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Darwin's Worms and the Skin of the Earth: An Introduction to Charles Darwin's *The Formation of Vegetable Mould, Through the Action of Worms, With Observations on Their Habits* (Selections)

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Abstract

Charles Darwin's discovery of the theory of evolution by natural selection is unquestionably one of the most profound scientific achievements in history. Darwin was heavily influenced by the great geologist Charles Lyell, who developed uniformitarianism, the methodological and substantive doctrine that sought to explain all geological formations as the result of the accumulation of small events happening continually over long periods of time. In *The Formation of Vegetable Mould, Through the Action of Worms, with Observations on Their Habits*, Darwin—inspired by Lyell's grand conception—focused on how worms transform the surface of the earth through their constant, everyday activities. They contribute to the formation of soil, turning it over and over, which enhances the circulation of nutrients within ecosystems. All studies of nature are indebted to Darwin for his devotion to illustrating the power of the materialist approach and for illuminating how the world works through its natural processes, including the invisible labor of worms.

Keywords

Darwin, materialism, ecology, soil science, environmental change

The naturalist Charles Darwin (1809-1882) sparked a revolution in science with his theory of evolution by natural selection, which was a strictly materialist conception of nature dethroning both religious teleology and anthropocentric views of the natural world. Darwin famously presented one long argument that all species, including humans, are the product of an evolutionary process governed by natural laws and historical contingency. Darwin insisted that the world must be explained

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in terms of itself and that there is continuity among all life-forms, which are connected through common ancestors. His theory overthrew the argument of design in nature, propounded notably by natural theologians typically connected to the Church of England, opening the way for a greater understanding of nature and humanity. This year marks the bicentennial of Darwin's birth and the 150th anniversary of the publication of *On the Origin of Species By Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life,* which is perhaps the most profound scientific work ever produced.

The evolutionary perspective Darwin developed is central to ecological studies, highlighting the complexity and the transformation of life and the earth over millions of years. While many of his books offer important ecological insights, his last book, *The Formation of Vegetable Mould, Through the Action of Worms, With Observations on Their Habits*, published a year before his death, is particularly interesting, given his analysis of how worms regularly transform the world simply through their daily living. By studying this work, we can gain an appreciation of the importance of how small creatures can change the world through activities and see how our world is being continuously made and remade.

Charles Darwin was born on February 12, 1809, in Shrewsbury, England. His father Robert Darwin was a doctor and a freethinker. His mother Susanna Darwin—who died when he was 8 years old—was the daughter of Josiah Wedgwood, the wealthy founder of a china company. His grandfather, Erasmus Darwin, was also a freethinker. He wrote *Zoonomia*—a book that put forward his own evolutionary theory. Both Erasmus Darwin and Josiah Wedgwood were members of the Lunar Society, an informal group of progressives who worked to further the development of science and industry (Uglow, 2002). The two of them opposed slavery and tirelessly campaigned and mobilized against it in the late 18th century, directly challenging the racist ideology that was used to justify slavery (Browne, 1995, pp. 196-197; Desmond & Moore, 2009). Charles Darwin grew up during a tumultuous period in England, given the repression of radicalism by the state, industrialism, the dominance of the church, the advances and discoveries of science, struggles to expand human freedom, and massive social upheaval in general. He was exposed to the major debates and clashes between design and materialism as proponents of the latter struggled against reactionary social currents.

In 1825, Darwin was sent to Edinburgh to study medicine, but he became more interested in natural history and philosophy. His teacher and mentor, Robert Edmond Grant, was a materialist and deist who supported the transmutationist positions of Erasmus Darwin, Etienne Geoffroy Saint-Hilaire, and Jean-Baptiste Lamarck. The two of them went on long walks and collected specimens together. Grant talked about evolutionary issues, such as the common origin of the plant and animal kingdoms. He encouraged Darwin to read Lamarck's *System of Invertebrate Animals* and to study Lamarck's theory of evolution—a theory founded on the inheritance of acquired traits. While at Edinburgh, Darwin joined the Plinian Society—a student science club that studied natural science, collected specimens, and presented papers to each other—deepening his passion for natural history (Browne, 1995, pp. 72-78; Desmond & Moore, 1994, pp. 33-40; Desmond, Moore, & Browne, 2007).

He was later sent to Christ's College, at Cambridge University, to study to become a clergyman at a country parish. Darwin figured that this path would provide the freedom for him to continue his studies of nature. Here he studied botany, geology, and philosophy. At the time, natural theology was one of the cornerstones of the science program. Thus, Darwin studied William Paley's books *Evidences of Christianity*, *Principles of Moral and Political Philosophy*, and *Natural Theology*, finding "much delight" in the detailed accounts of how animals were perfectly adapted to their environments as a result of contrivance, due to the intelligence and work of the divine designer (Browne, 1995; Darwin, 2005, pp. 50-51; de Beer, 1964; Paley, 1803, 1867, 1874). He went on scientific excursions collecting specimens and studying the geology of Great Britain. He learned to take geological measurements, interpret the results, and generalize his findings (Browne, 1995, pp. 117-143; Desmond & Moore, 1994, pp. 74-97). He studied John Herschel's *A Preliminary Discourse on the Study of Natural Philosophy*

(1831/1966), which provided a model of the interplay between observation and theory and insisted that nature is governed by specific laws that were often difficult to discover. Alexander von Humboldt's *Personal Narrative*, which provided an account of his voyage to the American tropics, "stirred up" in Darwin a passion for scientific exploration and "a burning zeal to add even the most humble contribution to the noble structure of Natural Science" (Darwin, 2005, pp. 57-58; see also, Browne, 1995, pp. 117-143; Desmond & Moore, 1994, pp. 74-97; Herschel, 1966; Humboldt, 1907).

