The Sixth Extinction

INTRODUCTION

BRIEF BIOGRAPHY OF ELIZABETH KOLBERT

Elizabeth Kolbert grew up in the Bronx, and studied English at Yale University. She won a prestigious Fulbright Scholarship, and studied at the University of Hamburg, in Germany. While in Germany, she began working for the *New York Times*, and eventually became a columnist for the newspaper. In 1999, Kolbert became a staff writer for the *New Yorker*, where she has written many popular articles about science and technology. Kolbert's most successful book, both critically and financially, was *The Sixth Extinction*, which won the Pulitzer Prize for General Nonfiction in 2014.

HISTORICAL CONTEXT

Kolbert alludes to many important historical events, but two of the most important are the "Out of Africa" diaspora that took place about 115,000 years ago. According to this theory, humans migrated out of Africa and eventually colonized Eurasia, Australia, and the Americas, paving the way for many mass extinctions. Another key historical event was the publication of *The Origin of Species* in 1859, which sparked a scientific revolution and paved the way for research into the topic of extinction.

RELATED LITERARY WORKS

While *The Sixth Extinction* doesn't allude to many works of literature, it has been compared to the 1962 environmental science classic *Silent Spring* by Rachel Carson. Carson criticizes the use of pesticides in farming, and goes on to make broader points about the role of humanity in destroying the environment. While Carson is critical of the pesticide industry, she adopts a more nuanced tone when speaking of the human race's environmental activities, similar to the way Kolbert ultimately makes a nuanced point about how humans can preserve the world's biodiversity. Another important book for Kolbert is Charles Darwin's *On the Origin of Species* (1859), the first popular explanation of the modern theory of natural selection. In his book, Darwin described life as a constant competition between life forms for a finite number of resources. In her own book, Kolbert sometimes uses the Darwinian paradigm to analyze why certain animals die out over time.

KEY FACTS

- **Full Title:** The Sixth Extinction: An Unnatural History
- **When Written:** 2011-2013
- **Where Written:** New York City and Albany
- **When Published:** Fall 2014
- **Literary Period:** Environmentalism
- **Genre:** Nonfiction, popular science
- **Antagonist:** While Kolbert doesn't demonize her own species, human development, which has resulted in many extinctions already, could be considered the antagonist of the book
- **Point of View:** First person

EXTRA CREDIT

Seriously funny After completing *The Sixth Extinction*, Kolbert appeared on many TV shows to promote her work. One of Kolbert's most memorable TV appearances took place on *The Daily Show with Jon Stewart*. Stewart: "It took a giant asteroid to cause the last big extinction. Now we're doing it ourselves …it's impressive, if you think about it."

Awards awards awards. Kolbert has won more than her fair share of big awards for writing and journalism: in addition to her Pulitzer Prize for *The Sixth Extinction*, she's won two National Magazine awards, the Heinz Award, and a Guggenheim Fellowship.

PLOT SUMMARY

In *The Sixth Extinction*, Elizabeth Kolbert studies the relationship between human beings and the environment, and concludes that human behavior is on the verge of causing (or may have already caused) a mass-extinction—the sixth in the history of the planet. All over the world, different species are already going extinct, thanks to the declining amount of available undeveloped land, and the rising temperature. In Panama, for example, the population of golden frogs—once impossible to avoid—has dwindled to a few dozen. Kolbert's visit to Panama to study the golden frog inspired her to learn more about extinction and its place in the history of science.

Kolbert learned that, for most of the history of science, humans didn't understand that some animals went extinct. It was Georges Cuvier, the influential naturalist, who first proposed that some species that lived thousands of years ago are no longer alive. Cuvier and his contemporaries discovered prehistoric fossils of large mammals, such as the mastodon and the giant sloth, further legitimating the theory of extinction. However, Cuvier believed that extinction is a slow, gradual, and somewhat random process. Even after Charles Darwin

published his influential book, *On the Origin of Species*, scientists didn't grasp that human beings are capable of influencing the environment to the point where certain species die out. It wasn't until the late 19th century that the scientist Alfred Newton, in an effort to preserve the surviving population of great auks (a bird) in Iceland, pioneered the idea that humans could play a role in preserving species at risk of going extinct. It took much longer for scientists to realize that humans were responsible for the extinction of hundreds of animals.

A major milestone in scientists' understanding of extinction was the paper penned by Walter Alvarez and Luis Alvarez in the 1980s, arguing that the dinosaurs went extinct because of a large asteroid that hit the Earth. While the Alvarezes' theory was dismissed at first, it gradually became an accepted theory. This reinforced the theory of mass-extinction—that is, the notion that many species go extinct at almost the same time, rather than dying out gradually over time. One reason that species go extinct is that once-useful evolutionary qualities usually don't remain useful over time. For example, the ammonite—a prehistoric, nautilus-like creature—was once extremely common because currents swept its small, delicate eggs across the globe. But after an asteroid struck the Earth, the ammonite's eggs were too weak to survive the catastrophe—in short, a useful evolutionary trait became a major liability. The Earth is constantly experiencing sudden changes in temperature, pressure, and climate, which means that species are always facing challenges to their survival.

Kolbert argues that we are living in the Anthropocene period of planetary history—an epoch defined by human beings' attempts to manipulate their environments, resulting in the extinction or near-extinction of many different species. Examining the fossil record, one notices many points in planetary history when there may have been a mass-extinction. However, the Sixth Extinction, in which we're all living, will be unique in the Earth's history because it will have been caused by human beings. By burning fossil fuels and cutting down forests, human beings have drastically increased the temperature and acidity of ocean water, meaning that sea creatures will have to adapt to the changing environment, or die out. The increased acidity of the oceans has been devastating to calcifiers—sea creatures such as clams, barnacles, and starfish—that rely on calcium for their shells and exoskeletons.

Kolbert travels to the **Great Barrier Reef**, where scientists show her the impact that increased temperature and acidity have had on the diversity of life in coral reefs. Warmer temperatures will increase the amount of algae and plankton in the ecosystem, which will in turn decrease the amount of available nutrition for larger animals. She also visits the tropical rainforests of South America, where she sees the phenomenal diversity of life there. In the last few decades, scientists have found evidence that different rainforest species are being forced to migrate, in the hopes of finding an environment comparable to the one to which they're most accustomed. At the same time, the total amount of available land for wild creatures is constantly decreasing, thanks to the deforestation of the rainforests by farmers and ranchers. Some rainforest species will survive the environmental changes facing the planet, but others will not. Furthermore, the extinction of even a few rainforest species will have a massive impact on the overall biodiversity of the rainforest, since rainforest species are connected to one another very closely.

Another important factor in the Sixth Extinction is human travel. Since prehistoric times, different species have been confined to different ecosystems; each ecosystem has developed a complex equilibrium, predicated on its isolation from the rest of the world. Due to modern human travel and transportation, however, different species have traveled around the world, upsetting the equilibrium of the new ecosystems they enter (for example, the introduction of toads to Australia in the 1930s caused the extinction of dozens of different plant and insect species). Species introduced to a new environment—or "invasive species"—tend to reduce biodiversity in the long run.

In an effort to stave off the Sixth Extinction, some scientists have been trying to get endangered animals, such as the rhinoceros, to reproduce more quickly. Yet the only reason that rhinos and other large animals are on the verge of extinction is that humans overhunted them. Indeed, humans have been hunting large mammals for tens of thousands of years. Despite some controversy in the scientific community, it's highly likely that prehistoric creatures such as the mastodon and the giant sloth went extinct because early human beings wiped them out, suggesting that, in a sense, the Sixth Extinction began thousands of years ago, long before the Industrial Revolution.

Kolbert travels to Germany, where she learns about the Neanderthal—an early, humanoid creature that went extinct thousands of years ago. While the popular, cartoonish model of the Neanderthal is a hairy, ape-like creature, it's likely that Neanderthals were technologically advanced for their time, stood up straight, buried their dead, and had larger brains than modern *Homo sapiens*. Based on their genetic research, scientists believe that early human beings, migrating from Africa, interbred with the Neanderthals, meaning that some modern human beings have Neanderthal DNA. Perhaps the fact that humans have survived extinction and Neanderthals have not is indicative of a uniquely human quality—"mad ambition." For as long as they've existed, humans have explored the world with intense curiosity. Perhaps the Neanderthals were a more peaceful, docile species, and human beings either outcompeted them or actively wiped them out.

Kolbert acknowledges that her book paints a bleak picture of the human race. However, it's important to keep in mind that humans, for all their power to change the environment, also

have the power to preserve, nurture, and protect. Humans need to continue working to preserve endangered species, and to recognize that, no matter what they do in the future, their actions have already ushered in a Sixth Extinction that will shape the world for millennia.

CHARACTERS

MAJOR CHARACTERS

Charles Darwin – Famous English biologist and naturalist whose theory of natural selection formed the basis for modern evolutionary biology. At many points, Kolbert cites Darwin's ideas (particularly the notion that life is a constant competition for resources) but notes that Darwin drastically underestimated the influence of human-caused extinctions (as did every notable scientist up until the mid-20th century).

Jean-Baptiste Lamarck – Late 18th and early 19th century naturalist who proposed an early, largely debunked version of the theory of evolution based on the idea that individual animals changed based on what parts of their body they most used (i.e. an animal's neck would lengthen if it had to stretch to reach leaves high in trees).

MINOR CHARACTERS

Louis Agassiz – 19th century student of Georges Cuvier, who first proposed the now-common theory of "ice ages."

John Alroy – Scientist who conducted simulations to study early humans' ability to wipe out large mammal species.

Luis Alvarez – Father of Walter Alvarez, and, with Walter, co-author of an influential paper arguing that an asteroid wiped out the dinosaurs.

Walter Alvarez – Geologist who, along with his father, Luis Alvarez, first proposed the influential theory that an asteroid caused the mass-extinction of the dinosaurs.

Aristotle – Highly influential ancient Greek scientist and polymath who nevertheless failed to take extinction into account when writing about animals.

Ken Caldeira – Scientist whose research focuses on the pH (acidity) of seawater.

Captain James Cook – 18th century English explorer who sailed to Australia and was probably the first European to see the famous Great Barrier Reef.

Maria Cristina Buia – Marine biologist who researches the biodiversity of waters surrounding Castello Aragonese, a small island in the middle of the Tyrrhenian Sea.

Mario Cohn-Haft – Ornithologist who specializes in birdsong.

Paul Crutzen – The scientist who coined the term, "Anthropocene," referring to the modern, human era of global history.

Georges Cuvier – Important late 18th and early 19th century biologist who pioneered the theory of extinction, and helped spark an international "craze" for fossils and paleontology.

Barbara Durrant – Reproductive physiologist who specialized in the near-extinct Hawaiian crow.

Charles Elton – Scientist who, in the 1950s, pioneered the study of invasive species.

Terry Erwin – Entomologist who estimated that rainforest contained about 30 million arthropod species.

Kenneth Feeley – A student of Miles Silman.

Edgardo Griffith – The director of the El Valle Amphibian Conservation Center in Panama, and an expert in frogs.

Jason Hall-Spencer – Marine biologist who conducts research in the waters surrounding Castello Aragonese, a small island in the middle of the Tyrrhenian Sea.

Al Hicks – Biologist who researches bats in the New England area.

Thomas Jefferson – American founding father and noted fossil collector.

Thomas Kuhn – Important science historian who pioneered the theory that the history of human understanding can be organized into discrete "paradigm shifts."

Neil Landman – Paleontologist who specializes in the ammonite (a prehistoric, nautilus-like creature).

Charles le Moyne, Baron Longueuil – French aristocrat who discovered some of the earliest mastodon fossils.

Carl Linnaeus – Influential 18th century biologist who pioneered the modern system of species taxonomy, yet failed to consider the possibility of extinction.

Louis XV – Early 18th century French monarch who collected fossils.

Tom Lovejoy – Founder of the Biological Dynamics of Forest Fragments Project, or BDFFP.

Charles Lyell – Influential British geologist who popularized the idea of extinction as a slow, gradual process.

Alfred Newton – English naturalist who, along with John Wooley, tried to track down the legendary great auk in Iceland, and spent the remainder of his adult life pioneering the field of wildlife conservation.

Svante Pääbo – Director of the department of evolutionary genetics at the Max Planck Institute for Evolutionary Biology in Leipzig.

Charles Willson Peale – Founder of the Philadelphia Natural History Museum.

Terri Roth – A conservationist who specializes in the rhinoceros.

Miles Silman – A professor at Wake Forest University, and an important forest ecologist who conducts research in the tropical rainforests of South America.

Pascal Tassy – The director of the Paris Museum of Natural History.

William Whewell – President of the London Geological Society, and coiner of the term "catastrophist," describing a scientist who believes that the history of the planet is marked with periodic global catastrophes that cause mass-extinction.

John Wooley – English naturalist who, along with Alfred Newton, tried to track down the legendary great auk in Iceland.

Jan Zalasiewicz – Important stratigrapher (scientist who studies different eras of planetary history) who popularized the term "Anthropocene," which refers to the modern human era of global history.

TERMS

Natural selection – A theory, developed by **Charles Darwin** in the mid-19th century, that posits that the Earth's species are locked in a perpetual struggle to survive and reproduce. Darwin had two key insights. First, that some species have certain traits—strength, intelligence, speed, etc.—that make them more likely to survive in the long run than other species. Second, that individual animals within each species have slight differences that they may pass down to their children. Nature will "select" only the fittest individuals to survive, thus selecting which individuals will have the most offspring, and which traits will be passed down. Over generations, the selection of traits will shift and change the development of entire species.

Catastrophism – Popularized by **Georges Cuvier** in the early 19th century, catastrophism is a theory positing that species go extinct because of sudden, catastrophic events. Examples could include earthquakes, floods, or the massive asteroid impact that killed the dinosaurs. It is a theory that stands in contrast to uniformitarianism.

Acidification – A process in which the Earth's oceans absorb carbon dioxide and quickly becomes more acidic, endangering the survival of many marine species, including coral. Because it is caused by the absorption of carbon dioxide from the atmosphere into the ocean, it is directly impacted by the increase in atmospheric carbon dioxide that is a result of humanity's consumption of fossil fuels.

Uniformitarianism – The theory, popularized by **Charles Lyell** in the early 19th century, that species gradually go extinct over extended periods as a result of gradual changes, such as environmental changes, decreasing resources, and so on. As a theory on the causes of extinction in species it stands in contrast to catastrophism.

Anthropocene – A term for the modern era of the Earth, though the start of this era is up for debate—some experts date it to the Agricultural Revolution between 12,000 and 15,000 years ago, while others argue that it began as recently as 1945. The term "Anthropocene," which literally means "age of man," suggests that the defining event in the Earth's recent history is the wide-scale alteration of the environment by human beings.

THEMES

In LitCharts literature guides, each theme gets its own color-coded icon. These icons make it easy to track where the themes occur most prominently throughout the work. If you don't have a color printer, you can still use the icons to track themes in black and white.

MASS-EXTINCTION AND MORALITY

The central theme of *The Sixth Extinction* is, unsurprisingly, extinction. In the book, Elizabeth Kolbert examines the different ways that scientists have understood species extinction. In particular, she argues for the "catastrophist" theory of extinction. According to this theory, species do not go extinct slowly and gradually; instead, there are eras of planetary history during which global catastrophe causes many thousands of species to go extinct almost simultaneously. It is likely, she argues, that we are living in an age of mass-extinction caused by human attempts to reshape the environment. Kolbert's analysis of the catastrophist theory leads her to ask an important question: given that humans may be causing a mass-extinction, what moral obligation do they have to their environment, and to other species?

In the first half of the book, Kolbert draws an important distinction between ordinary extinction and mass-extinction, based on Charles Darwin's theory of natural selection. According to Darwin, plants and animals are locked in a constant competition for the Earth's resources, particularly food and shelter. The result is that some species will succeed in feeding and protecting themselves, and will therefore bear offspring, while less successful species will fail to survive and have offspring, and will therefore go extinct. In such a way, extinction is an inevitable result of the fact that there are too many species competing for too few resources. While Kolbert doesn't disagree with Darwin's reasoning, she argues (citing many 21st century scientists) that there have been some eras in planetary history in which sudden environmental changes caused many species to die out suddenly. The most famous example of this is the extinction of the dinosaurs after an asteroid hit the Earth hundreds of millions of years ago, but Kolbert posits that there have been at least six major global catastrophes in the Earth's history, each of which caused a mass-extinction.

While mass-extinction isn't a uniquely contemporary phenomenon, Kolbert argues that the current age of mass-extinction is different from its predecessors because it's manmade. Humans aren't the only creatures to alter their environments, but they do so to a far greater degree than any other life form on Earth. Since the Industrial Revolution, humans have consumed billions of tons of coal and gas, greatly increasing the amount of carbon dioxide in the atmosphere. They have also cut down millions of trees, an act which scientists believe has already raised the Earth's temperature. The effect of human activity on the environment has been enormous and devastating, particularly for other life forms. CO2 emissions have changed the acidity of the oceans and increased the temperature of the world's coral reefs and rainforests, making it difficult, if not impossible, for thousands of species to survive. Kolbert argues that, if humans continue their behavior unchecked, rising temperatures and other environmental changes could result in the extinction of a huge chunk of the world's species—perhaps even more than half.

Kolbert's book is neither a diatribe nor an instruction manual: she lets readers make up their own minds about what humanity's response to the Sixth Extinction should be, rather than telling them exactly what to do. Nevertheless, Kolbert personally seems to believe that humans have an obligation to change their behavior and protect endangered or at-risk species from dying out. Kolbert offers two main reasons for humanity's obligation to other species, one selfless, the other selfish. First, she suggests that human beings have a moral obligation not to cause pain or harm to other beings, even if these other beings are non-human. Second, she suggests that human beings should not alter their environments because they'd be harming their own interests. Manmade climate change endangers human life by disturbing "environmental equilibrium" and unleashing new viruses and bacteria—and, more abstractly, by altering their own environments, humans are cheating themselves out of the world's wonder and beauty. Ultimately, *The Sixth Extinction* argues that manmade extinctions are unlike anything in the history of the planet, and, as such, the book suggests that humans will need to change their behavior to an unprecedented degree.

NATURAL SELECTION AND MASS-EXTINCTION

Charles Darwin's theory of natural selection is central to Kolbert's study of the Sixth Extinction. Darwin posits that species are in a constant process of adapting to environmental changes based on competition for a finite number of resources (such as food, water, and shelter). The "fit" species (which can access the world's resources and have offspring) survive, while "unfit" species die out. Generally, the "fit" species succeed at accessing resources because of their ability to adapt to their changing environments by bearing offspring with genetic qualities that are better suited to new conditions. For example, Darwin posits that the existence of wolves and other predators made good hearing a valuable survival trait for rabbits—hence, rabbits developed their characteristic long ears over the course of generations.

"Generations" is a key word here; for the most part, the Darwinian process of natural selection presupposes that a species has a lot of time—perhaps multiple generations—in which to bear offspring that might survive environmental change. Darwin couldn't have predicted the magnitude and speed of the environmental changes facing the planet in the 21st century, which means that, for many species, there isn't enough time to bear offspring with new, useful genetic traits. Kolbert demonstrates that the Sixth Extinction is, in effect, an extreme example of Darwin's theory: a new and dramatic circumstance to which a significant portion of the world's species cannot adapt, essentially condemning them to extinction. This is apparent, for example, in the rapid acidification of ocean water (caused largely by humans burning fossil fuels) that has caused creatures, such as barnacles and clams, to have thinner and more fragile exteriors. As the oceans are acidifying at a faster rate than barnacles and clams can reproduce, these species may go extinct before they can adapt to the changes to their habitats. Seen in Darwinian terms, life in the age of the Sixth Extinction is a "race against the clock": species must reproduce quickly in the hope that some of their offspring will be able to survive the changing environment.

Ultimately, Kolbert argues that the Sixth Extinction is both highly Darwinian and beyond the scope of Darwin's thinking. The process by which species are dying out reflects the basic rules of natural selection. However, Kolbert stresses that Darwin believed extinction to be a gradual process, not a sudden catastrophe that could wipe out the planet's biodiversity. The difference between extinction as Kolbert understands it, and extinction as Darwin understood it, perhaps explains the tonal difference between Kolbert and Darwin's writings. In *On The Origin of Species*, Darwin adopted an impartial, descriptive tone while describing the process of natural selection, reflecting his belief that natural selection was an inevitable part of life on Earth. Kolbert, on the other hand, seems to believe that the Sixth Extinction could be partly averted if humans were to change their behavior now. Due to this, she adopts a more forceful, insistent tone, and encourages her readers to find ways to preserve the world's endangered species.

