deep history a thousand times older than that conceived by the Western religions. Its study has brought new revelations of great moral importance. It has made us realize that *Homo sapiens* is far more than a congeries of tribes and races. We are a single gene pool from which individuals are drawn in each generation and into which they are dissolved the next generation, forever united as a species by heritage and a common future. Such are the conceptions, based on fact, from which new intimations of immortality can be drawn and a new mythos evolved.

Which world view prevails, religious transcendentalism or scientific empiricism, will make a great difference in the way humanity claims the future. During the time the matter is under advisement, an accommodation can be reached if the following overriding facts are realized. On the one side, ethics and religion are still too complex for present-day science to explain in depth. On the other, they are far more a product of autonomous evolution than hitherto conceded by most theologians. Science faces in ethics and religion its most interesting and possibly humbling challenge, while religion must somehow find the way to incorporate the discoveries of science in order to retain credibility. Religion will possess strength to the extent that it codifies and puts into enduring, poetic form the highest values of humanity consistent with empirical knowledge. That is the only way to provide compelling moral leadership. Blind faith, no matter how passionately expressed, will not suffice. Science for its part will test relentlessly every assumption about the human condition and in time uncover the bedrock of the moral and religious sentiments.

The eventual result of the competition between the two world views, I believe, will be the secularization of the human epic and of religion itself. However the process plays out, it demands open discussion and unwavering intellectual rigor in an atmosphere of mutual respect.

CHAPTER 12

To What End?

IT IS THE CUSTOM of scholars when addressing behavior and culture to speak variously of anthropological explanations, psychological explanations, biological explanations, and other explanations appropriate to the perspectives of individual disciplines. I have argued that there is intrinsically only one class of explanation. It traverses the scales of space, time, and complexity to unite the disparate facts of the disciplines by consilience, the perception of a seamless web of cause and effect.

For centuries consilience has been the mother's milk of the natural sciences. Now it is wholly accepted by the brain sciences and evolutionary biology, the disciplines best poised to serve in turn as bridges to the social sciences and humanities. There is abundant evidence to support and none absolutely to refute the proposition that consilient explanations are congenial to the entirety of the great branches of learning.

The central idea of the consilience world view is that all tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics. In support of this idea is the conclusion of biologists that humanity is kin to all other life forms by common descent. We share essentially the same DNA genetic code, which is transcribed into RNA and translated into proteins with the same amino acids. Our anatomy places us among the Old World monkeys and apes. The fossil record shows our immediate ancestor to be either *Homo ergaster* or *Homo erectus*. It suggests that the point of our origin was Africa about two hundred thousand years ago. Our hereditary human nature, which evolved during hundreds of millennia before and afterward, still profoundly affects the evolution of culture.

These considerations do not devalue the determining role of chance in history. Small accidents can have big consequences. The character of individual leaders can mean the difference between war and peace; one technological invention can change an economy. The main thrust of the consilience world view instead is that culture and hence the unique qualities of the human species will make complete sense only when linked in causal explanation to the natural sciences. Biology in particular is the most proximate and hence relevant of the scientific disciplines.

I know that such reductionism is not popular outside the natural sciences. To many scholars in the social sciences and humanities it is a vampire in the sacristy. So let me hasten to dispel the profane image that causes this reaction. As the century closes, the focus of the natural sciences has begun to shift away from the search for new fundamental laws and toward new kinds of synthesis—"holism," if you prefer—in order to understand complex systems. That is the goal, variously, in studies of the origin of the universe, the history of climate, the functioning of cells, the assembly of ecosystems, and the physical basis of mind. The strategy that works best in these enterprises is the construction of coherent cause-and-effect explanations across levels of organization. Thus the cell biologist looks inward and downward to ensembles of molecules, and the cognitive psychologist to patterns of aggregate nerve cell activity. Accidents, when they happen, are rendered understandable.

No compelling reason has ever been offered why the same strategy should not work to unite the natural sciences with the social sciences and humanities. The difference between the two domains is in the magnitude of the problem, not the principles needed for its solution. The human condition is the most important frontier of the natural sciences. Conversely, the material world exposed by the natural sciences is the most important frontier of the social sciences and humanities.

The consilience argument can be distilled as follows: The two frontiers are the same.

The map of the material world, including human mental activity, can be thought a sprinkling of charted terrain separated by blank expanses that are of unknown extent yet accessible to coherent interdisciplinary research. Much of what I have offered in earlier chapters has been "gap analysis," a sketch of the position of the blank spaces, and an account of the efforts of scholars to explore them. The gaps of greatest potential include the final unification of physics, the reconstruction of living cells, the assembly of ecosystems, the coevolution of genes and culture, the physical basis of mind, and the deep origins of ethics and religion.

If the consilience world view is correct, the traverse of the gaps will be a Magellanic voyage that eventually encircles the whole of reality. But that view could be wrong: The exploration may be proceeding across an endless sea. The current pace is such that we may find out which of the two images is correct within a few decades. But even if the journey is Magellanic, and even if the boldest excursions of circumscription consequently taper off, so that the broad outline of material existence is well defined, we will still have mastered only an infinitesimal fraction of the internal detail. Exploration will go on in a profusion of scholarly disciplines. There are also the arts, which embrace not only all physically possible worlds but also all conceivable worlds innately interesting and congenial to the nervous system and thus, in the uniquely human sense, true.

Placed in this broader context—of existence coherent enough to be understood in a single system of explanation, yet still largely unexplored—the ambitions of the natural sciences might be viewed in a more favorable light by nonscientists. Nowadays, as polls have repeatedly shown, most people, at least in the United States, respect science but are baffled by it. They don't understand it, they prefer science fiction, they take fantasy and pseudoscience like stimulants to jolt their cerebral pleasure centers. We are still Paleolithic thrill seekers, preferring *Jurassic Park* to the Jurassic Era, and UFOs to astrophysics.

The productions of science, other than medical breakthroughs and the sporadic thrills of space exploration, are thought marginal. What really matters to humanity, a primate species well adapted to Darwinian fundamentals in body and soul, are sex, family, work, security, personal expression, entertainment, and spiritual fulfillment—in no particular order. Most people believe, I am sure erroneously, that science has little to do with any of these preoccupations. They assume that the social sciences and humanities are independent of the natural sciences and more relevant endeavors. Who outside the technically possessed really needs to define a chromosome? Or understand chaos theory?

Science, however, is not marginal. Like art, it is a universal possession of humanity, and scientific knowledge has become a vital part of our species' repertory. It comprises what we know of the material world with reasonable certainty.

If the natural sciences can be successfully united with the social sciences and humanities, the liberal arts in higher education will be revitalized. Even the attempt to accomplish that much is a worthwhile goal. Profession-bent students should be helped to understand that in the twenty-first century the world will not be run by those who possess mere information alone. Thanks to science and technology, access to factual knowledge of all kinds is rising exponentially while dropping in unit cost. It is destined to become global and democratic. Soon it will be available everywhere on television and computer screens. What then? The answer is clear: synthesis. We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.

And this much about wisdom: In the long haul, civilized nations have come to judge one culture against another by a moral sense of the needs and aspirations of humanity as a whole. In thus globalizing the tribe, they attempt to formulate humankind's noblest and most enduring goals. The most important questions in this endeavor for the liberal arts are the meaning and purpose of all our idiosyncratic frenetic activity: *What are we, Where do we come from, How shall we decide where to go?* Why the toil, yearning, honesty, aesthetics, exaltation, love, hate, deceit, brilliance, hubris, humility, shame, and stupidity that collectively define our species? Theology, which long claimed the subject for itself, has done badly. Still encumbered by precepts based on Iron Age folk knowledge, it is unable to assimilate the great sweep of the real world now open for examination. Western philosophy offers no promising substitute. Its involuted exercises and professional timidity have left modern culture bankrupt of meaning.

The future of the liberal arts lies, therefore, in addressing the fundamental questions of human existence head on, without embarrassment or fear, taking them from the top down in easily understood language, and progressively rearranging them into domains of inquiry that unite the best of science and the humanities at each level of organization in turn. That of course is a very difficult task. But so are cardiac surgery and building space vehicles difficult tasks. Competent people get on with them, because they need to be done. Why should less be expected from the professionals responsible for education? The liberal arts will succeed to the extent that they are both solid in content and as coherent among themselves as the evidence allows. I find it hard to conceive of an adequate core curriculum in colleges and universities that avoids the cause-and-effect connections among the great branches of learning—not metaphor, not the usual second-order lucubrations on why scholars of different disciplines think this or that, but material cause and effect. There lies the high adventure for later generations, often mourned as no longer available. There lies great opportunity.