When Darwin set out on the *Beagle* on his 5-year voyage (1831-1836) around the world, he was already dedicated to trying to understand the complexity of the natural world. He was a meticulous scientist, committed to careful observation and reasoned arguments. He had been exposed to the major scientific debates, including those between design and transmutation of species. He left as a natural theologian tied to creationist ideas but also as a freethinker open to discovery and rational inquiry. Darwin remarked that this voyage was "by far the most important event of my life and has determined my whole career." It radically transformed him and eventually our entire understanding of the natural world (Darwin, 2005, pp. 64, 71).

The Materialist Theory of Evolution and the *Origin of Species*

Throughout his life, Darwin exhibited an enormous amount of patience and caution as a scientist as he collected immense amounts of data for his research projects in order to illustrate his theoretical and scientific claims. In this, the emergence of his materialist theory of evolution was a complex scientific journey whereby Darwin came to confront and challenge arguments of design.

Over the course of his voyage around the world on the *Beagle*, Darwin took extensive notes of the plants and animals that he encountered. He studied the geology of the lands that he visited. He discovered fossilized remains of both extinct and extant mammals. These finds forced him to contemplate why both extant and extinct species were found together (Darwin, 1937; Darwin, 2005, pp. 65-69). When the *Beagle* stopped at the Galápagos Islands, Darwin noticed, as he had been told, that the species of tortoises and mockingbirds varied across the islands. He took extensive notes and collected specimens of animals so that experts in England could later study the samples. He was intrigued by the relationship between the species on the different islands and their counterparts on the South American continent, which seemed to be similar species. Natural scientists, at the time, accepted that species had a slight pliancy as they spread from the point of creation. But Darwin contemplated on "how far a species could be pushed" noting that if the divergence from the original stock was sufficiently great, it "would undermine the stability of Species" argument (Barlow, 1963; Darwin, 1937, pp. 376-405; Desmond & Moore, 1994, p. 186). This issue continued to gnaw at him, so he started a notebook on the relationships among species. When the expedition reached Australia, he observed the behaviors of birds that were similar to those in England, but were obviously of a different species, as well as miniature kangaroos that acted like rabbits and platypuses reminiscent of the European water rats. Darwin (1934, p. 383) exclaimed in his diary that "the strange character of the animals of this country as compared to the rest of the World" would seem to the "unbeliever in everything beyond his own reason" that "two distinct Creators must have been at work" and "that the periods of Creation have been distinct & remote the one from the other."

Darwin's family had long been involved in the abolitionist movement. In 1807, Britain made the slave trade illegal, and in 1811, engaging in this trade was deemed a capital offense. But other nations continued the trade, and British colonies still used slave labor on plantations (Browne, 1995, pp. 196-197). Many of Darwin's closest mentors at Christ's College, including John Stevens Henslow, who recommended Darwin as a naturalist for the *Beagle*, were morally opposed to slavery and worked to end its practice. While at sea, Darwin continued to read Humbodlt's account of his voyage to South America. Here Humboldt (1907) condemned all nations participating in slavery, detailing how slave sugar production was organized and noting the number of Africans killed in this system of oppression. On his own voyage, Darwin witnessed the cruelty of slavery; he heard proponents of slavery attempt to dehumanize Africans—proclaiming a separateness and ranking of races—in order to justify social inequalities and exploitation. He wrote in his diary, "The extent to which the trade is carried on; the ferocity with which it is defended; the respectable (!) people who are concerned in it are far from being exaggerated at home" (Darwin, 1934, pp. 42-43). He noted that the miseries suffered are "even greater" than imagined. Darwin noted the diversity of human populations but also emphasized the unity of humankind. His moral opposition to slavery and his "humanitarian roots" nourished Darwin's latter work on evolution (Desmond & Moore, 2009).

Aboard the *Beagle*, Darwin studied Charles Lyell's three-volume collection *Principles of Geology* (1830-1833), impressed by the grand theoretical scheme interwoven throughout the books. Lyell proposed and argued that geology should be aligned in accordance with his methodological and substantive doctrine of uniformitarianism. In this, it was asserted that natural processes, such as erosion, if given sufficient time could generate all known geological formations. Lyell proposed that geologic change was uniform, gradual, and steady. His doctrine was foundational to the development of geological science. Darwin was inspired by how simple natural processes could in the sweep of geological time yield great transformations. Darwin extended Lyell's theory to the formation of coral reefs and the Andes, determined to make a contribution to the field of geology. In fact, after his return from the *Beagle* voyage, Darwin's initial reputation among scientists was primarily due to his geological work, and he was deeply influenced throughout his life by his research in geology (Herbert, 2005). Lyell's uniformitarianism was arguably the single greatest influence on Darwin's thought. He accepted that the earth had been shaped over countless years by gradual processes that were constantly operating. It is here that Darwin starts to assemble some of the conceptions that informed his theory of evolution as well as his studies of natural history, including the actions of worms in transforming the surface of the earth (Desmond & Moore, 1994, pp. 115-118; Gould, 1977, pp. 147-152; Lyell, 1860; York & Clark, 2005).

