he says, but in terms of metabolic benefits, "it was a bust."

As far as we know, there's only one way to fight nature's plan for a thickening middle and its attendant risks—and you know where this is going. Eat less or exercise more as you age, or do both. Adding more muscle will also keep your metabolic rate perky, so best to hit the gym. SA

Illustration by Celia Krampien

David Pogue is the anchor columnist for Yahoo Tech and host of several *NOVA* miniseries on PBS.

Weirdest Hardware Product Ever?

Google's new camera decides what to photograph, based on AI algorithms

By David Pogue

Google's Clips camera is a tiny sliver of a camera, the size of two Wheat Thins crackers. You can set it down anywhere or clip it to anything. Once you turn it on, you don't have to press a button or use a self-timer to take pictures. The *camera* decides when to snap, based on Google's artificial-intelligence algorithms.

The Clips's heart is in the right place. It solves some real problems for its target audience, which is parents (of kids or of pets).

First, if you're in that category, you're probably never in any of your own photographs, because you're always behind the camera. Second, babies and young children often stop whatever cute thing they're doing the moment you pull out your phone. They get distracted by it or feel self-conscious. But the Clips avoids that problem because it's unobtrusive and because you're not holding it between your face and the kid's.

Truth is, I suspect the Clips will probably flop. The camera isn't very impressive next to those in some smartphones, and $250 is a steep price for a one-trick pony. But its central idea—AI as photographer—is fascinating.

AI isn't organic. It has to be *programmed*—taught or coded by engineers. In other words, the AI doesn't ultimately decide what makes a good picture; its programmers, informed by photography experts, do.

Some of the AI's decision making in the Clips is obvious. It looks for scenes of activity. It favors familiar subjects—people whose faces it sees most often. It avoids capturing an image when something is blocking the lens, like your fingers or your grabby baby's hands. It prefers good lighting. It takes its best shots three to eight feet away.

But here's where things get more complicated: The camera is also designed to wait for happy facial expressions. It tends not to capture anybody who is sad, angry, sleepy, bored or crying.

That AI rule, unfortunately, rules out a lot of great picture taking. Let's face it—a young child's life is full of micro tragicomic moments that might be worth recording, even if they produce brief bursts of tears. You know: His ice cream falls off the cone onto the floor. A puppy licks her face a little too energetically. A well-meaning clown scares him.

Google is aware of the problem and plans to add a new preference setting—not a check box called "Include Misery" but an option that makes the camera watch for *changes* in facial expression. In the meantime, the Clips's preference for joyous moments tends to exaggerate two happiness filters we already put on our lives.

First, we already self-edit our video and photographic memories simply by choosing what to shoot. Most people, most of the time, record high points such as celebrations and travel. Your collection probably contains very few pics of you fighting with your spouse, depressed by your job or in pain from an injury.

Second, we further curate our recordings by choosing which to post online. At this point, we don't just risk deceiving *ourselves* about the overall happiness balance in our lives; we're explicitly trying to paint a picture of a wonderful life for our followers. We become brand ambassadors for our supposedly flawless lives.

Studies have shown that the result of all this happy filtering can sadden *other* people on social media, who develop "Facebook envy."

You begin to wonder why we take pictures and videos in the first place. What's the purpose of those acts? Is it to create a faithful record of our lives, both high and low moments? Is there anything wrong with immortalizing only the bright spots, permitting the darker stuff to fade out of view—and maybe out of memory?

Answering those questions depends, in part, on who your audience is. An older you? Your descendants? Your Facebook friends?

There's no right answer. We all take and curate pictures—or don't—for different reasons. If Google's Clips camera achieves nothing more than throwing those questions into sharper focus, its invention won't have been in vain. SA

SCIENTIFIC AMERICAN ONLINE
READ MORE ABOUT "FACEBOOK ENVY":
scientificamerican.com/may2018/pogue

Illustration by Jay Bendt

The Agenda Setters

Bringing Science to Life









Biotech Comes to Broadway

Marriott Marquis Times Square | New York City | February 12th, 2018

Scientific American's Custom Media division hosted a unique salon-style event in collaboration with Immunomic Therapeutics on Monday, February 12th in the heart of Manhattan's Times Square. The forum, *Hot Topics in Biotech: Cancer at a Crossroads*, co-located and held in association with the BIO CEO & Investor Conference at the New York Marriott Marquis, attracted a rich audience of trailblazers and investors. Nearly 85 attendees joined the party for a dynamic discussion exploring the second wave of immuno-oncology innovation and what it will look like for biopharma companies large and small.

After a few welcoming remarks by **Jeremy Abbate**, VP & Publisher of Scientific American, **David Thomas**, Senior Director of Industry Research and Analysis at the Biotechnology Innovation Organization, jump-started the conversation by highlighting the repatriation of cash for investment among the biopharma set and how it is changing the deal-making climate. The interactive discussion that followed, moderated by Scientific American's Executive Editor for Partnerships, **Cliff Ransom**, explored what the second wave of immuno-oncology will look like for businesses. Expert panelists weighing in included **Bill Hearl**, CEO of Immunomic Therapeutics, **Barbara Ryan**, life sciences capital markets advisor, **Garo Armen**, CEO & Chairman of Agenus and **Randy Burkholder**, VP of Policy and Research at PhRMA.

This was the third reception hosted in a series of partner events with Immunomic Therapeutics aimed to open up the conversation of the future of development and investment in cancer vaccines and immunotherapies.

EVOLUTION

THE UNLIKELY TRIUMPH OF DINOSAURS

New fossils and analyses topple the long-standing explanation of how dinosaurs came to rule the earth

By Stephen Brusatte

Illustration by James Gurney

IMPROBABLE CHAMPION: *Dromomeron*, a dinosaur precursor, warily approaches the water's edge for a drink 212 million years ago in an oasis in what is now Ghost Ranch in New Mexico. *Koskinonodon*, a giant amphibian, lies in wait.

Stephen Brusatte is a paleontologist at the University of Edinburgh in Scotland. His research focuses on the anatomy and evolution of dinosaurs. He is author of the new book *The Rise and Fall of the Dinosaurs* (William Morrow, 2018).

WHEN I WAS A TEENAGER AT THE TURN OF THE MILLENNIUM, RIGHT around the time I became smitten with fossils, the Field Museum in Chicago dismantled its *Brachiosaurus* and installed a *Tyrannosaurus rex*. In essence, the institution was trading one dinosaur icon for another. Out went the plant-eating colossus, heavier than 10 elephants, its neck arcing gracefully far above the museum's second-floor viewing gallery. In came the biggest, baddest predator of all time: a bus-sized brute with railroad-spike teeth that shattered the bones of its prey.

These were the dinosaurs that fired my imagination as I grew up 75 miles down the road from Chicago, in a flat expanse of Midwestern corn and bean fields. I visited them as often as I could convince my parents to make the drive. Standing underneath their skeletons was hypnotic: their size, their strength, their bodies so alien compared with those of any animals alive today. No wonder they ruled the earth for more than 150 million years. They were magnificent.

But how did dinosaurs get this way? It was a question I rarely contemplated during those obsessive years. In the same way that it was hard to envision that my parents were once my age, I just assumed dinosaurs materialized at some point in the deep past as fully formed long-necked and sharp-toothed giants. I didn't know it at the time, but that wasn't too far off from the scientific consensus for much of the late 20th century. Dinosaurs were special, this convention held, endowed with such superior speed, agility and metabolism that they quickly and easily outcompeted their early rivals, spread across the planet and established an empire.

Over the past 15 years, however, a wealth of new fossil discoveries from around the globe, fresh insights into the physical world the first dinosaurs inhabited, and novel approaches to building family trees and analyzing evolutionary trends have challenged that long-standing view. From these advances, a rather different story has emerged: the rise of dinosaurs was gradual, and for the first 30 million years of their history they were restricted to a few corners of the world, outpaced by other species. Only after catching a couple of lucky breaks did they rise up to take over the planet.

HUMBLE ORIGINS

LIKE MANY SUCCESSFUL ORGANISMS, dinosaurs were born of catastrophe. Around 252 million years ago, at the tail end of the Permian Period, a pool of magma began to rumble underneath Siberia. The animals living at the surface—an exotic menagerie of large amphibians, knobby-skinned reptiles and flesh-eating forerunners of mammals—had no inkling of the carnage to come. Streams of liquid rock snaked through the mantle and then the crust, before flooding out through mile-wide cracks in the earth's surface. For hundreds of thousands, maybe millions, of years the eruptions continued, spewing heat, dust, noxious gases and enough lava to drown several million square miles of the Asian landscape. Temperatures spiked, oceans acidified, ecosystems collapsed and up to 95 percent of the Permian species went extinct. It was the worst mass extinction in our planet's history. But a handful of survivors staggered into the next period of geologic time, the Triassic. As the volcanoes quieted and ecosystems stabilized, these plucky creatures now found themselves in a largely empty world. Among them were various small amphibians and reptiles, which diversified as the earth healed and which later diverged into today's frogs, salamanders, turtles, lizards and mammals.

Scientists know about these animals from the handprints and footprints they left in layer after layer of river and lake sediments now exposed in the Holy Cross Mountains in Poland. For more than 20 years Grzegorz Niedźwiedzki, who grew up in these hills and is now a paleontologist based at Uppsala University in Sweden, has meticulously collected these fossil tracks, occasionally with me by his side. In 2005, while fossil hunting

IN BRIEF

The conventional view of dinosaur origins holds that they were endowed with such superior speed, agility, metabolism and intelligence that as soon as they debuted they quickly outcompeted the competition and spread across the globe.

New fossil discoveries and analyses have upended that scenario, showing that dinosaurs languished on the evolutionary sidelines for tens of millions of years before they were able to surpass their rivals and conquer the planet.

FOSSIL TRACKS of *Prorotodactylus* show that around 250 million years ago dinosaur precursors called dinosauromorphs roamed what are now the Holy Cross Mountains in Poland.

GRZEGORZ NIEDŹWIEDZKI *Uppsala University*

near the village of Stryczowice, along a narrow stream tangled with brambles, Niedźwiedzki discovered an unusual type of track that did not seem to match any of the more common reptile and amphibian traces. The strange prints are about the size of a cat's paw, arranged in narrow trackways, with the five-fingered handprints positioned in front of the slightly larger footprints, which have three long central toes flanked by a toe nubbin on each side. The tracks go by the genus name *Prorotodactylus*. All that we know about this creature comes from these prints—there are no known fossils of the animal itself.

The *Prorotodactylus* tracks date to about 250 million years ago, just one or two million years after the volcanic eruptions that brought the Permian to a close. Early on it was clear from the narrow distance between the left and right tracks that they belonged to a specialized group of reptiles called archosaurs that emerged after the Permian extinction with a newly evolved upright posture that helped them run faster, cover longer distances and track down prey with greater ease. The fact that the tracks came from an early archosaur meant that they could potentially bear on questions about the origins of dinosaurs. Almost as soon as the archosaurs originated, they branched into two major lineages, which would grapple with each other in an evolutionary arms race over the remainder of the Triassic: the pseudosuchians, which led to today's crocodiles, and the avemetatarsalians, which developed into dinosaurs. Which branch did *Prorotodactylus* belong to?

To find out, I conducted a study with Niedźwiedzki and Richard J. Butler, now at the University of Birmingham in England. Our analysis of the prints, published in 2011, revealed peculiarities of the footprints that link them to signature features of the dinosaur foot: the digitigrade arrangement of the bones, in which only the toes make contact with the ground while walking, and the very narrow foot with three main toes. *Prorotodactylus* is therefore a dinosauromorph: not a dinosaur per se but a primitive member of the avemetatarsalian subgroup that includes dinosaurs and their very closest cousins. Members of this group had long tails, big leg muscles, and hips with extra bones connecting the legs to the trunk, which allowed them to move even faster and more efficiently than other archosaurs.

These earliest dinosauromorphs were hardly fearsome, however. Fossils indicate that they were only about the size of a house cat, with long, skinny legs. And there were not very many of them either: less than 5 percent of all Stryczowice tracks belong to *Prorotodactylus,* which is far outnumbered by tracks of small reptiles, amphibians and even other archosaurs. The dinosauromorphs' time had not come. Yet.

THE FIRST DINOSAURS

OVER THE NEXT 10 MILLION to 15 million years the dinosauromorphs continued to diversify. The fossil record from this time period shows an increasing number of track types in Poland and then around the world. The tracks get larger and develop a greater variety of shapes. Some trackways stop showing impressions of the hand, a sign the makers were walking only on their hind legs. Skeletons start to turn up as well. Then, at some point between 240 million and 230 million years ago, one of these primitive dinosauromorph lineages evolved into true dinosaurs. It

was a radical change in name only—the transition involved just a few subtle anatomical innovations: a long scar on the upper arm that anchored bigger muscles, some tablike flanges on the neck vertebrae that supported stronger ligaments, and an open, windowlike joint where the thighbone meets the pelvis that stabilized upright posture. Still, modest though these changes were, they marked the start of something big.

The oldest unequivocal dinosaur fossils, which date to around 230 million years ago, come from the otherworldly landscapes of Ischigualasto Provincial Park in Argentina. Scientists have collected there for decades, beginning with legendary American paleontologist Alfred Romer in the 1950s and continuing with Argentine researchers Osvaldo Reig and José Bonaparte in the 1960s. More recently, Paul Sereno of the University of Chicago and Ricardo N. Martínez of the National University of San Juan in Argentina led expeditions to Ischigualasto in the 1980s and 1990s. Among the fossils they found there were those belonging to *Herrerasaurus, Eoraptor* and other creatures representing all three of the main branches of the dinosaur family: the meat-eating theropods; the long-necked, plant-eating sauropodomorphs and the beaked, plant-eating ornithischians.

By the middle part of the Triassic, around 230 million to 220 million years ago, these three main dinosaur subgroups were on the march, siblings setting out to form their own broods in a world we would barely recognize. Back then a single supercontinent called Pangea stretched from pole to pole, surrounded by a global ocean called Panthalassa. It was not a safe place to call home. The earth was much warmer, and because Pangea was centered on the equator, half the land was always scorching in the summer while the other half was cooler in the winter. These marked temperature differences fueled violent "mega monsoons" that divided Pangea into environmental provinces characterized by varying degrees of precipitation and wind. The equatorial region was unbearably hot and muggy, flanked by subtropical deserts on both sides. The midlatitude regions were slightly cooler and much wetter.

Herrerasaurus, Eoraptor and the other Ischigualasto dinosaurs were ensconced in the comparatively hospitable midlatitudes. So were their counterparts from Brazil and India, known from exciting recent fossil discoveries. But what about other parts of the supercontinent? Did early dinosaurs colonize these harsher regions just as capably, as the conventional wisdom about them suggests? In 2009, a few months after our first jaunt together in Poland, Butler and I teamed up with Octávio Mateus of the Museum of Lourinhã in Portugal to test this hypothesis by exploring a remnant of the subtropical arid belt of northern Pangea in what is now southern Portugal. We were hoping to find dinosaurs, but what we found instead was a mass graveyard of hundreds of Smart car–sized amphibians that we assigned to a new species, *Metoposaurus algarvensis*. These rulers of the Triassic lakes and rivers had been victims of a freak shift in the capricious Pangean weather that probably caused their lakes to dry up. We returned later to excavate the bone bed and started to also find fossils of various fishes, poodle-sized reptiles and archosaurs from the line leading to crocodiles. But still, to this day, we have yet to come across even a scrap of dinosaur bone.

We probably never will. Spain, Morocco and the eastern seaboard of North America have stellar fossil sites from this same time between 230 million and 220 million years ago that show

Family Feud

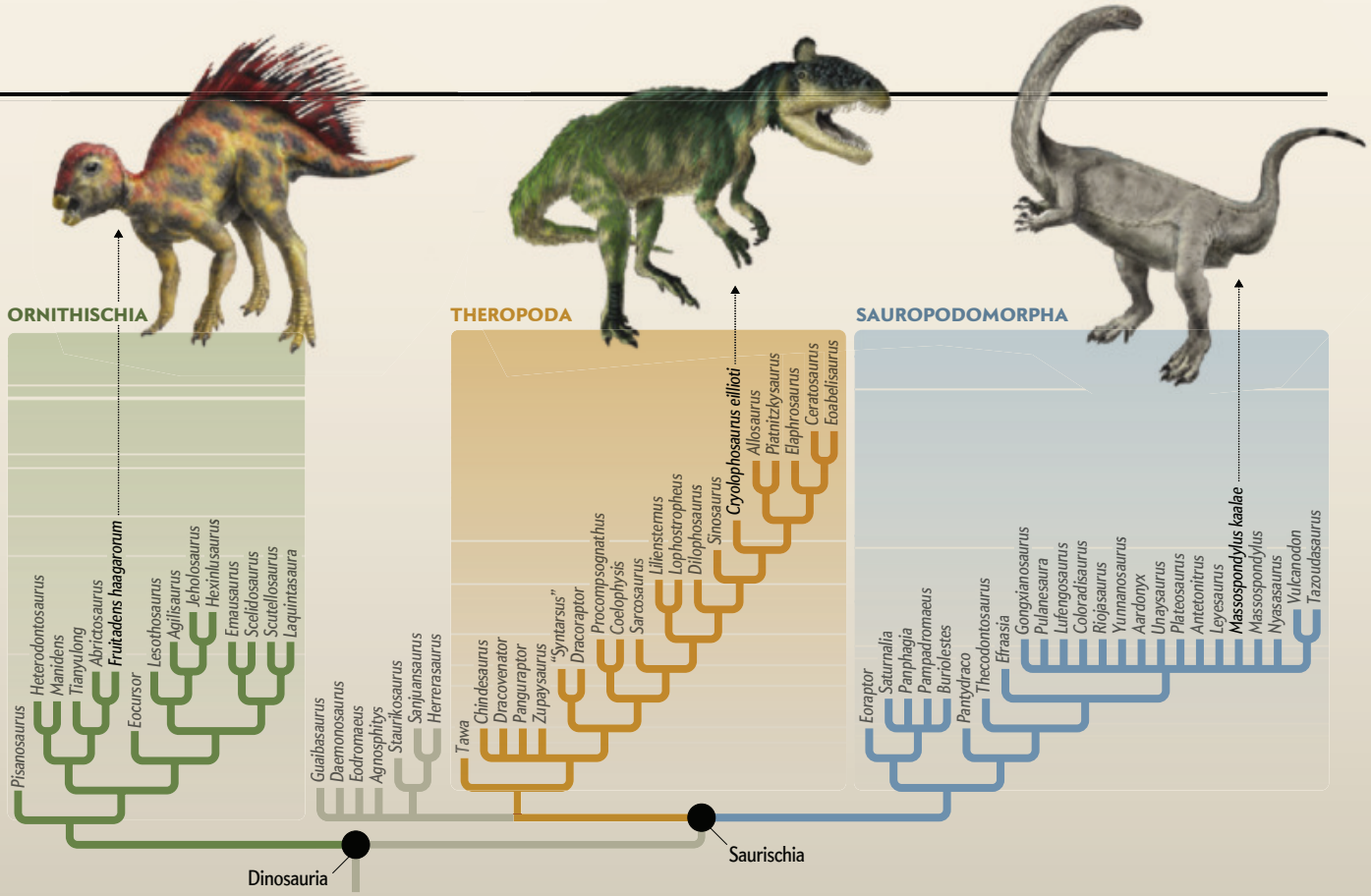
Perhaps the most heated debate in contemporary dinosaur research concerns how the theropods, sauropodomorphs and ornithischians are arranged on the family tree. In 1887 British paleontologist Harry Govier Seeley surveyed the flood of new fossils from Europe and the American West and argued that dinosaurs could be separated into two distinct types, based on the structure of their hip bones. Theropods and sauropodomorphs both have a pubis bone pointing forward, as modern lizards do, so he placed them together in a group he called Saurischia—the "lizard-hipped" species. Ornithischians, with their pubis projecting backward like that of modern birds, were deemed a separate branch of "bird-hipped" dinosaurs. This basic dichotomy persists today as the standard dinosaur classification scheme that I and all my fellow dinosaur hunters learned as students.

It might be incorrect, however. In a bombshell study published in *Nature* early last year, University of Cambridge Ph.D. student Matthew Baron and his colleagues presented a new dinosaur genealogy based on an analysis of an expansive data set of early dinosaurs and their anatomical features. Their tree links together theropods and ornithischians into a group they call Ornithoscelida, with sauropodomorphs perched outside on a separate limb. Instead of saurischians versus ornithischians, the new dinosaur dichotomy is ornithoscelidans versus sauropodomorphs.

Or maybe not. Soon after Baron's study was released, I was approached by Max C. Langer, a Brazilian paleontologist who has described a slew of new Triassic dinosauromorphs and dinosaurs from his homeland over the past decade, including *Ixalerpeton* (a dinosaur precursor very similar to the one that left the *Prorotodactylus* tracks from Poland) and *Saturnalia* (a dog-sized protosauropodomorph). He was skeptical of the new genealogy and recruited a team of experts on early dinosaurs to pore over Baron's data set. Because I had studied the Polish trackways and other key Triassic fossils, Langer asked me to be part of the group. For a month we carefully picked through the data set and noted our various disagreements about how the other team had characterized certain features. We then reran the analysis of the traits with our corrections. The resulting family tree shifted back to saurischians versus ornithischians, although statistical tests showed that this arrangement was not a significantly better fit to the data than Baron's ornithoscelidan versus sauropodomorph tree. We presented our results in a follow-up *Nature* paper in the autumn of 2017.

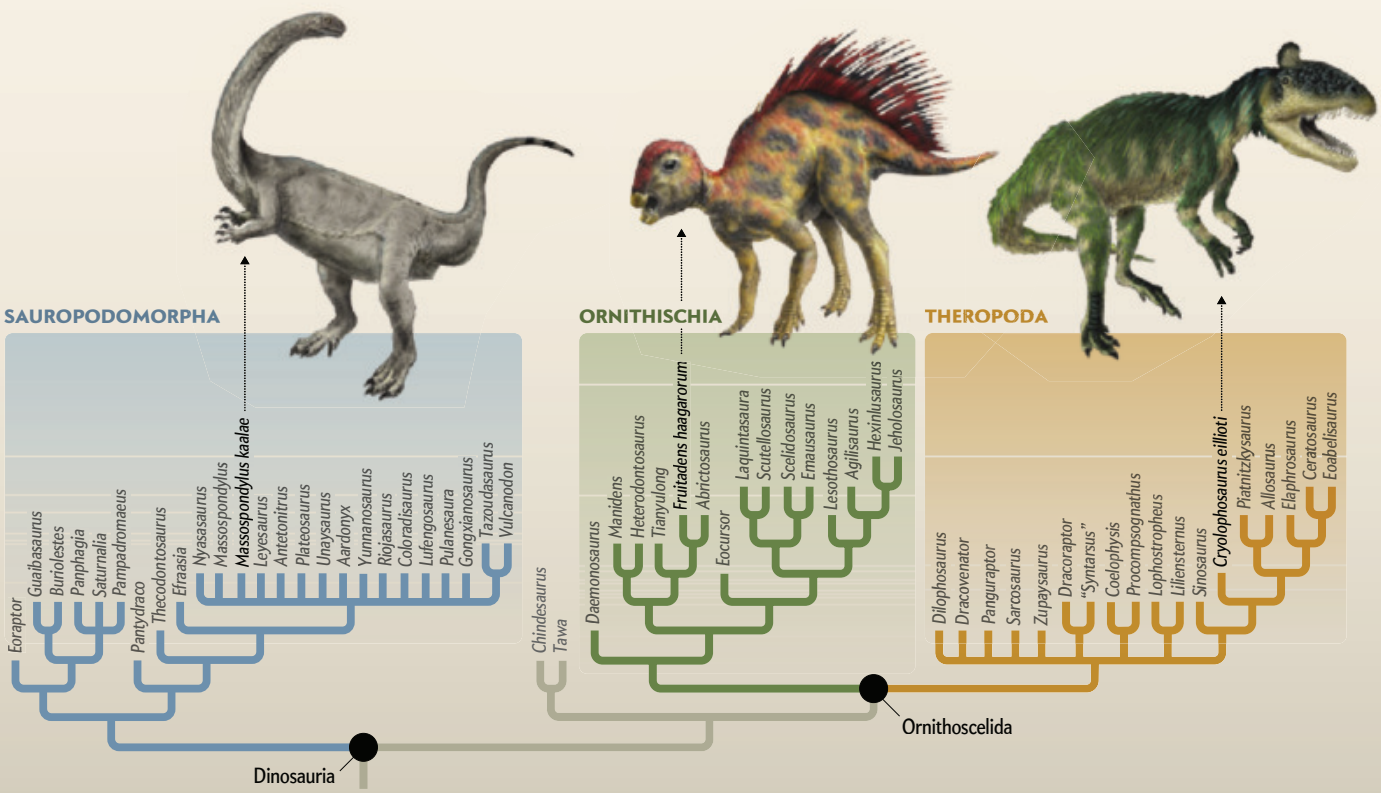
What this ambivalence in the results means is that paleontologists do not currently have a good understanding of the basic shape of the dinosaur tree. It seems that the rush of new discoveries in Argentina, Brazil, Poland and elsewhere over the past 15 years has muddied the picture. We now realize that the earliest members of the three major dinosaur lineages were remarkably similar in body size and anatomy, which makes untangling their relationships difficult. This puzzle is ripe to be solved by the next generation of paleontologists, probably the way these arguments are usually settled: with new fossils. —*S.B.*

SOURCES: "UNTANGLING THE DINOSAUR FAMILY TREE." BY MAX C. LANGER ET AL., IN *NATURE*, VOL. 551. PUBLISHED ONLINE NOVEMBER 1, 2017; "BARON ET AL. REPLY." BY MATTHEW G. BARON ET AL., IN *NATURE*, VOL. 551. PUBLISHED ONLINE NOVEMBER 1, 2017



Traditional View

Paleontologists have long divided dinosaurs into the bird-hipped Ornithischia and the lizard-hipped Saurischia, which includes the theropods and sauropodomorphs.



New Hypothesis

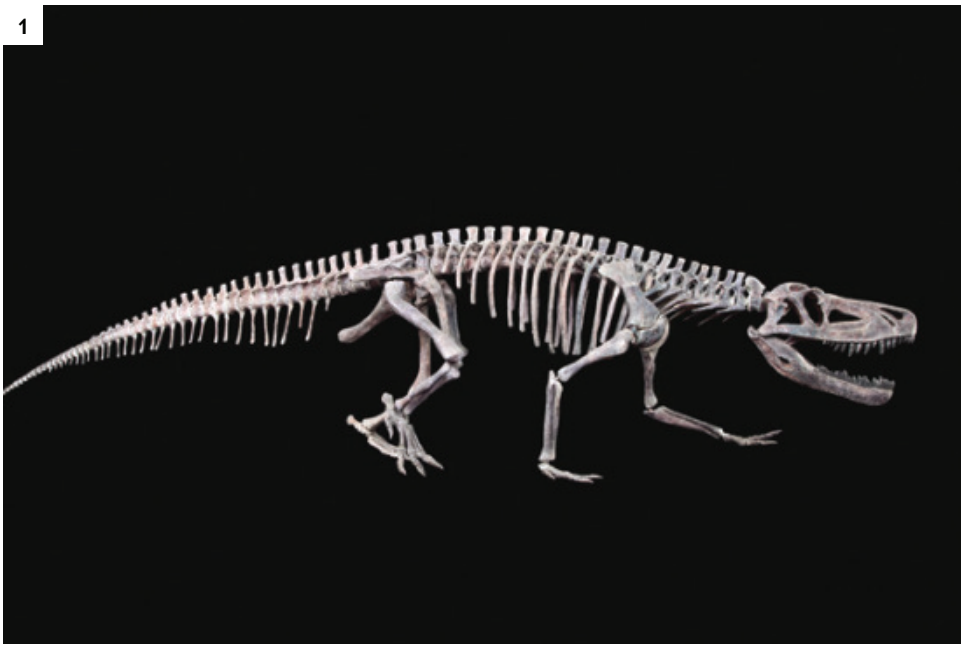
A recent analysis of dinosaur traits concluded that theropods and ornithischians belong to a group called Ornithoscelida and that sauropodomorphs sit on a separate branch.

