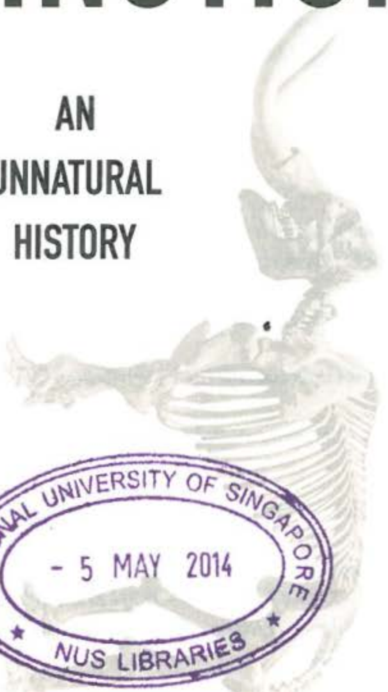
THE SIXTH EXTINCTION

AN UNNATURAL HISTORY



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CHAPTER XI

THE RHINO GETS AN ULTRASOUND

Dicerorhinus sumatrensis

THE FIRST VIEW I GOT OF SUCI WAS HER PRODIGIOUS BACKSIDE. It was about three feet wide and stippled with coarse, reddish hair. Her ruddy brown skin had the texture of pebbled linoleum. Suci, a Sumatran rhino, lives at the Cincinnati Zoo, where she was born in 2004. The afternoon of my visit, several other people were also arrayed around her formidable rump. They were patting it affectionately, so I reached over and gave it a rub. It felt like petting a tree trunk.

Dr. Terri Roth, director of the zoo's Center for Conservation and Research of Endangered Wildlife, had arrived at the rhino's stall wearing scrubs. Roth is tall and thin, with long brown hair that she had pinned up in a bun. She pulled on a clear plastic glove that stretched over her right forearm, past the elbow, almost to her shoulder. One of Suci's keepers wrapped the rhino's tail in what looked like Saran Wrap and held it off to the side. Another keeper grabbed a pail and stationed himself by Suci's mouth. It was hard for me to see over Suci's bottom, but I was told he was feeding the rhino slices of apples, and I could hear her chomping away at them. While Suci was thus distracted, Roth pulled a second glove over the first and grabbed what looked like a video game remote. Then she stuck her arm into the rhino's anus.

Of the five species of rhinoceros that still exist, the Sumatran rhino—*Dicerorhinus sumatrensis*—is the smallest and, in a manner of speaking, the oldest. The genus *Dicerorhinus* arose some twenty million years ago, meaning that the Sumatran rhino's lineage goes back, relatively unchanged, to the Miocene. Genetic analysis has shown that the Sumatran is the closest living relative of the woolly rhino, which, during the last ice age, ranged from Scotland to South Korea. E. O. Wilson, who once spent an evening at the Cincinnati Zoo with Suci's mother and keeps a tuft of her hair on his desk, has described the Sumatran rhino as a "living fossil."

Sumatrans are shy, solitary creatures that in the wild seek out dense undergrowth. They have two horns—a large one at the tip of their snouts and a smaller one behind it—and pointy upper lips, which they use to grasp leaves and tree limbs. The animals' sex life is, from a human perspective at least, highly unpredictable. Females are what are known as induced ovulators; they won't release an egg unless they sense there's an eligible male around. In Suci's case, the nearest eligible male is ten thousand miles away, which is why Roth was standing there, with her arm up the rhino's rectum.

About a week earlier, Suci had been given a hormone injection designed to stimulate her ovaries. A few days after that, Roth had tried to artificially inseminate the rhino, a process that had involved threading a long, skinny tube through the folds of Suci's cervix, then pumping into it a vial of thawed semen. According to notes Roth had taken at the time, Suci had "behaved very well" during the procedure. Now it was time for a follow-up ultrasound. Grainy images appeared on a computer screen propped up near Roth's elbow. Roth located the rhino's bladder, which appeared on the screen as a dark bubble, then continued on. Her hope was that an egg in Suci's right ovary, which had been visible at the time of the insemination, had since been released. If it had, there was a chance Suci could become pregnant. But the egg was right where Roth had last seen it, a black circle in a cloud of gray.