GRANTED THERE IS also a whiff of brimstone in the consilient world view and a seeming touch of Faust to those committed to its humanistic core. And these too need to be closely examined. What was it that Mephistopheles offered Faust, and how was the ambitious doctor to pay? From Christopher Marlowe's play to Goethe's epic poem the bargain was essentially the same: earthly power and pleasure in exchange for your soul. Then there were the differences. Marlowe's Faust was irrevocably damned when he made the wrong choice; Goethe's Faust was saved because he could not feel the happiness promised him through material gain. Marlowe upheld Protestant piety, Goethe the ideals of humanism.

In our perception of the human condition we have moved beyond Marlowe and Goethe. Today not one but two Mephistophelean bargains can be distinguished. From them, as from the original, hard choices must be made. Both illustrate the value of considering the consilient vision.

The first Faustian choice was actually made centuries ago, when humanity accepted the Ratchet of Progress: The more knowledge people acquire, the more they are able to increase their numbers and to alter the environment, whereupon the more they need new knowledge just to stay alive. In a human-dominated world, the natural environment steadily shrinks, offering correspondingly less and less per capita return in energy and resources. Advanced technology has become the ultimate prosthesis. Take away electric power from a tribe of Australian Aborigines, and little or nothing will happen. Take it away from residents of California, and millions will die. So to understand why humanity has come to relate to the environment in this way is more than a rhetorical question. Greed demands an explanation. The Ratchet should be constantly re-examined, and new choices considered.

The second Mephistophelean promise, generated by the first and strangely echoing the original Enlightenment, is due within a few decades. It says: You may alter the biological nature of the human species in any direction you wish, or you may leave it alone. Either way, genetic evolution is about to become conscious and volitional, and usher in a new epoch in the history of life.

Let us examine the two bargains, the second first for logical coherence, and consider the alternative fates they seem to imply.

It is useful to know, before peering into the future, where we are now. Is genetic change still occurring in the old-fashioned way, or has civilization brought it to a halt? The question can be put more precisely as follows: Is natural selection still operating to drive evolution? Is it forcing our anatomy and behavior to change in some particular direction in response to survival and reproduction?

The answer, like so many responses required in subjects of great complexity, is yes and no. To my knowledge no evidence exists that the human genome is changing in any overall new direction. It may come immediately to your mind that the forces most afflicting humanity, including overpopulation, war, outbreaks of infectious disease, and environmental pollution, must somehow be pushing the species along in a directed manner. But these pressures have existed around the world for millennia, forcing the periodic decline of populations and even the destruction and replacement of entire peoples. Much of the adaptation expected to arise has probably already done so. Contemporary human genes are therefore likely to reflect the necessities these malign forces imposed in the past.

We do not, for example, appear as a species to be acquiring genes for larger or smaller brains, more efficient kidneys, smaller teeth,

greater or lesser compassion, or any other important adjustments in body and mind. The one undoubted global change is of lesser consequence. It is the shift occurring worldwide in the frequencies of racial traits such as skin color, hair type, lymphocyte proteins, and immunoglobulins, due to more rapid population growth in developing countries. In 1950, 68 percent of the world's population lived in developing countries. By 2000 the figure will be 78 percent. That amount of change is having an effect on the frequencies of previously existing genes, but none of the traits involved, so far as we know, have world-shaping consequence. None affect intellectual capacity or the fundamentals of human nature.

A few local quirks have been detected as well. There is, for example, brachycephalization. For the past ten thousand years, the heads of people have been growing rounder in populations as far apart as Europe, India, Polynesia, and North America. In rural Poland, between the Carpathian Mountains and the Baltic Sea, anthropologists have documented the trend in skeletons from around 1300 to the early twentieth century, embracing about thirty generations. The change is due principally to the slightly higher survival rate of round-heads, and not to the influx of brachycephalics from outside Poland. The trait has a partial genetic basis, but the reason for its greater Darwinian success, if any, remains unknown.

Many hereditary divergences of local populations have been discovered in blood types, disease resistance, aerobic capacity, and the ability to digest milk and other foodstuffs. Most such differences can at least be tentatively linked to higher survival and reproduction in known conditions of the local environment. The frequency of adults able to digest milk, one of the most thoroughly studied traits, is highest in populations that have relied on dairying for many generations. Another local trend of adaptive nature was reported in 1994 by a group of Russian geneticists. Turkmen-speaking people from the hot deserts of Middle Asia, they discovered, produce more heat shock proteins in their skin fibroblasts (cells that form part of the loose connective tissue) than do people who have lived for many generations in nearby moderate climates. The difference, which is genetically based, confers higher rates of survival following severe heat stress.

None of these regional trends appear to entail properties in anatomy or behavior of major consequence. Even the changes due to differential population growth are likely to prove short-lived if—as in present-day Thailand—birth rates in less developed countries drop to the levels prevailing in North America, Europe, and Japan.

The big story in recent human evolution is not directional change, not natural selection at all, but homogenization through immigration and interbreeding. Populations have been in flux throughout history. Tribes and states have pressed into and around the territories of rivals, often absorbing these neighbors, occasionally extinguishing them altogether. The historical atlases of Europe and Asia, when their pages are flipped chronologically through five millennia, become film clips of changing ethnic boundaries. As we race forward from one decade to the next in the clips, chiefdoms and states spring into existence, expand like hungry two-dimensional amoebae, and vanish as others move in to take their place.

The mixing sharply accelerated when Europeans conquered the New World and transported African slaves to its shores. Homogenization took a smaller leap in the nineteenth century with the European colonization of Australia and Africa. In more recent times it has quickened yet again through the spread of industrialization and democracy, the two signature traits of modernity that render people restless and international borders porous. Most human populations remain differentiated on a geographical basis, and some ethnic enclaves will probably endure for centuries more, but the trend in the opposite direction is unmistakably strong. It is also irreversible.

Homogenization is not dynamic on a global scale. It changes local populations, often swiftly, but cannot by itself consistently drive evolution of the human species as a whole in one direction or another. Its main consequence is the gradual erasure of previous racial differences—those statistical differences in hereditary traits that distinguish whole populations. It also increases the range of individual variation within the populations and across the entire species. Many more combinations of skin color, facial features, talents, and other traits influenced by genes are now arising than ever existed before. Yet the *average* differences between people in different localities around the world, not very great to start with, are narrowing.

Genetic homogenization has similarities to the stirring together of liquid ingredients. The contents change dramatically, and many new kinds of products emerge at the level of gene combinations within individuals. Variance increases, the extremes are extended, new forms of hereditary genius and pathology are more likely to arise. But the most elemental units, the genes, remain unperturbed. They stay about the same in both kind and relative abundance.

Continued over tens or hundreds of generations the present rates of emigration and intermarriage could in theory eliminate all population differences around the world. People residing in Beijing might become statistically the same as those in Amsterdam or Lagos. But this is not the key issue of future genetic trends, because the rules under which evolution can occur are about to change dramatically and fundamentally. Thanks to advances of genetics and molecular biology underway, hereditary change will soon depend less on natural selection than on social choice. Possessing exact knowledge of its own genes, collective humanity in a few decades can, if it wishes, select a new direction in its evolution and move there quickly. Or, if future generations prefer the free market of genetic diversity that existed in the past, they can choose simply to do nothing and live on their million-year-old heritage.

The prospect of this "volitional evolution"—a species deciding what to do about its own heredity—will present the most profound intellectual and ethical choices humanity has ever faced. The dilemma at its core is far from science fantasy. Medical researchers, motivated by the need to understand the genetic basis of disease, have begun in earnest to map the fifty thousand to one hundred thousand human genes. Reproductive biologists have cloned sheep, and presumably could do the same for human beings, if the procedure were allowed. And thanks to the Human Genome Project, geneticists will be able to read off the complete sequence of our DNA letters, 3.6 billion in all, within one or two decades. Scientists are also experimenting with a limited form of molecular engineering, in which genes are altered in a desired direction by substituting snippets of DNA. Still another fast-moving enterprise in the biological sciences is the tracking of individual development from genes to protein synthesis and thence to the final products of anatomy, physiology, and behavior. It is entirely possible that within fifty years we will understand in considerable detail not only our own heredity, but also a great deal about the way our genes interact with the environment to produce a human being. We can then tinker with the products at any level: change them temporarily without altering heredity, or change them permanently by mutating the genes and chromosomes.

If these advances in knowledge are even just partly attained, which seems inevitable unless a great deal of genetic and medical research is halted in its tracks, and if they are made generally available, which is problematic, humanity will be positioned godlike to take control of its own ultimate fate. It can, if it chooses, alter not just the anatomy and intelligence of the species but also the emotions and creative drive that compose the very core of human nature.

The engineering of the genome will be the final of three periods that can be distinguished in the history of human evolution. During almost all of the two-million-year history of the genus *Homo*, culminating in *Homo sapiens*, people were unaware of the ultramicroscopic hereditary codes shaping them. In historical times, over the past ten thousand years, populations still experienced racial differentiation, largely in response to local climatic conditions, just as they had throughout the more distant past.

