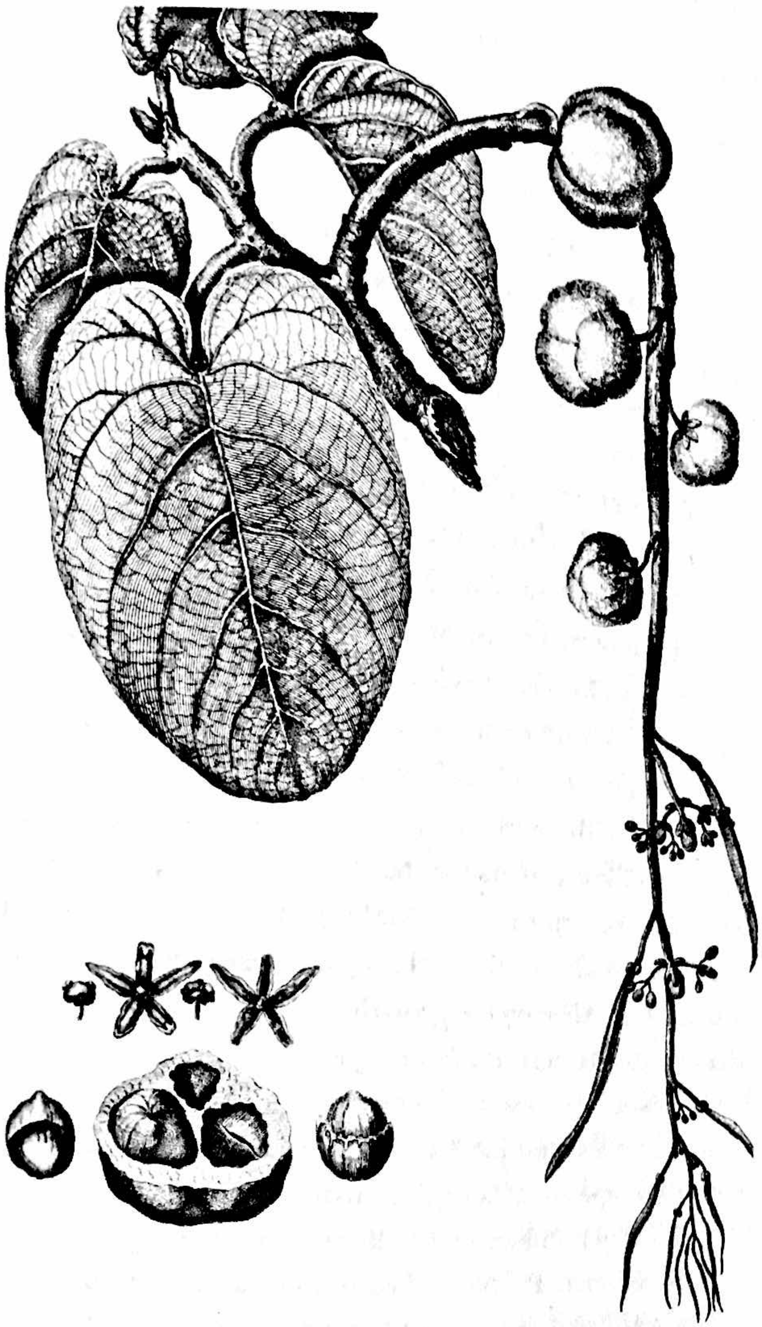


The vine Ronnowia domingensis. *Pierre-Joseph Buc'hoz, 1779.*

20

THREADING THE BOTTLENECK

The Half-Earth solution does not mean dividing the planet into hemispheric halves or any other large pieces the size of continents or nation-states. Nor does it require changing ownership of any of the pieces, but instead only the stipulation that they be allowed to exist unharmed. It does, on the other hand, mean setting aside the largest reserves possible for nature, hence for the millions of other species still alive.

The key to saving one-half of the planet is the ecological footprint, defined as the amount of space required to meet all of the needs of an average person. It comprises the land used for habitation, fresh water, food production and delivery, personal transportation, communication, governance, other public functions, medical support, burial, and entertainment. In the same way the ecological footprint is scattered in pieces around the world, so are Earth's surviving wildlands on the land and in the sea. The pieces range in size from the major desert and forest wildernesses to pockets of restored habitats as small as a few hectares.