"Suci did not ovulate," Roth announced to the half-dozen zookeepers who had gathered around to help. By this point, her entire arm had disappeared inside the rhino. The group let out a collective sigh. "Oh, no," someone said. Roth pulled out her arm and removed her gloves. Though clearly disappointed by the outcome, she didn't seem surprised by it.

THE Sumatran rhino was once found from the foothills of the Himalayas, in what's now Bhutan and northeastern India, down through Myanmar, Thailand, Cambodia, and the Malay Peninsula, and on the islands of Sumatra and Borneo. In the nineteenth century, it was still common enough that it was considered an agricultural pest. As southeast Asia's forests were felled, the rhino's habitat shrank and became fragmented. By the early nineteen-eighties, its population had been reduced to just a few hundred animals, most in isolated reserves on Sumatra and the rest in Malaysia. The animal seemed to be heading inexorably toward extinction when, in 1984, a group of conservationists gathered in Singapore to try to work out a rescue strategy. The plan they came up with called for, among other things, establishing a captive breeding program to insure against the species' total loss. Forty rhinos were caught, seven of which were sent to zoos in the U.S.

The captive breeding program got off to a disastrous start. Over a span of less than three weeks, five rhinos at a breeding facility in Peninsular Malaysia succumbed to trypanosomiasis, a disease caused by parasites spread by flies. Ten animals were caught in Sabah, a Malaysian state on the eastern tip of Borneo. Two of these died from injuries sustained during capture. A third was killed by tetanus. A fourth expired for unknown reasons, and, by the end of the decade, none had produced any offspring. In the U.S., the mortality rate was even higher. The zoos were feeding the animals hay, but, it turns out, Sumatran rhinos cannot live off hay; they require fresh leaves and branches. By the time anyone figured this out, only three of the seven animals that had been sent to America were still living, each in a different city. In 1995, the journal *Conservation Biology* published a paper on the captive breeding program. It was titled "Helping a Species Go Extinct."

That year, in a last-ditch effort, the Bronx and the Los Angeles Zoos sent their remaining rhinos—both females—to Cincinnati, which had the only surviving male, a bull named Ipuh. Roth was hired to figure out what to do with them. Being solitary, the animals couldn't be kept in the same enclosure, but obviously unless they were brought together, they couldn't mate. Roth threw herself into the study of rhino physiology, collecting blood samples, analyzing urine, and measuring hormone levels. The more she learned, the more the challenges multiplied.

"It's a very complicated species," she told me once we were back in her office, which is decorated with shelves full of wooden, clay, and plush rhinos. Rapunzel, the female from the Bronx, turned out to be too old to reproduce. Emi, the female from Los Angeles, seemed to be the right age but never seemed to ovulate, a puzzle that took Roth nearly a year to solve. Once she realized what the problem was—that the rhino needed to sense a male around—she began to arrange brief, carefully monitored "dates" between Emi and Ipuh. After a few months of fooling around, Emi got pregnant. Then she lost the pregnancy. She got pregnant again, and the same thing happened. This pattern kept repeating, for a total of five miscarriages. Both Emi and Ipuh developed eye problems, which Roth eventually determined were the result of too much time in the sun. (In the wild, Sumatran rhinos live in the shade of the forest canopy.) The Cincinnati Zoo invested a half a million dollars in custom-made awnings.