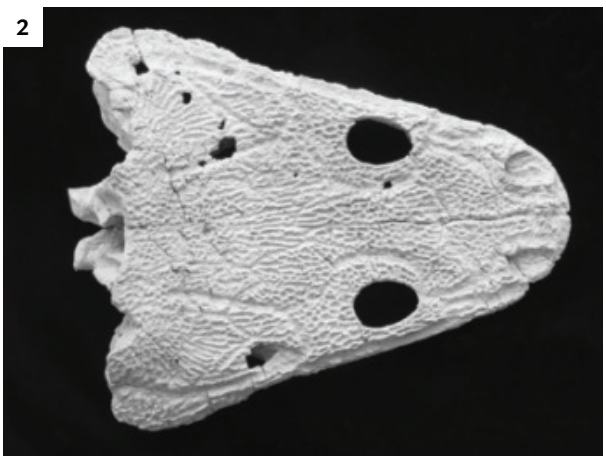
Illustrations by Portia Sloan Rollings, Graphics by Jen Christiansen

the same pattern we saw in Portugal: plenty of amphibians and reptiles but nary a dinosaur. All these places were in the arid sector of Pangea. Together these sites indicate that during the formative years of their evolution, dinosaurs were slowly diversifying in the humid temperate regions but were seemingly unable to colonize the deserts. It is an unexpected story line: far from being superior creatures that swept across Pangea the moment they originated, dinosaurs could not handle the heat. They were geographically localized—mere bit players in the drama playing out across a world still recovering from the great End Permian extinction.

But then, just when it seemed that dinosaurs would never escape their rut, they received two lucky breaks. First, in the humid zone, the dominant large herbivores of the time—reptiles called rhynchosaurs and mammal cousins called dicynodonts—went into decline, disappearing entirely in some areas for reasons still unknown. Their fall from grace between 225 million and 215 million years ago gave primitive plant-eating sauropodomorphs such as *Saturnalia,* a dog-size species with a slightly elongated neck, the opportunity to claim an important niche. Before long these sauropod precursors were the main herbivores in the humid parts of the Northern and Southern Hemispheres. Second, around 215 million years ago dinosaurs finally broke into the deserts of the Northern Hemisphere, probably because shifts in the monsoons and the amount of carbon dioxide in the atmosphere made differences between the humid and arid regions less severe, allowing dinosaurs to migrate between them more easily.

They still had a long road ahead of them, however. The best records of these first desert-dwelling dinosaurs come from areas that are once again deserts today, in the colorful badlands of the southwestern U.S. For more than a decade a team of young researchers has been methodically excavating the Hayden Quarry, a fossil-rich locality in artist Georgia O'Keeffe's much loved retreat of Ghost Ranch in New Mexico. Randall Irmis of the University of Utah, Sterling Nesbitt of Virginia Tech, Nathan Smith of the Natural History Museum of Los Angeles County, Alan Turner of Stony Brook University and Jessica Whiteside of the University of Southampton in England have found a bounty of skeletons: monster amphibians closely related to our Portuguese *Metoposaurus,* primitive crocodile relatives, and a host of curious swimming and tree-hopping reptiles. There are also dinosaurs in the Hayden Quarry, though not many of them: only a few species of predatory theropods, each represented by a few fossils. There were no plant eaters: none of the ancestral long-necked species so common in the humid zones, none of the ornithischian forebears of *Triceratops.* The team argued that, once again, the paucity of dinosaurs came down to the weather: these deserts were unstable environments of fluctuating temperatures and rainfall, with raging wildfires during some parts of the year and humid spells in others. Plants had difficulty establishing stable communities, which meant that plant-eating dinosaurs did not have a steady source of food. Thus, some 20 million years after they had originated and even after they had taken over the big herbivore role in humid ecosystems and started to settle the tropical deserts, dinosaurs had yet to mount a global revolution.





STIFF COMPETITION: For much of the Triassic period dinosaurs were a marginal group, overshadowed by the likes of crocodile relatives such as *Saurosuchus* (*1*) and giant amphibians such as *Metoposaurus* (*2*).

RICARDO N. MARTÍNEZ *Institute and Museum of Natural Sciences, National University of San Juan* (*1*); TOMASZ SULEJ *Institute of Paleobiology, Polish Academy of Sciences* (*2*)

CROC COMPETITION

NO MATTER WHICH INTERVAL you look at in the Triassic, from the time the first dinosaurs appeared around 230 million years ago until the period ended 201 million years ago, the story is the same. Only some dinosaurs were able to live in some parts of

the world, and wherever they lived—humid forests or parched deserts—they were surrounded by all kinds of bigger, more common, more diverse animals. In Argentina's Ischigualasto, for instance, those earliest dinosaurs made up only about 10 to 20 percent of the total ecosystem. The situation was similar in Brazil and, millions of years later, at the Hayden Quarry. In all cases, the dinosaurs were vastly outnumbered by mammal forerunners, giant amphibians and eccentric reptiles.

More than anything, however, Triassic dinosaurs were being outgunned by their close cousins the so-called pseudosuchians, on the crocodile side of the archosaur family. At Ischigualasto, a crocodile-line archosaur called *Saurosuchus* ruled the food chain, with its sharp teeth and muscular jaws. Hayden Quarry harbored numerous pseudosuchian species: semiaquatic ones with long snouts, armored ones that ate plants, and even toothless ones that sprinted on their hind legs and bore a striking resemblance to some of the theropod dinosaurs they lived alongside.

As a master's student in the late 2000s, around the time many of these fossils were being discovered, I found this pattern peculiar. At the same time I was following the onslaught of new fossils, I started reading classic studies by giants in the field of paleontology, including Robert Bakker and Alan Charig, who effusively argued that dinosaurs were so perfectly adapted, with speed and endurance and smarts, that they quickly took out their crocodile cousins and other competitors during the Triassic. But this idea did not seem to jibe with the fossil record. Was there some way I could test it?

After immersing myself in literature on statistics, I realized that two decades earlier paleontologists who study invertebrate animals had come up with a method for measuring anatomical diversity in a group of species, which had so far been ignored by dinosaur researchers. This measurement is called morphological disparity. If I could track the disparity of dinosaurs and pseudosuchians over the Triassic, I could see whether they were becoming more or less diverse and at what rate—which would indicate whether they became successful gradually or abruptly—and whether one group was pulling ahead of the other.

Working with my then supervisors at the University of Bristol in England—Michael Benton, Marcello Ruta and Graeme Lloyd—I compiled a large data set of Triassic dinosaurs and pseudosuchians, assessing more than 400 characteristics of their anatomy. When we analyzed it statistically, we came up with a startling result that we published in 2008 in *Science*. All throughout the Triassic the pseudosuchians were significantly more anatomically diverse than the dinosaurs, which indicates that they were experimenting with more diets, more behaviors and more ways of making a living. Both groups were becoming more diverse as the Triassic unfolded, but the pseudosuchians always outpaced the dinosaurs. Contrary to the leading view of dinosaurs as superior soldiers slaying their rivals, they were actually losing to the pseudosuchians for most of their long coexistence.

CARPE DIEM

OUR STATISTICAL ANALYSIS led us to an iconoclastic conclusion: the first dinosaurs were not particularly special, at least compared with the variety of other animals they were evolving alongside during the Triassic. If you were around back then to survey the Pangean scene, you probably would have considered the dinosaurs a fairly marginal group. And if you were of a gambling persuasion, you would probably have bet on some of the other animals, most likely those hyperdiverse pseudosuchians, to eventually become dominant, grow to massive sizes and conquer the world. But of course, we know that it was the dinosaurs that became ascendant and even persist today as more than 10,000 species of birds. In contrast, only two dozen or so species of modern crocodilians have survived to the present day.

How did dinosaurs eventually wrestle the crown from their crocodile-line cousins? The biggest factor appears to have been another stroke of good fortune outside the dinosaurs' control. Toward the end of the Triassic great geologic forces pulled on Pangea from both the east and west, causing the supercontinent to fracture. Today the Atlantic Ocean fills that gap, but back then it was a conduit for magma. For more than half a million years tsunamis of lava flooded across much of central Pangea, eerily similar to the enormous volcanic eruptions that closed out the Permian 50 million years prior. Like those earlier eruptions, the End Triassic ones also triggered a mass extinction. The crocodile-line archosaurs were decimated, with only a few species—the ancestors of today's crocodiles and alligators—able to endure.

Dinosaurs, on the other hand, seemed to have barely noticed this fire and brimstone. All the major subgroups—the theropods, sauropodomorphs and ornithischians—sailed into the next interval of geologic time, the Jurassic Period. As the world was going to hell, dinosaurs were thriving, somehow taking advantage of the chaos around them. I wish I had a good answer for why—was there something special about dinosaurs that gave them an edge over the pseudosuchians, or did they simply walk away from the plane crash unscathed, saved by sheer luck when so many others perished? This is a riddle for the next generation of paleontologists to solve.

Whatever the reason dinosaurs survived that disaster, there is no mistaking the consequences. Once on the other side, freed from the yoke of their pseudosuchian rivals, these dinosaurs had the opportunity to prosper in the Jurassic. They became more diverse, more abundant and bigger than ever before. Completely new dinosaur species evolved and migrated widely, taking pride of place in terrestrial ecosystems the world over. Among these newcomers were the first dinosaurs with plates on their backs and armor covering their bodies; the first truly colossal sauropods that shook the earth as they walked; carnivorous ancestors of *T. rex* that began to get much bigger; and an assortment of other theropods that started to get smaller, lengthen their arms and cover themselves in feathers—predecessors of birds. Dinosaurs were now dominant. It took more than 30 million years, but they had, at long last, arrived. SA

MORE TO EXPLORE

The Origin and Early Radiation of Dinosaurs. Stephen L. Brusatte et al. in *Earth-Science Reviews,* Vol. 101, Nos. 1–2, pages 68–100; July 2010.

Footprints Pull Origin and Diversification of Dinosaur Stem Lineage Deep into Early Triassic. Stephen L. Brusatte, Grzegorz Niedźwiedzki and Richard J. Butler in *Proceedings of the Royal Society B,* Vol. 278, pages 1107–1113; April 7, 2011.

Untangling the Dinosaur Family Tree. Max C. Langer et al. in *Nature,* Vol. 551. Published online November 1, 2017.

FROM OUR ARCHIVES

Rise of the Tyrannosaurs. Stephen Brusatte; May 2015.

scientificamerican.com/magazine/sa

ASTRONOMY

Astronomers' newfound ability to see the same cosmic events in light, particles and gravitational waves—**a synthesis called multimessenger astronomy**—gives them a fuller picture of some of the universe's most mysterious phenomena

Messengers from the Sky

By Ann Finkbeiner

Illustration by Maria Corte Maidagan

Ann Finkbeiner is a science writer based in Baltimore. She specializes in writing about astronomy, cosmology, and the intersection of science and national security. Her most recent book is *A Grand and Bold Thing* (Free Press, 2010) about the Sloan Digital Sky Survey project to map the entire night sky.

A NEUTRINO HIT ON SEPTEMBER 22, 2017, AT 4:54 P.M. EASTERN TIME. THE NEARLY MASSLESS ELEMENTARY particle barreled through the sensors of the IceCube Neutrino Observatory, an experiment buried in the Antarctic ice. This neutrino was rare, carrying an energy of more than 100 tera electron volts, about 10 times the energy reachable by particles inside the most powerful accelerators on Earth. Thirty seconds later IceCube's computers sent out an alert with the neutrino's energy, the time and date, and roughly where it came from in the sky.

At the University of Maryland, College Park, IceCube team member Erik Blaufuss got the alert via text and knew that, with that energy, the particle probably came from beyond the solar system. Blaufuss had already seen 10 or so neutrinos in the past year with energies that high, but he thought, "It's a pretty event—let's send it out there." At 8:09 P.M. he issued a public notice over one of astronomy's heads-up networks about the particle, now called IceCube-170922A. IceCube's more than 5,000 sensors, which look for flashes of light made by neutrinos interacting with atoms in the ice, can trace the path of the flash back to the particle's origin in the sky. And Blaufuss hoped the nighttime notice would "catch observers coming online," astronomers who could look at the same area of the sky the neutrino came from. If they were really lucky, they might find the galaxy or other celestial object that sent it.

Neutrinos are just one of the many things in the sky that flare, ping, bang, shudder and shine. For a long time astronomers could see mainly those that shine, that emit light. Then, roughly 30 years ago, they started to detect little hits of neutrinos from beyond our solar system. And since 2015 they have been able to detect the rolling waves of gravity. But combining these different signals to study individual objects—a technique called multimessenger astronomy—is mostly a recent development.

One great advantage of multimessenger astronomy is that unlike light—an electromagnetic wave that can get reflected, absorbed and misdirected, obscuring information about its source—almost nothing stops gravitational waves or neutrinos. The message they carry is pure; it comes in directly and at or near the speed of light. Another plus is that their sources—colliding black holes or collapsing supernovae or merging neutron stars—are transient, unspeakably violent perplexities. They were predicted but not seen, were seen but not understood, or were by any other means invisible. But with more messengers, astronomers can finally understand these complex phenomena. "These sources are complicated," says Francis Halzen, a physicist at the University of Wisconsin–Madison and principal investigator of IceCube. "Unless you have many ways to look at them, you're not going to figure them out."

THE TEXAS SOURCE

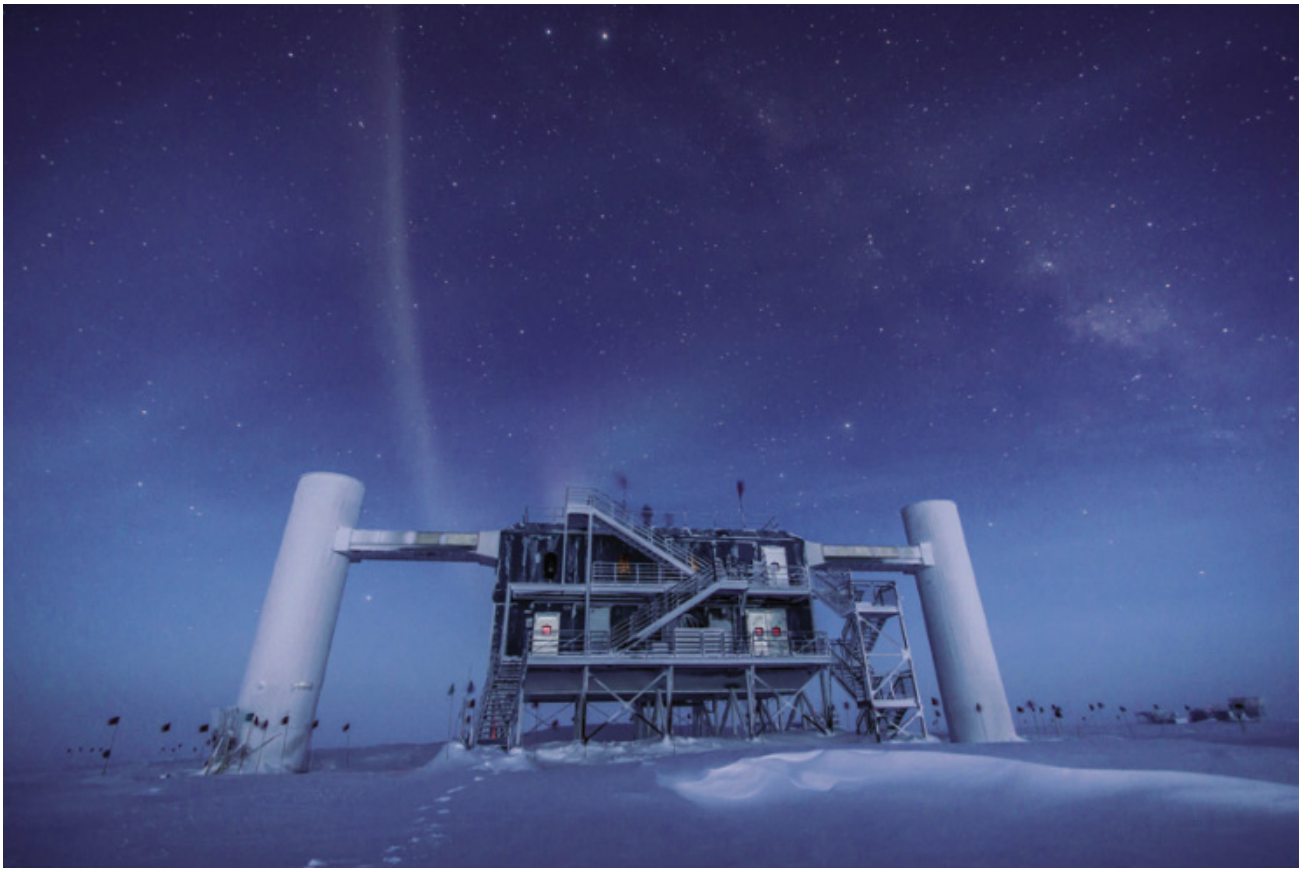
FOUR DAYS AFTER BLAUFUSS sent the IceCube notice, scientists at the Swift Observatory's x-ray space telescope reported that since the alert they had counted nine things emitting x-rays in the area of the sky that IceCube-170922A came from.

Just two days after that, on September 28, at 6:10 A.M., the Fermi orbiting telescope, sensitive to gamma wavelengths, reported gamma rays at the same position as both IceCube-170922A and Swift's second x-ray source. Sara Buson, a member of the Fermi team at NASA's Goddard Space Flight Center, and her colleagues sent out a public notice saying that the gamma source was already known and named TXS 0506+056, which astronomers later nicknamed "the Texas source." "It was very exciting," Buson says. "The neutrino was exactly on top of the gamma, the first time we had such a nice coincidence." In the previous two weeks, Buson's notice said, Fermi had seen the Texas source flare up by a factor of six.

On the same day at 2:00 P.M., scientists working on a survey called ASAS-SN (pronounced "assassin"), operating at optical wavelengths, announced that the Texas source had in fact been brightening over the past 50 days and was the brightest it had been in several years. The next day, September 29, at 9:00 A.M., another optical telescope found that the Texas source was a blazar, a supermassive black hole at the center of a galaxy that spo-

IN BRIEF

Two recent celestial events have ushered in the age of multimessenger astronomy—the technique of observing the same phenomena through light, particles and gravitational waves. **These different messengers** carry unique information, so that combining them gives scientists insight into some of the most mysterious cosmic objects. **Astronomers have traced** gravitational waves and multiple wavelengths of light back to a collision of two dense neutron stars. They have also observed light and neutrino particles coming from what appears to be a huge mass-absorbing black hole.



BURIED IN THE ICE at the South Pole, thousands of sensors make up the IceCube Neutrino Observatory. These sensors look for signs of rare interactions between neutrino particles from space and atoms in the ice. A particularly high-energy neutrino observed in 2017 set off multiple observations from ground- and space-based telescopes to identify the particle's source.

radically flares up as matter falls into it, sending out jets aimed straight at us. Then, on October 17, the Very Large Array in New Mexico, operating at radio wavelengths, confirmed the light was coming from a blazar's jet.

Blazars were already well known but had never been observed in multiple wavelengths and simultaneously identified as the source of a neutrino. More interestingly, the Texas source was also the first time a high-energy neutrino coincided in space and time with a similarly high-energy gamma-ray photon. Halzen notes that over the whole sky, the number of high-energy neutrinos and the number of gamma-ray photons are roughly the same, so "the obvious thing is," he says, "it means you could be seeing the same sources." The similarity in numbers, says Imre Bartos, a physicist at the University of Florida, is "a remarkable and suggestive coincidence." But the implication that they are coming from the same cosmic objects, from blazars, Halzen adds, "is a looong extrapolation." Nevertheless, the neutrino discovery could help scientists discriminate between different theories about how blazars manage to accelerate their jets to such energies. "This is a good first step," Bartos says, "but what we need is more multimessenger observations."

A LONG WAIT

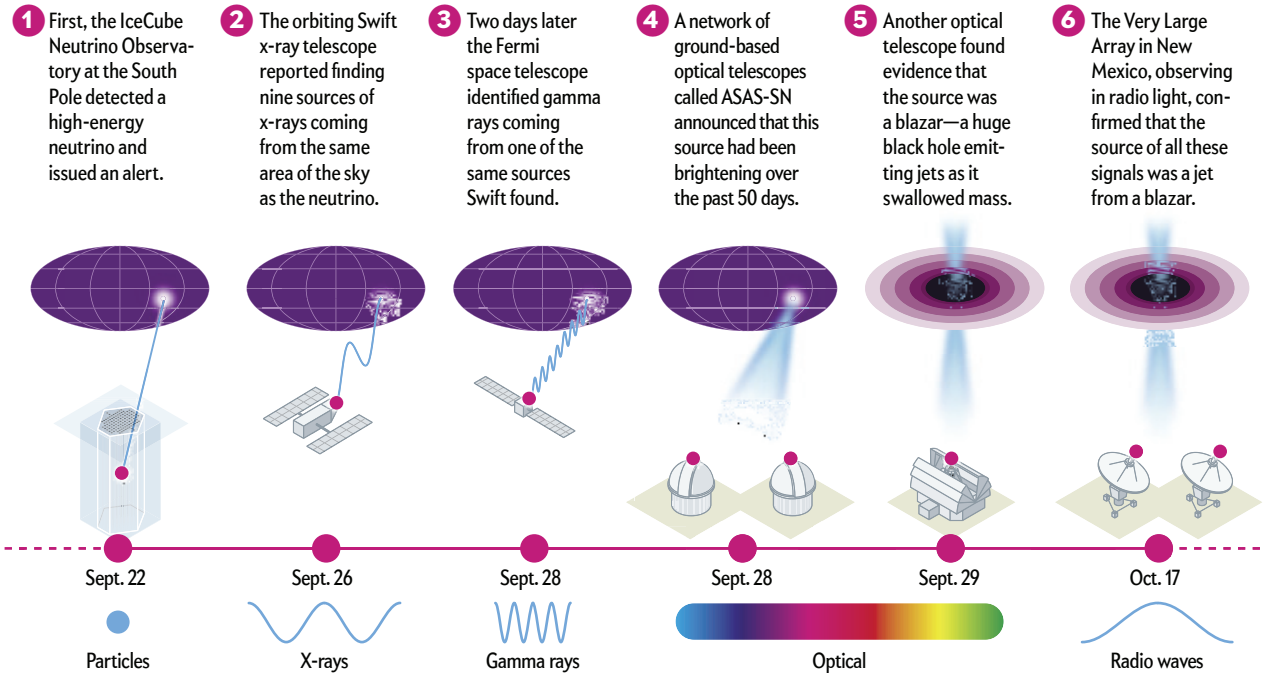
THE FIRST MESSENGER that was not light was the neutrino. It came in February 1987 from Supernova 1987A—a dying star whose core collapsed under the weight of its own gravity and then exploded. All in all, scientists detected 25 neutrinos in Japan, the U.S. and Russia. Three hours later optical light came from a shock wave breaking through the star's surface. By November x-rays and gamma rays arrived from decaying radioactive elements and infrared light came from new heavy elements, all created in the explosion. Supernova 1987A helped astronomers understand the way this type of supernova goes off, says Doug Cowen, a physicist at Pennsylvania State University, who is on the IceCube team, and how most of the explosive energy comes out in the form of neutrinos. That was 30 years ago, Halzen says, "and we've been waiting ever since." The coincidence of the IceCube-170922A neutrino with the Texas source—which was eventually observed by at least 19 instruments in gamma rays and x-rays and optical and radio wavelengths—now makes the second neutrino multimessenger event.

Neutrinos might be excellent messengers, but the most outlandish ones are gravitational waves. These once lived solely in the realm of theory, a century-old prediction of Albert Einstein's general relativity. The theory explained the attraction of one mass to another—the apple to Earth—by proposing that mass curved the spacetime around it; the greater the mass, the deeper the curvature. The apple does not so much fall to Earth as it spirals down along the curvature our planet's mass has made in spacetime. The theory went on to predict that if a mass accelerates, the curvature moves outward in waves. The waves are

FELIPE PEDREROS, ICECUBE AND NATIONAL SCIENCE FOUNDATION

Cosmic Chain of Events

Over three and a half weeks in 2017, astronomers observed the same celestial event—what they believe to be a flare-up from matter falling into a supermassive black hole—through multiple wavelengths of light, as well as particles called neutrinos. The combined observations offer scientists much more information about these mysterious phenomena than any measurement alone.



spacetime itself compacting and stretching. So if a gravitational wave moved, for example, through the body of Szabolcs Marka, a physicist at Columbia University, he "would be taller and thinner," he says, "then shorter and wider."

General relativity is widely accepted, and scientists have seen, indirectly, the predicted curvature made by star- and galaxy-sized masses. Gravitational waves themselves, however, had not been seen. In 2014 physicists upgraded an experiment called the Laser Interferometer Gravitational-Wave Observatory (LIGO): two observatories, each with two four-kilometer tubes at right angles to each other. A laser shot from one end of each tube first hits a mirror at the other end, then bounces back, its travel timed. A gravitational wave moving through LIGO would compact and stretch the tubes so that the lasers' travel times would change by one part in 10^{21}, meaning that the four-kilometer tube would be altered by 1/10,000th the diameter of a proton, Marka says, which is like changing the U.S. national debt by one millionth of a cent.

Even with that extraordinary level of precision, LIGO can detect gravitational waves only from extremely dense and massive sources, such as neutron stars: the dropping apple also makes gravitational waves, but comparing an apple's waves to those of a neutron star is not a meaningful exercise. And LIGO's resolution—its ability to locate sources in the sky—is as good as it can be but is still dreadful. With three detectors, one on either side of the U.S. and a third called Virgo in Italy, scientists can trace gravitational waves back to within tens of degrees (the full moon is 0.5 degree across). For an astronomer, says Andy Howell of the University of California, Santa Barbara, that is like waving your hand at the sky and saying, "It's probably somewhere over there."

