I.1

What Is Evolution?

Jonathan Losos

OUTLINE

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Evolution refers to change through time as species become modified and diverge to produce multiple descendant species. *Evolution* and *natural selection* are often conflated, but evolution is the historical occurrence of change, and natural selection is one mechanism—in most cases the most important—that can cause it. Recent years have seen a flowering in the field of evolutionary biology, and much has been learned about the causes and consequences of evolution. The two main pillars of our knowledge of evolution come from knowledge of the historical record of evolutionary change, deduced directly from the fossil record and inferred from examination of phylogeny, and from study of the process of evolutionary change, particularly the effect of natural selection. It is now apparent that when selection is strong, evolution can proceed considerably more rapidly than was generally envisioned by Darwin. As a result, scientists are realizing that it is possible to conduct evolutionary experiments in real time. Recent developments in many areas, including molecular and developmental biology, have greatly expanded our knowledge and reaffirmed evolution's central place in the understanding of biological diversity.

GLOSSARY

Evolution. Descent with modification; transformation of species through time, including both changes that occur within species, as well as the origin of new species.

Natural Selection. The process in which individuals with a particular trait tend to leave more offspring in the next generation than do individuals with a different trait.

Approximately 375 million years ago, a large and vaguely salamander-like creature plodded from its aquatic home and began the vertebrate invasion of land, setting forth the chain of evolutionary events that led to the birds that fill our skies, the beasts that walk our soil, me writing this chapter, and you reading it. This was, of course, just one episode in life's saga: millions of years earlier, plants had come ashore, followed soon thereafter—or perhaps simultaneously—by arthropods. We could go back much earlier, 4 billion years or so, to that fateful day when the first molecule replicated itself, an important milestone in the origin of life and the beginning of the evolutionary pageant. Moving forward, the last few hundred million years have also had their highs and lows: the origins of frogs and trees, the end-Permian extinction when 90 percent of all species perished, and the rise and fall of the dinosaurs.

These vignettes are a few of many waypoints in the evolutionary chronicle of life on earth. Evolutionary biologists try to understand this history, explaining how and why life has taken its particular path. But the study of evolution involves more than looking backward to try to understand the past. Evolution is an ongoing process, one possibly operating at a faster rate now than in times past in this human-dominated world. Consequently, evolutionary biology is also forward looking: it includes the study of evolutionary processes in action today—how they operate, what they produce—as well as investigation of how evolution is likely to proceed in the future. Moreover, evolutionary biology is not solely an academic matter; evolution affects humans in many ways, from coping with the emergence of agricultural pests and disease-causing organisms to understanding the workings of our own genome. Indeed, evolutionary science has broad relevance, playing an important role in advances in many areas, from computer programming to medicine to engineering.

1. WHAT IS EVOLUTION?

Look up the word "evolution" in the online version of the *Oxford English Dictionary*, and you will find 11 definitions and numerous subdefinitions, ranging from mathematical ("the successive transformation of a curve by the alteration of the conditions which define it") to chemical ("the emission or release of gas, heat, light, etc.") to military ("a manoeuvre executed by troops or ships to adopt a different tactical formation"). Even with reference to biology, there are several definitions, including "emergence or release from an envelope or enclosing structure; (also) protrusion, evagination," not to mention "rare" and "historical" usage related to the concept of preformation of embryos. Even among evolutionary biologists, evolution is defined in different ways. For example, one widely read textbook refers to evolution as "changes in the properties of groups of organisms over the course of generations" (Futuyma 2005), whereas another defines it as "changes in allele frequencies over time" (Freeman and Herron 2007).

One might think that—as in so many other areas of evolutionary biology—we could look to Darwin for clarity. But in the first edition of *On the Origin of Species*, the term "evolution" never appears (though the last word of the book is "evolved"); not until the sixth edition does Darwin use "evolution." Rather, Darwin's term of choice is "descent with modification," a simple phrase that captures the essence of what evolutionary biology is all about: the study of the transformation of species through time, including both changes that occur within species, as well as the origin of new species.

2. EVOLUTION: PATTERN VERSUS PROCESS

Many people—sometimes even biologists—equate evolution with natural selection, but the two are not the same. Natural selection is one process that can cause evolutionary change, but natural selection can occur without producing evolutionary change. Conversely, processes other than natural selection can lead to evolution.