But, you may ask, doesn't a rising population and per-capita consumption doom the Half-Earth prospect or any other measure aimed at confining the Anthropocene? It does, but only if the human population continues growing as it has in the past, through the remainder of the twenty-first century and on into the twenty-second century. In this aspect of its biology, however, humanity appears to have won a throw of the demographic dice. Its population growth has begun to decelerate autonomously, without pressure one way or the other from law or custom. In every country where women have gained some degree of social and financial independence, their average fertility has dropped by a corresponding amount through individual personal choice. In Europe and among native-born Americans, it has already reached and continued to hold below the zero-growth threshold of 2.1 children per woman surviving to maturity. Given even a modest amount of personal freedom and an expectation of future security, women choose the option of what ecologists call K-selection, that favoring a small number of healthy well-prepared offspring, as opposed to r-selection, hedging the bet with a larger number of poorly prepared offspring.

There won't be an immediate drop in the total world population. An overshoot still exists due to the longevity of the more numerous per-mother offspring of earlier, more fertile generations. There also remain high-fertility countries, with an average of more than three surviving children born to each woman, thus higher than the 2.1 children per woman that yields zero population growth. They include Patagonia, the Middle East, Pakistan, and Afghanistan, plus all of sub-Saharan Africa exclusive of South Africa. The shift to lower fertility can happen during one or two generations. The United Nations biennial report on population in 2014 projected an

80 percent probability that by 2100 the world population, even as it decelerates toward zero growth, will reach between 9.6 billion and 12.3 billion, up from the 7.2 billion existing in 2014. That is a heavy burden for an already overpopulated planet to bear, but unless women worldwide switch back from the negative population trend of fewer than 2.1 children per woman, a turn downward in the early twenty-second century is inevitable. Another way of looking at the population problem is that it will be solved as an unintended consequence of human nature, namely the flip from r-strategy reproduction to K-strategy reproduction in favorable environments.

But then, what of per-capita consumption? Won't it rise enough to break any resolve for large-scale conservation? It might if the components of the ecological footprints were to remain the same as today. But they will not stay the same. The footprint will evolve, not to claim more and more space, as you might at first suppose, but less. The reason lies in the evolution of the free market system, and the way it is increasingly shaped by high technology. The products that win competition today, and will continue to do so indefinitely, are those that cost less to manufacture and advertise, need less frequent repair and replacement, and give highest performance with a minimum amount of energy. Just as natural selection drives organic evolution by competition among genes to produce more copies of themselves per unit cost in the next generation, raising benefit-to-cost of production drives the evolution of the economy. Almost all of the competition in a free market, other than in military technology, raises the average quality of life. Teleconferencing, online purchase and trade, e-book personal libraries, access on the Internet to all literature and scientific data, online diagnosis and medical practice, food production per hectare sharply raised by indoor vertical gardens with LED lighting, genetically engineered crops and microorganisms, long-distance business conferences and social visits by life-sized images, and not least the best available education in the world free online to anyone, anytime, and anywhere. All of these amenities are now fully available or soon will be. Each will yield more and better results with less per-capita material and energy, and thereby will reduce the size of the ecological footprint.

In viewing the future this way, I wish to suggest a means to achieve almost free enjoyment of the world's best places in the biosphere that I and my fellow naturalists have identified. The cost-benefit ratio would be extremely small. It requires only a thousand or so high-resolution cameras (small and unobtrusive, thanks to the continuing information technology revolution) that broadcast live around the clock from sites within reserves. People would still visit any reserve in the world physically, but they could also travel there virtually and in continuing real time with no more than a few keystrokes in their homes, schools, and lecture halls. Perhaps a Serengeti water hole at dawn? Or the diel cycles of a teeming Amazon canopy? There would also be available streaming video of summer daytime on the coast in the shallow offshore waters of Antarctica, and cameras that continuously travel through the great coral triangle of Indonesia and New Guinea. With species identifications and brief expert commentaries unobtrusively added, the adventure would be forever changing, and safe.