By the end of the voyage, Darwin was completely enthralled by nature and its grandeur. On his return to England, he quickly became part of the scientific community, forging relationships with the leading scientists of the day, supplying plant and animal specimens for further study to other scientists, presenting scientific papers, and preparing manuscripts. In addition to presenting geological papers based on his research in South America, one of his earliest presentations, in November 1837, was a study of the role of worms in the formation of soil. His active participation in the scientific community, at this point in time, helped propel Darwin's study of natural history, driving him toward his materialist conception of evolution. Richard Owen, the comparative anatomist, determined that the unknown fossils that Darwin had found were distant relatives of mammals currently occupying South America. John Gould, a leading ornithologist, concluded that the bird specimens that Darwin brought back from the Galápagos Islands—which Darwin believed were a mixture of finches, wrens, and blackbirds—were all finches, which differed across the various islands. Further investigation of the mockingbirds, rodents, and tortoises confirmed that the different islands had similar, yet distinct, species (Browne, 1995, pp. 362-363; Desmond & Moore, 1994).

Darwin began raising critical questions in regard to the relationships among species in his *Red Notebook*, which he started while still on the *Beagle* but continued writing in after his return (Eldredge, 2005). After reflecting on the information that Owen and Gould provided concerning the fossils and the distribution of species, Darwin firmly embraced transmutation in March 1837 (Sulloway, 1982a, 1982b). He returned to his previous notes and started the first—*Notebook B*—of his transmutation notebooks as he recorded his attempts to determine the mechanism that drove transmutation, the explanation for organic change, and the common origin of all life, where humans shared with all other animals "one common ancestor" (Darwin, 1987, p. 229).

Darwin sought a unified theory of evolution that could be clearly articulated and firmly established. In part, he knew that a materialist theory of evolution had to be irrefutable given the challenge that it presented to both leading scientists of the day and to society in general, (Foster, 2000; Foster, Clark, & York, 2008). As a result, the working out of this theory was a slow, arduous process as Darwin wanted to not only put forth an argument for evolution but also to define the mechanism of change and to detail how it operated within the world at large. In his *Autobiography* he explained

> It was evident . . . that species gradually become modified; and the subject haunted me. But it was equally evident that neither the action of the surrounding conditions, nor the will of the organisms (especially in the case of plants), could account for the innumerable cases in which organisms of every kind are beautifully adapted to their habits of life. (Darwin, 2005, p. 98)

Thus, in his notebooks, Darwin hid his materialism as he forged his theory against the notion of "Providential Design." In fact, it is in engaging and criticizing design arguments that Darwin sharpened his own evolutionary position. Following Comte, he noted his theory was "against all contrivance." He clearly recognized the implications of his position. He insisted that the claims of natural theology—such as those by William Whewell who proposed that the whole universe was organized and designed to meet human needs in accordance with a divine plan—were instances of "arrogance!" Here he explained, in a nonanthropocentric view of evolution, that life was a branching tree. Thus, it was "absurd to talk of one animal being higher than another" (Darwin, 1987, pp. 189, 213, 347). Different animals could be seen as the highest depending upon the criteria. He contended that the argument that certain plants and animals are created by "the *will* of the deity is no explanation—*it has not the character of a physical law*." It "is therefore utterly useless" (Darwin, 1987, pp. 633-635, 637). Invoking Bacon's critique of final causes, Darwin proclaimed that declarations of perfect fit in accordance with a supernatural plan are empty and barren constructions yielding nothing. All human "races" were related to one another through common ancestry, as all of humanity was connected with the rest of the animal kingdom. Thus, there was a unity of humankind as well as between all living species. To be perfectly clear in regard to his transmutation position, he proclaimed "If all men were dead then monkeys make men.—Men makes angels." In other words, "Read monkeys for preexistence" (Darwin, 1987, pp. 189, 213, 291, 532, 551). Human ancestry was linked to other mammals, and even reptiles and fish, in a long chain of evolutionary descent. He studied the expressions of monkeys to find common, universal characteristics shared by humans and other animals. His commitment to materialism directed him to the point of noting that even the "love of deity" was an "effect of organization" (Darwin, 1987, pp. 291, 532, 551). Here Darwin establishes the depth of his commitment to materialism.

In his notebooks, Darwin outlined important aspects of his conception of evolution, but he continued to refine and develop his theory of evolution in the following years. In the fall of 1838, he reflected on Thomas Malthus's *An Essay on the Principle of Population,* which argued that the human capacity for reproduction greatly exceeded the capacity to expand food production and, therefore, starvation was an inevitable check on the growth of human population. He wondered in the Malthusian struggle for existence, which must occur when there is not enough food to feed all people, what would determine which individuals survived and which perished. This led him to see how when applied to the natural world, the Malthusian insight could potentially explain evolutionary change. Darwin recognized the principle of variation—"individuals in a population differ from each other in the form of particular characteristics" (Lewontin, 2009, p. 20). He also noted the principle of heritability—"offspring resemble their parents more than they resemble unrelated individuals" (Lewontin, 2009, p. 20). He combined these with the Malthusian concept of struggle for existence to develop the principle of natural selection, where "the resources necessary for life and reproduction are limited. Individuals with different characteristics differ in their ability to acquire those resources and thus to survive and leave offspring in the next generations" (Lewontin, 2009, p. 20). In this, Darwin indicated "favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of new species" (Darwin, 2005, pp. 98-99).

