Timberlane High School Science Summer Reading Assignment:

Course: Botany

Instructions

- Please read the following selection(s) from the book A Short History of Nearly Everything by Bill Bryson.
- Please provide written answers (short essay style) to the questions at the end of the reading

  •Questions adapted from Random House Publishing Inc.
  https://www.randomhouse.com/catalog/teachers_guides/9780767908184.pdf
- The written assignment is to be turned into your teacher by **Thursday, September 5th and Friday, September 6th,** for potential full credit. Accepted until Sept 12th with 10% deduction in grade per day. Not accepted after Sept 12th.
- This is a graded assignment worth up to 3% of your quarter 1 grade.

Grading Rubric:

The writing will be assessed on the following 0 to 3 scales

- Each answer should be in a short essay style (minimum one paragraph).
  - 1: most answers are short one word answers.
  - 3: complete thoughts and sentences that fully convey the answers.
- Each answer should demonstrate evidence of reading to comprehension.
  - 1: answers indicate that the reading was not completed o 3: answers show clear comprehension of the reading
- Each answer should be correct, relevant to the topic, should strive for detail and completeness.
  - 1: answers are not relative to question or reading o 3: Answers demonstrate clear relevancy to passage and get to the heart of the rationale for question in relation to subject area.
- Each answer should refer to a specific statement or include a quote from the reading.
  - 1: the writing is vague, incomplete and contains little detail o 3: writing is detailed, complete and references specific statements or quotes from the reading passage.
- Each answer should be original (no plagiarism)
- Questions adapted from Random House Publishing Inc.

Tips on how to read science text for comprehension:

Break the reading into more than one session (2 to 4 pages per day). This should take about 15 minutes each time. Read slowly! Understand each sentence before reading the next. Be sure to examine unfamiliar words and concepts; try to determine meaning from the reading (or look them up). Make notes on each paragraph! It is OK to reread as you go or even reread the entire text. Read to understand, think about the ideas as you read and relate to what you already know, and what you may want to find out.

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WHEN YOU CONSIDER it from a human perspective, and clearly it would be difficult for us to do otherwise, life is an odd thing. It couldn't wait to get going, but then, having gotten going, it seemed in very little hurry to move on.

Consider the lichen. Lichens are just about the hardiest visible organisms on Earth, but among the least ambitious. They will grow happily enough in a sunny churchyard, but they particularly thrive in environments where no other organism would go—on blowy mountaintops and arctic wastes, wherever there is little but rock and rain and cold, and almost no competition. In areas of Antarctica where virtually nothing else will grow, you can find vast expanses of lichen—four hundred types of them—adhering devotedly to every wind-whipped rock.

For a long time, people couldn't understand how they did it. Because lichens grew on bare rock without evident nourishment or the production of seeds, many people—educated people—believed they were stones caught in the process of becoming plants. "Spontaneously, inorganic stone becomes living plant!" rejoiced one observer, a Dr. Homschuch, in 1819.

Closer inspection showed that lichens were more interesting than magical. They are in fact a partnership between fungi and algae. The fungi excrete acids that dissolve the surface of the rock, freeing minerals that the algae convert into food sufficient to sustain both. It is not a very exciting arrangement, but it is a conspicuously successful one. The world has more than twenty thousand species of lichens.

Like most things that thrive in harsh environments, lichens are slow-growing. It may take a lichen more than half a century to attain the dimensions of a shirt button. Those the size of dinner plates, writes David Attenborough, are therefore "likely to be hundreds if not thousands of years old." It would be hard to imagine a less fulfilling existence. "They simply exist," Attenborough adds, "testifying to the moving fact that life even at its simplest level occurs, apparently, just for its own sake."

It is easy to overlook this thought that life just is. As humans we are inclined to feel that life must have a point. We have plans and aspirations and desires. We want to take constant advantage of all the intoxicating existence we've been endowed with. But what's life to a lichen? Yet its impulse to exist, to be, is every bit as strong as ours—arguably even stronger. If I were told that I had to spend decades being a furry growth on a rock in the woods, I believe I would lose the will to go on. Lichens don't. Like virtually all living things, they will suffer any hardship, endure any insult, for a moment's additional existence. Life, in short, just wants to be. But—and here's an interesting point—for the most part it doesn't want to be much.