In simplest terms, both shrinkage of the ecological footprint and the resulting improvement of biodiversity conservation are favored because of the acceleration of the replacement of extensive economic growth by intensive economic growth. Extensive

economic growth, which prevailed through the twentieth century to the present time, is the increase of per-capita income by adding more capital, more population, and more undeveloped land. Intensive economic growth is that generated by the invention of high-performance new products added to the improved design and use of existing products. The iconic example of the transition is Moore's Law, for its inventor Gordon Moore, cofounder of Intel (and incidentally a leading activist in global conservation): the cost of microchip transistors will fall because the number that can be etched into a fixed area of computer microprocessor will double every two years. The law held between 2002 and 2012, with production rising from 2.6 million per dollar to twenty million per dollar, before beginning to level off.

A closely linked consequence of economic evolution in the twenty-first century is the shift in worldview from wealth based on quantity to wealth based on quality, with the latter made permanent through ecological realism. The central idea is to view the entire planet as an ecosystem, to see Earth as it is and not as we wish it to be. Given that stability in the economy and in the environment are closely linked, they both require striving for the quality of life through self-understanding as opposed to the conventional accumulation of material wealth, based on the assumption that the wealth can eventually be traded for quality of life.

The ecological-realism worldview has been expressed with resonance in *People and the Planet*, a report of Britain's Royal Society. Its recommendations have been endorsed by the global network of national science academies.

In the most developed and the emerging economies unsustainable consumption must be urgently reduced. This will entail scaling back or radical transformation of damaging material consumption and emissions and the adoption of sustainable technologies, and is critical to ensuring a sustainable future for all. At present, consumption is closely linked to economic models based on growth. Improving the wellbeing of individuals so that humanity flourishes rather than survives requires moving from current economic measures to fully valuing natural capital. Decoupling economic activity from material and environmental throughputs is needed urgently.

The pathway of economic evolution will be set by growth that is increasingly intensive and less extensive. Its most advanced products will empower individuals with instruments capable of achieving more and more with less and less per-capita consumption of materials and energy. The environmental consequence of its success will be the opposite of that envisioned by supporters of Anthropocene ideology. Achieved, it will reduce the world ecological footprint, and free space and resources for the rest of life, not constrict it as a perceived necessity of a growing economy. The biosphere and the ten million species that compose it will no longer be treated as a commodity, but as something vastly more important—a mysterious entity still beyond the boundaries of our imagination yet vital to long-term human existence.

With innovation and effort, we will find a way to steer through the climate-change crisis without having to resort to the gargantuan and dangerous programs of geoengineering now being discussed. In particular, let us hope that desperation from fear of a declining

future will not force the human race to scrub the atmosphere of excess carbon dioxide, then somehow put the carbon gathered back into the ground. Or, alternatively, coat Earth's surface with sulfates to reflect part of the sun's energy. Or, even worse but still talked about, add lime to seawater to absorb excess carbon dioxide out of the atmosphere.

The spearhead of intensive economic evolution, and with it hope for biodiversity, is contained in the linkage of biology, nanotechnology, and robotics. Two ongoing enterprises within it, the creation of artificial life and artificial minds, seem destined to preoccupy a large part of science and high technology for the rest of the present century. They are also by happenstance well on track to help reduce the ecological footprint, providing a better quality of life with less energy and resources. This result should yield an unintended consequence of entrepreneurial innovation, in this case participating in the protection of Earth's biodiversity for future generations.

The creation of artificial life-forms is already a reality. On May 20, 2010, a team of researchers at the J. Craig Venter Institute in California announced the second genesis of life, this time by human rather than divine command. They had built live cells from the ground up. With simple chemical reagents off the shelf, they assembled the entire genetic code of a bacterial species, *Mycoplasma mycoides*, a double helix of 1.08 million DNA base pairs. During the process they modified the code sequence slightly, implanting a statement made by the late theoretical physicist Richard Feynman, "What I cannot create, I do not understand," in order to detect daughters of the altered mother cells in future tests. Then they transplanted the altered DNA into a recipient cell from which the original DNA had been removed. The newly encoded cell fed and multiplied like a natural cell.

The entity was given a seventeenth century Latinized name with an appropriately robotic surname, *Mycoplasma mycoides* JCVI-syn 1.0. Hamilton O. Smith, speaking for the research team, wrote that with this synthetic entity, and with the new tools and techniques designed to complete the project, "We now have the means to dissect the genetic instruction set of a bacterial cell to see and understand how it really works."

In fact, the new technology is ready to do a great deal more. In 2014, a second team, led by Jef Boeke at Johns Hopkins University, constructed a completely artificial chromosome of a yeast cell. This feat also represents an important advance. Yeast cells are more complex than bacterial cells in possessing organelles such as chromosomes and mitochondria.