During this passage through evolutionary time, shared with all other organisms, human populations were also subject to stabilizing selection; gene mutants that caused disease or infertility were weeded out in each generation. These defective alleles were able to persist only when recessive in their expression, which means their effects could be overridden by the activity of dominant genes paired with them. Possession of two recessive genes, however, causes genetic disorders, as exemplified by cystic fibrosis, Tay-Sachs disease, and sickle-cell anemia. Their double-dose carriers die young. Stabilizing selection, in this case through early death, continually sheds the genes from the population, making them mercifully rare.

With the advent of modern medicine, human evolution has entered its second period. More and more of the hereditary defects can be deliberately moderated or averted, even when the genes themselves remain unaltered and present in double dose. Phenylketonuria, for example, until recent time afflicted one out of ten thousand infants with severe mental retardation. Researchers discovered that the cause of phenylketonuria is a single recessive gene, which in double dose prevents normal metabolism of phenylalanine, a common amino acid. Abnormal metabolic products of the substance build up in the blood, causing brain damage. With this elementary fact in their reference books, physicians are now able to prevent the symptoms entirely by restricting phenylketonuric infants to phenylalanine-free diets.

Examples like the circumvention of phenylketonuria are becoming common and will be multiplied many times over in the years

immediately ahead. For the first time people are using scientific knowledge to gain conscious control over their heredity, progressing one gene at a time. The evolutionary effect will be to relax stabilizing selection at an increasing rate and thereby increase the genetic variability of humanity as a whole. This second period, the suppression of stabilizing selection, is only beginning. Over many generations, the moderation of the effects of harmful genes could result in a substantial change in human heredity at the population level. The benefits accruing will have to be bought, of course, with a growing dependence on exacting and often expensive medical procedures. The age of gene circumvention is also the age of medical prosthesis.

We should not, however, worry that such destabilizing of selection will go too far. The second period of human evolution is ephemeral. It will not last enough generations to have an important impact on heredity of the species as a whole, because the knowledge that made it possible has brought us swiftly to the brink of the third period, that of volitional evolution. If we understand what changes in the genes cause particular defects, down to the nucleotide letters of the DNA code, then in principle the defect can be permanently repaired. Geneticists are hard at work to make this feat, called gene therapy, a reality. They are hopeful that cystic fibrosis, to cite the most advanced current project, can be at least partly cured by introduction of unimpaired genes into the lung tissues of patients. Another class of defects that seem permanently treatable within a few years includes hemophilia, sickle-cell anemia, and certain other inherited blood diseases.

Progress in gene therapy has admittedly been slow in the early period. But it will accelerate. Too much hope is at stake, and too much venture capital poised, to permit failure. Once established as a practical technology, gene therapy will become a commercial juggernaut. Thousands of genetic defects, many fatal, are already known. More are discovered each year. Each such gene is carried in single or double dose by thousands to millions of people around the world, and each individual person bears on average at least several different kinds of defective genes somewhere on his chromosomes. In most cases the genes are recessive and loaded in single dose; but the carrier, even if he does not suffer the defect, risks having a child with a double dose and full-blown symptoms. It is obvious that when genetic repair becomes safe and affordable, the demand for it will grow swiftly.

Some time in the next century that trend will lead into the full

no limits to science + human enterprise?

volitional period of evolution. The advance will create a new kind of ethical problem, which will be the Faustian decision of which I spoke: How much should people be allowed to mutate themselves and their descendants? Consider that your descendants, whom you may wish to alter in some beneficent manner, may well be my descendants also through intermarriage in the years ahead. With that in mind, can we ever agree on how much DNA tinkering is moral? In making such choices, there is an important line to be drawn between the remedy of clear-cut genetic defects on one side and the improvement of normal, healthy traits on the other. The scientific imagination will think it but a small step from, say, severe dyslexia (one gene region discovered in 1994 on chromosome number 6) to mild dyslexia, and another short hop to unimpaired learning ability, and, finally one step more to superior learning ability. I suffer from a mild form of dyslexia called visual sequencing disability, habitually reversing numbers (8652 too easily becomes 8562) and struggling to grasp words spelled out to me letter by letter (I apologize and ask to see them in writing). I would certainly prefer not to suffer this minor but inconvenient debility. If it is genetic in origin, I would be pleased to learn instead that it had been fixed when I was an embryo. My parents, had they known and been able, would probably have agreed and taken care of the problem.

Fair enough, but what about altering genes in order to enhance mathematical and verbal ability? To acquire perfect pitch? Athletic talent? Heterosexuality? Adaptability to cyberspace? In a wholly different dimension, citizens of states and then of all humanity might choose to make themselves less variable, in order to increase compatibility. Or the reverse: They might choose to diversify in talent and temperament, aiming for varied personal excellence and thus the creation of communities of specialists able to work together at higher levels of productivity. Above all, they will certainly aim for greater longevity. If such engineering for long life proves even just partly successful, it will create vast social and economic dislocations.

The present trajectory of science ensures that future generations will acquire the technical ability to make such choices. We are not in the volitional period yet, but we are close enough to make the prospect worth thinking about. *Homo sapiens*, the first truly free species, is about to decommission natural selection, the force that made us. There is no genetic destiny outside our free will, no lodestar provided

by which we can set course. Evolution, including genetic progress in human nature and human capacity, will be from now on increasingly the domain of science and technology tempered by ethics and political choice. We have reached this point down a long road of travail and self-deception. Soon we must look deep within ourselves and decide what we wish to become. Our childhood having ended, we will hear the true voice of Mephistopheles.

We will also come to understand the true meaning of conservatism. By that overworked and confusing term I do not mean the pietistic and selfish libertarianism into which much of the American conservative movement has lately descended. I mean instead the ethic that cherishes and sustains the resources and proven best institutions of a community. In other words, true conservatism, an idea that can be applied to human nature as well as to social institutions.

I predict that future generations will be genetically conservative. Other than the repair of disabling defects, they will resist hereditary change. They will do so in order to save the emotions and epigenetic rules of mental development, because these elements compose the physical soul of the species. The reasoning is as follows. Alter the emotions and epigenetic rules enough, and people might in some sense be "better," but they would no longer be human. Neutralize the elements of human nature in favor of pure rationality, and the result would be badly constructed, protein-based computers. Why should a species give up the defining core of its existence, built by millions of years of biological trial and error?

What lifts this question above mere futurism is that it reveals so clearly our ignorance of the meaning of human existence in the first place. And illustrates how much more we need to know in order to decide the ultimate question: To what end, or ends, if any in particular, should human genius direct itself?

THE PROBLEM OF collective meaning and purpose is both urgent and immediate because, if for no other reason, it determines the environmental ethic. Few will doubt that humankind has created a planet-sized problem for itself. No one wished it so, but we are the first species to become a geophysical force, altering Earth's climate, a role previously reserved for tectonics, sun flares, and glacial cycles. We are also the greatest destroyer of life since the ten-kilometer-wide meteorite that landed near Yucatán and ended the Age of Reptiles sixty-five million years ago. Through overpopulation we have put ourselves in danger of running out of food and water. So a very Faustian choice is upon us: whether to accept our corrosive and risky behavior as the unavoidable price of population and economic growth, or to take stock of ourselves and search for a new environmental ethic.

That is the dilemma already implicit in current environmental debates. It springs from the clash of two opposing human self-images. The first is the naturalistic self-image, which holds that we are confined to a razor-thin biosphere within which a thousand imaginable hells are possible but only one paradise. What we idealize in nature and seek to re-create is the peculiar physical and biotic environment that cradled the human species. The human body and mind are precisely adapted to this world, notwithstanding its trials and dangers, and that is why we think it beautiful. In this respect *Homo sapiens* conforms to a basic principle of organic evolution, that all species prefer and gravitate to the environment in which their genes were assembled. It is called "habitat selection." There lies survival for humanity, and there lies mental peace, as prescribed by our genes. We are consequently unlikely ever to find any other place or conceive of any other home as beautiful as this blue planet was before we began to change it.

The competing self-image—which also happens to be the guiding theme of Western civilization—is the exemptionalist view. In this conception, our species exists apart from the natural world and holds dominion over it. We are exempt from the iron laws of ecology that bind other species. Few limits on human expansion exist that our special status and ingenuity cannot overcome. We have been set free to modify Earth's surface to create a world better than the one our ancestors knew.

For the committed exemptionalist, *Homo sapiens* has in effect become a new species, which I will now provide with a new name, *Homo proteus*, or "shapechanger man." In the taxonomic classification of Earth's creatures, the diagnosis of hypothetical *Homo proteus* is the following:

Cultural. Indeterminately flexible, with vast potential. Wired and information-driven. Can travel almost anywhere, adapt to any environment. Restless, getting crowded. Thinking about the colonization of space. Regrets the current loss of Nature and all those vanishing species, but it's the price of progress and has little to do with our future anyway.