This is perhaps a little odd because life has had plenty of time to develop ambitions. If you imagine the 4,500-billion-odd years of Earth's history compressed into a normal earthly day, then life begins very early, about 4A.M., with the rise of the first simple, single-celled organisms, but then advances no further for the next sixteen hours. Not until almost 8:30 in the evening, with the day five-sixths over, has Earth anything to show the universe but a restless skin of microbes. Then, finally, the first sea plants appear, followed twenty minutes later by the first jellyfish and the enigmatic Ediacaran fauna first seen by Reginald Sprigg in Australia. At 9:04P.M. trilobites swim onto the scene, followed more or less immediately by the shapely creatures of the Burgess Shale. Just before 10P.M. plants begin to pop up on the land. Soon after, with less than two hours left in the day, the first land creatures follow.

Thanks to ten minutes or so of balmy weather, by 10:24 the Earth is covered in the great carboniferous forests whose residues give us all our coal, and the first winged insects are evident. Dinosaurs plod onto the scene just before 11P.M. and hold sway for about three-quarters of an hour. At twenty-one minutes to midnight they vanish and the age of mammals begins. Humans emerge one minute and seventeen seconds before midnight. The whole of our recorded history, on this scale, would be no more than a few seconds, a single human lifetime barely an instant. Throughout this greatly speeded-up day continents slide about and bang together at a clip that seems positively reckless. Mountains rise and melt away, ocean basins come and go, ice sheets advance and withdraw. And throughout the whole, about three times every minute, somewhere on the planet there is a flashbulb pop of light marking the impact of a Manson-sized meteor or one even larger. It's a wonder that anything at all can survive in such a pummeled and unsettled environment. In fact, not many things do for long.

Perhaps an even more effective way of grasping our extreme recentness as a part of this 4.5-billion-year-old picture is to stretch your arms to their fullest extent and imagine that width as the entire history of the Earth. On this scale, according to John McPhee in Basin and Range, the distance from the fingertips of one hand to the wrist of the other is Precambrian. All of complex life is in one hand, "and in a single stroke with a medium-grained nail file you could eradicate human history."

Fortunately, that moment hasn't happened, but the chances are good that it will. I don't wish to interject a note of gloom just at this point, but the fact is that there is one other extremely pertinent quality about life on Earth: it goes extinct. Quite regularly. For all the trouble they take to assemble and preserve themselves, species crumple and die remarkably routinely. And the more complex they get, the more quickly they appear to go extinct. Which is perhaps one reason why so much of life isn't terribly ambitious.

So anytime life does something bold it is quite an event, and few occasions were more eventful than when life moved on to the next stage in our narrative and came out of the sea.

Land was a formidable environment: hot, dry, bathed in intense ultraviolet radiation, lacking the buoyancy that makes movement in water comparatively effortless. To live on land, creatures had to undergo wholesale revisions of their anatomies. Hold a fish at each end and it sags in the middle, its backbone too weak to support it. To survive out of water, marine creatures needed to come up with new load-bearing internal architecture—not the sort of adjustment that happens overnight. Above all and most obviously, any land creature would have to develop a way to take its oxygen directly from the air rather than filter it from water. These were not trivial challenges to overcome. On the other hand, there was a powerful incentive to leave the water: it was getting dangerous down there. The slow fusion of the continents into a single landmass, Pangaea, meant there was much, much less coastline than formerly and thus much less coastal habitat. So competition was fierce. There was also an omnivorous and unsettling new type of predator on the scene, one so perfectly designed for attack that it has scarcely changed in all the long eons since its emergence: the shark. Never would there be a more propitious time to find an alternative environment to water.

Plants began the process of land colonization about 450 million years ago, accompanied of necessity by tiny mites and other organisms that they needed to break down and recycle dead organic matter on their behalf. Larger animals took a little longer to emerge, but by about 400 million years ago they were venturing out of the water, too. Popular illustrations have encouraged us to envision the first venturesome land dwellers as a kind of ambitious fish—something like the modern mudskipper, which can hop from puddle to puddle during droughts—or even as a fully formed amphibian. In fact, the first visible mobile residents on dry land were probably much more like modern wood lice, sometimes also known as pillbugs or sow bugs. These are the little bugs (crustaceans, in fact) that are commonly thrown into confusion when you upturn a rock or log.

For those that learned to breathe oxygen from the air, times were good. Oxygen levels in the Devonian and Carboniferous periods, when terrestrial life first bloomed, were as high as 35 percent (as opposed to nearer 20 percent now). This allowed animals to grow remarkably large remarkably quickly.