Between September 14, 2015, and August 14, 2017, LIGO-Virgo detected five different sources of gravitational waves, each produced by the collisions of two black holes that merged into single black holes. These were triumphant observations—the first direct proof not just of gravitational waves but also of the existence of black holes themselves. But they were not multimessenger astronomy. Black holes, being black, are single-messenger events. Current dogma is that they are so dense that light cannot escape them, so their merger is detectable only via gravitational waves. No one expected to see light or neutrinos from these collisions, and although many detectors looked, none did.

COSMIC CRASH

THEN THREE DAYS AFTER the most recent black hole merger sighting, an event occurred that became a poster child for multimessenger astronomy. On August 17, 2017, LIGO-Virgo detected gravitational waves. Just 1.74 seconds later the Fermi telescope saw a burst of gamma rays. The event, called GW170817, seemed to be created by the collision and merger not of black holes but of the densest of all stars: neutron stars.

Neutron stars are the collapsed cores of past supernovae, so compact that all their protons and electrons have squished together to make neutrons; they are the final state of stars not quite massive enough to form black holes. The gravitational waves LIGO-Virgo saw would have come from the two stars'

Illustration by Nigel Hawtin

inspiral right before they smashed and the gamma-ray burst from their blazing merger—when "all hell breaks loose," says Penn State's Peter Mészáros.

Over the next 24 hours—"like dropping raw meat into a bear pit," says Maryland astronomer M. Coleman Miller—detectors in all frequencies of light on the ground and in the sky scrambled to observe the signal. They pinpointed the merger to a nearby galaxy called NGC 4993 and watched most of its light immediately fade.

The infrared light, however, kept brightening until day three, a sign that as the stars merged, they ejected detritus in which the heaviest of chemical elements were forming. Over the next weeks x-ray and radio light brightened as well, meaning that a near-light-speed jet was pushing through the ejecta. No neutrinos came through, however, so the jets must not have been aimed at us; neutrino detectors "would definitely have seen if it had pointed in our direction," Halzen says. Put together, the messengers were evidence of a phenomenon predicted but never seen, let alone watched in real time: the explosive collision of two neutron stars, called a kilonova. The end stage was either another neutron star, a neutron star on its way to becoming a black hole, or a black hole.

Put together, the messengers were evidence of a phenomenon predicted but never seen, let alone watched in real time: the explosive collision of two neutron stars.

Two months after the kilonova, astronomers announced GW 170817 to the world. That day, October 16, 2017, arXiv.org, a Web site that publishes preprints of science's scholarly papers, received 67 papers. In two months the number of papers roughly doubled: "arXiv is too much," Alessandra Corsi of Texas Tech University says. "I'm having a hard time keeping track."

And just like that, several of astronomy's unsolved problems dropped like swatted flies. The particular kind of gamma-ray burst, a variety that had been seen for decades but whose source had never been directly identified, was now known to come from neutron star mergers. And kilonovae were now understood for the first time to be the birthplaces of a large fraction of the universe's heaviest elements, including platinum, uranium and "about 100 Earth masses in gold," says Samaya Nissanke of Radboud University in the Netherlands. In the weeks afterward, chemists had to rejigger their listings of the sources of the elements on the periodic table. Furthermore, the details of the forms of the gravitational waves cast doubt on the set of alternatives to general relativity proposed to account for the existence of dark matter—possibly excluding the alternative that the universe exists in more than four dimensions.

As always, the finding brought up just as many questions. Astronomers want to know what happens after neutron stars merge. They want to see a neutron star merging with a black hole and to discover how jets arise and what powers them. They still do not know how the cores of stars collapse into supernovae, and they want to watch supermassive black holes in the centers of galaxies merging with other supermassive black holes in the centers of other galaxies.

Thus, aside from the multitude of new and planned detectors of light, scientists envision a whole raft of new multimessenger detectors. LIGO has siblings under construction in Japan and India. The Laser Interferometer Space Antenna (LISA) will be an orbiting gravitational-wave detector scheduled to launch in the 2030s; its arms are lasers zipping among three spacecraft arranged so they form a triangle with sides extending around a million miles. And new high-energy neutrino detectors are in the works, including a next-generation IceCube and KM3NeT, a cubic kilometer of sensors 3,500 meters down in the Mediterranean Sea.

THE WAGER

MEANWHILE ASTRONOMERS like nothing better than finding things in the sky they were not sure they would ever see. Nissanke got her physics Ph.D. in 2007 from the Paris Institute of Astrophysics, and every day since, she says, she has been thinking about how to see the sources of gravitational waves in light. She would give talks on the subject and would get critical questions. "Astronomers would say, 'You have huge uncertainties, you're measuring tiny displacements, you have huge sky errors.'" When they were not asking questions, they were unimpressed: "Half the audience would look at me like I was on something," Nissanke says. "The other half was asleep." She did this for 10 years.

On August 17, 2017, while speaking at a conference in Amsterdam, she predicted that the first multimessenger events with light and gravitational waves would come in the 2020s. "And the hands went up," she says: "'Samaya, aren't you being overly optimistic?'" After the talk, she had lunch with the LIGO-India consortium, during which she upped her ante: "I don't [usually] bet, but I said I think we'll see the first neutron star merger." Scientists on LIGO-India said not before 2019 and took the wager, a "gentleman/woman's handshake bet," Nissanke says. An hour later LIGO-Virgo saw the neutron star merger. A member of the consortium wrote to her: Before the next conference, let's "tempt nature" and talk about whether we'll see a neutron star–black hole merger.

Nissanke pauses in her story. "I did predict the neutron star's merger, this golden binary, but it took several hours for it to sink in that we were really seeing it," she says. "There's going to be more excitement and many, many, many more papers. It's amazingly fun." SA

MORE TO EXPLORE

Multi-messenger Observations of a Binary Neutron Star Merger. B. P. Abbott et al. in *Astrophysical Journal Letters*, Vol. 848, No. 2, Article No. L2; October 20, 2017. http://iopscience.iop.org/article/10.3847/2041-8213/aa91c9

FROM OUR ARCHIVES

Ripples in Spacetime. W. Wayt Gibbs; April 2002.
Neutrinos at the Ends of the Earth. Francis Halzen; October 2015.

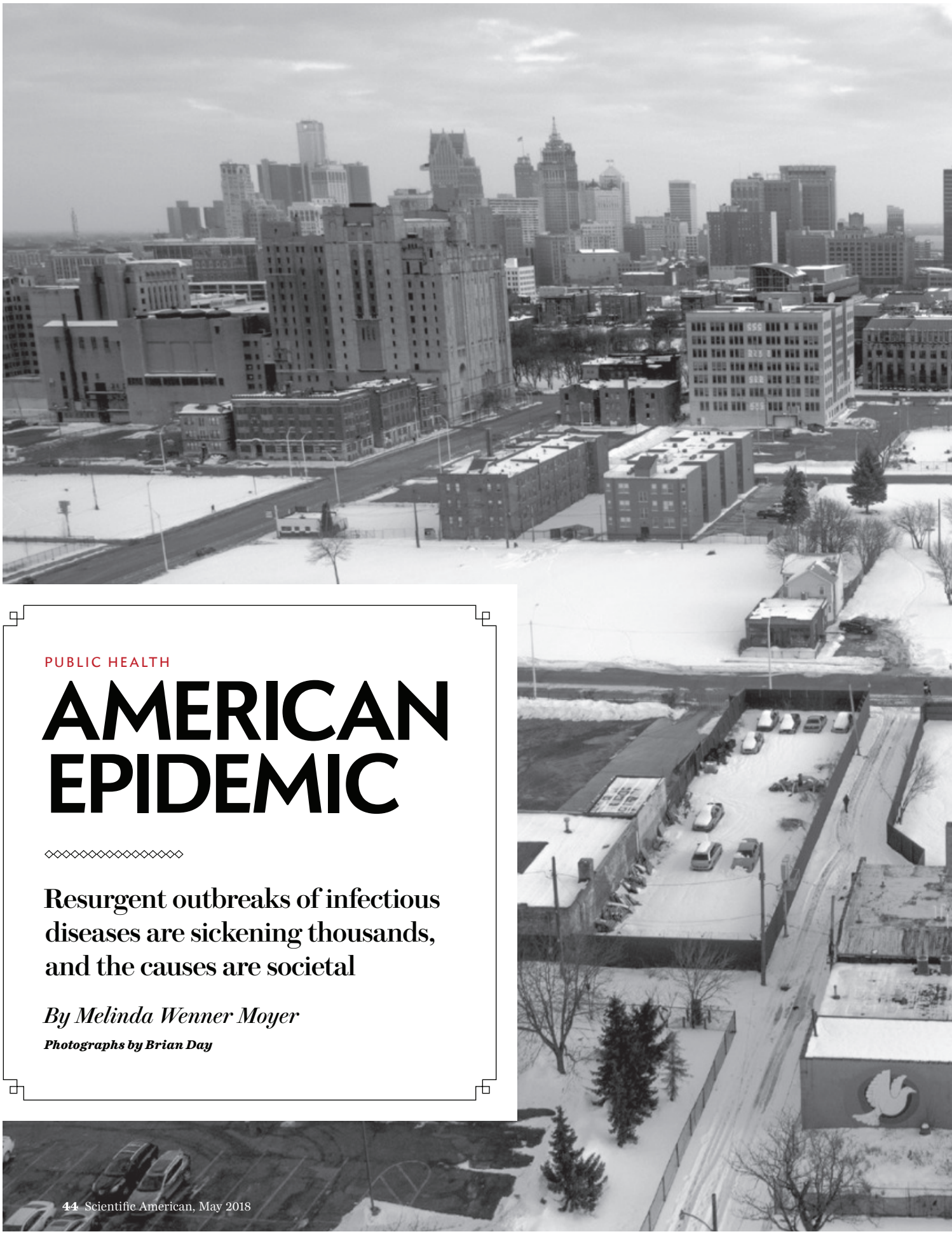
scientificamerican.com/magazine/sa

THE FUTURE OF MEDICINE 2018

EMERGING DISEASE IN A CHANGING WORLD

"IN AN UNCHANGING WORLD, YOU DON'T SEE A LOT OF EMERGING disease," epidemiologist William Karesh told *Scientific American* contributor Lois Parshley during her reporting for this issue. The world, of course, is changing fast. In the U.S., growing economic inequality is driving a resurgence of deadly hepatitis, Legionnaires' and other infections. Globally, climate change and unchecked urbanization are creating conditions in which diseases emerge faster and spread farther. As the six articles in this special report show, hope resides with interdisciplinary collaborations—epidemiologists, climatologists, ecologists, and others working together to solve medical problems with deep social roots.

Illustrations by Hanna Barczyk



PUBLIC HEALTH

AMERICAN EPIDEMIC

Resurgent outbreaks of infectious diseases are sickening thousands, and the causes are societal

By Melinda Wenner Moyer

Photographs by Brian Day

MIDTOWN DETROIT'S Cass Corridor neighborhood has new construction, as well as a population of sick and homeless people.

Contributing editor **Melinda Wenner Moyer** won an Award for Excellence in Health Care Journalism for her December 2016 *Scientific American* article "The Looming Threat of Factory-Farm Superbugs."

DEAN CARPENTER ZIGZAGS HIS WAY through a row of men seated in hard plastic chairs at Detroit's Tumaini Center, a crisis support organization for the chronically homeless in Michigan's biggest city. The center has no beds, so some men have been living in those chairs for weeks, even years, while case workers try to secure them housing. Carpenter, the center's nurse practitioner, has seen patients with many ailments over the years: scabies, trench foot and, most recently, hepatitis A, which he is on a mission to vanquish. "You want a hepatitis A vaccine? There's an outbreak in Detroit," Carpenter says quietly to one older man. The man nods, rises and follows Carpenter to the conference room, where a second nurse practitioner and a team of Michigan State University medical students wait with needles.

IN BRIEF

Rising rates of hepatitis A, Legionnaires' disease and other scourges carried by viruses, bacteria and parasites are scarring U.S. cities. **Infectious diseases,** once thought to be on the wane, are making a comeback, driven by widening economic inequality and microbe-vulnerable buildings. **Not only the poor** but the well off are at risk, as disease transmission crosses lines of health and wealth.

It was January 8, 2018, and Detroit was in the midst of the largest hepatitis A outbreak in the city's history. Since August 2016 the disease has stretched across southeastern Michigan, sickening more than 770 people, and it has become the biggest such outbreak in the U.S. since a vaccine became available in 1995. Cases were still mounting as this article went to press. And Michigan's situation is not unique. Hepatitis A, caused by a virus, has infected 700 people in California—primarily San Diego—between November 2016 and the end of February, and parts of Utah, Colorado, Wyoming and Kentucky have been hit hard, too. The extent is unusual. In many other cases, the illness infects people in small, short-lived, food-associated clusters—sick restaurant workers contaminate food and infect a dozen or so customers. Sustained person-to-person spread like this is rare.

The severity of this epidemic also stands out. An estimated 81 percent of those infected in Michigan have been hospitalized subsequent to liver damage, and 25 have died, as of early March. That is much worse than the typical hospitalization rates, which hover between 11 and 22 percent, according to a 2017 report optimistically entitled *Progress Toward Viral Hepatitis Elimination in the United States,* penned by researchers at the U.S. Centers for Disease Control and Prevention. "To be making rounds on individuals who have been previously healthy but are now in liver failure is really staggering," says Stuart Gordon, a liver specialist at Henry Ford Hospital in Detroit. "We are seeing a much more severe outbreak than we've ever seen before."

Other infections have also been tearing through U.S. cities. In 2017 New York City diagnosed a record number of cases of Legionnaires' disease—65 percent more than in 2016—a serious pneumonia caused by bacteria growing in water systems. In San Francisco, rates of gonorrhea, a sexually transmitted infection that has become worryingly resistant to antibiotics, increased 22 percent between 2015 and 2016; in fact, the incidence of all three nationally reported sexually transmitted infections—chlamydia, gonorrhea and syphilis—have recently reached record highs throughout the country. The list goes on: Cases of cyclosporiasis, an intestinal illness caused by a parasite in drinking water and swimming pools, nearly doubled between 2016 and 2017. Rates of hepatitis C, another virus that damages the liver and one that often becomes chronic, have nearly tripled over the past five years.

1

2

GRAFFITI in Detroit shows champion boxer Joe Louis with a homeless man called Dreadlock Mike, who died several years ago (*1*). A man enters the Tumaini Center in the city, which cares for the homeless today (*2*).

These surging infections in the U.S. are not what the medical world expected. Infectious diseases are less of a threat in this country than they were a century ago, thanks to mass vaccination, improved sanitation, and scientific advances in diagnostics, treatment and epidemiology. Rates of HIV and tuberculosis are still continuing to decline overall. But some infections are making a strong comeback in America, and researchers worry that the effects of the diseases could be more devastating now because the country has a more aged, chronically ill and vulnerable population. Infections rarely seen in the U.S. are also ripe for emergence, some scientists say, and a handful of parasitic diseases are becoming established—yet are woefully underdiagnosed. "We're going to start seeing more and more infectious disease outbreaks," says Margot Kushel, a physician and scientist at the University of California, San Francisco, Center for Vulnerable Populations, which is at the Zuckerberg San Francisco General Hospital and Trauma Center.

There are many causes for these rising infectious tides, but researchers agree that a major driver is the country's ever worsening income inequality. The disparity between America's highest and lowest earners exceeds that of virtually every other developed country, and it is still widening. The number of households earning less than $15,000 a year grew by 37 percent between 2000 and 2016. Households earning $150,000 or more increased by exactly the same amount. In poor areas, where almost half the people live below federal poverty levels, populations doubled during this period. People on these bottom rungs of society's ladder live in crowded, often unclean conditions, have limited health care, must work when sick, have poor nutrition, experience debilitating stress, and are more likely than others to abuse drugs and alcohol—all known infection risk factors.

What makes for large outbreaks, however, is that when illnesses start spreading through America's urban poor, they do not stay there. Between 2000 and 2013 the country's urban population increased by 24 million people, and crowding facilitates transmission. More city-dwelling Americans take public transportation and travel now than ever before, too, turning the nation into the equivalent of a crowded, germ-trading global market.

Infections by the Numbers

Outbreaks of infectious diseases are rising around the world, although deaths are dropping. Here we show several snapshots that capture these trends. Recently in the U.S., the number of people getting sick (A) from certain ailments has risen. Worldwide, the number of people killed from many types of infections (B) has decreased over the long term, although the trend varies at different economic levels. Overall, disease outbreaks (C), a measure that includes both sickness and death, have become more frequent, with more varied causes.

GLOSSARY

Infectious Disease: Illness caused by microorganisms, such as bacteria, viruses, parasites or fungi, that can spread from one person to another or from an animal to a person.

Endemic: Describes the baseline level of a disease usually present in a community.

Epidemic or Outbreak: An increase, often sudden, in the number of cases of a disease above normal levels in a region. An outbreak sometimes refers to an increase in a smaller geographical area.

Pandemic: An epidemic that has spread across several countries or continents and usually affects a large number of people.

Zoonosis: A type of infectious disease that originates in vertebrate animals and moves to people. It can be spread by direct contact or carried from animals to humans by a vector such as a biting insect.

Measures of Disease

Mortality: The number of deaths caused by a disease in a population at a particular time.

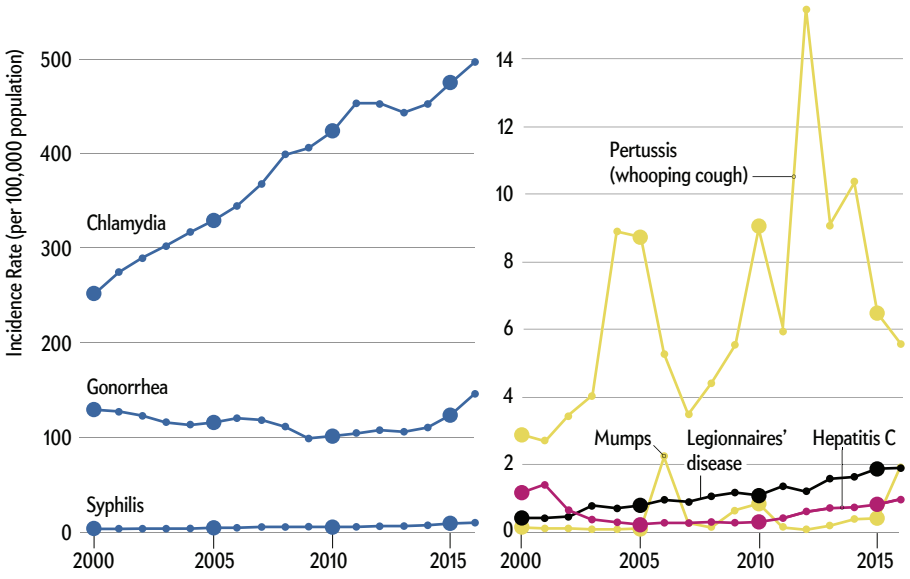
Incidence: The number of new cases of a disease in a population at a particular time.

SOURCES: AMANDA HOBBS (*research*); "SUMMARY OF NOTIFIABLE INFECTIOUS DISEASES AND CONDITIONS—UNITED STATES" REPORTS FOR 2014 AND 2015, IN *MORBIDITY AND MORTALITY WEEKLY REPORT*; 2016 ANNUAL TABLES OF INFECTIOUS DISEASE DATA, NATIONAL NOTIFIABLE DISEASES SURVEILLANCE SYSTEM, CENTERS FOR DISEASE CONTROL AND PREVENTION, 2017 *www.cdc.gov/nndss/infectious-tables.html* (*Legionnaires', mumps, pertussis* and *hepatitis C data*); *SEXUALLY TRANSMITTED DISEASE SURVEILLANCE 2016*. CDC, SEPTEMBER 2017 (*STD data*); *GLOBAL HEALTH ESTIMATES 2015: DEATHS BY CAUSE, AGE, SEX, BY COUNTRY AND BY REGION, 2000–2015*. WORLD HEALTH ORGANIZATION, 2016 (*mortality data*); "GLOBAL RISE IN HUMAN INFECTIOUS DISEASE OUTBREAKS," BY KATHERINE F. SMITH ET AL., IN *JOURNAL OF THE ROYAL SOCIETY INTERFACE*, VOL. 11, NO. 101; DECEMBER 6, 2014 (*outbreak data*)

Graphics by Jen Christiansen

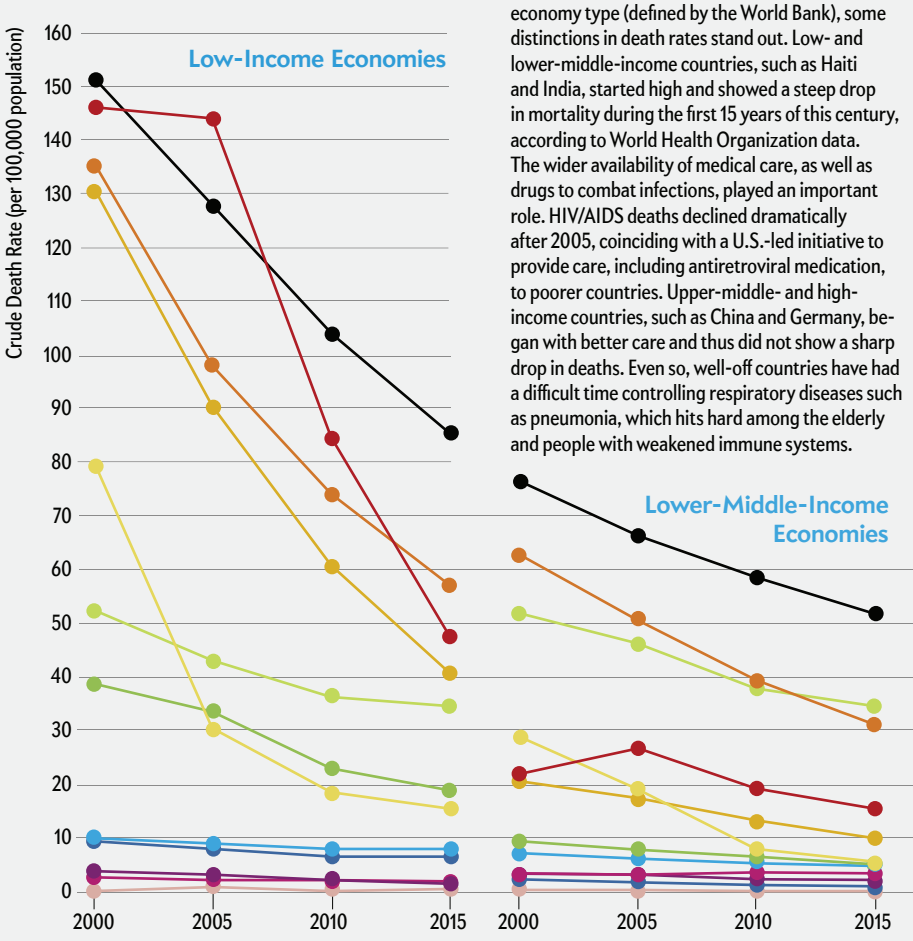
(A) Rising Infections in the U.S.

Historically, the country has done a good job of controlling infections. Recently, though, new cases of certain ailments have gone up, and scientists attribute the rise to growing poverty and increasingly vulnerable populations. Newly diagnosed cases of sexually transmitted disease have increased, U.S. Centers for Disease Control and Prevention data show. Chlamydia, gonorrhea and syphilis have all spiked. Legionnaires' disease and hepatitis C have been climbing as well. Some childhood diseases such as pertussis (whooping cough), for which there are vaccines, appear to rise and then drop.



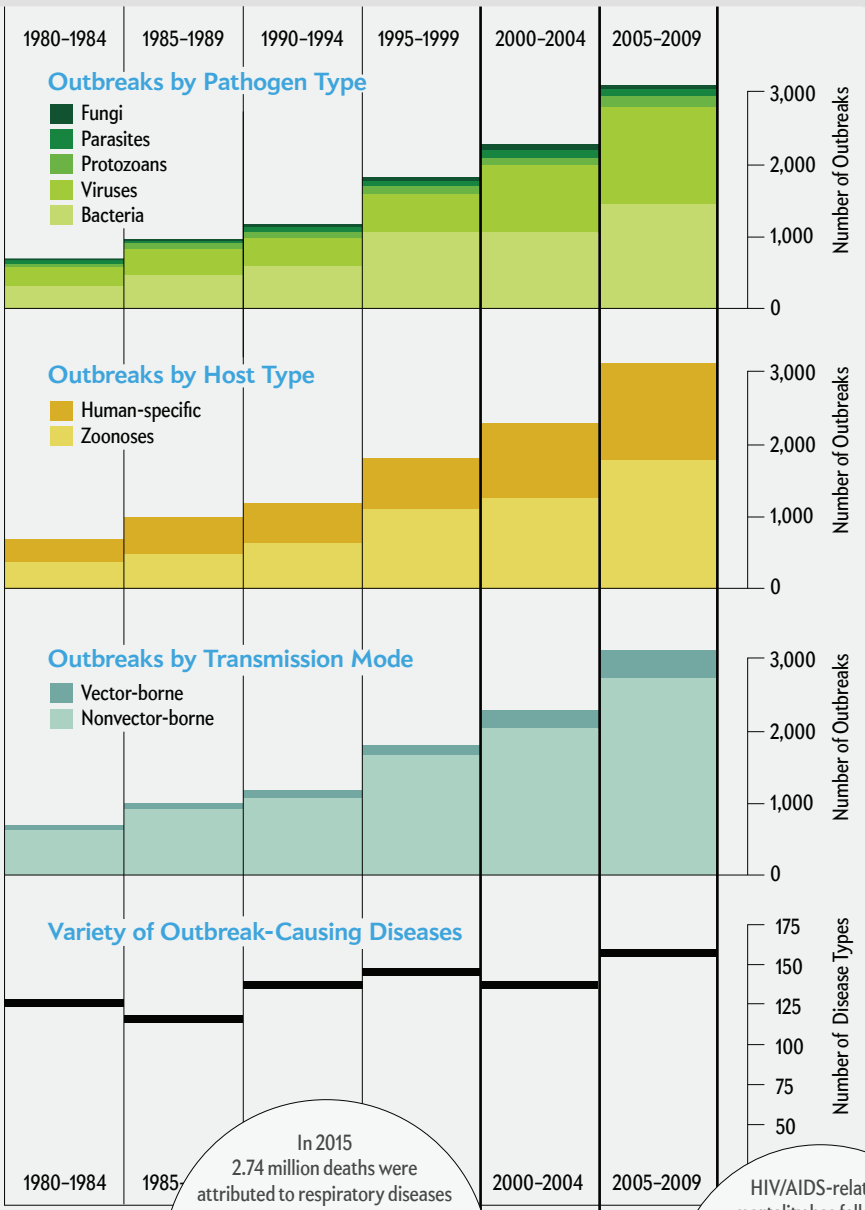
(B) Global Mortality Drops but Differs by Economy

When the countries of the world are divided by economy type (defined by the World Bank), some distinctions in death rates stand out. Low- and lower-middle-income countries, such as Haiti and India, started high and showed a steep drop in mortality during the first 15 years of this century, according to World Health Organization data. The wider availability of medical care, as well as drugs to combat infections, played an important role. HIV/AIDS deaths declined dramatically after 2005, coinciding with a U.S.-led initiative to provide care, including antiretroviral medication, to poorer countries. Upper-middle- and high-income countries, such as China and Germany, began with better care and thus did not show a sharp drop in deaths. Even so, well-off countries have had a difficult time controlling respiratory diseases such as pneumonia, which hits hard among the elderly and people with weakened immune systems.