At one point, Darwin considered "saltationism"—abrupt, sudden changes in lineages—as a possible characteristic of evolution (Eldredge, 2005; see Gould, 2002, for a discussion of theories of abrupt evolutionary change). But he eventually decided that evolution proceeds in a slow, smooth, gradual manner, reminiscent of Lyell's uniformitarianism. In 1842, Darwin prepared a 35-page *Sketch* outlining his theory of natural selection. In 1844, he shared his conception with his confidant, Joseph Dalton Hooker, the renowned botanist, who encouraged him to continue this line of inquiry. Darwin expanded his *Sketch* into a 230-page *Essay*, fleshing out in even more detail his theory of evolution. Ever cautious, Darwin was determined that his argument had to be impregnable. He was well aware of the controversy generated when *Vestiges of the Natural History of Creation* was published. (The book was anonymous, but it was later revealed that Robert Chambers was the author.) *Vestiges* argued that all life was interconnected and that the universe and life developed through natural laws. Darwin felt that the book was scientifically inadequate, and he determined that any argument of transmutation must have a solid scientific foundation on all fronts, in order to challenge established thought and religious orthodoxy (Desmond & Moore, 1994, pp. 320-323; Secord, 2000).

While skeptical of Darwin's theory, Lyell—who became a close friend—encouraged him to prepare a preliminary paper for the scientific record. Darwin set to work on a manuscript entitled *Natural Selection*, which was to be three to four times the size of what was eventually published in the *Origin of Species*. Darwin continued to share parts of his evolutionary work with Hooker, who was supportive and encouraging. In 1857, Darwin prepared a summary of his argument and mailed it to the Harvard botanist Asa Gray. Gray admired Darwin and was persuaded as to the truth of evolution and Darwin's theory of natural selection, although, due to his religious convictions, he never fully accepted Darwin's deep materialism, believing that "God might create favourable variations and thereby still oversee the evolutionary process from a distance" (Browne, 2002, p. 156; see also Dupree, 1988). Darwin also began to engage Thomas Henry Huxley, attempting to sway him to the former's evolutionary view. Early in his career, Huxley had shown some hostility to evolutionary views, but he was progressively persuaded by Darwin of the fact of evolution and became one of Darwin's strongest supporters (Desmond, 1997). Darwin steadily built the scientific network he needed to gain support for his theory. He had been accumulating facts and details to demonstrate his theory of evolution for 20 years, but his long delay was to come to an end (Gould, 1977).

Alfred Russel Wallace, who was on an expedition in the Malay Archipelago, was also attempting to establish a materialist theory of evolution. In 1858, Wallace sent Darwin a paper that he was preparing, "On the Tendency of Varieties to Depart Indefinitely from the Original Type; Instability of Varieties Supposed to Prove the Permanent Distinctness of Species," in which he argued that evolution took place through divergence and the struggle for survival, presenting an explanation equivalent to Darwin's. Wallace asked Darwin for his help in publishing the paper. Darwin, recognizing that Wallace had developed the same materialist mechanism, consulted with Lyell and Hooker and sought their guidance in how to handle this difficult situation fairly. Darwin was in turmoil, having been put in an awkward spot. He did not want to lose credit for his theory, but he also did not want to seem dishonorable. He considered publishing Wallace's paper, as he had requested, and giving up his own claim to originality. Hooker and Lyell persuaded him to let them present an abstract from the *Essay*, Darwin's letter summarizing natural selection to Asa Gray, and Wallace's paper to the Linnean Society on July 1, 1858. As a result, both Darwin and Wallace were recognized as codiscovers of natural selection, each reaching his insight independently (Clark & York, 2007; Slotten, 2004, pp. 151-156). This delicate arrangement was happily accepted by Wallace, who did not hear about the outcome until many months after it was long complete, being away in the Malay Archipelago (Slotten, 2004).

These events prompted Darwin to quickly prepare an abstract of *Natural Selection* in order to present his theory of evolution to the general public. In November 1859, *Origin of Species* was published, incorporating only a third of the material Darwin had prepared for *Natural Selection* (Desmond & Moore, 2009, p. 310). With the *Origin of Species*, Darwin accomplished two major feats. First, he presented an enormous amount of evidence that demonstrated the reality of evolution—that species change over time and are connected to one another through common descent. The case for transmutation had never been presented in such a scientific fashion with copious evidence to demonstrate it. Here he argued for the *fact* of evolution. Second, Darwin presented his *theory* of natural selection as the force that drove the evolution of species, given the principle of variation and heritability (even though the specific laws of heredity were not known at the time), creating descent with modification—the transformation of a lineage through the accumulation of favorable traits. Much of the scientific community, after some initial resistance, accepted the first feat. The theory of natural selection was more controversial, and it was not until the middle of the 20th century, following scientific advances in genetics, biogeography, and paleontology, that the case was firmly established, being accepted by virtually all scientists (Browne, 2006; Darwin, 1968).