And how, you may reasonably wonder, can scientists know what oxygen levels were like hundreds of millions of years ago? The answer lies in a slightly obscure but ingenious field known as isotope geochemistry. The long-ago seas of the Carboniferous and Devonian swarmed with tiny plankton that wrapped themselves inside tiny protective shells. Then, as now, the plankton created their shells by drawing oxygen from the atmosphere and combining it with other elements (carbon especially) to form durable compounds such as calcium carbonate. It's the same chemical trick that goes on in (and is discussed elsewhere in relation to) the long-term carbon cycle—a process that doesn't make for terribly exciting narrative but is vital for creating a livable planet.

Eventually in this process all the tiny organisms die and drift to the bottom of the sea, where they are slowly compressed into limestone. Among the tiny atomic structures the plankton take to the grave with them are two very stable isotopes—oxygen-16 and oxygen-18. (If you have forgotten what an isotope is, it doesn't matter, though for the record it's an atom with an abnormal number of neutrons.) This is where the geochemists come in, for the isotopes accumulate at different rates depending on how much oxygen or carbon dioxide is in the atmosphere at the time of their creation. By comparing these ancient ratios, the geochemists can cunningly read conditions in the ancient world—oxygen levels, air and ocean temperatures, the extent and timing of ice ages, and much else. By combining their isotope findings with other fossil residues—pollen levels and so on—scientists can, with considerable confidence, re-create entire landscapes that no human eye ever saw.

The principal reason oxygen levels were able to build up so robustly throughout the period of early terrestrial life was that much of the world's landscape was dominated by giant tree ferns and vast swamps, which by their boggy nature disrupted the normal carbon recycling process. Instead of completely rotting down, falling fronds and other dead vegetative matter accumulated in rich, wet sediments, which were eventually squeezed into the vast coal beds that sustain much economic activity even now.

The heady levels of oxygen clearly encouraged outsized growth. The oldest indication of a surface animal yet found is a track left 350 million years ago by a millipede-like creature on a rock in Scotland. It was over three feet long. Before the era was out some millipedes would reach lengths more than double that.

With such creatures on the prowl, it is perhaps not surprising that insects in the period evolved a trick that could keep them safely out of tongue shot: they learned to fly. Some took to this new means of locomotion with such uncanny facility that they haven't changed their techniques in all the time since. Then, as now, dragonflies could cruise at up to thirty-five miles an hour, instantly stop, hover, fly backwards, and lift far more proportionately than any human flying machine. "The U.S. Air Force," one commentator has written, "has put them in wind tunnels to see how they do it, and despaired." They, too, gorged on the rich air. In Carboniferous forests dragonflies grew as big as ravens. Trees and other vegetation likewise attained outsized proportions. Horsetails and tree ferns grew to heights of fifty feet, club mosses to a hundred and thirty.

The first terrestrial vertebrates—which is to say, the first land animals from which we would derive—are something of a mystery. This is partly because of a shortage of relevant fossils, but partly also because of an idiosyncratic Swede named Erik Jarvik whose odd interpretations and secretive manner held back progress on this question for almost half a century. Jarvik was part of a team of Scandinavian scholars who went to Greenland in the 1930s and 1940s looking for fossil fish. In particular they sought lobe-finned fish of the type that presumably were ancestral to us and all other walking creatures, known as tetrapods.

Most animals are tetrapods, and all living tetrapods have one thing in common: four limbs that end in a maximum of five fingers or toes. Dinosaurs, whales, birds, humans, even fish—all are tetrapods, which clearly suggests they come from a single common ancestor. The clue to this ancestor, it was assumed, would be found in the Devonian era, from about 400 million years ago. Before that time nothing walked on land. After that time lots of things did. Luckily the team found just such a creature, a three-foot-long animal called an Ichthyostega. The analysis of the fossil fell to Jarvik, who began his study in 1948 and kept at it for the next forty-eight years. Unfortunately, Jarvik refused to let anyone study his tetrapod. The world's paleontologists had to be content with two sketchy interim papers in which Jarvik noted that the creature had five fingers in each of four limbs, confirming its ancestral importance.

Jarvik died in 1998. After his death, other paleontologists eagerly examined the specimen and found that Jarvik had severely miscounted the fingers and toes—there were actually eight on each limb—and failed to observe that the fish could not possibly have walked. The structure of the fin was such that it would have collapsed under its own weight. Needless to say, this did not do a great deal to advance our understanding of the first land animals. Today three early tetrapods are known and none has five digits. In short, we don't know quite where we came from.

