Humans and the Soil

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The way we farm, the kinds of backyards and landscapes we favor, and the way we control patterns of development are creating an invisible crisis through their affects upon soil ecology. The invisibility of soil ecosystems, the seemingly alien properties of the organisms that inhabit them, and the specialized knowledge required to understand them create obstacles to moral concern for these fountains of life. Our treatment of soils has reached the point of crisis. Obstacles to moral thinking about soils might be overcome by supplying the moral imagination with a deeper understanding of our own biological identity as ecosystems analogous in organization and functions to soil ecosystems. Not only have microbes created the conditions necessary for human life, but they have shaped our evolutionary history and helped constitute the human genome. Our biological identity encompasses communities of microbes, such that humans (and all organisms) are most properly understood as ecosystems. For this reason, moral concern for humans implies moral concern for ecosystems.

INTRODUCTION

The alarming disproportion between the seriousness of environmental problems and the level of moral concern they evoke emphasizes the obstacles to environmental reform. These impediments are especially great when the problems are difficult to visualize, require specialized knowledge to understand, and do not easily arouse the moral emotions, imagination, and sentiments. One such problem is occurring beneath our feet. Human practices are destroying the life of the soil upon which our existence depends. Outside of a relatively small number of scientists the nature and urgency of these problems are hardly understood. One would have a hard time discovering any mention of the problem in the news media. It seems that those who are creating the crisis by the way they farm, by the kinds of backyards and landscapes they favor, and by the way they control patterns of development are hardly aware of the consequences of their actions. The unprecedented nature of this and other environmental crises requires broader understanding of both soil ecology and human nature. In what follows, I briefly describe the scientific basis for claiming that our treatment of soils has reached the point of crisis. I then discuss the obstacles to moral thinking about soils, and how they might be overcome by supplying the moral imagination with a deeper understanding of the biological nature of organisms, including humans. I make the case that not only have microbes created the conditions necessary for human life, but that they have shaped our evolutionary history and helped constitute the human genome. Our biological identity encompasses communities of microbes, such that humans (and all organisms) are

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most properly understood as ecosystems. For this reason, moral concern for humans implies moral concern for ecosystems. I then propose norms that should govern our attitudes towards the invisible components of soil ecosystems.

SOIL ECOSYSTEMS

Soil has been commonly viewed as something analogous to an inert medium that anchors plants and acts as a sponge, absorbing and conveying to the roots the nutrients we supply through chemical fertilizers. This view contrasts sharply with the growing body of scientific knowledge that shows soil fertility to depend on an exceedingly complex ecosystem or food web in which plants are active participants. Much of the carbohydrates, amino acids, and other organic compounds produced by photosynthesis are exuded into the rhizosphere (the zone of soil under the influence of plants' roots) where they provide nutrients for bacteria, fungi, and other organisms. The diversity of microorganisms in soil by far exceeds that in any other ecosystem. A square meter of an organic agricultural soil may contain thousands of species of organisms with astounding densities of population. A single gram of soil may contain more than a thousand fungal hyphae and a million or more individual bacterial colonies. The microbes nourished by plants produce extracellular compounds with adhesive properties which aggregate the mineral and organic components of the soil and provide food for larger organisms such as protozoa and nematodes, which then become prey for collembola and other arthropods. Most microbial activity is fundamentally governed by the availability of fixed carbon provided by the organic wastes decomposed by the activities of fungi, bacteria, and arthropods. The soil community also benefits from earthworms and other fauna that mix, aerate, and structure the soil so that it retains water and nutrients. Earthworms ingest mineral soil and organic matter, mixing them with organic secretions, nutrients from plants, and microbes and egest particles bound together with secreted polymers that stabilize and enhance the fertility of the soil. Mycorrhizae, a symbiosis between fungi and the roots of ninety-five percent of all plants, have been increasingly understood to play a central role in soil ecosystems. Fungi penetrate roots and exchange nutrients with them. Because the strands of fungi extend much farther than the roots, and penetrate smaller spaces in the soil, they increase the range of nutrients available to plants.[1] Soil organisms define the architecture of the soil, governing the movements of gases, liquids, particulates, and organisms and providing sites for colonization by microorganisms. The relationship between soil

[1] James B. Nardi, *Life in the Soil: A Guide for Naturalists and Gardeners* (Chicago: University of Chicago Press, 2007), pp. 11–15; David C. Coleman et al., *Fundamentals of Soil Ecology* (Amsterdam, Boston, London, and New York: Elsevier, 2004), pp. 36-46; Roger D. Finlay, "The Fungi in Soil," in Jan Dirk van Elsas et al., *Modern Soil Microbiology,* 2nd ed. (Boca Raton, Fla.: Taylor and Francis Group, 2007), p. 142.

organisms and soil structure suggests that healthy soil is a self-organizing system which can be disrupted by changes to soil structure as well as soil biota.[2]

Soil fertility, pest and disease control, and other important ecological functions of soil systems originate from a flow of energy produced by photosynthesis in plants that converges with energy produced by decomposers of dead organic matter at higher trophic levels. The two energy pathways are also linked by the nutrient cycling of mycorrhizal fungi and nitrogen-fixing bacteria in symbiotic relations with the roots of plants. Overlaps in biotic relationships make soil a complexly integrated ecosystem, such that disturbance of one ecological function effects the dynamics of others.[3] Healthy soil sequesters greenhouse gases, detoxifies noxious chemicals, reduces the need for water management, pesticides, and fertilizer inputs, and decreases runoff and erosion.

