INTRODUCTION: THE MICROCOSM

WHEN people look at life on Earth, it is easy to think we are supreme. The power of consciousness, of our society and our technical inventions, has made us think we are the most advanced form of life on the planet. Even the great blackness of space seen does not humble us. We view space as a no man's land to penetrate and conquer as we believe we have conquered the Earth.

Life on Earth has traditionally been studied as a prologue to humans: "lower" forms of life lacking intelligence preceded us and we now stand at the pinnacle of evolution. Indeed, so godlike do we consider ourselves that we may think we are taking evolution into our own hands by manipulating DNA, the mainspring of life, according to our own design. We study the microcosm—the age-old world of microorganisms—to discover life's secret mechanisms so that we can take better control, perhaps even "perfect" ourselves and the other living things on the Earth.

But during the past three decades, a revolution has taken place in the life sciences. Fossil evidence of primeval microbial life, the decoding of DNA, and discoveries about the composition of our own cells have exploded established ideas about the origins of life and the dynamics of evolution on Earth.

First, they have shown the folly of considering people as special, apart and supreme. The microscope has gradually exposed the vastness of the microcosm and is now giving us a startling view of our true place in nature. It now appears that microbes—also called microorganisms, germs, bugs, protozoans, and bacteria, depending on the context—are not only the building blocks of life, but occupy and are indispensable to every known living structure on the Earth today. From the paramecium to the human race, all life forms are meticulously organized, sophisticated aggregates of evolving microbial life. Far from leaving microorganisms behind on an evolutionary "ladder," we are both surrounded by them and composed of them. Having survived in an unbroken line from the beginnings of life, all organisms today are equally evolved.

This realization sharply shows up the conceit and presumption of attempting to measure evolution by a linear progression from the simple—so-called lower—to the more complex (with humans as the absolute "highest" forms at the top of the hierarchy). As we shall see, the simplest and most ancient organisms are not only the forebears and the present substrate of the Earth's biota, but they are ready to expand and alter themselves and the rest of life, should we "higher" organisms, be so foolish as to annihilate ourselves.

Next, the view of evolution as chronic bloody competition among individuals and species, a popular distortion of Darwin's notion of "survival of the fittest," dissolves before a

new view of continual cooperation, strong interaction, and mutual dependence among life forms. Life did not take over the globe by combat, but by networking. Life forms multiplied and complexified by co-opting others, not just by killing them.

Because we cannot see the microcosm with the unaided eye, we tend to discount its significance. Yet of the three-and-a-half billion years that life has existed on Earth, the entire history of human beings from the cave to the condominium represents far less than one percent. Not only did life originate on earth very early in its history as a planet, but for the first full two billion years, Earth was inhabited solely by bacteria.

In fact, so significant are bacteria and their evolution that the fundamental division in forms of life on Earth is not that between plants and animals, as is commonly assumed, but between prokaryotes—organisms composed of cells with no nucleus, that is, bacteria—and eukaryotes—all the other life forms.[1] In their first two billion years on Earth, prokaryotes continuously transformed the Earth's surface and atmosphere. They invented all of life's essential, miniaturized chemical systems—achievements that so far humanity has not approached. This ancient high *bio*technology led to the development of fermentation, photosynthesis, oxygen breathing, and the removal of nitrogen gas from the air. It also led to worldwide crises of starvation, pollution, and extinction long before the dawn of larger forms of life.

These staggering events early in life's history came about by the interaction of at least three recently discovered dynamics of evolution. The first is the remarkable orchestrating abilities of DNA. Identified as the heredity-transmitting substance in 1944 by Oswald T. Avery, Colin MacLeod, and

Maclyn McCarty, DNA's code was cracked in the 1960s after its method of replication was revealed by James Watson and Francis Crick in 1953. Governed by DNA, the living cell can make a copy of itself, defying death and maintaining its identity by reproducing. Yet by also being susceptible to mutation, which randomly tinkers with identity, the cell has the potential to survive change.