But come we did, though reaching our present state of eminence has not of course always been straightforward. Since life on land began, it has consisted of four megadynasties, as they are sometimes called. The first consisted of primitive, plodding but sometimes fairly hefty amphibians and reptiles. The best-known animal of this age was the Dimetrodon, a sail-backed creature that is commonly confused with dinosaurs (including, I note, in a picture caption in the Carl Sagan book Comet). The Dimetrodon was in fact a synapsid. So, once upon a time, were we. Synapsids were one of the four main divisions of early reptilian life, the others being anapsids, euryapsids, and diapsids. The names simply refer to the number and location of small holes to be found in the sides of their owners' skulls. Synapsids had one hole in their lower temples; diapsids had two; euryapsids had a single hole higher up.

Over time, each of these principal groupings split into further subdivisions, of which some prospered and some faltered. Anapsids gave rise to the turtles, which for a time, perhaps a touch improbably, appeared poised to predominate as the planet's most advanced and deadly species, before an evolutionary lurch let them settle for durability rather than dominance. The synapsids divided into four streams, only one of which survived beyond the Permian. Happily, that was the stream we belonged to, and it evolved into a family of protomammals known as therapsids. These formed Megadynasty 2.

Unfortunately for the therapsids, their cousins the diapsids were also productively evolving, in their case into dinosaurs (among other things), which gradually proved too much for the therapsids. Unable to compete head to head with these aggressive new creatures, the therapsids by and large vanished from the record. A very few, however, evolved into small, furry, burrowing beings that bided their time for a very long while as little mammals. The biggest of them grew no larger than a house cat, and most were no bigger than mice. Eventually, this would prove their salvation, but they would have to wait nearly 150 million years for Megadynasty 3, the Age of Dinosaurs, to come to an abrupt end and make room for Megadynasty 4 and our own Age of Mammals.

Each of these massive transformations, as well as many smaller ones between and since, was dependent on that paradoxically important motor of progress: extinction. It is a curious fact that on Earth species death is, in the most literal sense, a way of life. No one knows how many species of organisms have existed since life began. Thirty billion is a commonly cited figure, but the number has been put as high as 4,000 billion. Whatever the actual total, 99.99 percent of all species that have ever lived are no longer with us. "To a first approximation," as David Raup of the University of Chicago likes to say, "all species are extinct." For complex organisms, the average lifespan of a species is only about four million years—roughly about where we are now.

Extinction is always bad news for the victims, of course, but it appears to be a good thing for a dynamic planet. "The alternative to extinction is stagnation," says Ian Tattersall of the American Museum of Natural History, "and stagnation is seldom a good thing in any realm." (I should perhaps note that we are speaking here of extinction as a natural, long-term process. Extinction brought about by human carelessness is another matter altogether.)

Crises in Earth's history are invariably associated with dramatic leaps afterward. The fall of the Ediacaran fauna was followed by the creative outburst of the Cambrian period. The Ordovician extinction of 440 million years ago cleared the oceans of a lot of immobile filter feeders and, somehow, created conditions that favored darting fish and giant aquatic reptiles. These in turn were in an ideal position to send colonists onto dry land when another blowout in the late Devonian period gave life another sound shaking. And so it has gone at scattered intervals through history. If most of these events hadn't happened just as they did, just when they did, we almost certainly wouldn't be here now.

Earth has seen five major extinction episodes in its time—the Ordovician, Devonian, Permian, Triassic, and Cretaceous, in that order—and many smaller ones. The Ordovician (440 million years ago) and Devonian (365 million) each wiped out about 80 to 85 percent of species. The Triassic (210 million years ago) and Cretaceous (65 million years) each wiped out 70 to 75 percent of species. But the real whopper was the Permian extinction of about 245 million years ago, which raised the curtain on the long age of the dinosaurs. In the Permian, at least 95 percent of animals known from the fossil record check out, never to return. Even about a third of insect species went—the only occasion on which they were lost en masse. It is as close as we have ever come to total obliteration.