Darwin's strictly materialist argument of evolution by natural selection overthrew the hold of natural theology and teleological views of nature. He explained how natural selection led to the adaptation of organisms in nature without resorting to final causes. Furthermore, the conditions of nature change, so the individuals and species that are best able to survive vary. Thus, there is no inherent superiority/inferiority in species that determines that they are predestined to survive (Eiseley, 1958; Gould, 1977, 1989; Schweber, 1977). In reflecting upon the materialist significance of natural selection, Hermann von Helmholtz (1873, p. 385) stated, "Darwin's theory contains an essentially new creative thought. It shows how adaptability of structure in organisms can result from a blind rule of a law of nature without any intervention of intelligence." The importance of Darwin's theory of evolution has only increased since his time. Theodosius Dobzhansky, the prominent geneticist, claimed, "Nothing in biology makes sense except in the light of evolution" (as quoted in Coyne, 2006, p. 11).

Darwin, himself, in defending his theory of natural selection against critiques, counterpoised it to design arguments. Whereas the former opens up the world to rational inquiry and can be tested and/or used to advance knowledge of the world, the latter fails to expand the realm of human understanding. He explained:

> On the ordinary view of each species having been independently created, we gain no scientific explanation of any one of these facts. We can only say that it has so pleased the Creator to command that the past and present inhabitants of the world should appear in a certain order and in certain areas; that He has impressed on them the most extraordinary resemblances, and has classed them in groups subordinate to groups. But by such statements we gain no new knowledge; we do not connect together facts and laws; we explain nothing. (Darwin, 1920, p. 9)

Darwin, in contrast, presented a unified theory of evolution—an approach to studying natural history in all of its grandeur. While Darwin avoided public debate, his scientific work was steadfast in its commitment to materialism and it descriptions of the machinations of nature.

Adrian Desmond and James Moore (2009), historians of science, indicate that Darwin intended to discuss origins of humankind in the *Origin of Species*. But this subject was omitted because Darwin felt that he "lacked the overwhelming evidence to convince a sceptical world" (Desmond & Moore, 2009, p. 310). At the time, slavery pundits, as well as those invested in creating a racial hierarchy and sustaining social inequalities, argued that humankind was divided into separate species. This position was associated with the polygenist position. In opposition, abolitionists advocated a monogenist position that contended that humankind was a single species. Despite the absence of this issue in the *Origin of Species*, much of the public clearly understood that the book was truly about humankind in relation to the rest of the world. And finally, with the *Descent of Man* (1871/2004), Darwin presented an extensive account of human origins, explicitly uniting humans and other creatures through evolution by common descent and highlighting how the same materialistic forces influence the historical development of all life. In regard to the social implications of evolution on the question of race, Darwin (1871/2004, p. 210) stated, "Finally, we may conclude that when the principle of evolution is generally accepted, as it surely will be before long, the dispute between the monogenists and the polygenists will die a silent and unobserved death." While evolution indicates that natural history is bound by natural laws, it is also an open process whereby novelty is an inherent outcome. In connecting all of humankind, it was a declaration of emancipation (Desmond & Moore, 2009).

Worms and the Transformation of Earth

Throughout his adult life, Darwin remained the ever-diligent scientist, persistent in demonstrating the centrality of evolution and the importance of a materialist approach for comprehending natural history. At his Down House in the country, he pursued a wide range of scientific interests with the same patience and at the same pace as he did working out his theory of natural selection. In all of this, he sought a deeper understanding of how the world operated and how the physical world was conserved and transformed through its own processes. Toward the end of his life, he prepared a final manuscript on a topic that he had researched for over 40 years—the habits of worms and their role in the formation of soil. Darwin was interested in explaining how the earth was kept abundant with rich soil. He looked to the ground, the skin of the earth itself, to discover and illustrate some of the processes on which life depends—the invisible labor of worms. This research reveals not only the continuation of Darwin's commitment to materialism but also the notion of how small, persistent processes—which are often hidden and taken for granted—are significant in the fact that they create changes that accumulate through the years and influence the conditions of life. It also highlights the dialectical interchange between environment and organism as the latter actively transforms the former through living (such as collecting food and constructing shelter)—while being dependent at the same time on material conditions resulting from past evolution. For Darwin, worms, despite their "lowly" position, played a crucial role in the *organization* of natural conditions and processes, contributing to the emergent evolution of terrestrial life in general.

As noted above, one of Darwin's presentations after returning from his voyage around the world detailed the action of worms in the creation of "vegetable mould" (high-quality soil that had been processed by worms). He remained interested in this subject for the rest of his life. While a great number of other research projects occupied his time, he also committed himself to conducting a thorough investigation of the lives of worms. He was inspired by how humble actions can create great changes. *The Formation of Vegetable Mould, Through the Action of Worms, With Observations on Their Habits* (Darwin, 1881) was part of his

> undogmatic shuffling of the hierarchies to see earthworms—traditionally associated with death and corruption and lowliness—as maintaining the earth, sustaining its fertility. The poor, he would imply, had already inherited the earth: the worms, the poorest creatures of all. (Phillips, 2000, p. 42)

Darwin was worried whether he would have time and energy to finish this short book. Plus, he was concerned with whether anyone would appreciate it. Much to his surprise, it ended up being "by far his most popular" book, during his life (Browne, 2002, p. 490). (Reprinted here, following this article, are selections from Chapter III and the conclusion.)

