EON	ERA	PERIOD	EPOCH	DATES
PHANEROZOIC	CENOZOIC	Quaternary	Pleistocene	2.58 million – 12,000 ya
		Neogene	Pliocene	5.333 – 2.58 mya
			Miocene	23.03 – 5.333 mya
		Palaeogene	Oligocene	33.9 – 23.03 mya
			Eocene	56 – 33.9 mya
			Paleocene	66 – 56 mya
	MESOZOIC	Cretaceous		145 – 66 mya
		Jurassic		201.3 – 145 mya
		Triassic		251.9 – 201.3 mya
	PALAEOZOIC	Permian		298.9 – 251.9 mya
		Carboniferous		358.9 – 298.9 mya
		Devonian		419.2 – 358.9 mya
		Silurian		443.8 – 419.2 mya
		Ordovician		485.4 – 443.8 mya
		Cambrian		541 – 485.4 mya
PROTEROZOIC	NEOPROTEROZOIC	Ediacaran		635 – 541 mya

Introduction
The House of Millions of Years

'Let no one say the past is dead.
The past is all about us and within'

– Oodgeroo Noonuccal, *The Past*

'What tempest blows me into that deep
ocean of ages past, I do not know'

– Ole Worm

I am looking out of the window, across farmland, houses, and parks, towards a place that for hundreds of years has been known as World's End. It has this name because of its past remoteness from London, a city that has now grown to absorb it. But not too long ago this really was the end of the world. The soil here was laid down in the last ice age, a gravelly mixture deposited by rivers that once flowed into the Thames. As the glaciers advanced, they diverted its course, and the Thames now enters the sea more than 100 miles south of where it used to flow. From the ridged hills, clay crumpled by the weight of ice, it is possible, just about, to mentally strip away the hedgerows, the gardens, the streetlamps, and imagine another land, a cold world on the edge of an ice sheet extending hundreds of miles away. Below the icy gravel lies the London Clay, in which even older residents of this land are preserved – crocodiles, sea turtles, and early relatives of horses. The landscape in which they lived was filled with forests of mangrove palm and pawpaw, and waters rich in seagrass and giant lily pads, a warm, tropical paradise.

The worlds of the past can sometimes seem unimaginably distant. The geological history of the Earth stretches back about 4.5 billion years. Life has existed on this planet for about four billion years, and life larger than single-celled organisms for perhaps two billion years. The landscapes that have existed over geological time, revealed by the palaeontological record, are varied and, at times, quite other to the world of today. The Scottish geologist and writer Hugh Miller, musing on the length of geological time, said that all the years of human history 'do not extend into the yesterday of the globe, far less touch the myriads of ages spread out beyond'. That yesterday is certainly long. If all 4.5 billion years of Earth's history were to be condensed into a single day and played out, more than three million years of footage would go by every second. We would see ecosystems rapidly rise and fall as the species that constitute their living parts appear and become extinct. We would see continents drift, climatic conditions change in a blink, and sudden, dramatic events overturn long-lived communities with devastating consequences. The mass extinction event that extinguished pterosaurs, plesiosaurs and all non-bird dinosaurs would occur 21 seconds before the end. Written human history would begin in the last two thousandths of a second.[1]

At the beginning of the last thousandth of a second of that condensed past, a mortuary temple complex was built in Egypt, near the modern-day city of Luxor, the burial place of the pharaoh Ramesses II. Looking back to the building of the Ramesseum is a mere glance over the dizzying precipice of deep geological time, and yet that building is well known as a proverbial reminder of impermanence. The Ramesseum is the site that inspired Percy Bysshe Shelley's poem 'Ozymandias', which contrasts the bombastic words of an all-powerful pharaoh with a landscape of what was, when the poem was written, nothing but sand.[2]

When I first read that poem, I had no knowledge of what it was about, and mistakenly assumed Ozymandias to be the name of some dinosaur. The name was long and unusual, and it was hard to figure out a pronunciation. The descriptive language used in the poem was that of tyranny and power, of stone, and of kings. The pattern, in short, fitted that of my childhood illustrated books about prehistoric life. At '*I met a traveller from an antique land who said: two vast and trunkless legs of stone stand in the desert*', I thought of a plaster jacket being applied to the remains of some terrible beast from prehistory. A true tyrant lizard king, perhaps, now broken into bones and fragments of bones in the badlands of North America.

Not all that is broken is lost. The lines '*on the pedestal these words appear: "My name is Ozymandias, king of kings; Look on my works, ye Mighty, and despair!" Nothing beside remains.*' might be seen as time having the last laugh over a self-important ruler, but the world of that pharaoh *has* been remembered. The statue is evidence of its existence; the content of the words, the details of its style, clues to its context. Read like this, 'Ozymandias' gives us a way to think about fossilized organisms and the environments in which they lived. Take out the hubris, and the poem can be read as being about finding the reality of the past from the remnants that survive to the present. Even a fragment can tell a story in itself, a piece of evidence for something beyond the lone and level sands, for something else that used to be here. For a world that no longer exists but is still discernible, hinted at by what lies among the rocks.

The Ramesseum itself was originally known by a name that translates as 'The House of Millions of Years', an epithet that could easily be appropriated for the Earth. Our planet's past also lies hidden under the dirt. It wears the scars of its formation and change in its crust, and it, too, is a mortuary, memorializing its inhabitants in stone, fossils acting as grave marker, mask and body.[3]

Those worlds, those otherlands, cannot be visited – at least, not in a physical sense. You can never visit the environments through which titanic dinosaurs strode, never walk on their soil nor swim in their water. The only way to experience them is rockwise, to read the imprints in the frozen sand and to imagine a disappeared Earth.

This book is an exploration of the Earth as it used to exist, the changes that have occurred during its history, and the ways that life has found to adapt, or not. In each chapter, guided by the fossil record, we will visit a site from the geological past to observe the plants and animals, immerse ourselves in the landscape, and learn what we can about our own world from these extinct ecosystems. By visiting extinct sites with the mindset of a traveller, a safari-goer, I hope to bridge the distance from the past to the present. When a landscape is made visible, made present, it is easier to get a sense of the often-familiar ways that organisms live, compete, mate, eat and die there.

One site has been chosen for each geological epoch up to the last of the 'big five' mass extinctions 66 million years ago, which together constitute the Cenozoic, our own era. Preceding that mass extinction, one site has been chosen for each geological period (which comprises several epochs) back to the beginnings of multicellular life in the Ediacaran more than 500 million years ago. Some sites have been chosen for their remarkable biology, some for their unusual environment, some because they have been preserved so precisely and give us an unusually clear glimpse of how life existed and interacted in the past.