Global Outbreaks Rise

The number of infectious disease outbreaks worldwide rose steadily during the 30 years following 1980. The variety of outbreak-causing diseases went up as well, according to an analysis of 10,643 outbreaks that was reported in 2014 in the *Journal of the Royal Society Interface*. Viruses and bacteria were the most common causes of disease during those three decades. And the number of outbreaks driven by both person-to-person transmission and vectors such as insects climbed. Epidemics from zoonotic diseases increased over time, slightly more so than did human-specific illnesses. Most of these zoonotic outbreaks were traced to a few familiar causes. One was salmonellosis, a bacterial zoonosis responsible for 855 outbreaks, the most of any disease in the data set. Although outbreaks are on the upswing, the actual number of people infected as a percent of the total world population declined (*data not shown here*) as the international community increased epidemic containment efforts for diseases such as Ebola and H1N1 influenza.

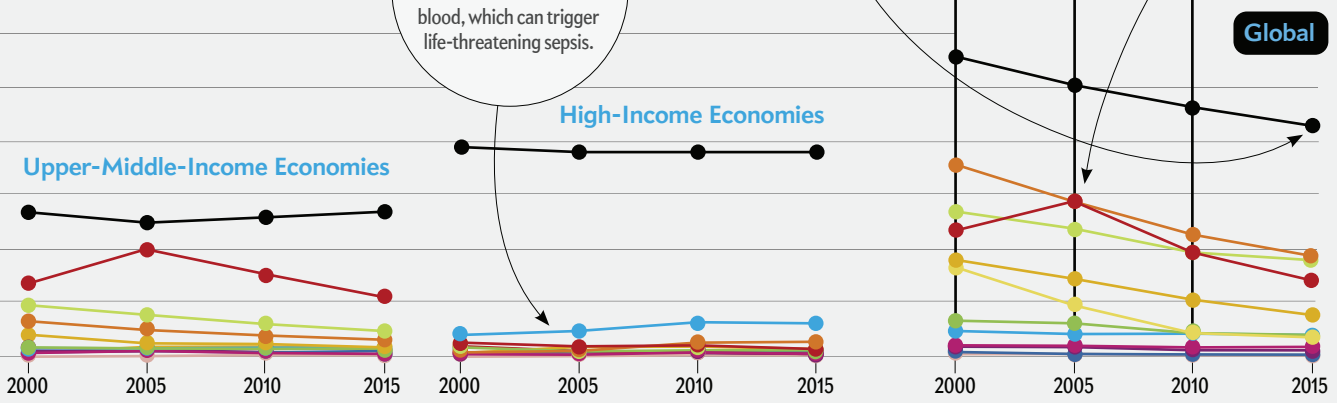


- Respiratory diseases (including influenza and pneumonia)
- HIV/AIDS
- Diarrheal diseases
- Parasitic and vector diseases (including malaria)
- Childhood-cluster diseases (including measles)
- Tuberculosis
- Meningitis
- Other infectious diseases
- STDs (excluding HIV)
- Encephalitis
- Hepatitis (does not include hepatitis-related cirrhosis or liver cancer)
- Leprosy

In 2015 2.74 million deaths were attributed to respiratory diseases such as pneumonia and influenza. Deaths in children decreased, but those numbers were countered by deaths among a larger aging population: pneumococcal pneumonia killed more than 690,000 people aged 70 and older that year.

HIV/AIDS-related mortality has fallen by about 48 percent since a 2005 peak, thanks to widespread antiretroviral therapy. But the disease still takes a terrible toll: in 2016 one million people died from AIDS-related illnesses worldwide.

This trend likely reflects an ongoing struggle to treat dangerous bacterial infections in the blood, which can trigger life-threatening sepsis.



1

Changes in city infrastructure also drive up current infection risk. The huge water towers that provide buildings with air-conditioning are perfect breeding grounds for the bacterium that causes Legionnaires' disease; well-meaning attempts to conserve energy by reducing flow and water temperature in these tower systems "really amplify the conditions that allow *Legionella* to thrive," says Ruth Berkelman, director of the Center for Public Health Preparedness and Research at Emory University's Rollins School of Public Health. Many public housing and school buildings in U.S. cities are more than 100 years old and suffer from poor ventilation, which causes microbes to concentrate on surfaces and in indoor air pockets; some new buildings intentionally minimize ventilation to conserve energy. And water pipes are aging and increasingly leaking, breaking and becoming contaminated with microbes.

These disease-driving forces are social and economic rather than biological and medical, and they have been overlooked by many scientists and politicians. Few researchers have been studying how larger societal issues increase infection risk, and on the policy side, investment in disease prevention and control has been dropping. "We look more and more like the developing world, with very, very rich people and very, very poor people, and the very, very poor people are living in really abysmal situations," Kushel says. Inattention to this divide, and not any shortfall in medical innovation, is leaving our doors wide open for infectious catastrophe.

HOW THE OTHER HALF DIES

AN HOUR AFTER CARPENTER'S ROUNDS, a dozen men and women had received hepatitis A vaccines in the conference room. Then a shivering middle-aged African-American woman sought the help of Carpenter and his partner that day, nurse practitioner Nicole Merenius. The woman had been having chills, a cough and congestion for several days. Carpenter administered a rapid influenza test, but it came back negative. At this point, most doctors would tell their patients to go home and rest. But for this woman, a chair in the crowded Tumaini center room *was* home, at least for now. She had nowhere else to go.

The nation's homeless are among the most at risk for infectious disease for a number of reasons. They are either living on the streets, where they do not have easy access to toilets, sinks and showers, or they are staying in crowded shelters with similar problems. They are often surrounded by coughing, sneezing, sick people. Public health agencies such as the CDC tell Americans to wash their hands frequently and to stay home when ill, yet the homeless do not have the opportunity to do either. They offer profound testimony to the problem with conventional wisdom that says that infections are caused solely by germs. The truth is

2

AT THE TUMAINI CENTER, people live in chairs because the center has no beds (*1*). The homeless, and the city in general, have been in the grip of a hepatitis A epidemic; at the center a man gets vaccinated against the disease (*2*).

that a person's life and circumstances strongly shape their risk.

There are good data to back up this idea. One century ago the 1918 Spanish flu swept across the globe, taking 50 million lives. In a 2016 study published in the *Proceedings of the National Academy of Sciences USA,* a team of biologists and epidemiologists showed how demographics and socioeconomic status changed the risk of death in Chicago during the outbreak. Although pandemics by nature are supposed to put everyone equally in peril, the researchers found something quite different. In census tracts housing more people who were illiterate—a marker for a poverty, among other things—mortality rates were much higher than in areas with high literacy rates. With every 10 percent increase in the illiteracy rate, they found, there was a corresponding 32 percent increase in flu-triggered death. Scientists discovered, too, that the flu spread much more quickly in Chicago areas that were more crowded and had higher rates of illiteracy and unemployment compared with other city regions.

The homeless might be uniquely susceptible to infectious disease, but for similar reasons home- and apartment-dwelling individuals who live in poverty are not much better off. Financial woes incite stress, which has been shown to amplify infectious disease risk. In a paper published in 1991 in the *New England Journal of Medicine,* researchers assessed the stress levels of 394 individuals and then gave them nasal drops containing either one of five types of respiratory viruses or a saline solution. The more stress the people were under, the more likely they were to fall ill if the drops they had been given contained a virus. Poor Americans also have a harder time maintaining a healthy diet. A 2017 survey of nearly 2,000 supermarkets across the U.S. found that, per serving, healthy foods such as fruits and vegetables cost twice as much as unhealthy foods such as sweets and salty snacks. Nutritious foods are also harder to find in poor areas: Johns Hopkins researchers reported that stores in lower-income Baltimore neighborhoods had less healthy food on offer than did stores in more affluent ones. And when nutritious food is hard to get, prognoses worsen. Researchers reported in a 2016 study that certain nutritional deficiencies make it more likely for patients admitted to infectious disease clinics to die.

The aging population is yet another booming disease risk. The number of Americans aged 65 and older is expected to double between now and 2060, and as individuals age, their immune systems weaken and have a harder time fighting off microbial insults. Then, when they do get sick, they fare poorly. Elderly patients are three times as likely to die from common infections than younger individuals. Pneumonia and influenza, for instance, are the fourth-leading cause of death among American adults 65 and older but only the ninth most common cause among those 25 to 44. And rates of obesity and diabetes are increasing—particularly among lower-income groups—which compounds the problem. "One of the main things that diabetes does is impair your immunity," Kushel says. "As we see more and more people living with obesity and diabetes, we're going to see more infectious diseases."

Substance abuse is also pushing susceptibility higher. The skyrocketing number of new hepatitis C infections in the U.S.—a 15-year high, according to the May 2017 CDC data—is in part because of needle sharing occurring as part of the growing opioid epidemic. Hepatitis C already kills more Americans than any other infectious disease, and the death rate is poised only to increase. The opioid epidemic could also in part explain why Michigan's hepatitis A outbreak has been so deadly: 50 percent of cases were substance users, and 27 percent of them had underlying hepatitis C, which means they were hit with two liver infections at once. Substance abuse leads to risky behavior, too, including unprotected sex. A syphilis outbreak tied to drug use swept through Oklahoma City beginning in March 2017, and during the next 12 months it sickened 241 people.

The working poor in urban areas are also uniquely positioned to spread infectious diseases because of their job conditions. More than one million low-income Americans work as food preparers, which pays an average of $13,200 a year. Many of these workers go in even when they are ill. In a 2015 study, researchers at state health departments interviewed 426 restaurant managers around the country and reported that many of the restaurants' policies regarding working while ill violated U.S. Food and Drug Administration recommendations. Seventy percent of the managers said they had worked while sick—even with a stomach bug—because they felt obligated or worried that they would not get paid otherwise. According to a 2014 report by nonprofit Families and Work Institute, only 52 percent of employers offer paid sick leave, and among those who do, 41 percent offer it only to employees who have worked there for at least a year. "You can just imagine that if people feel they have to work or they won't get paid for that time, that you're going to have a lot of sick people at work," says Jonathan Fielding,

a health policy researcher at the U.C.L.A. Fielding School of Public Health. In Michigan's outbreak, 32 of the individuals who have gotten hepatitis A have been food workers; some unwittingly spread the infection because they worked while harboring the virus.

Yet if the seed of an infectious illness can be traced back to poverty, when it spreads widely enough, no class gets spared. Stanley Kozlowicz, a retired General Motors engineer living in Dearborn Heights, a city 12 miles west of Detroit, needed a liver transplant after he caught hepatitis A. He believes he was infected from restaurant food in July 2017, although the county health department has not been able to pinpoint the source. "I was in really good shape, walking six and a half miles a day," Kozlowicz says. Weeks later "a doctor said, 'Well, it's in God's hands—we've done everything.'" He had his transplant in August 2017, but his health woes continued. He had a second operation because of leaking bile, a common liver transplant complication. Then he developed sepsis, and then his body partially rejected the new liver. This January, Kozlowicz was back in the hospital because a liver biopsy—his third since catching hepatitis A—had caused internal bleeding. But he was optimistic. "I think we've finally turned a corner," he says.

Kozlowicz is among many middle- and upper-class Michigan residents who have fallen ill during the epidemic. "It really is a human society issue because while it may have started in [the homeless population], it can easily transmit to the whole of society—we've seen that," says Henry Ford Hospital's Gordon. One large New York City outbreak of Legionnaire's disease was traced back to the posh Opera House Hotel in the South Bronx. And sexually transmitted infections do not heed class boundaries, either. "We're seeing disproportionate increases in STDs based on social disparities," says David Harvey, executive director of the National Coalition of STD Directors, an organization representing health department STD directors and community-based partners. But "we are seeing increases across the board, and in all populations in the U.S. In fact, right now we have the highest number of STD cases in American history."

Once they reach critical mass, epidemics then become difficult to stop. Michigan's hepatitis A problem has been boiling for more than 18 months. "I don't know how long this is going to go on, but there is a possibility that despite our best efforts, this is going to run its course naturally" and continue for quite some time, says Kevin Lokar, medical director of Michigan's Macomb County Health Department, 21 miles north of Detroit. The natural course of an infection can, in some cases, take decades. In the early 1900s tuberculosis began spreading throughout Cape Town, South Africa—a city with extreme poverty as well as exorbitant wealth—and despite careful attempts to control it over the years, rates are still as high today. "Things have changed very little," said Robin Wood, director of the Desmond Tutu HIV Center at the University of Cape Town, at a conference held at Washington, D.C.'s National Academies of Sciences, Engineering, and Medicine in December 2017.

RISKY BUILDINGS

THE WAY CITIES GET BUILT shapes infection risks, too. On March 14, 2003, a 33-year-old man from Shenzhen, China, started to feel unwell. He had a fever, muscle aches and stomach woes, but he was well enough to visit his brother on the 16th floor of block E of Amoy Gardens, a huge Hong Kong complex consisting of 19

Vaccine Inequality

The same preventive shot may be less effective in poor neighborhoods than in rich ones

By Lee Riley

Health service shortfalls are often blamed for high disease rates in slums, but service problems are not the only reason poor neighborhoods fare worse than wealthy ones. Infectious diseases can differ at a basic biological level between rich and poor locales, and these differences can cripple vaccines intended to fight them.

My colleagues and I have seen these effects with rheumatic heart disease in poor parts of Brazil. This ailment has virtually disappeared from high-income countries, where antibiotics are readily available, but it is a major cause of heart trouble in less affluent nations, and it is often fatal. The disease is caused by repeated throat infections from group A streptococcal, or GAS, bacteria. When the body's immune system attacks these microbes, some proteins in heart valve cells that look similar to the bacterial proteins get attacked as well.

A vaccine against GAS could thwart such infections. But the bacteria are difficult targets. There are more than 120 different strains of these bacteria, and a typical sore throat from these pathogens can be caused by any number of these strains. Each has a different version of a gene that codes for M protein, a molecule that is a key part of the bacterium's outer membrane. To make an experimental vaccine, researchers included M proteins from 26 common strains to try to ensure immunity. Yet when scientists looked at non-European and non–North American patients with GAS infections, the 26 types appeared much less often or not at all. While these strains were frequent in high-income countries, where the vaccine was developed, they were rarities elsewhere, where the vaccine would be less effective.

Biological differences occur even within the same city. My research team compared GAS strains from children in slums and in wealthy neighborhoods in Salvador, Brazil. The collection of strains in a community is given a number called a diversity index. The greater the number of strains with different M protein genes, the higher the index. The diversity index of GAS strains of well-to-do children—they attended a private clinic and could afford private insurance—was close to that reported from high-income countries, around 0.90. But the index for slum children was higher, about 0.96. There was another distinction: the two most common strains in high-income countries accounted for 36 percent of GAS samples in wealthier Brazilian children but only for 19 percent of samples from two slum clinics. If this experimental vaccine were to be adminis-

tered to the children in Salvador, it would be far less effective in the slums.

The higher diversity of GAS strains in slums may be the result of bacteria changing by trading genes back and forth. Trades may be easier when extreme human crowding exists, which means more frequent contact among different bacterial cells and more gene-trading chances. Strain diversification may increase the chances of a bad immune reaction against the heart.

Germ-level disparity has also been recognized as a potential problem with current widely used vaccines against cervical cancer. These injections target strains of cancer-causing human papillomavirus, or HPV. Research has indicated that a portion of African-American women living in some parts of the southeastern U.S. have different HPV strain infections, however. We do not know if these racial and geographical differences in virus types will ultimately affect vaccine effectiveness. What we do know now is that it is not just access to a clinic that determines what therapies work but also differences among disease-driving germs—distinctions created by the social environment.

***Lee Riley** heads the division of infectious diseases and vaccinology at the University of California, Berkeley, School of Public Health. He is a physician trained in epidemiology and molecular biology.*

33-story apartment towers. While he was there, the man—identified to this day only as patient YY—had a bout of diarrhea and flushed the toilet.

Ten days later other block E residents, including patient YY's brother and sister-in-law, started getting sick. By April 15, 99 people in block E had been diagnosed with severe acute respiratory syndrome, or SARS, a viral disease that kills between one and two of every 10 infected people. Another 222 people in other apartment blocks had the infection as well. The outbreak, which killed 42 people, ended up accounting for nearly 20 percent of all reported SARS cases in Hong Kong during its infamous 2002–2003 contagion.

Scientists spent months trying to understand why the disease hit Amoy Gardens so hard. In a paper published in April 2004 in the *New England Journal of Medicine,* researchers at the University of Hong Kong and the Chinese University of Hong Kong solved the mystery. Each column of bathrooms in the tall building, they discovered, was connected by vertical drainage pipes that branched out to each apartment's fixtures. Every branch had a U-shaped section of pipe that fills with water to prevent rodents, insects and sewer gases from entering each flat from the system. Some U-traps, however, were just below rarely used floor drains in each bathroom, so they never filled up. Many tenants had also installed bathroom fans that created strong negative pressure, drawing air into the bathroom from those empty U-traps. One of those traps became a viral reservoir. When patient YY, who had SARS, flushed his diarrhea on March 14 (he did the same thing during a second visit to his brother on March 19), virus particles in stool droplets made it into the trap. Then the negative pressure from the fan sucked contaminated droplets into other apartments—and also out their windows and into neighboring buildings.

So when it comes to infectious disease, buildings and infrastructure matter a lot. The design of a city determines where sewage, air and water go and whether they get contaminated along the way. If rooms are poorly ventilated, the microbes people exhale or the stool droplets that permeate the air during a toilet flush get more heavily concentrated in the air over time. Yet in an otherwise laudable attempt to promote energy conservation, restricted ventilation is now a construction trend. A handful of states, including New York, Maryland, Illinois and Massachusetts, have passed laws requiring that new homes pass stringent air-tightness tests. Older buildings are being modified, too. "I'm seeing this in college buildings and other buildings, where people have tried to conserve energy and have sealed up all the leaks," says Donald Milton, an environmental health scientist at the University of Maryland School of Public Health. In 2016 researchers at the University of Hong Kong modeled the spread of influenza in various indoor environments and concluded in a paper that "ventilation rate has a strong influence on the outbreak dynamics." Opening a window, they noted, can reduce infection risk as much as getting vaccinated.

Water pipes are another infection source, as Amoy Gardens shows, but pipe-related problems appear badly underreported. In 2013 and 2014 the CDC reported 42 disease outbreaks associated with drinking water in the U.S., but "what makes it to the CDC outbreak database is a dramatic underestimation of true waterborne disease incidence," says Kelly Reynolds, an environmental and occupational health scientist at the University of Arizona School of Public Health. A number of steps have to oc-

cur in succession for an illness to be categorized as outbreak-related: A doctor has to see a sick individual, order a lab test that comes back positive for a reportable infection and then submit the results to the CDC. Next the CDC has to decide to conduct an investigation and determine that an outbreak is indeed taking place. A more realistic estimate of true waterborne disease burden, Reynolds says, is that 19 million to 21 million Americans are sickened by microbe-contaminated water from taps, swimming pools, hot tubs and showers every year, based on data from epidemiological and sampling studies.

Microbes build up in water for a number of reasons. In swimming pools, hot tubs and water parks, people swim while sick or while symptom-free but still contagious, contaminating the water with infected fecal matter. (A standard dose of pool chlorine does not kill all types of germs quickly.) In addition, many drinking-water distribution pipes, particularly in older cities, have become old and leaky; estimates suggest that between 10 and 20 percent of water that leaves water utilities leaks out along the way to its destination, and "where water can leak out, contaminants can leak in," Reynolds says. Well-meaning energy conservation efforts worsen the problem by reducing water flow, which allows microbial biofilms to build up on pipe surfaces, and by reducing the upper threshold of water temperature.

The worrying increase in Legionnaires' disease in the U.S. highlights yet another water-related challenge. Cooling towers are increasingly popular in urban areas because they efficiently cool large buildings through water-based heat exchange. But *Legionella* bacteria, which naturally occur in water, thrive in such warm conditions and can sicken people when they get aerosolized and pumped out of air vents. Aerosolized shower water, fountain water and even supermarket vegetable misters can pose risks, too. Although some of the increase in Legionnaires' diagnoses—which rose by a factor of five in the U.S. between 2000 and 2015—could be to the result of increased awareness and testing by doctors, scientists argue that the infection is likely becoming more common. "One hundred years ago we didn't have heating ventilation and cooling systems the way we do now. Now we've got these bigger buildings, we've got the increased complexity of these plumbing systems," Emory's Berkelman says.

Large cities also increasingly struggle with waste management—and where there is waste, there are disease-carrying rodents. A 2007 study reported that 65 percent of rats tested in Baltimore were infected with leptospirosis, a bacterial disease that people can catch from rat urine. It can cause renal failure and lung hemorrhage. (Pets are also at increased risk, so much so that there is now a popular canine leptospirosis vaccine.) It is another potentially underestimated source of disease; some scientists worry that it is somewhat common but treated by doctors as an unidentified bacterial infection. "There's a laundry list of pathogens that infect both humans and animals that you find in urban rats," explains Gregory Glass, an infectious disease researcher at the University of Florida's Emerging Pathogens Institute. "Yet if you ask how many cases of any of those have been spotted in the past 10 years, the answer is probably pretty close to zero, not because that's the real background but because people just don't look for it."

Rarely diagnosed infections known as neglected tropical diseases are also likely to be more common than doctors expect. These include Chagas disease, a blood-borne parasitic infection transmitted through the bite of a kissing bug. CDC researchers estimated in a 2009 paper that more than 300,000 Americans suffer from Chagas and that 30,000 to 45,000 of them develop heart disease or heart failure every year as a direct result. The agency also estimates that 1.1 million are infected annually with trichomoniasis, a parasitic sexually transmitted disease, and that 1,000 are hospitalized yearly with neurocysticercosis, a brain tapeworm that causes epileptic seizures. "Most physicians are poorly trained in parasitic and tropical diseases. They don't realize they're widespread," says Peter Hotez, dean of the National School of Tropical Medicine at the Baylor College of Medicine. "And they're mostly diseases of people who live in poverty in the U.S.—that's another reason they don't get attention."

SOCIAL VULNERABILITY

SCIENTISTS AND PUBLIC HEALTH AGENCIES are starting to acknowledge that social factors such as poverty and living environment play an enormous role in infectious disease, yet little research directly investigates the link between the two. "It's kind of a macro-level factor that is surely behind the risk, but it's not specifically examined in much of the research," says Stephen Hwang, director of the Center for Urban Health Solutions at St. Michael's Hospital in Toronto.

One reason for this inattention is lack of money. The National Institutes of Health likes to fund research that is focused on specific diseases—on the epidemiology of hepatitis A, for instance, rather than the relation between homelessness and hepatitis A—so a broader exploration of these links "doesn't lend itself to a sustainable research career," Hwang says. Hotez agrees, noting that the study of the social causes of disease requires interdisciplinary investigations, work that is not generally well supported. "We don't have a good mechanism in the U.S. to bridge disciplines," he says. "We don't think about teaming up with an economist, political scientist and anthropologist to solve these problems. But we're paying the price for that."

The Michigan hepatitis A outbreak is a perfect example of this type of tunnel vision. To curb the infection surge, the state is pouring resources into vaccine distribution, a disease-centric approach that will undoubtedly help but also overlooks the many problems, such as substance use and dangerous sick-leave policies, that made it possible for the outbreak to occur in the first place. (Many low-income Michigan residents are also refusing the vaccine, which health department officials suspect could be caused by distrust of the medical and political establishment.) And what if there is no vaccine for the next infection? In recent years pharmaceutical companies have indicated a waning interest in vaccine development; emergency vaccine efforts to combat sudden epidemics are especially expensive, risky ventures. "It's very disruptive, and that's not the way that we want to do business going forward," Rip Ballou, director of the U.S. research and development center for GSK Global Vaccines, told STAT News in January. Novartis closed its vaccine division in 2014.

When the U.S. does put money into controlling an infectious disease, it also tends to stop once things improve, says Ron Valdiserri, a senior research associate at the Johns Hopkins Bloomberg School of Public Health and former deputy assistant secretary for health responsible for infectious diseases

Beyond the Flu Shot

An experimental approach may arm immune cells against many strains, eliminating annual guesswork

By Dina Fine Maron

The flu takes a formidable toll every year. Researchers and health workers save lives by routinely rolling out seasonal vaccines and deploying drugs to fight the virus and its secondary infections. But in the U.S. alone, the flu still kills tens of thousands of people and hospitalizes hundreds of thousands more.

A big part of the problem has been correctly predicting what strains of the influenza virus health officials should try to combat in a given season. A team of scientists from the U.S. and China now says it has designed a nasal spray vaccine that could take the guesswork out of seasonal flu protection by boosting the immune system's capacity to combat many viral strains.

The University of California, Los Angeles–led group recently reported in *Science* that it may have created the "Goldilocks" of flu vaccines—one that manages to trigger a very strong immune response without making infected animals sick. And unlike current flu vaccines, the new version fuels a strong reaction from disease-fighting white blood cells called T cells. Existing flu inoculations elicit antibodies that home in on a pathogen's shape—and that differs in each flu strain. But because T cells would be on the lookout for many different features of the flu virus, a T cell response would likely defend against a variety of strains. "This is really exciting," says Kathleen Sullivan, chief of the Division of Allergy and Immunology at Children's Hospital of Philadelphia, who was not involved in the work.

So what makes the U.C.L.A. team's flu approach different from others? Flu vaccines typically include a cocktail of several strains of killed virus. Injecting this mix into the body prompts the development of antibodies that can latch onto any intruder that resembles the flu—helping to prevent infection. But that standard method does not lead to a significant T cell reaction, because the virus is dead. The new spray, in contrast, uses a live virus, so it triggers both an antibody response and T cell immunity—at least in lab ferrets and mice. "It has the magic of both great antibody response and the induction of a strong, strong T cell response that will be a safety net—so if a virus breaks through the first line of defense, you will have T cells to make sure you don't get very sick," Sullivan says.

The researchers dissected the flu virus in lab dishes and tested how different mutations in each segment responded when exposed to interferon, a protein released by the body when viruses attack that helps to keep influenza infections in check. The scientists were able to identify which mutations made the virus most likely to provoke action from protective interferons. Armed with that information, the researchers then designed a mutant flu strain that was powerful enough to replicate well but highly susceptible to our body's own ability to control the virus—the ideal ingredients for a vaccine.

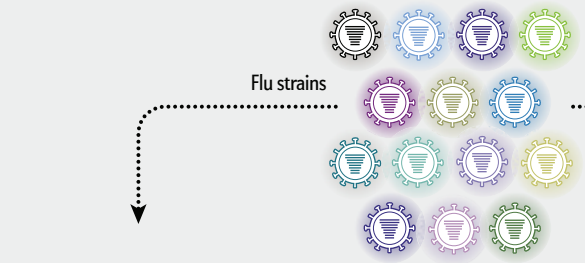
The resulting inoculation looks promising in both ferrets and mice, the most commonly used models of flu infection. If this approach is proved to work as well in humans, the authors say their invention could negate the need for annual flu shots. (Although they are not sure how long their vaccine would remain effective in humans, T cell responses tend to confer longer-term immunity.) The scientists believe that because they included eight mutations in their lab-made viral strain, it is unlikely the virus will revert back to its original, more dangerous form (a common concern with any live-virus vaccine). There may also be other applications from this work, they say: researchers could similarly take other viruses apart in the lab, scour them for important mutations and create vaccines against a plethora of other infections.