ENVIRONMENTAL CHANGE AND HUMAN NATURE

Given the catastrophic effects of human activity on the environment, *The Sixth Extinction* bumps up against one of the most frightening and mysterious questions about human nature: what kind of creatures are human beings,

that they have the ability and the need to cause the Sixth Extinction?

To explore this question, Kolbert first defines who human beings are based on what they can do; she posits that the human species' defining characteristic is its ability to change the environment. Humans have altered their environments profoundly for as long as they've been human, and almost every major milestone in human history (the Agricultural and Industrial Revolutions, for example) reflects an increase in human control over the environment. While many people would intuitively define humans in terms of their powerful cognitive abilities, Kolbert argues that human intelligence, while impressive, isn't definitive. Chimpanzees and other apes often outperform young children in puzzles, and they show the capacity for abstract reasoning and logical inference. Furthermore, there have been other highly intelligent species in history, such as the Neanderthals. Instead, Kolbert argues that the species' most lasting legacy (and, therefore, its most noteworthy trait) is its ability to change planet Earth itself. For this reason, some scientists have named the modern era the "Anthropocene"—the age of man.

Kolbert ties human beings' unique achievements to their unique ambition, drive, and passion—qualities which, one could argue, fall into the category of "madness." Humans, it would seem, are the only creatures on the planet who feel a need to explore other places, even when their current environments are satisfactory. They are also the only creatures on the planet who seem to aspire to be remembered after their deaths. To emphasize the fundamental strangeness of human ambition, Kolbert contrasts human beings with their close relatives, the Neanderthals, who lived in Europe thousands of years ago. Early humans explored other environments, but Neanderthals were, it seems, content to remain in their homes. Scientists have argued that humans have a unique "madness gene," which pushes them to discover and conquer the rest of the word. In such a sense, humans' "madness" is the fuel that drives them to alter the environment, and represents a basic part of their nature.

Kolbert offers a final (and more optimistic) definition of human nature: the ability to nurture and protect others. While it's true that humans have caused an enormous amount of damage to the environment, it is also notable that humans are the only creatures who seem to expend their time and effort protecting other species. (Indeed, much of *The Sixth Extinction* consists of Kolbert visiting the many wildlife preserves and endangered species facilities around the world.) Ultimately, then, Kolbert offers a nuanced, even contradictory, view of human nature. Humans are both destructive and creative; they're capable of wiping out entire species without caring, but also of preserving endangered species with incredible care and kindness. Perhaps humans have the freedom to choose what kind of lives they want to live, and which aspects of their nature they want to indulge—this, Kolbert suggests, is humanity's best hope against the Sixth Extinction.

SCIENCE AND PARADIGM SHIFTS

One of the most important points that *The Sixth Extinction* makes is that humans only learned about natural selection, extinction, and environmental degradation very recently. (Only a few decades ago, for instance, scientists didn't realize that fossil fuels could change the pH of the oceans, devastating marine life.) In addition to being a study of extinction, then, Kolbert's book is about the way science changes over time. Interpreted in this way, environmental science is a particularly clear example of the general process by which a new idea or set of assumptions—a paradigm—is introduced into the scientific community, gradually accepted within the scientific community, and is then accepted by the general public.

Kolbert cites the ideas of the science historian Thomas Kuhn in order to characterize science as a constant process of evidence gathering and "paradigm-testing." At any given time, Kuhn argued, a scientific community will coalesce around a theory that explains a complex, real-world phenomenon. This theory—a paradigm—may be correct or incorrect. For example, in the years leading up to the career of Georges Cuvier, the European scientific community believed that different kinds of animals never died out—the concept of "extinction" wasn't a part of the discourse. The purpose of a paradigm is to explain evidence; therefore, every new piece of evidence acts as a "test" of the paradigm. Furthermore, if a paradigm is flawed, then further evidence will tend to challenge the paradigm and show its weaknesses. For example, the abundance of fossils discovered in the 18th century slowly showed the "no extinction paradigm" to be factually incorrect.

Following Kuhn, Kolbert argues that when a paradigm becomes conspicuously weak (i.e., when it fails to support the evidence), a scientist will eventually propose a new, stronger paradigm. For example, Georges Cuvier studied the evidence of fossil remains and developed a new biological paradigm: animals go extinct over time. If a new paradigm is strong, and supports all the existing evidence—as Cuvier's did—then the scientific community will adopt it. The final step in the process is for scientists to introduce the new paradigm to the general public in a simple, understandable way. Within a few decades of Cuvier's theory, for example, there was an international "fossil craze," reflecting people's new understanding of the theory of extinction. One could even argue that, by writing *The Sixth Extinction*, Kolbert is participating in "paradigm popularization"; while she was not involved in the scientific discoveries described in her book, she is introducing the lay-reader to complex, cutting-edge concepts of biology and ecology.

Kuhn's theory of paradigms is important to *The Sixth Extinction*

because it shows that science is constantly approximating the truth. As Kolbert acknowledges, current theories of environmental change are not perfect: there are some pieces of evidence that environmental scientists cannot yet explain, and there are many questions about the environment that scientists have been unable to answer. Put another way, the current environmental paradigms are strong, in the sense that they can explain a lot of the evidence, but they need to be stronger. Thus, Kuhn's theory of science as a constant process of evidence gathering and paradigm refining encourages the reader to go out, learn more about the environment, and develop new ideas about how to respond to the unprecedented environmental changes in the 21st century.

SYMBOLS

Symbols appear in **teal text** throughout the Summary and Analysis sections of this LitChart.

GROTTE DES COMBARELLES

There aren't very many symbols in *The Sixth Extinction*. However, Kolbert has an interesting habit of ending each chapter with a symbolically loaded image. At the end of Chapter 12, Kolbert visits the Grotte des Combarelles, a prehistoric cave in France, which leads her to realize how "mad" ancient human beings must have been to explore the world. In this way, the cave symbolizes the drive and mad ambition of the human species—qualities which have led human beings to colonize the entire world.

GREAT BARRIER REEF

Kolbert writes about the Great Barrier Reef, located off the coast of Australia, and how the increased acidity of the water has been destroying it for the last few decades. In this way, the Great Barrier Reef is a synecdoche (symbol where a part of something represents the whole) for the planet itself, and a symbol for the way that human behavior is destroying the planet's beauty and complexity.

QUOTES

Note: all page numbers for the quotes below refer to the Picador edition of *The Sixth Extinction* published in 2015.

Prologue Quotes

The process continues, in fits and starts, for thousands of years, until the species, no longer so new, has spread to practically every corner of the globe. At this point, several things happen more or less at once that allow *Homo sapiens*, as it has come to call itself, to reproduce at an unprecedented rate. In a single century the population doubles; then it doubles again, and then again. Vast forests are razed.

Related Themes:

Page Number: 2

Explanation and Analysis

In the prologue to her book, Kolbert paints an eerie picture of the human race. Instead of writing in terms of "we humans," Kolbert distances readers from their own species, portraying humans as a strange, even barbaric race: humans have colonized the entire planet, massacring other species, and permanently altering the surface of the planet, leading to a global environmental crisis.

The passage is important because it uses a literary technique called "defamiliarization," in other words, portraying a familiar subject (here, the human race) in a strange or confusing way. Kolbert is writing about the human race and its connection to the Sixth Extinction, and she wants her readers to look at humanity with fresh eyes. Many of the human practices that Kolbert writes about, such as driving cars, using electricity, flying or sailing to other countries, etc., are utterly uncontroversial. And yet, by defamiliarizing humans, Kolbert allows readers to see how objectively bizarre their own species is. In this way, Kolbert allows us to understand how greatly we human beings have damaged our own planet.

Chapter 1 Quotes

The history of life thus consists of "long periods of boredom interrupted occasionally by panic."

Related Themes:

Page Number: 16

Explanation and Analysis

In the long history of the planet, species tend to go extinct. Here, Kolbert succinctly describes one theory for the process of extinction, which combines two previously-dueling scientific ideas. These ideas, as Kolbert will go on to

outline, are "uniformitarianism" and "catastrophism"—the former is the belief (following Darwin) that extinction occurs slowly as a result of natural selection, and the latter holds that there can be sudden and widespread extinctions due to catastrophic events.

This quotation is notable for two reasons. One is that it is the product of the scientific method at work. The two previous theories of extinction individually failed to explain the historical evidence, which was compelling when cherry picked to apply to each theory, but could never account for the evidence supporting the other theory. The combination of these two theories is a good example of the ways in which scientific thought advances. It often dialectically combines competing ideas in order to arrive at a theory that most compellingly explains the entire array of available evidence. This process emphasizes the "unfinished" nature of science—it is always evolving as new ideas and evidence arise. Second, this quote is important because it introduces a moral tone. By using the word "panic" to describe catastrophic phases of mass extinction, Kolbert is implicitly labeling the present day as a period of panic. It's a strong and startling word to apply, and one that points towards the need for action.

Chapter 2 Quotes

❝ By the middle of the nineteenth century, many of [Georges Cuvier's] ideas had been discredited. But the most recent discoveries have tended to support those very theories of his that were most thoroughly vilified, with the result that Cuvier's essentially tragic vision of earth history has come to seem prophetic.

Related Characters: Georges Cuvier

Related Themes:   

Page Number: 25

Explanation and Analysis

In Chapter Two, Kolbert discusses the life and ideas of a great French naturalist, Georges Cuvier. Cuvier is important in the history of naturalism because he was one of the first notable thinkers to propose that some animals go extinct over time. Cuvier examined the fossils of extinct creatures, and theorized that animals die out over time, leaving their skeletons to be discovered millions of years later. As Kolbert points out here, Cuvier had many incorrect ideas about biology and naturalism (notably, he rejected the theory of evolution). However, Cuvier's theories about extinction have been proven correct by the evidence, making him an important figure in scientific history.

The passage is a great example of how new scientific theories—or, to use the terminology of Thomas Kuhn, "paradigms"—appear over time. Often, a scientific figure, such as Cuvier, will propose a new paradigm to explain the existing evidence. Cuvier's paradigm—that some animals go extinct over time—was unpopular at first, but eventually, it became an accepted part of scientific discourse.

Another important thing to note about this passage is Kolbert's use of the word "tragic." Cuvier was, first and foremost, a scientist—his duty was to describe natural phenomena, not to pass moral judgments about them. But even if Cuvier took a more dispassionate view of extinction, Kolbert, in her book, views the Sixth Extinction, and extinction in general, through a moral lens. She argues that the mass-extinction of life on the planet is a tragedy, and she implies that human beings should try to prevent such a tragedy from continuing.

❝ ... if there were four extinct species, Cuvier declared there must be others. The proposal was a daring one to make given the available evidence. On the basis of a few scattered bones, Cuvier had conceived of a whole new way of looking at life. Species died out. This was not an isolated but a widespread phenomenon.

Related Characters: Georges Cuvier

Related Themes:   

Page Number: 30

Explanation and Analysis

In this passage, Kolbert writes about Georges Cuvier's most influential scientific insight. Like many naturalists of his era, Cuvier had studied the fossils of extinct animals and decided that these animals were no longer in existence. However, Cuvier went one step further with his analysis—he argued that there must be many, many animals that had once walked the Earth, but were now extinct. In such a way, Cuvier became the first major scientist to believe in a theory of extinction—the notion that, over time, species die out altogether.

It's important to note that Cuvier's theory, while a big step forward for Western science, wasn't perfect. Cuvier recognized that animals went extinct, but he didn't have a convincing explanation for *why* (Charles Darwin, writing

more than half a century later, would provide one). All in all, Cuvier's contributions to naturalism exemplify the importance of paradigms in scientific discourse. As Thomas Kuhn argued, a paradigm (like Cuvier's idea of extinction) is never a dead-end—instead, a new paradigm raises new questions, and it challenges other scientists to develop new theories of their own (just as Cuvier's extinction paradigm brought up a natural question for his colleagues to answer—why do some animals go extinct while others don't?). Science is a constant process of approximating the truth, with each successive paradigm doing a slightly better job of explaining the world than the paradigm before it.

❝ Cuvier's essay was pointedly secular. He cited the Bible as one of many old (and not entirely reliable) works, alongside the Hindu Vedas and the *Shujing*. This sort of ecumenicalism was unacceptable to the Anglican clergy who made up the faculty at institutions like Oxford, and when the essay was translated into English, it was construed … as offering proof of Noah's flood.

Related Characters: Georges Cuvier

Related Themes:

Page Number: 45

Explanation and Analysis

In this interesting passage, Kolbert talks about how the European community in general interpreted Georges Cuvier's theory of extinction. Cuvier, later in his life, tried to answer the question that his own theory of extinction posed: why do some animals go extinct? Cuvier's answer to his own question was that some animals die in natural disasters and global catastrophes, such as floods and earthquakes. Cuvier's discussion of floods prompted certain people, especially Anglican professors at Oxford University, to interpret his extinction theory as proof of the account of world history in the Biblical Book of Genesis—in other words, people thought that extinct species like mammoths and mastodons had died in Noah's flood.

The passage is a good example of how the general public can misinterpret and decontextualize science to reconfirm their beliefs about the world. Implicitly, Kolbert suggests that it's important for people to interpret scientific theories fairly and accurately, instead of distorting them to confirm what they already think they know. Authors like Kolbert herself play an important part in the scientific process: they "translate" scientists' complex ideas for the lay-reader, ensuring that ordinary people understand what the scientific community has discovered.

Chapter 3 Quotes

❝ Darwin's familiarity with human-caused extinction is also clear from *On the Origin of Species*. In one of the many passages in which he heaps scorn on the catastrophists, he observes that animals inevitably become rare before they become extinct, "we know this has been the progress of events with those animals which have been exterminated, either locally or wholly, through man's agency." It's a brief allusion and in its brevity, suggestive. Darwin assumes that his readers are familiar with such "events" and already habituated to them. He himself seems to find nothing remarkable or troubling about this.

Related Characters: Charles Darwin

Related Themes:

Page Number: 69

Explanation and Analysis

In this chapter, Kolbert discusses the life and ideas of Charles Darwin. Darwin played an important role in the history of extinction theory by arguing that species go extinct because they fail, for whatever reason, to reproduce (a process that Darwin famously summed up as "survival of the fittest"). However, as Kolbert argues in the passage, Darwin's understanding of extinction wasn't perfect. He recognized that species go extinct slowly and gradually, and he even recognized that human beings could contribute to extinction, but he didn't realize that sometimes many species go extinct in rapid succession, and he certainly didn't realize the magnitude of the implications of his acknowledgement of human involvement in extinction. Instead, Darwin treated human-caused extinctions as isolated, unimportant examples, an attitude that was reflected in the scientific understanding of extinction for many years afterwards.

While Kolbert has a lot of respect for Darwin, she makes it clear that Darwin's ideas about natural selection were highly limited. For the century after Darwin's death scientists continued to doubt that humans had the capacity to permanently their environments. It has only been in the last few decades, in fact, that the paradigm has changed—the scientific community now believes that humans have the power to cause mass-extinctions.

But how, then, to make sense of cases like the great auk or the Charles Island tortoise or, to continue the list, the dodo or the Steller's sea cow? These animals had obviously not been done in by a rival species gradually evolving some competitive advantage. They had all been killed off by the same species, and all quite suddenly—in the case of the great auk and the Charles Island tortoise over the course of Darwin's own lifetime. Either there had to be a separate category for human-caused extinction, in which case people really did deserve their "special status" as a creature outside of nature, or space in the natural order had to be made for cataclysm, in which case, Cuvier— distressingly—was right.

Related Characters: Georges Cuvier, Charles Darwin

Related Themes:

Page Number: 69

Explanation and Analysis

In this passage, Kolbert further explores the differences between Darwin's theory of extinction and the modern scientific understanding of extinction. Darwin, who believed that animals go extinct simply because of the inevitable process of natural selection, was committed to the belief that human beings are "just animals" who obey the same rules of natural selection as other species. This belief—while held under the auspices of good, dispassionate science—blinded Darwin to the special role human beings play in species extinction.

While Kolbert accepts Darwin's premise that humans, no less than other species, obey the laws of natural selection, she disagrees that humans are no different than other species. Instead, she argues that humans are unique in the history of the Earth, since they're the only species that has ever altered its own environment so dramatically.

The modern theory of extinction is, in a way, a hybrid of Darwin's belief that extinctions take place slowly and gradually and Cuvier's theory that animals go extinct because of sudden catastrophes. Kolbert shows, then, that, Darwin and Cuvier were both right: sometimes, animals go extinct because of ordinary natural selection, and sometimes, they don't. However, just because each had lasting ideas does not mean that all their ideas were equally valid.

Chapter 4 Quotes

Darwin's successors inherited the "much slow extermination" problem. The uniformitarian view precluded sudden or sweeping change of any kind. But the more that was learned about the fossil record, the more difficult it was to maintain that an entire age spanning tens of millions of years, had somehow or other gone missing. This growing tension led to a series of increasingly tortured explanations. Perhaps there had been some sort of "crisis," at the close of the Cretaceous but it had to have been a very slow crisis. Maybe the losses at the end of the period did constitute a "mass extinction."

Related Characters: Charles Darwin

Related Themes:

Page Number: 79

Explanation and Analysis

In this passage, Kolbert describes the lead-up to a major paradigm shift in evolutionary science. In the decades following the death of Charles Darwin, scientists interpreted the theory of evolution to mean that animals went extinct because of the gradual process of natural selection. However, over time, it became clear that such an interpretation didn't support the existing evidence. There were major gaps in the "fossil record"—in other words, it appeared that there were long stretches of planetary history in which there were almost no life forms. This evidence suggested that, at various points in the past, global catastrophes wiped out the Earth's life—the opposite of the slow, gradualistic view of life that Darwin and his disciples favored.

The passage is a good example of the way that paradigms change over time. In the mid-20th century, naturalists tried to use the old, gradualist paradigm to explain the fossil evidence, but to no avail. Eventually, the evidence made it clear that science needed a new paradigm—a hybrid theory, according to which animals occasionally experienced mass-extinctions. It's notable that Kolbert describes the gradualist attempts to fit an outdated paradigm onto new evidence as "tortured explanations" of the fossil record—this shows a major peril of scientific thought, which is the inability to let go of a bad explanation that has been heretofore accepted as truth. It's important, then, for scientists to be more loyal to the scientific method than to the theories that have been previously posited.

Ammonites produced very tiny egg, only a few hundredths of an inch across. The resulting hatchling, or ammonitellae had no means of locomotion; they just floated near the surface of the water, drifting along with the current. Nautiluses, for their part lay very large eggs among the largest of all invertebrates, nearly an inch in diameter.

Related Themes:

Page Number: 90

Explanation and Analysis

In this passage, Kolbert discusses the extinction of a prehistoric animal, the ammonite. Ammonites resembled the modern-day nautilus in many ways—they had, for example, the same spiral-shaped shells. However, there is evidence to suggest that nautiluses survived the mass-extinction that took place at the end of the Cretaceous period of the Earth's history, while ammonites went extinct around the same time. Here, Kolbert outlines the crucial difference, which is a seemingly small discrepancy between the egg sizes of each animal. That such a specific detail could doom one species and save another shows just how non-linear natural selection can be; certain biological qualities are evolutionary advantages at times, and disadvantages at other times. For millions of years, the ammonite's small eggs helped the species survive (small eggs were more likely to drift far through the ocean, scattering ammonites across the globe). But after the extinction of the dinosaurs, small eggs became a huge evolutionary liability. As Kolbert says later in the book, past success is no guarantee of future results.

Chapter 5 Quotes

The history of the science of extinction can be told as a series of paradigm shifts. Until the end of the eighteenth century, the very category of extinction didn't exist. The more strange bones were unearthed—mammoths, Megatherium, mosasaurs—the harder naturalists had to squint to fit them into a familiar framework. And squint they did. The giant bones belonged to elephants that had been washed north, or hippos that had wandered west, or whales with malevolent grins. When Cuvier arrived in Paris, he saw that the mastodon's molars could not be fit into the established framework, a "My God" moment that led him to propose a whole new way of seeing them.

Related Characters: Georges Cuvier

Related Themes:

Page Number: 93

Explanation and Analysis

In this passage, Kolbert introduces the concept of paradigm shifts. Citing the ideas of Thomas Kuhn, she suggests that the scientific community has interpreted extinction using a succession of different theories, or paradigms. The first important paradigm for understanding extinction was Georges Cuvier's: specifically, Cuvier's theory that animals die out over time. Later paradigms included the Darwinian paradigm (that species die out because of the competition for finite resources), and the modern, hybrid paradigm that the Earth occasionally goes through phases of mass-extinction.

Kuhn argued that the scientific community makes progress over time by forming paradigms that explain available evidence and then testing them rigorously as new evidence appears. When a paradigm no longer does a good job of explaining all the available evidence, a new paradigm will arise that describes the known world better. Kolbert uses Kuhn's ideas to suggest that, in the last 150 years or so, scientists have become steadily better at understanding the complex phenomenon of extinction; furthermore, scientists will continue to get better at understanding extinction in the future.