"It was, truly, a mass extinction, a carnage of a magnitude that had never troubled the Earth before," says Richard Fortey. The Permian event was particularly devastating to sea creatures. Trilobites vanished altogether. Clams and sea urchins nearly went. Virtually all other marine organisms were staggered. Altogether, on land and in the water, it is thought that Earth lost 52 percent of its families—that's the level above genus and below order on the grand scale of life (the subject of the next chapter)—and perhaps as many as 96 percent of all its species. It would be a long time—as much as eighty million years by one reckoning—before species totals recovered.

Two points need to be kept in mind. First, these are all just informed guesses. Estimates for the number of animal species alive at the end of the Permian range from as low as 45,000 to as high as 240,000. If you don't know how many species were alive, you can hardly specify with conviction the proportion that perished. Moreover, we are talking about the death of species, not individuals. For individuals the death toll could be much higher—in many cases, practically total. The species that survived to the next phase of life's lottery almost certainly owe their existence to a few scarred and limping survivors.

In between the big kill-offs, there have also been many smaller, less well-known extinction episodes—the Hemphillian, Frasnian, Famennian, Rancholabrean, and a dozen or so others—which were not so devastating to total species numbers, but often critically hit certain populations. Grazing animals, including horses, were nearly wiped out in the Hemphillian event about five million years ago. Horses declined to a single species, which appears so sporadically in the fossil record as to suggest that for a time it teetered on the brink of oblivion. Imagine a human history without horses, without grazing animals.

In nearly every case, for both big extinctions and more modest ones, we have bewilderingly little idea of what the cause was. Even after stripping out the more crackpot notions there are still more theories for what caused the extinction events than there have been events. At least two dozen potential culprits have been identified as causes or prime contributors: global warming, global cooling, changing sea levels, oxygen depletion of the seas (a condition known as anoxia), epidemics, giant leaks of methane gas from the seafloor, meteor and comet impacts, runaway hurricanes of a type known as hypercanes, huge volcanic upwellings, catastrophic solar flares.

This last is a particularly intriguing possibility. Nobody knows how big solar flares can get because we have only been watching them since the beginning of the space age, but the Sun is a mighty engine and its storms are commensurately enormous. A typical solar flare—something we wouldn't even notice on Earth—will release the energy equivalent of a billion hydrogen bombs and fling into space a hundred billion tons or so of murderous high-energy particles. The magnetosphere and atmosphere between them normally swat these back into space or steer them safely toward the poles (where they produce the Earth's comely auroras), but it is thought that an unusually big blast, say a hundred times the typical flare, could overwhelm our ethereal defenses. The light show would be a glorious one, but it would almost certainly kill a very high proportion of all that basked in its glow. Moreover, and rather chillingly, according to Bruce Tsurutani of the NASA Jet Propulsion Laboratory, "it would leave no trace in history."

What all this leaves us with, as one researcher has put it, is "tons of conjecture and very little evidence." Cooling seems to be associated with at least three of the big extinction events—the Ordovician, Devonian, and Permian—but beyond that little is agreed, including whether a particular episode happened swiftly or slowly. Scientists can't agree, for instance, whether the late Devonian extinction—the event that was followed by vertebrates moving onto the land—happened over millions of years or thousands of years or in one lively day.

One of the reasons it is so hard to produce convincing explanations for extinctions is that it is so very hard to exterminate life on a grand scale. As we have seen from the Manson impact, you can receive a ferocious blow and still stage a full, if presumably somewhat wobbly, recovery. So why, out of all the thousands of impacts Earth has endured, was the KT event so singularly devastating? Well, first itwas positively enormous. It struck with the force of 100 million megatons. Such an outburst is not easily imagined, but as James Lawrence Powell has pointed out, if you exploded one Hiroshima-sized bomb for every person alive on earth today you would still be about a billion bombs short of the size of the KT impact. But even that alone may not have been enough to wipe out 70 percent of Earth's life, dinosaurs included.

The KT meteor had the additional advantage—advantage if you are a mammal, that is—that it landed in a shallow sea just ten meters deep, probably at just the right angle, at a time when oxygen levels were 10 percent higher than at present and so the world was more combustible. Above all the floor of the sea where it landed was made of rock rich in sulfur. The result was an impact that turned an area of seafloor the size of Belgium into aerosols of sulfuric acid. For months afterward, the Earth was subjected to rains acid enough to burn skin.