Emi got pregnant again in the fall of 2000. This time, Roth put

Suci at the Cincinnati Zoo.

her on liquid hormone supplements, which the rhino ingested in progesterone-soaked slices of bread. Finally, after a sixteen-month gestation, Emi gave birth to Andalas, a male. He was followed by Suci—the name means "sacred" in Indonesian—and then by another male, Harapan. In 2007, Andalas was shipped back to Sumatra, to a captive breeding facility in Way Kambas National Park. There, in 2012, he fathered a calf named Andatu—Emi and Ipuh's grandson.

The three captive-bred rhinos born in Cincinnati and the fourth in Way Kambas clearly don't make up for the many animals who died along the way. But they have turned out to be pretty much the only Sumatran rhinos born anywhere over the past three decades. Since the mid–nineteen-eighties, the number of Sumatran rhinos in the wild has declined precipitously, to the point that there are now believed to be fewer than a hundred left in the world. In an ironic twist, humans have brought the species so low that it seems only heroic human efforts can save it. If *Dicerorhinus sumatrensis* has a future, it's owing to Roth and the handful of others like her who know how to perform an ultrasound with one arm up a rhino's rectum.

And what's true of *Dicerorhinus sumatrensis* is, to one degree or another, true of all rhinos. The Javan rhino, which once ranged across most of southeast Asia, is now among the rarest animals on earth, with probably fewer than fifty individuals left, all in a single Javanese reserve. (The last known animal to exist somewhere else—in Vietnam—was killed by a poacher in the winter of 2010.) The Indian rhino, which is the largest of the five species and appears to be wearing a wrinkled coat, as in the Rudyard Kipling story, is down to around three thousand individuals, most living in four parks in the state of Assam. A hundred years ago, in Africa, the population of black rhinos approached a million; it has since been reduced to around five thousand animals. The white rhino, also from Africa, is the only rhino species not currently classified as threatened. It was hunted nearly to oblivion in the nineteenth century, made a remarkable comeback in the twentieth, and now, in the twenty-first, has come under renewed pressure from poachers, who can sell rhino horns on the black market for more than twenty thousand dollars a pound. (Rhino horns, which are made of keratin, like your fingernails, have long been used in traditional Chinese medicine but in recent years have become even more sought-after as a high-end party "drug"; at clubs in southeast Asia, powdered horn is snorted like cocaine.)

Meanwhile, of course, rhinos have plenty of company. People feel a deep, almost mystical sense of connection to big "charismatic" mammals, even if they're behind bars, which is why zoos devote so many resources to exhibiting rhinos and pandas and gorillas. (Wilson has described the evening he spent in Cincinnati with Emi as "one of the most memorable events" of his life.) But almost everywhere they're not locked up, big charismatic mammals are in trouble. Of the world's eight species of bears, six are categorized either as "vulnerable" to extinction or "endangered." Asian elephants have declined by fifty percent over the last three generations. African elephants are doing better, but, like rhinos, they're increasingly threatened by poaching. (A recent study concluded that the population of African forest elephants, which many consider to be a separate species from savanna elephants, has fallen by more than sixty percent just in the last ten years.) Most large cats—lions, tigers, cheetahs, jaguars—are in decline. A century from now, pandas and tigers and rhinos may well persist only in zoos or, as Tom Lovejoy has put it, in wildlife areas so small and heavily guarded they qualify as "quasi zoos."

THE day after Suci's ultrasound, I went to visit her again. It was a cold winter morning, and so Suci was confined to what is euphemistically referred to as her "barn"—a low-slung building made out of cinderblocks and filled with what look like prison cells. When I arrived, at around 7:30 AM, it was feeding time, and Suci was munching on some ficus leaves in one of the stalls. On an average day, the head rhino-keeper, Paul Reinhart, told me, she goes through about a hundred pounds of ficus, which has to be specially flown in from San Diego. (The total cost of the shipments comes to nearly a hundred thousand dollars a year.) She also consumes several gift baskets' worth of fruit; on this particular morning, the selection included apples, grapes, and bananas. Suci ate with what seemed to me to be lugubrious determination. Once the ficus leaves were gone, she started in on the branches. These were an inch or two thick, but she crunched through them easily, the way a person might bite through a pretzel.

