nature. If a reader is looking to justify the Kayapó's way of life as being better than Maggi's, or to prove civilization's imminent demise, this is not the book to find those arguments. Neither does this book argue that the bulldozers represent an endpoint in our progression toward a healthier, happier, or more prosperous way of life for our species. Instead, this book's purpose is to look back on humanity's journey, and to tease apart the pathways that show how we got to where we are now. Perhaps we can learn about our future on this planet by looking at the past.

1: A BIRD'S-EYE VIEW

SOCRATES, SPEAKING TO HIS DISCIPLES in his final hours, imagined the view if he could "take the wings of a bird and fly upward" and peer down upon the Earth. "I believe that the earth is very vast," he surmised, with little more than water, patches of earth, and "an endless slough of mud." Humanity's significance wanes against the vastness of the world below in this long-ago view.

More than a hundred generations later, the view from above tells a story that Socrates could scarcely have imagined. Whether from airplane windows or images beamed down from space, the picture is clear. Roads crisscross the landscape. Fields where people sow wheat, rice, potatoes, and a multitude of other crops pockmark the countryside. Pastures where grazing cows are raised to supply meat and milk for their owners expand to the horizon. Bright lights beam to the sky from buildings in towns and cities. Socrates's view from above diminished our significance in the world. Today, that same view signifies our powerful role. Signs of human presence are nearly everywhere.

Our species, one among millions that inhabit the planet, has transformed the Earth. The imprint on the planet is visible from far-off space.

And much of the change—from the fertile prairies of North America to the verdant rice paddies of the Mekong Delta—has occurred for one reason: our species has commandeered nature to fill our stomachs.

Humanity's unmistakable imprint on the planet typically evokes one of two antagonistic reactions. In one, the Earth's dramatic transformation is proof that human ingenuity can trump any barriers nature presents. Every problem has a technological solution. Run out of food or energy? No need to worry, someone will devise a clever technology and find a way out. According to Julian Simon, the classic protagonist of this view, human ingenuity not only stretches natural resources, but can make them infinite. The ultimate resource is not coal, water, or copper, but human ingenuity. Nature poses no limits. The future is secure.

The counterargument views our enormous imprint as the height of folly and proof that humanity is headed toward disaster. Monopoly by a single species, the reasoning goes, is bound to lead to catastrophe, starvation, and collapse. Resources, by definition, are finite, and humanity's expansion will inevitably butt up against the limit or create side-effects so severe that civilization will not survive. A long list of scholars follows this line of thinking, most famously the Reverend Thomas Robert Malthus, with his predictions of famine. More recent thinkers have used suggestive titles for their writings to reflect this view, such as Donella Meadows, with *Limits to Growth*, and Johan Rockström, with *Planetary Boundaries*. Nature will have the last say, they claim. Humanity is slurping up resources and spewing wastes with catastrophic consequences. Humans are a destructive force.

Does the bird's-eye view reveal hubris or success, folly or triumph? Perhaps this is not even the right question. Within a narrow perspective, both views might seem correct at different points in history or in different places around the world. But both prove incapable of describing the world from a long-term and broader perspective. Simon's view of technological fixes fails to foresee the problems that these fixes can create.

Rockström's view of future catastrophes underestimates the ability of human societies to adapt and change. Both fail to consider the reality of humanity's long and complex relationship with nature. Neither offers guidance for addressing humanity's current conundrums.

A broader and longer-term perspective reveals a species that, like any other, manipulates its surroundings to expand its territory and grow in numbers. The difference is the extraordinary ability of our species to twist food from nature. To comprehend how our species—which for tens of thousands of years hunted prey and gathered wild plants like any other animal—became such a dominant force demands that we leave behind narrow-minded moralizing about conquest or destruction. A broader perspective views human civilization as neither right nor wrong, neither good nor bad, but as part of the evolution of life on this planet.

This book traces humanity's remarkable journey from an ordinary mammal to a world-dominating, urban-dwelling species. Striking patterns emerge from this long-term view. One is that we have always lived off of the food that we have managed to squeeze from our surroundings, just like any other species, from the smallest microbe to the largest carnivore. Another is that civilization's attempts to extract food from nature are experiments. Through trial and error, we have found new ways to extract more food with less work. Our capacity to build knowledge across generations, a hallmark of our species, has allowed one experiment to build on the last in a never-ending progression. If one experiment fails, we lurch, stumble, and try some other path. Even today's massive manipulation of nature to feed billions is simply one more experiment in a long chain.

