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GUARDIAN

The Uninhabitable Earth

A STORY OF THE FUTURE

David Wallace-Wells

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About the Author

David Wallace-Wells is deputy editor of *New York* magazine, where he also writes frequently about climate change and the near future of science and technology. In July 2017 he published a cover story surveying the landscape of worst-case scenarios for global warming that became an immediate sensation, reaching millions of readers on its first day and, in less than a week, becoming the most-read story the magazine had ever published -and sparking an unprecedented debate, ongoing still today among scientists and journalists, about just how we should be thinking, and talking, about the planetary threat from climate change.

For Risa and Rocca,
My mother and father

I

CASCADES

It is worse, much worse, than you think. The slowness of climate change is a fairy tale, perhaps as pernicious as the one that says it isn't happening at all, and comes to us bundled with several others in an anthology of comforting delusions: that global warming is an Arctic saga, unfolding remotely; that it is strictly a matter of sea level and coastlines, not an enveloping crisis sparing no place and leaving no life undeformed; that it is a crisis of the "natural" world, not the human one; that those two are distinct, and that we live today somehow outside or beyond or at the very least defended against nature, not inescapably within and literally overwhelmed by it; that wealth can be a shield against the ravages of warming; that the burning of fossil fuels is the price of continued economic growth; that growth, and the technology it produces, will allow us to engineer our way out of environmental disaster; that there is any analogue to the scale or scope of this threat, in the long span of human history, that might give us confidence in staring it down.

None of this is true. But let's begin with the speed of change. The earth has experienced five mass extinctions before the one we are living through now, each so complete a wiping of the fossil record that it functioned as an evolutionary reset, the planet's phylogenetic tree first expanding, then collapsing, at intervals, like a lung: 86 percent of all species dead, 450 million years ago; 70 million years later, 75 percent; 125 million years later, 96 percent; 50 million years later, 80 percent; 135 million years after that, 75 percent again.[1, 2] Unless you are a teenager, you probably read in your high school textbooks that these extinctions were the result of asteroids. In fact, all but the one that killed the dinosaurs involved climate change produced by greenhouse gas.[3] The most notorious was 250 million years ago; it began when carbon dioxide warmed the planet by five degrees Celsius, accelerated when that warming triggered the release of methane, another greenhouse gas, and ended with all but a sliver of life on Earth dead.[4] We are currently adding carbon to the atmosphere at a considerably faster rate; by most estimates, at least ten times faster.[5] The rate is one hundred times faster than at any point in human history before the beginning of industrialization.[6] And there is already, right now, fully a third more carbon in the atmosphere than at any point in the last 800,000 years—perhaps in as long as 15 million years.[7, 8] There were no humans then. The oceans were more than a hundred feet higher.[9]

Many perceive global warming as a sort of moral and economic debt, accumulated since the beginning of the Industrial Revolution and now come due after several centuries. In fact, more than half of the carbon exhaled into the atmosphere by the burning of fossil fuels has been emitted in just the past three decades.[10] Which means we have done as much damage to the fate of the planet and its ability to sustain human life and civilization since Al Gore published his first book on climate than in all the centuries—all the millennia—that came

before. The United Nations established its climate change framework in 1992, advertising scientific consensus unmistakably to the world; this means we have now engineered as much ruin knowingly as we ever managed in ignorance. Global warming may seem like a distended morality tale playing out over several centuries and inflicting a kind of Old Testament retribution on the great-great-grandchildren of those responsible, since it was carbon burning in eighteenth-century England that lit the fuse of everything that has followed. But that is a fable about historical villainy that acquits those of us alive today—and unfairly. The majority of the burning has come since the premiere of *Seinfeld.* Since the end of World War II, the figure is about 85 percent.[11] The story of the industrial world's kamikaze mission is the story of a single lifetime—the planet brought from seeming stability to the brink of catastrophe in the years between a baptism or bar mitzvah and a funeral.

We all know those lifetimes. When my father was born in 1938—among his first memories the news of Pearl Harbor and the mythic air force of the industrial propaganda films that followed—the climate system appeared, to most human observers, steady. Scientists had understood the greenhouse effect, had understood the way carbon produced by burned wood and coal and oil could hothouse the planet and disequilibrate everything on it, for three-quarters of a century.[12] But they had not yet seen the impact, not really, not yet, which made warming seem less like an observed fact than a dark prophecy, to be fulfilled only in a very distant future—perhaps never. By the time my father died, in 2016, weeks after the desperate signing of the Paris Agreement, the climate system was tipping toward devastation, passing the threshold of carbon concentration—400 parts per million in the earth's atmosphere, in the eerily banal language of climatology—that had been, for years, the bright red line environmental scientists had drawn in the rampaging face of modern industry, saying, *Do not cross.*[13] Of course, we kept going: just two years later, we hit a monthly average of 411, and guilt saturates the planet's air as much as carbon, though we choose to believe we do not breathe it.[14]

The single lifetime is also the lifetime of my mother: born in 1945, to German Jews fleeing the smokestacks through which their relatives were incinerated, and now enjoying her seventy-third year in an American commodity paradise, a paradise supported by the factories of a developing world that has, in the space of a single lifetime, too, manufactured its way into the global middle class, with all the consumer enticements and fossil fuel privileges that come with that ascent: electricity, private cars, air travel, red meat. She has been smoking for fifty-eight of those years, unfiltered, ordering the cigarettes now by the carton from China.

It is also the lifetime of many of the scientists who first raised public alarm about climate change, some of whom, incredibly, remain working—that is how rapidly we have arrived at this promontory. Roger Revelle, who first heralded the heating of the planet, died in 1991, but Wallace Smith Broecker, who helped popularize the term "global warming," still drives to work at the Lamont-Doherty Earth Observatory across the Hudson every day from the Upper West Side, sometimes picking up lunch at an old Jersey filling station recently

outfitted as a hipster eatery; in the 1970s, he did his research with funding from Exxon, a company now the target of a raft of lawsuits that aim to adjudicate responsibility for the rolling emissions regime that today, barring a change of course on fossil fuels, threatens to make parts of the planet more or less unlivable for humans by the end of this century. That is the course we are speeding so blithely along—to more than four degrees Celsius of warming by the year 2100.[15] According to some estimates, that would mean that whole regions of Africa and Australia and the United States, parts of South America north of Patagonia, and Asia south of Siberia would be rendered uninhabitable by direct heat, desertification, and flooding.[16] Certainly it would make them inhospitable, and many more regions besides. This is our itinerary, our baseline. Which means that, if the planet was brought to the brink of climate catastrophe within the lifetime of a single generation, the responsibility to avoid it belongs with a single generation, too. We all also know that second lifetime. It is ours.

I am not an environmentalist, and don't even think of myself as a nature person. I've lived my whole life in cities, enjoying gadgets built by industrial supply chains I hardly think twice about. I've never gone camping, not willingly anyway, and while I always thought it was basically a good idea to keep streams clean and air clear, I also always accepted the proposition that there was a trade-off between economic growth and cost to nature—and figured, well, in most cases I'd probably go for growth. I'm not about to personally slaughter a cow to eat a hamburger, but I'm also not about to go vegan. I tend to think when you're at the top of the food chain it's okay to flaunt it, because I don't see anything complicated about drawing a moral boundary between us and other animals, and in fact find it offensive to women and people of color that all of a sudden there's talk of extending human-rights-like legal protections to chimps, apes, and octopuses, just a generation or two after we finally broke the white-male monopoly on legal personhood. In these ways—many of them, at least—I am like every other American who has spent their life fatally complacent, and willfully deluded, about climate change, which is not just the biggest threat human life on the planet has ever faced but a threat of an entirely different category and scale. That is, the scale of human life itself.