The textbook example of elementary artificial selection of the past ten millennia is the transformation of teosinte, a species of wild grass with three races in Mexico and Central America, into maize (corn). The food found in the ancestor was a meager packet of hard kernels. Over centuries of selective breeding it was altered into its modern form. Today maize, after further selection and widespread hybridization of inbred strains that display "hybrid vigor," is the principal food of hundreds of millions.

The first decade of the present century thus saw the beginning of the next new major phase of genetic modification beyond hybridization: artificial selection and even direct substitution in single organisms of one gene for another. If we use the trajectory of progress in molecular biology during the previous half century as a historical guide, it appears inevitable that scientists will begin routinely to

build cells of wide variety from the ground up, then induce them to multiply into synthetic tissues, organs, and eventually entire independent organisms of considerable complexity.

If people are to live long and healthy lives in the sustainable Eden of our dreams, and our minds are to break free and dwell in the far more interesting universe of reason triumphant over superstition, it will be through advances in biology. The goal is practicable because scientists, being scientists, live with one uncompromising mandate: Press discovery to the limit. Hand the baton from one to the next, if necessary, but never let the effort die. There has already emerged a term for the manufacture of organisms and parts of organisms: synthetic biology. Its potential benefits, easily visualized as spreading through medicine and agriculture, are limited only by imagination. Synthetic biology will also bring onto center stage the microbe-based increase of food and energy.

The potential power of synthetic biology also leads directly to a vexing question: Can we create a human being? Some enthusiasts believe that in time we ultimately can. If scientists succeeded, even if in just good part, we will have drawn close to the Feynman equation: to construct is to understand. But we will also be forced to solve the ultimate problem of philosophy: What is the meaning of humanity?

A note on history is appropriate at this point. A century ago artificial intelligence (AI) engineers and brain scientists began pursuit of separate goals served by different technologies. The primary purpose of artificial intelligence was and remains the creation of devices that perform physical tasks beyond human capacity. Brain science, in contrast, is more focused. Its central and ultimate goal is whole brain emulation (WBE), the modeling and ultimately the construction of a human-grade mind. Today the two endeavors are converging, and in many ways they already overlap. The technology of artificial intelligence has proven essential to whole brain emulation, while activities observed in the living brain promise advances in artificial intelligence.

The greatest challenge in whole brain emulation is the explanation of consciousness. Neurobiologists almost universally agree that it is a material phenomenon with a cellular physical base. As such it is part of what is called the neuronal workspace, and thus subject to experimentation and mapping. Whole brain emulation is still proceeding in baby steps, but each is longer than the one before. If the current trajectory and pace of research can be sustained, it seems likely that WBE will be attained within the present century. Its culmination will rank as one of the greatest achievements of all time. Exactly what will WBE have accomplished? It will have achieved the construction of artificial self-aware minds, reflective, emotional, eager to learn and grow.

Researchers drawn by this goal or key parts of it are unafraid of what they will find and what might become of it. The most successful scientists are like prospectors exploring an unknown territory. What they mostly care about is making a strike—to be the first to find intellectual gold, silver, or oil. People want it, so lay claim to it, let others worry about the consequences. Later in life they become philosophers, and worry. Meanwhile, they are confident that humanity will ultimately be accompanied by man-made intelligence that knows the meaning of intelligence and can be transferred safely to mobile robots. On the other hand, the people in the general public, influenced by Hollywood scriptwriters, are apprehensive. As citizens of still-violent cultures besotted with religious dogma and superstition, even well-educated people are willing to believe almost anything. In AI and WBE they see a blueprint for possible catastrophe. It is easy to imagine human-grade robots gone berserk and wreaking havoc, avatars (robotic human copies) united in revolt against their human creators, and human minds downloaded into computers that are able (as "transhumans") to dominate those who choose to remain mortal flesh and blood. It helps the myths that they are often featured in technically excellent science-fiction films, for example *2001: A Space Odyssey* (1968), *Star Wars* (1977), *The Terminator* (1984), *I, Robot* (2004), *Avatar* (2009), and *Transcendence* (2014), which are among the most entertaining of this genre ever made, thanks to their epic dramas bolstered by brilliant special effects.