Reinhart described Suci to me as a "good mix" between her mother, Emi, who died in 2009, and her father, Ipuh, who still lives at the Cincinnati Zoo. "Emi, if there was trouble to get into, she'd get into it," he recalled. "Suci, she's very playful. But she's also more hard-headed, like her dad." Another keeper walked by, pushing a large wheelbarrow full of steaming reddish-brown manure—Suci and Ipuh's output from the previous night.

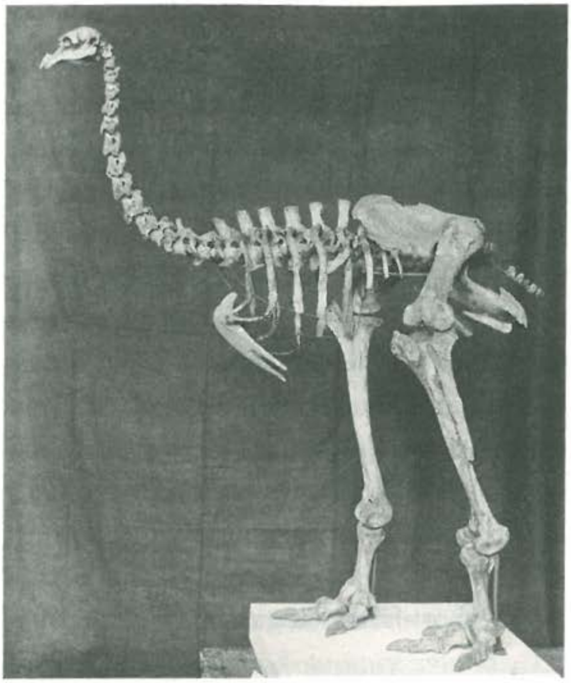
Suci is so used to being around people, some of whom feed her treats and some of whom stick their hands up her rectum, that Reinhart let me hang out with her while he went off to do other chores. As I stroked her hairy flanks, I was reminded of an overgrown dog. (In fact, rhinos are most closely related to horses.) Though I can't say I sensed much playfulness, she did seem to me to be affectionate, and when I looked into her very black eyes, I could have sworn I saw a flicker of interspecies recognition. At the same time, I recalled the warning of one zoo official, who had told me that if Suci suddenly decided to jerk her enormous head, she could easily break my arm. After a while, it was time for the rhino to go get weighed. Some pieces of banana were laid out in front of a pallet scale built into the floor of the next stall over. When Suci trudged over to eat the bananas, the readout from the scale was 1,507 pounds.

Very big animals are, of course, very big for a reason. Already at birth, Suci weighed seventy pounds. Had she been born on Sumatra, at that point she could have fallen victim to a tiger (though nowadays Sumatran tigers, too, are critically endangered). But probably she would have been protected by her mother, and adult rhinos have no natural predators. The same goes for other so-called megaherbivores; full-grown elephants and hippos are so large that no animal dares attack them. Bears and big cats are similarly beyond predation.

Such are the advantages of being oversized—what might be called the "too big to quail" strategy—that it would seem, evolutionarily speaking, to be a pretty good gambit. And, indeed, at various points in its history, the earth has been full of colossal creatures. Toward the end of the Cretaceous, for instance, *Tyrannosaurus* was just one group of enormous dinosaurs; there was also the genus *Saltasaurus,* whose members weighed something like seven tons; *Therizinosaurus,* the largest of which were over thirty feet long; and *Saurolophus,* which were probably even longer.