A second evolutionary dynamic is a sort of natural genetic engineering. Evidence for it has long been accumulating in the field of bacteriology. Over the past fifty years or so, scientists have observed that prokaryotes routinely and rapidly transfer different bits of genetic material to other individuals. Each bacterium at any given time has the use of accessory genes, visiting from sometimes very different strains, which perform functions that its own DNA may not cover. Some of the genetic bits are recombined with the cell's native genes; others are passed on again. Some visiting genetic bits can readily move into the genetic apparatus of eukaryotic cells (such as our own) as well.

These exchanges are a standard part of the prokaryotic repertoire. Yet even today, many bacteriologists do not grasp their full significance: that as a result of this ability, all the world's bacteria essentially have access to a single gene pool and hence to the adaptive mechanisms of the entire bacterial kingdom. The speed of recombination over that of mutation is superior: it could take eukaryotic organisms a million years to adjust to a change on a worldwide scale that bacteria can accommodate in a few years. By constantly and rapidly adapting to environmental conditions, the organisms of the microcosm support the entire biota, their global exchange network ultimately affecting every living plant and animal. Human beings are just learning these techniques in the science of genetic engineering, whereby biochemicals are produced by introducing foreign genes into reproducing cells. But prokaryotes have been using these "new" techniques for billions of years. The result is a planet made fertile and inhabitable for larger forms of life by a communicating and cooperating worldwide superorganism of bacteria.

Far-reaching as they are, mutation and bacterial genetic transfer alone do not account for the evolution of all the life forms on the earth today. In one of the most exciting discoveries of modern microbiology, clues to a third avenue of change appeared in the observation of mitochondria—tiny membrane-wrapped inclusions in the cells of animals, plants, fungi, and protists alike. Although they lie outside the nucleus in modern cells, mitochondria have their own genes composed of DNA. Unlike the cells in which they reside, mitochondria reproduce by simple division. Mitochondria reproduce at different times from the rest of the cell. Without mitochondria, the nucleated cell, and hence the plant or animal, cannot utilize oxygen and thus cannot live.

Subsequent speculation brought biologists to a striking scenario: The descendants of the bacteria that swam in primeval seas breathing oxygen three billion years ago exist now in our bodies as mitochondria. At one time, the ancient bacteria had combined with other microorganisms. They took up residence inside, providing waste disposal and oxygen-derived energy in return for food and shelter. The merged organisms went on to evolve into more complex oxygen-breathing forms of life. Here, then, was an evolutionary mechanism more sudden than mutation: a symbiotic alliance that becomes permanent. By creating organisms that are not simply the sum of their symbiotic parts—but something more like the sum of all the possible combinations of their parts—such alliances push developing beings into uncharted realms. Symbiosis, the merging of organisms into new collectives, proves to be a major power of change on Earth.[2]

As we examine ourselves as products of symbiosis over billions of years, the supporting evidence for our multimicrobe ancestry becomes overwhelming. Our bodies contain a veritable history of life on Earth. Our cells maintain an environment that is carbon- and hydrogen-rich, like that of the Earth when life began. They live in a medium of water and salts like the composition of the early seas. We became who we are by the coming together of bacterial partners in a watery environment. Although the evolutionary dynamics of DNA, genetic transfer, and symbiosis were not discovered until almost a century after Charles Darwin's death in 1882, he had the shrewdness to write, "We cannot fathom the marvellous complexity of an organic being; but on the hypothesis here advanced this complexity is much increased. Each living creature must be looked at as a microcosm—a little universe, formed of a host of self-propagating organisms, inconceivably minute and as numerous as the stars in heaven."[3] The strange nature of this little universe is what this book is about.

The detailed structure of our cells betrays the secrets of their ancestors. Electron microscopic images of nerve cells from all animals reveal numerous conspicuous "microtubules." The waving cilia in the lining of our throats and the whipping tail of the human sperm cell both have the same unusual "telephone dial" arrangement of microtubules as do the cilia of ciliates, a group of successful microbes including more than eight thousand different species. These same microtubules appear in all cells of plants, animals, and fungi each time the cells divide. Enigmatically, the microtubules of dividing cells are made of a protein nearly identical to one found in our brains; and this is a protein exceedingly similar to some of those found in certain fast-moving bacteria shaped like corkscrews.