The process goes something like this. It starts with a hungry person in search of the easiest and quickest way to get a meal. At some point, a way to manipulate nature emerges, perhaps when someone tames an edible plant or devises a way to spread scarce nutrients so crops can grow. Maybe the twist of nature is intentional, or perhaps someone stumbles

upon some random good fortune. With more food to go around, the success ratchets up the number of our species, and people expand into new places. Inevitably, any innovation reaches its limit, creating demands it cannot satisfy, generating too much pollution, or creating some other unforeseen obstacle. Once again, specters of not enough food to go around appear, and prospects look grim. The hatchet falls. Then a new pivot, a new way to use nature's endowments, emerges. The ratchet turns again, providing more and more people with food, committing civilization to keeping the growing number of people fed. At some point there's an even bigger hurdle, perhaps from the sheer number of people or from disease, drought, or some other calamity. Ratchet, hatchet, pivot; ratchet, hatchet, pivot. In every cycle, the stakes get higher, as our species expands in numbers and in the extent of its reach across the world. In every cycle, new obstacles emerge. And in every cycle, millennium after millennium, humanity as a whole has muddled through.

Those cycles continue today, but in a different guise. For most of human history the hatchets were famine and shortage. As we will see in later chapters, our current problems are more about abundance than about lack of food. Our species has never before had to grapple with such surplus. What once seemed like a dream has led to new crises: exploding numbers of overweight people, others still without enough despite the plenty, and an excess that leaks pollutants into the air and water. The pattern of unintended and unforeseen consequences continues, but the hatchets are new.

Within the lifetimes of most of the people reading these pages, humanity has devised ways to extract food from nature on a scale like never before. We have lived through the Big Ratchet—the extraordinary second half of the twentieth century—when our twists of nature sped up so fast that the trajectory of human civilization changed course. Before the Big Ratchet, our species was already exceptional. We were the

only mammal that farmed, though not the only other farming species in the animal kingdom. But now, at the Big Ratchet's crest, most of us live in cities and consume food that is produced far away by a minority of the human population. This change makes us unique.

Our species passed this milestone in May 2007. After that fateful date, more than half of us have lived in cities. We stepped over the threshold from mostly farmers to mostly urban-dwellers. And our evolution to an urban species reaches into the fundamentals of our lives—our diets, our health, the size of our families, where we live and work, our perceived links with nature, and the future of the planet itself. The shift is as fundamental as our transition from forager to farmer more than 10,000 years ago.

During the Big Ratchet, a year's production of corn and rice nearly tripled worldwide, and wheat more than doubled. With the abundance of corn to feed cows, pigs, and chickens, the amount of meat more than tripled. Food became cheaper than ever before. The share of a family's income devoted to food is now lower than at any other time in modern history. Many people, though by no means all, can spend more on education, cars, houses, and food than they would have been able to afford just half a century ago. They can live in cities and get their groceries from a corner shop, rather than laboring in the fields, or from a large supermarket that holds a cornucopia that our ancestors could not have imagined. At the same time, millions of families around the world are reaping the benefits of sanitation from flush toilets, vaccinations against big killers such as smallpox, antibiotics to cure infections, cleaner drinking water, pesticides to control diseases like malaria, and other health-care advances. For nearly all of human history, the average life span at birth was about thirty years. That statistic rose by about two decades during the second half of the twentieth century, though a person's lifetime in a poor country was still many years shorter than that of someone living in one of the richer parts of the world.

Such a massive shift is bound to reverberate into a family's decisions about how many children to bring into the world. When humans pivoted long ago from nomadic forager to settled farmer, women began to have more children. The Big Ratchet has seen precisely the opposite shift. With more children surviving, and contraception becoming available, women began to have fewer children, especially when they had access to education and jobs. A rationale for large families disappeared as labor-intensive farm life gave way to city living. Women married and had children later in life. We can all probably trace this arc of large to small families with a view back a few generations into our own family trees.

The shift from high death and birth rates to low rates for both is known as the demographic transition. It is responsible for the massive explosion in the number of mouths to feed during the Big Ratchet, although it began in around 1800 in northwestern Europe. The Big Ratchet's transition ranks among the largest demographic upheavals in human history, and in most countries it is still underway. In 1800, there were 950 million people in the world. By 1900, there were slightly more than 1.5 billion. And then the population began to explode: to 2.5 billion in 1950, 6 billion in 2000, and nearly 7 billion by 2010.

The dramatic upswing in numbers probably won't level off until 2050, by which time there could be 9 billion people on the planet. By that time, nearly seven out of ten people will likely be living in cities, up from three out of ten at the midpoint of the twentieth century. Human ingenuity will be put to the test yet again by all of those mouths to feed and stomachs to fill, by all of those people in cities buying their food in stores rather than growing it on the farm.