On the one hand, the paradigm is a generally accepted idea in the history of science. On the other hand, however, Kolbert's book is a bit allergic to the idea of natural "progress"—it's steeped in Darwin's idea that natural selection propels change that is more about random circumstance than concerted improvement, and Kolbert is unwilling to entertain that humans are making progress, morally or logistically, in confronting their environmental challenges. Thus, it's notable that Kolbert is able to concede the possibility of linear progress to the field of science alone. It's unclear whether this is an assumption that is as rigorously examined as her others.

"Because of these anthropogenic emissions" Crutzen wrote, the global climate is likely to "depart significantly from natural behavior for many millennia to come."

Crutzen published "Geology of Mankind" in 2002. Soon, the 'Anthropocene" began migrating out into other scientific journals.

Related Characters: Paul Crutzen

Related Themes:

Page Number: 108

Explanation and Analysis

At the end of Chapter Five, Kolbert introduces the word, "Anthropocene," which describes the "age of man." The scientist Paul Crutzen argued that the modern era is defined by the behavior of the human race. Human beings, he pointed out, are the only animals in the history of the planet who have altered the face of the Earth so extensively. Humans block off rivers, cut down trees, expel billions of tons of carbon dioxide into the atmosphere, etc. As a result, the most accurate way to describe the modern era is to call it the age of man—in other words, the Anthropocene.

It is a mark of the newness of environmental science that Crutzen coined the word "Anthropocene" less than twenty years ago. The notion that humans have the power to irreversibly alter the planet is still fairly new. While virtually everyone in the scientific community believes in such an idea, it has yet to catch on with the general public. By writing *The Sixth Extinction*, Kolbert could play an important role in popularizing the new theory of the Anthropocene.

Chapter 6 Quotes

❝ Ocean acidification increases the cost of calcification by reducing the number of carbonate ions available to begin with. To extend the construction metaphor, imagine trying to build a house while someone keeps stealing your bricks.

Related Themes:

Page Number: 121

Explanation and Analysis

In Chapter Six, Kolbert explores one specific aspect of the environment in which humans have played a major role: the acidity of the oceans. By emitting billions of tons of carbon dioxide into the atmosphere, humans have caused the oceans to absorb larges quantities of carbon dioxide; as a result, the oceans have become considerably more acidic since the dawn of the industrial Revolution, when humans began burning large amounts of fossil fuels, such as coal and gasoline. Because the oceans are becoming more acidic, certain creatures, known as calcifiers—i.e., marine creatures such as barnacles, clams, or oysters, who have a calcium-heavy shell or exoskeleton—are having a lot of trouble surviving.

As Kolbert notes later in the chapter, scientists only recently discovered that carbon dioxide emissions have a major impact on the acidity of the oceans. Now that the scientific community recognizes the impact of human technology on the oceans, it's clear that humans are indirectly causing the mass-extinction of calcifiers, among many other marine species. Kolbert drives this point home with a literary analogy meant to provoke human sympathy for calcifiers (who are, themselves, without the characteristics that generally endear nature to humans, such as intelligence, cuteness, or essential utility for human life). It's significant that Kolbert uses the verb "stealing" in the phrase "someone keeps stealing your bricks"; this strongly points a finger at humans (whose activities are corroding the calcifiers' shells), implying that human activity is, in this case, violent and unethical.

Chapter 7 Quotes

❝ Thousands—perhaps millions—of species have evolved to rely on coral reefs, either directly for protection or food, or indirectly, to prey on those species that come seeking protection or food. This coevolutionary venture has been under way for many geologic epochs. Researchers now believe it won't last out the Anthropocene.

Related Themes:

Related Symbols:

Page Number: 130

Explanation and Analysis

In Chapter Seven, Kolbert explores another kind of ecosystem that's being threatened by the advent of human industry: the coral reef. Near Australia's Great Barrier Reef, Kolbert interviews scientists and researchers, who tell her that, if humans continue to pollute the atmosphere at their current rate, then the average ocean temperature will continue to rise to the point where the Great Barrier Reef—and almost any other coral reef—will begin to disintegrate.

The passage is a good example of the strong emotional tone that Kolbert adopts throughout her book. Kolbert is writing a serious science book: in this chapter, for example, she uses chemistry, biology, and ecology to study the erosion of coral reefs. However, Kolbert sometimes adopts a more overtly poignant tone. Here, for example, she conveys the unspeakable tragedy of the Sixth Extinction by stressing that, after countless years and epochs, human beings are

going to destroy the Great Barrier Reef, one of the most beautiful things on the face of the planet. She also stresses the vast (and, perhaps, unknowable) ripple effects of destroying such a complex organism, which points to the foolishness of this human-fuelled destruction.

Chapter 8 Quotes

There are various ways to calculate migration rates: for instance, by the number of trees or, alternatively, by their mass. Feeley grouped the trees by genus. Very roughly speaking, he found that global warming was driving the average genus up the mountain at a rate of eight feet per year. But he also found the average masked a surprising range of response. Like cliques of kids at recess, different trees were behaving in wildly different ways.

Related Characters: Kenneth Feeley

Related Themes:

Page Number: 159

Explanation and Analysis

A team of scientists, including Miles Silman, and his student, Kenneth Feeley, are measuring the rate of natural selection in the rainforests of South America. One way of quantifying this is by measuring the rate at which temperature change pushes tree species to higher altitudes, which is an adaptive mechanism by which the tree species seeks out a temperature to which it is accustomed.

In short, Kolbert is describing a sped-up version of the natural selection process that Charles Darwin described in *On the Origin of Species* more than 150 years ago. As Darwin pointed out, species are in a constant struggle to adapt to their changing surroundings. However, Darwin believed that the environment changes at an incredibly slow, gradual rate. The rainforests of South America, on the other hand, are getting warmer year after year. In this sped-up scenario, the "stakes" of adaptation are extremely high: if species can't find a way to migrate up the hill, it will die out. This is particularly frightening considering that, on average, a tree species must migrate eight feet per year—a stunning change for a species that we don't generally consider to be mobile.

Kolbert's "cliques of kids at recess" metaphor is also notable. For one, she uses it to humanize tree species, painting them as being similar to human children in their individuality. She also uses it to dramatize the significance of their migration—trees seem much more dynamic when their movements are compared to the choices and reactions of children at recess.

How many species overall will be capable of moving fast enough remains an open question, though, as Silman pointed out to me, in the coming decades we are probably going to learn the answer, whether we want to or not.

Related Characters: Miles Silman

Related Themes:

Page Number: 162

Explanation and Analysis

In this passage, Kolbert continues with her analysis of the mass-extinction taking place in the rainforests. Due to the escalating temperature of the ecosystem, species have had to migrate to new areas of the rainforest. While some species have been successful in seeking the cooler temperatures of their old environments, other species have failed to do so; as a result, they've begun going extinct. As Silman says in this passage, the future of the rainforests looks pretty bleak: species will be forced to adapt or die—and, in all probability, many rainforest species are going to die out altogether.

The passage is important because it conveys some of the inevitability of mass-extinction. Kolbert suggests that, after hundreds of years of burning coal and cutting down trees, the "damage is done." In other words, no matter what the human race chooses to do from now on, species will continue going extinct. However, there are other passages of *The Sixth Extinction* in which Kolbert takes a more optimistic view of the future of mass-extinction. While it's probably true that plants and animals will continue going extinct for decades to come, perhaps it's possible that, by changing their behavior now, humans will be able to stave off the extinction of some species.

You could be studying a chain of islands or a rainforest or a nearby state park, and you'd find that the number of species varies according to the same insistent equation: S = cA squared.

Related Themes:

Page Number: 166

Explanation and Analysis

At the end of Chapter Eight, Kolbert introduces an important mathematical law. According to the law, there is a directly proportional relationship between the number of species on the planet (S) and the square of the amount of available space in which those species can live. Put another way, the more natural land human being develop and clear, the fewer total species there will be on the face of the Earth.

The species-area law is depressing for a number of reasons. Most obviously, the amount of untouched land on Earth is constantly decreasing—humans cut down trees, clear forests, burn fields, etc. As a result, the number of different species on Earth is always going down.

While Kolbert will discuss the precise reasons for the direct relationship between diversity and land area in the following chapter, the basic reason for relationship is clear: species need untouched land in which they can live safely. When humans destroy rainforests and burn fields, they're indirectly causing thousands of animals to go extinct. The clarity of a mathematic formula, though, implies a solution: perhaps by "de-colonizing" developed land (by re-planting trees, introducing wild species, or other actions) humans could undo some of the damage that they've done to the environment, and increase the number of living species once again.

Chapter 9 Quotes

❝ Smaller areas harbor smaller populations, and smaller populations are more vulnerable to chance. To use an extreme example, an island might be home to a single breeding pair of birds of species X. One year, the pair's nest is blown out of a tree in a hurricane. The following year, all the chicks turn out to be males, and the year after that, the nest is raided by a snake. Species X is now headed toward local extinction. If the island is home to two breeding pairs, the odds that both will suffer such a string of fatal bad luck is lower, and if it's home to twenty pairs, it's a great deal lower. But low odds in the long run can still be deadly.

Related Themes:

Page Number: 180

Explanation and Analysis

In this passage, Kolbert gives a partial explanation for the mathematical law she described in the previous chapter. As she'd discussed, there is a direct relationship between the number of living species on the Earth and the amount of available land. One reason that this is the case is that, in smaller land areas, the chances of catastrophic mass-extinctions are greater. This drives home the point that, first of all, the vagaries of nature (as Darwin knew) can have profound evolutionary effects. This might suggest that humans have less responsibility for extinction than Kolbert has previously argued, but Kolbert's specificity about the connection between land area and survival odds makes it clear that there is a human role to play in both endangerment and protection of species. If human beings continue to reduce the amount of natural land then the odds of extinction for species that rely on such lands will continue to increase. Kolbert, though, is also implicitly positing a relatively straightforward way to go about protecting species; by increasing the amount of available land (through reclamation of developed lands and by halting development activities), humans can easily increase the odds that more species will survive.

❝ I thought about this as we trudged back to camp. If Cohn-Haft was right, then in its crazy, circus-like complexity the ant-bird-butterfly parade was actually a figure for the Amazon's stability. Only in a place where the rules of the game remain fixed is there time for butterflies to evolve to feed on the shit of birds that evolved to follow ants.

Related Characters: Mario Cohn-Haft

Related Themes:

Page Number: 192

Explanation and Analysis

At the end of Chapter Nine, Kolbert describes an important experience she had in the Amazon. Late one night, she and her friend, the scientist Mario Cohn-Haft, woke up in the hopes of witnessing army ants marching through the forest. However, Kolbert was disappointed to find that the army ants were nowhere to be found.

As Kolbert points out in this passage, the disappearance of the army ants from the Amazon is a symbol for the plummeting biodiversity of the Earth itself. Over the course of the last few thousand years, species have been going extinct at a phenomenal rate. Furthermore, the disappearance of a few species is causing a "chain reaction." The extinction of army ants, for example, would threaten the survival of hundreds of other species that depend on army ants for food and nutrition. The birds that eat army ants, and the butterflies that do the same, will have to find

new food sources, or face extinction. And because species are already going extinct at an alarming rate, it's doubtful that birds and butterflies would have enough time to adapt to their changing circumstances—in all likelihood, they would go extinct, too, furthering the chain reaction. In general, Kolbert shows that different species are connected to one another in close, significant ways, meaning that the extinction of one species may lead to the extinction of many other species, too.

Chapter 10 Quotes

Long-term relationships between pathogens and their hosts are often characterized in military terms; the two are locked in an "evolutionary arms race," in which, to survive, each must prevent the other from getting too far ahead. When an entirely new pathogen shows up it's like bringing a gun to a knife fight. Never having encountered the fungus (or virus or bacterium) before, the new host has no defenses against it.

Related Themes:

Page Number: 204

Explanation and Analysis

In Chapter Ten, Kolbert discusses another impact of human development on biodiversity. Because humans travel around the world, they transport plants,, animals, and pathogens with them (sometimes knowingly, sometimes unknowingly). The result is that humans have introduced many life forms, particularly microscopic life forms, to new environments. Often, this causes major problems. Every ecosystem on the planet has its own delicate equilibrium: pathogens, plants, and animals balance one another out by consuming each other. The introduction of a new pathogen often poses a grave threat to an ecosystem, because there are no predators or rivals to keep the pathogen's population low.

It's significant that Kolbert continues to use metaphors about social activity to humanize nonhuman entities. "Bringing a gun to a knife fight," for instance, is a phrase that evokes a certain kind of unfairness. If a human were to do this, he or she would be accused of manipulation or not playing by the rules. By applying this logic to the struggle between a pathogen and a host, Kolbert is adding a moral tone to a situation that might otherwise seem purely natural. Introducing a pathogen to an unfamiliar environment is unfair to that environment because the environment has no adequate protection against the pathogen, which is metaphorically figured here to be violent. Kolbert often uses metaphor to impose a moralistic tone on a natural situation without overtly expressing her opinion.

If we look even farther ahead than Elton did—millions of years farther—the biological world will, in all likelihood, become more complex again. Assuming that eventually travel and global commerce cease, the New Pangaea will, figuratively speaking, begin to break up. The continents will again separate, and islands will be re-isolated. And as this happens, new species will evolve and radiate from the invasives that have been dispersed around the world. Hawaii perhaps will get giant rats and Australia giant bunnies.

Related Characters: Charles Elton

Related Themes:

Page Number: 213

Explanation and Analysis

In this passage, Kolbert suggests that, at some point in the future, the world will develop a new "biological equilibrium." This is based on the scientist Charles Elton's argument that the world's ecosystems are perfectly balanced: plants, animals, and microbes consume one another, preventing any single species' population from growing out of control. However, in the modern era, thanks to human travel, life forms have migrated to new ecosystems, growing out of control and rupturing the fragile biological equilibrium.

The implication of the passage is that, at some point in the future, human beings will go extinct, likely due to the chaos that their own actions have set in motion on the planet. The post-human future that Kolbert suggests is notably dystopian and even rings as science fiction (giant rats ruling Hawaii, for example). This is a passage meant to shock and dismay through its sheer uncaring about the future of the human animal. The "new equilibrium" sounds like exactly what a forward-thinking human being would want, but here the new equilibrium is predicated on the extinction of the creature that ruined the pre-existing equilibrium in the first place.

Chapter 11 Quotes

If, on the other hand, people were to blame—and it seems increasingly likely that they were—then the import is almost more disturbing. It would mean that the current extinction event began all the way back in the middle of the last ice age. It would mean that man was a killer—to use the term of art an "overkiller"—pretty much right from the start.

Related Themes:

Page Number: 239-240

Explanation and Analysis

In Chapter Eleven, Kolbert addresses the hypothesis—which is becoming increasingly common in the scientific community—that prehistoric human beings were responsible for the extinction of many large mammals, including the mammoth, the mastodon, and the giant sloth. There is considerable evidence that large prehistoric mammals had survived ice ages, heat waves, and other sudden environmental changes leading up to the dawn of man—this suggests that humans (and not some mysterious temperature change, as certain scientists continue to believe) caused the large mammals to die out.

As Kolbert acknowledges in this passage, the idea that humans wiped out prehistoric species is disturbing, because it suggests that humans have been mass-killers for as long as they've been in existence. One could even argue that the ability to cause mass-extinction is the essence of human nature. Humans seem to have a strong, innate desire to destroy their environments, killing off life forms without, until recently, thinking of the consequences.

Chapter 12 Quotes

It's only fully modern humans who start this thing of venturing out on the ocean where you don't see land. Part of that is technology, of course; you have to have ships to do it. But there is also, I like to think or say, some madness there. You know? How many people must have sailed out and vanished on the Pacific before you found Easter Island? I mean, it's ridiculous. And why do you do that? Is it for the glory? For immortality? For curiosity? And now we go to Mars. We never stop.

Related Characters: Svante Pääbo (speaker)

Related Themes:

Page Number: 251

Explanation and Analysis

In Chapter Twelve, Kolbert sheds some new light onto the concept of human nature by contrasting human beings with their close cousins, Neanderthals. While most people think of Neanderthals as primitive, crude, apelike creatures, it's possible that Neanderthals were intelligent (their brains are larger than those of modern human beings), compassionate (they took care of their sick and wounded), and spiritual (they planted flowers on the graves of their dead).

The paleogeneticist (scientist who specializes in the DNA of prehistoric creatures) Svante Pääbo has developed an interesting theory about why Neanderthals went extinct while human beings didn't. In this passage, Kolbert uses his ideas to argue that human beings have an innate desire to explore, conquer, and colonize—in short, a "madness gene." Humans escaped the extinction that faced the Neanderthals because they had a strong desire to explore the rest of the world—as a result, they migrated around the world, found new resources, and eventually prospered. Neanderthals, on the other hand, may have been more passive and docile (in spite of their intelligence)—as a result, they may have died out because they weren't aggressive enough. Pääbo's theory supports the idea that curiosity and "wanderlust" are two of the defining traits of human beings. It also, perhaps, points to a central contradiction of human history (one that Darwin wouldn't find contradictory at all): that a trait that once helped humans prosper could, in turn, lead them to extinction.

The Neanderthals lived in Europe for more than a hundred thousand years and during that period they had no more impact on their surroundings than any other large vertebrate. There is every reason to believe that if humans had not arrived on the scene, the Neanderthals would be there still, along with the wild horses and the woolly rhinos. With the capacity to represent the world in signs and symbols comes the capacity to change it, which, as it happens is also the capacity to destroy it.

Related Themes:

Page Number: 258

Explanation and Analysis

Kolbert ends Chapter Twelve on an ambiguous note. She points out that Neanderthals may have been compassionate, gentle creatures—and yet there's very little evidence to suggest that they had art or language of any

kind. On the other hand, it's well-known that human beings have made art—cave paintings, carvings, sculptures, etc.—for tens of thousands of years. Furthermore, linguists argue that humans have had complex language skills for as long as there have been humans.

Kolbert interprets the absence of art and language in Neanderthal society in an interesting way. Perhaps humans' longstanding love for art and words are symptomatic of the "madness gene" that Paääbo has discussed. Humans have always wanted to explore and even conquer the world—perhaps, in a related sense, they went to use art, language, and symbols to understand and interpret the world. In other words, the human desire to make art and language, and the human desire to conquer the world, are two sides of the same coin—or, put another way, the two sides of human nature.

Chapter 13 Quotes

❝ Certainly humans can be destructive and shortsighted; they can also be forward-thinking and altruistic. Time and time again, people have demonstrated that … they're willing to make sacrifices on those creatures' behalf.

Related Themes:

Page Number: 261

Explanation and Analysis

Throughout her book, Kolbert has painted a pessimistic picture of human nature. Humans are destructive and, even worse, oblivious to their own destruction. They burn fossil fuels, indirectly wiping out entire species from the oceans, and don't even realize what they're doing. At the same time, Kolbert's view of human nature isn't entirely negative. As she points out here, humans are capable of incredible acts of altruism and kindness. Indeed, humans are perhaps the only life forms on the planet who devote their time and energy to preserving other species.

In the end, Kolbert offers a nuanced, ambiguous view of human nature. Humans are destructive, but also creative. They're cruel, but they're also compassionate. They're oblivious, but they're also capable of deep understanding. Perhaps, once they're fully aware of their own role in the world's Sixth Extinction, human beings will choose to change their behavior, protect the world's endangered species, and rebuild the disintegrating ecosystems of the Earth. Kolbert doesn't guarantee that this will be the outcome, but she offers the possibility.

❝ Among the many lessons that emerge from the geologic record, perhaps the most sobering is that in life, as in mutual funds, past performance is no guarantee of future results.

Related Themes:

Page Number: 267-268

Explanation and Analysis

At the end of her book, Kolbert reiterates one of her most important ideas, that natural selection is a constant process of adaptation. Different life forms are always facing a new version of the same challenge: in the face of a changing environment, they must adapt in order to continue gaining resources and reproducing. But, as Kolbert (following Darwin) reminds her readers, even if a species has successfully survived for millions of years, the advent of a sudden environmental change could still cause that species to go extinct. There's no such thing as natural selection that makes a species better and better prepared for the future, because the nature of future change is so unpredictable that advantage can turn to disadvantage on a dime.

The most disturbing thing about this passage is that Kolbert isn't talking about ammonites, dinosaurs, or army ants: she's talking about people. While most people would disagree with the idea that human beings could ever go extinct, it seems inevitable that, at some point in the future, *Homo sapiens* will die out. Throughout *The Sixth Extinction*, Kolbert has implied that human beings need to become more aware of their own role in mass-extinction. Here, she suggests that, if the human race doesn't face the facts, it could wipe itself out, along with the rest of the life forms on the planet.