Natural selection within populations refers to the situation in which individuals with one variant of a trait (say, blue eyes) tend to leave more offspring that are healthy and fertile in the next generation than do individuals with an alternative variant of the trait. Such selection can occur in many ways, for example, if the variant leads to greater longevity, greater attractiveness to members of the other sex, or greater number of offspring per breeding event. The logic behind natural selection is unassailable. If some trait variant is causally related to greater reproductive success, then more members of the population will have that variant in the next generation; continued over many generations, such selection can greatly change the constitution of a population.

But there is a catch. Natural selection can occur without leading to evolution if differences among individuals are not genetically based. For natural selection to cause evolutionary change, trait variants must be transmitted from parent to offspring; if that is the case, then offspring will resemble their parents and the trait variants possessed by the parents that produce the most offspring will increase in frequency in the next generation.

However, offspring do not always resemble their parents. In some cases, individuals vary phenotypically not because they are different genetically, but because they experienced different environments during growth (this is the "nurture" part of the nature versus nurture debate; see chapters III.10 and VII.1). If, in fact, variation in a population is not genetically based, then selection will have no evolutionary consequence; individuals surviving and producing many offspring will not differ genetically from those that fail to prosper, and as a result, the gene pool of the population will not change. Nonetheless, much of the phenotypic variation within a population is, in fact, genetically based; consequently, natural selection often does lead to evolutionary change.

But that does not mean that the occurrence of evolutionary change necessarily implies the action of natural selection. Other processes—especially mutation, genetic drift, and immigration of individuals with different genetic constitutions—also can cause a change in the genetic makeup of a population from one generation to the next (see Section IV: Evolutionary Processes). In other words, natural selection can cause adaptive evolutionary change, but not all evolution is adaptive.

These caveats notwithstanding, 150 years of research have made clear that natural selection is a powerful force responsible for much of the significant evolutionary change that has occurred over the history of life. As the chapters in Section II: Phylogenetics and the History of Life, and Section III: Natural Selection and Adaptation, demonstrate, natural selection can operate in many ways, and scientists have correspondingly devised many methods to detect it, both through studies of the phenotype and of DNA itself (see also chapter V.14).

3. EVOLUTION: MORE THAN CHANGES IN THE GENE POOL

During the heyday of population genetics in the middle decades of the last century, many biologists equated evolution with changes from one generation to the next in gene frequencies (*gene frequency* refers to the frequencies of different alleles of a gene; for background on genetic variation, see chapter I.4). The "Modern Synthesis" of the 1930s and 1940s led to several decades in which the field was primarily concerned with the genetics of populations with an emphasis on natural selection (see chapter I.2). This focus was sharpened by the advent of molecular approaches to studying evolution. Starting in 1960 with the application of enzyme electrophoresis techniques, biologists could, for the first time, directly assess the extent of genetic variation within populations. To everyone's surprise, populations were found to contain much more variation than expected. This finding both challenged the view that natural selection was the dominant force guiding evolutionary change (see discussion of "neutralists" in chapters I.2 and V.1), yet further directed attention to the genetics of populations. With more advanced molecular techniques available today, the situation has not changed. There is much more variation than we first suspected.

The last 35 years have seen a broadening of evolutionary inquiry as the field has recognized that there is more to understanding evolutionary change than studying what happens to genes within populations—though this area remains a critically important part of evolutionary inquiry. Three aspects of expansion in evolutionary thinking are particularly important.

First, phenotypic evolution results from evolutionary change in the developmental process that transforms a single-celled fertilized egg into an adult organism. Although under genetic control, development is an intricate process that cannot be understood by examination of DNA sequences alone. Rather, understanding how phenotypes evolve, and the extent to which developmental systems constrain and direct evolutionary change, requires detailed molecular and embryological knowledge (see chapters V.10 and V.11).

Second, history is integral to understanding evolution (see introduction to Section II: Phylogenetics and the History of Life). The study of fossils—paleontology—provides the primary, almost exclusive, direct evidence of life in the past. Somewhat moribund in the middle of the last century, paleontology has experienced a resurgence in recent decades owing to both dramatic new discoveries stemming from an upsurge in paleontological exploration, and new ideas about evolution inspired by and primarily testable with fossil data, such as theories concerning punctuated equilibrium and stasis, species selection, and mass extinction. Initially critical in the development and acceptance of evolutionary theory, paleontology has once again become an important and vibrant part of evolutionary biology (see chapter II.9 and others in Section II).