Now here is the naturalistic, and I believe correct, diagnosis of old *Homo sapiens*, our familiar "wise man":

Cultural. With indeterminate intellectual potential but biologically constrained. Basically a primate species in body and emotional repertory (member of the Order Primates, Infraorder Catarrhini, Family Hominidae). Huge compared to other animals, parvihirsute, bipedal, porous, squishy, composed mostly of water. Runs on millions of coordinated delicate biochemical reactions. Easily shut down by trace toxins and transit of pea-sized projectiles. Short-lived, emotionally fragile. Dependent in body and mind on other earthbound organisms. Colonization of space impossible without massive supply lines. Starting to regret deeply the loss of Nature and all those other species.

The dream of man freed from the natural environment of Earth was tested against reality in the early 1990s with Biosphere 2, a 3.15-acre closed ecosystem built on desert terrain in Oracle, Arizona. Paneled in glass, stocked with soil, air, water, plants, and animals, it was designed to be a miniature working Earth independent of the mother planet. The planners synthesized fragments of rain forest, savanna, thornscrub, desert, pond, marsh, coral reef, and ocean to simulate the natural habitats of home. The only connections to the outside world were electrical power and communication, both reasonable concessions made for a primarily ecological experiment. The design and construction of Biosphere 2 cost $200 million. It incorporated the most advanced scientific knowledge and state-of-the-art engineering. Success of the experiment, if achieved, was expected to prove that human life can be independently sustained in hermetic bubbles anywhere in the solar system not lethally seared by heat or hard radiation.

On September 26, 1991, eight volunteer "Biospherians" walked into the completed enclosure and sealed themselves off. For a while everything went well, but then came a series of nasty surprises. After five months the concentration of oxygen in Biosphere 2 began to drop from its original 21 percent, eventually reaching 14 percent, an amount that normally occurs at 17,500 feet, too low to sustain health. At this point, to keep the experiment going, oxygen was pumped in from the outside. During the same period carbon dioxide levels rose sharply, despite the use of an artificial recycling procedure. Concentrations of nitrous oxide increased to levels dangerous to brain tissue.

Species used to build the ecosystems were drastically affected. Many declined to extinction at an alarmingly high rate. Nineteen of the twenty-five vertebrates and all of the animal pollinators vanished. At the same time, a few species of cockroaches, katydids, and ants multiplied explosively. Morning glory, passionflower, and other vines, planted to serve as a carbon sink, grew so luxuriantly they threatened other plant species, including the crops, and had to be laboriously thinned by hand.

The Biospherians coped heroically with these ordeals, managing to stay inside the enclosure the full two years originally planned. And as an experiment, Biosphere 2 was not at all a failure. It taught us many things, the most important of which is the vulnerability of our species and the living environment on which we depend. Two senior biologists who reviewed the data as part of an independent team, Joel E. Cohen of Rockefeller University and David Tilman of the University of Minnesota, wrote with feeling, "No one yet knows how to engineer systems that provide humans with the life-supporting services that natural ecosystems produce for free," and "despite its mysteries and hazards, Earth remains the only known home that can sustain life."

In its neglect of the fragility of life, exemptionalism fails definitively. To move ahead as though scientific and entrepreneurial genius will solve each crisis arising in turn implies that the decline of the global biosphere can be similarly managed. Perhaps that might be possible in future decades (centuries seem more likely), but the means are not yet in sight. The living world is too complicated to be kept as a garden on a planet that has been converted into an artificial space capsule. No biological homeostat is known that can be worked by humanity. To believe otherwise is to risk reducing Earth to a wasteland, and humanity to a threatened species.

How pressing is the risk? Enough, I think, to change thinking about human self-preservation fundamentally. The current state of the environment can be summarized thus:

The global population is precariously large, and will become much more so before peaking some time after 2050. *Humanity overall is improving per capita production, health, and longevity. But it is doing so by eating up the planet's capital, including natural resources and biological diversity millions of years old.* Homo sapiens *is approaching the limit of its food and water supply. Unlike any species that lived before, it*

is also changing the world's atmosphere and climate, lowering and polluting water tables, shrinking forests, and spreading deserts. Most of the stress originates directly or indirectly from a handful of industrialized countries. Their proven formulas for prosperity are being eagerly adopted by the rest of the world. The emulation cannot be sustained, not with the same levels of consumption and waste. Even if the industrialization of developing countries is only partly successful, the environmental aftershock will dwarf the population explosion that preceded it.

Some will, of course, call this synopsis environmental alarmism. I earnestly wish that accusation were true. Unfortunately, it is the reality-grounded opinion of the overwhelming majority of statured scientists who study the environment. By statured scientists I mean those who collect and analyze the data, build the theoretical models, interpret the results, and publish articles vetted for professional journals by other experts, often including their rivals. I do not mean by statured scientists the many journalists, talk-show hosts, and think-tank polemicists who also address the environment, even though their opinions reach a vastly larger audience. This is not to devalue their professions, which have separate high standards, only to suggest that there are better-qualified sources to consult for factual information about the environment. Seen in this light, the environment is much less a controversial subject than suggested by routine coverage in the media.

Consider, then, the assessment made through the mid-1990s by the statured scientists. Their quantitative estimates differ according to the mathematical assumptions and procedures variously used, but most still fall within limits from which trends can be projected with confidence.

By 1997 the global population had reached 5.8 billion, growing at the rate of 90 million per year. In 1600 there were only about half a billion people on Earth, and in 1940, 2 billion. The amount of increase during the 1990s alone is expected to exceed the entire population alive in 1600. The global growth rate, after reaching a peak during the 1960s, has been dropping ever since. In 1963, for example, each woman bore an average of 4.1 children. In 1996 the number had declined to 2.6. In order to stabilize the world population, the number must be 2.1 children per woman (the extra 0.1 allowing for child mortality). Long-term population size is extremely sensitive to this replacement number, as shown by the following projections. If the number were 2.1, there would be 7.7 billion people on Earth in 2050, leveling off at 8.5 billion in 2150. If 2.0, the population would peak at 7.8 billion, then drop by 2150 to 5.6 billion, the total in the mid-1990s. If 2.2, it would reach 12.5 billion in 2050, 20.8 billion in 2150; and if 2.2 could miraculously be maintained thereafter, the human biomass would eventually equal the weight of the world and then, after a few millennia, expanding outward at the speed of light, it would exceed the mass of the visible universe. Even if the global birth rate were reduced drastically and immediately, say to the Chinese goal of one child per woman, the population would not peak for one or two generations. The overshoot is ensured by the disproportionate number of young people already in existence, who look to long lives ahead.

How many people can the world support for an indefinite period? Experts do not agree, but a majority put the number variously between 4 and 16 billion. The true number will depend on the quality of life that future generations are willing to accept. If everyone agreed to become vegetarian, leaving nothing for livestock, the present 1.4 billion hectares of arable land (3.5 billion acres) would supply about 10 billion people. If humans utilized as food all the energy captured by plant photosynthesis, some 40 trillion watts, Earth could support about 16 billion people. From such a fragile world, almost all other life forms would have to be excluded.

Even if, by *force majeure*, the population levels off at well under 10 billion by mid-century, the relatively extravagant lifestyle now enjoyed by the middle classes of North America, Western Europe, and Japan cannot be attained by most of the rest of the world. The reason is that the impact of each country on the environment is multiplicative. It is dependent, in a complex manner, on the formula called PAT: population size *times* per capita affluence (hence consumption) *times* a measure of the voracity of the technology used in sustaining consumption. The magnitude of PAT can be usefully visualized by the "ecological footprint" of productive land needed to support each member of the society with existing technology. In Europe the footprint is 3.5 hectares (a hectare is 2.5 acres), in Canada 4.3 hectares, and in the United States 5 hectares. In most developing countries it is less than half a hectare. To raise the whole world to the U.S. level with existing technology would require two more planet Earths.

It matters little that North Dakota and Mongolia are mostly empty. It makes no difference that the 5.8 billion people in the world today

could be logstacked out of sight in a corner of the Grand Canyon. The datum of interest is the average footprint on productive land, which must somehow be lowered if significantly more people are to achieve a decent standard of living.