A few years ago, I began collecting stories of climate change, many of them terrifying, gripping, uncanny narratives, with even the most small-scale sagas playing like fables: a group of Arctic scientists trapped when melting ice isolated their research center, on an island populated also by a group of polar bears; a Russian boy killed by anthrax released from a thawing reindeer carcass, which had been trapped in permafrost for many decades.[17, 18] At first, it seemed the news was inventing a new genre of allegory. But of course climate change is not an allegory.

Beginning in 2011, about one million Syrian refugees were unleashed on Europe by a civil war inflamed by climate change and drought—and in a very real sense, much of the "populist moment" the entire West is passing through now is the result of panic produced by the shock of those migrants.[19] The likely flooding of Bangladesh threatens to create ten times as many, or more, received

by a world that will be even further destabilized by climate chaos—and, one suspects, less receptive the browner those in need.[20] And then there will be the refugees from sub-Saharan Africa, Latin America, and the rest of South Asia—140 million by 2050, the World Bank estimates, meaning more than a hundred times Europe's Syrian "crisis."[21, 22]

The U.N. projections are bleaker: 200 million climate refugees by 2050.[23] Two hundred million was the entire world population at the peak of the Roman Empire, if you can imagine every single person alive and living anywhere on the planet at that time dispossessed of their home and turned outward to wander through hostile territories in search of a new one.[24] The high end of what's possible in the next thirty years, the United Nations says, is considerably worse: "a billion or more vulnerable poor people with little choice but to fight or flee."[25] A billion or more. That was the entire global population as recently as 1820, with the Industrial Revolution well under way. Which suggests that we might better conceive of history not as a deliberate procession of years marching forward on a timeline but as an expanding balloon of population growth, humanity dilating across the planet almost to the point of full eclipse. One reason carbon emissions have accelerated so much in the last generation is also an explanation for why history seems to be proceeding so much faster, with so much more happening, everywhere, each year, even every day: this is what results when there are simply that many more humans around. Fifteen percent of all human experience throughout history, it's been estimated, belongs to people alive right now, each walking the earth with carbon footprints.[26]

Those refugee figures are high-end estimates, produced years ago by research groups designed to call attention to a particular cause or crusade; the true numbers will almost surely fall short of them, and scientists tend to trust projections in the tens of millions rather than the hundreds of millions. But that those bigger numbers are only the far upper reaches of what is possible should not lull us into complacency; when we dismiss the worst-case possibilities, it distorts our sense of likelier outcomes, which we then regard as extreme scenarios we needn't plan so conscientiously for. High-end estimates establish the boundaries of what's possible, between which we can better conceive of what is likely. And perhaps they will prove better guides even than that, considering the optimists have never, in the half century of climate anxiety we've already endured, been right.

My file of stories grew daily, but very few of the clips, even those drawn from new research published in the most pedigreed scientific journals, seemed to appear in the coverage about climate change the country watched on television and read in its newspapers. In those places, climate change was reported, of course, and even with some tinge of alarm. But the discussion of possible effects was misleadingly narrow, limited almost invariably to the matter of sea-level rise. Just as worrisome, the coverage was sanguine, all things considered. As recently as the 1997 signing of the landmark Kyoto Protocol, two degrees Celsius of global warming was considered the threshold of catastrophe: flooded cities, crippling droughts and heat waves, a planet battered daily by hurricanes and monsoons we used to call "natural disasters" but will soon normalize as simply

gauging just how much damage will come from turning up the temperature by two or four or six degrees. Which is why it is especially concerning that recent research into the deep history of the planet suggests that our current climate models may be underestimating the amount of warming we are due for in 2100 by as much as half.[34] In other words, temperatures could rise, ultimately, by as much as double what the IPCC predicts. Hit our Paris emissions targets and we may still get four degrees of warming, meaning a green Sahara and the planet's tropical forests transformed into fire-dominated savanna.[35] The authors of one recent paper suggested the warming could be more dramatic still—slashing our emissions could still bring us to four or five degrees Celsius, a scenario they said would pose severe risks to the habitability of the entire planet. "Hothouse Earth," they called it.[36]

Because these numbers are so small, we tend to trivialize the differences between them—one, two, four, five. Human experience and memory offer no good analogy for how we should think of those thresholds, but, as with world wars or recurrences of cancer, you don't want to see even one. At two degrees, the ice sheets will begin their collapse, 400 million more people will suffer from water scarcity, major cities in the equatorial band of the planet will become unlivable, and even in the northern latitudes heat waves will kill thousands each summer.[37, 38] There would be thirty-two times as many extreme heat waves in India, and each would last five times as long, exposing ninety-three times more people.[39] This is our best-case scenario. At three degrees, southern Europe would be in permanent drought, and the average drought in Central America would last nineteen months longer and in the Caribbean twenty-one months longer. In northern Africa, the figure is sixty months longer—five years. The areas burned each year by wildfires would double in the Mediterranean and sextuple, or more, in the United States. At four degrees, there would be eight million more cases of dengue fever each year in Latin America alone and close to annual global food crises.[41] There could be 9 percent more heat-related deaths.[40] Damages from river flooding would grow thirtyfold in Bangladesh, twentyfold in India, and as much as sixtyfold in the United Kingdom. In certain places, six climate-driven natural disasters could strike simultaneously, and, globally, damages could pass $600 trillion—more than twice the wealth as exists in the world today. Conflict and warfare could double.

Even if we pull the planet up short of two degrees by 2100, we will be left with an atmosphere that contains 500 parts per million of carbon—perhaps more. The last time that was the case, sixteen million years ago, the planet was not two degrees warmer; it was somewhere between five and eight, giving the planet about 130 feet of sea-level rise, enough to draw a new American coastline as far west as I-95.[42] Some of these processes take thousands of years to unfold, but they are also irreversible, and therefore effectively permanent. You might hope to simply reverse climate change; you can't. It will outrun all of us.

This is part of what makes climate change what the theorist Timothy Morton calls a "hyperobject"—a conceptual fact so large and complex that, like the internet, it can never be properly comprehended.[43] There are many features of climate change—its size, its scope, its brutality—that, alone, satisfy this

definition; together they might elevate it into a higher and more incomprehensible conceptual category yet. But time is perhaps the most mind-bending feature, the worst outcomes arriving so long from now that we reflexively discount their reality.

Yet those outcomes promise to mock us and our own sense of the real in return. The ecological dramas we have unleashed through our land use and by burning fossil fuels—slowly for about a century and very rapidly for only a few decades—will play out over many millennia, in fact over a longer span of time than humans have even been around, performed in part by creatures and in environments we do not yet even know, ushered onto the world stage by the force of warming. And so, in a convenient cognitive bargain, we have chosen to consider climate change only as it will present itself this century. By 2100, the United Nations says, we are due for about 4.5 degrees of warming, following the path we are on today.[44] That is, farther from the Paris track than the Paris track is from the two-degree threshold of catastrophe, which it more than doubles.

As Naomi Oreskes has noted, there are far too many uncertainties in our models to take their predictions as gospel.[45] Just running those models many times, as Gernot Wagner and Martin Weitzman do in their book *Climate Shock,* yields an 11 percent chance we overshoot six degrees.[46] Recent work by the Nobel laureate William Nordhaus suggests that better-than-anticipated economic growth means better than one-in-three odds that our emissions will exceed the U.[47]N.'s worst-case "business as usual" scenario. In other words, a temperature rise of five degrees or possibly more.

