Epilogue

Our charge in this book has been to investigate all the issues surrounding the mystery of dinosaur extinction. In the process, our investigation led to some startling conclusions. To begin with, it is difficult for us to believe that since we met at Berkeley, we witnessed and even participated in a solution to the long-standing mystery involving dinosaur extinction. But it wasn't a solution that either of us envisioned when we started. Like many breakthroughs in science, solving the mystery turned on asking the right question. The final solution required us to ask: "Did *all* dinosaurs really go extinct at the K-T boundary?" This was a very different question than the one scientists had asked for more than 150 years: "What caused the extinction of dinosaurs at the K-T boundary?" To our surprise, the solution didn't involve catastrophic asteroid impacts or cataclysmic volcanic eruptions, and we discovered that even in the “modern” scientific age, our world view could be jolted and turned upside down.

It was also surprising to see historic scientific arguments of the 19th century replayed in our contemporary setting. Several aspects of the classical debates over catastrophism vs. uniformitarianism that accompanied the emergence of geology as a science nearly two centuries ago were replayed by our colleagues over events at the K-T boundary. It was thrilling for us as graduate students to watch the renewed debate because it was evident that issues of historic proportion were at stake, just as before. The modern discovery of evidence of a great bolide impact at the end of the Cretaceous was an historic breakthrough in terms of available mechanisms for interpreting Earth history, and it certainly makes the sky and the future much more interesting for us all.

Also replayed in two different centuries was the debate over the ancestry of birds. In the modern drama, *Deinonychus* replaced *Compsognathus*, and far more evidence was brought to bear on the question. But the plot is basically the same. Today, the available information overwhelmingly supports the conclusion that Mesozoic theropods are the ancestors of birds, and this was the most strongly supported conclusion a century ago. More significantly, a classical battle over the theory of evolution was also replayed, framed this time as conflict between Linnaean taxonomists and phylogenetic systematists. Today’s battleground might seem different because nearly everyone claims to be an evolutionist. But conceptual tools forged by anti-evolutionists, like the theory of

homoplasy, are still at the root of the conflict. Pre-Darwinian tools for ordering the diversity of Life, like classifications based on overall similarity, also catalyzed both generations of the debate. As before, these outdated tools and concepts perform poorly in explaining all the available evidence or in making predictions about the future. The Darwinian revolution should have led to fundamentally new ways to classify Earth's biota. But it has taken more than a century for scientists to recognize the full implications of the theory of evolution and to adopt an armament of appropriate tools. With the new tools and techniques, the current generation of naturalists is rewriting the history of Life.

We had yet another kind of surprise over the course of our investigation, this one about how world views are shaped. Although we had learned about uniformitarianism and evolution as undergraduates, it was impossible at that time to foresee how many new discoveries would continue to cascade from these great ideas, or to predict the degree to which these ideas would continue to change our world views as scientists struggled to understand human's place in Nature. That uniformitarianism and evolution have been hotly discussed and debated for two centuries attests to their enormous explanatory power and the wealth of realizations that have flowed from them. Detecting what happened at the end of the Cretaceous and tracking the ancestry of birds were as much exercises in understanding the history of these two ideas as in compiling mountains of physical evidence. After all, Walter and Louis Alvarez recognized the great K-T bolide impact from an almost immeasurably small amount of iridium, and Carl Gegenbaur connected modern birds with Mesozoic dinosaurs using only two fossils – *Archaeopteryx* and *Compsognathus*.

While students of Nature have always encountered surprises such as these, we can see that today's students face a very different experience than did we or our predecessors. During the 18th and 19th centuries, the pace of discovery for living species was dazzling, and students at that time struggled to comprehend the seemingly unbounded and growing diversity of Life that naturalists were documenting with the first large-scale scientific explorations of the world. Thanks to Richard Owen and other great naturalists, the fossil record was slowly becoming known, although compared with the information on the living biota, data from ancient times was only slowly dribbling in.

Because these early naturalists did such a thorough job, by the time we were students, we were presented with a precise census of modern dinosaurian diversity and geographic distribution that has changed only slightly in the subsequent decades. Today, students can grasp the diversity of living birds from a single textbook on ornithology. In the year that it took to write this book, only two new species of living birds were discovered --one in the Andean forests, the other in the Philippines. With hundreds of thousands of amateur bird watchers and hundreds of trained naturalists studying the birds of the world, it is obvious that very nearly all of the species of birds alive today on the planet have been discovered and named. If we had wanted to discover and describe new species of living birds, we were born a century too late. Indeed, students of our generation often express their disappointment and sense of deep loss that Nature's frontiers, by the time we reached them, were so thoroughly explored. Compared to the prospects that faced a young Richard Owen, Charles Darwin, or John James Audubon, our own prospects often seem pitifully tame.

Although there remains no shortage of challenges in documenting the modern biota, for us the most enthralling scientific frontier has been the past, the deep history of birds and their extinct dinosaurian relatives. Like the students in Richard Owen's time, we recognized that only by measuring what has gone before can we predict what might lie ahead. But during our careers, the pace of discovery of extinct birds has greatly exceeded 19th century levels, so the ancient world was far more accessible to us than students a century ago. With modern radiometric dating methods, detailed geological maps, and a host of powerful technologies, we now have detailed chronologies and phylogenetic maps that trace the roots of our modern biota far back into time. The tumultuous pace of new fossil discoveries has presented a challenging and rapidly shifting view of the history of birds and other dinosaurs. And with a far richer picture of the history of Life, we now look ahead with an entirely different perspective than students did in the last century.