In a sense, an even greater question than that of what wiped out 70 percent of the species that were existing at the time is how did the remaining 30 percent survive? Why was the event so irremediably devastating to every single dinosaur that existed, while other reptiles, like snakes and crocodiles, passed through unimpeded? So far as we can tell no species of toad, newt, salamander, or other amphibian went extinct in North America. "Why should these delicate creatures have emerged unscathed from such an unparalleled disaster?" asks Tim Flannery in his fascinating prehistory of America, Eternal Frontier.

In the seas it was much the same story. All the ammonites vanished, but their cousins the nautiloids, who lived similar lifestyles, swam on. Among plankton, some species were practically wiped out—92 percent of foraminiferans, for instance—while other organisms like diatoms, designed to a similar plan and living alongside, were comparatively unscathed.

These are difficult inconsistencies. As Richard Fortey observes: "Somehow it does not seem satisfying just to call them 'lucky ones' and leave it at that." If, as seems entirely likely, the event was followed by months of dark and choking smoke, then many of the insect survivors become difficult to account for. "Some insects, like beetles," Fortey notes, "could live on wood or other things lying around. But what about those like bees that navigate by sunlight and need pollen? Explaining their survival isn't so easy."

Above all, there are the corals. Corals require algae to survive and algae require sunlight, and both together require steady minimum temperatures. Much publicity has been given in the last few years to corals dying from changes in sea temperature of only a degree or so. If they are that vulnerable to small changes, how did they survive the long impact winter?

There are also many hard-to-explain regional variations. Extinctions seem to have been far less severe in the southern hemisphere than the northern. New Zealand in particular appears to have come through largely unscathed even though it had almost no burrowing creatures. Even its vegetation was overwhelmingly spared, and yet the scale of conflagration elsewhere suggests that devastation was global. In short, there is just a great deal we don't know.

Some animals absolutely prospered—including, a little surprisingly, the turtles once again. As Flannery notes, the period immediately after the dinosaur extinction could well be known as the Age of Turtles. Sixteen species survived in North America and three more came into existence soon after.

Clearly it helped to be at home in water. The KT impact wiped out almost 90 percent of land-based species but only 10 percent of those living in fresh water. Water obviously offered protection against heat and flame, but also presumably provided more sustenance in the lean period that followed. All the land-based animals that survived had a habit of retreating to a safer environment during times of danger—into water or underground—either of which would have provided considerable shelter against the ravages without. Animals that scavenged for a living would also have enjoyed an advantage. Lizards were, and are, largely impervious to the bacteria in rotting carcasses. Indeed, often they are positively drawn to it, and for a long while there were clearly a lot of putrid carcasses about.

It is often wrongly stated that only small animals survived the KT event. In fact, among the survivors were crocodiles, which were not just large but three times larger than they are today. But on the whole, it is true, most of the survivors were small and furtive. Indeed, with the world dark and hostile, it was a perfect time to be small, warm-blooded, nocturnal, flexible in diet, and cautious by nature—the very qualities that distinguished our mammalian forebears. Had our evolution been more advanced, we would probably have been wiped out. Instead, mammals found themselves in a world to which they were as well suited as anything alive.

However, it wasn't as if mammals swarmed forward to fill every niche. "Evolution may abhor a vacuum," wrote the paleobiologist Steven M. Stanley, "but it often takes a long time to fill it." For perhaps as many as ten million years mammals remained cautiously small. In the early Tertiary, if you were the size of a bobcat you could be king.

But once they got going, mammals expanded prodigiously—sometimes to an almost preposterous degree. For a time, there were guinea pigs the size of rhinos and rhinos the size of a two-story house. Wherever there was a vacancy in the predatory chain, mammals rose (often literally) to fill it. Early members of the raccoon family migrated to South America, discovered a vacancy, and evolved into creatures the size and ferocity of bears. Birds, too, prospered disproportionately. For millions of years, a gigantic, flightless, carnivorous bird called Titanis was possibly the most ferocious creature in North America. Certainly it was the most daunting bird that ever lived. It stood ten feet high, weighed over eight hundred pounds, and had a beak that could tear the head off pretty much anything that irked it. Its family survived in formidable fashion for fifty million years, yet until a skeleton was discovered in Florida in 1963, we had no idea that it had ever existed.