Concurrently, a more fundamental revolution emphasizing the historical perspective has taken place over the last 30 years with the realization that information on phylogenetic relationships—that is, the *tree of life*, the pattern of descent and relationship among species—is critical in interpreting all aspects of evolution above the population level. Beginning with a transformation in the field of systematics concerning how phylogenetic relationships are inferred, this "tree-thinking" approach now guides study not only of all aspects of macroevolution but also of many population-level phenomena.

Finally, life is hierarchically organized. Genes are located within individuals, individuals within populations, populations within species, and species within clades (a *clade* consists of an ancestral species and all its descendants). Population genetics concerns what happens among individuals within a population, but evolutionary change can occur at all levels. For example, why are there more than 2000 species of rodents but only 3 species of monotremes (the platypus and echidnas), a much older clade of mammals? One cannot look at questions concerning natural selection within a population to answer this question. Rather, one must inquire about properties of entire species. Is there some attribute of rodents that makes them particularly prone to speciate or to avoid extinction? Similarly, why is there so much seemingly useless noncoding DNA in the genomes of many species (see chapter V.2)? One possibility is that some genes are particularly adept at mutating to multiply the number of copies of that gene within a genome; such DNA might increase in frequency in the genome even if such multiplication has no benefit to the individual in whose body the DNA resides. Just as selection among individual organisms on heritable traits can lead to evolutionary change within populations, selection among entities at other levels (species, genes) can also lead to evolutionary change, as long as those entities have traits that are transmitted to their offspring (be they descendant species or genes) and affect the number of descendants they produce. The upshot is that evolution occurs at multiple levels of the hierarchy of life; to understand its rich complexity we must study evolution at these distinct levels as well as the interactions among them. What happens, for example, when a trait that benefits an individual within a population (perhaps cannibalism—more food, fewer competitors!) has detrimental effects at the level of species?

Although evolutionary biology has expanded in scope, genetic change is still its fundamental foundation. Nonetheless, in recent years attention has focused on variation that is not genetically based. Phenotypic plasticity—the ability of a single genotype to produce different phenotypes when exposed to different environments—may itself be adaptive (see chapter III.10). If individuals in a population are likely to experience different conditions as they develop, then the evolution of a genotype that could produce appropriate phenotypes depending on circumstances would be advantageous. Although selection on these different phenotypes would not lead to evolutionary change, the degree of plasticity itself can evolve if differences in extent of plasticity lead to differences in the number of surviving offspring. Indeed, an open question is, why don't populations evolve to become infinitely malleable, capable of producing the appropriate phenotype for any environment? Presumably, plasticity has an associated cost such that adaptation to different environments often occurs by genetic differentiation rather than by the evolution of a single genotype that can produce different phenotypes. Such costs, however, have proven difficult to demonstrate.

Differences observed among populations may also reflect plastic responses to different environmental conditions and thus may not reflect genetic differentiation. However, if consistently transmitted from one generation to the next, such nongenetic differences may lead to divergent selective pressures on traits that are genetically determined, thus promoting evolutionary divergence between the populations. One particular example concerns behavior, which is highly variable in response to the environment—an extreme manifestation of plasticity (see chapter VIII.10). Learned behaviors that are transmitted from one generation to the next—often called *traditions* or *culture*—occur not only in humans but in other animals, not only our near relatives the apes but also cetaceans, birds, and others. Such behavioral differences among populations would not reflect genetic differentiation, but they might set the stage for genetic divergence in traits relating to the behaviors. One can easily envision, for example, how chimpanzee populations that use different tools—such as delicate twigs to probe termite mounds, or heavy stones to pound nuts—might evolve different morphological features to enhance the effectiveness of these behaviors. A concrete example involves human populations that tend cattle—surely a nongenetically based behavior—and have evolved genetic changes to permit the digestion of milk in adults.

4. IN THE LIGHT OF EVOLUTION

In a 1964 address to the American Society of Zoologists, the distinguished Russian-born biologist Theodosius Dobzhansky proclaimed "nothing makes sense in biology except in the light of evolution." Ever since, evolutionary biologists have trotted out this phrase (or some permutation of it) to emphasize the centrality of evolution in understanding the biological world. Nonetheless, for much of the twentieth century, the pervasive importance of an evolutionary perspective was not at all obvious to many biologists, some of whom considered Dobzhansky's claim to be self-serving hype. One could argue, for example, that the enormous growth in our understanding of molecular biology from 1950 to 2000 was made with little involvement or insight from evolutionary biology. Indeed, to the practicing molecular biologist in the 1980s and 1990s, evolutionary biology was mostly irrelevant.