The upper end of the probability curve put forward by the U.N. to estimate the end-of-the-century, business-as-usual scenario—the worst-case outcome of a worst-case emissions path—puts us at eight degrees. At that temperature, humans at the equator and in the tropics would not be able to move around outside without dying.[48]

In that world, eight degrees warmer, direct heat effects would be the least of it: the oceans would eventually swell two hundred feet higher, flooding what are now two-thirds of the world's major cities; hardly any land on the planet would be capable of efficiently producing any of the food we now eat; forests would be roiled by rolling storms of fire, and coasts would be punished by more and more intense hurricanes; the suffocating hood of tropical disease would reach northward to enclose parts of what we now call the Arctic; probably about a third of the planet would be made unlivable by direct heat; and what are today literally unprecedented and intolerable droughts and heat waves would be the quotidian condition of whatever human life was able to endure.[49, 50, 51, 52]

We will, almost certainly, avoid eight degrees of warming; in fact, several recent papers have suggested the climate is actually less sensitive to emissions than we'd thought, and that even the upper bound of a business-as-usual path would bring us to about five degrees, with a likely destination around four.[53] But five degrees is nearly as unthinkable as eight, and four degrees not much better: the world in a permanent food deficit, the Alps as arid as the Atlas Mountains.[54]

Between that scenario and the world we live in now lies only the open question of human response. Some amount of further warming is already baked

in, thanks to the protracted processes by which the planet adapts to greenhouse gas. But all of those paths projected from the present—to two degrees, to three, to four, five, or even eight—will be carved overwhelmingly by what we choose to do now. There is nothing stopping us from four degrees other than our own will to change course, which we have yet to display. Because the planet is as big as it is, and as ecologically diverse; because humans have proven themselves an adaptable species, and will likely continue to adapt to outmaneuver a lethal threat; and because the devastating effects of warming will soon become too extreme to ignore, or deny, if they haven't already; because of all that, it is unlikely that climate change will render the planet truly uninhabitable. But if we do nothing about carbon emissions, if the next thirty years of industrial activity trace the same arc upward as the last thirty years have, whole regions will become unlivable by any standard we have today as soon as the end of this century.

A few years ago, E. O. Wilson proposed a term, "Half-Earth," to help us think through how we might adapt to the pressures of a changing climate, letting nature run its rehabilitative course on half the planet and sequestering humanity in the remaining, habitable half of the world.[55] The fraction may be smaller than that, possibly considerably, and not by choice; the subtitle of his book was *Our Planet's Fight for Life*. On longer timescales, the even-bleaker outcome is possible, too—the livable planet darkening as it approaches a human dusk.

It would take a spectacular coincidence of bad choices and bad luck to make that kind of zero earth possible within our lifetime. But the fact that we have brought that nightmare eventuality into play at all is perhaps the overwhelming cultural and historical fact of the modern era—what historians of the future will likely study about us, and what we'd have hoped the generations before ours would have had the foresight to focus on, too. Whatever we do to stop warming, and however aggressively we act to protect ourselves from its ravages, we will have pulled the devastation of human life on Earth into view—close enough that we can see clearly what it would look like and know, with some degree of precision, how it will punish our children and grandchildren. Close enough, in fact, that we are already beginning to feel its effects ourselves, when we do not turn away.

It is almost hard to believe just how much has happened and how quickly. In the late summer of 2017, three major hurricanes arose in the Atlantic at once, proceeding at first along the same route as though they were battalions of an army on the march.[56] Hurricane Harvey, when it struck Houston, delivered such epic rainfall it was described in some areas as a "500,000-year event"—meaning that we should expect that amount of rain to hit that area once every five hundred millennia.[57]

Sophisticated consumers of environmental news have already learned how meaningless climate change has rendered such terms, which were meant to describe storms that had a 1-in-500,000 chance of striking in any given year. But the figures do help in this way: to remind us just how far global warming has

already taken us from any natural-disaster benchmark our grandparents would have recognized. To dwell on the more common 500-year figure just for a moment, it would mean a storm that struck once during the entire history of the Roman Empire. Five hundred years ago, there were no English settlements across the Atlantic, so we are talking about a storm that should hit just once as Europeans arrived and established colonies, as colonists fought a revolution and Americans a civil war and two world wars, as their descendants established an empire of cotton on the backs of slaves, freed them, and then brutalized *their* descendants, industrialized and postindustrialized, triumphed in the Cold War, ushered in the "end of history," and witnessed, just a decade later, its dramatic return. One storm in all that time, is what the meteorological record has taught us to expect. Just one. Harvey was the third such flood to hit Houston since 2015.[58] And the storm struck, in places, with an intensity that was supposed to be a thousand times rarer still.

That same season, an Atlantic hurricane hit Ireland, 45 million were flooded from their homes in South Asia, and unprecedented wildfires tilled much of California into ash.[59, 60] And then there was the new category of quotidian nightmare, climate change inventing the once-unimaginable category of obscure natural disasters—crises so large they would once have been inscribed in folklore for centuries today passing across our horizons ignored, overlooked, or forgotten. In 2016, a "thousand-year flood" drowned small-town Ellicott City, Maryland, to take but one example almost at random; it was followed, two years later, in the same small town, by another.[61] One week that summer of 2018, dozens of places all over the world were hit with record heat waves, from Denver to Burlington to Ottawa; from Glasgow to Shannon to Belfast; from Tbilisi, in Georgia, and Yerevan, in Armenia, to whole swaths of southern Russia.[62] The previous month, the daytime temperature of one city in Oman reached above 121 degrees Fahrenheit, and did not drop below 108 all night, and in Quebec, Canada, fifty-four died from the heat.[63] That same week, one hundred major wildfires burned in the American West, including one in California that grew 4,000 acres in one day, and another, in Colorado, that produced a volcano-like 300-foot eruption of flames, swallowing an entire subdivision and inventing a new term, "fire tsunami," along the way.[64, 65, 66] On the other side of the planet, biblical rains flooded Japan, where 1.2 million were evacuated from their homes.[67] Later that summer, Typhoon Mangkhut forced the evacuation of 2.45 million from mainland China, the same week that Hurricane Florence struck the Carolinas, turning the port city of Wilmington briefly into an island and flooding large parts of the state with hog manure and coal ash.[68, 69, 70] Along the way, the winds of Florence produced dozens of tornadoes across the region.[71] The previous month, in India, the state of Kerala was hit with its worst floods in almost a hundred years.[72] That October, a hurricane in the Pacific wiped Hawaii's East Island entirely off the map.[73] And in November, which has traditionally marked the beginning of the rainy season in California, the state was hit instead with the deadliest fire in its history—the Camp Fire, which scorched several hundred square miles outside of Chico, killing dozens and leaving many more missing in a place called, proverbially, Paradise.[74] The

devastation was so complete, you could almost forget the Woolsey Fire, closer to Los Angeles, which burned at the same time and forced the sudden evacuation of 170,000.