Multiple obstacles stand in the way of a future universal flu vaccine for humans, cautioned scientists at the Scripps Research Institute in an accompanying commentary in *Science*. Chief among them: although the U.C.L.A. team found some cross protection across a small set of strains—H1N1 and H3N2 subtypes—that may not hold true across all forms of the flu. Researchers will also have to examine if triggering a robust immune response to the virus puts people at risk, Sullivan notes, because a frenzied immune system response is what destroys lung tissue and sometimes proves deadly when people are infected with H5N1, a type of avian flu. "There are lots of practical questions about rolling this out for humans," she says. "But this is hugely innovative."

Dina Fine Maron *is an associate editor for biology and medicine at* Scientific American.

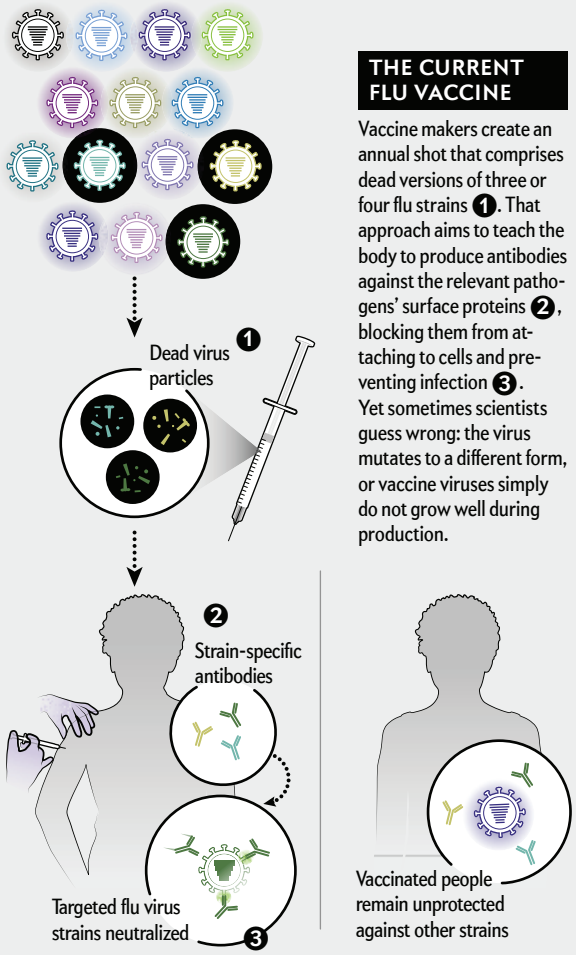
Vaccine Upgrade

Scientists use flu surveillance data to pick a few strains of the virus that could hit hard in the Northern and Southern Hemisphere, then put those into the annual flu shot. Sometimes they guess wrong. A universal flu vaccine—one that would thwart many different strains—would eliminate guesswork but has been elusive. Recent animal experiments using a novel vaccine approach may move closer to that goal.



THE CURRENT FLU VACCINE

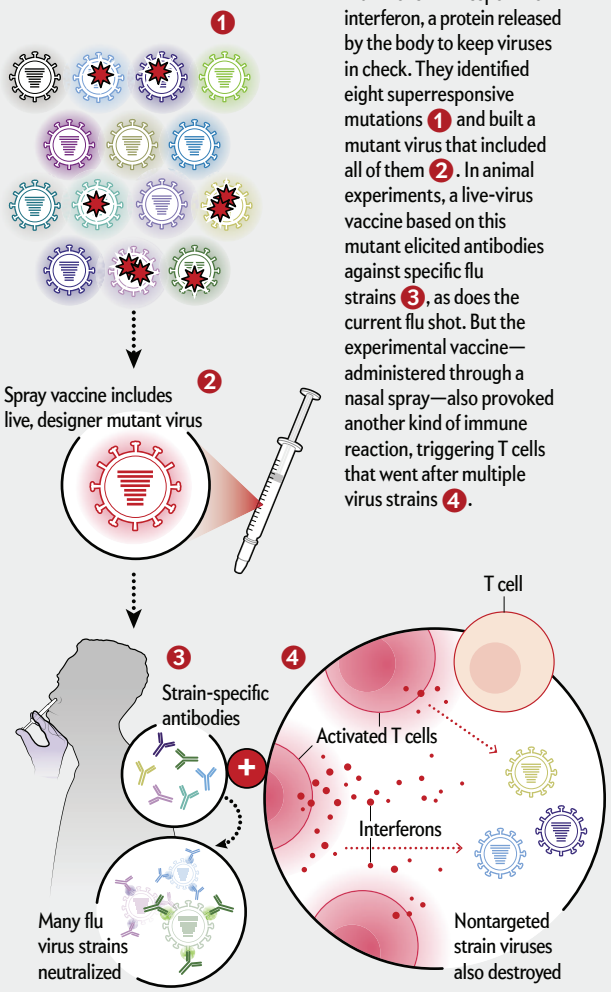
Vaccine makers create an annual shot that comprises dead versions of three or four flu strains 1. That approach aims to teach the body to produce antibodies against the relevant pathogens' surface proteins 2, blocking them from attaching to cells and preventing infection 3. Yet sometimes scientists guess wrong: the virus mutates to a different form, or vaccine viruses simply do not grow well during production.



Antibodies triggered by the current flu vaccine are strain-specific. They hunt for target molecules of a particular shape—a shape that varies by flu strain—but ignore strains that look different.

A VACCINE THAT COVERS MORE STRAINS

Scientists examined many flu viruses that circulate in the wild, hunting for mutations that respond to interferon, a protein released by the body to keep viruses in check. They identified eight superresponsive mutations 1 and built a mutant virus that included all of them 2. In animal experiments, a live-virus vaccine based on this mutant elicited antibodies against specific flu strains 3, as does the current flu shot. But the experimental vaccine—administered through a nasal spray—also provoked another kind of immune reaction, triggering T cells that went after multiple virus strains 4.



T cells most likely send chemical messengers to the rest of the immune system that help it recognize different flu strains. T cells also help to kill virus-infected cells directly.

Illustration by Tami Tolpa

TRINITY CEMETERY stretches in front of the abandoned giant Packard automotive plant in Detroit, which provided jobs and a decent living for thousands before it closed in the mid-1950s.

at the U.S. Department of Health and Human Services. There is "this notion that 'Oh, once we have a good handle on disease, we can forget it and move on to something else,'" he says. But "with many of these infectious diseases, even when you're successful and you can reduce new infections and you reduce incidence, they can spring back up again." HIV is following this pattern. Although overall incidence in the U.S. has been dropping, in some poor urban areas, ethnic groups and areas of the South, the opposite is true.

Although funding amounts will ultimately be decided by Congress, the Trump administration's budget request for the 2019 fiscal year for the CDC slashes $43 million from current programs for STD and tuberculosis prevention. (This includes HIV and viral hepatitis programs.) It cuts $704 million from public health preparedness and response, $44 million from immunization and respiratory diseases, and $60 million from emerging and zoonotic diseases. State and local health departments, which investigate and control infectious disease outbreaks on the ground as they occur, are also suffering. And their problems cannot be laid at the door of the current administration. In April 2016, before Donald Trump won the Republican presidential nomination, Gail Bolan, director of the CDC's Division of STD Prevention, noted in a congressional briefing that 43 percent of state and local health department STD clinics had reduced their hours, and 7 percent had closed their STD clinics entirely because of funding cuts.

Back at the windowless Tumaini Center, Carpenter cares for as many people as he can. He hands out medicine, answers questions, offers snacks, asks residents how they are doing. He only works there three days a week, so addressing their many health needs is a constant challenge. To make matters worse, financial support for the Tumaini Center's parent organization, the Neighborhood Service Organization, which provides programs and services for at-risk Detroit residents, is waning. From 2013 to 2016 the organization's revenue from donations and grants dropped by more than 20 percent.

The U.S. has come a long way since its early battles with smallpox, cholera and polio. But modern medicine isn't a panacea. The lives of microbes, like those of people they afflict, are shaped by their environments—and those environments are closely interwoven. As the country takes resources away from vulnerable citizens, it unwittingly enriches the strength of plagues among them. SA

MORE TO EXPLORE

Environmental Transmission of SARS at Amoy Gardens. Kelly R. McKinney et al. in *Journal of Environmental Health,* Vol. 68, No. 9, pages 26–30; May 2006.

Global Rise in Human Infectious Disease Outbreaks. Katherine F. Smith et al. in *Journal of the Royal Society Interface,* Vol. 11, No. 101, Article No. 20140950; December 6, 2014.

The State of the Nation's Housing 2016. Joint Center for Housing Studies of Harvard University. President and Fellows of Harvard College, 2016.

Potential Impact of a Ventilation Intervention for Influenza in the Context of a Dense Indoor Contact Network in Hong Kong. Xiaolei Gao et al. in *Science of the Total Environment,* Vols. 569–570, pages 373–381; November 1, 2016.

FROM OUR ARCHIVES

Sick of Poverty. Robert Sapolsky; December 2005.

scientificamerican.com/magazine/sa

EPIDEMIOLOGY

CATCHING FEVER

Climate change is accelerating the spread of disease—and making it much harder to predict outbreaks

By Lois Parshley

Photographs by Sean McDermott

IN SOUTH AFRICA, researchers are trying to understand where the Rift Valley fever virus is lurking between outbreaks.

THE FUTURE OF MEDICINE 2018

KOBUS STEENKAMP'S FARM SPRAWLS along a dirt road in South Africa's central plains, where the sky makes everything seem small. Steenkamp woke up here one morning after the rains in 2010 to find something strange happening with his sheep. "You could see there's blood at their backs," he recalls. All his pregnant ewes were losing their lambs.

It was every farmer's nightmare: his herd had been infected by Rift Valley fever, a mosquito-borne virus that causes abortion and death in livestock and wildlife and can be transmitted to humans. Within days, dozens of people had also been infected. Most displayed only flulike symptoms, but in some cases, the illness escalated into a severe hemorrhagic fever akin to Ebola.

A similar scene was unfolding across the region. The survival rate in adult animals is as low as 10 percent, and nearly 100 percent of infected sheep abort their pregnancies. Dead lambs and calves were left bloating in fields until the state veterinary team came to collect and incinerate the carcasses. By the time the outbreak was under control, almost 9,000 animals and 25 people had died. Neighboring countries, such as Zimbabwe and Namibia, banned South African meat, shattering the livestock industry.

Ever since the virus was first identified in 1931 in Kenya's Rift Valley, outbreaks like this one had been confined to southern and eastern Africa. But in 1977 the disease migrated north through increased trade on the Nile River, causing what the World Health Organization called an "explosive outbreak" in Egypt. Then, in September of 2000, it jumped to the Arabian Peninsula, arriving in Saudi Arabia and Yemen—sparking anxiety that Europe and North America were next. The idea that the virus could spread across these continents in just a few years is not some hyperbolic scenario. Rift is transmitted through a broader range of hosts and vectors than West Nile virus, which arrived in New York City in 1999 and spread across the U.S. in less than six years. The U.S. Department of Agriculture has taken notice, naming Rift the third most dangerous animal pathogen, behind only bird flu and foot-and-mouth disease. But health officials are not just worried about its impact on animals and agriculture. Zoonotic diseases—infectious illnesses such as Rift and Zika that begin in animal populations and jump to humans—are the biggest risk for epidemics and pandemics. They have been responsible for some of history's worst, including bubonic plague and Ebola.

The fear of Rift growing into a global pandemic highlights that public health researchers still don't know how to effectively predict disease outbreaks, which have devastating consequences on health, economies and political stability. Meanwhile the threat of emerging zoonotic diseases is expanding—and often in unforeseen ways. Scientists are only just beginning to understand how outbreaks correlate with shifting weather patterns—a hallmark of climate change. As they do, the picture is becoming more complicated. Worldwide, temperatures are changing faster than anyone previously predicted, and as a result, habitats are, too—altering the ranges of animals, viruses and, increasingly, humans. These complex relationships are now more volatile than ever, leading one recent *Lancet* paper to conclude that climate change is "the biggest global health threat in the 21st century" and yet another in the *Lancet* to suggest that it "threatens to undermine the last half century of gains in development and global health."

Global warming and extreme weather patterns are already dramatic forces on public health. Intensified floods, droughts and storms do not just change landscapes—they are actively impacting how humans can use land and, ultimately, where we can live. As climatologists race to model what has changed so that coastal communities, for instance, can adapt to rising seas, epidemiologists are also realizing how critical it is to develop epidemic-prediction tools that incorporate new and impending weather patterns. In an ever more globalized world, such research is no longer just a matter of equity between developing and developed nations. It may be a question of averting a future of unprecedented pandemics.

Lois Parshley is an award-winning freelance journalist whose work has appeared in *Harper's Magazine*, the *Atlantic*, *Wired* and many others. She is a 2017–2018 Knight-Wallace journalism fellow and a former editor at *Popular Science* and *Foreign Policy*.

IN BRIEF

Researchers still cannot predict how diseases turn into epidemics. But a new approach that incorporates climate models may provide some key answers.
A rare, multidisciplinary project in South Africa is looking at Rift Valley fever to understand the volatile dynamics among weather, land use, humans and animals.
Climate change is complicating and hastening how diseases spread, with unforeseen consequences.

AN INTERCONNECTED APPROACH

TO GET TO STEENKAMP'S FARM, biologist Ettienne Theron has been driving for hours toward an endless horizon. His truck, loaded with coolers full of blood, bounces down a crumbling highway that is flanked by open grassland. These velds are where the last several Rift epidemics in South Africa began. It's here, in an area larger than the size of Maryland, that Theron and dozens more researchers are collecting and analyzing data for a project run by EcoHealth Alliance, a global nonprofit that focuses on pandemic prevention. The challenge for scientists and policy makers alike is to learn how to intervene before pathogens infect people. Once a pandemic emerges, said EcoHealth president Peter Daszak in a 2015 video, "all you can really do is put out the fire." The goal of this five-year, multidisciplinary project is to examine, for the first time, exactly how climate affects Rift Valley fever in southern Africa. In doing so, researchers hope to develop a data-based model that actually predicts outbreaks before they happen, a stepping-stone to making models for other viruses as well. Notably, the U.S. Department of Defense is funding the entire project. Rift can easily be used as an aerosol and was weaponized by both the U.S. and the Soviet Union during the cold war. But bioterrorism is only one concern; keeping diseases from reaching the U.S.'s shores—and knowing how to react if they do—is increasingly a matter of national security.

Theron finally arrives at an unmarked gate, and the team members, who collectively speak nine of the

languages represented in the Free State province, pile out of the truck and pull on muck boots. Using a random distribution of GPS points, the researchers have reached an agreement with 361 isolated farms like Steenkamp's, where, for two years in a row, they have taken blood samples from livestock and farm staff to test for Rift antibodies, trying to understand where the virus might be lurking when no one is reporting active cases. Steenkamp himself was infected during an outbreak in the 1970s, and according to the WHO, as many as 10,000 people a year contract the virus. That number will likely rise. A 2016 study published in *Emerging Microbes & Infections* reports that the "explosive nature" of recent epidemics suggests the virus has mutated into a more infectious and severe strain. As it migrates to new places, the virus may evolve further, becoming even more dangerous.

As the farm crew maneuvers sheep into a corner of a rusted corral, field coordinator Claudia Cordel unpacks an arrangement of empty vials, data sheets, latex gloves and a sharps box on a folding card table. A farm worker grabs an ewe. It bleats while Cordel draws blood from its jerking neck. In South Africa, *Aedes mcintoshi* mosquitoes are thought to be the main carrier of Rift. The females transmit the virus directly to offspring, and their eggs can survive years of drought—a typical occurrence in this region. When the new generation of infected mosquitoes eventually hatch, they transmit the virus to livestock and wildlife alike. The virus amplifies in these hosts, so that when wider-ranging mosquitoes, such as *Culex* and *Anopheles,* bite infected animals, the original outbreak transforms into a swift-moving epidemic.

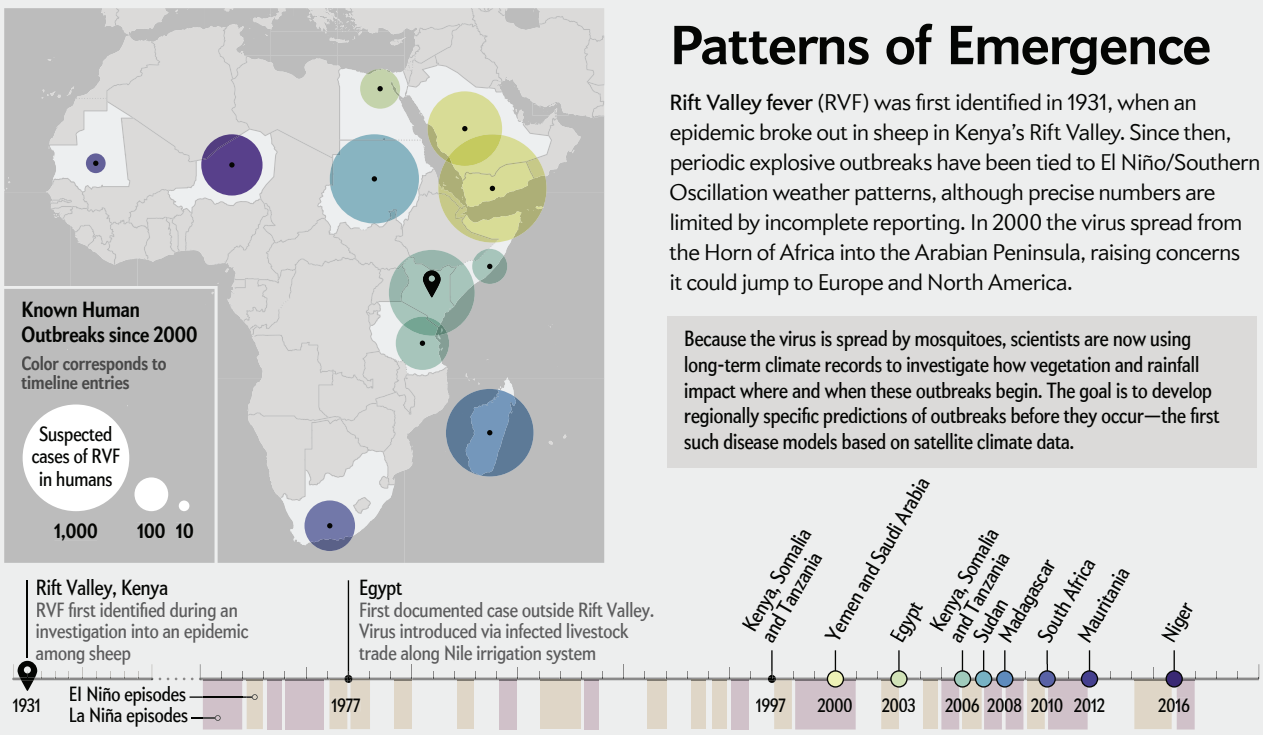
In another corral, Cordel wipes a cow's anus before piercing its tail vein. The cow lows and lets loose a squirt of green liquid toward her face. Cordel explains that though the basics of the virus transmission are known, "we have no idea how wildlife impacts people or livestock, or vice versa," adding that the feedback cycles are completely undocumented. That's why the EcoHealth team wants to get a more granular look at the interactions of weather, plants, insects, animals and people. At 22 research sites around the Free State and Northern Cape provinces, researchers are trapping mosquitoes to search for the virus, studying soil composition and vegetation, and setting up mini weather stations to monitor local conditions in conjunction with satellite data. This kind of

AT ONE OF 22 WEATHER STATIONS set up by the EcoHealth Alliance's Rift Valley fever project, Zikhona Gqalaqha, a graduate student at the University of the Free State in South Africa, collects data on soil moisture.

Patterns of Emergence

Rift Valley fever (RVF) was first identified in 1931, when an epidemic broke out in sheep in Kenya's Rift Valley. Since then, periodic explosive outbreaks have been tied to El Niño/Southern Oscillation weather patterns, although precise numbers are limited by incomplete reporting. In 2000 the virus spread from the Horn of Africa into the Arabian Peninsula, raising concerns it could jump to Europe and North America.

Because the virus is spread by mosquitoes, scientists are now using long-term climate records to investigate how vegetation and rainfall impact where and when these outbreaks begin. The goal is to develop regionally specific predictions of outbreaks before they occur—the first such disease models based on satellite climate data.



SOURCES: WORLD HEALTH ORGANIZATION AND CENTERS FOR DISEASE CONTROL AND PREVENTION (*outbreak data*); NATIONAL WEATHER SERVICE (*El Niño and La Niña data*)

Graphic by Tiffany Farrant-Gonzalez

comprehensive approach, which requires dozens of experts in epidemiology, ecology, climatology, veterinary medicine and entomology, is both costly and relatively rare. But it may be the future of understanding how infectious diseases emerge and spread.

"It makes sense that the health of an animal population is related to the health of the human population," says Melinda Rostal, one of the project's investigators. Animals often serve as early warning signs of a new outbreak; last year in Brazil, for example, local monkey populations were nearly wiped out eight months before a yellow fever epidemic. But structuring research around interactions among people, animals and the environment has only recently gained traction in the global health community. This strategy, first defined by epidemiologist Calvin Schwabe in 1964 and now called "One Health," is an increasingly popular intellectual framework for epidemiology. As far back as 400 B.C., Hippocrates understood that the environment—including weather—impacts disease, but systematically bringing together multidisciplinary research to better understand complex systems is relatively new. The Centers for Disease Control and Prevention did not establish a One Health office until 2009, when officials acknowledged that changing environmental interactions "have led to the emergence and reemergence of many diseases." Pursuing One Health research is expensive up front, but in the long run, it can actually be more efficient: by sending out collaborative teams instead of funding individual research trips, the EcoHealth Rift project reduced the cost of transportation for its study by 35 percent.

The longtime absence of this style of coordination is partly why the global health community is still playing catchup on emerging diseases. Consider Zika, for example: although it was first identified in Uganda in 1947, it was largely ignored until it began tearing through the Americas in 2015. Such diseases often lack attention when they first emerge because they affect the poorest populations of the world, meaning they are generally not profitable for pharmaceutical development. The result is that these so-called neglected tropical diseases, according to the CDC, have already cost 57 million years of life lost prematurely. So as one of the largest One Health projects to date, EcoHealth's Rift work is an important case study: Can broad, multidisciplinary research projects fill this dangerous knowledge gap?

As the setting sun turns the grass gold, Cordel and Theron finish the farm visit by checking on a weather station, where a lonely wind propeller ticks above barbed wire. Satellite data from NASA suggests that this region will see altered weather patterns, changing its risk of both Rift and other infectious diseases. Transmission is a complicated thing, but undoubtedly a key factor in future disease control will be understanding the implications of our changing climate.

FORECASTING CLIMATE ON A BACKYARD SCALE

ON THE LONG DRIVES between field sites, dead sunflowers droop under a relentless sky. South Africa has been in a drought for a few years, and the red soil has frazzled into puzzle pieces. Drought itself is a standard feature of El Niño weather patterns, and

A World of Trouble

A program to stop deadly diseases from spreading to the U.S. by helping foreign countries contain them now faces steep cuts

By Thomas Inglesby

When Ebola occurred in Liberia, Sierra Leone and Guinea between 2014 and 2016, it spread widely because those countries did not have the public health systems they needed to stop the virus. The U.S. Centers for Disease Control and Prevention, with other international and national institutions, helped to supply material and expertise essential to end that outbreak. To prevent this kind of disease disaster from happening again, the U.S. government then ramped up its global infectious disease preparedness as part of a new international initiative called the Global Health Security Agenda (GHSA). Many international health efforts aim to improve the response to one disease, but the GHSA builds infrastructure that can control a broad range of biological threats. Though focused on developing countries, the initiative directly helps the U.S. because, unchecked, diseases such as Ebola will reach America's shores. This work, done mostly through the CDC and the U.S. Agency for International Development, has produced hundreds of valuable interventions directed at enhancing countries' capacities to detect, prevent and respond to dangerous infections.

Despite the successes, the budget outlined by President Donald Trump this winter cut funding for the GHSA to $59 million for the coming fiscal year. This is a sharp reduction from the $1 billion that Congress gave for the years 2014–2019. The CDC will need to start closing down many of its overseas health security programs if Congress—which ultimately sets spending levels—does not increase the allocation.

What would we lose? The CDC has been training laboratories in other countries to identify novel strains of influenza, where flu appears before it hits the U.S. In Uganda, programs have strengthened lab capacity and helped to build an emergency operations center and train field epidemiologists. As a result, Uganda recently detected an outbreak of yellow fever in three days; in 2010 it took 40 days to recognize a similar epidemic. In India, CDC-supported efforts helped remote hospitals start diagnosing the causes of mystery fevers and illness. In Sierra Leone, the initiative enabled the identification of 4,000 previously undetected cases of measles, which led to the vaccination and protection of more than 2.8 million children. And in parts of the world where naturally occurring anthrax still kills people and animals, the CDC has been helping provide technical aid to contain those events and diminish their impact. These are exactly the capabilities that the world needs to detect and respond to the next emerging infectious disease threat, which could be a known disease or a novel one attacking humans for the first time. The appearance of diseases such as SARS, 2009 H1N1, MERS, bird flu, Zika and others underscores the urgency.

Other attempts to meet this need have not succeeded. In 2005 many countries signed a commitment called the International Health Regulations, a legally binding agreement to develop core national capacity to contain public health threats. But by 2014 less than a third of the signing countries had fulfilled their responsibilities under the agreement to develop expertise and infrastructure. That is why the GHSA was launched.

In contrast to the earlier effort, more than 60 countries now have joined this initiative. After the U.S. signed on as an early and very strong proponent, additional countries and major international organizations followed by delivering substantial funding and material assistance. The more that countries collaborate to support the initiative, the less they need to spend on their own.

If the U.S. curtails its part in this collaboration, countries at highest risk for new epidemics will have a harder time building up diagnostic and testing labs that provide early warnings of spreading infections, and efforts to train and equip local scientists and public health officials will be hurt. These cuts will diminish the enormous international goodwill that comes from these and other programs that use U.S. science for global good—and protect Americans at the same time. The GHSA is this county's first line of defense in a world where the next deadly disease is just a short airplane flight away.