So great has been this shift in perspective, that the students in today's classroom face a radically different situation from the one that we experienced just two decades ago at Berkeley. Having long gazed back over our shoulders into the Cretaceous to understand the K-T mass extinction, the destiny of dinosaurs now presents scientists with a profound irony. Although a diverse array of stupendous animals was wiped out at the

end of the Cretaceous, for dinosaurs the worst may still lie ahead. No matter what caused the K-T extinction, the dinosaur lineage survived to the present day. But the number of dinosaur species has dwindled alarmingly in the short time that humans have populated and exploited the world. Human proliferation across the Pacific islands, by everyone from Aboriginals to the British and American navies, wiped out more dinosaur species than whatever event or combination of events triggered the terminal Cretaceous extinctions. We are doing it again with the current wave of population expansion that is decimating the world's tropical rainforests--the greatest haven for modern dinosaur diversity. In spite of the remarkable progress that the scientific community has made in unraveling the evolutionary history of dinosaurs, we peer out toward the future from a perplexing perspective. Wouldn't it be tragic if, despite all our attempts to pin the atrocity on ancient catastrophes and cataclysms, dinosaurs were extinguished--not by the next extraterrestrial impact or volcanic eruption--but rather by the actions of our own human hands?

While a human role in the extermination of modern species has been acknowledged since Richard Owen’s time, only recently have we come to appreciate the full scope of that role. Today’s students will be the first generation of scientists to live with the realization, from the earliest stages of their careers, that they are witnessing one of the greatest global extinctions of all time. When we share the bleak irony of modern dinosaur extinction with this next generation of naturalists training in our classrooms, our students sometimes express their humiliation in belonging to the human species and the hopelessness of cleaning up our mess. These are new attitudes and they reflect a huge shift in world view from when we were students.

But in spite of the ample cause for pessimism, it is important for today’s students to recognize that they themselves did not create this situation, even if their human forebears did. More importantly, they must understand that they and their human descendants will shape and witness the ultimate destiny of dinosaurs. And since we now understand that so much of the modern extinction was human caused, it is evident that human solutions can be found. It is also important for today’s students to realize that their ability to preserve the modern diversity of dinosaurs, as for biodiversity in general, will be predicated upon the skills and knowledge that they assemble today. Great universities and natural history museums have been established in many parts of the

world, and so the mechanism is largely in place to attack the next great frontiers of natural history. For the coming generation of students, these frontiers will include the heavens as well as the Earth itself, and the great issues for them will now include future biodiversity in addition to refining our measures of the diversity of the present and past. So, the prospects of great challenges and heroic accomplishments for the next generation of scientists are rich indeed.

That is, if sufficient resources are provided to them. Across the United States, geology departments were shut down in many colleges and universities following a depression in oil prices and cutbacks in petroleum exploration over the last two decades. Richard Owen's Natural History Museum – once the world's greatest center for the study of natural history -- has slashed its curatorial and research staff owing to a budget crisis in England. For the same reasons, the great London Zoological Gardens were recently forced to cutback their public displays and to give away many of the rare and endangered animals in their collections. Research budgets are diminishing everywhere, and as biodiversity continues to decline at an alarming rate, the remaining opportunities for us to study Nature and to plan for the future are rapidly dwindling. Whereas a great, if aging, infrastructure of universities, museums, research laboratories, government agencies, and libraries is now in place to train a new generation of naturalists, what is lacking is a wide-spread political will to prioritize funding toward education in general and natural history in particular. The Texas state government, to cite a tragically absurd example, now invests more public funding in building new prisons than building new schools or maintaining the schools already in operation.

Still, there is time to educate our politicians and public, and to accomplish a great deal of good in the decades ahead. For endangered birds, projects like the ongoing attempts to restore natural populations of California Condors and to rebuild natural populations of the Whooping Crane, offer both hope and informative examples for future strategies. Experiments in the preservation of large, diverse habitats are underway in Costa Rica and Irian Jaya, and these may lead to conservation of huge regions. The recent biotechnology revolution is sufficiently advanced that we can only say that it is impossible to predict where we will be a century from now or what role this exciting breakthrough will play in conservation biology. For students willing to take the risk of a

long, difficult apprenticeship and uncertain job prospects, the next generations of natural historians will face the greatest challenges but also some of the greatest rewards.

We now work out of academic centers in New York City and Austin, Texas. We still go into the field whenever we can, to continue searching for evidence of what happened at the end of the Cretaceous and to refine the evolutionary map of vertebrate history. These opportunities to explore natural history in the field, and the chance for new discoveries out in the badlands, are the primary reasons we put up with all those painful tests in school. It remains the most exhilarating work we can imagine, and it has only become more invigorating as we have come to appreciate the growing importance of natural history. The examples set by Owen, Darwin, Audubon, and the many naturalists since their time, present great models for future scientists by showing the fabulous impact that natural historians can have on the world view of all people. But in many ways today's challenges offer far greater opportunities for significant contributions than were available to our predecessors. Today, we can read a far deeper significance for the future in by exploring the past, and this provides the greatest motivation we have ever had to go into Nature and to explore the history of our world.