It is tempting to look at these strings of disasters and think, *Climate change is here.* And one response to seeing things long predicted actually come to pass is to feel that we have settled into a new era, with everything transformed. In fact, that is how California governor Jerry Brown described the state of things in the midst of the state's wildfire disaster: "a new normal."[75]

The truth is actually much scarier. That is, the end of normal; never normal again. We have already exited the state of environmental conditions that allowed the human animal to evolve in the first place, in an unsure and unplanned bet on just what that animal can endure. The climate system that raised us, and raised everything we now know as human culture and civilization, is now, like a parent, dead. And the climate system we have been observing for the last several years, the one that has battered the planet again and again, is not our bleak future in preview. It would be more precise to say that it is a product of our recent climate past, already passing behind us into a dustbin of environmental nostalgia. There is no longer any such thing as a "natural disaster," but not only will things get worse; technically speaking, they have already gotten worse. Even if, miraculously, humans immediately ceased emitting carbon, we'd still be due for some additional warming from just the stuff we've put into the air already. And of course, with global emissions still increasing, we're very far from zeroing out on carbon, and therefore very far from stalling climate change. The devastation we are now seeing all around us is a beyond-best-case scenario for the future of warming and all the climate disasters it will bring.

What that means is that we have not, at all, arrived at a new equilibrium. It is more like we've taken one step out on the plank off a pirate ship. Perhaps because of the exhausting false debate about whether climate change is "real," too many of us have developed a misleading impression that its effects are binary. But global warming is not "yes" or "no," nor is it "today's weather forever" or "doomsday tomorrow." It is a function that gets worse over time as long as we continue to produce greenhouse gas. And so the experience of life in a climate transformed by human activity is not just a matter of stepping from one stable ecosystem into another, somewhat worse one, no matter how degraded or destructive the transformed climate is. The effects will grow and build as the planet continues to warm: from 1 degree to 1.5 to almost certainly 2 degrees and beyond. The last few years of climate disasters may look like about as much as the planet can take. In fact, we are only just entering our brave new world, one that collapses below us as soon as we set foot on it.

Many of these new disasters arrived accompanied by debate about their cause —about how much of what they have done to us comes from what we have done to the planet. For those hoping to better understand precisely how a monstrous hurricane arises out of a placid ocean, these inquiries are worthwhile, but for all practical purposes the debate yields no real meaning or insight. A particular hurricane may owe 40 percent of its force to anthropogenic global warming, the

avalanches are on the rise, with 50,000 people killed by avalanches globally between 2004 and 2016.[83] In Switzerland, climate change has unleashed a whole new kind, thanks to what are called "rain-on-snow" events, which also caused the overflow of the Oroville Dam in Northern California and the 2013 flood of Alberta, Canada, with damages approaching $5 billion.[84] But there are other kinds of cascade, too. Climate-driven water shortages or crop failures push climate refugees into nearby regions already struggling with resource scarcity. Sea-level rise inundates cropland with more and more saltwater flooding, transforming agricultural areas into brackish sponges no longer able to adequately feed those living off them; flooding power plants, knocking regions offline just as electricity may be needed most; and crippling chemical and nuclear plants, which, malfunctioning, breathe out their toxic plumes. The rains that followed the Camp Fire flooded the tent cities hastily assembled for the first disaster's refugees. In the case of the Santa Barbara mudslides, drought produced a state full of dry brush ripe for a spark; then a year of anomalously monsoonish rain produced only more growth, and wildfires tore through the landscape, leaving a mountainside without much plant life to hold in place the millions of tons of loose earth that make up the towering coastal range where the clouds tend to gather and the rain first falls.

Some of those watching from afar wondered, incredulously, how a mudslide could kill so many. The answer is, the same way as hurricanes or tornadoes—by weaponizing the environment, whether "man-made" or "natural." Wind disasters do not kill by wind, however brutal it gets, but by tugging trees out of earth and transforming them into clubs, making power lines into loose whips and electrified nooses, collapsing homes on cowering residents, and turning cars into tumbling boulders. And they kill slowly, too, by cutting off food delivery and medical supplies, making roads impassable even to first responders, knocking out phone lines and cell towers so that the ill and elderly must suffer, and hope to endure, in silence and without aid.

Most of the world is not Santa Barbara, with its Mission-style impasto of infinite-seeming wealth, and in the coming decades many of the most punishing climate horrors will indeed hit those least able to respond and recover. This is what is often called the problem of environmental justice; a sharper, less gauzy phrase would be "climate caste system." The problem is acute within countries, even wealthy ones, where the poorest are those who live in the marshes, the swamps, the floodplains, the inadequately irrigated places with the most vulnerable infrastructure—altogether an unwitting environmental apartheid. Just in Texas, 500,000 poor Latinos live in shantytowns called "colonias" with no drainage systems to deal with increased flooding.[85]

The cleavage is even sharper globally, where the poorest countries will suffer more in our hot new world. In fact, with one exception—Australia—countries with lower GDPs will warm the most.[86] That is notwithstanding the fact that much of the global south has not, to this point, defiled the atmosphere of the planet all that much. This is one of the many historical ironies of climate change that would better be called cruelties, so merciless is the suffering they will inflict. But disproportionately as it will fall on the world's least, the devastation

of global warming cannot be easily quarantined in the developing world, as much as those in the Northern Hemisphere would probably, and not to our credit, prefer it. Climate disaster is too indiscriminate for that.

In fact, the belief that climate could be plausibly governed, or managed, by any institution or human instrument presently at hand is another wide-eyed climate delusion. The planet survived many millennia without anything approaching a world government, in fact endured nearly the entire span of human civilization that way, organized into competitive tribes and fiefdoms and kingdoms and nation-states, and only began to build something resembling a cooperative blueprint, very piecemeal, after brutal world wars—in the form of the League of Nations and United Nations and European Union and even the market fabric of globalization, whatever its flaws still a vision of cross-national participation, imbued with the neoliberal ethos that life on Earth was a positive-sum game. If you had to invent a threat grand enough, and global enough, to plausibly conjure into being a system of true international cooperation, climate change would be it—the threat everywhere, and overwhelming, and total. And yet now, just as the need for that kind of cooperation is paramount, indeed necessary for anything like the world we know to survive, we are only unbuilding those alliances—recoiling into nationalistic corners and retreating from collective responsibility and from each other. That collapse of trust is a cascade, too.

Just how completely the world below our feet will become unknown to us is not yet clear, and how we register its transformation remains an open question. One legacy of the environmentalist creed that long prized the natural world as an otherworldly retreat is that we see its degradation as a sequestered story, unfolding separately from our own modern lives—so separately that the degradation acquires the comfortable contours of parable, like pages from Aesop, aestheticized even when we know the losses as tragedy.

Climate change could soon mean that, in the fall, trees may simply turn brown, and so we will look differently at entire schools of painting, which stretched for generations, devoted to best capturing the oranges and reds we can no longer see ourselves out the windows of our cars as we drive along our highways.[87] The coffee plants of Latin America will no longer produce fruit; beach homes will be built on higher and higher stilts and still be drowned.[88] In many cases, it is better to use the present tense. In just the last forty years, according to the World Wildlife Fund, more than half of the world's vertebrate animals have died; in just the last twenty-five, one study of German nature preserves found, the flying insect population declined by three-quarters.[89, 90] The delicate dance of flowers and their pollinators has been disrupted, as have the migration patterns of cod, which have fled up the Eastern Seaboard toward the Arctic, evading the communities of fishermen that fed on them for centuries; as have the hibernation patterns of black bears, many of which now stay awake all winter.[91, 92, 93] Species individuated over millions of years of evolution but forced together by climate change have begun to mate with one another for the first time, producing a whole new class of hybrid species: the pizzly bear, the

coy-wolf.[94] The zoos are already natural history museums, the children's books already out of date.