The Big Ratchet that took place during the second half of the twentieth century has one remarkable feature: The amount of food produced not only kept pace with the ballooning number of people, it surpassed the amount available for each person when the Big Ratchet began. If all the people in the world were to receive equal shares of food, which of course

they do not, then each person would have had about 2,200 calories each day in 1960 and about 2,700 in 2000—despite the surge in population.

This is quite an accomplishment for a species whose members started to become farmers only 12,000 years ago. But here is the rub: only those who could afford to pay the bill could share in the bounty, and that leaves out a large portion of humanity. It leaves out most of the people living in the poor countries of Africa. It leaves out many in India, Brazil, and other countries, too, where economic engines have started to churn, but those on the bottom rungs of the ladder have been left out. The result is that the number of people who went to bed hungry every night dropped only slightly below the 1 billion mark, leaving about two out of every thirteen people undernourished at the end of the twentieth century. Even for those who can consume more calories, it's debatable whether they have healthier diets. Whether the planet can withstand the onslaught is another unknown.

We can only see the dynamics that drove humanity's journey from forager to farmer and then from farmer to urbanite with a long-term view. Societies adapt, learn, and alter course when conditions change. Simon's and Rockström's short-term views fail to grasp that there is no endpoint to this interplay between human ingenuity and nature. The long view circumvents outdated romantic notions of a pristine nature that humanity is violating. Human civilization is part of nature, and nature is part of human civilization. As long as civilization exists, we will be grappling with how to hijack nature to feed ourselves. And we will never escape the fact that all abundance, including the plenty in current times, results from temporary solutions.

Civilization's Engine

Food is the ultimate energy source for every human endeavor. It is more essential than coal, gas, or any of the other sources that power

our machines. Without food, there can be no cities, trade, cuisines, language, great artwork, symphonies, novels, theater, or any of the other hallmarks that set our species apart from others. From the wild plants of hunter-gatherers to the packaged cereals of the urban shopper, food has always been and will always be the engine of civilization. Although we normally think of civilization in terms of culture and technology, we might equally define it as a combination of nature and human ingenuity. This combination is what provides enough surplus to allow a portion of the population to engage in activities other than producing, preparing, and storing food.

Take, for example, ancient Jericho, the earliest known urban center, located near the Jordan River in Palestine. Today, ancient Jericho would seem like little more than a small town. About 2,000 people lived there by 8000 BCE. Perennial, clear spring water from a nearby oasis watered fields of wheat and barley. More grew in a single year than Jericho's people could eat. The surplus allowed some of the people to specialize in making pottery or jewelry, engaging in religious worship and rituals, keeping order, and performing other tasks. Not everyone's daily life had to be directly related to farming or preparing food.

Jericho and the towns that sprang up later were little more than isolated islands of sedentary farmers living amid nomadic groups who hunted and foraged for their food. But the towns set in motion the future of civilization and numerous inventions and achievements, including the plow, writing, bronze, modern science, machines, and medicine. Settled life also triggered stratified societies dominated by elites who controlled the surplus and usurped the benefits for themselves. For good and for bad, from the times of ancient Jericho until today's bustling cities of São Paulo, Mumbai, and New York, among many others, densely packed settlements with people specializing in different tasks would not be possible without agriculture to grow surplus food.

The link between farming and complex civilization is not unique to our species. Humans, in fact, are a relatively recent addition to the

list of species that farm. Our species devised the trick only 10,000 to 12,000 years ago. Insects had it figured out millions of years before. Leaf-cutter ants, found today in South and Central America and the southern United States, are among the original farmers, constructing complex mazes of underground caverns to house fungus farms. The ants bite green leaves into tiny pieces and carry them underground to the farm. There, they chew the leaves into pulp. They deposit the half-digested mass as it moves through their guts. Tiny, mushroom-like fungi then grow on the decaying rot of partly digested leaves, providing a nutritious food for the ants. Termites practice the same ecological trick, constructing fungi farms in underground combs beneath their mounds. Ambrosia beetles grow their fungi in intricate burrows bored deep into tree trunks, where they raise their broods of larvae on the nutritious fungi crop. So our use of livestock for meat and dairy animals for milk is not really all that unique.

Regardless of which species is farming—ants, beetles, termites, or humans—complex societies with specialized tasks are the norm once farming becomes the strategy to produce food. The evolution to farming made it possible for millions of individuals to live in the same mound,

nest, tree burrow, or city. The transition to farming and complex societies is so drastic, in fact, that no farming species is known to have reverted to a non-farming existence.