Now, nothing could be further from the truth. When results of the human genome sequencing project first appeared in 2000, many initially believed that a thorough understanding of human biology would soon follow, answering questions about the genetic basis of human diseases and phenotypic variation among individuals. These hopes were quickly dashed—the genetic code, after all, is nothing more than a long list of letters (A, C, G, and T, the abbreviations of the four nucleotide building blocks of DNA). Much of the genome of many species seems to have no function and is just, in some sense, functionless filler; as a result, picking out where the genes lie in this 4 billion–long string of alphabet spaghetti, much less figuring out how these genes function, is not easy.

So where did molecular biologists turn? To the field of evolutionary biology! Genomicists soon realized that the best way to understand the human genome was to study it in the context of its evolutionary history, by comparing human sequences with those of other species in a phylogenetic framework. One method for locating genes, for example, is to examine comparable parts of the genome of different species. The underlying rationale is that genes evolve more slowly than other parts of the genome. Specifically, nonfunctioning stretches of DNA tend to evolve differences through time as random mutations become established (the process of genetic drift; see chapter IV.1), but functioning genes tend to diverge less, because natural selection removes deleterious mutations when they arise, keeping the DNA sequence similar among species. As a result, examination of the amount of divergence between two species relative to the amount of time since they shared a common ancestor can pinpoint stretches of DNA where evolution has occurred slowly, thus identifying the position of functional genes. Moreover, how a gene functions can often be deduced by comparing its function with that of homologous genes in other species and using a phylogeny to reconstruct the gene's evolutionary history (see chapter V.14).

And thus was born the effort to sequence the genomes of other species (see chapter V.3). At first, the nascent field of comparative genomics focused on primates and model laboratory species such as mice and fruit flies, the former to permit comparisons of the human genome with that of our close evolutionary relatives, the latter to take advantage of the great understanding of the genomic systems of well-studied species.

More recently, the phylogenetic scope has broadened as it has become evident that useful knowledge can be gained by examining genomes across the tree of life—knowledge of the genetic causes of Parkinson's disease in humans, for example, can be gained from studying the comparable gene in fruit flies, and much of relevance to humans can be learned from understanding the genetic basis of differences among dog breeds.

Dobzhansky would not have been surprised. Evolutionary biology turns out to be integral to understanding the workings of DNA and the genome, just as it is key to understanding so many other aspects of our biological world (see chapter I.3).

5. CRITIQUES AND THE EVIDENCE FOR EVOLUTION

Unique among the sciences, evolutionary biology's foundation—that species evolve through time—is not accepted by a considerable number of nonscientists, especially in the United States, Turkey, and a few other countries. Public opinion polls repeatedly reveal that most Americans are either unsure about or do not believe in evolution. One yearly poll conducted for more than 30 years, for example, consistently finds that about 40 percent of the US population believes that God created humans in their present form in the recent past.

Yet, the scientific data for evolution is overwhelming (summarized in chapter I.3). Just like the composition and structure of genomes, many other biological phenomena are explicable only in an evolutionary context. Why, if evolution had not occurred, would whales have tiny vestiges of a pelvis buried deep within their blubber? Why would cave fish and crickets have eyes that are missing some parts and could not function even if there were light? Why do human fetuses develop, and then lose, fur and a tail? All these, and many other phenomena, are easily understood as a result of the evolutionary heritage of species but are inexplicable in the absence of evolution.

The case for evolution is built on two additional pillars. First is the fossil record, which documents both the major and minor transitions in the history of life (see chapters II.9–II.18); each year, exciting new discoveries further narrow the gaps in our understanding of life's chronicle. Second is our understanding of evolutionary process, in particular, natural selection, the primary driver of evolutionary divergence. Studies in the laboratory and in human-directed selective breeding clearly demonstrate the efficacy of selection in driving substantial genetic and phenotypic divergence; one need look no further than the enormous diversity of dog breeds to appreciate the power of sustained selection. Moreover, scientists are increasingly documenting the occurrence of natural selection in nature and its ability to transform species, sometimes over quite short periods of time.