Much more recently, toward the end of the last ice age, jumbosized animals could be found in pretty much all parts of the world. In addition to woolly rhinos and cave bears, Europe had aurochs, giant elk, and oversized hyenas. North America's behemoths included mastodons, mammoths, and *Camelops,* hefty cousins to modern camels. The continent was also home to: beavers the size of today's grizzlies; *Smilodon,* a group of saber-toothed cats; and *Megalonyx jeffersonii,* a ground sloth that weighed nearly a ton. South America had its own gigantic sloths, as well as *Toxodon,* a genus of mammals with rhino-like bodies and hippo-shaped heads, and glyptodonts, relatives of armadillos that, in some cases, grew to be as large as Fiat 500s. The strangest, most varied megafauna could be found in Australia. These included diprotodons, a group of lumbering marsupials colloquially known as rhinoceros wombats; *Thylacoleo carnifex,* a tiger-sized carnivore referred to as a marsupial lion; and the giant short-faced kangaroo, which reached a height of ten feet.

Even many relatively small islands had their own large beasts. Cyprus had a dwarf elephant and a dwarf hippopotamus. Madagascar was home to three species of pygmy hippos, a family of enormous flightless birds known as elephant birds, and several species of giant lemurs. New Zealand's megafauna was remarkable in that it was exclusively avian. The Australian paleontologist Tim Flannery has described it as a kind of thought experiment come to life: "It shows us what the world might have looked like if mammals as well as dinosaurs had become extinct 65 million years ago, leaving the birds to inherit the globe." On New Zealand, different species of moas evolved to fill the ecological niches occupied elsewhere by four-legged browsers like rhinos and deer. The largest of the moas, the North Island giant moa and the South Island giant moa, grew to be nearly twelve feet tall. Interestingly enough, the females were almost twice as giant as the giant males, and it is believed that the task of incubating the eggs fell to the fathers. New Zealand also had an enormous raptor, known as the Haast's



The largest moas grew to be nearly twelve feet tall.

eagle, which preyed on moas and had a wingspan of more than eight feet.

What happened to all these Brobdingnagian animals? Cuvier, who was the first to note their disappearance, believed they had been done in by the most recent catastrophe: a "revolution on the surface of the earth" that took place just before the start of recorded history. When later naturalists rejected Cuvier's catastrophism, they were left with a puzzle. Why *had* so many large beasts disappeared in such a relatively short amount of time?

"We live in a zoologically impoverished world, from which all the hugest, and fiercest, and strangest forms have recently disappeared," Alfred Russel Wallace observed. "And it is, no doubt, a much better world for us now they have gone. Yet it is surely a marvellous fact, and one that has hardly been sufficiently dwelt upon, this sudden dying out of so many large mammalia, not in one place only but over half the land surface of the globe."

* * *

As it happens, the Cincinnati Zoo is only about a forty-minute drive from Big Bone Lick, where Longueuil picked up the mastodon teeth that would inspire Cuvier's theory of extinction. Now a state park, Big Bone Lick advertises itself as the "birthplace of American vertebrate paleontology" and offers on its Web site a poem celebrating its place in history.

> At Big Bone Lick the first explorers
> found skeletons of elephants they said,
> found ribs of wooly mammoths, tusks.
> The bones
> seemed wreckage from a mighty dream,
> a graveyard from a golden age.

One afternoon while visiting Suci, I decided to check out the park. The unmapped frontier of Longueuil's day is, of course, long gone, and the area is gradually being swallowed up by the Cincinnati suburbs. On the drive out, I passed the usual assortment of chain stores and then a series of housing developments, some so new the homes were still being framed. Eventually, I found myself in horse country. Just beyond the Woolly Mammoth Tree Farm, I turned into the park entrance. "No Hunting," the first sign said. Other signs pointed to a campsite, a lake, a gift shop, a minigolf course, a museum, and a herd of bison.

During the eighteenth and early nineteenth centuries, untold tons of specimens—mastodon femurs, mammoth tusks, giant ground sloth skulls—were hauled out of the bogs of Big Bone Lick. Some went to Paris and London, some to New York and Philadelphia. Still others were lost. (One whole shipment disappeared when a colonial trader was attacked by Kickapoo Indians; another sank on the Mississippi.) Thomas Jefferson proudly displayed bones from the Lick in an ad hoc museum he set up in the East Room of the White House. Lyell made a point of visiting the site during an American tour in 1842 and while there purchased for himself the teeth of a baby mastodon.