To suppose that the living standard of the rest of the world can be raised to that of the most prosperous countries, with existing technology and current levels of consumption and waste, is a dream in pursuit of a mathematical impossibility. Even to level out present-day income inequities would require shrinking the ecological footprints of the prosperous countries. That is problematic in the market-based global economy, where the main players are also militarily the most powerful, and in spite of a great deal of rhetoric largely indifferent to the suffering of others. Few people in industrialized countries are fully aware of how badly off the poor of the world really are. Roughly 1.3 billion people, more than a fifth of the world population, have cash incomes under one U.S. dollar a day. The next tier of 1.6 billion earn $1–3. Somewhat more than 1 billion live in what the United Nations classifies as absolute poverty, uncertain of obtaining food from one day to the next. Each year more than the entire population of Sweden, between 13 and 18 million, mostly children, die of starvation, or the side effects of malnutrition, or other poverty-related causes. In order to gain perspective, imagine the response if Americans and Europeans were told that in the coming year the entire population of Sweden, or Scotland and Wales combined, or New England would die of poverty.

Of course the exemptionalists will say that new technology and the rising tide of the free-market economy can solve the problem. The solution, they explain, is straightforward: Just use more land, fertilizer, and higher-yield crops, and work harder to improve distribution. And, of course, encourage more education, technology transfer, and free trade. Oh, and discourage ethnic strife and political corruption.

All that will certainly help, and should have high priority, but it cannot solve the main problem, which is the finite resources of planet Earth. It is true that only 11 percent of the world's land surface is under cultivation. But that already includes the most arable part. The bulk of the remaining 89 percent has limited use, or none at all. Greenland, Antarctica, most of the vast northern taiga, and the equally vast ultra-dry deserts are not available. The remnant tropical forests and savannas can be cleared and planted, but at the cost of most of the species of plants and animals in the world, with minor agricultural gain. Nearly half their expanse is underlaid by soils of low natural fertility—42 percent of the untapped area of sub-Saharan Africa, for example, and 46 percent of that in Latin America. Meanwhile, cultivated and deforested lands are losing topsoil to erosion at ten times the sustainable level. By 1989, 11 percent of the world's cropland had been classified by soil experts as severely degraded. From 1950 to the mid-1990s the area of cropland per person fell by half, from 0.23 hectare to 0.12 hectare, less than a quarter the size of a soccer field. Widespread starvation was avoided because the Green Revolution during the same forty-year period boosted per hectare yield dramatically with new varieties of rice and other crops, better pesticide application, and increased use of fertilizer and irrigation. But even these technologies have limits. By 1985 the growth in yield slowed; that trend, when combined with the relentless growth of population, initiated a decline in per capita production. The shortfall first became apparent in the developing countries, whose grain self-sufficiency fell from 96 percent in 1969–71, at the height of the Green Revolution, to 88 percent in 1993–95. By 1996 the world grain carryover stocks, humanity's emergency food supply, had declined 50 percent from the all-time peak reached in 1987. At the beginning of the 1990s only a handful of countries—including Canada, the United States, Argentina, the European Union, and Australia—accounted for more than three-fourths of the world's grain resources.

Perhaps all these signs will miraculously disappear. If not, how will the world cope? Perhaps the deserts and nonarable dry grasslands can be irrigated to expand agricultural production. But that remedy also has limitations. Too many people already compete for too little water. The aquifers of the world, on which so much agriculture in drier regions depends, are being drained of their groundwater faster than the reserves can be replaced by natural percolation of rainfall and runoff. The Ogallala aquifer, a principal water source of the central United States, experienced a three-meter drop through a fifth of its area during the 1980s alone. Now it is half depleted beneath a million hectares in Kansas, Texas, and New Mexico. Still worse deficits are building in other countries, and often where they are least affordable. The water table beneath Beijing fell 37 meters between 1965 and 1995. The groundwater reserves of the Arabian peninsula are expected to be exhausted by 2050. In the meantime the oil-rich countries there are making up the deficit in part by desalinizing seawater—trading their

precious petroleum for water. On a global scale, humanity is pressing the limit, using a quarter of the accessible water released to the atmosphere by evaporation and plant transpiration, and somewhat more than half that available in rivers and other runoff channels. By 2025, 40 percent of the world's population could be living in countries with chronic water scarcity. New dam construction can add 10 percent to the runoff capture during the next thirty years, but the treadmill opposing it is unceasing: In the same three decades the human population is expected to grow by a third.

As the land gives out, might we turn to Earth's last frontier, the boundless sea? Unfortunately, no. It is not really boundless, having already given most of what it has to offer. All seventeen of the world's oceanic fisheries are being harvested beyond their capacity. Only those in the Indian Ocean have continued to rise in yield, a trend destined to end because the present rate of catch is not sustainable. Several fisheries, including most famously the northwestern Atlantic banks and the Black Sea, have suffered a commercial collapse. The annual world fish catch, after rising fivefold from 1950 to 1990, has leveled off at about 90 million tons.

The history of marine fisheries has been one of increasingly efficient mass capture and on-site processing, which increases yield by cutting ever deeper into existing stocks. By the 1990s proliferating fish farms had taken up part of the slack, adding 20 million tons to the total harvest. But aquaculture, the fin-and-shell revolution, also has limits. Expanding marine farms preempt the mangrove swamps and other coastal wetland habitats that serve as the spawning grounds for many offshore food fishes. Freshwater farms have more growth potential but must compete with conventional agriculture for the shrinking supplies of runoff and aquifer-borne water.

Meanwhile, in accordance with the general principle of life that all large perturbations are bad, Earth's ability to support the voracious human biomass is becoming even dicier through the acceleration of climatic change. During the past 130 years the global average temperature has risen by one degree Celsius. The signs are now strong—some atmospheric scientists say conclusive—that much of the change is due to carbon dioxide pollution. The connection is the greenhouse effect, in which carbon dioxide, along with methane and a few other gases, work like the glass enclosures used by gardeners. They admit sunlight but trap the heat generated by it. For the past 160,000 years, as tests of air bubbles in fossil ice show, the concentration of atmospheric carbon dioxide has been tightly correlated with the global average temperature. Now, boosted by combustion of fossil fuels and the destruction of tropical forests, the carbon dioxide concentration stands at 360 parts per million, the highest measure in the 160,000-year period.

The idea of climatic warming by human activity has been disputed by several scientists, with valid reasons. Atmospheric chemistry and climatic change are both extremely complex subjects. When compounded, they make exact predictions nearly impossible. Nevertheless, trajectories and velocities of the changes can be estimated within broad limits. That has been the goal of the Intergovernmental Panel on Climate Change (IPCC), a group of more than two thousand scientists working worldwide to assess incoming data and build models of future change with the aid of super-computers. The more difficult variables they must incorporate include the industrial discharge of sulfate aerosols, which counteract the greenhouse effect of carbon dioxide, together with the long-term capture of carbon dioxide by the ocean, which can throw off calculations of atmospheric change, and the tricky idiosyncrasies of local climatic change.

Overall, the IPCC scientists have made the following assessment. There will be an additional rise in the global average temperature of 1.0 to 3.5 degrees Celsius (1.8 to 6.3 degrees Fahrenheit) by the year 2100. Multiple consequences are likely, with few if any likely to be pleasant. Thermal expansion of marine waters and the partial breakup of the Antarctic and Greenland ice shelves will raise the sea level by as much as 30 centimeters (12 inches), causing problems for coastal nations. Kiribati and the Marshall Islands, two small atoll countries in the Western Pacific, risk partial obliteration. Precipitation patterns will change, and most likely as follows: Large increases will be experienced in North Africa, temperate Eurasia and North America, Southeast Asia, and the Pacific coast of South America, and comparable decreases in Australia and most of South America and southern Africa.

Local climates will turn more variable, as heat waves increase in frequency. Even a small rise in average temperature results in many more instances of extremely high temperatures. The reason is a purely statistical effect. A small shift in a normal statistical distribution in one direction lifts the former extreme in that direction from near zero to a

proportionately far higher number. (Thus, to take another example, if the average mathematical ability of the human species were raised ten percent, the difference in the mass of people might not be noticeable, but Einsteins would be commonplace.)

Because clouds and storm centers are generated over marine waters heated above 26°C, tropical cyclones will increase in average frequency. The eastern seaboard of the United States, to select one heavily populated region, will thereby suffer both more heat waves in the spring and more hurricanes in the summer. We can expect the hotter climatic zones to expand toward the North and South Poles, with the greatest changes occurring at the highest latitudes. The tundra ecosystems will shrink and may disappear altogether. Agriculture will be affected, in some areas favorably, in others destructively. In general, developing nations can expect to be hit harder than those in the industrialized North. Many natural systems and the species of microorganisms, plants, and animals composing them, unable to adapt to the shift in local conditions or emigrate to newly habitable areas quickly enough, will be extinguished.

To summarize the future of resources and climate, the wall toward which humanity is evidently rushing is a shortage not of minerals and energy, but of food and water. The time of arrival at the wall is being shortened by a physical climate growing less congenial. Humankind is like a household living giddily off vanishing capital. Exemptionalists are risking a lot when they advise us, in effect, that "Life is good and getting better, because look around you, we are still expanding and spending faster. Don't worry about next year. We're such a smart bunch something will turn up. It always has."