These and other living relics of once-separate individuals, detected in a variety of species, make it increasingly certain that all visible organisms evolved through symbiosis, the coming together that leads to physical interdependence and the permanent sharing of cells and bodies. Although, as we shall see, some details of the bacterial origin of mitochondria, microtubules, and other cell parts are hard to explain, the general outline of how evolution can work by symbiosis is agreed upon by those scientists who are familiar with the lifestyles of the microcosm.

The symbiotic process goes on unceasingly. We organisms of the macrocosm continue to interact with and depend upon the microcosm, as well as upon each other. Certain families of plants (such as the pea family, including peas, beans, and their relatives such as clover and vetch) cannot live in nitrogen-poor soil without the nitrogen-fixing bacteria in their root nodules, and we cannot live without the nitrogen that comes from such plants. Neither cows nor termites can digest the cellulose of grass and wood without communities of microbes in their guts. Fully ten percent of our own dry body weight consists of bacteria, some of which, although they are not a congenital part of our bodies, we can't live without. No mere quirk of nature, such coexistence is the stuff of evolution itself. Let evolution continue a few million years more, for example, and those microorganisms producing vitamin B_{12} in our intestines may become parts of our own cells. An aggregate of specialized cells may become an organ. The union of once-lethal bacteria with amoebae, creating over time a new species of hybrid amoeba, has even been witnessed in the laboratory.

This revolution in the study of the microcosm brings before us a breathtaking view. It is not preposterous to postulate that the very consciousness that enables us to probe the workings of our cells may have been born of the concerted capacities of millions of microbes that evolved symbiotically to become the human brain. Now, this consciousness has led us to tinker with DNA and we have begun to tap in to the ancient process of bacterial genetic transfer. Our ability to make new kinds of life can be seen as the newest way in which organic memory—life's recall and activation of the past in the present—becomes more acute. In one of life's giant, self-referential loops, changing DNA has led to the consciousness that enables us to change DNA. Our curiosity, our thirst to know, our enthusiasm to enter space and spread ourselves and our probes to other planets and beyond represents part of the cutting edge of life's strategies for expansion that began in the microcosm some three-and-a-half billion years ago. We are but reflections of an ancient trend.

From the first primordial bacteria to the present, myriads of symbiotically formed organisms have lived and died. But the microbial common denominator remains essentially unchanged. Our DNA is derived in an unbroken sequence from the same molecules in the earliest cells that formed at the edges of the first warm, shallow oceans. Our bodies, like those of all life, preserve the environment of an earlier Earth. We coexist with present-day microbes and harbor remnants of others, symbiotically subsumed within our cells. In this way, the microcosm lives on in us and we in it.

Some people may find this notion disturbing, unsettling. Besides popping the overblown balloon that is our presumption of human sovereignty over the rest of nature, it challenges our ideas of individuality, of uniqueness and independence. It even violates our view of ourselves as discrete physical beings separated from the rest of nature. To think of ourselves and our environment as an evolutionary mosaic of microscopic life evokes imagery of being taken over, dissolved, annihilated. Still more disturbing is the philosophical conclusion we will reach later, that the possible cybernetic control of the Earth's surface by unintelligent organisms calls into question the alleged uniqueness of human intelligent consciousness.

Paradoxically, as we magnify the microcosm to find our origins, we appreciate sharply both the triumph and the insignificance of the individual. The smallest unit of life—a single bacterial cell—is a monument of pattern and process unrivaled in the universe as we know it. Each individual that grows, doubles its size, and reproduces is a great success story. Yet just as the individual's success is subsumed in that of its species, so is the species subsumed in the global network of all life—a success of an even greater order of magnitude.

It is tempting, even for scientists, to get carried away by success stories. From the disciples of Darwin to today's genetic engineers, science has popularized the view that humans are at the top rung of Earth's evolutionary "ladder" and that with technology we have stepped outside the framework of evolution. Some eminent and sophisticated scientists, such as Francis Crick in his book, *Life Itself*, write that life in general and human consciousness in particular are so miraculous that they couldn't be earthly at all, but must have originated elsewhere in the universe.[4] Others still believe that humans are a product of a fatherly "higher intelligence"—the children of a divine patriarch.