Journeys have to begin at home, and the course of this journey will pass from the present day backwards in time. We will begin in the relatively homely surrounds of the Pleistocene ice ages, when glaciers locked up much of the world's water in ice, lowering sea levels worldwide, before travelling progressively further back in time. Life and geography will become less and less familiar. The geological epochs of the Cenozoic will take us back through the early days of humankind, past the largest waterfall ever to have existed on Earth and a temperate, forested Antarctica, then right up to the end-Cretaceous mass extinction.

Beyond that, we will meet the inhabitants of the Mesozoic and Palaeozoic, visiting dinosaur-dominated forests, a glass reef thousands of kilometres long, and a monsoon-soaked desert. We will explore how organisms adapt to entirely new ecologies, moving onto land and into the air, and how life, in creating new ecosystems, opens the possibility for even more diversity.

After a brief visit to the Proterozoic, some 550 million years ago, in the geological eon before our own, we will return to our own Earth, that of the present day. The landscapes of the modern world are changing rapidly, thanks to human-caused disturbances. Compared with the radical environmental upheavals of the geological past, what might we expect to happen in the near and more distant future?

We cannot experiment easily on the planet to discover what changes happen at a continental scale in a high-carbon atmosphere, nor do we have enough time to see for ourselves the long-term effects of global ecosystem collapse before mitigating it. Our predictions must be based on accurate models of how the world works. Here, Earth's dynamism throughout geological history provides a natural laboratory. Answers to long-term questions can only be found by looking at the times in which the past Earth mirrors what we expect of future Earth. There have been five major mass extinctions, isolation and rejoining of continental landmasses, changes in ocean and atmospheric chemistry and circulation, all of which add data to our understanding of how life on Earth functions over geological timescales.

Of our planet, we can ask questions. The biology of the past is not just a curiosity to be glanced at with a bemused eye, or something foreign and otherworldly. Ecological principles that apply to modern tropical rainforests and the lichen-world of the tundra equally applied to the ecosystems of the past. Although the cast is different, the play is the same.

Taken in isolation, a fossil can be a fantastic lesson on anatomical variation, on shape and function, and on what an organism can do with simple tweaks to a general developmental toolkit. But just as the statues of antiquity stood within the context of a culture, no fossil, whether animal, plant, fungus or microbe, ever existed in isolation. Each lived within an ecosystem, an interaction among myriad species and the environment, a complex mishmash of life, weather and chemistry also dependent on the spin of the Earth, the position of the continents, the minerals in the soil or the water, and the constraints imposed by an area's past inhabitants. Recreating the worlds in which fossils were laid down, and in which their makers lived, is a challenge that palaeontologists have been attempting to address since the eighteenth century; attempts which have gathered in both pace and detail over the last few decades.

Recent palaeontological advances have revealed details of past life that would have been thought impossible not long ago. By delving deep into the structure of fossils, we can now reconstruct the colours of feathers, of beetle shells, of lizard scales, and discover the diseases these animals and plants suffered. By comparing them with living creatures we can establish their interactions in food webs, the power of their bite or strength of their skull, their social structure and mating habits, and even, in rare cases, the sound of their calls. The landscapes of the fossil record are no longer merely collections of impressions on rocks and taxonomic lists of names. The latest research has revealed vibrant and thriving communities, the remnants of real, living organisms that courted and fell sick, showed off bright feathers or flowers, called and buzzed, inhabiting worlds that obeyed the same biological principles as those of the present day.[4]

This is, perhaps, not what people have in mind when they think of palaeontology. The image of the Victorian gentleman collector, travelling off to other lands and other cultures, hammer in hand, ready to break open the earth, is pervasive. When the physicist Ernest Rutherford supposedly declared, rather dismissively, that all science was 'physics or stamp collecting', he surely had in mind the rank and file of taxidermized beasts, drawers of butterflies with immaculately open wings, and looming skeletons, bolted together with industrial iron. Today, though, a palaeobiologist is as likely to be spending their day in front of a computer or using circular particle accelerators to fire X-rays deep into fossils in a lab as out in the heat of the desert. My own scientific work has mostly happened in basement museum collections and within computer algorithms, using shared anatomical features to try and work out the relationships among the mammals that lived in the aftermath of the last mass extinction.[5]

It is far from impossible to obtain insights about the history of life only from the life that exists in the present day, but it is like trying to understand the plot of a novel by reading only the last few pages. You will be able to infer some of what has gone before, and find out the present situation of the characters that make it to the end, but the richness of the plot, numerous characters and major beats of the story might be missing. Even including fossils, most of the history of life remains obscure to non-specialists. Dinosaurs and the ice age animals of Europe and North America are widely known, and those with a little more familiarity with the subject will have heard of trilobites and ammonites or perhaps of the Cambrian explosion. But these are fragments of the whole story. In this book, I want to fill in some of the gaps.

This book is, necessarily, a personal interpretation of the past. The long-gone past, true 'deep time', means different things to different people. To some, it is exhilarating, a dizzying vertigo to think of the time taken for the trillions of plankton to settle, compact and rise into the chalklands of Kent and Normandy – countrysides made of skeletons. To others, it is an escape, a chance to think of ways of life outwith those we experience now, of a time before the worries of human-caused extinction when the dodo was merely a future possibility. Everything that we will see is nonetheless grounded in fact, either directly observable from the fossil record, strongly inferred, or, where our knowledge is incomplete, plausible based on what we can say for sure. Where there is disagreement, I have selected one of the competing hypotheses, and run with it. Even so, a flurry of wings in a thicket, a half-seen hide or the sensation of something moving in the dark, is an integral part of experiencing nature. A little ambiguity can generate as much wonder as a fixed truth.

The reconstructions here are the result of the work of thousands of scientists over more than 200 years. Their interpretations of fossil remains are ultimately what has led to the factual elements of this book. To a palaeobiologist, the bumps, ridges and holes in bone, exoskeleton or wood give clues necessary to build a picture of an individual organism in life, whether that organism is alive today or not. To look at the skull of an extant freshwater crocodile is to read a character description. The buttressed processes and arches evoke Gothic architecture, here resisting not the weight of a cathedral roof but the powerful force of the jaw muscles. The high-set eyes and nostrils speak of low swimming, peering and breathing just above the water surface; the long series of teeth, pointed but round, and set in a long, sweeping snout, suggest a feeding style of swiping, grabbing and holding prey, suitable for catching slippery fish. The scars of life are there, with fractures sustained knitted together. Lives leave their marks in detailed, reproducible ways.