The scientists are certain they know better. In any case, we are on our way to moving the brain sciences to the center of biology and the humanities. The magnitude of artificial intelligence is rising as part of the overall exponential growth of machine computing. Measured in calculations performed per second per thousand dollars of hardware, computer performance has increased since 1960 from one ten-thousandth of a calculation per second (one every three hours) to ten billion calculations per second. All of modern civilization, in every country, both developed and developing, has joined the digital revolution. The effect is not reversible. It will continue to intensify relentlessly, and soon it will reach deeply into the lives of everyone. An example is the impact on the longevity of occupations. Carl Benedikt Frey and Michael A. Osborne, economist and mathematician, respectively, at the University of Oxford, have estimated that at least up to 2030, jobs will be relatively secure for recreational therapists, athletic trainers, dentists, clergy, chemical engineers, firefighters, and editors, but at high risk for second-level machinists, secretaries, real estate agents, accountants, auditors, and telemarketers.

Each passing year sees advances in artificial intelligence and their multitudinous applications—advances that would have been thought distantly futuristic a decade earlier. Robots roll over the surface of Mars. They travel around boulders and up and down slopes while photographing, measuring minutiae of topography, analyzing the chemical composition of soil and rocks, and scrutinizing everything for signs of life. In 2014, SCHAFT, a Japanese-built robot, won the International DARPA Robotics Challenge by navigating doorways and debris, cutting a hole in a wall with a power tool, connecting a fire hose, and driving a small automobile along a twisted path. Advanced computers have recently begun to learn and correct themselves with repeated trials. One programmed with this ability trained itself to recognize images of cats. Another programmed to converse at the level of a boy passed the Turing Test (named after the pioneer computer theorist Alan Turing) when a third of a panel of experts speaking with it for five minutes did not recognize it as a machine.

In 1976, Kenneth I. Appel and Wolfgang Haken revolutionized part of mathematics by using ten billion calculations on an early computer to prove the classic four-color map theorem (proof that no more than four colors are needed to draw any two-dimensional map broken into two-dimensional countries or other pieces), where traditional analytic methods to that time had failed. They justified at least in part the remark by Einstein that "God does not care about our mathematical difficulties. He integrates empirically." In other words, where something is countable, He prefers to count. In

some way not yet understood, might the same be true of the hundred billion neurons of the natural human brain?

In the early period of the digital revolution, innovators relied on machine design of computers without reference to the human brain, much as the earliest aeronautical engineers used mechanical principles and intuition to design aircraft instead of imitating the flight of birds. Their approach was required by simple ignorance. Neither computer technologists nor brain scientists were advanced enough to make practical connections to living organisms. With the contemporary swift growth of both fields, analogies and even one-on-one comparisons of processes in natural versus man-made are multiplying. The alliance of computer technology and brain science has given birth to whole brain emulation as one of the ultimate goals of science.

Do brain scientists know enough of the brain's circuits and processes to translate them into the algorithms of artificial intelligence? The orientations of the two disciplines remain different. Whereas artificial intelligence is substantially an engineering enterprise, seeking solutions to problems, whole brain emulation is focused on the central problem of brain and mind. The two are nevertheless thoroughly intertwined. According to Daniel Eth and his coworkers at Stanford University, it is realistic to conceive of simulating a human brain in its entirety on a computer, including its thoughts, feelings, memories, and skills. They identify four requisite technologies: first scanning brain cellular architecture totally, next translating the scan into a model, then running the model on a computer, and finally simulating sensory input from the body and the surrounding environment. All this, they and many others believe, can be accomplished well before the end of this century.

For their part, "neuromorphic engineers," researchers centered on computer development, foresee success in developing computers with characteristics that brains have and computers still lack. According to Karlheinz Meier of the University of Heidelberg, three big problems must be solved to use this reverse engineering successfully. The first is that supercomputers currently trying to emulate brains require millions of watts of power, where human brains use only about twenty watts. Another obstacle is that computers cannot as yet tolerate even small failures. The loss of just one transistor can wreck a microprocessor, whereas brains handle a constant loss of neurons. Finally, brains learn and change spontaneously during experiences in the environment and the vast complexity of child development, but computers must follow the fixed paths and branches of predetermined algorithms.