One way to measure the value of the ecosystem services provided by soils is to compare it to the costs of constructing and running modern systems of hydroponics that have been calculated to be more than $850,000 per hectare. When the benefits of cleansing toxins, processing organic wastes, recycling nutrients, and regulating greenhouse gases, such as carbon dioxide, methane, and nitrous oxides are added to this mix, soils provide services worth trillions of dollars annually.[4] The soil ecosystem is also one of the richest sources of compounds important for biotechnology and medicine, and its regulation of carbon, nitrogen, and sulfur cycles is likely to have made possible the evolution of life on Earth as we know it.[5]

Farming that employs heavy tillage, irrigation, or repeated applications of agrochemicals kills soil organisms, reduces the functional capacities of the soil ecosystem, destroys soil structure, produces salinized and alkalinized soils, depletes aquifers, and releases greenhouse gases. Growing crops in such a way replaces natural processes of nutrient cycling with an artificial ecosystem requiring constant management through continued applications of chemical inputs from non-renewable sources and intensive manipulation of the soil with all their harmful consequences.[6] Pesticides,

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[2] Vigdis Torsvik, and Lise Øvreås, "Microbial Phylogeny and Diversity in Soil," in van Elsas et al., *Modern Soil Microbiology*, p. 50; M. G. Kibblewhite et al., "Soil Health in Agricultural Systems," *Philosophical Transactions of the Royal Society Biology* 363 (2008): 386, 689; Coleman et al., *Fundamentals of Soil Ecology*, pp. 36–46, 169-81; Peter M. Groffman and Patrick J. Bohlen, "Soil and Sediment Biodiversity Cross-System Comparisons and Large-Scale Effects," *BioScience* 49 (1999): 139–48; Jim Prosser, "Microorganisms Cycling Soil Nutrients and Their Diversity," in van Elsas et al., *Modern Soil Microbiology,* pp. 238–39; Miguel A. Altieri, "The Ecological Role of Biodiversity in Agroecosystems," *Agriculture, Ecosystems and Environment* 74 (1999): 26–27.

[3] Kibblewhite et al., "Soil Health," p. 688; Diana H. Wall and John C. Moore, "Interactions Underground," *BioScience* 49 (1999): 109–17.

[4] Coleman et al., *Fundamentals of Soil Ecology*, p. 20.

[5] van Elsas, "Preface," *Modern Soil Microbiology*.

[6] Altieri, "The Ecological Role of Biodiversity," pp. 19–20, 26; Louise E. Buck et al., *Ecoagriculture: A Review and Assessment of its Scientific Foundations* (Washington, D.C.: Ecoagriculture Partners, 2004), pp. 30–31; Prosser, "Microorganisms," p. 246.

however they are applied, are likely to affect soil organisms and ecological functions of the soil. Industrially produced fertilizers inhibit nitrogen fixation in the soil, disrupt the nitrogen cycle, release greenhouse gases, diminish stratospheric ozone, contribute to smog, contaminate drinking water, acidify rain, and cause eutrophication in bays and estuaries which lead to dead zones. According to the U.S. Department of Agriculture about half of the fertilizer used each year in the United States does nothing more than provide a substitute for nutrients lost by topsoil erosion. Conventional farming consumes expensive non-renewable resources—fossil fuels—as a substitute for what healthy soils could renewably provide at little cost. But even though it makes economic sense in the long term and is a moral imperative for those who consider our duties to future generations, farmers have little economic incentive for changing their practices, because the annual reductions in crop yields that from result from erosion are usually negligible.[7] Cumulative effects over generations create the soil crisis as linear rates of degradation give way to devastating threshold effects. Recent studies have shown that today soil erosion decreases corn yields minimally until a particular threshold is crossed in the depth of topsoil, which varies according to the type of soil. After that threshold is passed, average yield losses are fifty-nine percent.[8]

In the last forty years, around one-third of the world's arable land has been lost to erosion. Earth scientist David Montgomery calculates that it takes 700 to 1,500 years to generate an inch of soil, or 300 to 600 years for a centimeter of soil. The thickness of undisturbed soil on hillsides in temperate and tropical latitudes is generally thirty to ninety centimeters thick. Using the rate of erosion caused by plowing, Montgomery predicts that agricultural civilizations which depend upon it will have a lifespan of 800 to 2,000 years, which matches the historical record for the decline of ancient cultures, such as the Greeks, Romans, and Mayans. Geoarchaeological studies confirm the connection between soil erosion and the collapse of many ancient cultures.