This book was written to show that these views underestimate the Earth and the ways of nature. There is no evidence that human beings are the supreme stewards of life on Earth, nor the lesser offspring of a superintelligent extraterrestrial source. But there is evidence to show that we are recombined from powerful bacterial communities with a multibillion-year-old history. We are a part of an intricate network that comes from the original bacterial takeover of the Earth. Our powers of intelligence and technology do not belong specifically to us but to all life. Since useful attributes are rarely discarded in evolution it is likely that our powers, derived from the microcosm, will endure in the microcosm. Intelligence and technology, incubated by humankind, are really the property of the microcosm. They may well survive our species in forms of the future that lie beyond our limited imaginations.

AUTHORS' PREFACE

What is the relationship between humans and Nature? The Linnaean, or scientific, name of our own species is *Homo sapiens sapiens*—"Man, the wise, the wise." But, as a humble proposal or wisecrack, we suggest that humanity be rechristened *Homo insapiens*—"Man, the unwise, the tasteless." We love to think we are Nature's rulers—"Man is the measure of all things," said Protagoras 2,400 years ago—but we are less regal than we imagine. *Microcosmos: Four Billion Years of Evolution from Our Microbial Ancestors* (New York: Summit Books, 1986) strips away the gilded clothing that serves as humanity's self-image to reveal that our self-aggrandizing view of ourselves is no more than that of a planetary fool.

Humans have long been the planetary or biospheric equivalent of Freud's ego, which "plays the ridiculous role of the clown in the circus whose gestures are intended to persuade the audience that all the changes on the stage are brought about by his orders." We resemble such a clown except that, unlike him, our egotism concerning our own importance for

Nature is often humorless. Freud continues, "But only the youngest members of the audience are taken in by him."[5] Perhaps human gullibility regarding planetary ecology is also a function of our youth—our collective immaturity as one of many species sharing the Earth. But even if we are Nature's brilliant child, we are not that scientific conceit, "the most highly evolved species." The human "emperor," from the revisionary perspective of *Microcosmos,* and in the humble opinion of its authors, is wearing no clothes.

A recent forum in *Harper's Magazine,* titled "Only Man's Presence Can Save Nature,"[6] exemplifies humanity's typically grandiose, almost solipsistic, view of itself. Atmospheric chemist James Lovelock speaks of the relationship between humans and Nature as an impending "war"; ecofundamentalist Dave Foreman declares that, far from being the central nervous system or brain of Gaia, we are a cancer eating away at her; while University of Texas Professor of Arts and Humanities Frederick Turner transcendentally assures us that humanity is the living incarnation of Nature's billion-year-old desire. We would like to take all these views to task. In medieval times an interesting prop of the jesting Fool, besides glittering jeweled bauble and wooden knife, was the globe. Picture this figure—capped and belled Fool, ear flaps a-dangling as he handles a mock Earth—for a more festive, if no less true, summary of how things stand between *Homo sapiens* and Nature.

Through Plato, Socrates speaks of the folly of inscribing one's opinions: although your views may change, your words as committed to paper remain. Socrates at least did not write, and what he knew, first and foremost, was that he did not know. We, however, did write. Reversing the usual inflated view of humanity, we wrote of *Homo sapiens* as a kind of latter-day permutation in the ancient and ongoing evolution

of the smallest, most ancient, and most chemically versatile inhabitants of the Earth, namely bacteria. We wrote that the physiological system of life on Earth, Gaia, could easily survive the loss of humanity, whereas humanity would not survive apart from that life. *Microcosmos* received generally favorable reviews, but was criticized on several scores, most vehemently for our cavalier attitude toward our own species. We outraged some with the implication that even nuclear war would not be a total apocalypse, since the hardy bacteria underlying life on a planetary scale would doubtless survive it. Unlike spoken words floating off noncommittally into the fickle winds of opinion, our words as hard symbols on paper sat, as here they sit—obstinately confronting us with dogma and didacticism instead of what otherwise might have been merely a provisional opinion. Happily, though, the occasion of the paperback reprinting of *Microcosmos* offers us an opportunity, if not to rewrite and revise, at least to reflect on the book and its main concerns.