Older fables, too, will be remade: the story of Atlantis, having endured and enchanted for several millennia, will compete with the real-time sagas of the Marshall Islands and Miami Beach, each sinking over time into snorkelers' paradises; the strange fantasy of Santa and his polar workshop will grow eerier still in an Arctic of ice-free summers; and there is a terrible poignancy in contemplating how desertification of the entire Mediterranean Basin will change our reading of the *Odyssey,* or how it will discolor the shine of Greek islands for dust from the Sahara to permanently blanket their skies, or how it will recast the meaning of the Pyramids for the Nile to be dramatically drained.[95, 96, 97] We will think of the border with Mexico differently, presumably, when the Rio Grande is a line traced through a dry riverbed—the Rio Sand, it's already been called.[98] The imperious West has spent five centuries looking down its nose at the plight of those living within the pale of tropical disease, and one wonders how that will change when mosquitoes carrying malaria and dengue are flying through the streets of Copenhagen and Chicago, too.

But we have for so long understood stories about nature as allegories that we seem unable to recognize that the meaning of climate change is not sequestered in parable. It encompasses us; in a very real way it governs us—our crop yields, our pandemics, our migration patterns and civil wars, crime waves and domestic assaults, hurricanes and heat waves and rain bombs and megadroughts, the shape of our economic growth and everything that flows downstream from it, which today means nearly everything. Eight hundred million in South Asia alone, the World Bank says, would see their living conditions sharply diminish by 2050 on the current emissions track, and perhaps a climate slowdown will even reveal the bounty of what Andreas Malm calls fossil capitalism to be an illusion, sustained over just a few centuries by the arithmetic of adding the energy value of burned fossil fuels to what had been, before wood and coal and oil, an eternal Malthusian trap.[99, 100] In which case, we would have to retire the intuition that history will inevitably extract material progress from the planet, at least in any reliable or global pattern, and come to terms, somehow, with just how pervasively that intuition ruled even our inner lives, often tyrannically.

Adaptation to climate change is often viewed in terms of market trade-offs, but in the coming decades the trade will work in the opposite direction, with relative prosperity a benefit of more aggressive action. Every degree of warming, it's been estimated, costs a temperate country like the United States about one percentage point of GDP, and according to one recent paper, at 1.5 degrees the world would be $20 trillion richer than at 2 degrees.[101, 102] Turn the dial up another degree or two, and the costs balloon—the compound interest of environmental catastrophe. 3.7 degrees of warming would produce $551 trillion in damages, research suggests; total worldwide wealth is today about $280 trillion.[103, 104] Our current emissions trajectory takes us over 4 degrees by 2100; multiply that by that 1 percent of GDP and you have almost entirely wiped out the very possibility of economic growth, which has not topped 5 percent globally in over forty years.[105] A fringe group of alarmed academics call this prospect

"steady-state economics," but it ultimately suggests a more complete retreat from economics as an orienting beacon, and from growth as the lingua franca through which modern life launders all of its aspirations.[106] "Steady-state" also gives a name to the creeping panic that history may be less progressive, as we've come to believe really only over the last several centuries, than cyclical, as we were sure it was for the many millennia before. More than that: in the vision steady-state economics projects of a state-of-nature competitive scramble, everything from politics to trade and war seems brutally zero-sum.

For centuries we have looked to nature as a mirror onto which to first project, then observe, ourselves. But what is the moral? There is nothing to learn from global warming, because we do not have the time, or the distance, to contemplate its lessons; we are after all not merely telling the story but living it. That is, trying to; the threat is immense. How immense? One 2018 paper sketches the math in horrifying detail. In the journal *Nature Climate Change,* a team led by Drew Shindell tried to quantify the suffering that would be avoided if warming was kept to 1.5 degrees, rather than 2 degrees—in other words, how much additional suffering would result from just that additional half-degree of warming. Their answer: 150 million more people would die from air pollution alone in a 2-degree warmer world than in a 1.[107]5-degree warmer one. Later that year, the IPCC raised the stakes further: in the gap between 1.[108]5 degrees and 2, it said, hundreds of millions of lives were at stake.

Numbers that large can be hard to grasp, but 150 million is the equivalent of twenty-five Holocausts. It is three times the size of the death toll of the Great Leap Forward—the largest nonmilitary death toll humanity has ever produced. It is more than twice the greatest death toll of any kind, World War II. The numbers don't begin to climb only when we hit 1.5 degrees, of course. As should not surprise you, they are already accumulating, at a rate of at least seven million deaths, from air pollution alone, each year—an annual Holocaust, pursued and prosecuted by what brand of nihilism?

This is what is meant when climate change is called an "existential crisis"—a drama we are now haphazardly improvising between two hellish poles, in which our best-case outcome is death and suffering at the scale of twenty-five Holocausts, and the worst-case outcome puts us on the brink of extinction.[109] Rhetoric often fails us on climate because the only factually appropriate language is of a kind we've been trained, by a buoyant culture of sunny-side-up optimism, to dismiss, categorically, as hyperbole.

Here, the facts are hysterical, and the dimensions of the drama that will play out between those poles incomprehensibly large—large enough to enclose not just all of present-day humanity but all of our possible futures, as well. Global warming has improbably compressed into two generations the entire story of human civilization. First, the project of remaking the planet so that it is undeniably ours, a project whose exhaust, the poison of emissions, now casually works its way through millennia of ice so quickly you can see the melt with a naked eye, destroying the environmental conditions that have held stable and steadily governed for literally all of human history. That has been the work of a

single generation. The second generation faces a very different task: the project of preserving our collective future, forestalling that devastation and engineering an alternate path. There is simply no analogy to draw on, outside of mythology and theology—and perhaps the Cold War prospect of mutually assured destruction.

Few feel like gods in the face of warming, but that the totality of climate change should make us feel so passive—that is another of its delusions. In folklore and comic books and church pews and movie theaters, stories about the fate of the earth often perversely counsel passivity in their audiences, and perhaps it should not surprise us that the threat of climate change is no different. By the end of the Cold War, the prospect of nuclear winter had clouded every corner of our pop culture and psychology, a pervasive nightmare that the human experiment might be brought to an end by two jousting sets of proud, rivalrous tacticians, just a few sets of twitchy hands hovering over the planet's self-destruct buttons. The threat of climate change is more dramatic still, and ultimately more democratic, with responsibility shared by each of us even as we shiver in fear of it; and yet we have processed that threat only in parts, typically not concretely or explicitly, displacing certain anxieties and inventing others, choosing to ignore the bleakest features of our possible future and letting our political fatalism and technological faith blur, as though we'd gone cross-eyed, into a remarkably familiar consumer fantasy: that someone else will fix the problem for us, at no cost. Those more panicked are often hardly less complacent, living instead through climate fatalism as though it were climate optimism.

Over the last few years, as the planet's own environmental rhythms have seemed to grow more fatalistic, skeptics have found themselves arguing not that climate change isn't happening, since extreme weather has made that undeniable, but that its causes are unclear—suggesting that the changes we are seeing are the result of natural cycles rather than human activities and interventions. It is a very strange argument; if the planet is warming at a terrifying pace and on a horrifying scale, it should transparently concern us more, rather than less, that the warming is beyond our control, possibly even our comprehension.