Scientists at Cornell University estimate that remediating soil erosion would cost the U.S. $44 billion a year, but that an annual investment of about $6 billion could reduce erosion rates to the level of soil production. They calculate that each dollar

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[7] Robert Socolow, "Nitrogen Management and the Future of Food: Lessons from the Management of Energy and Carbon," *Proceedings of the National Academy of Science, USA* 96 (1999): 6001–08; Kibblewhite et al., "Soil Health," p. 698; Domy Adrano et al., "Role of Soil Chemistry in Soil Remediation and Ecosystem Conservation," in Huang et al., *Soil Chemistry and Ecosystem Health* (Madison, Wis.: Soil Society of America, 1998), p. 368; Daniel Hillel, *Out of the Earth: Civilization and the Life of the Soil* (Berkeley and Los Angeles: University of California Press, 1991), p. 135; David R. Montgomery, *Dirt: The Erosion of Civilizations* (Berkeley, Los Angeles, and London: University of California Press, 2007), p. 200; S. P. Deng et al., "Animal Manure and Anhydrous Ammonia Amendment Alter Microbial Carbon Use Efficiency, Microbial Biomass, and Activities of Dehydrogenase and Amidohydrolases in Semiarid Agroecosystems," *Applied Soil Ecology* 33 (2006): 258–68.

[8] David Rapport et al., "Ecosystem Health and Its Relationship to the Health of the Soil Subsystem: A Conceptual and Management Perspective," in Huang et al., *Soil Chemistry*, p. 348.

invested in soil conservation would produce a savings of five dollars.[9] There is a vast literature on alternative methods of farming that have proven to be profitable without producing erosion and other damaging effects associated with conventional methods of farming.[10]

It is not only farming that is destroying the soil. The construction of roads, parking lots, and the way we build and landscape residences, office buildings, and industrial sites have profound impacts. The processes of construction increase erosion, compact the soil, and remove fertile topsoil. Instead of cultivating native grasses, shrubs, and flowers consistent with healthy soils, Americans are addicted to exotic flowers and grass lawns—monocultures of fescue which are green deserts. American lawns require huge inputs of water, chemical fertilizers, pesticides, and herbicides with the same devastating consequences for the soil community as industrial agriculture.[11]

At its ninth annual meeting in 1996, the International Soil Conservation Organization declared that the way we manage soils and use the land "should be considered to be more destructive than climate change" during the next decades. These same practices also contribute to climate change itself. The major greenhouse gases caused by human activity are carbon dioxide, methane, nitrous oxide, and halocarbons. Methane and nitrous oxide are produced mainly by microorganisms that are stimulated by human activities such as the increased use of fertilizer, cattle production, and waste management. Microorganisms play crucial roles in the cycling of other trace gases, such as carbon monoxide, hydrogen, nitric oxide, and reduced sulfur species, which indirectly influence the cycling of greenhouse gases by affecting atmospheric chemistry. The effects of human activity on the microbial communities in the soil are major contributors to the changing climate. A third of the total carbon dioxide that has been added to the atmosphere since the Industrial Revolution has come not from fossil fuels but from disturbance of soil ecosystems. Improved management of soils could convert them from sources of greenhouse gases to net carbon sinks.[12]

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[9] Jennifer Blesh and Gary Barrett, "Farmers' Attitudes Regarding Agrolandscape Ecology: A Regional Comparison," *Journal of Sustainable Agriculture* 28 (2006): 123; Montgomery, *Dirt*, p. 76; D. R. Montgomery, "Pay Dirt," *Scientific American* 299 (2007): 4–6.

[10] Montgomery, *Dirt*, pp. 20, 159, 176, 205. The Northeast Sustainable Agriculture Research and Education program (NE SARE) and the USDA Natural Resources Conservation Service (NRCS) are funding a study, by the Rodale Institute, to evaluate the effectiveness of a front-mounted roller-crimper that can kill cover crops mechanically. If successful, this device opens the door to no-till organic farming, which would further decrease harmful impacts on soil structure (http://www.rodaleinstitute.org/no-till_revolution). See also National Research Council: Committee on Twenty-First Century Systems Agriculture, *Toward Sustainable Agricultural Systems in the Twenty-First Century* (Washington, D.C.: National Acadamies Press, 2010), p. 94.

[11] See E. Marshall and J. Shortle, "Urban Development Impacts on Ecosystems," in Stephen J. Goetz et al., *Land use Problems and Conflicts: Causes Consequences and Solutions* (Oxford: Routledge, 2004), pp. 61–72.

[12] Ralf Conrad, "Soil Microbial Communities and Global Climate Change—Methanotrophic and Methanogenic Communities as Paradigms," in van Elsas et al., *Modern Soil Microbiology*, p. 264, Montgomery, "Pay Dirt"; Rapport et al., "Ecosystem Health," p. 342.