They, and most of the rest of us, have yet to learn the arithmetical riddle of the lily pond. A lily pad is placed in a pond. Each day thereafter the pad and then all of its descendants double. On the thirtieth day the pond is covered completely by lily pads, which can grow no more. On which day was the pond half full and half empty? The twenty-ninth day.

Shall we gamble? Suppose the odds are even that humankind will miss the environmental wall. Better, make it two to one: pass on through or collide. To bet on safe passage is a terrible choice, because the stakes on the table are just about everything. You save some time and energy now by making that choice and not taking action, but if you lose the bet down the line, the cost will be ruinous. In ecology, as in medicine, a false positive diagnosis is an inconvenience, but a false negative diagnosis can be catastrophic. That is why ecologists and doctors don't like to gamble at all, and if they must, it is always on the side of caution. It is a mistake to dismiss a worried ecologist or a worried doctor as an alarmist.

At best, an environmental bottleneck is coming in the twenty-first century. It will cause the unfolding of a new kind of history driven by environmental change. Or perhaps an unfolding on a global scale of more of the old kind of history, which saw the collapse of regional civilizations, going back to the earliest in history, in northern Mesopotamia, and subsequently Egypt, then the Mayan and many others scattered across all the inhabited continents except Australia. People died in large numbers, often horribly. Sometimes they were able to emigrate and displace other people, making them die horribly instead.

Archaeologists and historians strive to find the reasons for the collapse of civilizations. They tick off drought, soil exhaustion, overpopulation, and warfare—singly or in some permutation. Their analyses are persuasive. Ecologists add another perspective, with this explanation: The populations reached the local carrying capacity, where further growth could no longer be sustained with the technology available. At that point life was often good, especially for the ruling classes, but fragile. A change such as a drought or depletion of the aquifer or a ravaging war then lowered the carrying capacity. The death rate soared and the birth rate fell (from malnutrition and disease) until lower and more sustainable population levels were reached.

The principle of carrying capacity is illustrated by the recent history of Rwanda, a small and beautiful mountainous land that once rivaled Uganda as the pearl of Central Africa. Until the present century Rwanda supported only a modest population density. For five hundred years a Tutsi dynasty ruled over a Hutu majority. In 1959 the Hutu revolted, causing many of the Tutsi to flee to neighboring countries. In 1994 the conflict escalated, and Rwandan army units massacred over half a million Tutsi and moderate Hutu. Then an army of the Tutsi, the Rwandan Patriotic Front, struck back, capturing the capital town of Kigali. As the Tutsi advanced across the countryside, two million Hutu refugees ran before them, spreading out into Zaire, Tanzania, and Burundi. In 1997 Zaire, newly renamed the Republic of the

Congo, forced many of the Hutu refugees back to Rwanda. In the maelstrom, thousands died of starvation and disease.

On the surface it would seem, and was so reported by the media, that the Rwandan catastrophe was ethnic rivalry run amok. That is true only in part. There was a deeper cause, rooted in environment and demography. Between 1950 and 1994 the population of Rwanda, favored by better health care and temporarily improved food supply, more than tripled, from 2.5 million to 8.5 million. In 1992 the country had the highest growth rate in the world, an average of 8 children for every woman. Parturition began early, and generation times were short. But although total food production increased dramatically during this period, it was soon overbalanced by population growth. The average farm size dwindled, as plots were divided from one generation to the next. Per capita grain production fell by half from 1960 to the early 1990s. Water was so overdrawn that hydrologists declared Rwanda one of the world's twenty-seven water-scarce countries. The teenage soldiers of the Hutu and Tutsi then set out to solve the population problem in the most direct possible way.

Rwanda is a microcosm of the world. War and civil strife have many causes, most not related directly to environmental stress. But in general, overpopulation and the consequent dwindling of available resources are tinder that people pile up around themselves. The mounting anxiety and hardship are translated into enmity, and enmity into moral aggression. Scapegoats are identified, sometimes other political or ethnic groups, sometimes neighboring tribes. The tinder continues to grow, awaiting the odd assassination, territorial incursion, atrocity, or other provocative incident to set it off. Rwanda is the most overpopulated country in Africa. Burundi, its war-torn neighbor, is second. Haiti and El Salvador, two of the chronically most troubled nations of the Western Hemisphere, are also among the most densely populated, exceeded only by five tiny island countries of the Caribbean. They are also arguably the most environmentally degraded.

Population growth can justly be called the monster on the land. To the extent that it can be tamed, passage through the bottleneck will be easier. Let us suppose that the last of the old reproductive taboos fade, and family planning becomes universal. Suppose further that governments create population policies with the same earnestness they devote to economic and military policies. And that as a result the global population peaks below ten billion and starts to decline. With NPG (negative population growth) attained, there are grounds for hope. If not attained, humanity's best efforts will fail, and the bottleneck will close to form a solid wall.

Humanity's best efforts will include every technological fix for an overcrowded planet that genius can devise. Endless stand-by schemes are already on the board. Conversion of nitrogenased petroleum to food is one remote possibility. Algal farms in shallow seas is another. The water crisis might be eased by desalinization of seawater with energy from controlled fusion or fuel cell technology. Perhaps as polar ice shelves break up from global warming, more fresh water can be drawn from icebergs herded to dry coasts. With a surplus of energy and fresh water, the agricultural revegetation of arid wasteland is attainable. Pulp production can be increased in such recovered lands with "wood grass," fast-growing, nitrogen-fixing tree species that can be harvested with giant mowers and then sprout new shoots from the severed stocks. Many such schemes will be tried as demand rises, and a few will succeed. They will be driven by venture capital and government subsidy in the global free-market economy. Each advance will reduce the risk of short-term economic calamity.

But be careful! Each advance is also a prosthesis, an artificial device dependent on advanced expertise and intense continuing management. Substituted for part of Earth's natural environment, it adds its own, long-term risk. Human history can be viewed through the lens of ecology as the accumulation of environmental prostheses. As these manmade procedures thicken and interlock, they enlarge the carrying capacity of the planet. Human beings, being typical organisms in reproductive response, expand to fill the added capacity. The spiral continues. The environment, increasingly rigged and strutted to meet the new demands, turns ever more delicate. It requires constant attention from increasingly sophisticated technology.

The Ratchet of Progress seems irreversible. The message then for the primitivists, who dream of nature's balance in Paleolithic serenity: *Too late.* Put away your bow and arrow, forget the harvest of wild berries; the wilderness has become a threatened nature reserve. The message for the environmentalists and exemptionalists: *Get together.* We must plunge ahead and make the best of it, worried but confident of success, our hope well expressed by Hotspur's lines in *Henry IV*: *I tell you, my lord fool, out of this nettle, danger, we pluck this flower, safety.*

The common aim must be to expand resources and improve the quality of life for as many people as heedless population growth forces upon Earth, and do it with minimal prosthetic dependence. That, in essence, is the ethic of sustainable development. It is the dream that acquired general currency at the Earth Summit, the historic United Nations Conference on Environment and Development held in June 1992 in Rio de Janeiro. The representatives of 172 nations, including 106 heads of government, met to establish guidelines by which a sustainable world order might be reached. They signed binding conventions on climate change and the protection of biological diversity. They agreed to the forty nonbinding chapters of Agenda 21, offering procedures by which virtually all of the general problems of the environment can be addressed, if not solved. Most of the initiatives were blunted by political squabbles arising from national self-interest, and global cooperation afterward was principally limited to rhetorical exercise on state occasions. The $600 billion additional expenditure recommended to put Agenda 21 into effect, with $125 billion donated to developing countries by industrialized countries, has not been forthcoming. Still, the principle of sustainable development has been generally accepted, an idea previously little more than the dream of an environmentalist elite. By 1996 no fewer than 117 governments had appointed commissions to develop Agenda 21 strategies.

In the end, the measure of success of the Earth Summit and all other global initiatives will be the diminishment of the total ecological footprint. As the human population soars toward eight billion around 2020, the central question will be the area of productive land required on average to provide each person in the world with an acceptable standard of living. From it, the overriding environmental goal is to shrink the ecological footprint to a level that can be sustained by Earth's fragile environment.

Much of the technology required to reach that goal can be summarized in two concepts. Decarbonization is the shift from the burning of coal, petroleum, and wood to essentially unlimited, environmentally light energy sources such as fuel cells, nuclear fusion, and solar and wind power. Dematerialization, the second concept, is the reduction in bulk of hardware and the energy it consumes. All the microchips in the world, to take the most encouraging contemporary example, can be fitted into the room that housed the Harvard Mark 1 electromagnetic computer at the dawn of the information revolution.