That we know global warming is our doing should be a comfort, not a cause for despair, however incomprehensively large and complicated we find the processes that have brought it into being; that we know we are, ourselves, responsible for all of its punishing effects should be empowering, and not just perversely. Global warming is, after all, a human invention. And the flip side of our real-time guilt is that we remain in command. No matter how out-of-control the climate system seems—with its roiling typhoons, unprecedented famines and heat waves, refugee crises and climate conflicts—we are all its authors. And still writing.

Some, like our oil companies and their political patrons, are more prolific authors than others. But the burden of responsibility is too great to be shouldered by a few, however comforting it is to think all that is needed is for a few villains to fall. Each of us imposes some suffering on our future selves every

consumption patterns into performances of moral or environmental purity—less beef, more Teslas, fewer transatlantic flights. But the climate calculus is such that individual lifestyle choices do not add up to much, unless they are scaled by politics. America's rump climate party aside, that scaling should not be impossible, once we understand the stakes. In fact, the stakes mean, it must not be.

Annihilation is only the very thin tail of warming's very long bell curve, and there is nothing stopping us from steering clear of it. But what lies between us and extinction is horrifying enough, and we have not yet begun to contemplate what it means to live under those conditions—what it will do to our politics and our culture and our emotional equilibria, our sense of history and our relationship to it, our sense of nature and our relationship to it, that we are living in a world degraded by our own hands, with the horizon of human possibility dramatically dimmed. We may yet see a climate deus ex machina—or, rather, we may yet build one, in the form of carbon capture technology or geoengineering, or in the form of a revolution in the way we generate power, electric or political. But that solution, if it comes at all, will emerge against a bleak horizon, darkened by our emissions as if by glaucoma.

Especially those who have imbibed several centuries of Western triumphalism tend to see the story of human civilization as an inevitable conquest of the earth, rather than the saga of an insecure culture, like mold, growing haphazardly and unsurely upon it. That fragility, which pervades now everything humans might do on this planet, is the great existential insight of global warming, but it is only beginning to shake our triumphalism—though, if we had stopped to contemplate the possibilities a generation ago, it probably would not surprise us to see a new form of political nihilism emerging in the region of the world already baked hardest by global warming, the Middle East, and expressed there through suicidal spasms of theological violence. That region was once called, grandly, "the cradle of civilization." Today, political nihilism radiates almost everywhere, through the many cultures that arose, branching, from Middle Eastern roots. We have all already left behind the narrow window of environmental conditions that allowed the human animal to evolve in the first place, but not just evolve—that window has enclosed everything we remember as history, and value as progress, and study as politics.[121] What will it mean to live outside that window, probably quite far outside it? That reckoning is the subject of this book.

None of it is news. The science that makes up the following twelve chapters has been culled from interviews with dozens of experts, and from hundreds of papers published in the best academic journals over the previous decade or so. Since it is science, it is tentative, ever-evolving, and some of the predictions that follow will surely not come precisely to pass. But it is an honest and fair portrait of the state of our collective understanding of the many multiplying threats that a warming planet poses to all of us presently living on it, and hoping we may continue to do so, in an indefinite and undisturbed way.

Little of it is about "nature" per se, and none concerns the tragic fate of the planet's animals, which has been written about so elegantly and poetically by others that, like our sea-level myopia, it threatens to occlude our picture of what global warming means for us, the human animal. Until now, it seems to have been easier for us to empathize with the climate plight of other species than our own, perhaps because we have such a hard time acknowledging or understanding our own responsibility and complicity in the changes now unfolding, and such an easier time evaluating the morally simpler calculus of pure victimhood.

What follows is instead a kaleidoscopic accounting of the human costs of human life continuing as it has for a generation, which will fill up the planet with only more humans—what ongoing global warming spells for public health, for conflict, for politics and food production and pop culture, for urban life and mental health and the way we imagine our own futures as we begin to perceive, all around us, an acceleration of history and the diminishing of possibility that acceleration likely brings. The force of retribution will cascade down to us through nature, but the cost to nature is only one part of the story; we will all be hurting. I may be in the minority in feeling that the world could lose much of what we think of as "nature," as far as I cared, so long as we could go on living as we have in the world left behind. The problem is, we can't.

II

ELEMENTS OF CHAOS

Heat Death

Humans, like all mammals, are heat engines; surviving means having to continually cool off, as panting dogs do. For that, the temperature needs to be low enough for the air to act as a kind of refrigerant, drawing heat off the skin so the engine can keep pumping. At seven degrees of warming, that would become impossible for portions of the planet's equatorial band, and especially the tropics, where humidity adds to the problem.[1] And the effect would be fast: after a few hours, a human body would be cooked to death from both inside and out.[2]

At eleven or twelve degrees Celsius of warming, more than half the world's population, as distributed today, would die of direct heat.[3] Things almost certainly won't get that hot anytime soon, though some models of unabated emissions do bring us that far eventually, over centuries. But at just five degrees, according to some calculations, whole parts of the globe would be literally unsurvivable for humans.[4] At six, summer labor of any kind would become impossible in the lower Mississippi Valley, and everybody in the United States east of the Rockies would suffer more from heat than anyone, anywhere, in the world today.[5] New York City would be hotter than present-day Bahrain, one of the planet's hottest spots, and the temperature in Bahrain "would induce hyperthermia in even sleeping humans."[6]

Five or six degrees is unlikely by 2100. The IPCC furnishes us with a median prediction of over four degrees, should we continue down the current emissions path.[7] That would deliver what today seems like unthinkable impacts—wildfires burning sixteen times as much land in the American West, hundreds of drowned cities. Cities now home to millions, across India and the Middle East, would become so hot that stepping outside in summer would be a lethal risk—in fact, they will become that way much sooner, with as little as two degrees of warming. You do not need to consider worst-case scenarios to become alarmed.

With direct heat, the key factor is something called "wet-bulb temperature," which also measures humidity in a combined method as home-laboratory-kit as it sounds: the temperature is registered on a thermometer wrapped in a damp sock as it's swung around in the air. At present, most regions reach a wet-bulb maximum of 26 or 27 degrees Celsius; the true red line for habitability is 35 degrees, beyond which humans begin simply dying from the heat. That leaves a gap of 8 degrees. What is called "heat stress" comes much sooner.

Actually, we're there already. Since 1980, the planet has experienced a fiftyfold increase in the number of dangerous heat waves; a bigger increase is to come.[8] The five warmest summers in Europe since 1500 have all occurred since 2002, and eventually, the IPCC warns, simply working outdoors at that time of

year will be unhealthy for parts of the globe.[9, 10] Even if we meet the Paris goals, cities like Karachi and Kolkata will annually encounter deadly heat waves like those that crippled them in 2015, when heat killed thousands in India and Pakistan.[11] At four degrees, the deadly European heat wave of 2003, which killed as many as 2,000 people a day, will be a normal summer.[12] Then, it was one of the worst weather events in Continental history, killing 35,000 Europeans, including 14,000 French; perversely, the infirm fared relatively well, William Langewiesche has written, most of them watched over in the nursing homes and hospitals of those well-off countries, and it was the comparatively healthy elderly who accounted for most of the dead, many left behind by vacationing families escaping the heat, with some corpses rotting for weeks before the families returned.[13]

It will get worse. In that "business as usual" scenario, a research team led by Ethan Coffel calculated in 2017, the number of days warmer than what were once the warmest days of the year could grow by a factor of 100 by 2080.[14] Possibly by a factor of 250. The metric Coffel uses is "person-days": a unit that combines the number of people affected with the number of days. Every year, there would be between 150 and 750 million person-days with wet-bulb temperatures equivalent to today's most severe—i.e., quite deadly—heat waves. There would be a million person-days each year with intolerable wet-bulb temperatures—combinations of heat and humidity beyond the human capacity for survival. By the end of the century, the World Bank has estimated, the coolest months in tropical South America, Africa, and the Pacific are likely to be warmer than the warmest months at the end of the twentieth century.[15]