SUMMARY AND ANALYSIS

The color-coded icons under each analysis entry make it easy to track where the themes occur most prominently throughout the work. Each icon corresponds to one of the themes explained in the Themes section of this LitChart.

PROLOGUE

Our story begins with the emergence of a new species—a species that does not yet have a name, but which "has the capacity to name things."

The book begins on a note of mystery, defining human beings with the cryptic observation that they have the power to name, and yet have no names themselves. Kolbert's technique "distances" readers from their own species, allowing them to learn about the history of the human race with an open mind.

There aren't very many members of the new species, and most live in eastern Africa. The species isn't very strong, fast, or fertile—but it's exceptionally resourceful, capable of exploring many different environments, crossing oceans and deserts, and hunting different animals. Members of the species travel to Europe, where they meet "creatures very much like themselves," whom they interbreed with and then kill off.

The history of humanity is marked by both destruction and stunning achievement. The bravery required to travel across oceans and the cruelty required to kill other animals represent the two sides of human nature that Kolbert will discuss in the book.

As time goes on, the species continues to kill off different animals. Soon, the species—which now calls itself *Homo sapiens*—can be found in every corner of the Earth. Around this time, the species begins to change the atmosphere of the planet itself. In doing so, *Homo sapiens* raise the levels of the seas, killing other species and forcing many others to migrate away from their homes.

Here, Kolbert introduces the thesis that humans have begun to alter the very structure of the planet—the atmosphere, the oceans, etc. By situating humans in a long history of destruction and environmental interference, she suggests that human history is, at its most basic level, the history of how people have changed their environments.

No single species has altered the state of the planet as greatly as the *Homo sapiens*. And yet, there have been at least five other times when the planet underwent great changes that led to mass extinction; this makes the current wave of extinctions the Sixth Extinction. In this book, we'll look at the history of thirteen species, including mastodons, auks, and dinosaurs, and study why they failed to survive over time. Kolbert hopes that her readers "will come away with an appreciation of the truly extraordinary moment in which we live."

Kolbert will compare and contrast the current wave of mass-extinction with its five predecessors, showing how manmade environmental changes are unprecedented in planetary history. Notice that Kolbert doesn't advance a strong thesis about what the human race's response to mass-extinction should be; while she has her own ideas about what to do, her first priority is to convince the reader that mass-extinction is happening (which is an important project, considering that a lot of powerful people deny that humans have altered the environment in any significant ways).

CHAPTER 1: THE SIXTH EXTINCTION

The Panamanian town of El Valle de Antón, is located within a massive volcanic crater. Until very recently, golden frogs were an extremely common sight in El Valle. This species was known to be extremely toxic. Thus, when the golden frogs of El Valle began to disappear, few people saw it as a crisis.

Like the Prologue, Chapter One begins on a slightly mysterious note: what happened to the golden frogs of El Valle de Antón, a species that used to be ubiquitous in the community?

Kolbert herself found out about the golden frogs of El Valle in a children's nature magazine. The magazine said that biologists in the town were trying to build a special facility to save the golden frogs; in the meantime, they captured a few dozen frogs and kept them in a "frog hotel," where they pampered the frogs and fed them well. Around the same time, Kolbert came upon a scientific article arguing that the world was in the midst of a sixth mass extinction, which would be devastating for amphibians and many other life forms. According to the article, there had been five previous mass extinctions, the most recent of which took place during the Cretaceous period, when, famously, the dinosaurs died out. Kolbert was so struck by the article on mass extinction that she bought a ticket to Panama to learn more—surely a mass extinction, one of the rarest events in the history of life on Earth, was worth researching.

In this passage, Kolbert establishes herself as a kind of "character" in her own book. In addition to being a history of the science of extinction, The Sixth Extinction *describes some of Kolbert's travels around the world to learn about wildlife preservation and the vanishing natural world. The passage is also important because it emphasizes Kolbert's role as an "interpreter" between the scientific community and the general public. Kolbert isn't a researcher or an environmental specialist; however, she plays a crucial role—she interviews scientists and presents their ideas in a clear, understandable manner.*

In El Valle, Kolbert visits the El Valle Amphibian Conservation Center, or EVACC, which is largely devoted to saving the golden frog, or *Atelopus zeteki*, from going extinct. Edgardo Griffith, the director of the EVACC, is a young man who has spent most of his adult life studying different amphibians. Griffith claims that the world is losing frog species before people even know they exist. Though this is a tricky claim to prove, the fringe-limbed tree frog (which was discovered in 2005 and went extinct in the wild a few years later) suggests that it's possible, if not likely.

As Kolbert researches the disappearance of the golden frog, she begins to learn about the scope of the problem facing the world's frog population: many different species (not just the golden frog) are dying out, for reasons that Kolbert doesn't know yet.

The extinction of frog species is particularly noteworthy because, historically, frogs are some of nature's most resilient animals, capable of surviving in many different environments. The earliest amphibians appeared millennia ago, when the Earth's land was part of one landmass, now known as Pangaea. Today, there are at least 7,000 different frog species, which inhabit environments as different as the Arctic Circle and the Mojave Desert.

Different classes of animal go extinct at different rates, and, traditionally, frogs are an unusually resilient class of animal. Therefore, the fact that even frogs are going extinct doesn't bode well for the other plants and animals of the Earth. What, the passage implicitly asks, could be killing frogs, given that they can survive in the Arctic and the Mojave?

Why are frogs going extinct in the 21st century? One might think that frogs are disappearing in areas where many human beings live; however, frogs that live in pristine areas, where no humans live, are *also* going extinct. One of the first clues about what was killing frogs came from the National Zoo of Washington, D.C. A few years ago, the zookeepers discovered that their population of blue poison-dart frogs was dying off, thanks to an unidentified fungus called *Bactrachochytrium dendrobatidis*, or Bd, for short. Kolbert learned that the same mysterious fungus, Bd, had killed off most of the golden frogs in El Valle. Bd has also spread to Colombia, Australia, and New Zealand, decimating the frog populations.

The literal cause of the golden frogs' extinction is the arrival of Bd in El Valle. But, of course, in light of Kolbert's central concern with the impact of human activity and the ominous notion that frogs are dying where there are no humans, this passage raises the stakes beyond Bd in El Valle. It suggests that El Valle is symptomatic of a larger pattern of extinctions that is a ripple effect from human activity.

The distinction between "mass extinction" and "background extinction" is crucial to understanding the significance of mass extinction. Over millennia, scientists can expect a few species to go extinct—this is "background extinction." During a mass extinction, however, a huge number of species go extinct in a far shorter time period. One could say that the history of life on Earth consists of "long periods of boredom" (background extinction), punctuated by "panic" (mass extinction).

Here, Kolbert introduces the idea that, at different points in planetary history, the Earth's life forms have faced the threat of mass-extinction caused by changing environmental factors. Also notice the way that Kolbert alternates between passages on specific species and places (like the golden frogs in El Valle) and a more general analysis of extinction theory. Kolbert will use a similar technique throughout the book, using her investigations into specific species to illuminate her general analysis, and vice versa.

In the modern era, amphibians are the world's most endangered class of animal—they seem to be going extinct at a rate 45,000 times higher than the background rate. However, there are many other classes of life, including corals, mollusks, sharks, rays, birds, and mammals, that are going extinct at a roughly comparable speed.

Traditionally, amphibians are one of the most resilient (and, in a sense, "extinction-proof") kinds of animals. But now, it would seem, amphibians are more endangered than any other kind of animal—demonstrating that useful evolutionary traits don't always remain useful over time (a point that Kolbert will make again in later chapters).


Returning to Bd, Kolbert explores the mystery of why the fungus has spread around the world so quickly. Some argue that humans unintentionally spread Bd around the world in the 1960s, since it was an ingredient in a popular pregnancy test. Others speculate that North American bullfrogs spread Bd to other continents after human beings spread bullfrogs to Asia, Africa, and South America. In either case, the reason for the spread of Bd is the same: human travel, which has produced an "intercontinental reshuffling" that is "unprecedented in the … history of life."

Having identified Bd as the cause of frog extinction, Kolbert explores a deeper cause of this problem: humans altering their environments. Humans travel around the world, taking new microbes, fungi, and animals with them wherever they go. As Kolbert will show, humans are interfering with the natural "equilibrium" of the Earth, accelerating the process of mass-extinction.


One day, Kolbert goes with Griffith to explore the El Valle area for frogs. They drive through the rainforest and wait for night to fall (most amphibians are nocturnal). After a while, Griffith spots a San Jose Cochran frog, which he scoops up with gloves, and swabs to test for Bd. Griffith continues, swabbing many different species of frog. He brings two species back to EVACC: a blue-bellied poison frog, and a pale salamander, whose species he was unable to identify. Kolbert realizes that the two creatures Griffith took back to EVACC would never live in the rainforest again—they'd probably die in glass tanks.

Although the human race as a whole seems to be driving golden frogs (and other creatures) into extinction, there are individual human beings, like Griffith, who are trying to save species from extinction. Even so, Kolbert notes the small scale of the gesture—even if Griffith can save individual frogs from extinction, he can't preserve their natural rainforest habitat.

CHAPTER 2: THE MASTODON'S MOLARS

Extinction is one of the first scientific concepts that children learn about; when small children play with toy dinosaurs they learn that the dinosaurs died a long time ago. Strange as it sounds, a small child living in the 21st century has a better grasp of the history of life on Earth than scientists did thousands of years ago. Aristotle, for instance, wrote a long treatise on animals without considering the possibility that some animals went extinct. In the mid-18th century, when the great biologist Carl Linnaeus began taxonomizing the animal kingdom, he didn't address the possibility that some animals had died out long ago. Even today, there are some people who believe that no animals have ever gone extinct—or that the animals that went "extinct" drowned in the great flood described in the Biblical Book of Genesis.

Though the concept of extinction is relatively uncontroversial today (even children know about it), scientists only realized that animals go extinct very recently. Kolbert will study the process by which scientists introduce a new idea (for example, the idea that animals go extinct)—usually, the idea is dismissed and ridiculed at first, but eventually becomes an accepted fact. However, there are still some people who don't recognize the fact of extinction. Perhaps Kolbert's goal is to convince these people of the dangers of mass-extinction.

Scientists first proposed the concept of extinction in the late 18th century. A naturalist named Georges Cuvier studied the fossils of an animal now known as the American mastodon, or *Mammut americanum*, and concluded that all such creatures must have died out in the distant past. In his own lifetime, many of Cuvier's own ideas about extinction were harshly criticized—but now, hundreds of years later, Cuvier is praised for being ahead of his time.

Cuvier introduced the then-revolutionary idea that animals go extinct. Cuvier didn't understand why animals go extinct, meaning that he couldn't back up his idea with a detailed theory. However, Cuvier's analysis of fossils and animal remains convinced him that some of the animal species he discovered were no longer in existence, which was enough evidence to put in motion a paradigm shift in ideas about extinction.

European explorers probably discovered mastodon teeth in the early 18th century; then, in 1739, Charles le Moyne, the Baron de Longueuil, discovered mastodon bones while exploring present-day Ohio. His men carried the bones back to New Orleans, where they were shipped back to King Louis XV in France. Louis kept the mastodon bones in his museum.

One of the most important stages in scientific theory is gathering evidence. Although the explorers who traveled to Ohio probably didn't think of themselves as scientific research assistants, the fossils they discovered played a crucial role in moving scientific discourse forward.

For most of the 18th century, French scientists debated the origins of the mastodon remains. Some argued that the bones actually belonged to two or three creatures, including a hippopotamus. Other scientists proposed that the bones belonged to an entirely new animal—the "American elephant." Georges-Louis, Leclerc, Comte de Buffon, France's most famous naturalist, proposed that the remains belonged two three animals—an elephant, a hippopotamus, and a new species, which had disappeared a long time ago. Even Thomas Jefferson, a naturalist as well as a statesman, wrote a paper in which he argued that the remains must belong to an existent, undiscovered animal, probably the largest animal alive. Jefferson hoped to track down this mysterious animal somewhere in the American continent.

As the 18th century went on, it became gradually clearer that the existing theory about the world's animals—i.e., that species never appear or disappear—needed some major revisions. The mounting evidence of fossil records showed that some animals died out a long time ago. However, before Cuvier (and even afterwards, for a time), scientists and naturalists were convinced that the fossils belonged to species that were still in existence. This shows a moment when the dominant paradigm was fracturing based on evidence, clearing the way for a new theory.

Cuvier lived in Paris at the end of the 18th century, and worked as a lecturer for the Paris Museum of Natural History. On April 4, 1796, Cuvier delivered a revolutionary lecture in which he discussed the Mastodon remains from Ohio, as well as the remains of a similar creature that had been discovered in Russia. Cuvier proposed that the two sets of remains belonged to huge, elephantine creatures—two new animal species, neither one of which had survived. Cuvier called these kinds of creatures "espèces perdues," or "lost creatures." Cuvier based his theory of lost creatures on his own research into the Ohio and Russia fossils, as well as animal remains from Argentina. Finding evidence of other lost creatures among those remains, Cuvier concluded that they must have belonged to vanished species. He extrapolated these findings to conclude that there must be a huge number of species that died out over time. Cuvier did not, however, understand what could have led these lost species to die out.

Cuvier's conclusions about extinction suggest some important points about the way science works. First, notice that Cuvier based his findings on his analysis of all available evidence—the fossils from Ohio, Russia, and other places. But second, notice the "leap" that Cuvier made: instead of simply theorizing that a few fossils belonged to extinct animals, he went further, arguing that many *animals had gone extinct in the distant past. Cuvier's new theory did a better job of explaining the existing data (the fossils) than the accepted scientific theory of the era In the terminology of the philosopher Karl Popper, Cuvier's theory—like all good scientific theories—was both "robust" (explained a lot of evidence) and "falsifiable" (could be proved or disproved with further evidence).*

Kolbert meets with Pascal Tassy, the current director of the Paris Museum of Natural History. Tassy shows Kolbert the museum's vast collection of elephant, mammoth, and mastodon remains, including the mastodon teeth that Longueuil found in Ohio. Mastodon teeth are huge and brownish, but they have the same basic structure as human teeth; dentin, surrounded by brittle enamel. Tassy also shows Kolbert the "Maastricht animal," a famous fossil that Cuvier identified, correctly, as belonging to an extinct marine reptile (now known as the mosasaur).

Many of the fossils that Cuvier examined hundreds of years ago are still located in the same place—the Paris Museum of Natural History. Furthermore, notice that, in those hundreds of years, Cuvier has gone from a controversial, revolutionary figure to a celebrated scientific hero.

Cuvier's lectures at the Museum popularized the theory of extinction. However, Cuvier needed to find more fossils to bolster his claim that the Earth was once full of now-extinct species. Cuvier investigated the quarries surrounding Paris, eventually identifying twenty-three new species that he believed to be extinct. Cuvier traveled around Europe, exhibiting his fossils with a showman's theatricality. One of Cuvier's most famous discoveries was the pterodactyl, which he correctly identified as an extinct flying reptile.

Even after he developed his theory of extinction, Cuvier continued to move the scientific discourse forward. First, he continued to travel around the world, searching for more extinct species that could prove his controversial theory. But second, and perhaps more importantly, Cuvier made an effort to popularize his theory for the general public—a crucial part of the process by which a scientific theory becomes accepted.

The theory of extinction was particularly popular in the early United States, owing partly to the influence of Thomas Jefferson. Jefferson's close friend, Charles Willson Peale, established a natural history museum in Philadelphia, where he displayed many notable fossils discovered in North America. Peale arranged for fossils to be reconstructed at the museum—one of these, an American mastodon, was dubbed a "mammoth" because of its size. The popularity of the so-called "mammoth" (technically, a mastodon) sparked a national vogue of foods and taverns named after the creature. In 1806, Cuvier published a paper in which he officially named the creature a "mastodon"—however, the name "mammoth" had caught on by that time, creating a lasting confusion between the two terms. Later, scientists discovered another extinct, elephantine creature, and named it the "mammoth," further increasing the confusion.

Kolbert studies the way that extinction theory was received in the United States. Within only a few years, it seems, the general public had accepted Cuvier's theory. However, neither Cuvier not the general public understood why *the mastodon and other species went extinct in the first place—it would take a long time before scientists understood that humans played a decisive role in the mastodon's extinction. Notice, also, that the lasting confusion between mammoths and mastodons (which are two different animals) reflects the difficulty of popularizing technical and complex scientific theories.*

Toward the end of his life Cuvier became a hero throughout Europe and the U.S.—scientists accepted his theory of extinction, and wealthy aristocrats took up "fossil hunting" as a hobby. One fossil hunter discovered the remains of a huge, lizard-like creature, the ichthyosaur. Slowly, scientists began to notice a pattern with fossils—the older the fossil, the deeper in the earth it was likely buried (fossils discovered near the surface likely belonged to non-extinct animals).

Even though Cuvier had been a controversial figure as a younger man, he died a popular, respected scientist. Like all important scientists, Cuvier's ideas paved the way for further ideas—for instance, the "fossil craze" that Cuvier sparked led scientists to realize that older fossils were buried deeper, an insight that allowed them to estimate the fossils' ages.

Strangely, Cuvier's theories of extinction blinded him to the existence of biological evolution. He noticed that animals' bodies were perfectly calibrated to their diet and habitat—for example, horses have hooves, rather than claws, since they are herbivores that don't need to hunt other animals for food. Based on his observations, Cuvier concluded that it was impossible for animals to mutate or evolve over time, since even the tiniest changes in an animal's body would prevent it from surviving. Cuvier's great rival was his colleague at the Museum of Natural History, Jean-Baptise Lamarck. Lamarck proposed that animals could slowly change their own bodies over time—for example, he argued that giraffe's necks were long because giraffes had spent millennia reaching for leaves in tall trees. Cuvier ridiculed Lamarck's theories, citing the remains of ancient Egyptian cats as proof that animals today are no different from animals thousands of years ago.

Even though Cuvier's ideas represented an important step forward for science, Cuvier couldn't see the big picture. This goes to show that paradigms fracture and evolve gradually—important leaps forward in knowledge can be accompanied by the remains of outdated and false ideas. It's also important to note that Cuvier's "refutation" of Lamarck's theory of evolution (based on the similarity between modern and ancient Egyptian cats) was based on evidence. Even when his ideas were wrong, Cuvier was using the scientific method to advance them. Science, in other words, is a human process that is not infallible.

Cuvier had determined that some species went extinct over time. But he still needed an explanation for why this happened. At first, he proposed that one great disaster in the distant past had wiped out species simultaneously. Later, after fossil hunters had identified distinct "layers" of fossils, he changed his mind and argued that there had been multiple cataclysmic events that led to multiple extinctions. In 1812, Cuvier wrote an influential essay about the possibility of ancient, cataclysmic events. Although Cuvier made a point to cite multiple religious texts in his essay, the predominately Anglican staff of Oxford and Cambridge ensured that, when the essay was translated into English, it favored a Christian interpretation. In this way, Cuvier's research was used to "prove" the existence of Noah's flood.

Cuvier didn't understand why animals go extinct over time, but he tried to develop an explanation: natural disasters wipe out certain species. The reception of Cuvier's theory is a good example of how the general public sometimes distorts scientific theories into pseudo-science designed to support a specific ideology. The attempt to use Cuvier's secular, neutrally phrased ideas to support the Christian Bible's account of the Great Flood shows the messiness of shifting between paradigms—theories arise that conflate and garble existing knowledge and myth.

Many of Cuvier's ideas have been debunked, wholly or partially—for example, he believed that there was a mass-extinction just before the beginning of recorded history, which is untrue. However, his basic idea that species go extinct over time paved the way for future research. Interestingly, Cuvier pointed out that the American mastodon went extinct about 13,000 years ago, which is correct. However, though he thought this was due to floods or other large natural disasters, the mastodon probably went extinct because human beings hunted it to extinction.

As scientists in the 19th century continued to learn more about prehistoric animals and extinction, they didn't recognize the decisive role that human beings played in the extinction of other life forms. Indeed, scientists didn't fully grasp that human beings were responsible for the Sixth Extinction until just a few decades ago.

CHAPTER 3: THE ORIGINAL PENGUIN

In 1832, William Whewell, president of the Geological Society of London, coined an important word: "catastrophist." While this word has taken on some new meanings since 1832, Whewell didn't mean it as an insult: a catastrophist, as he understood it, was a scientist who believed that the history of the planet was characterized by sudden, global catastrophes that caused large numbers of species to go extinct. The opposite of catastrophism is uniformitarianism, which is closer to Darwin's idea of species and landscape gradually changing in tandem.