Much has occurred, in science and in the world, in the half decade since the hardcover first appeared. In "The Symbiotic Brain" (Chapter 9) we detailed the speculation that the sperm tails of men, which propel sperm to the eggs of women, evolved through symbiosis. We claimed that sperm tails and oviduct undulipodia (among other subvisible structures) derived from spirochete bacteria that became ancestral cell "whips." In 1989 three Rockefeller University scientists published an arcane report of a new special cell DNA.[7] Although the research has been challenged, their discovery of "kinetosome" DNA, outside the cell nucleus and tightly packed at the base of each cell whip (undulipodium), is the single most important scientific advance for the symbiotic theory of cell evolution since the 1953 discovery of DNA itself. *Microcosmos,* in contrast to the usual view of neo-Darwinian evolution as an unmitigated conflict in which only the strong survive, more than ever encourages exploration of an essential alternative: a symbiotic, interactive view of the history of life on Earth. And although we would be foolish to propose that competitive power struggles for limited space and resources play no role in evolution, we show how it is equally foolish to overlook the crucial importance of physical association between organisms of different species, symbioses, as a major source of evolutionary novelty. And during the last half decade events and moods have tended to underscore the importance of symbiosis and cooperation far beyond the microworld of evolving bacteria.

As symbolized by the deconstruction of the Berlin Wall and the end of the Cold War, it is folly not to extend the lessons of evolution and ecology to the human and political realm. Life is not merely a murderous game in which cheating and killing insure the injection of the rogue's genes into the next generation, but it is also a symbiotic, cooperative venture in which partners triumph. Indeed, despite the belittling of humanity that naturally occurs when one looks at "*Homo sapiens sapiens*" from a planetary perspective of billions of years of cell evolution, we can rescue for ourselves some of our old evolutionary grandeur when we recognize our species not as lords but as partners: we are in mute, incontrovertible partnership with the photosynthetic organisms that feed us, the gas producers that provide oxygen, and the heterotrophic bacteria and fungi that remove and convert our waste. No political will or technological advance can dissolve that partnership.

Another sign of this distinct sort of deserved grandeur is our involvement in a project that may well outlast our species as we know it: the introduction of biospheres[8] to other planets and to outer space. These expanding activities resemble nothing so much as the reproduction of the planetary living system—the truly physiologically behaving nexus of all life on Earth. The expansion and reproduction of the biosphere, the production of materially closed, energetically open ecosystems on the Moon, Mars, and beyond, depends upon humanity in its widest sense as a planetary-technological phenomenon. David Abram, a philosopher at SUNY–Stony Brook, has spoken of humanity "incubating" technology. A selfish attitude and an exaggerated sense of our own importance may have spurred the augmentation of technology and human population at the expense of other organisms. Yet now, after the "incubation phase," the Gaian meaning of technology reveals itself: as a human-mediated but not a human phenomenon, whose applications stand to expand the influence of all life on Earth, not just humanity.

In *Microcosmos* we retrace evolutionary history from the novel perspective of the bacteria. Bacteria, single and multicellular, small in size and huge in environmental influence, were the sole inhabitants of Earth from the inception of life nearly four billion years ago until the evolution of cells with nuclei some two billion years later. The first bacteria were anaerobes: they were poisoned by the very oxygen some of them produced as waste. They breathed in an atmosphere that contained energetic compounds like hydrogen sulfide and methane. From the microcosmic perspective, plant life and animal life, including the evolution of humanity, are recent, passing phenomena within a far older and more fundamental microbial world. Feeding, moving, mutating, sexually recombining, photosynthesizing, reproducing, overgrowing, predacious, and energy-expending symbiotic microorganisms preceded all animals and all plants by at least two billion years.