IMPEDIMENTS TO MORAL THINKING ABOUT SOILS

Our abuse of the soil certainly has many explanations. It is important to note that even as ancient civilizations were undermining their foundations by exhausting and eroding their soils some were aware of the harmful consequences of what they were doing. Although many prominent poets, philosophers, and politicians of the ancient world warned of the perils of inappropriate agricultural practices,[13] awareness of the problem by a prominent few was no guarantee of a cure. In our culture, short-sighted economic values, infatuation with expensive mechanisms that promise to ease the strain of labor, and the apparent success of the early years of the "green revolution" have created an agricultural ideology that is now entrenched among farmers, agricultural schools, and policy makers. So even the task of raising awareness of the problem is difficult. It also requires a great imaginative effort to include in our moral calculations the impacts of our activities on future generations, even when we recognize that among them are the infants we now carry in our arms. In addition, we suffer from what has been called "environmental generational amnesia." Our benchmarks are ever shifting, as each generation takes the environmental conditions of its youth as the standard against which to measure the degradation it perceives during its later years.[14] As David Montgomery observes:

> Even though Iceland has lost 60% of its vegetative cover and 96% of its tree cover, after 1,100 years of inhabitation most Icelanders find it difficult to conceive of their modern desert as having once been forested. Most don't comprehend how severely their landscape has been degraded. Just as at Easter Island, people's conception of what is normal evolves along with the land—if the changes occur slowly enough.[15]

The people of Scotland are not generally aware that their nation was once covered with a mighty forest; nor are the people of Iowa, who are surrounded with some of the richest soil on Earth, aware of how much of it they have lost. Jared Diamond describes a view of agricultural fields from an Iowa churchyard. The church built in the nineteenth century was surrounded by land that had been farmed since that time. Due to erosion in the agricultural land, the church stood ten feet above the surrounding fields.[16] In this case, our environmental memory was only corrected by an accident of history and the ability to read the land.

Concern for soils is made more difficult because the world beneath our feet is largely invisible and is populated with microbes, fungi, and invertebrates. Some central tools of ethical reflection—our imagination, moral emotions, and empathic

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[13] Montgomery, *Dirt*, pp. 49-81.

[14] Peter Kahn, "Children's Affiliations with Nature: Structure, Development, and the Problem of Environmental Generational Amnesia," in Peter Kahn and Stephen Kellert, *Children and Nature* (Cambridge, Massachusetts and London: MIT Press, 2002), p. 106.

[15] Montgomery, *Dirt*, p. 227.

[16] Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (New York, New York: Viking Press, 2005), p. 489.

reactions—seem to respond to other creatures in proportion to their similarity to our selves. We singularly fail to appreciate the complexity and even the beauty of most invertebrates. One day as I left a restaurant, I noticed a man outside the door suddenly and violently stomping his foot on the pavement before moving on. As I approached the spot, I saw the object of his visceral reaction—it was a large beetle. Its previous beauty was apparent in the iridescent greens and blues of its squashed wings and head. I marveled that this man was so impervious to its exquisite glory, seeing instead some loathsome creature worthy only of extermination.

Stephen Kellert's work on American attitudes reveals little knowledge of or appreciation for ecological systems. He speculates that this situation is due to the fact that "most ecological processes depend on the functioning of obscure invertebrate and microbial organisms." Most people, he thinks, have only the vaguest awareness of these organisms and the essential ecological services they provide. Their focus is upon the more visible and obvious organisms within the natural environment and the more prominent features of the landscape.[17] In fact, Kellert has documented that Americans have strong antipathy to insects and other "vermin,"[18] and every mushroom hunter has been dismayed by finding stands of choice, beautiful, and edible fungi kicked apart by someone who viscerally dislikes "toadstools."

EXTENDING THE SCOPE OF MORAL CONCERN

Changing our behavior to prevent abuse of soil requires more than knowledge, as evolutionary psychologists and analysts of cultural cognition have well documented.[19] But I focus here on knowledge, which must be part of any solution—knowledge of what we are, what organisms are, and our relationships to organisms and ecosystems—and what kinds of attitudes and values are appropriate in light of this. Attempts to construct an environmental ethic are often crippled by a failure to appreciate what humans really are biologically, which is a first step toward wisdom with regard to our role in the natural world.

The Myth of the Self-Contained Individual

We ourselves *are* ecosystems, with functional parts very similar to those in the soil community. Recently there have been important advances in what is called metagenomics. The human "metagenome" comprises both the collection of the

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[17] Stephen Kellert, *The Value of Life: Biological Diversity and Human Society* (Washington, D.C: Island Press/Shearwater Books, 1996), p. 13.

[18] Stephen Kellert, "Values and Perceptions of Invertebrates," *Conservation Biology* 7 (1993): 845–55.