As scientists became aware of extinction, they developed many theories about what caused extinction. These theories can be divided into two main camps: uniformitarianism and catastrophism. Contemporary scientists argue for a mixture of the two theories—in essence, that extinction is generally a uniform process until an era of mass-extinction, when it becomes catastrophist.

One early "uniformitarian," an associate of Whewell's, was the geologist Charles Lyell. Lyell was an Oxford-educated scientist who'd been friendly with Cuvier. Lyell studied the rocks of Paris, Italy, and England, and found no evidence that there had been a global catastrophe that caused species to go extinct—all the evidence pointed to a slow, gradual process of erosion in the planet's geological structure. Lyell proposed that, while some species certainly went extinct, extinction was a slow, gradual process, not a sudden, catastrophic mass-death. Lyell was a popular lecturer and author who toured the U.S. popularizing his ideas about geology.

Like Cuvier, Lyell was a great scientist. He was also a talented publicist who took pains to popularize his theories with the general public in the United States. Lyell's ideas about the slow, gradual nature of geological and biological change proved to be very influential—indeed, scientists have only begun to take a more catastrophist view of planetary history in the last few decades.

One of Lyell's most important readers was Charles Darwin, who was in his early twenties at the same time that Lyell was a major figure in the scientific community. Darwin sailed onboard the HMS Beagle, where he worked as a scientific researcher in the Galápagos Islands, among other places. After returning from his long voyage, Darwin began to develop his famous theory of evolution to explain the existence of some of the strange animals he'd encountered. Throughout this influential and historic voyage, Darwin was a prodigious reader of Charles Lyell's writings.

Lyell's notion that the history of the Earth is a history of slow, steady, and gradual change proved very influential for a young Charles Darwin. This adds complexity to Kuhn's theory of paradigm shifts. The relationship between Lyell and Darwin was one of direct influence more than it was a dramatic rupture in worldview. Indeed, scientific progress often happens at a more incremental level than the paradigm shift—it's often the accumulation of minor discrepancies, rather than a watershed discovery, that fractures a paradigm.

Although Lyell was an important advocate for the principle of gradualism in geology—he believed that the geological world was changing in small, almost immeasurable ways—he didn't believe in any theory of evolution. Darwin disagreed with Lyell, and proceeded to apply Lyell's principles of gradual change to life, not just geology. Darwin argued that there could be no extinction without the origin of *new* species. Life forms on Earth, he argued, were constantly in competition for the limited resources of food, water, and shelter. Species went extinct because *other* species had qualities that made them superior at finding food and shelter and, ultimately, reproducing. By the same logic, *new* species must appear over time, either surviving because of their superior qualities or dying out. Darwin argued that the origin of species was an incredibly drawn-out process, lasting many thousands of years. No human being had ever witnessed the origin of a new species, because it took so long—thus explaining why Cuvier's examination of fossilized cats didn't necessarily disprove evolution.

Darwin completed Cuvier's theory of extinction by arguing that, if some animals went extinct over time, then other animals must appear over time. Darwin's theory of natural selection was revolutionary because it was based on the premise that there are too many species competing for too few resources. Where many of Darwin's contemporaries conceived of the natural world as a peaceful, tranquil place, Darwin saw nature as a battleground—different species were racing against the clock to reproduce and avoid extinction. Darwin's gradual model of natural selection explains why Cuvier's objections to the theory of evolution were invalid—natural selection takes many tens of thousands of years, which explains why modern cats and ancient cats look the same.

Kolbert visits the Icelandic Museum of Natural History to learn about the great auk, an extinct bird that probably died out in the mid-19th century. At the Museum, she sees fossils belonging to the great auk, or *Pinginius impennis*. The great auk was a large bird, almost three feet tall, that resembled a penguin—it had tiny wings, and couldn't fly. It once lived in places as different as Norway, Italy, and Florida (the region now known as Newfoundland was once full of great auks, too). Great auks were excellent swimmers, and spent most of their life in the water. However, human beings hunted great auks into extinction. In America, for example, Native American tribesmen and, later, European fisherman, used auks for food and fuel.

Charles Darwin believed that no human being had ever witnessed the emergence of a new species, but this chapter demonstrates that humans have, at the very least, witnessed the extinction of an old species without even realizing it. The story of the auk, in a sense, supports Darwin's notion of nature as a battlefield for resources, though Darwin did not devote much time to the idea that one species might exploit another species out of existence.

The final home of great auks was probably the Icelandic island of Eldey. Kolbert traveled there, where she saw huge numbers of gannets—long-necked, cream-colored birds. 150 years ago, fishermen regularly rowed out to the island, where they would encounter great auks. Rumor has it that in 1844, three fishermen rowed to Eldey, where they found the last two great auks on the planet. The fishermen chased the birds around the island, and eventually captured them. In the chase, they broke an auk egg that the two birds had been guarding. Instead of eating the two dead auks, the fishermen sold their catch to an Icelandic dealer, who in turn sold the birds' remains to a naturalist. Fifteen years later, two naturalists named John Wooley and Alfred Newton went to Iceland to track down the great auk, only to realize that it had gone extinct. Newton spent the rest of his life campaigning for the preservation of sea birds, and eventually succeeded in lobbying for a bill to protect these creatures—one of the first wildlife protection laws in world history.

Alfred Newton is an important figure in the history of science, because he was one of the first scientists to recognize that humans could play an important role in preserving endangered species, such as sea birds. However, Newton probably didn't understand the extent to which human beings were responsible for mass-extinction—he wanted humans to help preserve endangered wildlife, but didn't realize that human beings caused wildlife to become endangered in the first place.

Around the same time that Newton and Wooley were returning from their journey to Iceland, Charles Darwin was publishing a revolutionary paper on the process of natural selection. Darwin's ideas immediately impressed Newton, and later in life they became friends. Personally, Darwin had encountered the phenomenon of human-caused extinction during his time in the Galápagos Islands. In 1835, Darwin first encountered the Galápagos tortoises, and learned that their population was shrinking at an alarming rate, due to the whalers and fishermen who ate the tortoises. Less than ten years later—by which time Darwin was back in England, Galápagos tortoises had gone extinct. In his most famous book, *The Origin of Species*, Darwin notes that species become rare before they go extinct, and briefly alludes to human-caused extinction.

Charles Darwin seems to have understood that humans could play a role in the extinction of a species—for instance, he noticed that human beings in the Galápagos Islands were overhunting the native tortoises, causing them to die out quickly. However, Darwin, for all his brilliance, didn't see the "big picture"—he didn't realize that human beings were responsible for the extinction of hundreds of different animals.

Although Darwin was clearly aware of human-caused extinction, he seems not to have found it a serious or troubling phenomenon. Darwin conceived of human beings as, fundamentally, subject to the same laws of natural selection as all other animals. He even recognized that human intelligence was just an evolutionary adaptation, similar to a lion's claws or a finch's beak. And yet, Darwin seemed not to understand that humans *were* unique among animals in one way: they were the only animals who caused other animals to go extinct. Furthermore, the fact that humans could cause other animals to suddenly go extinct suggested that Cuvier was right—cataclysmic events played a major role in extinction.

Darwin conceived of natural selection as a gradual, steady process, rather than a sudden, catastrophic, manmade mass-extinction. Perceptive as he was, he did not anticipate the paradigm shift towards catastrophism. This passage is also important because it introduces the theme of human nature. Implicitly, Darwin took a conservative view of human nature, arguing that humans were, for practical purposes, no different than any other kind of animal. Kolbert, however, argues that humans are fundamentally different from other species—they alter their environments and cause other species to die out.

CHAPTER 4: THE LUCK OF THE AMMONITES

A hundred miles north of Rome, there's a small town called Gubbio. Gubbio is notable for its beautiful limestone; indeed, there is a massive limestone gorge with steep, smooth walls. It was here, in the 1970s, that a geologist named Walter Alvarez discovered the traces of a huge asteroid—the asteroid, which, scientists later decided, hit the Earth during the Cretaceous period, causing the mass-extinction of the dinosaurs.

The most famous extinction in history is the extinction of the dinosaurs millions of years ago. While many schoolchildren grow up hearing that an asteroid killed the dinosaurs, such a theory was controversial only forty years, and unheard of half a century ago.

Walter Alvarez had come to Italy to study plate tectonics. Beneath the surface of the earth, he found layers of marine fossils. Yet, curiously, he also noticed that there were thick layers of clay, containing no fossils, imbedded in the limestone of Gubbio. Back in California, Walter Alvarez's father, Luis Alvarez (a Nobel Prize-winning scientist himself), suggested that Walter test the layers of clay for iridium, a radioactive element. Walter found that clay contained huge amounts of iridium, suggesting that the clay may have originated in an asteroid. Further tests showed that there were thick layers of iridium dating back to the end of the Cretaceous period. In 1980, Luis and Walter Alvarez co-wrote an influential paper arguing that an iridium-rich asteroid struck the Earth at the end of the Cretaceous era, killing the dinosaurs.

Walter and Luis Alvarez originated the now-popular theory that the dinosaurs were wiped out by an enormous asteroid that struck the Earth in the Cretaceous period. The asteroid is a classic example of the kinds of global catastrophe that are central to the catastrophist interpretation of extinction. It's also an example of the process of paradigm shift—new evidence emerged (iridium in clay) that suggested a completely different version of events from what was previously believed, and the Alvarezes created a theory that explained the new evidence.

From the beginning, biologists and paleontologists rejected the Alvarez theory of mass-extinction. They pointed out that extinction is a slow, gradual process, not the result of a sudden catastrophe like an asteroid collision. For more than a hundred years, scientists had known about sudden discontinuities in the fossil record, particularly the marked decrease in the number of fossils in soil layers corresponding to the end of the Cretaceous period. However, most scientists explained this decrease by positing that paleontologists would eventually discover more fossils from the period. Few scientists believed that there had been a sudden, global change at the end of the Cretaceous era—on the contrary, they took a uniformitarian view of the distant past.

Like many ideas that would ultimately prove to be powerful explanations of natural history, the Alvarezes' theory of the dinosaurs' extinction was initially met with disdain and indifference. However, the asteroid theory was strong because it offered an elegant explanation for a longstanding problem—the "fossil gap" that coincided with the extinction of the dinosaurs. The asteroid theory killed two birds with one stone—it explained why certain layers of the Earth were rich in iridium, and it explained what happened to the dinosaurs at the end of the Cretaceous period.

In spite of the unpopularity of the Alvarez theory, evidence continued to build that an asteroid had hit the Earth long ago. The first important piece of supporting evidence was the discovery of "shocked quartz" — quartz that has been exposed to sudden changes in pressure — that dated back to the end of the Cretaceous era. The next clue was the discovery of a layer of sandstone, seemingly caused by a huge tsunami wave that dated back to the same period. Finally, scientists uncovered an enormous crater in present-day Mexico, in which there were layers of melted rock from the end of the Cretaceous era.

Like all good scientific theories, the Alvarez theory of dinosaur extinction was "falsifiable," meaning that further evidence could be offered to support or disprove the theory. In the decades following the appearance of the theory, new evidence surfaced that seemed to support the Alvarezes. As a result, the scientific community came to accept the asteroid theory.

Kolbert meets with Neil Landman, a paleontologist who specializes in ammonites, or *Discoscaphites iris* (prehistoric, nautilus-like creatures). Landman shows Kolbert a fossil site near Princeton, New Jersey. There is a thick, iridium-rich layer of rock and soil at the site, along with hundreds of ammonite fossils.

Kolbert's travels to Princeton are important because she sees, first-hand, the consequences of a sudden global catastrophe. The ammonites used to be a successful, flourishing species; after the asteroid hit, however, their useful evolutionary qualities proved to be liabilities.

Ammonites were spiral-shaped mollusks, although there is some debate about what, exactly, they looked like (some scientists argue that ammonites had long tentacles, but Landman maintains that they did not). Ammonites probably evolved their distinctive spiral shells because the shells were capable of withstanding intense water pressure. The ammonite species may have existed for many millions of years, and ammonite fossils can be found in many different parts of the world.

Ammonites had many evolutionarily useful traits. They could swim in the ocean, and they had thick, durable shells that allowed them to survive in many different temperatures and pressures. For many millions of years, ammonites survived; however, the sudden global catastrophe was too dramatic and rapid for the ammonites to prevail.

In their paper on the extinction of the dinosaurs, the Alvarezes argued that the true killer wasn't the asteroid itself; it was the dust that the asteroid threw into the Earth's atmosphere. The dust—or, to use the scientific term, "bolide"—was extremely hot, and it moved around the Earth at a phenomenal speed, blotting out the sun and either scorching or smothering most of the planet's population. Large creatures like the dinosaurs were the first to go, followed by sea creatures and mammals. The mass-extinction of the dinosaurs brings up the concept of "preservation potential"—a way of measuring the likelihood that a species will go extinct. Scientists can approximate a species' preservation potential by measuring its population, the number of different places where the species lives, and the overall composition of the species (e.g., thick-shelled mollusks have a higher preservation potential than hollow-boned birds).

One reason that it's hard to measure the preservation potential of a species is that it's almost impossible to predict the likelihood of different catastrophic events. Thus, an ammonite might seem to have a very high preservation potential, because its shell is thick and strong. However, the arrival of a sudden catastrophe like an asteroid would immediately lower the ammonite's preservation potential (and, indeed, ammonites went extinct after the asteroid struck). This points to the tremendous uncertainty and vulnerability surrounding mass extinction.

Back in New Jersey, Kolbert watches Landman and his peers investigate the ammonite fossil site. Landman explains to Kolbert that, during the dinosaurs' extinction, the ammonites died out very quickly. But, oddly, nautiluses—probably the animals that most resemble ammonites—survived and still exist today. Why the difference? Landsman speculates that ammonites produced small eggs that grew into tiny, weak infant ammonites. Nautiluses, by contrast, lay large, robust eggs that can survive sudden changes in temperature or water pressure.

This passage shows the vagaries of natural selection. While some people have interpreted the theory as suggesting linear progress in which nature consistently selects the "best" traits, the story of the ammonites and nautiluses shows that natural selection is more random than that. The mass-extinction at the end of the Cretaceous period turned the small, fragile ammonite eggs—once evolutionarily advantageous for their mobility—into a liability that made the species extinct.

The survival of the nautiluses brings up an important point: every single life form on the planet today is descended from a species that survived the dinosaurs' extinction. However, the fact that today's species are descended from species that survived a past extinction does not mean that modern animals are "extinction-proof." On the contrary, the rules of survival are constantly changing—a creature that survives one mass-extinction might not be able to survive another. The ammonites, for example, had a high preservation potential leading up to the dinosaurs' extinction (because they laid small eggs that drifted throughout the ocean, increasing the number of places where ammonites lived), However, due to sudden changes in their habitat, ammonites' evolutionary advantages became huge disadvantages.

Kolbert's analysis of the Alvarezes' theory of the dinosaurs' extinction exemplifies the differences between catastrophism and uniformitarianism. Crucially, it also demonstrates that the two theories can coexist. For many millions of years, ammonites, dinosaurs, and other animals had competed in the slow, gradual process of natural selection. But the arrival of an asteroid altered the natural selection process, making it almost impossible to survive on the Earth. This shows a melding of two paradigms that seemed, at one time, to be at odds—another way that scientific thought can evolve.

CHAPTER 5: WELCOME TO THE ANTHROPOCENE

In 1949, there was a famous experiment in which students were asked to name a series of playing cards as the experimenters flipped them face-up. Some of the cards had been doctored—for example, there was a red six of spades (instead of the usual black card). When experimenters showed the cards quickly, students misread the cards; when they showed the cards more slowly, students were more likely to recognize their mistakes. The experiment proved to be an important influence on the thinking of the great science historian Thomas Kuhn. Kuhn argued that, throughout history, human beings are forced to adapt to changing environments. At first, they try to respond to their new environment using the same strategies and coping mechanisms they've already learned. But eventually, humans learn new strategies for living in their new environment—in brief, a new "paradigm" for survival.

Kolbert introduces the ideas of Thomas Kuhn, the science historian who first proposed the concept of the "paradigm shift." Although Kolbert's book is about the history of mass-extinction, it's also about the scientific process in general. Kuhn's work is an important tool for analyzing the different ways that scientists have conceived of mass-extinction in the last 250 years: again and again, a controversial scientist will introduce a new idea, or paradigm, and the paradigm will gradually become an accepted part of the scientific community.

Kuhn's ideas about paradigms and "paradigm shifts" are a good lens through which to study the history of evolutionary science. Leading up to every major biological discovery, there is an awkward transition period, in which scientists try to explain new phenomena using old rules. For example, when scientists studied the first fossils, they tried to argue that these fossils belonged to living species; it took Cuvier to introduce the new paradigm: some animals go extinct. The same is true of uniformitarianism: for a century, scientists tried to explain the "gap" in fossil layers by citing the old paradigm that species gradually go extinct. It took the Alvarezes, with their theory of an asteroid that wiped out the dinosaurs, to introduce the new paradigm of mass-extinction. Today, most scientists believe that species *usually* go extinct gradually, except when there's a sudden, catastrophic event, in which case many species go extinct very quickly.

Kolbert applies Kuhn's ideas to some of the science history she discussed in the previous chapters. Over time, scientific understanding of extinction has gone through a series of new paradigms, such as uniformitarianism, catastrophism, and the contemporary, hybrid paradigm of uniformitarianism-catastrophism. Over time, Kolbert seems to believe, the science of extinction has become more accurate; however, Kuhn's theories would imply that a new, more accurate paradigm of extinction science might come along in the future.

Kolbert travels to a cliff called Dob's Linn, located in the Scottish Highlands. There, she meets with a stratigrapher (a scientist who studies the different eras of planetary history) named Jan Zalasiewicz, who shows her layers of rock dating back 445 million years to the era immediately following the extinction of the dinosaurs. During this era, the Ordovician era, sea life grew rapidly and the first coral reefs were formed. Midway through the Ordovician era, moss-like plants appeared on land. But at the end of the era, almost all the life in the oceans—perhaps 85 percent—went extinct.

By interviewing Zalasiewicz, Kolbert picks up where she left off in the previous chapter: after the extinction of the dinosaurs some forms of life, including coral and moss, survived and flourished. But the extinction of the dinosaurs was not the only mass-extinction in global history—there were other, more recent mass-extinctions that eliminated the vast majority of life on Earth. This reinforces the catastrophism-gradualism paradigm, in which gradualist periods are interrupted by catastrophic events.

Zalasiewicz's specialty is the graptolite—a kind of marine animal that lived in a large colony of tubular shells. Graptolites used to be some of the most common creatures in the ocean; their long, thin, V-shaped bodies were strong and resilient to changes in temperature and pressure. Around 444 million years ago, something must have happened to make the graptolites' V-shaped bodies an evolutionary disadvantage.

Kolbert continues to use Darwin's ideas to analyze mass-extinction. For example, she writes about the graptolite's useful evolutionary traits, such as its strong, V-shaped body. The natural question raised by this is why the graptolite's evolutionary advantages became disadvantages.

After the Alvarezes published their paper on the asteroid that wiped out the dinosaurs, scientists slowly began to rethink their ideas about extinction. If an asteroid could explain one "fossil gap," perhaps other catastrophes could explain other fossil gaps. Some scientists argued that the periodic gaps in the fossil record could be explained by the presence of a small "companion star" that periodically showered comets on the Earth's surface, destroying almost all life. However, scientists haven't been able to back up this thesis with much empirical evidence.

Like Cuvier and Darwin, the Alvarezes influence on science extended far beyond the original scope of their project. Inspired by the Alvarezes theory of mass-extinction, other scientists argued that the extinction of the dinosaurs wasn't at all unique; there were many other mass-extinctions in the Earth's history. As Kolbert admits, there is relatively little evidence to explain the other mass-extinctions in the Earth's history—extinction is such a new scientific concept that scientists will have to gather a lot more evidence before they can develop satisfactory theories of mass-extinction.

At the moment, the most common theory of the mass-extinction that took place at the end of the Ordovician era is that glaciation killed many species. Around this time, carbon dioxide levels in the atmosphere dropped, causing temperatures to fall. Sea levels went down, wreaking havoc on marine life. While it's not clear why carbon dioxide levels went down so quickly, there's some evidence to suggest that the mossy plants that had appeared on land earlier in the Ordovician era drew the carbon dioxide out of the atmosphere—meaning that, in short, the mass-extinction of marine animals was caused by plants.

Kolbert acknowledges openly that scientists aren't particularly confident in their theory of the Ordovician mass-extinction; however, the most likely theory at the moment is that plants consumed too much of the Earth's carbon dioxide. The uncertainty surrounding the Ordovician extinction should alert readers to the possibility of the eventual emergence of a radical new theory that better explains this period. However, Kolbert is comfortable giving readers the most complete theory that currently exists with appropriate disclaimers.