Going beyond the individual specimen, and deciphering the characteristics of past ecosystems, the interactions, niches, food webs and flow of minerals and nutrients, is now commonplace in palaeobiology. Fossilized burrows and footprints can reveal details of movement and lifestyle that anatomy is silent on. Relationships between species help to tell us what factors were important to their biology and distribution, and what drove their evolution. The patterns and chemistry of sand grains in sedimentary rock record the environment – was this cliff face once a meandering river delta with the ever-changing courses of rivers snaking through a mudflat, or a shallow sea? Was that sea a sheltered lagoon, where fine silt drifted slowly to the floor in still water, or a place of crashing waves? What was the atmospheric temperature at the time? What was the global sea level? In which direction was the prevailing wind? All these, with the necessary knowledge, can be easily answerable questions.[6]

Not all of these types of information are available in any given location, but sometimes, many of the strands come together such that a palaeoecologist can build a rich picture of a landscape, from climate and geography to the creatures that inhabit it. These pictures of past environments, as vibrant as any today, often hold important lessons for how we approach our contemporary world.

Many parts of the natural world we take for granted today are relatively recent arrivals. Grasses, the main component of the largest ecosystems of the planet today, only arose at the very end of the Cretaceous, less than 70 million years ago, as rare parts of the forests of India and South America. Grass-dominated ecosystems did not emerge until about 40 million years before the present. There were never dinosaur grasslands, and, in the northern hemisphere, grass simply did not exist. We must drop preconceived ideas of what a landscape looks like, whether they arise because we have imprinted modern species on the past, or lumped together creatures that, although extinct, lived millions of years apart. More time passed between the lives of the last *Diplodocus* and the first *Tyrannosaurus* than passed between that of the last *Tyrannosaurus* and your birth. Jurassic creatures like *Diplodocus* not only did not see grasses, but never saw a flower either; the flowering plants only diversified in the middle Cretaceous.[7]

Today, with the biodiversity crisis brought on by habitat destruction and fragmentation, combined with the ongoing effects of climate change, we are very familiar with the idea that more and more organisms are going extinct. It is frequently said that we are in the midst of a sixth mass extinction. We are now used to hearing about widespread bleaching of coral reefs, melting of Arctic ice sheets, or deforestation in Indonesia and the Amazon basin. Less commonly discussed, though also extremely important, are the effects of land drainage on wetlands or the warming of tundra. The world that we inhabit is changing at the level of the landscape. The scale and ramifications of this are often difficult to comprehend. The thought that something as vast as the Great Barrier Reef, with all its vibrant diversity, might one day soon be gone, sounds inherently improbable. Yet the fossil record shows us that this sort of wholesale change is not only possible, but has repeatedly happened throughout Earth history.[8]

Today's reefs may be coral, but in the past clam-like molluscs, shelly brachiopods and even sponges have been reef-builders. Corals only took over as the dominant reef-building organisms when the mollusc reefs succumbed to the last mass extinction. Those reef-building clams originated in the Late Jurassic, taking over from the extensive sponge reefs, which had in turn filled the reef-building niche after brachiopod reefs were entirely wiped out by the end-Permian mass extinction. From the long-term perspective, continent-scale coral reefs might just end up being one of those ecosystems that never returns, a distinctively Cenozoic phenomenon, brought to a close by the human-driven mass extinction. Now, the future of coral reefs and other threatened ecosystems is in the balance, but the fossil record, in showing us how fast dominance can become obsolescence and loss, acts as a memorial and as a warning.[9]

Fossils may not seem like an obvious place to obtain insights into future life. The strangeness of fossil imprints, biological hieroglyphs, lends a distance to the past, a kind of uncrossable boundary, across which is an enticing other that can never be reached. The poet and academic Alice Tarbuck, in her poem 'nature is taxonomy which all small bones resist' captures this distance, saying 'give me leviathan trace, give me roiling sea-beast'. She yearns for 'footprints that lead down centuries, into the basement of what might be', and rejects the museum-label naming of classification with 'Let nobody sing taxonomy'.

Even as one of those who spend parts of their working life placing organisms in the series of phylum-class-order boxes, I too feel more of an affinity with the living thing than with the classification. A name can be evocative or meaningful but, for the most part, cannot evoke the sense of an organism. Latin names are mere markers, the Dewey decimal system of biology. A number would suffice, and indeed, this is essentially how the system works. For every single species and subspecies, there is somewhere in the world an individual specimen that marks what it means to be, for example, an Italian red fox. The definitive individual of *Vulpes vulpes toschii* is ZFMK 66-487, housed in the Alexander König Museum in Bonn. To be considered part of this subspecies you must be close enough, in anatomy and genetic make-up, to this particular Platonic fox, an adult female collected from Monte Gargano in 1961. Practical this may be, but it tells you nothing about the high-wire artistry of a city fox on a rickety garden fence, the purposeful hurry of padding adults, the mythological cunning of Reynard, or the carefree outdoor sleeping of cubs. And this is a creature we see around us today. What hope from name alone for those that are gone? My challenge in presenting them is to bridge the gap between the name and the reality, between the guinea's stamp and the gold. To see ancient life forms as if they were commonplace visitors to our world, as quivering, steaming beasts of flesh and instinct, as creaking beams and falling leaves.[10]

Today, where an extinct creature is portrayed as alive, it is frequently as a monster, something villainous, with an insatiable appetite. This dates back to the early nineteenth century sensationalizers of geology. Some were so keen to promote their vision of a dramatic and vicious past that woolly mammoths and ground sloths, known even then to be herbivorous, were presented by some as voracious meat-eaters. The mammoth, for instance, was introduced to the public as a powerful predator, lurking ominously in lakes to ambush their turtle prey, while the docile herbivorous ground sloth became 'huge as the frowning precipice; cruel as the bloody panther, swift as the descending eagle, and terrible as the angel of night!' Even today, the depiction of mindless, barbaric aggression of prehistoric animals continues in countless films, books and television programmes. But the predators of the Cretaceous were filled with no more bloodlust than a lion is today. Dangerous, certainly, but animals, not monsters.[11]

What the sedate collection of fossils as curios and the portrayal of extinct organisms as monsters have in common is a lack of real ecological context. Plants and fungi are typically absent, and invertebrates get only the most cursory look. And yet, the rock record of the Earth contains that context, revealing the settings in which extinct creatures lived, settings that shaped them into the forms that now seem so unusual. It is an encyclopaedia of the possible, of landscapes that have disappeared, and this book is an attempt to bring those landscapes to life once more, to break from the dusty, ironbound image of extinct organisms or the sensationalized, snarling, theme-park *Tyrannosaurus*, and to experience the reality of nature as one might today.

To consider the landscapes that once existed is to feel the draw of a temporal wanderlust. My hope is that you will read this in the vein of a naturalist's travel book, albeit one of lands distant in time rather than space, and begin to see the last 500 million years not as an endless expanse of unfathomable time, but as a series of worlds, simultaneously fabulous yet familiar.