[19] See, for example, Dustin J. Penn, "The Evolutionary Roots of Our Environmental Problems," *Quarterly Review of Biology* 78 (2003): 273–301, Dustin Pen and Iver Mysterud, *Evolutionary Perspectives on Environmental Problems* (New Brunswick and London: AldineTransaction, 2007), and Dan Kahan et al., "Fear of Democracy: A Cultural Evaluation of Sunstein on Risk," *Harvard Law Review* 119 (2006): 1071–1109.

genes contained in the *Homo sapiens* genome and in the microbial communities that colonize our bodies.

The organisms within these communities are collectively known as the human "microbiome."

> The metagenome of these communities encodes physiological traits that humans have not had to evolve, including the ability to harvest nutrients and energy from food that would otherwise be lost because we lack the necessary digestive enzymes. . . . Without understanding the inhabitants of the human microbiome and the mutualistic human-microbial interactions that it supports, our portrait of human biology will remain incomplete.[20]

Just the number of microbes inhabiting the surface of our skin is ten times greater than human cells in our bodies. The total amount of metabolic information encoded in our microbial symbionts is many times greater than that contained in our own genes.[21]

What we call our "selves" are not individuals but whole communities living in symbiosis, and this is true not only of ourselves, but of all organisms. Darwin himself observed, "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."[22] The microbiologist Lynn Margulis, whose work on symbiogenesis and microbial contributions to evolution has been revolutionary, concludes that "We must begin to think of organisms as communities, as collectives" the members of which exchange matter, energy and information. "And communities are ecological entities."[23]

Scientists are a long way from a complete description of the human microbiota, but it has been established that specific sites on our bodies (such as the skin, mucosal surfaces, and the gut) furnish homes for microbial communities that fulfill roles essential to our health and functioning. For example, bacteria make K and B vitamins that are absorbed through our intestinal walls.[24] Polysaccharides in plants are not digestible by humans, but provide substrates for microbial growth in the colon. Microbial fermentation in the colon, in turn, provides sources of energy for their host. Microbial symbionts secrete molecules that inhibit pathogens and detoxify harmful compounds in their hosts. Our microbial communities influence the expression of genes that govern physiological functions and send signals to

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[20] National Research Council: Committee on Metagenomics: Challenges and Functional Applications, *The New Science of Metagenomics: Revealing the Secrets of Our Microbial Planet* (Washington, D.C.: National Academy Press, 2007), p. 37.

[21] John Ingraham, *March of the Microbes* (Cambridge, Mass. and London: Harvard University Press, 2010), p. 88

[22] Charles Darwin, *The Variation of Animals and Plants under Domestication* (New York: Organe Judd, 1868), p. 204.

[23] Lynn Margulis and Dorian Sagan, *Acquiring Genomes: A Theory of the Origins of Species* (New York: Basic Books, 2002), p. 20.

[24] Ibid., p. 18.

the brain in ways that control the immune system. From the perspective of the various microbial communities that populate our bodies, we are simply complex environments.[25]

Once we recognize the degree to which we depend upon intimate and ongoing mutualistic interactions with the vast populations of microbes for which we provide habitat, our usual ways of thinking turn upside down. It is paradoxical to describe the value of microbes as merely instrumental, since we cannot live or function without them. We can no longer think of organisms as if they were single autonomous things. It is not even clear how we should describe or refer to them. Tom Wakeford asks, "Is a cow an animal or a microbial fermentation vessel, when without the microbes, the cow would not exist?"[26] We can ask similar questions about ourselves.

How We Came to Be

Questions about the biological identity of an organism arise not only from its ecosystematic features, but from its evolutionary history—the processes which made it what it is. Carl Woese makes this point forcefully: "The organism and its evolution are one. An organism's being cannot be separated from its becoming: the two are but different facets of the same germ."[27] As a result of our evolutionary history, the human metagenome contains thousands of times more genes than the human genome.[28] Inside of us, there is more viral DNA than DNA in human genes. Of the human genes more than half are viral genomes or viral fragments that have been naturally selected in the course of human history.[29]

Evolutionary biologists have, until recently, emphasized that random mutations in genes are the drivers of evolution. More recently biologists have recognized that some of the most significant agents of evolutionary change were microbes and their ecological relations. Among these were symbiotic relationships from which new species emerged through the fusion of what were previously distinct organisms. These organisms (now integrated as organelles into the cytoplasm of our cells)[30] reproduce in different ways and at different times from the rest of the cell. One such example are mitochondria, integral components of the human

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[25] Les Dethlefsen et al., "An Ecological and Evolutionary Perspective on Human–Microbe Mutualism and Disease," *Nature* 449 (2007): 811–18; Peter J. Turnbaugh, "The Human Microbiome Project," *Nature* 449 (2007): 804–10; Stephen M. Collins and Premysl Bercik, "The Relationship between Intestinal Microbiota and the Central Nervous System in Normal Gastrointestinal Function and Disease," *Gastroenterology* 136 (2009): 2003–14; Blaise Corthesy et al., "Cross-Talk between Probiotic Bacteria and the Host Immune System," *Journal of Nutrition* 137 (2007): 781S–90S.