We had heat waves back then, of course, deadly ones; in 1998, the Indian summer killed 2,500.[16] More recently, temperature spikes have gotten hotter. In 2010, 55,000 died in a Russian heat wave that killed 700 people in Moscow each day.[17] In 2016, in the midst of a heat wave that baked the Middle East for several months, temperatures in Iraq broke 100 degrees Fahrenheit in May, 110 in June, and 120 in July, with temperatures dipping below 100, most days, only at night. (A Shiite cleric in Najaf proclaimed the heat was the result of an electromagnetic attack on the country by American forces, according to *The Wall Street Journal,* and some state meteorologists agreed.)[18] In 2018, the hottest temperature likely ever recorded in April was registered in southeast Pakistan. In India, a single day over 95 degrees Fahrenheit increases annual mortality rates by three-quarters of a percent; in 2016, a string of days topped 120—in May. In Saudi Arabia, where summer temperatures often approach that mark, 700,000 barrels of oil are burned each day in the summer, mostly to power the nation's air-conditioning.[19]

That can help with the heat, of course, but air conditioners and fans already account for fully 10 percent of global electricity consumption.[20] Demand is expected to triple, or perhaps quadruple, by 2050; according to one estimate, the world will be adding 700 million AC units by just 2030.[21, 22] Another study suggests that by 2050 there will be, around the world, more than nine billion cooling appliances of various kinds.[23] But, the climate-controlled malls of the Arab emirates aside, it is not remotely economical, let alone "green," to wholesale air-condition all the hottest parts of the planet, many of them also the

requires not just carbon scale-back but what are called "negative emissions." These tools come in two forms: technologies that would suck carbon out of the air (called CCS, for "carbon capture and storage") and new approaches to forestry and agriculture that would do the same, in a slightly more old-fashioned way (bioenergy with carbon capture and storage, or "BECCS").

According to a raft of recent papers, both are something close to fantasy, at least at present. In 2018, the European Academies' Science Advisory Council found that existing negative-emissions technologies have "limited realistic potential" to even slow the increase in concentration of carbon in the atmosphere—let alone meaningfully reduce that concentration.[31] In 2018, *Nature* dismissed all scenarios built on CCS as "magical thinking."[32] It is not even so pleasant to engage in that thinking. There is not much carbon in the air, all told, just 410 parts per million, but it is everywhere, and so relying on carbon capture globally could require large-scale scrubbing plantations nearly everywhere on Earth—the planet transformed into something like an air-recycling plant orbiting the sun, an industrial satellite tracing a parabola through the solar system. (This is not what Barbara Ward or Buckminster Fuller meant by "spaceship earth.") And while advances are sure to come, bringing costs down and making more efficient machines, we can't wait much longer for that progress; we simply don't have the time. One estimate suggests that, to have hopes of two degrees, we need to open new full-scale carbon capture plants at the pace of one and a half per day every day for the next seventy years.[33] In 2018, the world had eighteen of them, total.[34]

This is not good, but indifference is unfortunately nothing new when it comes to climate. Projecting future warming is a foolish game, given how many layers of uncertainty govern the outcome; but if a best-case scenario is now somewhere between 2 and 2.5 degrees of warming by 2100, it seems that the likeliest outcome, the fattest part of the bell curve of probability, sits at about 3 degrees, or just a bit above. Probably even that amount of warming would require significant negative-emissions use, given that our use of carbon is still growing. And there is also some risk from scientific uncertainty, the possibility that we are underestimating the effects of those feedback loops in natural systems we only poorly understand. Conceivably, if those processes are triggered, we could hit 4 degrees of warming by 2100, even with a meaningful reduction in emissions over the coming decades. But the track record since Kyoto implies that human shortsightedness makes it unproductive to offer predictions about what *will* happen, when it comes to emissions and warming; better to consider what *could* happen. The sky is literally the limit.

Cities, where the world will overwhelmingly live in the near future, only magnify the problem of high temperature. Asphalt and concrete and everything else that makes a city dense, including human flesh, absorb ambient heat, essentially storing it for a time like a slow-release poison pill; this is especially problematic because, in a heat wave, nightly reprieves are vital, allowing bodies to recover.[35] When those reprieves are shorter, and shallower, flesh simply continues to simmer. In fact, the concrete and asphalt of cities absorb so much

heat during the day that when it is released, at night, it can raise the local temperature as much as 22 degrees Fahrenheit, turning what could be bearably hot days into deadly ones—as in the Chicago heat wave of 1995, which killed 739 people, the direct-heat effects compounded by broken public health infrastructure.[36, 37] That commonly cited figure only reflects immediate deaths; of the many thousands more who visited hospitals during the heat wave, almost half died within the year. Others merely suffered permanent brain damage. Scientists call this the "heat island" effect—each city its own enclosed space, and hotter the more crowded it is.

Of course, the world is rapidly urbanizing, with the United Nations estimating that two-thirds of the global population will live in cities by 2050—2.5 billion new urbanites, by that count.[38] For a century or more, the city has seemed like a vision of the future to much of the world, which keeps inventing new scales of metropolis: bigger than 5 million people, bigger than 10, bigger than 20. Climate change won't likely slow that pattern by much, but it will make the great migrations it reflects more perilous, with many millions of the world's ambitious flooding into cities whose calendars are dotted with days of deadly heat, gathering in those new megalopolises like moths to a flame.

In theory, climate change could even reverse those migrations, perhaps more totally than crime did in many American cities in the last century, turning urban populations in certain parts of the world outward as the cities themselves become unbearable. In the heat, roads in cities will melt and train tracks will buckle—this is actually happening already, but the impacts will mushroom in the decades ahead. Currently, there are 354 major cities with average maximum summertime temperatures of 95 degrees Fahrenheit or higher. By 2050, that list could grow to 970, and the number of people living in those cities and exposed to that deadly heat could grow eightfold, to 1.[39]6 billion. In the United States alone, 70,000 workers have been seriously injured by heat since 1992, and by 2050, 255,000 are expected to die globally from direct heat effects.[40, 41] Already, as many as 1 billion are at risk for heat stress worldwide, and a third of the world's population is subject to deadly heat waves at least twenty days each year; by 2100, that third will grow to half, even if we manage to pull up short of two degrees.[42] If we don't, the number could climb to three-quarters.

In the United States, heat stroke has a pathetic reputation—a plague you learn about from summer camp, like swimming cramps. But heat death is among the cruelest punishments to a human body, just as painful and disorienting as hypothermia.[43] First comes "heat exhaustion," mostly a mark of dehydration: profuse sweating, nausea, headache. After a certain point, though, water won't help, your core temperature rising as your body sends blood outward to the skin, hoping desperately to cool it down. The skin often reddens; internal organs begin to fail. Eventually you could stop sweating. The brain, too, stops working properly, and sometimes, after a period of agitation and combativeness, the episode is punctuated with a lethal heart attack. "When it comes to extreme heat," Langewiesche has written, "you can no more escape the conditions than you can shed your skin."