In fact, the difficulties facing the architects of whole brain emulation go much deeper than just the traditional obstacles implicit in engineering design. The most obvious is that the human brain is not a product of engineering but of evolution. It is a jury-rigged product, built from what was available at each interval from past evolution, fitted by natural selection to the environment of the moment. Across the 450 million years of vertebrate evolution, and further back into our invertebrate ancestry, the brain has evolved not so much as an organ of thought as an organ of survival. From the beginning it was programmed to run the autonomic controls of respiration and heartbeat, along with the sensory and motor controls of reflex. From the very start as well, the brain housed the staging centers of instinct. It was in these centers that appropriate stimuli (the "sign stimuli" of the ethologists) triggered inborn instincts ("consummatory acts").

From the time of the ancient human-destined line of amphibians,

then reptiles, then mammals, the neural pathways of every part of the brain were repeatedly altered by natural selection to adapt the organism to the environment in which it lived. Step-by-step, from the Paleozoic amphibians to the Cenozoic primates, the ancient centers were augmented by newer centers, chiefly in the growing cortex, that added to learning ability. Adaptation to a particular environment by evolving repertories of reflex and instinct expanded to include adaptability to changing environments. All other things being equal, the ability of organisms to function through seasons and across different habitats gave them an edge in the constant struggle to survive and reproduce.

Little wonder, then, that neurobiologists have found the human brain to be densely sprinkled with partially independent centers of unconscious operations, along with all of the operators of rational thought. Located through the cortex in what may look at first like random arrays are the headquarters of process variously for numbers, attention, face recognition, meanings, reading, sounds, fears, values, and error detection. Decisions tend to be made by the brute force of unconscious choice in these centers prior to conscious comprehension. Decision, even for simple physical action, can proceed without awareness. The process was anticipated clearly, and poetically, as far back as 1902 by Henri Poincaré:

> The subliminal self is in no way inferior to the conscious self; it is not purely automatic; it is capable of discernment, it has tact, delicacy; it knows better how to choose, to divine. What do I say? It knows better how to divine than the conscious self, since it succeeds where that has failed. In a word, is not the subliminal self superior to the conscious self?

Next in evolution came consciousness. Brain scientists don't know exactly what it is, but they are getting a grip on the role it plays as the newcomer in the human brain. Stanislas Dehaene, a leading theorist at the Collège de France, picked up Poincaré's thread in 2014 as follows:

> In fact, consciousness supports a number of specific operations that cannot unfold unconsciously. Subliminal information is evanescent, but conscious information is stable—we can hang on to it for as long as we wish. Consciousness also compresses the incoming information, reducing an immense stream of sense data to a small set of carefully selected bite-size symbols. The sampled information can then be routed to another processing stage, allowing us to perform what are fully controlled chains of operations, much like a serial computer. This broadcasting function of consciousness is essential. In humans, it is greatly enhanced by language, which lets us distribute our conscious thoughts across the social network.

What has brain science to do with biodiversity? With the human future coming more closely in focus, including an opening to the fountainhead of intellect, it is time—past time—to explore more carefully our moral reasoning with respect to the rest of life. Human nature evolved along a zigzag path as a continually changing ensemble of genetic traits. For all those millions of years to the beginning in this eleventh hour of the Anthropocene, our species let the biosphere continue to evolve on its own. Then, with scythe and fire, guided more by ignorant instinct than by reason, we changed everything.