[26] Tom Wakeford, *Liasons of Life* (New York, New York: John Wiley and Sons, 2001), p. 167.

[27] Carl Woese, "Evolving Biological Organization," in Jan Sapp, *Microbial Phylogeny and Evolution* (Oxford: Oxford University Press, 2005), p. 101.

[28] National Research Council, *The New Science*, p. 17.

[29] Gerald Callahan, *Infection: The Uninvited Universe* (New York: St. Martin's Press, 2006), p. 39.

[30] Organelles are specialized parts of a cell which are functionally analogous to organs.

metagenome which make aerobic respiration possible. Mitochondria are relicts of bacteria that, previously, were independently existing organisms capable of using oxygen to generate energy. Somewhere in the course of pre-human evolutionary history some single-celled eukaryotes engulfed these bacteria and found ways to use them for the generation of energy in the form of ATP (adenosine triphosphate). Mitochondria—with their own DNA, genes, and proteins—are present in every eukaryotic cell in our bodies.[31] Horizontal gene transfer, in which organisms, even of different species, exchange genes without sexually reproducing, has been increasingly recognized as a kind of invisible commerce or cooperation that shaped evolutionary development.[32] "The living subvisible world ultimately underlies the behavior, development, ecology and evolution of the much larger world of which we are a part and with which we co-evolved."[33] Around 250 of our human genes that code for proteins have been acquired from bacteria.[34] We would not be what we are without these invisible citizens of our planet.

What is Health?

Our treatment of the soil ought to be governed by norms analogous to those that govern medicine. Medical science is guided by the notion of health. Louis Pasteur introduced the world to microbes under the characterization of germs—invisible invaders which attack us with diseases and which must be hunted down and killed. Unquestionably, some microbes are pathogens which can adversely affect our health or even kill us. But health can in large measure be understood as an issue of ecological relationships among the cells, organs, and microbial communities inhabiting our bodies. [35] Recently, a woman afflicted with a wasting disease was cured by a procedure known as bacteriotherapy or fecal transplantation which restored the ecology of her intestinal microbiota.[36] Medical research has demonstrated that the notion of human health must be expanded to consider the principles and mechanisms of microbial communities and the roles they play as both pathogens and mutualists.[37]

Human health and soil health are both normative concepts. Human health is based on a normative conception of human well-being. Soil health is based on a

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[31] Margulis and Sagan, *Acquiring Genomes*, pp. 7, 30, 90, 72, 187; Lynn Margulis and Dorien Sagan, *What is Life?* (Berkeley and Los Angeles: University of California Press, 1995), pp. 179, 230, 236; Lynn Margulis, *Symbiotic Planet* (New York, New York: Basic Books, 1998), p. 39; John Ingraham, *March of the Microbes*, pp. 6, 111, 178, 180, 273, 299, 300.

[32] Margulis and Sagan, *Acquiring Genomes*, p. 41; William Martin, "Woe is the Tree of Life," in Sapp, *Microbial Phylogeny and Evolution*, p. 106; James Lake et al., "Fulfilling Darwin's Dream," in ibid., pp. 196, 201.

[33] Margulis and Sagan, *Acquiring Genomes*, p. 204.

[34] Ibid., p. 76.

[35] Ibid., p. 19.

[36] Carl Zimmer, "How Microbes Defend and Define Us," *New York Times,* 12 July 2010.

[37] Dethlefsen et al., "An Ecological and Evolutionary Perspective," p. 817.

normative conception of what constitutes a biologically productive and regenerative ecosystem: "Soil health is the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health."[38] Methods of manipulating (one might say "nurturing") soil ecosystems to reduce pathogens and increase fertility have been well researched and reveal ways of working with the soil food web to increase yields that do not require the use of chemical pesticides or fertilizers and that reduce erosion.[39]

Where We Live and Shaping Our Heritage

Holmes Rolston, III attempts to draw a line between "skin in" and "skin out" dimensions of organisms:

> Within an individual organism the organs are so tightly integrated that we do not term the organism a community at all. No one complains that the goods of heart and liver are only instrumental to the good of the organism. But communities, social or biotic, never have this kind of organization. Biotic communities leave individuals "on their own" as autonomous centers, spontaneous somatic selves defending their life program.[40]

With regard to "skin out," he says, organisms form communities:

> An ecosystem has no genome, no brain, no self-identification. It does not defend itself against injury or death as do blue jays, milkweeds, cougars. It is not irritable. An oak-history forest has no telos, no unified program it is set to execute.[41]

Of ecosystems, he says, we cannot say that their value is merely instrumental. Nor can we say it is intrinsic, "as though the system defended some unified form of life for itself." To express the value of ecosystems, he coins the term *systemic value,* by which he means the value of the ecological systems from which organisms, with intrinsic value, emerge or are "projected" through the course of evolutionary time.[42] But what I have been saying suggests that no such hard line can be drawn between organisms and ecosystems—the two are woven together. Not only are organisms biotic communities, bacteria created the very conditions that make our lives possible. Plants and animals would be starved for phosphorus without fungi.[43] Infants

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[38] John W. Doran and Michael R. Zeiss, "Soil Health and Sustainability: Managing the Biotic Component of Soil Quality," *Applied Soil Ecology* 15 (2000): 3.