Lascaux
European
Ice Sheet
Atlantic Ocean
Greenland
Ice Sheet
IKPIKPUK
Laurentide
Ice Sheet
Cordilleran
Ice Sheet
Pacific Ocean
Wrangel
Island
Brooks
Range
Sea ice
The Mammoth Steppe

1. *Thaw*

Northern Plain, Alaska, USA
Pleistocene – *20,000 years ago*

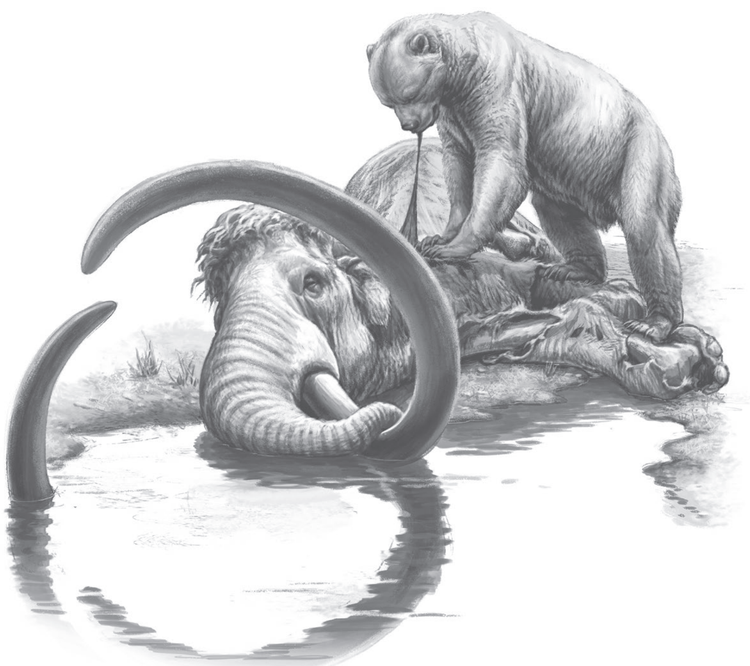
'Day and night, summer and winter, in foul weather or fine weather, it speaks of freedom. If someone has lost his freedom, the steppe will remind him of it'

– Vasily Grossman, *Life and Fate*

'Telipinu too went into the moor and blended with the moor. Over him the *halenzu*-plant grew'

– Hittite myth (tr. H.A. Hoffner)

Dawn is near breaking in the Alaskan night, where a small herd of horses, four adults and three foals, huddle against the frigid north-easterly wind. By this time, the sun has been gone for well over ten hours, and the air is skin-tighteningly cold. Two of the mares are taking their turn on sentinel duty, keeping their vigil against the dark while their family rests or forages. They stand together, flank on flank, nose to tail, a good way to reduce stress while staying close and warm while still watching in all directions. It is spring, but even through winter the ground has not been snow-covered, and it is carpeted instead with a profusion of dead grass and blown sand. The flatlands between the Brooks Range of northern Alaska and the coast of the perpetually frozen Arctic Ocean are exceptionally dry. Rain and snow alike have mostly passed this land by. A fickle stream making its way across pebbles, scarcely dribbling from the higher land to the south, is almost inaudible above the gale. Even this stream gives up before it reaches the sea, disappearing entirely as it is absorbed by encroaching dunes. The river flow is variable



Arctodus simus and *Mammuthus primigenius* from day to day but will peak in the next few months, being dependent on the thaw from the hills. In winter, there is little to eat; the ground is four fifths bare earth, one fifth dry brown stalks, and what meagre food there is is coated with abrasive dust. Even so, the desiccated remains of the summer's plenty are enough to support several small herds of these short-legged horses. In such anaesthetic temperatures as are found on the North Slope during the height of the last glaciation, overly long limbs would risk hypothermia. The Alaskan horses are closer to the size of ponies, resembling modern Przewalski's horses, but slenderer of limb. Their coats are shaggy and dun, their manes short, black and bristly. Those that are sleeping still move, absent-minded tail flicks twitching in the faint light of the aurora overhead. These are the truest inhabitants of the arid north, those that remain no matter the conditions. The summer visitors to the North Slope – large congregations of bison and caribou, and rare, scattered groups of muskoxen, moose and saiga – have left, less able than horses to survive on such poor fodder. Even for the horses, sustaining a living through the northern winter is difficult, made more so by the pregnancy of one of the mares. Each small herd contains a single male and several females, and the birth of foals is timed to coincide with late spring. Mortality is high, and life expectancy is half that of modern-day wild horses. Fifteen years is a typical lifespan for these Alaskan horses, living near the edge of their limits, in the face of a yowling wind.[1]

That wind blows from a sand sea of 7,000 square kilometres in the eastern half of what will become Alaska, bordered in the west by the Ikpikpuk River, a river that still exists in the modern day. Across this frigid desert crawl ridged dunes, 30 metres high, in rows 20 kilometres long. They blast their sand westwards across the steppe, coating the foothills of the Brooks Range in an icing-sugar dust of the loose, windblown sand-silt mixture known as loess. In the cold parts of the Pleistocene world, there is so little food during the cold months that every herbivore, from caribou to mammoth, ceases to grow. Like trees, their bones and teeth lay down growth marks, a physical scar of seasonality, a count of winters endured.

They subsist on what they can find, using little energy and relying on their bulk to hold out until better times return. Where there are herbivores predators will be lurking. At any moment, a pair of grasping paws could spring from the brush, a bite to the neck could crush the life from them. Across these scrubby landscapes, a small number of cave lion prides control large territories. They prowl silently across the steppe, shoulders sloping up and down with each footfall, and for the horses, there is little way of knowing whether they are near. Lion hunts rely on stalking and stealth, so the dark draws them closer. The mares are vigilant, any noise sending ears flickering over domed, pale foreheads.[2]

Three lions roam the Earth in the Pleistocene, and, of them, the African lion – the only survivor into modern times – is the daintiest. Across the other side of the Laurentide Ice Sheet and throughout North America, as far south as Mexico and even reaching South America, lives the American lion, the largest of the three. Slightly spotted, dusty-red beasts, up to 2.5 metres long, they are recent immigrants, descended from ancestors that moved across from Eurasia about 340,000 years before the present. Throughout the steppes of Europe and Asia, though, and here in Alaska, the major risk to these horses and caribou is from the Eurasian cave lion, *Panthera leo spelaea*, which diverged from lions of the modern day some 500,000 years before the present. Much of what we know about their appearance we have gathered from art – there are hundreds of detailed paintings and sculptures by northern Eurasian humans who documented many of the species of the mammoth steppe. About 10 per cent bigger than an African lion, the Eurasian cave lions are paler and shaggier, with a rough, coarse fur covering a dense, wavy, almost white undercoat, two layers of insulation against the cold. Neither male nor female is maned, although both have short beards; and males are substantially larger. Because animal remains tend to accumulate and lie undisturbed in caves, we know them as cave lions, but it is in the open that they are at home, wandering the steppe in small social groups, hunting caribou and horses.[3]