*Physician **Thomas Inglesby** is an infectious disease specialist who directs the Center for Health Security at the Johns Hopkins Bloomberg School of Public Health.*

when La Niña eventually comes and completes the cycle, the area will see heavy rains. But these cycles, while typical, are intensifying because of climate change, becoming drier and wetter, explains Assaf Anyamba, a research scientist at NASA's Goddard Space Flight Center. (This past March, South Africa declared a "national state of disaster" over its prolonged drought. In Cape Town, which is at risk of running out of water, it is the worst drought in 400 years.) Even as conditions grow more extreme, Anyamba says, the downpour associated with this rain pattern—known as the El Niño/Southern Oscillation (ENSO)—and the vegetable life that downpour creates are what makes it possible to predict the hatching of Rift-infected mosquitoes. In fact, Anyamba was able to successfully predict the 2006 and 2007 Rift outbreak in East Africa by adding satellite climate models to the mix instead of just relying on regional weather patterns. "To my knowledge," he says, "this is the only system of its kind for any disease."

With that promising model in hand, Anyamba looked to southern Africa and the Arabian Peninsula. If he could apply the tools he used in eastern Africa to predict Rift outbreaks elsewhere, perhaps he could expand the model to other diseases. But so far his Rift models have failed in South Africa. As the climate expert on the EcoHealth study, Anyamba is now trying to figure out why. Satellite data that show and forecast global weather patterns make it easier to predict changes with vegetation and insects. The downside is that this big-picture view is fairly imprecise. When researchers combine climate models with more granular regional data such as vegetation coverage, they are dealing with two different scales. Anyamba's eastern African satellite models relied on a vegetation index, for example, that did not reflect southern African plant species. Other factors that impact disease, such as the spread of vectors, can be even finer-grained. Many mosquitoes live in an area the size of a suburban backyard, so even remotely sensed data do not get at the scale with which pathogens interact with their hosts. Although weather has long been linked with disease—think "flu season"—it is this level of specificity that makes predicting outbreaks so challenging. A one-size-fits-all template will not work.

Anyamba's new tactic is to use the information the EcoHealth team gathers on mosquitoes and vegetation in South Africa to build a more customized prediction model for the region. Climate change may eventually make the Free State province drier, which would help prevent Rift outbreaks. Other parts of the country, however, will likely get warmer and wetter, increasing Rift and the other diseases that floods tend to foster. Learning how to build more regionally sensitive tools will help scientists understand how disease burdens may change, both locally and globally.

Getting there is a matter of urgency. While it is rare to find sweeping conclusions in epidemiology, it is clear that greater climate variability—and therefore greater disease fluctuation—is already here. The first conclusive evidence of the trend was likely initially reported in a 2002 study published in the *Proceedings of the National Academy of Sciences USA,* which looked at chol-

era prevalence in Bangladesh over a 70-year period and found that "warming trends over the last century are affecting human disease." Mosquito and other insect habitats have expanded because of warming, exposing new populations to viruses. Preliminary research shows that malaria, for example, is globally on the rise. A temperature bump of just two degrees Celsius—a mark we are quickly approaching—would expand the number of people at risk of malaria by several hundred million, according to the WHO. Strangely, places that are now ideal climates for malaria may see less of it as they warm; prevalence will likely occur where malaria hasn't yet arrived, such as the U.S.

This type of vexing nuance has troubling consequences. Take bluetongue virus, a highly lethal ruminant disease that is spread by biting midges called *Culicoides*. Historically it was confined to tropical regions, but by 2006 there was enough warming in western Europe that some of those midges moved north and infected animals. Scientists were surprised when another kind of midge then picked up the virus from sickened sheep and carried it all the way to Norway. Corrie Brown, a veterinary pathologist at the University of Georgia, says bluetongue is a prime example of how climate change introduces species to one another for the first time—expanding how diseases can spread in an unpredictable manner.

Experts disagree on the best way to handle these risks. The U.S. Agency for International Development supports a strategy that focuses on identifying new pathogens, but Brown thinks merely discovering new viruses is an inefficient use of limited research funding. "I can see how very good it'd be for the investigators, because they'd get a lot of papers published," Brown says, but she is bearish on its value in preventing people from getting sick. Instead Brown and others who advocate for a One Health approach think strengthening local infrastructure—building monitoring and surveillance systems and training community nurses, for instance—is the most effective way to grapple with the fickle burdens of emerging diseases. "If we improve the level of expertise of health care professionals all around the world, we'll be in a better place," she says.

Local detection systems are especially important in places where humans are the ones who have moved into new environments, exposing themselves to diseases they haven't yet encountered. "In an unchanging world, you don't see a lot of emerging disease," says William Karesh, an epidemiologist and the Rift study's principal investigator. "It's when systems alter that microbes reveal themselves in new ways." Often epidemics and their ripple effects "happen at the edge, where humans are living next to wild spaces," says Carrie La Jeunesse, a former AAAS Congressional Science & Technology Policy Fellow who worked on Ebola. Since 2009 USAID has developed a heat map for emerging diseases with pandemic potential; it is remarkably similar to maps of regions threatened by human impact. In a 2012 paper published in the *Lancet,* Karesh and his colleagues summarized these findings by explaining that "many zoonoses can be linked to large-scale changes in land use."

That is certainly true in South Africa. "We actually farm with arboviruses," the viruses transmitted by arthropods such as ticks, says Alan Kemp, an entomologist on the EcoHealth project. "With Rift, it's almost certain that thanks to cattle breeding and importing exotic breeds that aren't resistant, we're actually literally farming Rift." He sighs and says, "To be honest, to a large extent, we're guilty of our own demise."

THE HUMAN STRAIN

THE THOUSANDS of blood samples EcoHealth has procured end up under the fluorescent gleam of a biosafety level–four laboratory in Johannesburg. Like Ebola, work with Rift is allowed only in the highest level of containment, and investigator Janusz Paweska wears a pressurized protective suit to examine Rift specimens under a microscope. The study will not be finished until 2019, but analysis here is already under way. "Some scientists refer to nature as the most terrible bioterrorist, which I dislike," says Paweska from his office, after he has been through the elaborate decontamination process. As head of South Africa's Center for Emerging Zoonotic and Parasitic Diseases, he does not mince words: "Who creates this environment for emergence? You can't accuse nature. Uncontrolled urbanization, climate change, poverty—that's not nature. The answer is that *we* create the situation for the emergence of many of these diseases."

Arguably poverty is already the greatest risk factor for getting sick. "The major trigger or determinant of health is economic," says Antoine Flahault, director of the Institute of Global Health in Geneva, explaining that an unequal distribution of health care is the primary problem. The WHO estimates that in low-income countries, diseases of poverty that are often preventable or treatable (think diarrhea, malnutrition and parasitic infections) account for 45 percent of deaths. Climate change is expected to drive at least 122 million people into extreme poverty in the next few decades, forcing many to leave their homes and leading to rapid urbanization, all of which tends to foster disease. Flahault expects that one of the major disease contributions of climate change will come from these consequences of forced migration. "We can expect a huge impact on health, not just because of direct impact on disease but because of the indirect economic impacts, which may be very severe," Flahault says.

But when countries with limited resources are asked to prepare for a future potential threat, often at the cost of immediate problems, "it's a hard trade-off," explains Susan Scribner, director of the Preparedness & Response project at the global development firm DAI. "What we do is called health, but in some ways, a lot of it has to do with good governance," she says. That is why projects such as the Rift study could be particularly powerful:

FIELD TEAM MEMBERS take blood samples from farm workers and livestock to test for Rift Valley fever antibodies. Researchers are trying to understand how the virus is maintained between outbreaks.

they provide data to many different stakeholders spanning agriculture, health and defense. Anyamba, EcoHealth's climate expert, sees the Rift study as the way of the future. "I envision more projects involving climate data, fused with advanced analytics and machine-learning technologies, that will begin to answer some questions [about] why particular disease outbreaks occur," he says. Policy makers may be juggling other priorities, but it is important that they understand this science, Scribner says, "because when a pandemic hits, scientists aren't the ones in charge of the response." In fact, the DOD's Defense Threat Reduction Agency is now funding similarly comprehensive research to predict and map areas at risk for chikungunya, another mosquito-borne viral infection. There is a long list of diseases, such as yellow fever, dengue and even rabies, that would benefit from the kind of resources the DOD can bring to bear.

But funding—and the politics that go into deciding whose research gets it—plays a critical role in which diseases are deemed worthy of attention. In the current political climate, support for the long-term resources that logistically complex projects (such as the Rift study) require is actively disappearing. Just as we are beginning to realize how urgent a collaborative approach to disease might be, the CDC is facing a massive budget cut to its global health security efforts. Funding global health is a complex endeavor managed by multiple agencies in the U.S. alone. Practically speaking, it is too soon to know how this cut might affect the feasibility of specific projects, but experts at the Brookings Institution think tank have written that it could be "devastating for global health," damaging economic growth as well as weakening international stability. (To read more about the potential fallout, see "A World of Trouble," by Thomas Inglesby, on page 62.)

Amid this limbo, EcoHealth's sweeping fieldwork presses on. Early one morning the team pulls up to a private game reserve near Mokala National Park to chase down kudu, a type of African antelope. Wildlife can both carry and transmit Rift to livestock and humans, but their blood samples are especially tricky to obtain. A helicopter arrives to lend a hand. Soon trucks are bouncing over the grass, a cloud of dust marking progress toward the herd. Beyond the front tires, the animals swerve and leap. They gleam like ribbons. The stillness when one is tranquilized from the sky is shocking. The scientists work quickly, sliding around a maze of arms and legs with syringes and vials. The kudu will wake in a matter of minutes.

After the blood is collected, the researchers begin their decontamination procedures, scrubbing dust off their boots to avoid spreading any diseases to the next property. Nearby, a caged lion lounges in a puddle of sunshine, awaiting the delivery of his next meal. He yawns at the stream of passing cars. Once this bushveld stretched wild over half of the country, but today it has been largely partitioned off and contained behind tall fences. There are few places now where game still wanders free. The world has already changed, even if we do not yet know the consequences. SA

MORE TO EXPLORE

Tackling Climate Change: The Greatest Opportunity for Global Health. Helena Wang and Richard Horton in *Lancet*, Vol. 386, pages 1798–1799; November 7, 2015.

Rift Valley Fever: An Emerging Mosquito-Borne Disease. Kenneth J. Linthicum et al. in *Annual Review of Entomology*, Vol. 61, pages 395–415; 2016.

Global Hotspots and Correlates of Emerging Zoonotic Diseases. Toph Allen et al. in *Nature Communications*, Vol. 8, Article No. 1124; October 24, 2017.

FROM OUR ARCHIVES

Emerging Viruses. Bernard Le Guenno; October 1995.

scientificamerican.com/magazine/sa

PSYCHOLOGY

Low emotional security can intensify our relationships to our belongings

By Francine Russo

Photographs by Timothy Archibald

Our Stuff,

Ourselves

Francine Russo is a veteran journalist, specializing in psychology and behavior. She is also a speaker and author of *They're Your Parents, Too! How Siblings Can Survive Their Parents' Aging Without Driving Each Other Crazy* (Bantam, 2010).

In a colorfully decorated classroom, a five-year-old boy is asked to describe his favorite belonging. He talks effusively about the dinosaur T-shirt his mom forced him to put in the wash that morning. Then he plays two simple computer games, trying, of course, to win. But the fix is in: experimenters have arranged that he will win one game and lose the other (and, to avoid suffering harm, will win a third and final game at the experiment's end). After winning and after losing, he, like the other boys and girls in this 2015 study conducted by psychologist Gil Diesendruck of Bar-Ilan University in Israel and his colleague, is asked by an adult whether he would be willing to lend this favorite thing to another child for one night.

This experiment set out to explore whether injury to young children's sense of self resulted in a stronger attachment to personally meaningful possessions. The results were dramatic. Children were almost twice as likely to be willing to share their most treasured belonging after winning the game than after losing. Yet in a control situation involving possessions they cared less about, the children's success or failure in the games had no effect on their willingness to part with the items.

Such experiments are among the latest efforts to understand the deeply emotional and psychologically complex relationship between humans, their sense of security and their material possessions. Much of this new research builds on the late 20th-century work of pioneering psychologists John Bowlby, Mary Ainsworth and Donald Winnicott. They famously theorized that an infant's attachment to his or her mother and the quality of that attachment significantly influenced that child's future relationships. Winnicott also suggested that as an infant begins to perceive that he or she has an independent self that is separate from the mother, that infant can learn to feel more secure with a "transitional object" that stands in for her. In popular parlance, we call this a "security blanket."

Since then, other branches of science, from evolutionary psychology and anthropology to consumer research and neuroscience, have affirmed that our belongings fill many emotional needs. They comfort us amid loneliness and boost our confidence about our abilities. In fact, our possessions do not just make us feel secure by substituting for important people in our lives; we actually see these objects as an extension of ourselves. We believe—or perhaps act as if we believe—that in some way, our very essence permeates our things. If these things become damaged or lost, we ourselves feel damaged or lost.

Stated baldly, our relationship with our stuff can sound a little crazy. But it is perfectly normal. "We all keep things and take great comfort in our possessions," says Nick Neave, an evolutionary psychologist at Northumbria University in England. "It's part of our evolutionary heritage." Keeping food—especially if it was hard to get—was and still is a major survival mechanism, Neave explains. The same is true of weapons and tools. "If you send someone into the world with nothing," he says, "they feel vulnerable. They need their possessions to make survival possible."

Human beings are, of course, social animals, so our needs for security are more complex than just the basics for physical survival. It may be helpful to recall psychologist Abraham Maslow's classic hierarchy of needs, expressed visually as a pyramid. Published in 1943, the pyramid's large base represents physiological needs (food, air and water), then builds upward through layers of physical safety (shelter, weapons), love and belonging (relationships and community) to esteem (ego strength) and, at its peak, self-actualization (optimal emotional health in which we realize our full potential). With the possible exception of self-actualization, our belongings can play a role in affording security in all these areas, including ego security and confidence in our relationships.

THEORIES OF ATTACHMENT

CAN YOU NAME your so-called attachment style? Probably not, unless you have had psychoanalysis. The psychoanalytic literature has identified four major attachment categories. If as a small

IN BRIEF

Human beings are social animals. To feel emotionally secure, we require ego strength and confidence in our relationships with other people.

When we lack secure attachment to our loved ones, we might imbue our inanimate possessions with deep meaning or human qualities to fill that void.

Through physical contact, we might believe that our things are infused with our essence and that we pick up others' essences by touching their things.

Anthropomorphizing our treasured belongings is normal. But for some vulnerable people, it can contribute to the pathological condition of hoarding.

child, you felt that your caregiver was reliably present and dependably met your needs, you developed a secure attachment style. But if your caregiver pushed you away in times of need, you probably developed attachment avoidance, learning to be independent and emotionally distant. Meanwhile if you perceived that your caregiver was inconsistent in meeting your needs, you may have developed an anxious attachment style, where you cling to or are constantly monitoring people in your intimate circle to make sure they will be there for you. Those who felt harmed in some way by their caregivers in early childhood develop a fearful/avoidant attachment style, making them afraid to get close to others. A classic American study in 1987 by researchers Cindy Hazan and Phillip Shaver, both then at the University of Denver, found that 56 percent of us have a secure attachment style, about 20 percent are anxious and about 24 percent are avoidant.

By drawing on this early psychoanalytic work, scientists have recently created provocative experiments that are beginning to nail down the roles various attachment styles play in our love affair with our things. Notably, anxious and other insecure attachment styles may be on the rise. A 2014 meta-analysis of studies involving American college students found that the percentage of students who scored as having secure attachment decreased from about 49 percent in 1988 to about 42 percent in 2011. The authors speculated on explanations or correlations, including reported increases in individualism, narcissism and materialism.

As more people suffer from insecure attachment styles, the behavior of seeking emotional solace from material objects is likely rising, too. According to an intriguing three-part study by psychologist Lucas A. Keefer, now at the University of Southern Mississippi, and his colleagues, people cling more tightly to their belongings when they feel less confident about the people they care for. In this research, published in 2012 in the *Journal of Experimental Social Psychology,* the first participants were randomly asked to write about three recent instances when someone close to them had let them down. Subjects in a second group either wrote about when a stranger had let them down or when they had let themselves down. Only people in the first group—primed to consider the unreliability of their close friends or romantic partners—reported greater uncertainty that they could count on others and an increased attachment to objects.

In the third part of the study, undergraduates were asked to write a few sentences either on uncertainties they felt about their abilities or uncertainties they felt about their relationships. Then the experimenter asked all the participants to relinquish their cell phone, which would be returned as soon as they completed an open-ended writing assignment. Keefer found that those asked to write about uncertainties regarding their relationships reported greater separation anxiety from their phone and showed (by how fast they finished the writing task) a more urgent need to get it back. This was true even when the researchers controlled for the phone's perceived usefulness as a social tool.

Why do we reach for things when people we care about let us down? That worn sweatshirt is not human. It does not show us compassion. Neither does a teddy bear or a coffee mug. But, scientists point out, these objects are utterly reliable, always present and under our control. We can count on them.

HOW THINGS REPLACE PEOPLE

INANIMATE THINGS LACK HUMAN CAPABILITIES. Yet many of us relate to them as if they were people. Ever named your car? Patted the hood when it gets you somewhere safely? There is a whole literature of research on how and why we anthropomorphize our things, as well as animals, tools and machines. Basically people need human connection and must find a way to fill this need,

even when there are no other humans around. Think of Tom Hanks's character in the movie *Cast Away,* washed up alone on an island. His best and only friend is a volleyball on which he has drawn a face—with his blood.

When the people we care about are not physically present, we can think in ways that make us feel as if they are with us. In one study, McGill University researchers asked a group of participants to think about someone whom they felt close to and could trust. They then asked the subjects to visualize what it would be like to be with him or her and to write a few sentences about the perceived experience. Another group was asked to do the same, except with a mere acquaintance.

The results, published in 2016 in *Psychological Science* by psychologists Jennifer Bartz, Kristina Tchalova and Can Fenerci, confirm previous research showing that some people try to increase their sense of social connection by assigning human attributes to things. In this study, all the participants rated four objects on their social and nonsocial attributes. (One was an alarm clock that rolls away when it rings.) The subjects who were tasked with writing about an acquaintance—as well as those who tested as having an anxious attachment style—were more likely to anthropomorphize the objects, giving them higher ratings for social attributes. Only those who were asked to imagine being present with a loved one were less likely than the acquaintance group to rate objects as humanlike. "It was a little surprising to us," Bartz says, "that such a relatively minor manipulation—thinking about and visualizing a close other whom you could trust—could have such an impact."

Consciously or not, many of us feel that our possessions are part of our extended self. A deeper, even less conscious belief is that through physical contact, our things actually become imbued with our essence.

Humanizing important belongings may do more than compensate for when we feel unsure about our relationships with close people, according to a recent study by Keefer. Some individuals, he says, see human qualities in objects because of a situation—for example, stemming from a breakup or a move to a foreign city. Others, research has shown, simply have a greater tendency to anthropomorphize as a character trait. In an experiment with undergraduates, reported in 2016 in the *Journal of Individual Differences,* Keefer found that for this latter type of person, being reminded of a favorite belonging could—like a reliable caregiver during childhood—serve as a secure base from which to explore and take risks. This tendency shows that our favorite things not only compensate for deficiencies but can help us grow, Keefer says. He suggests that humanlike technology such as robots and Alexa-type digital personal assistants may be able to offer people additional sources of emotional security.

STUFF AS SALVE

REMEMBER THAT EXPERIMENT where the young boy lost a game? Because losing made him feel less confident about himself, he *needed* to think of his favorite T-shirt as unequivocally his. A raft of literature shows that we adults also use our "toys" to compensate when we feel unsure of ourselves. In a research review published in 2017 in the *Journal of Consumer Psychology,* lead author Naomi Mandel, a marketing professor at Arizona State University, and her colleagues find that the things we buy can offer a "psychological salve" to help us feel better about ourselves. They suggest that tangible objects can symbolically stand in for the assuredness and comfort we lack. They cite a classic example from a 1982 study by psychologists Robert A. Wicklund and Peter M. Gollwitzer that found that M.B.A. students who had fewer job offers or worse grades than their peers were likelier to display such symbols of business success as expensive suits and fancy watches.

In a 2016 study, social psychologist and Berea College marketing professor Ian Norris also concludes that craving consumer products is partly fed by interpersonal insecurity. In a 2012 article entitled "Can't Buy Me Love?" in *Personality and Individual Differences,* Norris found that people with an anxious attachment style might substitute relationships with objects for relationships with people when they feel lonely—that is, when they experience the discrepancy between the closeness they *want* with others versus the closeness they actually have.

These results seem consistent with the attachment-style work of Winnicott, Norris says: "Other people are an extension of our self-concept. We don't develop a stable sense of self without meaningful social relationships. The 'self,' to a large extent, is a social construct: my relationship with others contributes greatly to my understanding of who I am. When those relationships are unstable or unfulfilling, people may lack the connection they need and attach meaning to products that fill the void."

WE ARE EVERYTHING WE CAN CALL OURS

BACK IN 1890 psychologist and philosopher William James proposed that a man's self included not just his body and consciousness but everything that he owned and that pertained to him, including his family and friends, "his lands and horses, and yacht and bank-account." Consciously or not, many of us feel that our possessions are part of our extended self. A deeper, even less conscious belief is that through physical contact, our things actually become imbued with our essence. Although this belief in "contagion" was identified in "primitive" societies by anthropologists at the end of the 19th century, much research has shown that contagion beliefs are alive and well in modern American and European cultures, according to Olga Stavrova, a social psychologist at Tilburg University in the Netherlands. In Stavrova's 2016 article in *Judgment and Decision Making,* she and her co-authors wrote that research consistently shows that people feel disgusted by the thought of making contact with items such as a serial killer's sweater or a Nazi officer's hat. The authors found similar responses for art and music. "People tend to implicitly believe that music

is imbued with its composer's essence," Stavrova says. They would go to some trouble to avoid listening to a piece if the composer was a highly immoral person.

This belief in contagion also appears in youngsters—and with an interesting wrinkle. When Diesendruck and his colleagues were researching children's willingness to share a cherished possession, they conducted another experiment: An adult shows a girl a photograph of another child who is the same age and gender. This child in the photograph, the girl is told, is mean. She hits her friends and does not listen to her parents or teachers. "Would you be willing to give this girl your favorite shirt?" She is adamant: *No, no, no.* "But what if we wash the shirt first?" the adult asks. "What if we wash it a lot?" Well … *maybe* then.

This conversation with children, held repeatedly by researchers, showed that kids believe that their belongings contain—and retain—some particles of themselves. When this essence is "removed" from the object, by washing, for example, they can better tolerate the idea that it came into contact with someone "bad." This example of "backward contagion" is especially interesting, Diesendruck says, because unlike "forward contagion," it is not consistent with our understanding of biological contamination.

What is remarkable, Diesendruck adds, is that the child believes another person's contact with an object that is no longer present can somehow still affect him or her. Diesendruck suggests thinking of this concept as a string, with the self on one end, and the object on the other end. It is as if the self travels through the string to the object, touches someone "bad," and then that badness travels back through the string to the self.

Provocatively, several brain studies have recently provided evidence that we do indeed regard our belongings as part of our extended selves. In one experiment that appeared in 2013 in *Social Cognitive and Affective Neuroscience,* psychologists Kyungmi Kim and Marcia Johnson, both then at Yale University, found that during functional magnetic resonance imaging, objects that a person had previously imagined as "mine" activated the same brain regions as references to a person's self.

WHEN ATTACHMENT BECOMES OBSESSION

IT IS NOW CLEAR that people with an anxious attachment style may be more likely to assign human attributes to their things, regarding them as an extension of themselves. These same individuals may be more vulnerable to developing a hoarding problem. Most of us want to save items of sentimental value, but cherishing our things becomes a pathological condition—which about 4 to 5 percent of the adult population has, scholars say—when people keep acquiring stuff and cannot get rid of any of it regardless of its utility or value, even if it endangers their health, life and relationships. In 2013 clinical hoarding syndrome was recognized as its own complex condition, separate from obsessive-compulsive disorder, in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders.* Researchers, however, have been laboring to pin down its causes for decades.

For those who hoard, possessions create sentimental associations with people and events in an intensified manner. Researchers tell us that some who hoard speak of "wanting to die" when they let go of a treasured item or liken it to "losing a part of oneself." Whereas most work on hoarding has been done in the U.S. and Europe, some research suggests that it may also arise in Eastern cultures, although a new study on Taiwanese children still under review indicates that people in collectivist societies versus individualist societies may relate differently to material things.

Between the mid-1990s and 2007 Smith College researcher Randy Frost and Boston University social work researcher Gail Steketee developed the widely accepted model of hoarding based on cognitive-behavioral therapy—a method that aims to change people's patterns of thinking to modify how they feel and behave. They see hoarding as a result of three basic factors. The first is the presence of disorders such as depression and anxiety, which make people emotionally vulnerable. Hoarding sufferers use their belongings to safeguard their identity, to "soothe their fears" and to build "fortresses" to make them feel more secure. The second factor is maintaining faulty beliefs about objects. For example, those who hoard feel responsible for taking care of their possessions as if they are living creatures. They believe that piles of brochures and ancient newspapers may contain important information they may one day need and cannot afford to be without.

Finally, people who hoard experience extreme emotional reactions when acquiring things and when getting rid of them. This pattern includes sensations of intense pride and pleasure when they get something new and guilt, fear and grief when they attempt to dispose of objects. Ongoing research has found that the relationship between people who hoard and their things is complex and thorny. Cognitive-behavioral therapy has been shown to achieve clinically significant improvement in only about 35 percent of those who hoard, according to a 2015 meta-analysis. Researchers and clinicians say they still have much to learn before they can bring relief to the majority of those in thrall to their possessions.

If people who have an uncontrollable need to save everything are on the extreme end of a continuum all of us occupy, the other end has those who possess the typical impulse to save things that remind us of meaningful moments and people. "Sentimental attachment is normal and can be good," says Russell Belk, a consumer researcher and psychologist at York University in Toronto. Belk did foundational work in the late 1980s on how our possessions become part of our extended self. He documented how victims of natural disasters feel personally injured by the loss of their things. As we watch news footage of the latest hurricane or wildfire victims weeping over the loss of their precious possessions—a coffee cup their child made, their grandfather's worn tool chest—we can easily identify. We all have things that mark ourselves, our histories and our loved ones. Losing them hurts. SA

MORE TO EXPLORE

Attachment to Objects as Compensation for Close Others' Perceived Unreliability. Lucas A. Keefer et al. in *Journal of Experimental Social Psychology,* Vol. 48, No. 4, pages 912–917; July 2012.

Toys Are Me: Children's Extension of Self to Objects. Gil Diesendruck and Reut Perez in *Cognition,* Vol. 134, pages 11–20; January 2015.

Emotional Regulation, Attachment to Possessions and Hoarding Symptoms. Philip J. Phung et al. in *Scandinavian Journal of Psychology,* Vol. 56, No. 5, pages 573–581; October 2015.

The Role of Attachment Style and Anthropomorphism in Predicting Hoarding Behaviours in a Non-Clinical Sample. Nick Neave et al. in *Personality and Individual Differences,* Vol. 99, pages 33–37; September 2016.

FROM OUR ARCHIVES

Clutter, Clutter Everywhere. Scott O. Lilienfeld and Hal Arkowitz; Facts & Fictions in Mental Health, *Scientific American Mind,* September 2013.

scientificamerican.com/magazine/sa

NATURAL RESOURCES

IS DEEP-SEA MINING WORTH IT?