The public debate is ironic given that manifestation of evolution has so many important societal consequences (see chapter VIII.1). Evolutionary adaptation of disease-causing organisms has rendered many drugs ineffective, leading to a huge public health toll as diseases thought to have been vanquished have reemerged as deadly scourges (see chapter VIII.3). A recent example is the evolution of resistance to antibiotics in the bacterium *Staphylococcus aureus*, which leads to more than 100,000 infections and 19,000 fatalities a year in the United States. A similar story exists about insect pest species that devour our crops and spread diseases. In the United States alone, the evolution of pesticide resistance results in agricultural losses totaling between $3 billion and $8 billion per year. Perhaps most scary is the realization that the human population is an enormous resource to many organisms and that natural selection continually pushes these species to become more adept at making use of this potential bonanza. Ebola, AIDS, influenza—all are diseases caused by viruses that adapt to take advantage of us; a particularly worrisome concern is that some form of avian flu could evolve to become more virulent to or transmissible between humans, with the potential to produce a pandemic that could kill millions (see chapter VIII.2). All these problems are the result of evolutionary phenomena, and all are studied using the tools of evolutionary biology.

6. THE PACE OF EVOLUTION

For more than a century after the publication of *On the Origin of Species*, biologists thought that evolution usually proceeded slowly. To a large extent, this thinking was a result of Darwin's writing—"We see nothing of these slow changes in progress, until the hand of time has marked the long lapse of ages" (*On the Origin of Species*, chap. 4, 1859). Darwin was, after all, right about so many things, big and small, from accurately deducing the manner in which coral atolls form to correctly predicting the existence of an unknown moth with a 12-inch proboscis from the morphology of a Malagasy orchid. Hence, biologists have learned that it doesn't generally pay to disagree with what Darwin said.

Nonetheless, Darwin was not right about everything. One major mistake was the mechanism of heredity, not surprising, since Mendel's work was unknown to him, and the discovery that DNA is the genetic material was still a century in the future. A second error concerned the pace at which evolution occurs. Darwin expected that natural selection would be weak and consequently that evolutionary change would happen slowly, taking many thousands or millions of years to cause detectable change. Of course, in his day there were no actual data underlying this conclusion; rather, this expectation sprang from Darwin's appreciation of the view promulgated by his mentor, the geologist Charles Lyell, that the slow accumulation of changes caused by weak forces would lead in the fullness of geologic time to major changes, a position in agreement with the prevailing Victorian wisdom about the slow and gradual manner in which change occurs—or should occur—in both nature and human civilization.

Darwin's view influenced evolutionary biologists for more than a century—well into the 1970s, most thought that evolution usually occurred at a snail's pace. Spurred by the results of long-term field studies of natural selection that began in earnest around that time, we now know that Darwin was far off the mark. Many studies now clearly indicate that selection in nature is often strong, and that as a result, evolutionary change often occurs very rapidly (see chapter III.7).

One important consequence of this realization is that we can observe evolution in real time. Pioneered by the study of Galápagos finches by Peter and Rosemary Grant, who documented rapid evolutionary change in these birds (appropriately named after Darwin) from one generation to the next in response to weather-induced environmental changes, the study of real-time evolutionary change in nature has become a cottage industry, with hundreds, or perhaps now thousands, of well-documented examples. This work not only clearly demonstrates the occurrence of evolution but also provides great insights into the processes (usually, but not always, natural selection) that cause it.

Perhaps most exciting, the rapidity by which evolution can occur has opened the door to evolutionary experiments in which researchers can alter environmental conditions and test evolutionary hypotheses over a several-year period. Work at the forefront in this area involved studies on the color of guppies in Trinidad. Observing that the fish were generally much more colorful when they occurred in streams without predators, John Endler moved some fish from streams with predators to nearby areas lacking them; very quickly, the populations evolved exuberant coloration, apparently a result of a female preference for brighter males, which, left unchecked by the absence of predators, led to rapid evolution over 14 generations. Subsequent studies have shown that the guppies freed from predation evolve many other differences, such as in growth and reproductive rates (see chapter III.11). Many similar studies are now ongoing, and it is a safe prediction that field experiments will be an important tool for understanding evolutionary processes in the future.

7. EVOLUTION, HUMANS, AND SOCIETY

Evolution has important implications for humans in a number of ways. Some have already been discussed: humans have used evolutionary principles to alter many species to our own ends (see chapter VIII.5); conversely, wild species are responding to human-caused changes in the environment, adapting to our efforts to control them and responding to new opportunities (see chapter VIII.3). Consequently, it's no surprise that knowledge of evolution is important for efforts to improve artificial selection and combat our evolutionary foes. What is more surprising, perhaps, is the diversity of areas in which an understanding of evolutionary processes is relevant to human society. These include not only medicine (see chapters VIII.1 and VIII.2), conservation (see chapter VIII.6), and criminal forensics (see chapter VIII.4), but also important human pursuits such as creating new molecules in the laboratory (see chapter VIII.7) and devising algorithms to solve analytically intractable problems (see chapter VIII.8).