Very few species farm, but all plants and animals play ecological tricks to produce food, expand their numbers, occupy every possible niche, and outcompete their rivals for space and nutrients. Microbes in the deep sea extract energy from the heat of vents on the ocean floor. Plants fuel growth by combining the sun's energy with carbon from the air. Animals eat plants and other animals, exploiting the sun's energy through plants as intermediaries. But our species has one trick that others do not. Other species rely on genes to shape their evolution. But humans have memes as well, an idea Richard Dawkins articulated to describe the ideas that spread and shape human culture. Successful memes persist and evolve. Unsuccessful memes die a quick death, just as species unable to survive go extinct.

Memes to fill our stomachs have persisted, spread, and morphed into bigger and better memes throughout the history of human culture. Memes to purposefully select edible plants and animals, to move water to irrigate crops in places where nature does not supply a ready source, and to extract fertilizers from air and rocks are only a few of the ingenious innovations humans have used to enhance nature's bounty. Today's view from above reveals tens of thousands of years of successive, ever more clever ways to wrestle food from nature, ratchet up our numbers, and expand across the planet.

The Irish Pivot

One infamous example of the ratchet-hatchet-pivot cycle centers on the humble potato and Ireland's Great Famine. The potato's ascent as an Irish staple began with Christopher Columbus's 1492 arrival in the Americas. Eventually, ships carried South America's native potato from the New

World to the Old. The first evidence of the potato's arrival in Europe comes from the record of a hospital purchase in Seville, Spain, in 1573.

The potato diffused slowly throughout Europe, encumbered by suspicions of poison and notions that its bumpy resemblance to a leprosy patient meant that it spread the disease. Gradually, potatoes earned a prized place on farms, thanks to their advantages over other staple crops. The energy- and vitamin-rich potato required less land than wheat, barley, and other staples to grow the same amount of calories. People could subsist almost solely on a diet of potatoes supplemented by only a bit of meat or dairy. Potatoes stored easily, and they could grow along with other crops. All of these factors made the potato wildly popular. By the beginning of the eighteenth century, potatoes were common throughout Europe.

People grew taller with potatoes in their diets. French soldiers growing up in potato-eating villages were about half an inch taller in the late 1700s than their predecessors a century earlier. Thanks partly to the potato, people lived longer and had more children. Historians today estimate that the potato accounts for about one-quarter of the growth of Europe's population between 1700 and 1900, with better health and sanitation explaining the rest. The pivot to the potato set in motion a powerful ratchet.

No one relied on the potato more than the poor peasants of Ireland. At the beginning of the nineteenth century, with the industrial revolution in full swing, factories in England were drumming cottage industries out of business, compelling more Irish families to farm for their daily meal. At the same time, rich landowners were evicting tenant farmers from their estates so they could produce more profitable livestock and grains for export to England. As landowners usurped more land, potatoes became the only viable choice for peasant families. A few decades into the century, the growing population of poor Irish peasants was subsisting almost exclusively on the common Lumper potato.

A useful attribute of potatoes is that a plant can sprout directly from another potato planted in the soil. There was no need for the farmer to buy seeds. But this key feature proved to have a devastating downside. Potatoes were genetic clones of each other. And because fields were close together, the potato plants were perfect targets for pests. Unlike in South America, no genetic variants that might have been able to withstand an onslaught stood in the way of a fatal pest sweeping across the fields.

The fungus that caused the potato blight hit hard in 1845, setting in motion the Great Irish Famine. The potato had ratcheted up the number of mouths to feed. Then the hatchet fell: pestilence, famine, and death. Potatoes rotted in field after field. Few potatoes remained from which to plant a new crop, and the fungus returned in later years to prey on those that did. Lack of jobs and limited prospects for more land left the poor with few options. A million people, one-eighth of the Irish population, died. Another million left for other parts of the United Kingdom and the New World.

The Irish population has never recovered to the 8 million of 1841, but there has not been a major famine in Ireland since. For those who remained behind, new varieties of potatoes offered respite against blights. Pastures took the place of many potato fields, and factory jobs replaced farming. Today, the fungus still plagues potato farmers, but blight-resistant strains bred from South American wild potatoes, combined with pesticides and potatoes being planted further apart, have reduced the threat. The pivot followed the hatchet in a new twist of the cycle.

Seen through a political lens, British exploitation of their neighbors and disregard for the peasant's plight were at the heart of the famine. The genetic clones and the fungus are to blame if one views the famine through a purely ecological lens. With a short-term lens, the famine was an unmitigated disaster for many—indeed, very nearly a collapse. None of these lenses alone, however, captures the whole story

of Irish resilience in the face of a devastating tragedy. The picture of a society that changed and adapted, rather than collapsed, emerges only from a view through the long-term lens. The story of the Great Famine is a microcosm of humanity's journey through the ratchets, hatchets, and pivots that typify our history. We can only see the journey clearly through multiple lenses.