After his death, some scholars came to downplay Darwin's achievement, seeing him as a dotty old Victorian naturalist who bumbled around his house studying worms, orchids, and other small things, producing works of minor importance in his later years (Gould, 1983, pp. 120-133). This view was most unfair, since it missed the fact that in focusing on small things Darwin sought to understand and illustrate big ideas. As Stephen Jay Gould (1983, pp. 120-133) has noted, each of Darwin's books sought to demonstrate the power of a particular theory or concept. His worm book was no exception.

His focus on the powerful transformative effects of small processes over the fullness of time was an attempt to show the power of the gradualist perspective he had developed from Lyell's uniformitarianism (Gould, 1983, pp. 120-133). Thus, his aim was not only to explore the particulars of the behavior of worms, although he was clearly truly fascinated by these, but also to further strengthen a key underpinning of his theory of natural selection—the argument that great changes come from the accumulation of seemingly insignificant processes happening all around us. Just as natural selection shapes species over geological time, worms transform the surface of the earth dialectically through small but constant action.

The Formation of Vegetable Mould is a fascinating account of the various methods of observation and the tests that Darwin conducted over the decades of studying worms. It provides a rich discussion of the habits of worms. He describes how worms live, what they eat, and how they respond to different stimuli. Here Darwin details the various experiments that he did with worms that he kept in the house as well as those in the natural environment. He studied what plant matter worms preferred to eat, giving them cabbage, turnips, onions, and so on. He concluded that worms had a preference for raw fat, as they quickly devoured it whenever it was made available. He tested their sensitivity to light, warmth, and vibrations. For the last, he placed a pot with worms in it on his piano and struck different notes, determining that worms were responsive to vibrations (Darwin, 1881, pp. 19-33). These tests helped him evaluate the senses of worms.

Darwin was also concerned with assessing the intelligence of worms. To approach this topic, he examined how worms pull leaves into their burrows. He noted that this material is gathered, no doubt, as food, but it is also used to plug "the mouths of their burrows" (Darwin, 1881, p. 58). He expressed that it was instinctual that worms conduct this work, but what he found particularly interesting is the manner in which worms drag leaves into their burrows. The majority of the time, worms seized the foot-stalk of leaves and pulled them into the hole with ease rather than attempting to drag a leaf in by the middle. Thus, Darwin contended that worms demonstrate "some degree of intelligence," as they utilize their sense of touch to properly determine the general shape of leaves and to manipulate the debris that they draw into their burrows (Darwin, 1881, p. 98).

In outlining the habits of worms, Darwin also identified the role of worms in contributing to the transformation and maintenance of the soil. Here he described how worms take part in creating their immediate environment through their daily actions of obtaining food and constructing shelter. In this coevolutionary perspective, Darwin (1881, p. 4) noted that what has become known as "vegetable mould" is truly "animal mould"—the product of the actions of worms and other soil organisms. In creating burrows, worms both push away and swallow the earth. He found that "worms swallow a larger quantity of earth" than what was necessary to create their burrows (Darwin, 1881, p. 102). In fact, "if earth were swallowed only when worms deepened their burrows or made new ones, castings would be thrown up only occasionally" (Darwin, 1881, p. 102). He explained that "worms do not burrow to a great depth, except when the weather is very dry or intensely cold" (Darwin, 1881, p. 103). Nonetheless, fresh castings are evident almost every morning at the mouths of burrows. Darwin deduced that "worms swallow earth" to extract "any nutritious matter which it may contain" (Darwin, 1881, pp. 102, 108). Thus, worms constantly produce castings, which they eject carefully around the openings of their burrows. But they also dispose of it into any available cavity within their burrows. The quality and quantity of castings vary in accordance with the surrounding environment and the condition of the soil. Poor pastureland often had larger castings than land with bountiful vegetation. Darwin concluded, "Worms have to swallow a greater amount of earth on poor than on rich land, in order to obtain sufficient nutriment" (Darwin, 1881, p. 162).

It is here that Darwin establishes that worms play an important part in the transformation and creation of the environment throughout the world as they constantly "cast up" the earth, helping build new soil. Darwin weighed and measured castings to calculate how much earth was brought to the surface through the action of worms. To confirm his hypotheses, in 1842, he spread chalk across a field. In 1871, he dug a trench in the field to observe the depth of the layer of chalk after the invisible labor of worms had "thrown up" soil that buried the chalk. He did the same experiment with coal cinders, over the same duration, to measure the depth of this material and to calculate how much soil was cast up per year. In another field, he noted that in 1841 it was known as "the stoney field" given that it was covered with rocks. The field was left fallow for 30 years. By 1871, the field was completely transformed as all the rocks—both small and large—had disappeared due to "the work of the worms" (Darwin, 1881, pp. 130-144). A trench was dug, so Darwin could measure the amount of soil that had been brought to the surface. He discerned that this process worked almost everywhere as the sinking of objects, due to the working up of the soil, helped preserve "ancient objects" and buildings for archeological study, as worms buried them (Darwin, 1881, pp. 176-177).