By now, Big Bone Lick has been so thoroughly picked over by collectors that there are hardly any big bones left. The park's paleontological museum consists of a single, mostly empty room. On one wall, there's a mural depicting a herd of melancholy-looking mammoths trudging across the tundra, and on the opposite wall some glass cases display a scattering of broken tusks and ground sloth vertebrae. Nearly as big as the museum is the adjacent gift shop, which sells wooden nickels and candy and T-shirts with the slogan, "I'm not fat—just big boned." A cheerful blonde was manning the shop's cash register when I visited. She told me that most people didn't appreciate the "significance of the park"; they just came for the lake and the minigolf, which, unfortunately, in winter was closed. Handing me a map, she urged me to follow the interpretive trail out back. I asked if she might be able to show me around, but she said, no, she was too busy. As far as I could tell, we were the only two people in the park.

I headed out along the trail. Just behind the museum, I came to a life-size mastodon, molded out of plastic. The mastodon had its head lowered, as if about to charge. Nearby was a ten-foot-tall plastic ground sloth, standing menacingly on its hind legs, and a mammoth that appeared to be sinking in terror into a bog. A dead, half-decomposed plastic bison, a plastic vulture, and some scattered plastic bones completed the grisly tableau.

Farther on, I came to Big Bone Creek, which was frozen over. Beneath the ice, the creek bubbled lazily along. A spur on the trail led to a wooden deck built over a patch of marsh. The water here was open. It smelled sulfurous and had a chalky white coating. A sign on the deck explained that during the Ordovician, ocean had covered the region. It was the accumulated salt from this ancient seabed that had drawn animals to drink at Big Bone Lick, and in many cases to die there. A second sign noted that among the remains found at the Lick were "those of at least eight species that became extinct around ten thousand years ago." As I continued along the trail, I came to still more signs. These gave an explanation—actually two different explanations—for the mystery of the missing megafauna. One sign offered the following account: "The change from coniferous to deciduous forest, or maybe the warming climate that brought about that change, caused the continent-wide disappearance of the Lick's extinct animals." Another sign put the blame elsewhere. "Within a thousand years after man arrived, the large mammals were gone," it said. "It seems likely that paleo-Indians played at least some role in their demise."

As early as the eighteen-forties, both explanations for the megafauna extinction had been proposed. Lyell was among those who favored the first account, as he put it, the "great modification in climate" that had occurred with the ice age. Darwin, as was his wont, sided with Lyell, though in this case somewhat reluctantly. "I cannot feel quite easy about the glacial period and the extinction of large mammals," he wrote. Wallace, for his part, initially also favored a climatic gloss. "There must have been some physical cause for this great change," he observed in 1876. "Such a cause exists in the great and recent physical change known as 'the Glacial Epoch.'" Then he had a change of heart. "Looking at the whole subject again," he observed in his last book, *The World of Life,* "I am convinced that . . . the rapidity of the extinction of so many large Mammalia is actually due to man's agency." The whole thing, he said, was really "very obvious."

Since Lyell, there's been a great deal of back and forth on the question, which has implications that extend far beyond paleobiology. If climate change drove the megafauna extinct, then this presents yet another reason to worry about what we are doing to global temperatures. If, on the other hand, people were to blame—and it seems increasingly likely that they were—then the import is almost more disturbing. It would mean that the current extinction

Diprotodon optatum was the largest marsupial ever.

event began all the way back in the middle of the last ice age. It would mean that man was a killer—to use the term of art an "overkiller"—pretty much right from the start.