The race is on to exploit—and protect—the ocean floor

By Thomas Peacock and Matthew H. Alford

Photograph by Brett Stevens

MANGANESE NODULES plucked from the ocean bottom contain valuable metals.

Thomas Peacock is a mechanical engineering professor and director of the Environmental Dynamics Laboratory at the Massachusetts Institute of Technology.

Matthew H. Alford is a physical oceanography professor and associate director of the Marine Physical Laboratory at the Scripps Institution of Oceanography.

WE ARE 50 KILOMETERS OFF THE COAST OF SAN DIEGO

IN LATE FEBRUARY, HOLDING STATION IN 1,000 METERS of water. Onboard our research vessel, the RV *Sally Ride,* are eight containers, each as large as a compact car, filled with sediment dredged from the deep Pacific Ocean floor. This morning we mixed the sediment with seawater in a huge tank, and over an hour we pumped the entire contents through a wide discharge hose that extended 60 meters down into the water from the side of the ship.

For six hours we tracked a plume of particles that dispersed down and away from the boat, pulled by ocean currents. A sophisticated array of sensors hanging from the ship allowed us to measure the plume shape and sediment concentration in the water column, the signals getting ever weaker.

Our goal was to obtain ocean data about a pressing issue that could soon greatly impact the ocean: mining the deep seafloor.

After years of contemplation, governments and companies around the world are beginning to explore the deep seabed for valuable minerals, chief among them nickel, copper and cobalt. One type of deposit—fist-sized nodules containing these metals—lies thousands of meters underwater. Robotic collector machines, each one as big as a combine harvester, would crawl along the seabed, sucking up the top sediment layer containing the nodules, kicking up a cloud of sediment in their wake. The collectors would pump the nodules up wide, kilometers-long tubes to large surface vessels. The ships would sift through the material, separating out millions of dense metallic nodules a day, and return the remaining sediment back into the sea, sending a plume downward.

How would all of this activity affect the life on the ocean floor and in the waters above? Our discharge test was an early step toward one part of an answer.

Global demand for metals is rising relentlessly. Some of the higher-grade land-based mines are running low. Several companies, such as Global Sea Mineral Resources (GSR) and UK Seabed Resources, are pursuing deep-sea mining because they think it can be less costly than land-based mining, especially as terrestrial producers are forced to turn to sites that have lower-grade ores that are also harder to extract.

Certain countries that do not have many mineral resources on land, such as Japan and South Korea, want to get into the game by prospecting at sea, where some deposits are vast. In September 2017 the Japan Oil, Gas and Metals National Corporation conducted one of the first large commercial trials. A prototype excavator gathered tons of zinc and other metals from deposits 1,600 meters deep near Okinawa, inside Japan's exclusive economic zone (EEZ)—its national waters. Small island nations and regions, such as Tonga and Cook Islands, which have limited resources to build such an industry themselves, are discussing whether to offer mining rights inside their EEZs to outside investors. And the International Seabed Authority (ISA), which regulates commercial activity in international waters, has issued 28 exploration permits to institutions from 20 countries to sample seafloor minerals.

Scientists are working hard to learn more about potentially damaging effects and what steps could minimize them. Right now governments, industry, the ISA, universities and science organizations are cooperating on shared research ventures akin to ours. Unlike the history of coal, oil, phosphorus and other natural resources, the scientific community has an opportunity to work with all parties to establish effective safeguards before a large extraction industry

IN BRIEF

Demand for certain metals is rising rapidly. Some economical land deposits are running low, so countries and companies may opt to mine the deep seabed.

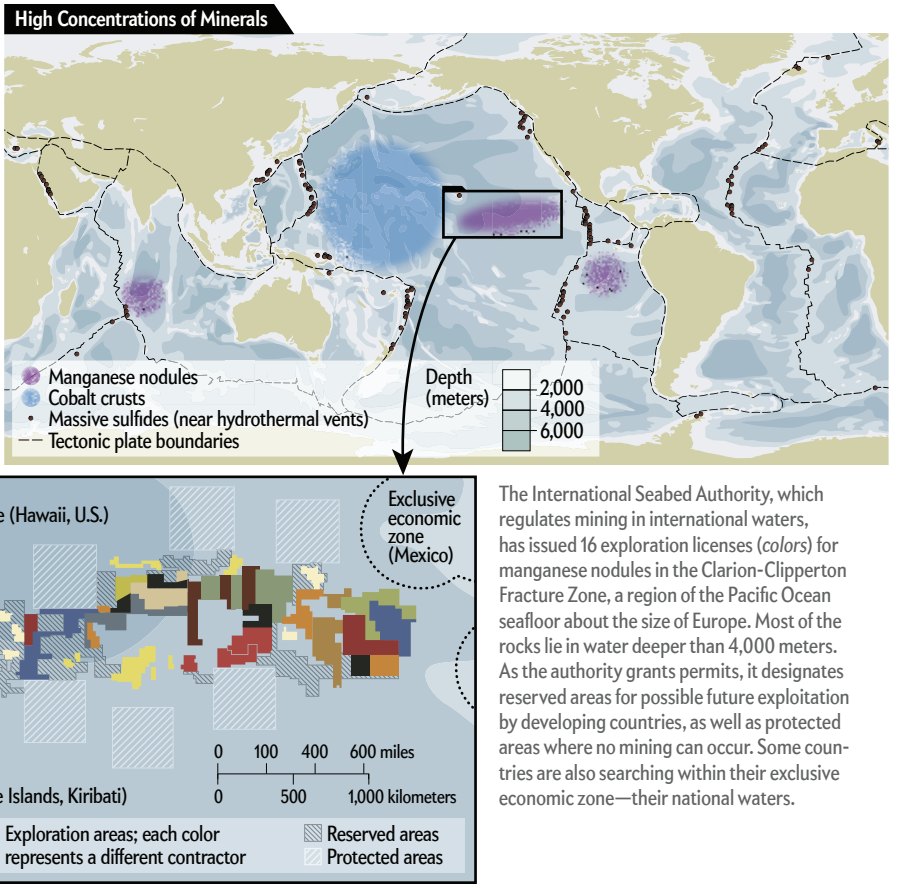
Nickel, copper and cobalt are plentiful in fist-sized nodules strewn across the ocean bottom in various locations deeper than 4,000 meters.

Machines would scoop up nodules, casting sediment across the seafloor. Processing ships would send sediment into the ocean above. But land mining has environmental effects, too.

Finding ways to minimize impacts could lead to wise regulations—if research continues as the industry forms.

Treasure Hunt

Many countries and companies mine the shallow ocean floor for oil, sand and diamonds. Now they are exploring the deep seabed for critical metals such as nickel and cobalt. Researchers have mapped three types of deposits in international waters that seem particularly promising (*colored regions*). Manganese nodules may be the most economical to extract.



The International Seabed Authority, which regulates mining in international waters, has issued 16 exploration licenses (*colors*) for manganese nodules in the Clarion-Clipperton Fracture Zone, a region of the Pacific Ocean seafloor about the size of Europe. Most of the rocks lie in water deeper than 4,000 meters. As the authority grants permits, it designates reserved areas for possible future exploitation by developing countries, as well as protected areas where no mining can occur. Some countries are also searching within their exclusive economic zone—their national waters.

forms and to determine the relative impacts of sea-based mining versus land-based mining.

NICKEL, COPPER AND COBALT REWARDS

SWEDISH EXPLORERS first discovered ocean mineral deposits a century and a half ago, in the Kara Sea off Siberia. The treasures were confirmed in the 1870s, during the celebrated HMS *Challenger* expedition that advanced modern oceanography. In the 1970s the CIA planned an elaborate hoax in which an ostensible dive for manganese nodules in the Pacific Ocean would be cover for its attempt to exhume the sunken Soviet submarine *K-129*. But technological challenges and low mineral prices discouraged actual commercial exploration.

Interest has picked up markedly over the past decade. Increasing global population, urbanization, rising consumption and aggressive development of technologies that depend heavily on certain metals are pushing market forecasts substantially higher. For example, annual global demand for nickel, now around two million metric tons, is estimated to rise 50 percent by 2030. Around 76 million metric tons exist in land-based reserves. Roughly the same amount, in the form of nodules, lies on the seafloor within the Clarion-Clipperton Fracture Zone (CCFZ) alone, an elongated abyssal plain stretching from Hawaii to the Baja California Peninsula. The story for cobalt is similar: land reserves of about seven million metric tons are matched or even exceeded by nodules in the zone.

Three principal forms of deposits are promising. One comprises active and inactive hydrothermal vents—fissures opened by volcanic activity that spew hot material along the boundaries of tectonic plates. These so-called seafloor massive sulfides are rich local deposits of minerals such as copper, zinc, lead and gold. Papua New Guinea has granted Canadian firm Nautilus Minerals a license to extract these sulfides at an inactive site known as Solwara 1 inside its EEZ. The ISA has granted seven sulfide exploration contracts at inactive sites in international waters. Scientists have called for a mining moratorium at active sites because of their unique ecosystems.

A second type of deposit, cobalt crusts, forms on the hard rock summits and flanks of seamounts, as metals naturally precipitate out of the seawater. Such crusts grow very slowly, a few millimeters every million years, typically reaching thicknesses of five to 10 centimeters. In addition to cobalt, they contain nickel and other desirable metals. Although the ISA has issued four exploration licenses for the western Pacific Ocean, mining of cobalt crusts is challenging because it is difficult to strip off the crusts from underlying rock and because the rock faces are typically steep and hard to negotiate underwater.

The majority of deep-sea mining ventures target deposits of polymetallic "manganese" nodules. (The remainder of this article addresses just this kind of mining.) The nodules are strewn across the seafloor or are partially buried in the sediment across many large areas. They form at depths of several thou-

SOURCES: *WORLD OCEAN REVIEW 1*. PUBLISHED BY MARIBUS, 2010 (*world map*); INTERNATIONAL SEABED AUTHORITY: DATABASE BY S. CLAUS ET AL. *Flanders Marine Institute*. ACCESSED AT WWW.MARINEREGIONS.ORG ON NOVEMBER 24, 2016 (*inset*)

Maps by Dolly Holmes

sand meters as metals precipitate out of seawater around a piece of detritus, forming a kernel that grows in diameter at about one centimeter every million years.

The ISA has granted 16 nodule exploration licenses in the CCFZ. Although composition varies, a typical nodule there contains around 3 percent by weight of nickel, copper and cobalt, which are the real prizes. About 25 percent is manganese, which if mined at scale would greatly increase global supply. The rest is mostly hardened material of no economic interest.

NODULES ARE THE NEW GOLD

SURVEYING A POTENTIAL SITE takes months with ship-based instruments, autonomous underwater vehicles and box-shaped collectors lowered from the ship to gather samples. Because the areas being explored are so large, the test samples are statistically extrapolated across the entire field. Prospectors consider a mining site economically viable if the nodule concentration exceeds about 10 kilograms per square meter, the nodules are covered by little or no sediment so they are easy to pick up, and the seafloor's slope is less than 10 percent, making it manageable for the collector machines, which typically crawl on heavy rolling tracks.

The centerpiece of a mining operation would be the collector vehicle, powered by an electric umbilical cable from the ship. It would scour the seabed, covering about 50 kilometers a day, most likely back and forth in a kilometer-scale grid pattern across a field of nodules. Autonomous submersible vehicles would help guide it along and monitor the surrounding environment.

As the collector sucks or scoops up the nodules and accompanying sediment, it would perform some rough separations of nodules, expelling the unwanted sediment in a cloud behind it. A long hose, with a series of pumps, would send the nodule slurry up to the operations ship—a riser system based on established technology used by the oil, gas and dredging industries. The vessel would separate nodules, sending unwanted sediment back down into the sea through a discharge hose. Large cargo vessels would take the nodules to a processing plant on land, which would extract the desired metals.

Economic viability studies indicate that to turn a profit, companies would need to collect three million metric tons of dry nodules a year, yielding about 37,000 metric tons of nickel, 32,000 metric tons of copper, 6,000 metric tons of cobalt and 750,000 metric tons of manganese.

EFFECTS ON LIVING ORGANISMS

THE ISA WAS ESTABLISHED under the United Nations Convention on the Law of the Sea (UNCLOS), which requires that signatory nations take all measures to protect the marine environment. The ISA grants exploration licenses to tracts that are 150,000 square kilometers. Because those who ratified or acceded to UNCLOS—167 nations and the European Union—view the international seabed as a resource for the "common heritage of mankind," a company or organization that wants to mine must be sponsored by a country that has ratified the convention. After surveying is done, the company splits a parcel into two halves, and the ISA decides which half to reserve for a developing country for possible exploitation.

Studies indicate that of a company's 75,000-square-kilometer parcel, it is likely to find about 10,000 square kilometers (about 0.2 percent of the CCFZ) economically viable to mine. The collector would remove the top 10 to 15 centimeters of the seafloor and compact the seabed in this region. A varied array of life at a scale of 50 microns or larger live on the nodules or in the sediment. Most of these creatures will die from the scouring or be smothered by the sediment cloud as it settles.

CRITICAL METALS contained in manganese nodules are hauled up from the Pacific Ocean seafloor during a sampling operation by Nautilus Minerals.

Smaller microorganisms such as bacteria account for the rest of the biomass. It is unclear how well these tiny species will fare. They will be kicked up with the sediment and settle back down many kilometers away. Those that rely on the nodules as a substrate for their existence will likely do poorly. Given that nodules take millions of years to form and that biological communities away from hydrothermal vents in the deep ocean are very slow to develop, harvested regions are unlikely to recover on any human timescale. Nearly 30 years ago German researchers used a sledge to dredge simulated mining tracks in the seabed 4,100 meters down in the Peru Basin. When investigators revisited them in 2015, the tracks looked as if they had just been created.

The impact of the collector's sediment plumes is another concern. Weak background currents in the deep ocean, which move at several centimeters a second, could carry sediment particles many kilometers away from where a collector is operating. Much of the sediment is fine, around 0.02 millimeter in diameter, with a typical settling speed of around one millimeter per second. Such sediment from collector plumes reaching 10 meters high or so in the background currents could travel around 10 kilometers away from the mining site.

This estimate may be oversimplified because fine sediments tend to aggregate into larger flocs that would settle faster than individual particles would, thereby potentially limiting the horizontal extent of plumes. The background sedimentation rate in the deep ocean is so low, however—on the order of one millimeter per 1,000 years—that biologists think trace amounts of sediment emitted by a collector could smother seafloor life even farther away. Compacting the seabed is also a concern. Studying the effects of occasional abyssal storms that scour

NAUTILUS MINERALS

sediment from the deep seafloor could provide valuable insights.

Estimating the impact of sediment plumes from the ship on the ocean environment and ecology is challenging. Upper ocean currents are faster, and there is more turbulence. The discharge hose could extend hundreds of meters down. The sediment plume coming out of it would take a roughly conical shape, tens of meters in scale, that currents would dilute, twist and transport several kilometers a day. In our February experiment off San Diego, we tracked the discharge plume with a variety of instruments. Ocean currents made it sinuous, and tendrils formed that intertwined. A towed, underwater device took samples from the tendrils. We will need a month or two to analyze all the data and figure out the key information, including what the sediment concentrations were close to and far from the hose.

Meanwhile researchers are trying to determine the extent to which the loss of life in a mining zone would affect local biological systems, as well as adjacent deep-sea communities and even those many kilometers away. In the CCFZ, the ISA has designated nine large protected regions and is also developing protocols for establishing preservation zones within each license area. Experts will monitor these and other places to see what impacts arise.

MINING LAND VS. SEA

IT IS IMPORTANT to weigh the environmental pros and cons of deep-sea mining with mining on land. In the Democratic Republic of the Congo, for example, which supplies around 60 percent of the world's cobalt, terrestrial mining causes deforestation and water and air pollution—and also involves child labor. In some countries, companies that mine for nickel are exhausting deposits that are relatively easy to access, so they are moving into deposits that are harder to extract, requiring more energy and chemical processing and thereby leading to greater environmental impact.

Processing facilities for nodules brought onshore from seabed mining will have land consequences as well. If only 30 percent of a nodule is desirable metals, 70 percent is waste, typically a slurry. Land miners often send this slurry back down the hole they have created. Slurry from millions of ocean nodules will be new material that has to go somewhere. On the upside, collectors and ships can leave an area and move to a new one; surface-mining infrastructure, once built, is hard to remove.

To reduce extraction and environmental impacts, it is vital that society develop effective global recycling programs. But recycling alone cannot keep up with rising demand. Today it is difficult to say whether seabed mining will be environmentally worse or better than the equivalent degree of land-based mining.

Of course, regulation will affect that outcome. The ISA, based in Kingston, Jamaica, regulates more than half of the planet's ocean floor—in international waters, also known simply as the Area. The ISA, which has no ships to inspect operations, has shared this responsibility with sponsor nations. It could revoke a company or country's license, suspend operations or impose a fine if it was determined that mining in a region was exceeding environmental impact standards.

The U.N. has 14 member states that have signed UNCLOS but have not ratified it—most notably the U.S.—and another 15 member states that have not signed it. These 29 nations could ostensibly try to mine in international waters and flout ISA statutes. The ISA would have to appeal to global politics to settle this kind of situation.

The organization has released draft exploitation regulations for the Area. They are intended to eventually cover everything from how the authority approves or rejects exploration and exploitation contracts to the obligations of contractors and the protection and conservation of the marine environment. The ISA expects to have exploitation regulations in place by 2020. Countries will have to write their own regulations for land-based nodule-processing facilities.

Also intriguing is what happens within countries' EEZs. These national waters account for more than one third of the world's oceans. Some countries do not have "deep seas" within 200 nautical miles (370 kilometers) of shore. But others do, particularly island nations in the Pacific. A few countries, such as Palau, have simply said no to any seabed mining. Other nations and regions, including Tonga, Kiribati and the Cook Islands, are developing regulations as they seek industrial and international partners. The Cook Islands has signed a contract with Ocean Minerals, based in the U.S., that gives the company a priority right to apply to explore 23,000 square kilometers of the islands' waters for cobalt-rich nodules.

Such actions show that seabed mining is poised to become a reality. Given the growing economic and strategic interest, some nations may start exploratory mining in the next five to 10 years. As noted, Japan has already begun.

A worthwhile path forward is for all interested parties to cooperate, as they have done so far, with small-scale industrial testing proceeding hand-in-hand with much needed scientific research. Indeed, a great deal of what is known about ecosystems and resources in the CCFZ has come from contractor-related studies. Our expedition from San Diego, for example, was a joint program funded by the Massachusetts Institute of Technology and the Scripps Institution of Oceanography, in collaboration with the ISA, the U.S. Geological Survey and GSR. In 2019 Europe's JPI Oceans program will conduct a study with the ISA and GSR in the CCFZ.

Some guidelines and standards for commercial operations might be adapted from existing industries, and others might be wholly new. If the parties can continue to work together, deep-sea mining could set a global benchmark. Historically, regulations have lagged behind industrial extraction—think about fracking—forcing regulators and citizens to try to catch up. As Conn Nugent of Pew Charitable Trusts says, "There is an opportunity to write the rule book that will govern an extractive activity before it begins." SA

MORE TO EXPLORE

Biodiversity, Species Ranges, and Gene Flow in the Abyssal Pacific Nodule Province: Predicting and Managing the Impacts of Deep Seabed Mining. ISA Technical Study No. 3. International Seabed Authority, 2008.

International Seabed Authority: www.isa.org.jm

Plumes Experiment at the Scripps Institution of Oceanography: www.mod.ucsd.edu/plumex

FROM OUR ARCHIVES

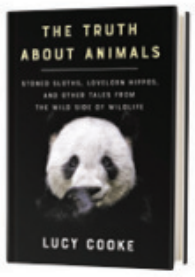
Journey to the Bottom of the Sea. Mark Schrope; April 2014.

scientificamerican.com/magazine/sa

By Andrea Gawrylewski

The Truth about Animals:
Stoned Sloths, Lovelorn Hippos, and Other Tales from the Wild Side of Wildlife

by Lucy Cooke. Basic Books, 2018 ($28)



HOFFMANN'S TWO-TOED SLOTH (*Choloepus hoffmanni*): Six-month-old orphan at the Sloth Sanctuary of Costa Rica.

Aristotle thought eels were spontaneously produced by mud, and 17th-century Europeans believed ostriches could digest iron. Filmmaker Cooke, who has a background in zoology, sifts through some of the most egregious myths about the animal kingdom and sets the record straight. In her quest for the facts, she watches panda porn, narrowly escapes a pack of hyenas and stalks drunken moose. She is especially eloquent in defending her beloved sloth, which she calls "one of the world's most misunderstood creatures," unfairly maligned as indolent and lazy when it actually efficiently makes use of its available resources. Cooke, founder of the Sloth Appreciation Society, raises the profile of many poorly understood animals, revealing surprising, and often hilarious, truths that are much better than the fictions. *—Clara Moskowitz*

Chasing New Horizons:
Inside the Epic First Mission to Pluto

by Alan Stern and David Grinspoon. Picador, 2018 ($28)

On July 14, 2015, after a journey of more than three billion miles, NASA's New Horizons spacecraft flew by Pluto, beaming back astounding images of cryogenic geology and completing a robotic reconnaissance of the solar system that began more than half a century ago. Far from being an inert snowball, Pluto proved to be an active world of mountains, glaciers and perhaps even a subsurface liquid-water ocean. Stern, the mission's principal investigator, collaborated with Grinspoon, an astrobiologist, to deliver a spellbinding insider's account of New Horizons's long journey to Pluto, its important results and what comes next in exploring the solar system's last frontier. *—Lee Billings*

The Order of Time

by Carlo Rovelli. Riverhead Books, 2018 ($20)

Time defines our lives; alarm clocks wake us; we spend segments of time in school and at work; we mark the lengths of relationships and sporting matches. Time goes in one direction: a glass shatters into thousands of pieces, but time does not reverse so that the pile of shards can reconstruct itself into a glass. Surprisingly, this experience of time may be a product of our brain and not an intrinsic feature of the universe. Further, any explanations or equations that physicists have devised about the universe and existence lack the element of time completely. Rovelli, a physicist and one of the founders of loop quantum gravity theory, uses literary, poetical and historical devices to unravel the properties of time, what it means to exist without time and, at the end, how time began.

The Feather Thief:
Beauty, Obsession, and the Natural History Heist of the Century

by Kirk Wallace Johnson. Viking, 2018 ($27)

A most unusual heist took place in June 2009 at the Natural History Museum in London—a 20-year-old musician stole 299 bird skins, many collected about 150 years earlier by naturalist Alfred Russel Wallace. The thief, a champion fly tyer, sold some of the rare bird skins and feathers—altogether potentially worth about $1 million—for use on fly-fishing hooks. Years later Johnson, a humanitarian advocating to resettle Iraqi refugees, was fly-fishing in New Mexico on a day off when his guide first told him about the heist. Johnson embarked on a five-year investigation into the crime and the whereabouts of the lost feathers—talking to hundreds of people, including the feather thief himself. *—Yasemin Saplakoglu*

SUZI ESZTERHAS *Getty Images*

BRIGHT HORIZONS 36

SCIENTIFIC AMERICAN Travel

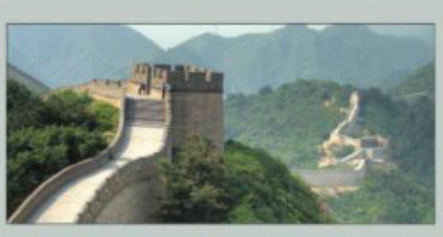
China | October 27th – November 6th, 2018

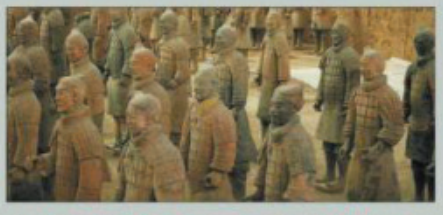
Embark on Bright Horizons 36's journey of discovery in China and send your senses reeling. Taste dim sum in Hong Kong and local brewed beer in Qingdao. Soak in powder blue hot springs and taste the umami of oyster pancakes in the Taiwanese night markets. Hear the roar of urban life and share the quiet of China's temples and gardens with a friend.

While we sail the Yellow Sea and the East and South China Seas, absorb Earth science from an expert and study the roots of Chinese culture in exclusive Bright Horizons classes.

The time is ripe to visit China and Taiwan. Update your Earth science knowledge and get an unparalleled view of China and her history and culture.

Cruise prices vary from $3,599 for an Ocean View Stateroom to $9,624 for a Owner's Suite, per person (pp) based on double occupancy. For those attending our SEMINARS, there is a $1,675 fee. Add'l pp fees: gov't taxes and fees ($440), a non-refundable Booking Service Fee ($150), and the Tour Leader gratuities ($100), and the option Program/Conference fee ($1,675). The Program, cruise pricing, and options are subject to change. For more information email us at info@InsightCruises.com.





ULTIMATE CHINA

PRE-CRUISE LAND TRIP OCTOBER 19TH – 27TH, 2018

Enhance your once-in-a lifetime trip to China with an optional 8-night, 5-star precruise tour of Beijing, Xi'an's Terracotta Warriors, and rural Guilin's iconic landscapes with Insight Cruises and Imperial Tours. You'll enjoy privileged access behind the scenes in the Forbidden City's "Palace of Double Glory"; see the Terracotta Warriors as visiting dignitaries do, walking between and among them; view 1,000 y.o. Tang frescos up close. Dine *on* the Great Wall, raft through rural China, visit a distinguished art collector — immerse yourself in China's ways to enrich your Bright Horizons cruise conference.

If you have wanted to see China's key sites but hesitate because of language, unfamiliarity with available housing, intra-China travel arrangements (this package includes three flights), or analysis paralysis, we can take you there. Effortlessly. Accompanied by a China host as well as very select area guides, you will see China's touchstones in a seamless and unforgettable experience.

Insight Cruises and Imperial Tours will take care of all the details so you can focus on China with peace of mind.

SEMINARS

EARTH SCIENCE:

- Scales of Change: Why Time Matters to Science and Being Human
- Climate Through the Ages
- How Mountain Building and Climate Shape the Land
- The Early Earth and Life's Origins
- Life: A Brief History
- The "Ice Ages", Rapid Climate Change, and Human Impacts

SPEAKER: Ron Martin, Ph.D.

UNDERSTANDING CONTEMPORARY CHINA:

- How History Informs Contemporary Chinese Attitudes and Actions
- China as a Global Power

EXPERIENCING IMPERIAL CHINA:

- The Grand Canal and the Great Wall
- Being a Chinese Peasant
- Being a Chinese Scholar
- Imperial China and the Maritime World

SPEAKER: Andrew Wilson, Ph.D.