What is humanity? The Earth? The relationship of the two, if in fact they are two? *Microcosmos* approaches these large questions from the particular perspective of a planet whose evolution has been largely a bacterial phenomenon. We believe this formerly slighted perspective is a highly useful, even essential, compensation required to balance the traditional anthropocentric view which flatters humanity in an unthinking, inappropriate way. Ultimately we may have overcompensated. In the philosophical practice known as deconstruction, powerful hierarchical oppositions are dismantled by a dual process Jacques Derrida caricatures or characterizes as "reversal and displacement." This process is at work in *Microcosmos:* humanity is deconstructed as the traditional hierarchy—recently evolved humans on top, evolutionarily older "lower" organisms below—is reversed. *Microcosmos* removes man from the summit, showing the immense ecological and evolutionary importance of the lowest of the small organisms, bacteria. But from the view of deconstructive practice, *Microcosmos,* which reverses the hierarchical opposition, does not take the next step of displacement: man is taken off the top of Nature only to be put on the bottom. What ultimately must be called into question is not the position assumed by humans in the opposition Man/Nature but the oppositional distortions imposed by the hierarchy itself. (A more parochial matter for deconstruction, apparently of interest to Derrida himself, is the hierarchy humanity/animality.) If we were to entirely rewrite *Microcosmos,* we might try to redress the naïveté of this inversion, which—like turning the king into a fool—upsets our conventions, but only in a preliminary fashion without truly dismantling them. Nearly all our predecessors assumed that humans have some immense importance, either material or transcendental. We picture humanity as one among other microbial phenomena, employing *Homo insapiens* as a nickname to remind ourselves to stave off the recurring fantasy that people master (or can master) Gaia. The microbial view is ultimately provisional; there is no absolute dichotomy between humans and bacteria. *Homo insapiens,* our more humbling name, seems more fitting, somehow more "Socratic." At least we know, it says, that we do not know.

The *Harper's* debate presented a diversity of characterizations of the relationship between "Man" and "Nature." And despite the title, "Only Man's Presence Can Save Nature," the editors dutifully informed us that one of the most significant contributions to the debate on humanity's status is that "Nature has ended." In *Microcosmos* we take a stance against the division of humans beings from the rest of "Nature." People are neither fundamentally in conflict with nor essential to the global ecosystem. Even if we accomplish the extraterrestrial expansion of life, it will not be to the credit of humanity *as humanity.* Rather it will be to the credit of humanity as a symbiotically evolving, globally interconnected, technologically enhanced, microbially based system. Given time, raccoons might also manufacture and launch their ecosystems as space biospheres, establishing their bandit faces on other planets as the avant-garde of Gaia's strange and seedlike brood. Maybe not black-and-white raccoons, but diaphanous nervous-system fragments of humanity, evolved beyond recognition as the organic components of reproducing machines, might survive beyond the inevitable explosion and death of the sun. Our microcosmic portrayal of *Homo sapiens sapiens* as a kind of glorified sludge has the merit of reminding us of our bacterial ancestry and our connections to a still largely bacterial biosphere.

An old metaphysical prejudice, a thinly disguised axiom of western philosophy, is that human beings are radically separate from all other organisms. Descartes held that nonhuman animals lacked souls. For centuries scientists have suggested that thought, language, tool use, cultural evolution, writing, technology—something, *anything*—unequivocally distinguishes people from "lower" life forms. As recently as 1990 nature writer William McKibben wrote, "In our modern minds nature and human society are separate things . . . this separate nature . . . is quite real. It is fine to argue, as certain poets and biologists have, that we must learn to fit in with nature, to recognize that we are but one species among many. . . . But none of us, on the inside, quite believe it."[9] Perhaps this anthropocentric self-glorification spurred our ancestors on, gave them the confidence to be "fruitful and multiply"—to rush to the very brink we are on now of a punctuated change in global climate, accompanied by mass extinctions and a shift in the Gaian "geophysiology."

It is usually thought that Darwin, by presenting evidence for the theory of evolution by natural selection, dramatically knocked the pedestal out from under the feet of humanity, undermining the case for God, leaving us uncomfortably in the company of other animals by broadcasting the taboo secret of our apish origins. The Darwinian revolution has often been compared to that of Copernicus, who showed that the Earth is not the center of the Universe but merely a dust speck in the corner of our galactic Milky Way cobweb. From a philosophical point of view, however, far from the Darwinian revolution destroying our special relationship as the unique life form, as a chosen species made in God's image and with connections to saints and angels, what seems to have happened in the wake of the Darwinian revolution is that we, *Homo sapiens sapiens*—man, the wise, the wise—have come to replace God. No longer are we junior partners, second in command. Darwinism may have destroyed the

anthropomorphic deity of traditional religion, but instead of humbling us into awareness of the protoctists and all other sibling life forms (the plants, fungi, bacteria, and other animals), it rendered us greedy to assume God's former place. We put ourselves in the self-assumed position of divine rulers over life on Earth, ambitiously devising planet-scale technologies and, in short, engineering the world.