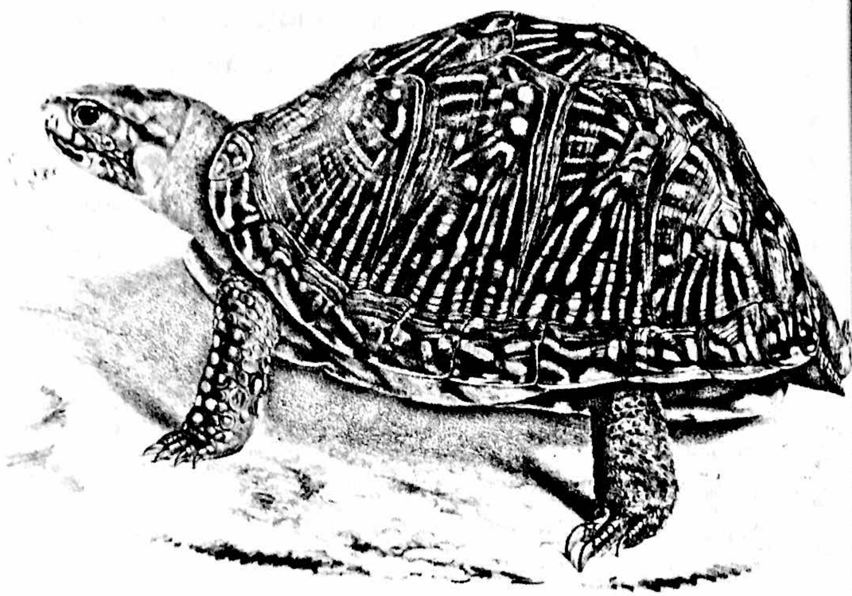
The endgame of biodiversity conservation is being played out in the twenty-first century. The explosive growth of digital technology, by transforming every aspect of our lives and changing our self-perception, has made the "bnr" industries (biology, nanotechnology, robotics) the spearhead of the modern economy. These three have the potential either to favor biodiversity or to destroy it. I believe they will favor it, by moving the economy away from fossil fuels to energy sources that are clean and sustainable, by radically improving agriculture with new crop species and ways to grow them, and by reducing the need or even the desire for distant travel. All are primary goals of the digital revolution. Through them the size of the ecological footprint will also be reduced. The average person can expect to enjoy a longer, healthier life of high quality yet with less energy extraction and raw demand put on the land and sea. If we are lucky (and smart), world population will peak at a little more than ten billion people by the end of the century or soon thereafter. Not only will the world population decline afterward but the ecological footprint as well—perhaps precipitously. The reason is that we are thinking organisms trying to understand how the world works. We will come awake.

Meanwhile, digital technologies have serendipitously made it possible to complete the census of global biodiversity, and with it to determine the status of each of the millions of species that compose Earth's fauna and flora. That process is already under way, albeit still far too slowly—with the end in sight in the twenty-third century. We and the rest of life with us are in the middle of a bottleneck of rising population, shrinking resources, and disappearing species. As its stewards we need to think of our species as being in a race to save the living environment. The logical primary goal is to make it through the bottleneck to a better, less perilous existence while carrying through as much of the rest of life as possible. If global biodiversity is given space and security, most of the large fraction of species now endangered will regain sustainability on their own.

Furthermore, advances made in synthetic biology, artificial intelligence, whole brain emulation, and other, similar mathematically based disciplines can be imported to create an authentic, predictive science of ecology. In it the interrelations of species will be explored as fervently as we now search through our own bodies for health and longevity. It is often said that the human brain is the most complex system known to us in the universe. That is incorrect. The most complex is the individual natural ecosystem, and the collectivity of ecosystems comprising Earth's species-level biodiversity. Each species of plant, animal, fungus, and microorganism is guided by sophisticated decision devices. Each is intricately programmed in its own way to pass with precision through its respective life cycle. It is instructed on when to grow, when to mate, when to disperse, and when to shy away from enemies. Even the single-celled *Escherichia coli*, living in the bacterial paradise of our intestines, moves toward food and away from toxins by spinning its tail cilium one way, then the other way, in response to chemosensory molecules within its microscopic body.

How all these minds and the decision-making devices within and around them evolve, and how they interact with ecosystems—whether tightly or loosely—is a vast area of biology that remains mostly uncharted—and still even undreamed by those scientists who devote their lives to it. The analytic techniques coming to bear on neuroscience, on Big Data theory, on interoperability studies, on simulations with robot avatars, and on other comparable enterprises will find applications in biodiversity studies. They are ecology's sister disciplines.

It is past time to broaden the discussion of the human future and connect it to the rest of life. The Silicon Valley dreamers of a digitized humanity have not done that, not yet. They have failed to give much thought at all to the biosphere. With the human condition changing so swiftly, we are losing or degrading to uselessness ever more quickly the millions of species that have run the world independently of us and free of cost. If humanity continues its suicidal ways to change the global climate, eliminate ecosystems, and exhaust Earth's natural resources, our species will very soon find itself forced into making a choice, this time engaging the conscious part of our brain. It is as follows: Shall we be existential conservatives, keeping our genetically based human nature while tapering off the activities inimical to ourselves and the rest of the biosphere? Or shall we use our new technology to accommodate the changes important solely to our own species, while letting the rest of life slip away? We have only a short time to decide.