Hunger

Climates differ and plants vary, but the basic rule of thumb for staple cereal crops grown at optimal temperature is that for every degree of warming, yields decline by 10 percent.[1] Some estimates run higher.[2] Which means that if the planet is five degrees warmer at the end of the century, when projections suggest we may have as many as 50 percent more people to feed, we may also have 50 percent less grain to give them. Or even less, because yields actually decline faster the warmer things get. And proteins are worse: it takes eight pounds of grain to produce just a single pound of hamburger meat, butchered from a cow that spent its life warming the planet with methane burps.[3]

Globally, grain accounts for about 40 percent of the human diet; when you add soybeans and corn, you get up to two-thirds of all human calories.[4, 5] Overall, the United Nations estimates that the planet will need nearly twice as much food in 2050 as it does today—and although this is a speculative figure, it's not a bad one.[6] Pollyannaish plant physiologists will point out that the cereal-crop math applies only to those regions already at peak growing temperature, and they are right—theoretically, a warmer climate will make it easier to grow wheat in Greenland. But as a pathbreaking paper by Rosamond Naylor and David Battisti pointed out, the tropics are already too hot to efficiently grow grain, and those places where grain is produced today are already at optimal growing temperature—which means even a small warming will push them down a slope of declining productivity.[7] The same, broadly speaking, is true for corn. At four degrees of warming, corn yields in the United States, the world's top producer of maize, are expected to drop by almost half. Predicted declines are not quite as dramatic in the next three biggest producers—China, Argentina, Brazil—but in each case the country would lose at least a fifth of its productivity.[8]

A decade ago, climatologists might have told you that although direct heat undermined plant growth, the extra carbon in the atmosphere would have the opposite effect—a kind of airborne fertilizer. The effect is strongest on weeds, though, and does not seem to hold for grain. And at higher concentrations of carbon, plants grow thicker leaves, which sounds innocuous. But thicker leaves are worse at absorbing CO_2, an effect that means, by the end of the century, as much as 6.39 billion additional tons in the atmosphere each year.[9]

Beyond carbon, climate change means staple crops are doing battle with more insects—their increased activity could cut yields an additional 2 to 4 percent—as well as fungus and disease, not to mention flooding. Some crops, like sorghum, are a bit more robust, but even in those regions where such alternatives have been a staple, their production has diminished recently; and while grain

breeders have some hope that they can produce more heat-tolerant strains, they've been trying for decades without success. The world's natural wheat belt is moving poleward by about 160 miles each decade, but you can't easily move croplands north a few hundred miles, and not just because it's difficult to suddenly clear the land occupied now by towns, highways, office parks, and industrial installations. Yields in places like remote areas of Canada and Russia, even if they warmed by a few degrees, would be limited by the quality of soil there, since it takes many centuries for the planet to produce optimally fertile dirt. The lands that are fertile are the ones we are already using, and the climate is changing much too fast to wait for the northern soil to catch up. That soil, believe it or not, is literally disappearing—75 billion tons of soil lost each year.[10] In the United States, the rate of erosion is ten times as high as the natural replenishment rate; in China and India, it is thirty to forty times as fast.[11, 12]

Even when we try to adapt, we move too slowly. Economist Richard Hornbeck specializes in the history of the American Dust Bowl; he says that farmers of that era could conceivably have adapted to the changing climate of their time by cultivating different crops. But they didn't, lacking credit to make the necessary investments—and were therefore unable to shake inertia and ritual and the rootedness of identity.[13] So instead the crops died out, in cascading waves crashing through whole American states and all the people living in them.

As it happens, a similar transformation is unfolding in the American West right now. In 1879, the naturalist John Wesley Powell, who spent his downtime as a soldier during the Battle of Vicksburg studying the rocks that filled the Union trenches, divined a natural boundary running due north along the 100th meridian.[14] It separated the humid—and therefore cultivatable—natural farmland of what became the Midwest from the arid, spectacular, but less farmable land of the true West.[15] The divide ran through Texas, Oklahoma, Kansas, Nebraska, and the Dakotas, and stretches south into Mexico and north into Manitoba, Canada, separating more densely populated communities full of large farms from sparser, open land that was never truly made valuable by agriculture. Since just 1980, that boundary has moved fully 140 miles east, almost to the 98th parallel, drying up hundreds of thousands of square miles of farmland in the process. The planet's only other similar boundary is the one separating the Sahara desert from the rest of Africa.[16] That desert has expanded by 10 percent, too; in the winter, the figure is 18 percent.[17]

The privileged children of the industrialized West have long laughed at the predictions of Thomas Malthus, the British economist who believed that long-term economic growth was impossible, since each bumper crop or episode of growth would ultimately produce more children to consume or absorb it—and as a result the size of any population, including that of the planet as a whole, was a check against material well-being. In 1968, Paul Ehrlich made a similar warning, updated for a twenty-first-century planet with many times more people on it, with his widely derided *The Population Bomb,* which proposed that the economic and agricultural productivity of the earth had already reached its natural limit—and which was published, as it happened, just as the productivity gains from

what's called the "green revolution" were coming into focus. That term, which today is sometimes used to describe advances in clean energy, first arose to name the incredible boom in agricultural yields produced by innovations in farming practices in the middle of the twentieth century. In the half century since, not only has the world's population doubled but the fraction of people living in extreme poverty has fallen by a factor of about six—from just more than half of humanity to 10 percent. In the world's developing countries, undernourishment has dropped from more than 30 percent in 1970 to close to 10 percent today.[18]

These developments counsel sanguinity in the face of all kinds of environmental pressures, and in his recent book on the meaning of the twentieth-century agricultural boom, the writer Charles Mann divides those who respond to the seeming challenge of resource scarcity with reflexive optimism, whom he calls "wizards," from those who see collapse always around the corner, whom he calls "prophets." But though the green revolution seems almost too perfectly conceived and executed to refute Ehrlich's alarmism, Mann himself is not sure what the lessons are. It may yet be a bit early to judge Ehrlich—or perhaps even his godfather, Malthus—since nearly all of the astonishing productivity gains of the last century trace back to the work of a single man, Norman Borlaug, perhaps the best argument for the humanitarian virtue of America's imperial century. Born to Iowa family farmers in 1914, he went to state school, found work at DuPont, and then, with the help of the Rockefeller Foundation, developed a new collection of high-yield, disease-resistant wheat varieties that are now credited with saving the lives of a billion people worldwide.[19] Of course, if those gains were a onetime boost—engineered, in large part, by a single man—how comfortably can we count on future improvements?

The academic term for the subject of this debate is "carrying capacity": How much population can a given environment ultimately support before collapsing or degrading from overuse? But it is one thing to consider what might be the maximum yield of a particular plot of earth and another to contemplate how fully that number is governed by environmental systems—systems far larger and more diffusely determined than even an imperial wizard like Borlaug could reasonably expect to command and control. Global warming, in other words, is more than just one input in an equation to determine carrying capacity; it is the set of conditions under which all of our experiments to improve that capacity will be conducted. In this way, climate change appears to be not merely one challenge among many facing a planet already struggling with civil strife and war and horrifying inequality and far too many other insoluble hardships to iterate, but the all-encompassing stage on which all those challenges will be met—a whole sphere, in other words, which literally contains within it all of the world's future problems and all of its possible solutions.

Curiously, maddeningly, these can be the same. The graphs that show so much recent progress in the developing world—on poverty, on hunger, on education and infant mortality and life expectancy and gender relations and more—are, practically speaking, the same graphs that trace the dramatic rise in global carbon emissions that has brought the planet to the brink of overall catastrophe.

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