All cats are ambush predators, their anatomy adapted for stalking and surprising prey, with at most a short sprint. This kind of stalking requires stealth, but in the openness of the steppe, stealth is difficult, and, compared with other cats, cave lions are relatively good at chasing down prey. Drawings of cave lions often show their markings – dark lines emerging from their eyes like cheetahs, helping them to avoid being dazzled by sunlight, and a clear division between their darker backs and pale underbellies.[4]

Today, lions, elephants and wild horses are not associated with the northern parts of North America. Then again, neither are snowless grounds, rainless skies or sand seas. When imagining parts of the natural world, we tend to think of them as a whole, every part of the ecosystem defining a sense of place. What would the Sonoran Desert of south-western North America be without the giant saguaro cactuses, tarantulas and rattlesnakes? If you are familiar with a place, there is a sense of intrinsic correctness in its elements. While this sense is very strong, ecosystems are built piecemeal. The aggregations of species that produce a feeling of place also provide a sense of time. A community – the census of organisms from microbes to trees to giant herbivores – is a temporary association of living things that depends on evolutionary history, climate, geography and chance.

I grew up on the edge of the Black Wood of Rannoch in the Scottish Highlands: steep, quartzite-studded slopes covered with musky bracken cloisters and cushions of blaeberry, woods with stained-glass ceilings of birch leaves or cracked pine pillars; a fragment of temperate rainforest among moor and open hill. I have a strong nostalgia for the inhabitants of that place – marten and diver, siskin and deer. To me, they are avatars of childhood, and separating the place from the wildlife is near impossible. But these are only those creatures that shared the wood and the world in my time, and, taking the long view, nature forswears such nostalgia. Thousands of years into the Pleistocene, while herds of wild horses roam the wild expanse of Alaska, Rannoch is a dead place, a glacial scour under 400 metres of ice. Before the ice advanced, and while the ice remains, it is not the place I know; my sense of the Black Wood is as tied to our current geological epoch, the Holocene, as it is to the bedrock on which it grows.[5]

Fossil communities do not map neatly onto modern preconceptions. A species' range today might reflect where its ancestors lived, but equally it might not. Camels and llamas, for example, are each other's closest relatives, having separated about 8.5 million years before the present. Llamas are descendants of the tribe (in the Linnaean sense) that remained in the camelids' ancestral homeland of the Americas, while camels crossed over the Bering Strait to Asia and beyond. Even up until 11,000 years before the present, during the warmer parts of the cyclical glaciations of the ice age, herds of camels were wandering what would become Canada. At this moment in the Pleistocene, near the largest extent of ice, camels inhabit as far south as California – we know this from those unlucky enough to become trapped in the natural asphalt seeps at La Brea, where tar has bubbled from the ground for thousands of years.[6]

The first people have already arrived in the Americas; the footprints of a gleeful group of children, running through tufts of ditchgrass into the mud of a chalky lakeshore, 22,500 years before the present, are still visible in the white sands of New Mexico. As the populations of these first Americans grow in numbers, they will hunt both native camels and horses. As a result, like so many large mammals of the Pleistocene, they will have become extinct only a few short thousand years after human arrival. For now, those human populations are still small, and there is little direct evidence of exactly where they lived. At the time of the most recent glacial period, which reached its maximum extent about 25,000 years before the present day, humans thrive in the low plains of Beringia, moving along the southern Alaskan coast where the ice is scarcer into this new continent full of resources. To the north of the ice sheet, in the dry eastern edge of Beringia, hundreds of kilometres east of Ikpikpuk, there may be campfires lit by small communities of eastern Beringian humans – lakes there preserve chemicals characteristic of human faeces and of charcoal – but these are few and far between. As the climate changes, and humans gain an ever-deeper foothold in the continent, many of the native species will not survive for long, battered by the warming world and these versatile new predators.[7]

Traces of historical associations can long outlast actual contact. In the dense, subtropical forests from India across to the South China Sea, venomous snakes are common, and there is always an advantage in pretending to be something dangerous. The slow loris, a weird, nocturnal primate, has a number of unusual features that, taken together, seem to be mimicking spectacled cobras. They move in a sinuous, serpentine way through the branches, always smooth and slow. When threatened, they raise their arms up behind their head, shiver and hiss, their wide, round eyes closely resembling the markings on the inside of the spectacled cobra's hood. Even more remarkably, when in this position, the loris has access to glands in its armpit which, when combined with saliva, can produce a venom capable of causing anaphylactic shock in humans. In behaviour, colour and even bite, the primate has come to resemble the snake, a sheep in wolf's clothing. Today, the ranges of the loris and cobras do not overlap, but climate reconstructions reaching back tens of thousands of years suggest that once they would have been similar. It is possible that the loris is an outdated imitation artist, stuck in an evolutionary rut, compelled by instinct to act out an impression of something neither it nor its audience has ever seen.[8]

In the case of the lorises and cobras, and that of the Arctic camels, it is climate, along with geography, that has defined their evolutionary history and their interactions with other animals. An ecosystem is not a solid entity – it is made up of hundreds and thousands of individual parts, each species with their own tolerance to heat, salt, water availability, acidity, and each with their own role. In its broadest sense, an ecosystem is the network of interactions between all living members of the community and the land or water that forms its environment. Alone, a species has properties of its own, but the interactions of an ecosystem bring complexity. We call the possible survivable conditions for any given species its 'fundamental niche'. When interactions with other organisms limit that niche, we call the reality of a species distribution its 'realized niche'. No matter how wide the fundamental niche is, if the environment changes, and passes outwith the limits of that niche, or if the realized niche slips to a size of zero, that species has gone extinct.[9]

The Pleistocene North Slope in winter is one time and place where the environment passes out of the fundamental niche of many creatures. Horses survive here thanks to their ability to subsist on poor fodder, as long as there is enough of it. Sleeping and rousing in fits and bursts, they spend up to about sixteen hours a day feeding to ensure they get enough nutrition. Mammoths also thrive on poor-quality food, though their digestion is less efficient, and they require more bulk than the sparse winter grazing can provide. In times of scarcity, they are known to turn to eating their own dung, to access any remaining nutrition. Bison, living in herds thousands strong elsewhere, have to let their food ferment in their four-stomach digestive system, so they cannot eat as much as quickly. That means their food needs to be of a higher quality, and in winter these arid northern plains cannot provide.[10]