The single greatest intellectual obstacle to environmental realism, as opposed to practical difficulty, is the myopia of most professional economists. In Chapter 9 I described the insular nature of neoclassical economic theory. Its models, while elegant cabinet specimens of applied mathematics, largely ignore human behavior as understood by contemporary psychology and biology. Lacking such a foundation, the conclusions often describe abstract worlds that do not exist. The flaw is especially noticeable in microeconomics, which treats the patterns of choices made by individual consumers.

The weakness of economics is most worrisome, however, in its general failure to incorporate the environment. After the Earth Summit, and after veritable encyclopedias of data compiled by scientists and resource experts have shown clearly the dangerous trends of population size and planetary health, the most influential economists still make recommendations as though there is no environment. Their assessments read like the annual reports of successful brokerage firms. Here, for example, is Frederick Hu, head of the World Economic Forum's competitiveness research team, explaining the conclusions of the Forum's influential *Global Competitiveness Report 1996*:

> Short of military conquest, economic growth is the only viable means for a country to sustain increases in national wealth and living standards . . . An economy is internationally competitive if it performs strongly in three general areas: abundant productive inputs such as capital, labour, infrastructure and technology; optimal economic policies such as low taxes, little interference and free trade and sound market institutions such as the rule of law and the protection of property rights.

This prescription, resonant with the hard-headed pragmatism expected in an economics journal, is true for medium-term growth of individual nations. It is surely the best policy to recommend during the next two decades for Russia (competitiveness index −2.36) and Brazil (−1.73) if they wish to catch up with the United States (+1.34) and Singapore (+2.19). No one can seriously question that a better quality of life for everyone is the unimpeachable universal goal of humanity. Free trade, the rule of law, and sound market practices are the proven means to attain it. But the next two decades will also see the global population leap from six to eight billion, mostly among the poorest nations. That interval will witness water and arable soil running out, forests being stripped, and coastal habitats used up. The planet is already in a precarious state. What will happen as giant China (−0.68) strives to overtake little Taiwan (+0.96) and the other Asian tigers? We tend to forget, and economists are reluctant to stress, that economic miracles are not endogenous. They occur most often when countries consume not only their own material resources, including oil, timber, water, and agricultural produce, but those of other countries as well. And now the globalization of commerce, accelerated by technology and the liquidity of paper assets, has made the mass transfer of material assets far easier. The wood products of Japan are the destroyed forests of tropical Asia, the fuel of Europe the dwindling petroleum reserves of the Middle East.

In national balance sheets economists seldom use full-cost accounting, which includes the loss of natural resources. A country can cut down all its trees, mine out its most profitable minerals, exhaust its fisheries, erode most of its soil, draw down its underground water, and count all the proceeds as income and none of the depletion as cost. It can pollute the environment and promote policies that crowd its populace into urban slums, without charging the result to overhead.

Full-cost accounting is gaining some credibility within the councils of economists and the finance ministers they advise. Ecological economics, a new subdiscipline, has been formed to put a green thumb on the invisible hand of economics. But it is still only marginally influential. Competitive indexes and gross domestic products (GDPs) remain seductive, not to be messed up in conventional economic theory by adding the tricky complexities of environment and social cost. The time has come for economists and business leaders, who so haughtily pride themselves as masters of the real world, to acknowledge the existence of the *real* real world. New indicators of progress are needed to monitor the economy, wherein the natural world and human well-being, not just economic production, are awarded full measure.

TO THE SAME END I count it paramount, and feel obliged to plead, that the new reckoning include a powerful conservation ethic. We hope—surely we must believe—that our species will emerge from the environmental bottleneck in better condition than we entered. But there is another responsibility to meet as we make the passage: preserving the Creation by taking as much of the rest of life with us as possible.

Biological diversity, or biodiversity for short—the full sweep from ecosystems to species within the ecosystems, thence to genes within the species—is in trouble. Mass extinctions are commonplace, especially in tropical regions where most of the biodiversity occurs. Among the more recent are more than half the exclusively freshwater fishes of peninsular Asia, half of the fourteen birds of the Philippine island of Cebu, and more than ninety plant species growing on a single mountain ridge in Ecuador. In the United States an estimated 1 percent of all species have been extinguished; another 32 percent are imperiled.

Conservation experts, responding to what they now perceive as a crisis, have in the past three decades broadened their focus from the panda, tiger, and other charismatic animals to include entire habitats whose destruction endangers the existence of many species.

Familiar "hot spots" of this kind in the United States include the mountain forests of Hawaii, the coastal heath of southern California, and the sandy uplands of central Florida. Arguably the nations with the most hot spots in the world are Ecuador, Madagascar, and the Philippines. Each of these countries has lost two-thirds or more of its biologically rich rain forest, and the remainder is under continuing assault. The logic of conservation experts in addressing the issue is simple: By concentrating conservation efforts on such areas, the largest amount of biodiversity can be saved at the lowest economic cost. If the effort is also made part of the political process during regional planning, the rescue of biodiversity can also gain the widest possible public support.

It is notoriously difficult to estimate the overall rate of extinction, but biologists, by using several indirect methods of analysis, generally agree that on the land at least, species are vanishing at a rate one hundred to a thousand times faster than before the arrival of *Homo sapiens*. Tropical rain forests are the site of most of the known damage. Although they cover only 6 percent of the land surface, they contain more than half the species of plants and animals of the entire world. The rate of clearing and burning of the surviving rain forests averaged about 1 percent a year through the 1980s and into the 1990s, an area about equal to the entire country of Ireland. That magnitude of habitat

loss means that each year 0.25 percent or more of the forest species are doomed to immediate or early extinction. How much does the rate translate into absolute numbers? If there are ten million species in the still mostly unexplored forests, which some scientists think possible, the annual loss is in the tens of thousands. Even if there are a "mere" one million species, the loss is still in the thousands.

These projections are based on the known relationships between the area of a given natural habitat and the number of species able to live for indefinite periods within it. Such projections may in fact be on the low side. The outright elimination of habitat, the easiest factor to measure, is the leading cause of extinction. But the introduction of aggressive exotic species and the diseases they carry come close behind in destructiveness, followed in turn by the overharvesting of native species.

All these factors work together in a complex manner. When asked which ones caused the extinction of any particular species, biologists are likely to give the *Murder on the Orient Express* answer: They all did it. A common sequence in tropical countries starts with the building of roads into wilderness, such as those cut across Brazil's Amazonian state of Rondônia during the 1970s and '80s. Land-seeking settlers pour in, clear the forest on both sides of the road, pollute the streams, introduce alien plants and animals, and hunt wildlife for extra food. Many native species become rare, and some disappear entirely. The soil wears out within several years, and the settlers cut and burn their way deeper into the forest.

The ongoing loss of biodiversity is the greatest since the end of the Mesozoic Era sixty-five million years ago. At that time, by current scientific consensus, the impact of one or more giant meteorites darkened the atmosphere, altered much of Earth's climate, and extinguished the dinosaurs. Thus began the next stage of evolution, the Cenozoic Era or Age of Mammals. The extinction spasm we are now inflicting can be moderated if we so choose. Otherwise, the next century will see the closing of the Cenozoic Era and a new one characterized not by new life forms but by biological impoverishment. It might appropriately be called the "Eremozoic Era," the Age of Loneliness.

I have found, during many years of studying biological diversity, that people commonly respond to evidence of species extinction by entering three stages of denial. The first is simply, Why worry? Extinction is natural. Species have been dying out through more than three billion years of life's history without permanent harm to the biosphere. Evolution has always replaced extinct species with new ones.

All these statements are true, but with a terrible twist. Following the Mesozoic spasm, and after each of the four greatest previous spasms spaced over the earlier 350 million years, evolution required about 10 million years to restore the predisaster levels of diversity. Faced with a waiting time that long, and aware that we inflicted so much damage in a single lifetime, our descendants are going to be—how best to say it?—peeved.

Entering the second stage of denial, people commonly ask, Why do we need so many species anyway? Why care, especially since the vast majority are bugs, weeds, and fungi? It is easy to dismiss the creepy-crawlies of the world, forgetting that less than a century ago, before the rise of the modern conservation movement, native birds and mammals around the world were treated with the same callow indifference. Now the value of the little things in the natural world has become compellingly clear. Recent experimental studies on whole ecosystems support what ecologists have long suspected: The more species that live in an ecosystem, the higher its productivity and the greater its ability to withstand drought and other kinds of environmental stress. Since we depend on functioning ecosystems to cleanse our water, enrich our soil, and create the very air we breathe, biodiversity is clearly not something to discard carelessly.

Each species is a masterpiece of evolution, offering a vast source of useful scientific knowledge because it is so thoroughly adapted to the environment in which it lives. Species alive today are thousands to millions of years old. Their genes, having been tested by adversity over so many generations, engineer a staggeringly complex array of biochemical devices to aid the survival and reproduction of the organisms carrying them.