Scientists have also argued that there was a mass-extinction about 252 million years ago, caused by a sudden *increase* in carbon dioxide levels in the atmosphere. The average ocean temperature went up by some 18 degrees, water became more acidic, and the amount of oxygen in the water decreased, suffocating many species. As a result, about ninety percent of the world's species went extinct. It's likely that the increases in temperature also triggered the growth of poisonous bacteria, accelerating the extinction process. In general, it appears that each mass-extinction is a little different than the one before it. There is no general theory of mass-extinction; instead, there are multiple ways for many species to go extinct simultaneously.

Although each mass extinction is unique, Kolbert's description of the mass-extinction that took place 252 million years ago parallels her discussion of the current Sixth Extinction: then and now, the carbon dioxide concentration of the atmosphere increased, threatening the many different life forms that rely on oxygen to survive. The point that mass-extinctions are all different is an important one, because it stresses that periods of mass-extinction are defined by what happens to species, rather than the specific nature of environmental change. This means that the current period, though distinct in its specifics from all other mass-extinctions, should still be considered a mass-extinction.

During Kolbert's time in Scotland, she learned about Zalasiewicz's theory of giant rats. In the future, Zalasiewicz argues, rats will take over the planet; they'll reproduce, growing larger and more powerful. While such an idea seems implausible, it's undeniable that humans have rearranged the world's ecosystems, and wherever humans go, rats follow—for example, when European explorers sailed to Australia, China, and South America, rats snuck aboard their ships, and adapted to their new homes. The result is that rats are among the most resilient creatures on the planet, and it's likely that, in the event of a mass-extinction, rats will survive.

The implication of this passage is that, at some point in the future, human beings will go extinct, due to the changing composition of the Earth's atmosphere (changes that humans played a major role in causing). Zalasiewicz's rat theory relies on the idea of "preservation potential," which suggests that rats (because of their ubiquity across the globe) would be capable of surviving calamity. However, readers should be a little skeptical of this, considering that other species with high preservation potential (like the ammonite) have gone extinct.

The premise of Zalasiewicz's theory of giant rats is that humans have ushered in a new era of mass-extinction. The most popular term for the "age of humans" is Anthropocene. Paul Crutzen, the scientist who coined the term in 2000, argued that humans have fundamentally changed their planet in several ways: 1) humans have majorly transformed almost half of the world's land surface; 2) humans have either damned or diverted the majority of the world's rivers; 3) human agriculture has dramatically increased the amount of nitrogen in the atmosphere; 4) humans have eliminated more than a third of the primary marine life of oceans' coastal waters; 5) humans consume more than half of the world's available fresh water; 6) humans have dramatically changed the composition of the Earth's atmosphere by releasing carbon dioxide and methane gas. On the basis of these six points, Crutzen argued that humans have brought about a new epoch in the Earth's history. Moreover, Crutzen argued that the result of these manmade changes in the environment will be a new mass-extinction.

In this important passage, Kolbert lays out the case that human beings have altered their planet in important, fundamental ways. A further implication of Crutzen's Anthropocene theory is that human beings' defining characteristic—the essence of human nature—is their ability to change their environments. Notice that Crutzen developed his ideas about the Anthropocene very recently—for most of the history of science, human beings weren't fully aware of how greatly they could shape their own planet. Now, by contrast, it is human activity that, perhaps, defines this geological era on Earth.

Zalasiewicz is one of the most vocal notable supporter's of Crutzen's Anthropocene argument. Shortly before Kolbert visited him in Scotland, he lobbied the ICS (International Commission on Stratigraphy) to recognize the Anthropocene as an official epoch of the Earth's history. If he's successful, "every geology textbook in the world immediately will become obsolete."

Crutzen's ideas about the Anthropocene—and, indeed, the idea that humans are capable of fundamentally altering the planet—are so recent that many people don't believe them at all. Figures like Zalasiewicz (and Kolbert, too) play an important role in introducing the new paradigm to the public.

CHAPTER 6: THE SEA AROUND US

There is a small island in the middle of the Tyrrhenian Sea called Castello Aragonese. The island formed many millions of years ago, due to the pressure between the African and Eurasian tectonic plates—a phenomenon that sometimes causes the release of carbon dioxide gas. Kolbert travels to Castello Aragonese in the winter in order to investigate the carbon dioxide levels of the surrounding waters.

In the previous chapter, Kolbert brought up an important topic: the effect of atmospheric carbon dioxide levels on the Earth's oceans. In this chapter, she'll study the topic more closely. Castello Aragonese, because it is close to a tectonic plate, is a kind of "crystal ball" for scientists—the state of marine life there suggests what the oceans will look like in half a century.

At Castello Aragonese, Kolbert meets two marine biologists named Jason Hall-Spencer and Maria Cristina Buia. Buia and Hall-Spencer take Kolbert scuba diving and they show her the huge green bubbles rising from the vents in the sea floor. Near the vents, there is very little sea life.

Right away, the marine life at Castello Aragonese doesn't look very healthy: the high levels of carbon dioxide in the water seem to be interfering with life (for reasons we don't fully understand yet). If Castello Aragonese is a "crystal ball," the future doesn't look good.

Since the Industrial Revolution began in the early 19th century, human beings have burned huge quantities of fossil fuels (like coal, oil, and natural gas), a process that has added many billions of metric tones of carbon to the atmosphere. Humans have also cut down many trees, further increasing the amount of carbon in the air. At the current rate of growth, Kolbert asserts, humans can expect the carbon dioxide concentration of the atmosphere to become double what it was before the Industrial Revolution began. The average world temperature could increase by as much as seven degrees Fahrenheit, melting the world's glaciers and dramatically changing the marine environment. The changes in temperature and sea level could then trigger further changes for the world's ecosystems. The increase in carbon in the atmosphere is also tied to increased acidity of ocean water—indeed, ocean water is almost thirty percent more acidic than it was in the year 1800, and by the year 2050, Kolbert predicts, it will be 150 percent more acidic than it was in 1800.

One of the most important ways that human beings alter their environment is by burning fossil fuels. Indeed, the burning of fossil fuels has been a fixture of civilization since the Industrial Revolution (when scientists realized that burning coal could power a steam engine, and, later, that gasoline could power an internal combustion engine). Operating under an old paradigm, scientists believed that burning fossil fuels didn't alter the Earth's atmosphere in any major way; under the new paradigm, however, it seems clear that humanity's fuel consumption will have major ramifications for the temperature and acidity of the oceans.

Back on land, Hall-Spencer and Buia show Kolbert some of the animals they've rescued from the ocean, including a starfish with a missing arm, and a large sea cucumber. The carbon dioxide-emitting sea vents of the ocean have eroded the shells of many sea creatures, considerably endangering their survival. In the waters surrounding Castello Aragonese, one can determine how close a sea creature lived to a carbon dioxide vent based on the erosion in its shell—the more erosion, the closer it lived. Furthermore, Hall-Spencer and Buia can study the sea-life near a carbon dioxide vent to predict what the Earth's oceans in general will be like in another century. Based on the data at Castello Aragonese, entire ecosystems, comprising many different species, will vanish.

The most immediate impact of increased oceanic acidity on marine life is the erosion of sea creatures' shells. Much like the ammonites in the previous mass-extinction, mollusks used to have a huge evolutionary advantage (their shells kept them safe), but now they seem to be at an evolutionary disadvantage (their shells erode easily). While humans aren't directly responsible for the high acidity of water in Castello Aragonese (natural vents add carbon dioxide to the water), they're responsible for the overall, rapid acidification of the oceans.

In 2008, Hall-Spencer wrote an influential paper on the acidification of the oceans; since that year, there's been considerable interest in the topic. Other scientists and research projects have confirmed Hall-Spencer's basic point: carbon dioxide emissions will greatly decrease the quantity and variety of life in the oceans. Many small bacteria and plankton will thrive in the newly acidic oceans, consuming more nutrients and depriving larger creatures of nutrition. Acidification probably played a large role in at least two of the "Big Five" mass-extinctions, and it will probably play a major role in the sixth.

Again, notice how recent the scientific articles on ocean acidity are—only a decade old. The notion that human beings have the power to acidify the oceans is still unfamiliar to the average person. Therefore, it's the duty of science writers like Kolbert to publicize this important information. Also, notice that increased acidity won't kill all *life in the oceans; as with previous mass-extinctions, some creatures will thrive in their new environment, while others will die out.*

Ocean acidification is dangerous for many reasons. It deprives large animals of nutrition, interferes with photosynthesis, and wipes out existing ecosystems. One group of creatures that will be particularly harmed by acidification is calcifiers, or creatures that build themselves calcium shells (e.g., clams, oysters, sea urchins, barnacles, and starfish). Acidification wears away at marine animals' calcium exteriors, which Kolbert compares to "trying to build a house while someone keeps stealing your bricks."

Calcifiers are some of the most common animals in the sea, which means that, if the acidity of the oceans continues to rise, a significant chunk of the animals that live in the oceans will die out or have to adapt rapidly to their changing environments. A clam that cannot form a thick, durable shell will not be able to survive for very long—therefore, it's possible that clams will go extinct.

In general, carbon dioxide emissions are particularly deadly for ocean life because oceans absorb about a third of the carbon dioxide that humans pump into the atmosphere. The problem, Kolbert argues, isn't so much that humans have added carbon dioxide to the ocean (carbon dioxide is always entering the ocean in some form), but that they've added it to the ocean *quickly*, effectively "running geologic history … at warp speed." If humans continue at their current rates, the Anthropocene epoch will be one of the most "cataclysmic" events in planetary history.

There is nothing unprecedented about the projected acidity of the oceans—as Kolbert says here, the oceans have experienced growing and declining acidity at many points in the history of the planet. Kolbert's point is that humans are increasing the acidity of the oceans quickly*—so quickly, in fact, that species don't have enough time to adapt to their changing environments.*

CHAPTER 7: DROPPING ACID

At the southernmost tip of the **Great Barrier Reef** in Australia, there's a place called One Tree Island (which actually has many trees). On the island, there's a small research station affiliated with the University of Sydney. In the station, teams of scientists from around the world study the chemical composition of the nearby coral reefs.

Continuing the themes of the previous chapter, the research facilities at One Tree Island measure the changing biodiversity of the oceans; as we'll see, scientists have determined that biodiversity is falling at an alarming rate.

The first Europeans to see the **Great Barrier Reef** were Captain James Cook and his crew in 1770. Cook had never seen a coral reef before, and he didn't understand how it was formed. More than half a century later, Charles Darwin visited a coral reef in Tahiti, and concluded that it was really a large atoll (i.e., a ring-shaped coral structure) that had become submerged in water due to rising sea levels. Scientists now know that coral reefs are "part animal, part vegetable, and part mineral." Coral reefs contain many calcifying creatures—indeed, a coral reef itself is largely composed of a calcium-rich structure that contains many different plants, animals, and minerals. Like a human city, coral reefs grow over time, but the crucial difference is that they grow by adding new life forms to their composition, rather than annihilating them. A series of recent scientific papers have argued that, by the year 2050, the **Great Barrier Reef** will have eroded into a "rubble bank."

Coral reefs are enormously complex structures: they're composed of minerals, but also plants and animals. Furthermore, coral reefs can grow over time, meaning that Darwin was wrong to think that they were "fixed" geological structures that had become submerged over time. Kolbert contrasts the elegance and inclusiveness of the coral reefs with the destruction and ground-clearing inherent to the building of a human city. In doing so, Kolbert reinforces one of the book's most important themes: for most of human history, civilization has flourished at the "price" of environmental destruction. The impending destruction of the Great Barrier Reef reconfirms the antagonistic relationship between civilization and the environment.

During her time on One Tree Island, Kolbert meets a scientist named Ken Caldeira. Caldeira's research focuses on the impact of carbon dioxide on ocean pH (i.e., acidity), but he has also studied the chemical composition of forests and the recent changes in global temperature. Caldeira takes Kolbert on a diving expedition to photograph octopi, and Kolbert feels some of the same mystification that Cook must have felt when he first saw the **Great Barrier Reef** more than two centuries years ago.

The Great Barrier Reef continues to convey a sense of wonder and awe to visitors. By writing about her own experiences at the reef, Kolbert adds a poignant note to her analysis of growing acidification. Climate change won't just wipe out entire species; it will also destroy one of the most beautiful places on the face of the planet.

The first evidence that carbon dioxide could destroy coral reefs came in the late 1980s with the Biosphere Project in Arizona, which was a huge, glass structure designed to be a self-sustaining ecosystem. While the earliest version of Biosphere was a failure—the people who tried to live there got altitude sickness because the carbon dioxide levels were too high—it yielded some interesting conclusions. The high carbon dioxide levels eroded the composition of coral inside the Biosphere, challenging the then-common notion that coral reefs are immune to changes in carbon dioxide levels. In recent years, scientific studies have shown that coral reefs erode significantly when carbon dioxide levels rise in the surrounding water, meaning that, at the current rate of carbon dioxide emission, reefs are expected to "dissolve" in the next half-century.

It's remarkable that scientists didn't even know that carbon dioxide could interfere with the growth of coral reefs until the late 1980s. The study of climate change is so recent that many of the ideas that Kolbert discusses aren't yet common knowledge. For many hundreds of years, scientists worked with the paradigm that humans could do whatever they want without permanently changing their planet's environment. Now, it's becoming clear that the opposite is true: human actions have tremendous (and possibly irreversible) consequences for the planet. That the effects of these environmental changes are so poorly understood adds to the sense of potential calamity.

Kolbert goes snorkeling with the scientists stationed on One Tree Island and sees beautiful sea life—sting rays, turtles, sharks, fish, and, above all, coral. The diversity of coral reefs is astounding, especially considering that tropical waters are usually low in nitrogen and phosphorus. The nitrogen and phosphorous levels mean that, theoretically, the waters surrounding Australia should be barren. This is a puzzle that Charles Darwin was the first to point out, one which scientists have yet to solve

The passage reinforces some of the beauty and complexity of the Great Barrier Reef. At the same time, Kolbert notes that science hasn't yet been able to solve some of the mysteries of the reef, reminding us that the study of climate change is still very recent—there are still many questions that need answers, and the consequences of our actions cannot be fully known.

Coral reefs have come and gone throughout the planet's history—in the Triassic Era, for example, nearly all the world's reefs dissolved. It's likely that coral reefs will disappear faster than they've disappeared at any point in the past, since they face the combined threats of carbon dioxide emissions, overfishing, and pollution. The rising temperature of ocean water also poses a significant threat to coral reefs. Warm water threatens coral reefs by increasing the amount of algae and plankton in the ecosystem, which in turn decreases the food available for larger coral species.

The disintegration of coral reefs isn't unprecedented in planetary history, and rising water temperatures won't destroy all life in the oceans; indeed, it will cause some algae species to thrive. Nevertheless, the destruction of the coral reefs due to human activity is a process that Kolbert presents as tragic. The reefs are beautiful and complex and they stand, symbolically, for the earth as a whole.

During her final days on One Tree Island, which coincides with "mating season" in the natural world, Kolbert observes the mating of the birds. As she explores the coastal area, she looks up at the stars and feels a profound sense of her own smallness and insignificance. Later, she notes the irony of her feeling—even though she'd come to One Tree Island to write about the enormous influence of human beings on the environment, she herself felt utterly insignificant when contemplating the environment.

Although Kolbert is writing a book on science, she also includes moments like this one, in which she conveys a more abstract, even spiritual message. Perhaps the passage is meant to suggest the ultimate insignificance of human culture relative to the total history of the planet. Kolbert also conveys the beauty and majesty of the natural world, a world that's now falling apart, thanks to human behavior.

Once per year, the corals of the **Great Barrier Reef** participate in a "mass spawning," an event during which corals reproduce asexually, creating millions of tiny egg-sperm bundles. One of the most common kinds of coral in the reef, *Acropora millepora*, produces "bundles" containing many dozens of eggs and thousands of sperm. Scientists have studied samples of *Acropora millepora* in order to test the impact of acidification on coral. So far, their findings have been discouraging—acidification can wipe out coral egg-sperm bundles. Late at night, however, Kolbert witnesses the spawning of coral in the Great Barrier Reef—from a human perspective, the corals seem to release a sudden stream of vivid pink bubbles.

Kolbert ends the chapter on a note of wonder. The sight of "coral spawning" is both beautiful and poignant, since, based on the evidence Kolbert offers throughout the chapter, it's possible that there won't be many more years of coral spawning in the future. Like the eggs of the ammonites millions of years ago, sperm/egg bundles probably won't be able to withstand the increasing acidification of the waters.

CHAPTER 8: THE FOREST AND THE TREES

In Peru, Kolbert meets with a scientist named Miles Silman. Silman, a professor at Wake Forest University, is a forest ecologist, and studies the tropical ecosystems of South America. While global warming is often interpreted as being most dangerous for animals in cold climates, global warming poses an equally severe threat to tropical life forms.

Having studied the impact of global warming on the oceans, Kolbert turns to another rich, vibrant ecosystem: the rainforests of South America. Her conclusions about rainforests will be similar to the conclusions she's drawn in previous chapters (increasing temperatures are threatening biodiversity), which provides more evidence for the idea that we are experiencing the Sixth Extinction.

Imagine that you're standing at the North Pole. You might decide to venture south, toward Greenland, followed by Quebec. As you walk farther south, you'll see more and more trees. By the time you get about two thousand miles south, you'll encounter a huge forest, stretching almost a billion acres. Continue walking south and you'll encounter the forests of the United States, which have significantly more tree diversity than their Canadian counterparts. Continue south to the equator, and the diversity of the forests further increases—indeed, there are more than a thousand different tree species in Peru, where Silman conducts his research. There are a staggering number of species of frogs, birds, fungi, etc.

The purpose of Kolbert's tour of the Americas is to convey the relationship between biodiversity and climate. Up to a certain point, the combination of moisture and increasing temperature tends to encourage biodiversity; tropical rainforests, with their moist, warm climates, contain millions of different species, while the arctic is sparser. This adds complexity to Kolbert's previous observations that increasing temperatures are reducing biodiversity in the oceans.

Why are tropical climates so conducive to biodiversity? One theory suggests that, in tropical areas, "the evolutionary clock ticks faster"—animals reproduce faster, leading to more genetic mutations, which leads to more varieties of species. Another theory argues that there's more biodiversity in tropical climates because tropical climates have relatively low temperature fluctuation, and, therefore, different zones (the tops of trees, the bases of trees, etc.) can only harbor life with very specific thermal tolerances. As a result, the theory posits, different animals self-stratify based on the temperatures they can withstand, and new species gradually emerge over time. Another theory argues that tropical ecosystems are diverse because they're so much older than other ecosystems and they have been able to accumulate great diversity over time.

There are many different theories about why rainforests are so conducive to biodiversity. Some of these theories suggest that there is an inherently positive relationship between stable climate and biodiversity. Other theories imply that no such relationship exists. Whatever the precise reason, the biodiversity of rainforests suggests that an ecosystem is a complex structure in which the slightest changes (in temperature, moisture, etc.) would interfere with the overall structure of life.

In the thick forests of Peru, Silman shows Kolbert some of the different species of trees that he has discovered in the last few years. He takes Kolbert to some of the different "levels" of the forest, each with its own unique temperature, humidity, and, therefore, life forms. For more than a decade, Silman has been recording the diversity of life at seventeen different "tree plots." At each one, Silman and his assistants record the average diameter of a tree, the different life forms they find, and other pieces of information. Silman, working with one of his students, Kenneth Feeley, has found that, on average, the increasing temperatures of the Peruvian forests have driven plants and animals to higher altitudes at a rate of eight feet per year. For example, there is a Peruvian tree of the genus *Schefflera*, which has an especially short lifespan. Every year, *Schefflera* trees die off, and every year, their replacements show up at a higher altitude, reflecting the overall changing temperatures of the forests. Other trees, such as those in the genus *Ilex*, are so resilient that they've remained largely "inert" in the last decade.

Silman's research into rainforests suggests that, if given the option, life forms will try to "hold onto" the ecosystem with which they're most familiar, even if doing so requires them to migrate somewhere else. Thus, plants and animals have slowly "migrated" northwards through the rainforests in the hopes of finding a new climate with the temperature and humidity to which they're most accustomed. Furthermore, different species adapt to the changing climate with different degrees of success: some migrate successfully, while others don't. The further implication of this passage, however, is that eventually, plants and animals will have nowhere to go: they will be unable to find the climates they need.

Every species on the planet has evolved in some capacity to cope with changes in temperature. The world's average temperature changes over time—for example, 35 million years ago, global temperatures declined precipitously, forming the glaciers of Antarctica. The theory of "ice ages" was first proposed by a student of Cuvier named Louis Agassiz; however, it took another hundred years before scientists knew *why* the world's average temperature dropped at different points in time. Most scientists now believe that the gravitational pulls of Jupiter and Saturn alter the "distribution of sunlight" across different latitudes of the planet. When other planets' gravitational pulls are strong, less sunlight hits the northern latitudes, and snow builds up. The buildup of snow further triggers global carbon dioxide levels to fall, leading to a significant drop in temperature.