[39] National Research Council: Committee on Twenty-First Century Systems Agriculture, *Toward Sustainable Agricultural Systems in the Twenty-First Century* (Washington, D.C.: National Acadamies Press, 2010), pp. 141–42.

[40] Holmes Rolston, III, *Environmental Ethics: Duties to and Values in the Natural World* (Philadelphia: Temple University Press, 1988), pp. 182–83.

[41] Ibid., pp. 162, 173.

[42] Ibid., p. 188.

[43] Margulis and Sagan, *What is Life?* p. 181.

acquire the microbiota they need for survival from their environments, during the first weeks, months, or years of their lives.[44]

The relationship between what we do to the ecology of our environment and the future of our species has been recognized in the role of *niche construction* as one of the causes of evolutionary development. This concept further emphasizes the degree to which we cannot understand ourselves apart from the environments that surround us. The movement, behavior, choices, and even the metabolisms of all organisms modify their environments. "In doing so, they transform some of the selection pressures in the environments that subsequently select them." As a consequence, succeeding generations of organisms will evolve under the influence of "selection pressures previously transformed by their own, or by their ancestors', niche-constructing activities."[45]

This point can be illustrated by Aldo Leopold's discussion of the differing landscapes on the north and south slope of Germany's Spessart Mountain:

> Its south slope bears the most magnificent oaks in the world. American cabinet makers, when they want the last word in quality, use Spessart oak. The north slope, which should be the better, bears an indifferent stand of Scotch pine. Why? Both slopes are part of the same state forest; both have been managed with equally scrupulous care for two centuries. Why the difference?[46]

The difference, he explains, was only recently discovered through advances in soil science that determined that clear cutting of the north side during the Middle Ages had so radically altered the ecology of the soil that centuries could not mend it.

The ecological inheritance we impart to our children will determine their evolutionary fate. Humans, then, however we think of them, impair their own fitness, as well as the fitness of other members of the ecological community, by degrading their environment. These are morally serious grounds for a profound reevaluation of our mode of existence.

NORMATIVE ATTITUDES

Knowledge of how we ought to change our treatment of soils is readily available. A blueprint for agricultural reform has just been published by the National Research Council.[47] Planners, zoning commissions, and citizens could, with a little knowledge and guidance, change their ways. As Leopold famously pointed out, through the course of history humans have managed to expand their moral awareness by moving creatures, such as the slave girls of Odysseus, from the class

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[44] Dethlefsen et al., "An Ecological and Evolutionary Perspective," p. 814.

[45] John Odling-Smee, "Niche Inheritance," in Massimo Pigliucci and Gerd Müller, *Evolution—The Extended Synthesis* (Cambridge, Mass.: MIT Press), p. 176.

[46] Aldo Leopold, *Round River* (Oxford and New York: Oxford University Press, 1993), p. 147.

[47] National Research Council, *Toward Sustainable Agricultural Systems.*

of propertied things to persons. J. Baird Callicott points to Leopold's emphasis on the role of ecologically and evolutionarily informed imaginative activity to make possible the new kinds of perception we need.[48] Leopold, discussing Daniel Boone's perception of the natural world, claims that

> Daniel Boone's reaction depended not only on the quality of what he saw, but on the quality of the mental eye with which he saw it. Ecological science has wrought a change in the mental eye. It has disclosed origins and functions for what to Boone were only facts. It has disclosed mechanisms for what to Boone were only attributes. We have no yardstick to measure this change, but we may safely say that, as compared with the competent ecologist of the present day, Boone saw only the surface of things. The incredible intricacies of the plant and animal community—the intrinsic beauty of the organism called America, then in the full bloom of her maidenhood—were as invisible and incomprehensible to Daniel Boone as they are today to Mr. Babbit. The only true development in American recreational resources is the development of the perceptive faculty in Americans.[49]

Leopold insists that this sort of development is not the sole province of ecologists, but rather a new way of looking at the most ordinary things around us, such as "weeds in a city lot."[50]

I am not defending a view that assigns rights to microorganisms, or inhumanely refuses to distinguish between those that are pathogens and those upon which we depend. I am suggesting that the evolutionary history through which we came to be what we are and our current dependency on certain communities of microorganisms, both in our bodies and in the soil, link us so closely to them as to make instrumental valuation of them paradoxical. Lynn Margulis observes that "The environment is so interwoven with bacteria, and their influence is so pervasive, that there is no really convincing way to point your finger and say this is where life ends and this is where the inorganic realm of nonlife begins."[51]