The Formation of Vegetable Mould highlights "that worms play an important part in nature" as soil "passes over and over again through their bodies and is brought to the surface" (Darwin, 1881, pp. 173-175). Other forces help distribute soil, such as the wind and rain, but it is the "action of worms" that gradually increases the soil, while sifting it, mixing it with organic matter, and saturating it with "intestinal secretions"—which add humic acids to the top soil (Darwin, 1881, pp. 173-175). Darwin indicated that "the triturating power of worms" is a significant geological force that enriches the conditions of life (Darwin, 1881, p. 230). The mould that worms produce is a dark color as it is mixed with the decaying organic matter (such as leaves) that worms drag into their burrows for food, to line their dens, and to plug the entrance to their burrows. "The leaves which they consume are moistened, torn into small shreds, partially digested, and intimately commingled with earth; and it is this process which gives to vegetable mould its uniform dark tint" (Darwin, 1881, pp. 239-240). This process helps enrich the soil with nutrients. Worms are everywhere, working the soil, out of sight. "The entire mass of the mould over every field, passes, in the course of a few years, through their [i.e., worm's] alimentary canals" (Darwin, 1881, p. 243). The importance of this was not lost on Darwin:

> Worms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds. They periodically expose the mould to the air, and sift it so that no stones larger than the particles which they can swallow are left in it. They mingle the whole intimately together, like a gardener who prepares fine soil for his choicest plants. In this state it is well fitted to retain moisture and to absorb all soluble substances, as well as for the process of nitrification. The bones of dead animals, the harder parts of insects, the shells of land-molluscs, leaves, twigs, &c., are before long all buried beneath the accumulated castings of worms, and are thus brought in a more or less decayed state within reach of the roots of plants. (Darwin, 1881, pp. 309-310)

Darwin's detailed account of the agency of worms brought about an appreciation for how worms help enhance the world. Hooker commented, "I must own I had always looked on worms as amongst the most helpless and unintelligent members of the creation; and am amazed to find that they have a domestic life and public duties!" (as quoted in Browne, 2002, p. 490).

Darwin's research on worms and vegetable mould "helped open the door for the modern view of soil as the skin of the earth" (Montgomery, 2007, p. 12). David R. Montgomery, a geomorphologist, notes that

> soil is a dynamic system that responds to changes in the environment. If more soil is produced than erodes, the soil thickens. As Darwin envisioned, accumulating soil eventually reduces the rate at which new soil forms by burying fresh rock beyond the reach of soil-forming processes. (Montgomery, 2007, p. 13)

Thus, the labor of worms enhances the circulation of necessary nutrients within an ecosystem. In other words, worms transform the environment in ways that are beneficial to other organisms, especially plants, as well as future generations of worms, in a positive feedback cycle (Wilkinson, 2006, pp. 57-59). This process is vital to the operation of ecosystems, as

> the availability of soil nutrients constrains the productivity of terrestrial ecosystems. The whole biological enterprise of life outside the oceans depends on the nutrients soil produces and retains. These circulate through the ecosystem, moving from soil to plants and animals, and then back again into the soil. (Montgomery, 2007, p. 15; see also Liebig, 1859)

Within the soil, worms, along with microbes, work as they reproduce themselves, releasing nutrients from organic matter and rock, helping build the soil through replenishing needed nutrients for plant growth. Social practices can greatly alter this process. The use of pesticides destroys important microbes. Tilling decreases the number of worms and kills other soil organisms. Large-scale, conventional agriculture diminishes biodiversity, hindering the ecological processes that enrich soil. As a result, "earth's thin soil mantle," on which life depends, is gradually striped off as the rate of soil erosion surpasses the rate of soil formation (Montgomery, 2007, pp. 20-25). Recognition of these interconnections and processes illuminates central issues in regard to ecological sustainability.

In closing *The Formation of Vegetable Mould*, Darwin noted that worms—through their dialectical, coevolutionary interchange with the environment—were a geological force reshaping the land over millions of years:

> When we behold a wide, turf-covered expanse, we should remember that its smoothness, on which so much of its beauty depends, is mainly due to all the inequalities having been slowly levelled by worms. It is a marvellous reflection that the whole of the superficial mould over any such expanse has passed, and will again pass, every few years through the bodies of worms. The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organised creatures. (Darwin, 1881, p. 313)

All studies of nature are indebted to Darwin for his profound insight in regard to the interconnectedness of all life through evolutionary descent. Throughout his adult life, he committed himself to the study of natural history, illuminating the power of a materialist conception for understanding how the world works through its natural processes. While evolutionary theory continues to develop, opening up new terrains for human investigation, it is important to appreciate the breadth of Darwin's scholarship. He was tenacious in his appreciation of how small, unseen forces could transform the land with the passing of time. The world constantly changes but persists due to the work of any number of natural cycles and processes as well as the action of worms. In Darwin's final book, he reminds us that small creatures play an important role in the overall health of ecosystems.

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References

Barlow, N. (1963). Darwin's ornithological notes. *Bulletin of the British Museum—Natural History, Historical Series 2*, No. 7, 201-278.

Browne, J. (1995). *Charles Darwin: Voyaging*. Princeton, NJ: Princeton University Press.

Browne, J. (2002). *Charles Darwin: The power of place*. Princeton, NJ: Princeton University Press.

Browne, J. (2006). *Darwin's origin of species: A biography*. New York: Grove Press.