It is the physical geography of this corner of the world that has resulted in the dry, windy weather. The constant ankle-stinging wind that hisses through the Ikpikpuk dunes is part of a vast, anti-clockwise gyre of wind centred far to the south-west of here. By the time it has whipped up the water of the Pacific and driven clouds over central Alaska and the Yukon, what moisture it once held has been lost. Most of the rain has dropped over the moister bison plains that run close to the great wall of ice that separates this land from the rest of North America. That ice sheet covers almost all of modern-day Canada and reaches southwards, forming a frozen barrier from the Pacific to the Atlantic. It is in places up to 2 miles deep, and the carving and gouging forces it exerts on the landscape are even now excavating what will become the Great Lakes. As the ice melts, the water pooling against the southern border of the Laurentide Ice Sheet will be released, cutting out new riverbeds, eroding the deposited moraines of glaciers, and forming spectacles such as the Niagara Falls.[11]

The water locked up in this continental ice sheet, and its near neighbour in northern Europe, has been drawn from oceanic reserves. Sea levels worldwide are lower than those in the modern day by about 120 metres, and so growth of the ice has exposed shallow seabeds, building so-called ‘land bridges’ between continents.

Alaska may be isolated from North America, but just such a bridge connects the Alaskan wildlife with Asian communities to the west, bringing it into a continuum that covers half the circumference of the world. The Bering Strait, that stretch of water that in the present separates Alaska from Chukotka in Russia's Far East, is dry and hospitable, and gives its name to the biological province of Beringia. Beringia may be a cold land in winter, but it grows bright and warm in the hotter months. Meadows of wildflowers bloom throughout the spring and summer. Most of the trees are shrubby: short willows write wordless calligraphy on the wind with flourished ink-brush catkins, while dwarf birch shrubs hide ptarmigans. Above, skeins of snow geese wing and cry their way to the sea. In autumn, the more sheltered parts of Beringia shine with a pouring of molten gold as the cottonwoods and aspens turn yellow, set off by the blue-green of tall spruce. These lowlands are refugia for many species of plants and animals, a part of the world with a fairer, milder climate where those that cannot tolerate the extended ice age cold can survive. In places, bog-dwelling sphagnum moss oozes, while elsewhere silver-haired prairie sage releases its warming scent under the hoof-step of bison.[12]

The total area of the Beringian land bridge that will be sunken by the sea – including the land north of what will become Russia – is vast, about the size of California, Oregon, Nevada and Utah put together. This province is itself merely one part of an extensive biome – a landscape made up of consistent communities of plants and animals, and with a relatively consistent climate – that begins in eastern Beringia and ends on the Atlantic coast of Ireland. From the depths of the exposed Beringian plain, up into the hills of Alaska, the air cools and dries, the plants grow shorter and hardier, but the grassland continues. On its eastern margins, the edge of the sea of dunes at Ikpikpuk marks one end of the largest contiguous ecosystem the world has ever seen – the mammoth steppe.[13]

The steppe continues to exist because of this very connectivity. Ice age weather patterns are volatile, with conditions often wildly different from year to year. If you were to drive tent pegs into the loose ground and set up camp for years in one place, the populations would seem to go through extreme cycles of boom and bust, with the weather and plant life one year favouring horses, then bison, then mammoths, and so on. Because the mammoth steppe is contiguous, species can move to follow their ideal climates, and stay within the bounds of their niches. In a wildly variable environment, mobility is crucial to long-term survival. Somewhere on the continent, there will always be refuge. Throughout the high Arctic, there is a constantly repeated pattern of local extinction followed by re-establishment from just such refugia. Even in the modern day, the largest Arctic herbivores, reindeer and saiga, take part in the biggest terrestrial migrations on the planet. Elsewhere, in the Mongolian steppe, a Beringia-like environment where humans herd goats and other livestock, the climate is still volatile, its winter temperatures unpredictable year on year. As climate change makes the Mongolian steppe warmer and drier, the grasslands are becoming less productive, restricting the areas in which herds can be grazed. Because migration distances are increasingly limited, people are increasingly vulnerable to various kinds of harsh winter or *zud* – enough snow to prevent grazing, not enough snow for drinking water, frozen ground, cold winds – that can devastate herd populations and herder livelihoods. In a variable environment, the ability to up sticks and move elsewhere is critical, for wild animals and humans alike. As climates change in the modern day, that way of life is under threat, in a way that directly mirrors the demise of the mammoth steppe.[14]

The continuity of Beringia will be broken. Ultimately, the seas will rise; about 11,000 years before the present day, Beringia will drown. The steppe that ringed the world will be severed into smaller, less connected chunks as the vast taiga forests of spruce and larch grow northwards, the tundra shifts south, the weather warms, and long-distance migration between those favourable fragments of land suited to cold-adapted species is no longer possible. Migration cannot save a population if there is nowhere to go. If wiped out, there is no surviving group from which to replenish the lost creatures, and so they become locally, and eventually globally, extinct. Others may persist but must reduce the area over which they roam. In

Alaska, of all the species that once roamed the mammoth steppe, only the caribou, brown bear and muskox, this last solely through reintroduction, have survived.[15]

As day breaks, the expanse of the mammoth steppe emerges. The weak sun rises, topping the dunes one by one. Soon, every grain on the leeward side is casting a shadow, and the dunes glitter. The recumbent horses snort and stand, shaking themselves quickly awake; they never sleep deeply or for long. Broad, dark hooves shuffle impatiently, their edges flared; with less walking over winter, they have not been worn down, and are rather overgrown.[16]

Under a clear, crisp sky, summer begins to unfurl. Foals and thaw lakes appear, and thundering squadrons of caribou and bison return to the north, bound for the new vegetation. The vast mammoth herds return, too – the populations of mammoth make up nearly half of the herbivore mass on the North Slope. The sun rapidly warms the air, and the horses head for a low cloud swirling beyond a hillock. The hanging mist signals the presence of a rare pool, formed from the melt that has gathered in a warmer, sheltered hollow. Kept in shadow, the groundwater has until recently been frozen, but standing water in the river floodplain is a magnet for those that need to drink, and home to a diverse insect community – diving beetles, pill beetles and arid-adapted ground beetles are all common around the Ikpikpuk River.[17]