Which brings us to another reason for our uncertainty about extinctions: the paltriness of the fossil record. We have touched already on the unlikelihood of any set of bones becoming fossilized, but the record is actually worse than you might think. Consider dinosaurs. Museums give the impression that we have a global abundance of dinosaur fossils. In fact, overwhelmingly museum displays are artificial. The giant Diplodocus that dominates the entrance hall of the Natural History Museum in London and has delighted and informed generations of visitors is made of plaster—built in 1903 in Pittsburgh and presented to the museum by Andrew Carnegie. The entrance hall of the American Museum of Natural History in New York is dominated by an even grander tableau: a skeleton of a large Barosaurus defending her baby from attack by a darting and toothy Allosaurus. It is a wonderfully impressive display—the Barosaurus rises perhaps thirty feet toward the high ceiling—but also entirely fake. Every one of the several hundred bones in the display is a cast. Visit almost any large natural history museum in the world—in Paris, Vienna, Frankfurt, Buenos Aires, Mexico City—and what will greet you are antique models, not ancient bones.

The fact is, we don't really know a great deal about the dinosaurs. For the whole of the Age of Dinosaurs, fewer than a thousand species have been identified (almost half of them known from a single specimen), which is about a quarter of the number of mammal species alive now. Dinosaurs, bear in mind, ruled the Earth for roughly three times as long as mammals have, so either dinosaurs were remarkably unproductive of species or we have barely scratched the surface (to use an irresistibly apt cliché).

For millions of years through the Age of Dinosaurs not a single fossil has yet been found. Even for the period of the late Cretaceous—the most studied prehistoric period there is, thanks to our long interest in dinosaurs and their extinction—some three quarters of all species that lived may yet be undiscovered. Animals bulkier than the Diplodocus or more forbidding than tyrannosaurus may have roamed the Earth in the thousands, and we may never know it. Until very recently everything known about the dinosaurs of this period came from only about three hundred specimens representing just sixteen species. The scantiness of the record led to the widespread belief that dinosaurs were on their way out already when the KT impact occurred.

In the late 1980s a paleontologist from the Milwaukee Public Museum, Peter Sheehan, decided to conduct an experiment. Using two hundred volunteers, he made a painstaking census of a well-defined, but also well-picked-over, area of the famous Hell Creek formation in Montana. Sifting meticulously, the volunteers collected every last tooth and vertebra and chip of bone—everything that had been overlooked by previous diggers. The work took three years. When finished they found that they had more than tripled the global total of dinosaur fossils from the late Cretaceous. The survey established that dinosaurs remained numerous right up to the time of the KT impact. "There is no reason to believe that the dinosaurs were dying out gradually during the last three million years of the Cretaceous," Sheehan reported.

We are so used to the notion of our own inevitability as life's dominant species that it is hard to grasp that we are here only because of timely extraterrestrial bangs and other random flukes. The one thing we have in common with all other living things is that for nearly four billion years our ancestors have managed to slip through a series of closing doors every time we needed them to. Stephen Jay Gould expressed it succinctly in a well-known line: "Humans are here today because our particular line never fractured—never once at any of the billion points that could have erased us from history."

We started this chapter with three points: Life wants to be; life doesn't always want to be much; life from time to time goes extinct. To this we may add a fourth: Life goes on. And often, as we shall see, it goes on in ways that are decidedly amazing.

Chapter 22: Good-bye to All That

1. How are lichens actually a partnership between two different kingdoms of life?
2. How long does it take some lichens to reach the size of a shirt-button?
3. What major challenges does dry land pose to water-dwelling creatures?
4. What was one "incentive" or better, "evolutionary pressure" that might have played a role in favoring and driving the invasion of land?
5. What were the first land-dwelling <u>organisms</u>?
6. What were the first land-dwelling <u>animals</u>? (be specific)
7. What likely allowed animals to remarkably large during the Devonian and Carboniferous periods?
8. What group of animals first evolved flight? Can you name three other groups of animals that evolved flight independently? (hint: one of these groups is unfortunately extinct today)
9. How did Erik Jarvik stall our investigations of early terrestrial vertebrates? What do you think were Jarvik's motivations?
10. What are Bryson's four *megadynasties*?
11. What is the average life-span of a species in the fossil record?
12. How many major mass extinctions have there been throughout Earth's history?
13. Which extinction was the biggest one? What percentage of <u>known</u> animals species went extinct?
14. Why is the survival of amphibians following the KT-Impact event difficult to explain?
15. Why might it have been advantageous to be "small, warm-blooded, nocturnal, flexible in diet, and cautious by nature" following the KT-Impact event?
16. What kind of carnivore was dominant in North America for millions of years following the KT-event?