THERE are several lines of evidence that argue in favor—or really against—humans. One of these is the event's timing. The megafauna extinction, it's now clear, did not take place all at once, as Lyell and Wallace believed it had. Rather, it occurred in pulses. The first pulse, about forty thousand years ago, took out Australia's giants. A second pulse hit North America and South America some twenty-five thousand years later. Madagascar's giant lemurs, pygmy hippos, and elephant birds survived all the way into the Middle Ages. New Zealand's moas made it as far as the Renaissance.

It's hard to see how such a sequence could be squared with a single climate change event. The sequence of the pulses and the sequence of human settlement, meanwhile, line up almost exactly. Archaeological evidence shows that people arrived first in Australia, about fifty thousand years ago. Only much later did they reach the Americas, and only many thousands of years after that did they make it to Madagascar and New Zealand.

"When the chronology of extinction is critically set against the chronology of human migrations," Paul Martin of the University of Arizona wrote in "Prehistoric Overkill," his seminal paper on the subject, "man's arrival emerges as the only reasonable answer" to the megafauna's disappearance.

In a similar vein, Jared Diamond has observed: "Personally, I can't fathom why Australia's giants should have survived innumerable droughts in their tens of millions of years of Australian history, and then have chosen to drop dead almost simultaneously (at least on a time scale of millions of years) precisely and just coincidentally when the first humans arrived."

In addition to the timing, there's strong physical evidence implicating humans. Some of this comes in the form of poop.

Megaherbivores generate mega amounts of shit, as is clear to anyone who's ever spent time standing behind a rhino. The ordure provides sustenance to fungi known as *Sporormiella*. *Sporormiella* spores are quite tiny—almost invisible to the naked eye—but extremely durable. They can still be identified in sediments that have been buried for tens of thousands of years. Lots of spores indicate lots of large herbivores chomping and pooping away; few or no spores suggest their absence.

A couple of years ago, a team of researchers analyzed a sediment core from a site known as Lynch's Crater, in northeastern Australia. They found that fifty thousand years ago, *Sporormiella* counts in the area were high. Then, rather abruptly around forty-one thousand years ago, *Sporormiella* counts dropped almost to zero. Following the crash, the landscape started to burn. (The evidence here was tiny grains of charcoal.) After that, the vegetation in the region shifted, from the sorts of plants you'd find in a rainforest toward more dry-adapted plants, like acacia.

If climate drove the megafauna to extinction, a shift in vegetation should *precede* a drop in *Sporormiella*: first the landscape would have changed, then the animals that depended on the original vegetation would have disappeared. But just the opposite had happened. The team concluded that the only explanation that fit the data was "overkill." *Sporormiella* counts dropped prior to changes in the landscape because the death of the megafauna *caused* the landscape to change. With no more large herbivores around to eat away at the forest, fuel built up, which led to more frequent and more intense fires. This, in turn, pushed the vegetation toward fire-tolerant species.

The megafauna extinction in Australia "couldn't have been driven by climate," Chris Johnson, an ecologist at the University of Tasmania and one of the lead authors on the core study, told me when I spoke to him on the phone from his office in Hobart. "I think we can say that categorically."

Even clearer is the evidence from New Zealand. When the Maori reached New Zealand, around the time of Dante, they found nine species of moa living on the North and South Islands. By the time European settlers arrived, in the early eighteen hundreds, not a single moa was to be seen. What remained were huge middens of moa bones, as well as the ruins of large outdoor ovens—leftovers of great, big bird barbecues. A recent study concluded that the moas were probably eliminated in a matter of decades. A phrase survives in Maori referring, obliquely, to the slaughter: *Kua ngaro i te ngaro o te moa*. Or "lost as the moa is lost."