Somewhat surprisingly to those not versed in the ways of feedback, this self-serving attitude of human glorification at the expense of other species no longer serves us. Our extreme self-centeredness and hyperpopulation of the planet have brought on wholesale ecological carnage, the greatest threat of which is to ourselves. The traditional religious perspective—kept alive, as we have seen, even inside secular Darwinism—is that human beings are separate, unique, better. This is the attitude of ecological arrogance. The perspective of *Microcosmos* differs in that it is a deep-ecology, a particular variety of "green" perspective. Referring now to Lewis Thomas's tracing of the early word *human* in the Foreword, *Microcosmos* tries to develop an attitude of ecological *humility*. Retelling the story of life from the vantage point of microbes, *Microcosmos* diametrically inverts the usual hierarchy: indeed, by claiming that the planetary system of life has no essential need for man, that humanity is a temporary pointillist epiphenomenon of the essential and anciently recombining microorganisms, we may have overstated, exaggerated the case. The problem with the reversal that places microbes on top and people underneath is that dichotomization—important versus unimportant, essential versus unessential—remains. Woody Allen once said that he always put his wife *under* a pedestal. Confronting our ecological arrogance does not solve the problem of the pedestal: it is still assumed that one organism is better, higher, or "more evolved" than the other. To deconstruct our destructive attitude of ecological arrogance, it is necessary to put ourselves down. Once we recognize our energetic and chemical intercourse with other species, however, and the nonnegotiability of our connections with them, we must remove the pedestal altogether.

In tandem with its attempt to carry to the limits Darwin's "Copernican" revolution, *Microcosmos* stresses the symbiotic history of life. Since the publication of the hardcover, more striking evidence has accumulated to show that symbiosis, the living together and sometimes merging of different species of organisms, has been crucial to the evolution of life forms on Earth. The most important examples of symbiosis—the chloroplasts of all plants and the mitochondria of all animals, both of which were formerly independent bacteria—are of course well detailed in *Microcosmos*. But symbiosis now appears to be particularly good as an explanation of "jumps" in evolution that have momentous ecological importance. Submarine fishes, luminously spotlighting the blackest of waters, may have evolved into myriads of kinds, spurred on by eye-patch, esophageal, or anal light organs harboring glowing symbiotic bacteria.[10] Different symbioses of fish and beetles with glow-in-the-dark bacteria abound.

Another example of recent symbiosis research suggests that the green algal transition to land plants resulted from a merging of the genomes (genetic material) of a fungus with some aquatic green alga ancestor. Lichens are well-known products of symbioses. All lichens are fungi symbiotic with cyanobacteria or fungi symbiotic with green algae. The two types of life—photosynthesizer and consumer—intertwine to form a novel green low-lying plantlike organism with remarkable longevity—the lichen. The amazing capacity of lichens to proliferate on the bare face of rocks depends

on the symbiosis, the equally combined fungal and photosynthetic partners that comprise the lichen entity. The newest twist is that vascular plants—including herbs and shrubs and all trees—may originally have been "inside-out lichens." Their evolution may have involved a new partnership between widely differing species from different kingdoms of life. If Professor Peter Atsatt's theory[11] is correct, then the interactive venture between two kinds of organisms, fungi and protoctistan green algae, accounted not for the appearance of some minor entity in the backwoods of evolution but for the momentous evolution of the Kingdom Plantae, the woods themselves.

The illusion of the independence of humans from Nature is dangerous ignorance. An unbroken continuum of life exists now as it has since life's inception—through Darwinian time (four billion years) and Vernadskian space (a twenty-five kilometer ring, extending ten kilometers down to the abyss and fifteen to the top of the troposphere). Inside this living system we are all embedded: to escape it is tantamount to death. Emily Dickinson, noting "what mystery pervades a well,"[12] charmingly described us and Nature. It is fitting to cite her prior to the descent into the microcosm:

> But nature is a stranger yet;
> The ones that cite her most
> Have never passed her haunted house,
> Nor simplified her ghost.
> To pity those that know her not
> Is helped by the regret
> That those who know her,
>   know her less
> The nearer her they get.[13]

—Dorion Sagan and Lynn Margulis
January 1991