While scientists have known about ice ages for more than a century, the explanation for ice ages is very recent. The fact that interplanetary forces influence the temperature of the Earth might suggest that there is a limit to how much humans could change their environment. However, Kolbert will show that, in many ways, humans play an even greater role in determining the average temperature of the Earth than Jupiter and Saturn do. This shows just how powerful a force human activity is on the climate.

During the Pleistocene period of Earth's history, the planet became significantly cooler. Charles Darwin speculated that, during such periods of global cooling, animals tended to migrate toward the equator in search of the temperatures to which their bodies were calibrated—a theory that contemporary scientists have confirmed. Scientists predict that, during the next century, the average world temperature will increase considerably, and at a faster rate than at any other time in the history of the Earth. The speed at which the temperature will increase poses a significant threat to the world's life, and it's not clear which species will be able to migrate north quickly enough to survive.

In principle, there is nothing unusual about climate change—the world's average temperature has changed many times in the past. However, the speed at which the average temperature is rising is unprecedented in planetary history. As a result, it's likely that many species won't have enough time to adapt to their new environments, reproduce, and survive climate change—most species will probably be unable to find a stable climate, and, as a result, will die out.

Silman takes Kolbert on several expeditions to observe the tree plots and gather samples. She describes several significant moments with Silman that reveal his character and values. During one expedition, for example, Silman talked about the different trees of Peru, praising them for being "hilarious" or "clever." On another occasion, Kolbert woke up to learn that, while she was sleeping the previous night, a group of men selling coca leaves (used mostly for medical purposes, especially as a cure for aches) had walked through Silman's camp and tripped over his tent. Silman was so angry that he yelled at the coca salesmen—not, he later admitted, a wise decision.

In this passage, Kolbert paints a vivid portrait of her guide, Silman. Silman is an eccentric, who seems to excel at "interacting" with trees—he even gives them compliments—and yet sometimes fails to get along with other human beings (such as the coca leaf salesmen). Like many of the individual human beings Kolbert discusses in the book, Silman genuinely cares about preserving the environment; indeed, he has devoted most of his adult life to preserving the rainforests from destruction.

In ecology, there's a familiar rule that the greater the size of an area, the more species are likely to live there. There appears to be a strong positive correlation between the two variables, such that the number of species in a region is directly proportional to the square root of the region's total area. This law is helpful to understanding the impact of humanity on biodiversity. Humans decrease the amount of land available for species to inhabit, and therefore decrease the total number of species, too. Taking this principle into account, scientists have estimated that between 30 and 50 percent of the world's species will disappear by the year 2050. A more optimistic scenario would be that the world's species could prove to be resilient by migrating north to find temperatures at which they could survive. However, many species won't be able to find comparable temperatures. Several years ago, *National Geographic* published a story repeating the conclusion that half of the world's species could die out by 2050. Since the story was published, other scientists have challenged the original study's findings—some for overestimating the decrease in diversity, others for underestimating it.

The gist of the law Kolbert describes here is that when the available area for wild species shrinks at a given rate, the total diversity found in the wild shrinks at an even faster rate (for example, when the available land decreases by twenty-five percent, diversity could decrease by as much as fifty percent). Kolbert acknowledges that it's very difficult to measure the exact rate at which species will go extinct (the study of global warming is so recent that scientists have yet to get a precise figure). However, having a metric by which to measure the relationship between human land use and extinction makes it clear that humans need to do a better job of preserving wild land if they hope to preserve the world's biodiversity.

Back in Peru, Silman shows Kolbert a tree species called *Alzatea verticillata*. The tree has bright green leaves and tiny pale flowers. The species is one of the few in the Peruvian forests that hasn't "migrated" up the mountain in search of familiar temperatures. Silman's findings suggest an important point about the temperature changes facing mankind in the near future: some species will be able to adapt and survive, while others won't.

Alzatea verticillata *is one of the many species that hasn't been able to migrate away from the rising temperatures; if the decay of the rainforests continues into the 2050s, the tree will, in all likelihood, go extinct. Emphasizing the effect of climate change on an individual species helps to dramatize the tragedy.*

One afternoon, Kolbert, Silman, and Silman's assistants travel through the forest to a cluster of tourist lodges. There, Kolbert is surprised to find a group of different birds, including tanagers and cock-of-the-rocks. These species, Kolbert notes, are "cold-adapted"—for precisely this reason, they survived the last Ice Age. While it's true that many species will be able to adapt to the new rising temperatures, many other species will die out—a particularly large number, considering how rapid the upcoming temperature changes will be. Silman goes still farther, arguing that the changes facing the world's life forms in the next fifty years will be "apocalyptic."

It's a mark of the unprecedented nature of the Sixth Extinction that some of the same species that survived the last Ice Age will be unable to survive the next wave of mass-extinction. As Darwin argued, the environment is constantly changing—therefore, traits that were evolutionarily advantageous at one point in time won't necessarily remain advantageous in the future. The birds that Kolbert observes in this passage will have to make extreme adaptations or face extinction.

CHAPTER 9: ISLANDS ON DRY LAND

In Brazil, near the Venezuelan border, there is a square-shaped area known as Reserve 1202. Reserve 1202 consists of 25 acres of untouched rainforest, and all around it there is "scrub" (the remains of rainforest areas where the trees were cut down). There are many other similar Reserves in the area, all controlled by the Biological Dynamics of Forest Fragments Project (BDFFP), an organization founded in the 1970s by Tom Lovejoy. Lovejoy wanted a way to protect certain rainforest areas from farmers and ranchers cutting down trees. He presented a plan to the Brazilian government, and ever since then he has been given grants to study the rainforest preserves. Lovejoy's research involves making comparisons between the tiny reserves and the main rainforest area, miles away.

In the previous chapter, we discussed the direct relationship between land area and biodiversity. The purpose of Tom Lovejoy's organization is to isolate small patches of rainforest and measure the biodiversity there, in order to give science a better idea of what will happen in the future, when the entire rainforest has been reduced to a few 25-acre patches.

Of the approximately fifty million square miles of land on the surface of the Earth that contain no significant ice, humans have developed more than 25 million. Indeed, the development of ice-less land is one of the defining characteristics of the Anthropocene era. However, it can be difficult to decide what does and doesn't count as development—for example, is a tropical rainforest with a pipeline running through it developed or not? To the extent that there *is* undeveloped land anymore, it probably looks like Reserve 1202—an "island" in the middle of a "sea" of development.

One of the major challenges facing scientists who study global warming is to define what does and doesn't constitute undeveloped land. Furthermore, scientists have to face the possibility that developed land can still harbor considerable biodiversity; for example, a rainforest that has been partly destroyed to clear way for a pipe would continue to harbor great biodiversity. These complex questions exemplify the unprecedented difficulties of climate science.

Kolbert goes to Reserve 1202 with an ornithologist named Mario Cohn-Haft. Cohn-Haft takes Kolbert out into the forest late at night to listen to birdcalls. An expert at identifying birdsong, he explains that, over the course of his many years at Reserve 1202, he's noticed a gradual decline in the diversity of bird species, and in biodiversity overall.

Cohn-Haft's observations support a possibility that Kolbert suggested in the previous chapter: the decline in available land area will cause a marked decline in observed biodiversity, both for birds and in general.

Islands tend to have relatively few species when compared with the mainland. Perhaps the reason for this is that there isn't enough space for many different species to develop or even survive. Over time, islands experience a phenomenon called "relaxation"—a gradual reduction in biodiversity. This is due to the fact that, with a limited number of species and a small amount of space, temporary setbacks to diversity are more likely to be devastating. On a large continent, the destruction of a few bird eggs would have almost no impact on the species' success in the long run; on a small island, however, the destruction of these eggs could spell the end of the species.

In this passage, Kolbert explains why there is a direct relationship between land area and biodiversity. The smaller the land area, the greater the likelihood that an accident (such as the breaking of a few eggs) could prove catastrophic for an entire species. Theoretically, one might think that a small patch of rainforest could harbor the same amount of biodiversity as an entire rainforest—and at first, it would. But eventually, small accidents would reduce the total biodiversity in the patch.

Cohn-Haft drives Kolbert away from Reserve 1202 and into the main rainforest, where he conducts tests and collects samples to compare with those from Reserve 1202. He shows Kolbert dozens of different plants and animals, explaining that the rainforest is an extremely diverse ecosystem and focusing his comments on one species in particular—the army ant, *Eciton burchellii*. Army ants are unlike any other ant species on the planet—they're very aggressive and they travel constantly. There are more than 300 species that derive some kind of nutrition from army ants.

The army ant is an excellent example of a species on which other species depend. If all the army ants in a rainforest were to disappear, than hundreds of other species would lack for food. This further explains the direct relationship between biodiversity and land area—in a small area, where one species might be in greater danger of extinction, that species' extinction would set off a chain reaction that results in the extinction of other animals and plants, too.

Since the seventies, there has been a lot of research into the number of insect species in the rainforests. One entomologist (insect scientist) named Terry Erwin estimated that rainforests contained at least 30 million species of arthropod (a group representing insects, spiders, and centipedes). Other scientists have argued that Erwin was overestimating the biodiversity of rainforests, but, regardless, it's clear that rainforests are home to a staggering number of different life forms. One result of this biodiversity is that human deforestation efforts are particularly destructive to rainforest life. Some have estimated that even a one percent loss in the area of untouched rainforest results in a quarter of a percent loss of all the species in the rainforest. This means that some five thousand rainforest species go extinct every year.

Even if scientists like Erwin have overestimated the decline in biodiversity, it's clear that the decline of available land area poses a significant threat to the biodiversity of the world's rainforests. This is another example of the magnitude of the effects of human activity on the natural world. As we've seen, a small decline in the land available for rainforest creatures could set off a chain reaction resulting in the extinction of many interconnected plants and animals.

Throughout the nineties and 2000s, a series of science articles argued that a rainforest species went extinct every day, if not every minute. Later studies have shown that these estimates of the extinction rate were exaggerated. It is possible that the effects of reducing the amount of available land take time to set in. It is also possible that deforested areas can regrow over time—meaning that human development isn't necessarily permanently reducing the amount of available land on the planet. Another possibility is that humans aren't very good at counting the number of vanished species.

Kolbert introduces a couple of caveats to her observations so far. These caveats are important, as the science of biodiversity has yet to explain the observed conditions of the changing rainforests. The fact that Kolbert admits it when scientific research hasn't explained something satisfactorily lends weight to her conviction that, despite the lingering questions,, the bulk of the evidence suggests that deforestation will reduce biodiversity.

Lovejoy is still involved with BDFFP today, though he's in his seventies. His main priority is building support for the BDFFP, and for environmentalism in general, using evidence gathered from the BDFFP to educate the public. Lovejoy argues that many species have vanished from his reserves in the last few decades, suggesting that the fragmentation of the rainforest ecosystem results in rapidly shrinking biodiversity.

Lovejoy's personal anecdotes about the decline in biodiversity in the rainforests reinforce the findings of the scientists Kolbert has discussed elsewhere in this chapter. Deforestation is a devastating blow to biodiversity, even (or especially) in the most biodiverse places on earth.

One night at Reserve 1202, Kolbert wakes up to watch an "army ant parade." She'd been told that she'd see a huge group of ants marching through the forest, but no ants appeared. Cohn-Haft, who had woken up to watch as well, explains that the army ants were probably preparing to go into "statuary phase"—one of the few times when they remained in one place for an extended period—and thus wouldn't appear that night after all. Kolbert hears the sounds of birds, which had been expecting the ants to march, as well. She realizes that the night is a metaphor for the rainforest itself: for every one species that disappears, hundreds of other species are affected.

The chapter ends on another poignant note: the disappearance of the army ants from the rainforest symbolizes the gradual disappearance of biodiversity from the planet. If army ants do go extinct, then many other animals, such as birds, will have to find new food sources or go extinct, too. In short, the extinction of even one insignificant-seeming species could start a catastrophic chain-reaction, the result of which is mass-extinction.

CHAPTER 10: THE NEW PANGAEA

In 2007, a team of biologists decided to count the number of bats in Albany, New York. In the dead of winter, they climbed into caves with the expectation of seeing bats in hibernation. What they found was shocking: thousands of bats, seemingly lying dead on the ground, covered in a strange, powdery white substance. The next year, the scientists investigated the caves and again found freshly dead bats, covered in the same white substance. The bat die-off continued for years and spread to other states. Eventually, scientists learned that the white powder was a cold-loving fungus, *Geomyces destructans*, that is deadly to bats.

Like the golden frogs from Chapter One, the bats of the New England area are dying off at an alarming rate due to a new toxin. In this chapter, Kolbert will show what golden frogs and New England bats have in common, and what their deaths have to do with humans' attempts to alter their environments.

Darwin's ideas are helpful to understanding the significance of the bat die-off. Darwin argued that, for all intents and purposes, most animals cannot travel long distances. The idea of natural selection assumes the existence of isolated environments with natural barriers like mountains, oceans, rivers, etc. Thus, it's possible to speak of the Galápagos Islands or the western Caribbean as separate "units," each with its own unique life. The problem with Darwin's assumption, of course, is that many animals are capable of traveling long distances over natural barriers. And in the Anthropocene, animals are dispersed around the world, thanks to the actions of human beings. Humans travel to every different continent and they move animals, plants, and microbes with them—an event that is utterly unprecedented in planetary history.

For the purposes of his theory of evolution, Darwin conceived of the natural world as a series of distinct, isolated ecosystems. This passage shows another way in which the Anthropocene era has introduced complexity to the natural order that Darwin could never have anticipated. In addition to science changing by developing better and better theories to explain the natural world, sometimes scientific theories become outdated due to the changing conditions of the world over time. The speed of change in the Anthropocene era poses challenges to Darwin's theory that he could never have anticipated.

Kolbert, who lives near the Albany bat caves, discovered that the lethal fungus had spread as far as West Virginia. She met with Al Hicks, one of the scientists who had discovered the dead bats in Albany. Hicks took Kolbert into the Adirondacks, the mountains where his team was conducting environmental tests. Hicks counted brown bats (*Myotis lucifugus)* and other endangered bat species. Many bats had the telltale white fungus growing on their bodies.

As Kolbert investigates the deaths of bats, it becomes clearer and clearer that humans are to blame for the sudden changes in the bats' environments. This passage, in particular, is evocative of Rachel Carson's Silent Spring, a book that concentrates on the widespread and devastating effects of pesticides on birds.

In the Anthropocene, species move around the world in a process similar to Russian roulette. When a species encounters a new environment, two things can happen: 1) nothing; 2) the new environment kills the species. Most of the time, a species can't adapt to a new environment. But when a species does so, it reproduces and may sometimes spread to *other* surrounding environments. It's not clear why some species are better at adapting and proliferating than others—perhaps their success is as random as Russian roulette. However, scientists have hypothesized that when a species moves to a new environment it often has fewer evolutionary rivals and predators, and therefore its population explodes.

There is no rule for how a species behaves when it is introduced to a new environment. However, when the new species is successful, it can often take over its new habitat, irrevocably changing the world it inhabits. In short, each ecosystem has its own delicate equilibrium, and when a new species begins to dominate the ecosystem, that equilibrium is destroyed. This process evokes, perhaps, the spread of the human species across the globe and the ecosystem alterations that have followed.

When a species is introduced to a new environment, the species sometimes wipes out the diversity of life in that environment. For instance, humans brought the brown tree snake to Guam from Australia in the 1940s; within a few years, a huge chunk of Guam's bird species were extinct, eaten by the brown tree snake. New pathogens (viruses, bacteria, fungi, etc.) are particularly quick to spread; introducing a fungus to a new environment often leads to the near-extinction of other life forms. To give one example, the sudden appearance of a Japanese fungus in the U.S. in the early 20th century virtually wiped out the country's chestnut population. The white fungus that killed off bats in Albany is also an example of how dangerous a new pathogen can be.

Introducing a species to a new environment can be especially deadly when the species has no predators—the species will consume resources unchecked, depriving other species of the nutrition they need to survive. Kolbert lists many examples of species that flourished in their new homes while causing the extinction of other species that had previously thrived. Kolbert strongly implies that the white fungus that killed the bats of New England was introduced to the New England environment by human beings.

Chances are, wherever you are on Earth, you can see a couple of species that humans have introduced to the environment. There are vast databases of "invasive species"—species that have been introduced to a new environment and have harmed the environment's biodiversity. In Brisbane, Australia, for example, the cane toad, introduced in the early 20th century, has wiped out hundreds of plant and insect species. In a way, the phenomenon of global species travel is "turning back the clock" to the prehistoric time when the Earth's landmass was one huge supercontinent, Pangaea. In the "New Pangaea," there are, in effect, no natural barriers anymore—species can move anywhere in the world, thanks to human beings.

Arguably the most important and robust natural barriers on Earth are the oceans—there is virtually no way for a land animal (or a bacterium) to cross the water to travel to another landmass. However, in prehistoric times, when the Earth consisted of one enormous landmass, different species may have had an easier time migrating to different ecosystems. And now, in the 21st century, human technology has again eliminated the oceans as a natural barrier, resulting in a new species exchange. This is one of the more shocking and impactful comparisons in the book.

Kolbert and Hicks travel to the famous Aeolus Cave in Vermont, the home of one of the largest bat caves in America. As they enter the cave, they notice a huge pile of dead bats, some freshly dead, some badly decomposed. Hicks and his team proceed to put the dead bats in plastic bags so that they can be tested in a lab later on.

The chapter alternates between general analysis of species exchange and illustrations of how one particular species, the bat, has suffered because of species exchanges. Hicks tries to understand the phenomenon of species exchange by testing the bodies of dead bats.

When did the "New Pangaea" come into existence? Humans have used their ingenuity to cross natural barriers for many thousands of years, but particularly in the post-Columbian era, when nautical travel has become more common, the rate of species exchange has increased enormously. One group estimates that California alone acquires a new invasive species every sixty days. The short-term impact of species invasion is more diversity, since there is, literally, one extra species in the ecosystem. But in the long-term, biodiversity decreases as a result of the invasive species' dominance.

While humans have been crossing natural barriers for a very long time, it was only in the relatively recent past (the last 500 years or so) that they developed the maritime technology needed to circumvent the most important of all natural barriers, the oceans. The result, Kolbert predicts, will be less biodiversity, since some new species will cause other new species to go extinct.

The study of invasive species arguably began with the work of Charles Elton in the 1950s. Elton compared the movement of species to the exchange of gases in a set of tanks. If closed-off tanks of different gases were suddenly allowed to intermingle, the previously isolated gases would combine into new chemicals. In the short-term, there would be a lot of molecular movement. Eventually, however, the gases would reach a new equilibrium, in which there was *less* molecular variety. Following Elton's analogy, it seems that, in the future, the New Pangaea will reach a new equilibrium, but this new equilibrium will probably host fewer species than exist on Earth now. Perhaps many millions of years from now, if human commerce ceases, biodiversity will begin to grow again.

Elton's analogy is useful because it conceptualizes biodiversity as a chemical equilibrium. Just as different gases can coexist in a delicate equilibrium, the different species in an ecosystem can coexist. However, when these species are introduced to new environments, they disrupt the equilibrium: as a result, some animals will go extinct. However, Elton's analogy also suggests that, if given enough time, a new *equilibrium will emerge. The unsettling implication of this passage is that, one day in the future, humans could go extinct, their commerce could end, and animals could return to being divided up between natural barriers.*

Kolbert returns to the Aeolus Cave the next year, with a team of biologists from the Vermont Fish and Wildlife Department. The team counts only 112 bats—less than 10% of the norm. *Geomyces destructans* has thrived in New England because bats are highly sociable creatures; they spread the white fungus to other bats quickly. Meanwhile, the brown bat, and a few other bat species, has become endangered.

The chapter ends on a tragic note: the extinction of a certain species of bat in New England may spread to other bat species—another illustration of how the extinction of one animal can cause a domino effect, resulting in a mass-extinction.

CHAPTER 11: THE RHINO GETS AN ULTRASOUND

Kolbert travels to the Cincinnati Zoo to meet Suci, an enormous rhinoceros. Dr. Terri Roth, the conservation director for the zoo, tells Kolbert that Suci, a Sumatran rhinoceros (*Dicorohinus sumatrensis*), is one of only five rhino species left on the planet. Sumatran rhinos are small and endangered. Thus, Roth has been trying to artificially inseminate Suci with no success.