Beyond purely utilitarian functions, an understanding of evolution can tell us much about ourselves: where we came from and where we may be going, perhaps even shedding light on what it means to be human. In recent years, a series of important fossil discoveries have brought into focus many aspects of the human evolutionary story, from our early primate roots to our recent past. Sequencing of the genomes of humans past and present and of our close primate relatives has complemented these findings in important ways and in some cases has led to unexpected discoveries, such as evidence of lineages, like the Denisovans, for which little fossil data exist (see chapters II.18 and V.15).

But what about our evolutionary future? When I was a boy, the public service television station ran short filler promos speculating that in the future, humans would have a bulbous, brain-packed head with tiny eyes and nostrils. Where this idea came from I have no idea, but it probably represented a mixture of orthogenetic thinking —human evolution has been marked by rapid increase in brain size and so must continue in that direction—with a misguided notion that evolution equals progress, and because intelligence is the hallmark of the human species, it would surely continue to evolve into the future. Even then, I could sense that something was not quite right about this prediction, and today, in fact, many believe that human evolution has ended because selection no longer operates on phenotypic traits: not only has medical care ameliorated the negative consequences of many genetic traits, but human cultural practices such as birth control may have severed the positive link between beneficial traits (e.g., physical strength, intelligence) and reproductive output.

Although these points have validity, they are not absolute. In much of the developing world, selective agents such as malaria can still exert strong selective pressure in the absence of adequate medical care. Moreover, new diseases, such as AIDS, for which, at least initially, no treatment exists, continue to emerge and may impose selection on populations in all parts of the world. Even in the developed world, evidence suggests that some genetically based traits are correlated with survival and reproductive success, and thus that natural selection is still leading to evolutionary change (see chapters VII.11 and VIII.12). Finally, natural selection is only one of several evolutionary processes. Surely, the increased mobility of humans is increasing the homogenizing effects of gene flow and diminishing the diversifying effects of genetic drift that acts in small and isolated populations. Human populations never existed as discretely identifiable genetic "races" (see chapter VIII.11), but ongoing genetic exchange is diminishing the geographic variation that was the result of our past evolutionary history (see chapter VIII.12).

Although selection has been important in shaping human evolution, that does not mean that natural selection can explain all aspects of the human condition. Many human traits—our large brain, altruistic behavior, keen sense of smell—may have evolved as adaptations, but others may represent phenotypic plasticity or may have evolved for nonadaptive reasons. The field of evolutionary psychology focuses particularly on human behavior and is very controversial; some see in most human behavior evidence for adaptation to conditions past or present, but others are more skeptical (see chapter VII.12).

Many look to evolution to help address issues about what it means to be human. Those questions are primarily in the realm of philosophy rather than evolutionary biology and for the most part do not fall within the purview of this volume or this chapter. Nonetheless, I will end with two observations. First, recent advances make clear that plants and animals occupy only a small part of the evolutionary tree of life; a great variety of microbial species constitute most of life's diversity. As a result, the human species is just one of millions of tiny branches on the evolutionary tree, and these microbial species are as well adapted to their ecological niches as we are to ours. It is easy for humans to view life's history anthropocentrically as a great evolutionary progression leading ultimately to us, but microbial species adapted to a great diversity of extreme environments—Yellowstone's hot springs, deep-sea hydrothermal vents—might see things differently. Second, the dinosaurs—members of the class Reptilia—dominated the earth for more than 150 million years. For most of that time, they cohabited with our mammalian ancestors, who were generally small-bodied, minor players in Mesozoic ecosystems. Conventional wisdom has it that our mammal ancestors, thanks to their large brains and warm-blooded physiology, outcompeted dinosaurs, and ultimately would have displaced them. However, evidence for this view is slender; right before the end of their reign, dinosaurs were thriving and showed no evidence of being pushed out by mammals. It is thought provoking to contemplate what the world would be like—where we would be today—had an asteroid not slammed into the earth 65.3 million years ago, wiping out the dinosaurs and clearing the way for the evolutionary diversification of mammals, including our own species.

FURTHER READING

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