The Mexican box turtle Cistudo mexicana. Proceedings of the Zoological Society of London, *1848–1860.*

21

WHAT MUST BE DONE

In a world gaining so swiftly in biotechnology and rational capability, it is entirely reasonable to envision a global network of inviolable reserves that cover half the surface of Earth. But will people and their self-centered political leaders share with others what is theirs to dispose? It is popular to say that the first rule of altruism is never to expect anyone to do anything contrary to his personal interest. Because of the way the brain has evolved, it is especially difficult to protect distant environments if people imagine even a small amount of personal risk or sacrifice. True altruism, this logic continues, is limited to family, tribe, race, or nation, where our genes are seen as indirectly rewarded by our individual devotion to others. God is thought to favor the creation story of the believer's religion over those of all other religions. A patriot considers the moral precepts of his society to be the best in the world. It is the national anthem, not a hymn to human achievement, that is played for Olympic winners.

Even though self-rewarding behavior dominates human behavior, it does not act alone. An instinct for true altruism exists. It enters the decision centers of the brain most readily when an individual has some degree of power and hence the responsibility to achieve altruistic goals. The driving evolutionary force that has created it is group selection, as distinguished from individual selection. The essence of the process is the following: *if altruism toward other members of the group contributes to the group's success, the benefit the altruist's bloodline and genes received may exceed the loss in genes caused by the individual's altruism.*

Charles Darwin, who originated the broad outline of this idea, having confessed difficulty of grasping it at first (for one thing, he had no concept of genes), nevertheless expressed it clearly in *The Descent of Man*:

> It must not be forgotten that although a high standard of morality gives but a slight or no advantage to each individual man and his children over the other men of the same tribe, yet that an advancement in the standard of morality and an increase in the number of well-endowed men will certainly give an immense advantage to one tribe over another. There can be no doubt that a tribe including many members who, from possessing in a high degree the spirit of patriotism, fidelity, obedience, courage, and sympathy, were always ready to give aid to each other and to sacrifice themselves for the common good, would be victorious over most other tribes; and this would be natural selection. At all times throughout the world tribes have supplanted other tribes; and as morality is one element in their success, the standard of morality and the number of well-endowed men will thus everywhere tend to rise and increase.

This idea of multilevel selection (individual plus group selection), which has since been refined many times, then proved by theory and experiment, can be extended as part of social evolution to unrelated persons inside and out of the same tribe and even to other species. As I and other researchers have argued in earlier work, the phenomenon of biophilia, the innate love of the living process, applies even to the natural world, in other words humanity's ancestral environment.

The living world is in desperate condition. It is suffering steep declines in all the levels of its diversity. It will be helped but not saved by economic measures of its ecological services and potential products. Nor will the perception of God's holy will suffice: traditional religions are pivoted on the salvation of human beings, here and in the afterlife, above all other purposes that can be conceived. Only a major shift in moral reasoning, with greater commitment given to the rest of life, can meet this greatest challenge of the century. Wildlands are our birthplace. Our civilizations were built from them. Our food and most of our dwellings and vehicles were derived from them. Our gods lived in their midst. Nature in the wildlands is the birthright of everyone on Earth. The millions of species we have allowed to survive there, but continue to threaten, are our phylogenetic kin. Their long-term history is our long-term history. Despite all of our pretenses and fantasies, we always have been and will remain a biological species tied to this particular biological world. Millions of years of evolution are indelibly encoded in our genes. History without the wildlands is no history at all.

We should forever bear in mind that the beautiful world our species inherited took the biosphere 3.8 billion years to build. The intricacy of its species we know only in part, and the way they work together to create a sustainable balance we have only recently begun to grasp. Like it or not, and prepared or not, we are the mind and stewards of the living world. Our own ultimate future depends upon that understanding. We have come a very long way through the barbaric period in which we still live, and now I believe we've learned enough to adopt a transcendent moral precept concerning the rest of life. It is simple and easy to say: Do no further harm to the biosphere.

SOURCES AND FURTHER READING

Prologue

A bibliographic note: I first presented the basic argument for such a massively expanded reserve in *The Future of Life* (2002) and *A Window on Eternity: A Biologist's Walk Through Gorongosa National Park* (2014). The term "Half-Earth" was suggested for this concept by Tony Hiss in the article "Can the World Really Set Aside Half the Planet for Wildlife?" (*Smithsonian* 45(5): 66–78, 2014).

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