The Length of the Lens

The demise of the Irish potato in the mid-1800s and the many other twists of nature that we will see in this book may seem like classic cases of overshoot. A twist of nature for more food is followed by a society with more and more mouths to feed. At some point, nature reacts. A crash follows. The American sociologist William Catton Jr. described this pattern in his 1980 book *Overshoot: The Ecological Basis of Revolutionary Change*.

From a short lens, history illustrates many individual examples of overshoot. Towering statues of Easter Island, Mayan cities, the cliff dwellings of the Anasazi in the American Southwest, and the massive temple complexes of Angkor Wat in Cambodia all convey the demise of civilizations that once prospered. Some complicated combination of political strife, unexpected climate, social upheaval, or soils run dry of nutrients, as well as many unknowable factors, no doubt contributed. All of these civilizations had ratcheted up their numbers with sophisticated technologies, and none withstood the onslaught from intertwined social and ecological changes.

The short lens and a focus on those particular examples bias our interpretation of the past. The long lens paints a different picture, showing that overshoot leads not to collapse, but to the next pivot. This is the argument of the Danish economist Ester Boserup, who studied so-called primitive societies. Boserup claimed that when too many hungry stomachs

outstrip the available food supply, people work harder to produce more food by weeding and watering the crops. Instead of overshoot and ensuing collapse, human ingenuity kicks in. The pivot follows the hatchet. Individual societies may rise and fall, but for the species, the trajectory follows a path of successive ratchets and pivots.

The Boserupian view leans on human ingenuity to find pivots for ratchets. The environmentalists' idea of overshoot assumes that nature will run out of pivots. Neither of these views is sufficient in itself to explain the billions-strong dominance of our species on the planet, or to guide society's decisions about the future. If the bag of ecological tricks runs out, or if nature's backlash is so overpowering that no pivot can evolve quickly enough to help, then overshoot could truly ensue. So far, and in aggregate, though, history tells the opposite story. Humanity's manipulations of nature have transformed the planet's landscapes and ratcheted up our numbers again and again. By measures of numbers and extent, our species has achieved extraordinary success.

The Big Ratchet of the twentieth century brings us to a quandary. As described in later chapters, at no other time in history has food been so abundant, or our species so successful in expanding in numbers. At no other time have so many people been so prosperous. On the other side of the ledger, the gap between the rich and the poor has grown wider, the manipulations of nature have become more massive, and diets have become more loaded with unhealthy sugars and fats. Although history shows that ingenuity has brought humanity back from the brink of overshoot time and again, this history does not ensure that the same will occur in the future.

Without Socrates's bird's-eye view, it is difficult to tell where the present stands in the long arc of history. We would be, as the nineteenth-century philosopher Arthur Schopenhauer wrote, like "every man" who "takes the limits of his own field of vision for the limits of the world."

This book looks at the current times through the lens of the long arc of our species' quest to feed itself. From the multimillennia lens of ratchets, hatchets, and pivots, two themes emerge. One is that the ratchets, hatchets, and pivots will continue as long as human civilization exists. Solutions will create new problems, and problems will generate new solutions. The other is that we live in extraordinary times, at the crest of a ratchet that has manipulated nature so much that most of humanity can live in cities rather than grow their own food. Today's transformation from a farming to an urban species is as momentous for our lives and the planet as the long-ago transition from forager to farmer. We have yet to learn how to live with that change.

The story of humanity's journey from an ordinary mammal to a world-dominating species goes back millions, if not billions, of years. Only a planet with an amazing machinery to sustain the richness of life could give rise to an intelligent, large-brained species such as ours. Only an exceptional species with culture and knowledge could manipulate nature and produce enough food to dominate the world.

To recount the story of humanity's interplay with nature through a long-term lens is to bear witness to astonishing feats of human ingenuity that both solved problems and created new ones in their wake. The story begins with the two foundations that made our evolution from an ordinary mammal possible—endowments from a bountiful planet and the power of ingenuity. The amazing marvels of our planet's machinery, combined with the ingenuity of our species to harness that machinery for food, is the platform on which all civilization rests. As we leave aside the blithe reassurances of those who assume that technological fixes are always in store and the frenetic warnings of the doomsayers, we embrace a broader understanding of the interlocked path of human civilization and the planet. Only by acknowledging the long and complex interplay of nature and human ingenuity can we begin to address the next pivots that may be in store for our remarkable species.