In the sunshine, the weather is fine, not only drier and more fertile, but also warmer than modern Alaska. This may be the ice age, but Beringia is a relatively warm spot, with a continental climate – similar to modern-day Mongolia. There is a real distinction between coastal and continental places. Throughout the year, seawater temperatures do not vary a great deal, so they act as sinks or sources for heat on the nearby land, producing winds and cloud cover that limits the variability of the weather. Inland, the summer heat is stored more easily by the earth, and so continental climates maintain high temperatures in summer. By the same token, the land cools rapidly, which makes for frigid winters. This is why, for example, coastal St Petersburg today is on average 19°C in July and −5°C in January while continental Yakutsk, at only a slightly more northerly latitude, has an average of 20°C in July but −39°C in January. The North Slope of Pleistocene Alaska is more like Yakutsk than St Petersburg – it is warm in summer, cold in winter, and always dry. There is no nearby unfrozen sea, so the continually cloudy, drizzly world of modern Alaska cannot form. Without snow and rain, glaciers cannot form either, which is why it is an ice-free corridor into the rest of the world.[18]

Fresh shoots replenish the dry grass, and the herd of horses push westwards. With the caution of prey, they never stray far from one another; while some eat, others stare, but after a stationary winter, their horizons are expanding once again to hundreds of square kilometres. As the group tops a crest, there is a skip of panic among them, and they instinctively cluster around the youngest, a schiltrom of hooves and teeth. Across the horizontal stripe of green between the shadowed slope and the sky, an *Arctodus* is moving.

Compared with brown bears, even at their grizzliest, the short-faced bear *Arctodus simus* is big. The biggest of the Alaskan short-faced bears weighed over a ton, three times the weight of the biggest modern-day predator on land, the Siberian tiger, and four times that of an adult male grizzly bear. The eponymous short face and long-limbed stride are in part an optical illusion created by scale. Bears have short, sloping backs and deep jaws, and when a brown bear is scaled to the size of a short-faced bear, these features are accentuated. Certainly, the biggest modern bear, the polar bear, has a long snout, but this seems to be an adaptation to an exclusively meaty diet. *Arctodus* are not common on the North Slope, and their behaviour is poorly understood. Until recently, it was thought that their long limbs might be an adaptation to running, suggesting that *Arctodus* was a giant pursuit predator, a wolf pack combined into one terrifying individual. Others, citing the short-faced bear's close relationship with the tree-dwelling, almost exclusively vegetarian Spectacled Bear, have painted *Arctodus* as a gentle herbivore, a rootling, footling giant. Still others consider them to be scavengers, living the lifestyle of a bully, a kleptoparasite, stealing the carcasses from other carnivores who have made the kill. The reality is probably far closer to that of a larger brown bear, eating a mixture of small and large prey as well as plants.[19]

Nevertheless, of all the American populations of *Arctodus* from Alaska to Florida, the Beringian community is most likely to be found eating meat. Where the winter has removed much of the ground vegetation, the bear's flexible diet bends towards predation and scavenging. With its sheer size, an adult *Arctodus* is capable of dominating a kill site, preventing other predators from coming too close. Shoulders rolling, it plods towards the pool, where the giant carcass of an old woolly mammoth, dead from the cold, gives off a sickly, molten odour. It is a welcome prize. Prodding with broad, powerful paws, the bear tugs at the fur of the dead mammoth, stripping it to expose the sinewy meat. It is slow and laborious work; mammoth hide is thick and covered with two layers of dense fur. In death, even the icon of the Pleistocene megafauna looks diminutive against its consumer. Mammoths may have been 3 metres tall at the shoulder, but, rearing on their hind limbs, the largest *Arctodus* can stretch a metre further.[20]

Bears are fearsomely powerful beasts. Wherever humans have lived alongside the brown bear, mythologies have grown up around them. The founding myth of Korea is dependent on the patience of a bear who would be content to eat only wild garlic and ssuk, a type of mugwort, *Artemisia*, for 100 days. Both these plants are found in the Eurasian mammoth steppe. Even the names given to bears are shrouded in euphemism wherever humans and bears coexist, a linguistic theory called taboo deformation, avoiding the 'true' name to prevent manifesting the animal. To the Russians, who venerated the bear and took it as a national symbol of power and cunning, it is *medvědi*, the 'honey-eater'. Germanic languages, including English, use varieties of *bruin*, the 'brown one'. Across the world, the euphemism 'grandfather' is used. The bears to which these names refer are brown bears, the ancestors of the North American grizzlies. They, like their fellow Eurasian migrants, humans, are only now arriving, venturing throughout this land, and encountering *Arctodus*.[21]

Across the mammoth steppe, the large populations of herbivore herds, joined together, paint a picture of a thriving community. There are certain fundamental rules that all ecosystems must follow. Energy, usually harnessed from sunlight or, rarely, from the breakdown of minerals, must flow into the ecosystem to replace what is lost through activity and decay. The organisms that can access this energy are the producers, and those that cannot are consumers, feeding on other living things in order to survive. The more energy the producers produce, the more consumers can be supported. The Beringian steppe is remarkably productive. In the inhospitable far north of Siberia, about 10 tons of animals – equivalent to about 100 caribou – are supported in every square kilometre, far more than can survive in equivalent cold places in the modern day. The number of predators in an ecosystem is always lower than that of producers – in the summer on the North Slope, this reaches extremes; only 2 per cent of the animals here are carnivorous.[22]

For the short-faced bear, the mammoth carcass is particularly welcome, as prey have been declining in recent years. The number of bison that have made their way into the North Slope has begun to decrease, and the population of horses is declining, too. Underfoot, the world is beginning to soften, and the hegemony of grass is nearly at an end. Around the thaw pool are the beginnings of formation of peat. This is a worrying sign for all the creatures that live in this dusty, windswept world. Most of the mammoth steppe is like an enclosed courtyard, surrounded on all sides by dry, solid walls. Across its northern extent, the Arctic Ocean is frozen, with glaciers covering North America, Scandinavia and Britain. On the steppe's western flank, the Atlantic is frozen, and in the south, the many ranges of mountains from the Pyrenees, through the Alps, the Taurus and Zagros mountains, into the Himalayas and the Tibetan plateau form a near-continuous wall. This mountainous barrier shelters an entire continent from the monsoons to the south, with their harsh winter droughts and summer downpours, a high-pressure air system over Siberia maintaining year-long aridity. Beringia is the weak point, the place where the Pacific can throw moisture into the shallow, exposed strait. In the past, this has not been a problem; ice advances and retreats cyclically, and the steppe has grown and shrunk with it, existing in a stable equilibrium. But after 100,000 years of existence, this time it is different. This is the beginning of a transformation, the beginning of the end of the mammoth steppe.*

As the ice sheets melt and the sea levels rise, there is more water available for evaporation, more water that can be added to the landscape. Now, the variable climate sometimes produces warmer, wetter summers than usual, bringing humidity into Beringia, and with it summer clouds, and autumn rot. The mammoth steppe's existence has relied on aridity, on the clear and endless blue skies. When the summers are warm and wet, there is more chance that the water will fail to drain away, forming local bogs, decomposing the plant material and producing peat. The growth of peat begins a destructive cascade for a steppe. Sand sticks together, and blown dunes become wetter, stable hillsides. Soils dampen, acidify and lose their fertility. Wet ground stays cooler, and frost rises from beneath, pushing the water table nearer the surface and out above as clouds, which drop snow, insulate the ground from what sunlight remains and make it cooler still. Cold engenders cold, and as fungi slow in their decomposition of plant life, more and more turns into more peat, and the circle continues.[23]