The chapter begins with another endangered species: the Sumatran rhinoceros. However, unlike the previous chapter, Chapter Eleven begins by discussing conservationists like Dr. Roth, who have devoted their lives to preserving endangered species.

Sumatran rhinos used to live in the Himalayas, as well as on Sumatra and Borneo. They were once common, but they're now headed for extinction. Recognizing their inevitable extinction, a conservation group decided to send a small number of Sumatran rhinos to American zoos in hopes of perpetuating the species in captivity. However, five of these rhinos died almost immediately, thanks to a disease spread by flies. Then, several rhinos captured in Borneo died from tetanus and other injuries. To compound the problem, zookeepers then realized that rhinos couldn't eat dry hay—they needed fresh leaves to survive. By this time, there were only three Sumatran rhinos in the U.S. Roth's job is to inseminate a Sumatran rhino and perhaps prevent the species from dying out forever.

In this passage, Kolbert presents readers with a "before" and an "after"—rhinos were once very common throughout the world, but after the 20th century, rhinos began to go extinct. For the rest of the chapter, Kolbert will fill in the middle period, attempting to explain the role human beings played in the extinction of the rhinoceros. Kolbert's immediate highlighting of unexpected problems in rhino breeding also shows the extent to which the natural world is not within human control.

Roth had tried to inseminate a rhino named Emi, who was living in a zoo in Los Angeles. After many false starts, Emi birthed Suci and a male named Harapan. These are "pretty much" the only Sumatran rhinos born anywhere in the last thirty years. Much the same is true for other rhino species—humans have wiped out rhinos and scientists are now trying to preserve their numbers in captivity. Other large mammals, such as elephants, jaguars, pandas, and cheetahs, now exist mostly or entirely in zoos and preserves, where scientists are trying to get them to bear offspring.

In general, there has been a notable decline in the populations of large wild mammals, such as rhinos, cheetahs, elephants, and pandas. Here, Kolbert illuminates the Quixotic phenomenon of humans nearly wiping out large mammal species and then going to great lengths to protect them—by putting them in artificial, human-designed environments, of course.

Kolbert observes Suci eating food and is later permitted to pet Suci. "Face to face" with Suci, Kolbert is struck by the animal's awesome, "majestic" size. Many of the largest mammals in the world are peaceful herbivores; their size keeps them safe from dangerous predators like tigers and jaguars. At the end of the last Ice Age, the planet was full of enormous animals—cave bears, giant elk, mastodons, etc. As early as the mid-19th century, biologists had posed an important question—why is it that so many extinct species are exceptionally large, by modern-day standards? And, similarly, why did so many of these enormous creatures go extinct?

This passage blends together Kolbert's personal experiences (her face-to-face experience with Suci the rhino) and her more abstract thoughts about extinction in general. Thus, the question of why large mammals have gone extinct, as Kolbert presents it, is both abstract and personal; or, put another way, scientific and yet very poignant. With the extinction of large, peaceful mammals, humans are losing touch with some of the natural world's most majestic, beautiful creatures.

To answer the question, Kolbert travels to a famous fossil site, Big Bone Lick. Here, 19th century fossil-hunters discovered some of the world's most famous fossils. Some 19th century thinkers, such as Charles Lyell, argued that the creatures whose remains were discovered at Big Bone Lick went extinct because of a "great modification in climate." Charles Darwin agreed, writing that the end of an Ice Age must have killed off creatures like the mastodon. Other scientists, however, argued that these large creatures died out because human beings hunted them. The implications of such a theory are startling—the modern era of mass extinction, then, might actually have begun "in the middle of the last ice age," suggesting that human beings have always been capable of—or even prone to—bringing about extinction.

For most of the 19th century, scientists believed that large mammals went extinct because of the end of the last ice age, which reduced the evolutionary advantages of such traits as warm fur and large body mass. Only within the last few decades have scientists begun to suspect that large mammals went extinct because human beings hunted them. Such a theory has large implications for our understanding of human nature: it would seem that human beings have been murderous and destructive for as long as they've lived on the Earth. This is further support for Kolbert's decision to define humans by what they do, which is alter their environment.

There are a few good reasons to believe that humans were responsible for the mass-extinction of large mammals. First, it's likely that the extinction of large mammals took place in "pulses," not as one continuous event. This suggests that extinction "syncs up" with human colonization of the globe. Second, large mammals had survived numerous droughts and other environment catastrophes before the arrival of human beings. Third, the fossilized remains of large mammals' excrement show no signs of death from malnutrition. In all, the insufficiency of purely environmental explanations for large mammals' mass-extinction make it very likely that humans, not environmental factors, were responsible for the mass-extinction.

Kolbert acknowledges that prehistoric humans may not have hunted large prehistoric mammals into extinction—there are scientific theories with merit that suggest causes other than humans. However, the evidence Kolbert gives here suggests that it's at least feasible that humans played a major role in the mass-extinction of large prehistoric mammals. She is laying the groundwork here for a knockout blow to the notion that humans are not inherently prone to irrevocably altering and destroying the natural world.

There are also some researchers who argue that human beings did not wipe out the large mammals of the late Ice Age because humans couldn't have been that dangerous so many millennia ago. However, the scientist John Alroy has tested the hypothesis that small nomadic bands of humans could have wiped out large mammals, and he found that "humans could have done in" the large mammals with "only modest effort." Alroy's findings suggest that the Anthropocene really began many thousands of years ago, long before the Industrial Revolution.

Alroy's findings further strengthen the hypothesis that human beings played a decisive role in the extinction of large prehistoric mammals. Put another way, humans have been causing mass-extinction for as long as they've been in existence. This suggests that, in a way, the destruction of other life forms is one of the most basic facets of human nature. It also complicates the association of the Anthropocene era with modernity.

Before the dawn of man, it was an excellent "survival strategy" to be a large, peaceful mammal. However, environmental changes—above all, the new presence of human beings—made being a large mammal a "loser's game." Large mammals were slow to reproduce and were easy prey to human hunters. Today, most of the large mammals of the ancient world have died out, and smaller mammals like the rhinoceros are on the verge of extinction. It seems that there was never a time when "man lived in harmony with nature"—humans have always hunted other creatures.

The extinction of the mastodon, the wooly mammoth, and other large prehistoric mammals, confirms the random, unpredictable nature of survival. The arrival of human beings on the Earth meant that traits such as size and slowness, which had previously been evolutionary advantages, became major disadvantages. This passage also, importantly, positions the dawn of man as an environmental change comparable to an Ice Age or asteroid impact.

CHAPTER 12: THE MADNESS GENE

In Germany, there is a small valley know as *Das Neandertal*. Here, in the mid-19th century, workers stumbled upon the first Neanderthal remains. Since then, scientists have found Neanderthal remains in other parts of Europe and the Middle East. Neanderthals had sophisticated tools, wore animal skins to keep themselves warm, and hunted for food. Then, about 30,000 years ago, they vanished. Some researchers argue that environmental changes wiped out the Neanderthals, while others claim that *Homo sapiens* killed them. It's likely, however, that *Homo sapiens* interbred with the Neanderthals.

So far, Kolbert has written about the role humans have played in annihilating wild animals and plants. In this chapter, however, she'll address the role that humans may have played in wiping out their close cousins, Neanderthals—creatures who, it would seem, had big brains and complex societies. In this way, Chapter 12 paints an even bleaker portrait of human nature, suggesting that humans might have a propensity to destroy even beings that resemble themselves closely enough to interbreed.

Kolbert visits the Max Planck Institute for Evolutionary Anthropology in Leipzig. There, she meets Svante Pääbo, the director of the department of evolutionary genetics. Pääbo pioneered "paleogenetics," the study of ancient genetics. He hopes that, in the near future, humans will succeed in mapping the Neanderthal genome so that they can compare *Homo sapiens* and Neanderthal genetics side-by-side.

Kolbert introduces a new, cutting-edge field of science: paleogenetics. Under the right circumstances, it's possible to examine prehistoric remains and find fragments of DNA. Using DNA samples, scientists like Pääbo can reconstruct what long-extinct creatures looked like, a boon to the study of mass extinction.

At first, scientists thought that the remains of Neanderthals belonged to regular human beings. However, some specialists pointed out that the bones were bowed in unusual areas. In the coming decades, more Neanderthal bones surfaced, and researchers (or sometimes amateurs) noticed that the skeletons had unusually large skulls and unusually bowed femur bones. Early 20th century scientists portrayed Neanderthals as hairy, brutish creatures who could barely stand up straight, and this was taken as evidence of their uncivilized nature. However, after World War II, anatomists re-examined Neanderthal remains and made some striking conclusions. They decided that Neanderthals didn't walk with a slouch, weren't hairy, and, in fact, looked striking like modern humans. There is even some evidence that Neanderthals buried their dead and planted flowers on the graves.

This passage highlights the eagerness of scientists to distance humans from Neanderthals, an extinct species that humans may have wiped out. While science is shown throughout the book to be innovative and promising for the planet, the instances in which science falters and confirms some of humanity's worst impulses are equally important. The dehumanization of the Neanderthal by 20th century science shows that science is only as rigorous as the humans who carry it out—when misapplied, it can simply confirm prejudices.

DNA is often considered to be a "blueprint" for the structure of a human being. A human genome consists of billions of "lines" of four chemicals (adenine, thymine, guanine, and cytosine) housed in the nucleus of a cell. After human beings die, their genomic code deteriorates quickly, which means that it's very difficult to find any genetic information about humans (or Neanderthals) who lived in the distant past. However, scientists have succeeded in finding genetic code in Neanderthal bones. Analysis reveals that Neanderthal DNA is very similar to human DNA, with Europeans and Asians bearing more of a resemblance to Neanderthals than Africans do.

It is extremely difficult to reconstruct an entire genome from a few strands of ancient DNA. Therefore, paleogenetics is a slow, painstaking science, and a lot of work remains to be done before scientists reassemble the Neanderthal genome. However, the close similarities between Neanderthal and human DNA suggest that the two species cannot be considered distinct, at least not simplistically—Neanderthals shape the genetics of many modern humans.

The most popular theory for how humans evolved is the "Out of Africa" hypothesis, which states that modern humans are descendants of a small population of humans who were living in African about 200,000 years ago. Most of those humans' descendants migrated to the Middle East, followed by Europe, Asia, Australia, and the Americas. This suggests that Neanderthals were already living in Eurasia when the ancestors of modern humans traveled "Out of Africa."

The history of the human race begins with a story of migration, "out of Africa." This might suggest that, in some ways, humans are genetically predisposed to travel, explore, and wander, even when their current environments provide for all of their material needs.

One problem with the "Out of Africa" account of Neanderthals is that, were it true, one might think that all living humans have the same genetic overlap with Neanderthals—but in fact, some people's DNA has much more in common with Neanderthal DNA than other people's DNA does. Scientists have proposed a slight modification to the Out of Africa theory—the "leaky-replacement hypothesis," which states that early human beings interbred with Neanderthals when they first encountered Neanderthals in Eurasia. Furthermore, the fact that some Neanderthal DNA seems to have survived in human beings suggests that half-human, half-Neanderthal children were cared for, rather than being scorned or hated.

There is a lot of conflicting evidence concerning Neanderthals, but that Neanderthals and homo sapiens interbred and cared for one another's children certainly adds complexity to the hypothesis that homo sapiens led to the extinction of Neanderthals. This would suggest that malice, or even indifference, is not necessarily the driving force of human-fuelled mass extinction—perhaps it's a much more complicated combination of factors than we tend to intuitively assume.

What makes humans human? One might suppose that the deciding factor is intelligence—but, of course, apes and primates show many signs of intelligence. Scientists have shown that primates can make inferences, solve puzzles, etc.—in some ways, apes are better than human children at solving complex puzzles. However, human children always outscore apes in tests designed to measure their ability to read social cues. Perhaps one part of what makes humans human, then, is the ability to engage in "collective problem-solving" — solving a problem by communicating with other people.

Human history suggests that human nature is, in part, the ability to cooperate with other people and communicate and work together as a group. It's interesting, though, in light of Kolbert's previous observations about 20th century scientists' obsession with differentiating human from Neanderthal, that she focuses here on ways in which apes are lesser than humans. She has an important point, but it raises questions that Kolbert herself has asked about the eagerness of humans to differentiate themselves from the natural world.

What were Neanderthals like? To begin with, it's pretty clear that they made stone tools. It's also likely that they buried their dead. Neanderthal remains betray signs of serious injuries, suggesting, perhaps, the "rigors of hunting" in Neanderthal society. Interestingly, there is evidence that Neanderthals were seriously injured, but then survived their injuries, implying that they took care of each other. Neanderthals spread across Europe, but it seems probable that they never built boats to cross bodies of water.

There is limited evidence to suggest that Neanderthals were milder and gentler than human beings. They took care of their wounded instead of leaving them to die (as in many human societies, for instance, the Greek city of Sparta). And perhaps the fact that Neanderthals built some simple tools, but never boats, suggests that they lacked the same "spark" of creativity that defines the human race.

Pääbo has pioneered an intriguing theory about Neanderthals. It seems that restlessness, curiosity, and "mad ambition" are quintessential human qualities—and perhaps they're genetic. Perhaps Neanderthals lacked these genetic qualities—they never developed the ambition to cross bodies of water, conquer territory, wipe out other species, etc.

Kolbert has offered many competing definitions of human nature throughout her book. Here, she suggests, once again, that ambition and drive are vital components of human nature: unlike all other living creatures, humans feel a complex, irrational desire to discover the new. Perhaps it is this irrational desire that drives humans to hunt other species into extinction, permanently alter the environment, etc.

Pääbo has found plentiful evidence of species interbreeding in human fossils. For example, in analyzing a fossilized fragment of tooth that belonged to an early, humanoid species called the Denisovans, he concluded that it is likely that humans interbred with the Denisovans. It's possible that the Denisovans went extinct because of their low reproductive rates, and the same is true of humans' "next-closest kin," apes. In the 21st century, apes are going extinct because they're not reproducing quickly enough. In a few centuries, it's possible that humans' "sister species"—not just Neanderthals and Denisovans, but chimpanzees, apes, etc.—will be wiped out.

Another major reason that human beings have survived over the centuries is that they have a relatively fast reproduction rate (at least when compared with other similar species). The combination of rapid reproduction and "mad ambition" has led human beings to rule the planet, wiping out many other species, including their closest cousins, Neanderthals and Denisovans, in the process. When considering apes to be human cousins instead of simply animals, their mass extinction begins to seem more sinister.

Kolbert drives to La Ferrassie, a French site where the largest recorded assemblages of Neanderthal remains were discovered 100 years ago. As she watches a team of paleontologists at work, she imagines what life had been like for Neanderthals. She finds a beautiful hand-ax, almost perfectly symmetrical. When she tells a paleontologist that the ax is beautiful, he points out that Kolbert is "projecting the present" onto the past; in other words, there's no evidence that Neanderthals designed their tools to be beautiful. Indeed, no remains of Neanderthal art or adornment have yet been discovered.

So far, one could argue that Kolbert has taken "the Neanderthals' side"—she has characterized Neanderthals as peaceful, compassionate beings, as compared to human beings, their more brutal, ambitious relatives. But in this passage, Kolbert emphasizes some of the limitations of Neanderthal society. Neanderthals may not have been brutal, aggressive animals, but they also made no art. By the same token, humans may be brutal, greedy creatures, but they're also capable of producing cave paintings, and other things of great beauty. This passage also illustrates the interpretive dangers of viewing the whole world through a human-centric lens.

On her last day in France, Kolbert visits another archeological site, **Grotte des Combarelles**. There, she enters a cave where human beings once lived—on the walls, there are sketches and paintings. It occurs to Kolbert that prehistoric human beings must have been "a little bit mad" to go exploring the caves armed only with fire and axes. Perhaps if humans, with their madness, their ambition, and their "signs and symbols," had never existed, Neanderthals would still be around.

Ultimately, Chapter 12 portrays human nature as a set of contradictions. Humans are "madly ambitious," but also heroic and artistic in their curiosity. In a Greek tragedy, the hero's greatest strength—his or her intelligence, ambition, or wisdom—is usually also his or her fatal flaw, and one could say exactly the same about the human race as Kolbert portrays it in this book. Our incessant desire to explore the world and create civilization will also be our undoing.

CHAPTER 13: THE THING WITH FEATHERS

Kolbert goes to the Institute for Conservation Research (ICR) in San Diego to study a peculiar topic—the future. There, she is shown a set of vials, in which the last genetic remains of the black-faced honeycreeper, a nearly extinct Hawaiian bird, reside. Kolbert sees other vials that contain the genetic material of other extinct or near-extinct animals. In all, the ICR's collection of genetic material is known as the "frozen zoo."

While conservation is a very new field, there are scientists all over the world who have devoted their lives to preserving endangered species. The lengths to which ICR is willing to go in order to try to preserve endangered species illustrates the contradictory nature of humans—human activities endanger animals and also save them.

Kolbert wonders, "Does it have to end this way?"—do the world's beautiful plants and animals need to go extinct to make room for humanity? While it's true that humans can be destructive, they can also be "forward-thinking and altruistic." In 1974, Congress passed the Endangered Species Act, which arranged for the protection of animals on the verge of going extinct. Teams of scientists and conservationists have done a great deal to prevent species from being wiped out. It seems altogether better to save at-risk species than to "speculate gloomily about a future in which the biosphere is reduced to little plastic vials."

Kolbert takes a nuanced view of human nature: even if humans have enormous capacity for destruction (they've been wiping out other species for as long as they've been on this planet), they also have the capacity to nurture and protect. So perhaps it's possible that scientists, working with the general public, will be able to prevent certain at-risk species from dying out for good—at any rate, working towards protection is better than pessimistic speculation, which is one of Kolbert's few prescriptive statements in the book.

Next to the ICR, there's a veterinary hospital that serves both the ICR and the nearby San Diego zoo. Inside, Kolbert speaks with Barbara Durrant, a reproductive physiologist, about extinction and survival. Durrant tells Kolbert about a Hawaiian crow named Kinohi. As Hawaiian crows are endangered, Durrant was trying to get Kinohi to reproduce, but she had no success. It's indicative of how seriously humans take extinction that they are willing to spend thousands of hours getting crows, rhinos, and other species to bear offspring.

Barbara Durrant's efforts to get Kinohi to have offspring symbolize the collective effort that human beings—particularly scientists and conservationists—are putting into protecting endangered species. Perhaps if more people were aware of the Sixth Extinction, they would be willing to change their behavior and protect some endangered species. In this sense, Kolbert's book could play an important role in educating the public and protecting wildlife.

Throughout her book, Kolbert has been talking about the Anthropocene era, or, put another way, the Sixth Extinction: the mass-extinction of the world's life forms, caused by human behavior. It's not clear if the Sixth Extinction will continue to eliminate many more species, or if humans will be able to control their behavior and preserve what remains of the world's biodiversity. Humans have an enormous capacity for solving problems and behaving selflessly, so perhaps it's not inevitable that biodiversity will continue to plummet.

Kolbert does not come down forcefully on one side of this issue. Perhaps the "damage is done" and the Sixth Extinction will continue to cause the deaths of countless species across the Earth, or, perhaps, if humans are capable of altering their own environments, they'll be able to change their behavior and increase the planet's biodiversity once again. However, one thing is clear: if humans do nothing at all, species will continue to go extinct at an incredible rate.

In the middle of the American Museum of Natural History, there is a small exhibit about the Sixth Extinction. The exhibit shows some of the extinct animals of the past, and even implies that, one day, humans could go extinct, too. When we study the history of life on Earth, it becomes clear that "past performance is no guarantee of future results"—thus, the fact that humans have survived for so long doesn't prove that they'll continue to survive.

One implication of this passage is that, if human beings aren't conscious of the role they play in mass-extinction, they could go extinct themselves. Thus, for their own good, as well as for the good of the planet, humans need to find ways to preserve the ecosystem. Otherwise, the world's rising sea levels and plummeting biodiversity could have serious ramifications for human populations.

Some argue that human ingenuity will allow the species to survive indefinitely—perhaps we'll explore other planets and find more space to develop. But Kolbert argues that the survival of the human species, while important, isn't the *most* important question we should be asking. Perhaps, instead, we should focus on the present state of life on Earth: right now. Humans are unknowingly causing some species to go extinct and others to survive. No matter what decisions humans make, it's already clear that "the Sixth Extinction will continue to determine the course of life" for a long time to come.

To some extent, humans have changed their environment irreversibly (there's no chance, for example, that mastodons will walk the Earth again). However, it may be possible for humans to change their behavior and preserve what remains of the world's biodiversity. The first step toward preserving the environment must be education. At the moment, the theory of mass-extinction is familiar to a handful of scientific specialists, and unknown to much of the general public. Perhaps, by writing about mass-extinction in her book, Kolbert can educate the lay-reader and convince people to take climate change more seriously.

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