Clark, B., & York, R. (2007). The restoration of nature and biogeography: An introduction to Alfred Russel Wallace's "Epping Forest." *Organization & Environment, 20*, 213-234.

Coyne, J. A. (2006). Intelligent design: The faith that dare not speak its name. In J. Brockman (Ed.), *Intelligent thought: Science versus the intelligent design movement*. New York: Vintage pp. 3-23.

Darwin, C. (1881). *The formation of vegetable mould, through the action of worms, with observations on their habits*. London: John Murray.

Darwin, C. (1920). *The variation of animals and plants under domestication*. New York: D. Appleton.

Darwin, C. (1934). *Charles Darwin's diary of the voyage of H.M.S. "Beagle."* Cambridge, UK: Cambridge University Press.

Darwin, C. (1937). *The voyage of the beagle*. New York: P. F. Collier.

Darwin, C. (1968). *The origin of species*. Harmondsworth, UK: Penguin.

Darwin, C. (1987). *Charles Darwin's notebooks, 1836-1844: Geology, transmutation of species, metaphysical enquiries*. Ithaca, NY: Cornell University Press.

Darwin, C. (2004). *The descent of man*. New York: Penguin. (Original work published 1871.)

Darwin, C. (2005). *The autobiography of Charles Darwin, 1809-1882*. New York: W. W. Norton.

de Beer, G. (1964). *Charles Darwin: Evolution by natural selection*. Garden City, NY: Doubleday.

Desmond, A. (1997). *Huxley: From devil's disciple to evolution's high priest*. Reading, MA: Helix Books.

Desmond, A., & Moore, J. (1994). *Darwin: The life of a tormented evolutionist*. New York: W. W. Norton.

Desmond, A., & Moore, J. (2009). *Darwin's sacred cause*. Boston: Houghton Mifflin.

Desmond, A., Moore, J., & Browne, J. (2007). *Charles Darwin*. Oxford, UK: Oxford University Press.

Dupree, A. H. (1988). *Asa Gray: American botanist, friend of Darwin*. Baltimore, MD: Johns Hopkins University Press.

Eiseley, L. (1958). *Darwin's century: Evolution and the men who discovered it*. Garden City, NY: Doubleday.

Eldredge, N. (2005). *Darwin: Discovering the tree of life*. New York: W. W. Norton.

Foster, J. B. (2000). *Marx's ecology*. New York: Monthly Review Press.

Foster, J. B., Clark, B., & York, R. (2008). *Critique of intelligent design: Materialism versus creationism from antiquity to the present*. New York: Monthly Review Press.

Gould, S. J. (1977). *Ever since Darwin: Reflections in natural history*. New York: W. W. Norton.

Gould, S. J. (1983). *Hen's teeth and horse's toes: Further reflections in natural history*. New York: W. W. Norton.

Gould, S. J. (1989). *Wonderful life*. New York: W. W. Norton.

Gould, S. J. (2002). *The structure of evolutionary theory*. Cambridge, MA: Harvard University Press.

Helmholtz, H. von (1873). *Popular lectures on scientific subjects.* New York: D. Appleton.

Herbert, S. (2005). *Charles Darwin, geologist*. Ithaca, NY: Cornell University Press.

Herschel, J. (1966). *A preliminary discourse on the study of natural philosophy*. New York: Johnson Reprint. (Original work published 1831)

Humboldt, A. von (1907). *Personal narrative of travels to the equinoctial regions of America, during the years 1799-1804*. London: G. Bell.

Lewontin, R. (2009). Why Darwin? *New York Review of Books, 56*(9), 19-22.

Liebig, J. von (1859). *Letters on modern agriculture.* London: Walton & Maberly.

Lyell, C. (1860). *Principles of geology*. New York: D. Appleton.

Montgomery, D. R. (2007). *Dirt: The erosion of civilizations*. Berkeley: University of California Press.

Paley, W. (1803). *Natural theology*. London: R. Faulder.
Paley, W. (1867). *The principles of moral and political philosophy*. New York: Harper.
Paley, W. (1874). *Paley's evidences of Christianity*. New York: R. Carter.
Phillips, A. (2000). *Darwin's worms*. New York: Basic Books.
Schweber, S. S. (1977). The origin of the Origin revisited. *Journal of the History of Biology, 10*, 229-316.
Secord, J. (2000). *Victorian sensation: The extraordinary publication, reception, and secret authorship of Vestiges of the Natural History of Creation*. Chicago: University of Chicago Press.
Slotten, R. A. (2004). *The heretic in Darwin's court: The life of Alfred Russel Wallace*. New York: Columbia University Press.
Sulloway, F. J. (1982a). Darwin and his finches: The evolution of a legend. *Journal of the History of Biology, 15*(1), 1-53.
Sulloway, F. J. (1982b). Darwin's conversion: The Beagle voyage and its aftermath. *Journal of the History of Biology, 15*(3), 325-396.
Uglow, J. (2002). *The lunar men: Five friends whose curiosity changed the world*. New York: Farrar, Straus & Giroux.
Wilkinson, D. M. (2006). *Fundamental processes in ecology*. Oxford, UK: Oxford University Press.
York, R., & Clark, B. (2005). Natural history and the nature of history. *Monthly Review 57*(7), 21-29.

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