This is why, in addition to creating a habitable environment for humankind, wild species are the source of products that help sustain our lives. Not the least of these amenities are pharmaceuticals. More than 40 percent of all medicinals dispensed by pharmacies in the United States are substances originally extracted from plants, animals, fungi, and microorganisms. Aspirin, for example, the most widely used medicine in the world, was derived from salicylic acid, which in turn was discovered in a species of meadowsweet. Yet only a fraction of the species—probably fewer than 1 percent—have been examined for natural products that might serve as medicines. There is a critical need to press the search for new antibiotics and antimalarial agents. The substances most commonly used today are growing less effective as disease organisms acquire genetic resistance to the drugs. The universal staphylococcus bacterium, for example, has recently re-emerged as a potentially lethal pathogen, and the microorganism that causes pneumonia is growing progressively more dangerous. Medical researchers are locked in an arms race with the rapidly evolving pathogens that is certain to grow more intense. They are obliged to turn to a broader array of wild species in order to acquire new weapons of medicine in the twenty-first century.

Even when all this much is granted, the third stage of denial emerges: Why rush to save all the species right now? Why not keep live specimens in zoos and botanical gardens and return them to the wild later? The grim truth is that all the zoos in the world today can sustain a maximum of only two thousand species of mammals, birds, reptiles, and amphibians out of twenty-four thousand known to exist. The world's botanical gardens would be even more overwhelmed by the quarter-million plant species. These refuges are invaluable in helping to save a few endangered species. So is freezing embryos in liquid nitrogen. But such measures cannot come close to solving the problem as a whole. To add to the difficulty, no one has yet devised a safe harbor for the legion of insects, fungi, and other ecologically vital small organisms.

Even if all that were accomplished, and scientists prepared to return species to independence, the ecosystems in which many lived would no longer exist. Raw land does not suffice. Pandas and tigers, for example, cannot survive in abandoned rice paddies. Can the natural ecosystems be reconstituted by just putting all the species back together again? The feat is at the present time impossible, at least for communities as complex as rain forests. The order of difficulty, as I described it in Chapter 5, is comparable to that of creating a living cell from molecules, or an organism from living cells.

In order to visualize the scope of the problem more concretely, imagine that the last remnant of rain forest in a small tropical country is about to be drowned beneath the rising lake of a hydroelectric project. An unknown number of plant and animal species found nowhere else in the world will disappear beneath the waters. Nothing can be done. The electric power is needed; local political leaders are adamant. People come first! In the final desperate months, a team of biologists scrambles to save the fauna and flora. Their assignment is the following: Collect samples of all the species quickly, before the dam is closed. Maintain the species in zoos, gardens, and laboratory cultures, or else deep-freeze embryos bred from them in liquid nitrogen. Then bring the species back together and resynthesize the community on new ground.

The state of the art is such that biologists cannot accomplish such a task, not if thousands of them came with a billion-dollar budget. They cannot even imagine how to do it. In the forest patch live legions of life forms: perhaps 300 species of birds, 500 butterflies, 200 ants, 50,000 beetles, 1,000 trees, 5,000 fungi, tens of thousands of bacteria and so on down the long roster of major groups. In many of the groups a large minority of the species are new to science, their properties wholly unknown. Each species occupies a precise niche, demanding a certain place, an exact microclimate, particular nutrients, and temperature and humidity cycles by which the sequential phases of the life cycles are timed. Many of the species are locked in symbiosis with other species, and cannot survive unless arrayed with their partners in the correct configurations.

Thus even if the biologists pulled off the taxonomic equivalent of the Manhattan Project, sorting and preserving cultures of all the species, they could not then put the community back together again. Such a task anywhere in the world is like unscrambling an egg with a pair of spoons. Eventually, perhaps in decades, it can be done. But for the present the biology of the microorganisms needed to reanimate the soil is mostly unknown. The pollinators of most of the flowers and the correct timing of their appearance can only be guessed. The "assembly rules," the sequence in which species must be allowed to colonize in order to coexist indefinitely, are still largely in the realm of theory.

In this matter the opinion of biologists and conservationists is virtually unanimous: The only way to save the Creation with existing knowledge is to maintain it in natural ecosystems. Considering how rapidly such habitats are shrinking, even that straightforward solution will be a daunting task. Somehow humanity must find a way to squeeze through the bottleneck without destroying the environments on which the rest of life depends.

THE LEGACY of the Enlightenment is the belief that entirely on our own we can know, and in knowing, understand, and in understanding, choose wisely. That self-confidence has risen with the exponential growth of scientific knowledge, which is being woven into an increasingly full explanatory web of cause and effect. In the course of the enterprise, we have learned a great deal about ourselves as a species. We now better understand where humanity came from, and what it is. *Homo sapiens*, like the rest of life, was self-assembled. So here we are, no one having guided us to this condition, no one looking over our shoulder, our future entirely up to us. Human autonomy having thus been recognized, we should now feel more disposed to reflect on where we wish to go.

In such an endeavor it is not enough to say that history unfolds by processes too complex for reductionistic analysis. That is the white flag of the secular intellectual, the lazy modernist equivalent of The Will of God. On the other hand, it is too early to speak seriously of ultimate goals, such as perfect green-belted cities and robot expeditions to the nearest stars. It is enough to get *Homo sapiens* settled down and happy before we wreck the planet. A great deal of serious thinking is needed to navigate the decades immediately ahead. We are gaining in our ability to identify options in the political economy most likely to be ruinous. We have begun to probe the foundations of human nature, revealing what people intrinsically most need, and why. We are entering a new era of existentialism, not the old absurdist existentialism of Kierkegaard and Sartre, giving complete autonomy to the individual, but the concept that only unified learning, universally shared, makes accurate foresight and wise choice possible.

In the course of all of it we are learning the fundamental principle that ethics is everything. Human social existence, unlike animal sociality, is based on the genetic propensity to form long-term contracts that evolve by culture into moral precepts and law. The rules of contract formation were not given to humanity from above, nor did they emerge randomly in the mechanics of the brain. They evolved over tens or hundreds of millennia because they conferred upon the genes prescribing them survival and the opportunity to be represented in future generations. We are not errant children who occasionally sin by disobeying instructions from outside our species. We are adults who have discovered which covenants are necessary for survival, and we have accepted the necessity of securing them by sacred oath.

The search for consilience might seem at first to imprison creativity. The opposite is true. A united system of knowledge is the surest means of identifying the still unexplored domains of reality. It provides a clear map of what is known, and it frames the most productive questions for future inquiry. Historians of science often observe that asking the right question is more important than producing the right answer. The right answer to a trivial question is also trivial, but the right question, even when insoluble in exact form, is a guide to major discovery. And so it will ever be in the future excursions of science and imaginative flights of the arts.

I believe that in the process of locating new avenues of creative thought, we will also arrive at an existential conservatism. It is worth asking repeatedly: Where are our deepest roots? We are, it seems, Old World, catarrhine primates, brilliant emergent animals, defined genetically by our unique origins, blessed by our newfound biological genius, and secure in our homeland if we wish to make it so. What does it all mean? This is what it all means. To the extent that we depend on prosthetic devices to keep ourselves and the biosphere alive, we will render everything fragile. To the extent that we banish the rest of life, we will impoverish our own species for all time. And if we should surrender our genetic nature to machine-aided ratiocination, and our ethics and art and our very meaning to a habit of careless discursion in the name of progress, imagining ourselves godlike and absolved from our ancient heritage, we will become nothing.

NOTES

CHAPTER 1
THE IONIAN ENCHANTMENT

3 **Autobiographical details** of my introduction through religious experience to scientific synthesis are given in my memoir *Naturalist* (Washington, DC: Island Press/Shearwater Books, 1994).

4 The idea of the **Ionian Enchantment** is introduced and Einstein's expression of it used as an illustration by Gerald Holton in *Einstein, History, and Other Passions* (Woodbury, NY: American Institute of Physics Press, 1995).

7 Arthur Eddington, in order to celebrate boldness and risk-taking as components of major scientific endeavor, narrated the story of **Daedalus and Icarus** in his British Association Address of 1920. The metaphor was then used by Subrahmanyan Chandrasekhar to characterize the research style of his friend in *Eddington: The Most Distinguished Astrophysicist of His Time* (New York: Cambridge University Press, 1983).

CHAPTER 2
THE GREAT BRANCHES OF LEARNING

11–12 The divided and often contentious **nature of the philosophy of science** is graphically revealed in interviews and conversations recorded by Werner Callebaut in *Taking the Naturalistic Turn, or, How Real Philosophy of Science is Done* (Chicago: University of Chicago Press, 1993).