Emerging bogs also become barriers to migration, mires in which unsuspecting large herbivores can easily become trapped and drown. For the migratory herds of horses and caribou, the spread of peat means a nightmare for navigation as well as a loss of food, a runaway transformation of hard ground covered with grasses into soft, unforgiving wetland. The plants that thrive in peatlands jealously guard what little nutrition they can absorb, and grow defensive

* The loss of the mammoth steppe began about 19,000 years ago, but became particularly rapid 14,500 years before the present, during a sudden and humid warming known as the Bølling-Allerød Interval. This is associated with the point at which Antarctica began to deglaciate.

prickles, spines and hairs. In places, trees spread – moisture-tolerant plants like birches, alders and willows. As Beringia is submerged, this is the fate of the mammoth steppe.

On the North Slope of Alaska in modern-day conditions, the change from bare sand to a stable, long-term peat soil takes only a few hundred years. From Ireland to Russia to Canada, the ancient mammoth steppe is almost entirely gone, replaced by permafrost and peat bog. Steppe-tundra ecosystems still remain in isolated parts of Siberia, where relicts of smaller creatures, from small mammals to snails, live in a patchwork of habitats defined by the level of moisture. Today, the North Slope of Alaska is a mix of sedges, mosses and woody dwarf-shrubs, a semi-arid but water-saturated plain. Rain- and snowfall amount to only about 250 millimetres a year, roughly the same as San Diego, California, but the moisture stays in the soil, a high water table above the solid permafrost beneath. In summer, the soil thaws down to 50 centimetres depth, producing transient lakes and soft peat, with unpromising forage for the likes of horses or mammoths. Modern Alaska, with its sparser and more heavily defended vegetation and its waterlogged ground that sinks under the print of hooves, is just not survivable for wild horses any more. For the first time since they appeared in North America 55 million years before, horses will become regionally extinct, not returning until they arrive on European ships, only a few hundred years before the present day. The climate has shifted beyond their niche-space, just as it has for mammoths and mastodons, and even, in Alaska, bison. Caribou and muskoxen, those who inhabited the wetter parts of the mammoth steppe, are among the few large species still to live wild in Alaska in the present.[24]

Woolly mammoths survived on a small Beringian island called Wrangel, now part of Russia, until about 4,500 years before the present. That island is and was, however, too small to support a viable population for a long period of time, and, by the end, the Wrangel mammoths, the last surviving family anywhere in the world, were in serious genetic trouble. After 6,000 years of total isolation in a small community that numbered somewhere between 270 and 820 individuals, they were hugely inbred. From the DNA that is preserved in the Russian frost, we can read a catalogue of their genetic disorders. Their sense of smell was severely impaired, and their fur translucent, shining like satin but less able to protect them against the cold. They had problems with development and in their urinary systems, perhaps also their digestive systems. In all, we know of 133 genes for which no individual in the population had a functioning copy. Wrangel, too, was by this time a sedge-dominated peatland; the mammoths could not outlive their steppic landscape for long.[25]

The mammoth steppe is an entrancing vision of life gone by, attracting attention as a romantic vista filled with beasts we feel we can almost understand. Lonely, and buffeted by the Arctic wind, the mammoth is a universal symbol of a lost past. Somehow, because we as humans saw them, we as humans painted them, hunted them, perhaps revered them, they are a tangible link to Earth's history, even when gone for ever. Indeed, there are trees still living that emerged from their seeds while mammoths walked the Earth. The extinct past is closer than we often care to think, and alongside the decline of the Pleistocene came the rise of human civilizations. Humans may not yet have reached the Americas, but elsewhere they are capturing the detail of life of the Pleistocene world. Even as the horses of the North Slope grit their teeth in the wind, daubs of paint are being applied to a cave wall in France, scrubbed clean for the purpose, to represent the wild horses of Lascaux. A few thousand years later, a human will pick up a piece of antler to make a spear-thrower, an atlatl, decorating it with the features of a maned and bearded steppe bison, turning its head and licking, with stretching, curved tongue, the bite of some irritating insect on its back. The cultures of the Pleistocene humans in the north have largely faded, but there are parts of the globe where shadows of the previous epoch are still remembered, still passed on. On the underside of a rock-shelter in northern Australia called Nawarla Gabarnmang, the 'cleft in the rock', stylized wallabies, crocodiles and snakes are painted. The oldest was created, at a minimum, 13,000 years before the present, and painting continued into the twentieth century, a site preserving the cultural memories of the Jawoyn people over scarcely imaginable timescales. By the time the mammoth steppe finally came to an end, when Wrangel's mammoths glinted on cliffs overlooking the flooded plains of Beringia, the Great Pyramid of Giza and the Norte Chico in Peru had already existed for generations, and the civilizations of the Indus valley were centuries old.[26]

At about the time the last Wrangel mammoths died, the Mesopotamian city of Uruk was ruled by Gilgamesh, the Sumerian king and protagonist of the oldest written story, one of the oldest works of literature in any form. The story of Gilgamesh is one in which humankind attempts to escape nature. In it, the arrogant and powerful Gilgamesh, alongside his friend, the wild man Enkidu, trap and kill Humbaba, the guardian of the gods' cedar forest, in order to fell its trees and strengthen the walls of Uruk. Enkidu, the wild, untamed counterpart to Gilgamesh's seemly, royal urbanity, falls ill and dies, and Gilgamesh spends the rest of his tale searching futilely for immortality, before realizing the impossibility of his desire.

Nothing in nature is for ever, and the largest biome of the Pleistocene world will sink into mire. Gatherings of species in time and space may give the illusion of stability, but these communities can only last as long as the conditions that help to create them persist. When conditions of a biome change, whether its temperature, acidity, seasonality or rainfall, any number of its constituent species can lose a foothold there. For some, this means migration, following the environment across the landscape, as many plants did at the end of the last glaciation. Some environments, though, are not moved, but lost. When changes happen too rapidly, or pass a critical tipping point, runaway alterations can destroy even the most widespread landscape on the planet, and with it the communities it supports. This does not necessarily mean total disaster or an ecological blight, but can sometimes mean new combinations of creatures and landscapes, new worlds. Moss-dominated tundra, still occupied by caribou and saiga, peatlands inhabited by willows, alders and voles, and the atmospheric coniferous taiga forests of