FOR MORE INFO Please email: **info@InsightCruises.com** or visit: **ScientificAmerican.com/travel**

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com) and a Presidential Fellow at Chapman University. His new book is *Heavens on Earth: The Scientific Search for the Afterlife, Immortality, and Utopia.* Follow him on Twitter @michaelshermer

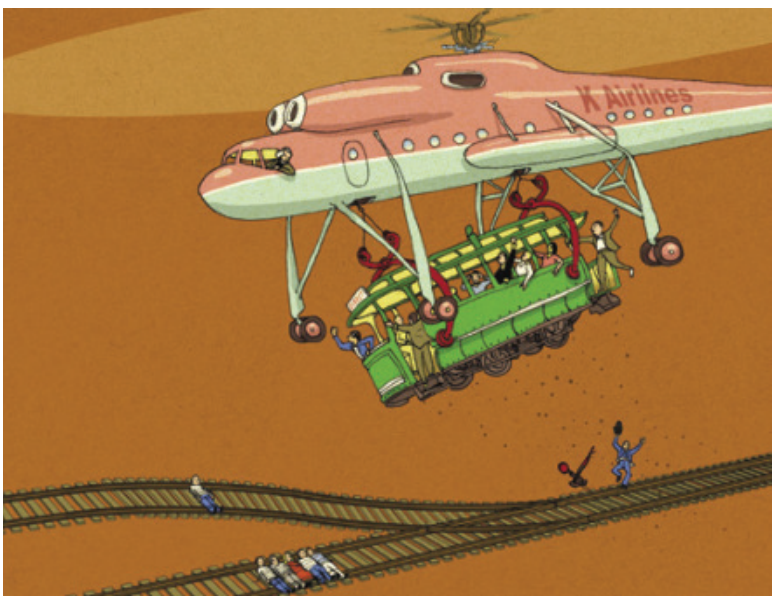
You Kant Be Serious

Utilitarianism and its discontents

By Michael Shermer

Would you cut off your own leg if it was the only way to save another person's life? Would you torture someone if you thought it would result in information that would prevent a bomb from exploding and killing hundreds of people? Would you politically oppress a people for a limited time if it increased the overall well-being of the citizenry? If you answered in the affirmative to these questions, then you might be a utilitarian, the moral system founded by English philosopher Jeremy Bentham (1748–1832) and encapsulated in the principle of "the greatest good for the greatest number."

Modern utilitarianism is instantiated in the famous trolley thought experiment: You are standing next to a fork in a trolley track and a switch to divert a trolley car that is about to kill five workers unless you throw the switch and divert the trolley down a side track where it will kill one worker. Most people say that they would throw the switch—kill one to save five. The problem with utilitarianism is evidenced in another thought experiment: You are a physician with five dying patients and one healthy person in the waiting room. Would you harvest the organs of the one to save the five? If you answered yes, you might be a psychopathic murderer.



In a paper published online in December 2017 in the journal *Psychological Review* entitled "Beyond Sacrificial Harm," University of Oxford scholars Guy Kahane, Jim A. C. Everett and their colleagues aim to rehabilitate the dark side of utilitarianism by separating its two dimensions: (1) "instrumental harm," in which it is permissible to sacrifice the few to benefit the many, and (2) "impartial beneficence," in which one would agree that "it is morally wrong to keep money that one doesn't really need if one can donate it to causes that provide effective help to those who will benefit a great deal." You can find out what type you are by answering the nine questions in the authors' Oxford Utilitarianism Scale. I scored a 17 out of a possible 63, which was at the time described as meaning "You're not very utilitarian at all. You Kant be convinced that maximising happiness is all that matters."

The cheeky reference to Immanuel Kant sets up a counter to utilitarianism in the form of the German philosopher's "categorical imperative," in which we can determine right and wrong by asking if we would want to universalize an act. For example, lying in even limited cases is wrong because we would not want to universalize it into lying in all instances, which would destroy all personal relations and social contracts. In the physician scenario, we would not want to live in a world in which you could be plucked off the street at any moment and sacrificed in the name of someone's idea of a collective good. Historically the application of a utilitarian calculus is what drove witch hunters to torch women they believed caused disease, plagues, crop failures and accidents—better to incinerate the few to protect the village. More recently, the 1:5 utilitarian ratio has too readily been ratcheted up to killing one million to save five million (Jews:"Aryan" Germans; Tutsi:Hutu), the justification of genocidal murderers.

Yet if you live in Syria and a band of ISIS thugs knocks on your door demanding to know if you are hiding any homosexuals they can murder in the mistaken belief that this fulfills the word of God—and you are—few moralists would object to your lying to save them.

In this case, both utilitarianism and Kantian ethics are trumped by natural-rights theory, which dictates that you are born with the right to life and liberty of both body and mind, rights that must not be violated, not even to serve the greater good or to fulfill a universal rule. This is why, in particular, we have a Bill of Rights to protect us from the tyranny of the majority and why, in general, moral progress has been the result of the idea that individual sentient beings have natural rights that override the moral claims of groups, tribes, races, nations and religions.

Still, if we can decouple the sacrificial side of utilitarianism from its more beneficent prescriptions, moral progress may gain some momentum. Better still would be the inculcation into all our moral considerations of beneficence as an internal good rather than an ethical calculation. Be good for goodness' sake. SA

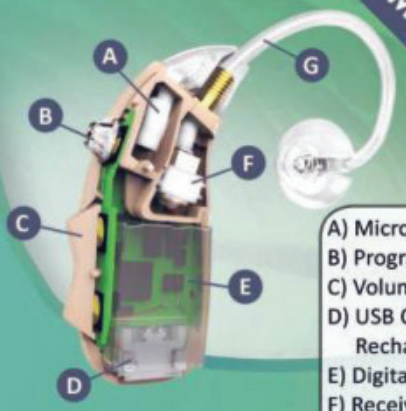
JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

Illustration by Izhar Cohen

NEW Rechargeable Digital Hearing Aid Technology Only $229!*

(*Each when you buy a pair)

The new more powerful HearClear™ **HCR2 rechargeable** hearing aid combines advanced technology with a low price to provide you with outstanding value.



New! Now With More Power!

A) Microphone
B) Program Button
C) Volume Control
D) USB Charging Port & Rechargeable Battery
E) Digital Processor
F) Receiver (Speaker)
G) Sound Tube

5 Star Reviews! ★★★★★

Outstanding Product! "This product is outstanding. Dad loves it, my mom loves it, and I am grateful! Don't believe that you have to spend a lot of money to get a quality hearing aid" - *Gilmore B.*

HCR2 Features!

- Digital sound processing chip provides **crystal clear sound and makes speech easier to understand** with less feedback than old analog technology
- Don't worry about replacing batteries! **Full Charge Gives 16 Hours of Use! (Charger Included)**
- Easy **On / Off Button**
- Automatic Noise Reduction and Feedback Cancellation
- **100% Money Back Guarantee**
- **4 Programs** for different listening situations

Even Better In Pairs!

Your brain is designed to use both ears working together. In fact, studies show that you may be able to **hear up to 3 times better** in noisy situations when using two hearing aids. Buy a pair for the best results and maximum savings!

Simple. Affordable. Rechargeable Digital Hearing Aid - For Only $229!*

The new HearClear™ HCR2 Rechargeable Digital Hearing Aids are now available to you for an unbelievably affordable price! The HCR2 is packed with same key technologies that all high end digital hearing aids share while leaving out the extra bells and whistles that increase cost and require expensive adjustments. This helps you **hear better, while saving you a lot of money.**

NOW ON SALE!
~~List Price: $849~~
Sale Price: $229*

Your new HearClear HCR2 hearing aids work at a fraction of the cost of name-brand hearing aids, and you don't have to keep changing the batteries! You will love the discreet, comfortable, lightweight Open-fit design. The HCR2 is **shipped directly to you and pre-programmed for most hearing losses.** It will help you hear better right out of the box and does not require professional appointments to make costly adjustments.

You can spend thousands for an expensive hearing aid, or you can spend just **$249** for a hearing aid that is great for most hearing losses **(only $229 each when you buy a pair – hear up to 3 times better than wearing just one).** We are so sure you will love your hearing aids that we offer a **100% Money Back Guarantee - Risk Free** if you are not satisfied for any reason.

*MONEY SAVING OFFER!

Use Coupon Code: **SA85**

1-888-296-1441

Only $229 Each When You Buy A Pair!
(Coupon Code & Price Valid For A Limited Time Only)

Advanced Affordable Hearing™
Affordable Quality Since 1996!

A+ BBB ACCREDITED BUSINESS | 100% MONEY BACK GUARANTEE | RISK FREE Trial | US Company Owned And Operated | FDA REGISTERED

Visit and Save: **www.AdvancedHearing.com/SA85**

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 36 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

Mothering, Wild Style

Some moms can be murder on the family

By Steve Mirsky

Along with its darling buds, the month of May features Mother's Day. The holiday is a time for Mom to be feted by her own darlings—because all us buds were brought into this world by a mother. But the human mother-child relationship is just one small slice of what nature has ordered up over the course of evolutionary time. The oddball (to us) ways of some other mothers—mostly mammals, but with a smattering of fish, reptiles, amphibians and birds—are illuminated in the new book *Wild Moms,* by biologist and author Carin Bondar.

In short, it can be a jungle out there.

For example, Bondar devotes a section to "cooperatively breeding mammals." In these species, the care of newborns is shared among the group. Some extreme cases involve meerkats, naked mole rats and selected primates that have come up with lifestyles that relegate most females to the role of caretakers while elevating a single female for baby making.

Those pop-up protagonists, meerkats (which are not cats but a kind of mongoose, which is not nearly a goose) have a system in which only about one in six females can ever ascend to baby-bearing status. Bondar compares it to the movie *Mean Girls,* except there's no "Spring Fling" dance at the end where everybody makes up.

Adult female meerkats who don't become queen wind up as her ladies-in-waiting. They spend their lives, Bondar writes, in "foraging, nest- and home-building, defense of the group from predators or competitors, babysitting, and allonursing, or wet nursing." It's good to be the queen.

Many of the ladies are the queen's close relatives, including sisters and daughters. And every once in a while one of these subordinates violates the rules in the implicit meerkat manual: she picks up a suitor on the sly and gives birth. Queens, who, as Bondar notes, "undergo a secondary growth spurt once they obtain a breeding position and are therefore of considerably larger size than submissives," will kill these pups—even though they may be the queen's own grandchildren. And you thought Shakespearean royal families were rough on each other.

Naked mole rats keep a much lower profile than meerkats do—they live in underground tunnels. Nicknamed "saber-toothed sausages," the critters engage in better living through chemistry: queens avoid committing familial infanticide by producing hormones released in their urine that stunt the development of the other females, rendering them incapable of having kids.

The sausage sovereign thus can concentrate on getting pregnant, giving birth and caring for her litter until the pups wean. And for the first two weeks postpartum, that care requires that she produce half her own body weight in milk every day. Before long, she's cooking up a new batch of the more than 900 babies she'll give birth to during her life. At an average of a dozen per litter, that's about 75 pregnancies. Eh, maybe it's not that good to be the queen.

Meanwhile, up in the sky, bats lead a much more egalitarian existence than do meerkats or mole rats. No Big Mama forbids anybody else to reproduce, and they care for one another's offspring in communal roosts. One reason for that behavior may be aerodynamics.

Like the mole rat, a female bat may produce half her body weight in milk every day. Unlike the mole rat, she needs to fly to forage. And to get clearance from the tower, she has to be streamlined. Which means dumping excess milk. As bats have yet to invent teeny tiny breast pumps, the mother's best option is to share her milk supply with the offspring of her roost mates. That arrangement also virtually guarantees some extra calories for her own pups from the other bat moms. Humans do a version of this arrangement, but they use cow's milk and call it a dairy cooperative.

Speaking of humans, give your mother a call if you can and thank her. Both for raising you and for being far less wild than a lot of other moms out there. SA

JOIN THE CONVERSATION ONLINE
Visit *Scientific American* on Facebook and Twitter or send a letter to the editor: editors@sciam.com

Illustration by Matt Collins

MAY

1968 The Moon, Unveiled

"In a corridor of the Boeing Space Center near Seattle there is a little sign that reads '5 for 5.' The sign briefly summarizes the fact that all five Lunar Orbiter missions, which were primarily designed to make photographs of the moon from spacecraft in lunar orbit, were successful. The results included complete photographic coverage of the side of the moon that is visible from the earth and coverage of more than 99.5 percent of the side that cannot be seen from the earth. The Lunar Orbiter series was one of three programs organized by the National Aeronautics and Space Administration in preparation for the Apollo missions in which men will land on the moon. The five Lunar Orbiter spacecraft made a total of 1,950 photographs. NASA has used them to select five potential Apollo landing sites from some 40 candidates that had been identified from Earth-based observations."

1918 Women's War Production

"As reported in dispatches from London, the Minister of Munitions said: 'Barring unforeseen circumstances, our supply of munitions would enable us to carry on a battle at the supreme pitch of intensity until winter without compromising our requirements for 1919.' We have all known that women are doing great work during the present war; but we were scarcely prepared for the astonishing statement, that more than nine-tenths of this huge output of shells is due to the labors of more than three-quarters of a million women, who, before the war, had never seen a lathe."

Aerograms

"It is self-evident that if an airplane can fly hundreds of miles with a cargo of bombs in all kinds of weather and under the most adverse conditions, surely the same machine can be made to fly with a cargo of mail or light merchandise or passengers in times of peace. It has remained for these United States to inaugurate the first aerial mail service really worthy of the name, between New York, Philadelphia and Washington. While we are not strictly the first nation to establish an aerial mail service, to be sure, we are undoubtedly the first to inaugurate a regular mail service through the air operating on a rigid schedule and opened to the public."

1868 A Greenhouse Climate

"The primitive atmosphere of the earth was greatly richer in carbonic acid gas [carbon dioxide] than the present, and therefore unfit for the respiration of the warm-blooded animals. The agency of plants in purifying this atmosphere was long ago pointed out. Dr. Tyndall's researches on radiant heat found that the presence of a few hundredths of carbonic acid gas in the atmosphere, while offering almost no obstacle to the passage of the solar rays, would suffice to prevent almost entirely the loss by radiation of obscure heat, so that the surface of the land, beneath such an atmosphere, would become like a vast orchard house, in which the conditions of climate necessary to a luxuriant vegetation would be extended even to the polar regions."

1968

1918

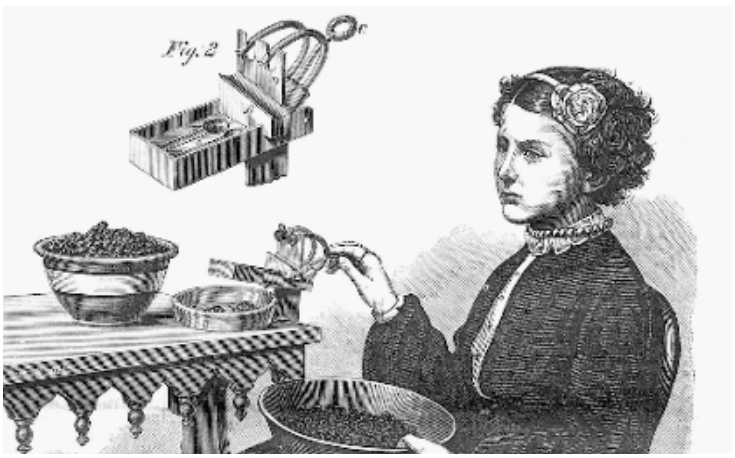

1868

Spiritualism

"Prof. Pepper has been doing, this last winter, a great work before the thousands who nightly visit the London Polytechnic Institute. Besides explaining the latest discoveries in electro-magnetism, light, etc., he discoursed on spiritual manifestations, pointing out the extensive impostures that have been practiced on the public in the name of mesmerism and spiritualism. He illustrates his lectures with startling illusions, such as the floating in the air of hats, tables, and even stout ladies. He does not only everything that spiritualists have pretended to do, but a great deal more; with this difference, however, that he explains how it is done."

The Fruits of Labor

"The preparation of fruit for culinary purposes or preserving is a monotonous and tiresome labor, at least the work of removing the seeds or pits. To facilitate the operation and render the task less irksome is the object of the inventor, from Illinois, of the neat little implement shown in the engraving. It never fails to remove the pits from cherries and the seeds from raisins, grapes, cranberries, etc., leaving the fruit in excellent condition without crushing or bruising it."



1868: Pitting cherries is annoying. This invention was designed, allegedly, to make it easier.

SCIENTIFIC AMERICAN, VOL. XVIII, NO. 19, MAY 9, 1868

Text by Mark Fischetti | Graphic by Nadieh Bremer

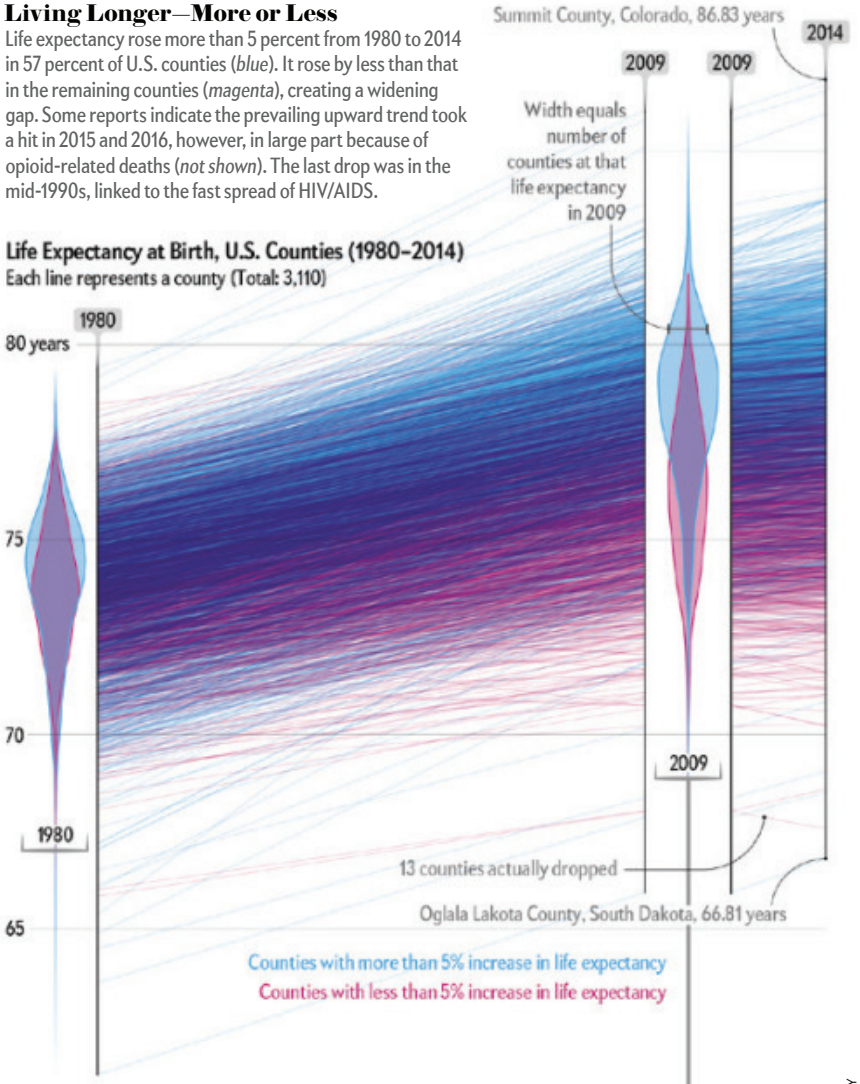
A Wider Life Gap

U.S. life span is rising disproportionately

People across the U.S. are living longer, but life expectancy for residents along the East and West Coasts and in central Colorado and Alaska has risen more than it has in the Southeast and other disparate locations. Although the national average increased from 73.8 to 79.1 years from 1980 to 2014, the gap between counties with the highest and lowest rates grew to a startling 20 years (*large graph*). Equally surprising is that the disparity is driven not so much by income or race—long thought to be the greatest factors—but by behaviors such as inactivity and metabolic conditions such as diabetes (*set of three graphs*). "Now that we've been able to pull out which risk factors are really important," says Laura Dwyer-Lindgren of the University of Washington, "we can figure out how to address them."

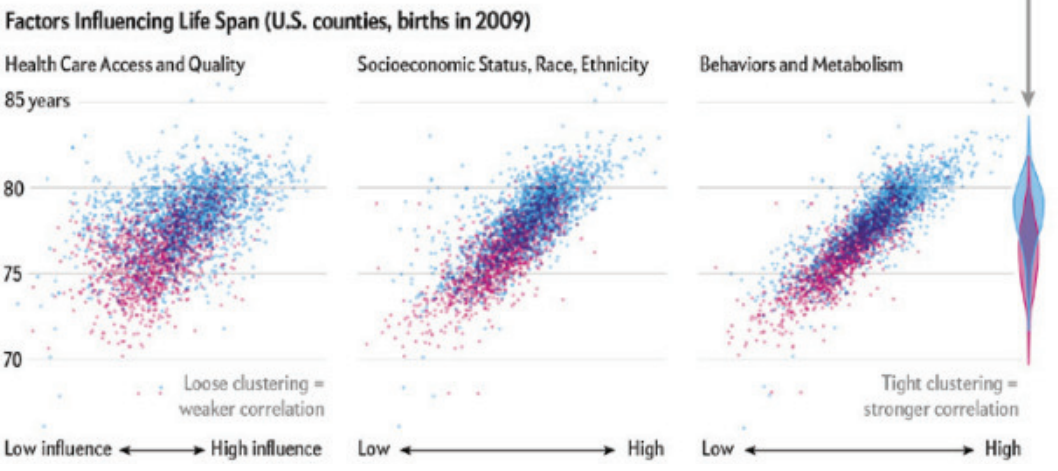
Living Longer—More or Less

Life expectancy rose more than 5 percent from 1980 to 2014 in 57 percent of U.S. counties (*blue*). It rose by less than that in the remaining counties (*magenta*), creating a widening gap. Some reports indicate the prevailing upward trend took a hit in 2015 and 2016, however, in large part because of opioid-related deaths (*not shown*). The last drop was in the mid-1990s, linked to the fast spread of HIV/AIDS.



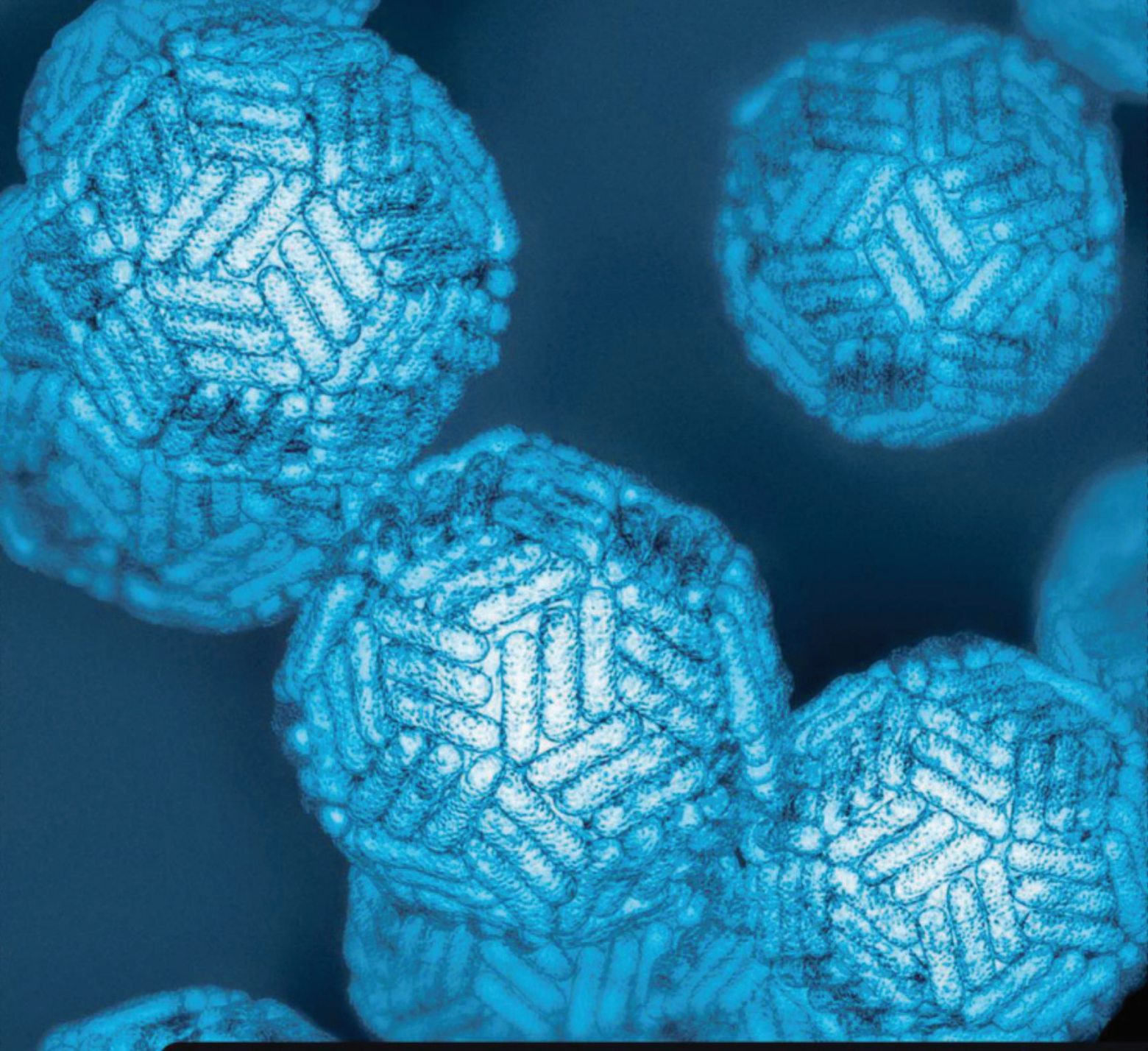
Behavior Matters Most

One set of risk factors—behaviors and metabolism—influences life expectancy much more than the other main categories: health care access and quality, and socioeconomic status and race. In fact, behaviors such as smoking and inactivity and metabolic conditions such as hypertension and diabetes underlie almost all the socioeconomic and race impacts as well.



SOURCE: "INEQUALITIES IN LIFE EXPECTANCY AMONG US COUNTIES, 1980 TO 2014: TEMPORAL TRENDS AND KEY DRIVERS," BY LAURA DWYER-LINDGREN ET AL., IN *JAMA INTERNAL MEDICINE*, VOL. 177, NO. 7, JULY 2017


2
billion
people
around the world have access to quality medicines, dietary supplements and food as a result of our standards, advocacy and education.
The foundation of quality we build helps:
• Scientists keep discovering
• Manufacturers keep producing
• Healthcare teams keep healing
Find out how we're empowering a healthy tomorrow: usp.org/impact
usp



FOR SOME ELITE SOLDIERS, THIS IS THE ENEMY.

Becoming a doctor on the U.S. Army health care team is an opportunity like no other. You'll be a part of the largest health care network in the world, covering over 90 unique medical fields and treating a range of threats, from breast cancer to the Zika virus. Thanks to our Health Professions Scholarship Program, you may also be eligible to receive full tuition assistance, plus a monthly stipend of more than $2,200. As a member of this elite team, you will be a leader—not just of Soldiers, but in medical innovation.

To see the benefits of being an Army medical professional call 800-431-6691
or visit healthcare.goarmy.com/ha84

U.S.ARMY