THOSE researchers who persist in believing that climate change killed the megafauna say that the certainty of Martin, Diamond, and Johnson is misplaced. In their view, nothing has been proved about the event, "categorically" or otherwise, and everything in the preceding paragraphs is oversimplified. The dates of the extinctions are not clear-cut; they don't line up neatly with human migration; and, in any case, correlation is not causation. Perhaps most profoundly, they doubt the whole premise of ancient human deadliness. How could small bands of technologically primitive people have wiped out so many large, strong, and in some cases fierce animals over an area the size of Australia or North America?

John Alroy, an American paleobiologist who now works at Australia's Macquarie University, has spent a lot of time thinking about this question, which he considers a mathematical one. "A very large mammal is living on the edge with respect to its reproductive rate," he told me. "The gestation period of an elephant, for example, is twenty-two months. Elephants don't have twins, and they don't start to reproduce until they're in their teens. So these are big, big constraints on how fast they can reproduce, even if everything is going really well. And the reason they're able to exist at all is that when animals get to a certain size they escape from predation. They're no longer vulnerable to being attacked. It's a terrible strategy on the reproductive side, but it's a great advantage on the predator-avoidance side. And that advantage completely disappears when people show up. Because no matter how big an animal is, we don't have a constraint on what we can eat." This is another example of how a modus vivendi that worked for many millions of years can suddenly fail. Like the V-shaped graptolites or the ammonites or the dinosaurs, the megafauna weren't doing anything wrong; it's just that when humans appeared, "the rules of the survival game" changed.

Alroy has used computer simulations to test the "overkill" hypothesis. He's found that humans could have done in the megafauna with only modest effort. "If you've got one species that's providing what might be called a sustainable harvest, then other species can be allowed to go extinct without humans starving," he observed. For instance, in North America, white-tailed deer have a relatively high reproductive rate and therefore probably remained plentiful even as the number of mammoths dropped: "Mammoth became a luxury food, something you could enjoy once in a while, like a large truffle."

When Alroy ran the simulations for North America, he found that even a very small initial population of humans—a hundred or so individuals—could, over the course of a millennium or two, multiply sufficiently to account for pretty much all of the extinctions in the record. This was the case even when the people were assumed to be only fair-to-middling hunters. All they had to do was pick off a mammoth or a giant ground sloth every so often, when the opportunity arose, and keep this up for several centuries. This would have been enough to drive the populations of slow-reproducing species first into decline and then, eventually, all the way down to zero. When Chris Johnson ran similar simulations for Australia, he came up with similar results: if every band of ten hunters killed off just one diprotodon a year, within about seven hundred years, every diprotodon within several hundred miles would have been gone. (Since different parts of Australia were probably hunted out at different times, Johnson estimates that continent-wide the extinction took a few thousand years.) From an earth history perspective, several hundred years or even several thousand is practically no time at all. From a human perspective, though, it's an immensity. For the people involved in it, the decline of the megafauna would have been so slow as to be imperceptible. They would have had no way of knowing that centuries earlier, mammoths and diprotodons had been much more common. Alroy has described the megafauna extinction as a "geologically instantaneous ecological catastrophe too gradual to be perceived by the people who unleashed it." It demonstrates, he has written, that humans "are capable of driving virtually any large mammal species extinct, even though they are also capable of going to great lengths to guarantee that they do not."

The Anthropocene is usually said to have begun with the industrial revolution, or perhaps even later, with the explosive growth in population that followed World War II. By this account, it's with the introduction of modern technologies—turbines, railroads, chainsaws—that humans became a world-altering force. But the megafauna extinction suggests otherwise. Before humans emerged on the scene, being large and slow to reproduce was a highly successful strategy, and outsized creatures dominated the planet. Then, in what amounts to a geologic instant, this strategy became a loser's game. And so it remains today, which is why elephants and bears and big cats are in so much trouble and why Suci is one of the world's last remaining Sumatran rhinos. Meanwhile, eliminating the megafauna didn't just eliminate the megafauna; in Australia at least it set off an ecological cascade that transformed the landscape. Though it might be nice to imagine there once was a time when man lived in harmony with nature, it's not clear that he ever really did.