In "Caring for Nature," Holmes Rolston, III provides a remarkable series of quotations from secular humanists and atheists who seem to find that nothing other than religious language can describe their attitudes towards the system of life.[52] Stephen Jay Gould writes

> Something almost unspeakably holy—I don't know how else to say this—underlies our discovery and confirmation of the actual details that made our worlds and also, in realms of contingency, assured the minutiae of its construction in the manner we

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[48] J. Baird Callicott, "The Land Aesthetic," in J. Baird Callicott, ed., *Companion to A Sand County Almanac: Interpretive and Critical Essays* (Madison: University of Wisconsin Press, 1987), pp. 157–72.

[49] Aldo Leopold, *A Sand County Almanac* (Oxford: Oxford University Press, 1949), pp. 173–74.

[50] Ibid., p. 174.

[51] Lynn Margulis and Dorion Sagan, *Microcosmos* (Berkeley: University of California Press, 1997), pp. 92–93.

[52] Holmes Rolston, III, "Caring for Nature," *Zygon* 39 (2004): 277–302.

> know, and not in any one of a trillion other ways, nearly all of which would not have included the evolution of a scribe to record the beauty, the fascination, and the mystery.[53]

E. O. Wilson writes, "The flower in the crannied wall—it *is* a miracle."[54] "The biospheric membrane that covers the Earth, and you and me, . . . is the miracle we have been given."[55] Even Daniel Dennett, who certainly has no sympathy with any recognizable form of religion, exclaims that "This world is sacred."[56] Clearly these statements are not to be taken literally, but the attitudes they express are profound reverence, humility, and a sense of something like grace. These kinds of attitudes toward the system of life are, in my view, normative. These are the kinds of attitudes we ought to have.

We ought to form attitudes toward these life forms that recognize the centrality of the kinds of organisms from which we evolved and upon which we depend. We have derived our being from them. They sustain our existence. They fill us and surround us. Our fate is in their hands and is tied to how we treat them. We ought to be grateful for what they give us, respectful of what they are, humbled by our dependency upon them, cautious in tampering with their life-generating and life-sustaining functions. Perhaps we ought even to be reverent of them. Certainly, we ought not to treat them callously and as unworthy of moral consideration. Bacteria perceive, communicate with one another,[57] "develop collective memory, use and generate common knowledge, develop group identity, recognize the identity of other colonies, learn from experience to improve themselves, and engage in group decision-making, and additional surprising social conduct that amounts to what should most appropriately be dubbed as social intelligence."[58]

We can more easily live without our legs and arms than without these microbial communities. We are ecosystems. Understanding what we are opens the door for moral concern for the soil community. Soil health is closely analogous to human health. Moral concern for humans encompasses moral concern for ecosystems, including those that create fertile soil. Planners, farmers, politicians, landscapers, and plain citizens treat the soil as they do because they know no better.

Evolutionarily speaking it is, if not quite literally true, then nearly so, that we were made from the soil. With regard to this point, we may credit Genesis 2 with a profound insight into human nature—an insight expanded upon by Daniel Hillel:

> The indissoluble link between man and soil is manifest in the very name 'Adam,' derived from *adama*—a Hebrew noun of feminine gender meaning earth, or soil. . . .

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[53] Stephen Jay Gould, *The Structure of Evolutionary Theory (*Cambridge: Harvard University Press, 2002), p. 1342.

[54] E. O. Wilson, *The Diversity of Life* (Cambridge: Harvard University Press, 1992), p. 345.

[55] E. O. Wilson, *The Future of Life* (New York: Alfred A. Knopf, 2002), p. 21.

[56] Daniel Dennett, *Darwin's Dangerous Idea (*New York: Simon and Schuster, 1995), pp. 520–21.

[57] Myra Hird, *The Origins of Social Life* (New York, New York: Palgrave MacMillan, 2009), pp. 41–51.

[58] Peter Godfrey-Smith, "Is It a Revolution?" *Biology and Philosophy* 22 (2007): 430.

> 'Hava' (rendered 'Eve' in translation) literally means 'living.' In the words of the Bible: 'And the man called his wife Eve because she was the mother of all living.' Together, therefore, Adam and Eve signify 'Soil and Life.'[59]

If we were made in God's image, then God is something like an ecosystem or biotic community. But even if we were not, the ecosystems of which we, every animal, and the soil are all types, are worthy of moral understanding and respect. We depend upon the soil community for the survival of our children and children not yet born. Appreciating the awesome complexity and beauty of the human metagenome—the human ecosystem—might enable us to see our own image in the ecology of the soil and in ourselves an image of the soil. The story of life in the soil and our connection to it offers rich resources for the moral imagination that could stimulate the ethical evolution upon which the survival of humanity depends.

[59] Hillel, *Out of the Earth*, p. 14.