# Darwin's Worms

"The subject may appear an insignificant one," Charles Darwin conceded, "but we shall see that it possesses some interest." Earthworms were the subject, and Darwin's lifelong fascination with them revealed as much about the unique qualities of his mind as it did about the surprising effects of the creatures' subterranean labors.

*by Amy Stewart*

When I stand on a patch of earth and wonder about the activity occurring underfoot, I'm not alone. Gardeners are inquisitive by nature; we're explorers; we like to turn over a log or pull up a plant by the roots to see what's there. Most of the gardeners I know are, like me, quite interested in earthworms, in the work they do churning the earth and making new dirt. We hold soil in our hands, squeeze it and smell it as if we're checking a ripe melon, and sift it to see what inhabits it. Ask a gardener about the earthworm population in her garden, and I guarantee she'll have something to say on the subject.

It seems strange, then, that most scientists before Charles Darwin (1809–82) didn't consider worms worthy of study. In fact, very little was known about them in the 19th century, when Darwin emerged as a sort of champion of worms, devoting his last book to painstakingly detailed research on their physiology and behavior. *The Formation of Vegetable Mould, Through the Action of Worms, With Observations on Their Habits* was published in 1881. Darwin was an old man when he wrote the book, but the subject had interested him for decades. How could so insignificant a creature as the worm capture the attention of so distinguished a scientist? Darwin knew from an early age that earthworms were capable of far more than most scientists gave them credit for. He recognized, in a way no scientist had before him, that they possessed an ability to bring about gradual geological changes over decades, even centuries. And this notion that the smallest changes could result in enormous outcomes fit perfectly with Darwin's work on evolution and the origin of species.

The story of Charles Darwin and his worms begins in 1837, when the scientist was not yet 30 years old. He'd just returned from a trip around the world on a British sailing ship called the *Beagle*. He had been offered passage because the captain, Robert FitzRoy, wanted a gentleman on board to share his table. The ship was to travel to the coast of South America, where Darwin would have ample opportunity to do the work of a naturalist, collecting specimens and recording his observations. Young Darwin could not resist the opportunity. He'd been try-


*A sly* **Punch** *cartoonist in 1881 was quick to fit earthworms into Darwin's evolutionary scheme.*

ing to find a way out of the career path his father had laid down for him: parson in a country parish, where he would have plenty of time to chase butterflies and beetles between his duties to the parishioners. It was not the ideal career for the man who would come to be known as the father of evolution; as one biographer put it, "There was, needless to say, the small matter of his faith." A journey around the world would defer the choice of a career for a while, and his father agreed to the expedition. But once on board the *Beagle*, Darwin realized that the experience would not be the idyllic adventure he had hoped for. The crew encountered more than its share of dangerous weather, the captain suffered some sort of breakdown midway through the voyage, and Darwin himself was often sick and discouraged. Still, he worked steadily, collecting artifacts and taking notes.

He was away from England five years, longer than he could ever have predicted, and he returned with a greater number of new discoveries than he could ever have imagined. He arrived in port with more than 2,000 journal pages, 1,500 preserved specimens, and nearly 4,000 skins, bones, and dried specimens. It would take years for him to organize the lot of them,

and even longer for him to realize the full impact of what he'd collected. In this great array of fossils, insects, and bird skeletons he would begin to see the patterns that would suggest to him a theory of evolution. With the vision of a quiet country parsonage long forgotten, Darwin chose for himself the life of a scientist.

But this was no easy path, and there was no steady employment even for a man of his talents. He arrived home from the voyage exhausted, overwhelmed by the work that lay ahead of him, and uncertain of his future once the work was done. At first he labored furiously on his collection of notes and field journals, but soon his health was so compromised that friends persuaded him to spend a few weeks in the country. He traveled to Shrewsbury to recuperate at the home of his uncle, Josiah Wedgwood. Upon arriving, he scarcely had time to set down his hat before Wedgwood had him out in the pastures, where he pointed to cinders and pieces of brick that had been spread on the ground years before and had since become buried some inches beneath. Wedgwood was convinced that the objects had been buried by the actions of earthworms, a feat that would have required far greater strength and single-minded purpose than had previously been attributed to the lowly creatures.

Despite all he had seen on his voyage around the world, Darwin was impressed with the discovery his uncle had made in his own backyard, and he made a presentation on the subject to the Geological Society of London later that year. Scientists of the day were asking such seemingly simple questions as Where does dirt come from? and Why does dust fall on ships at sea? (Darwin addressed the latter question in a paper he called, in his typically straightforward way, "An Account of the Fine Dust Which Often Falls on Vessels in the Atlantic Ocean.") After the visit to his uncle's home, he began to believe that earthworms, and earthworms alone, were responsible for the rich uppermost layer of soil, which was referred to at the time as vegetable mould.

> WHERE DOES DIRT COME FROM? WHY DOES DUST FALL ON SHIPS AT SEA?

Darwin made some revisions to his paper on earthworms, and the altered version was published in the Geological Society's journal a few years later. But by then he was focused on publishing his account of the *Beagle* voyage, and he'd already begun a number of other projects, including the manuscript that would become *On the Origin of Species* (1859). Over the next few decades, he published books on the habits of climbing plants, the expression of emotions in humans, the fertilization of orchids by insects, and the variations among domesticated animals, and he continued to revise his best-known works, *The Descent of Man* (1871) and *On the Origin of Species*. If earthworms occupied his thoughts during those

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years, they did not make much of an appearance in his published writings.

When Darwin returned to earthworms in his old age, the book he wrote about them, *The Formation of Vegetable Mould*, proved surprisingly popular. Despite what he had thought before publication ("As far as I can judge, it will be a curious little book. The subject has been to me a hobby-horse, and I have perhaps treated it in foolish detail."), nonscientific readers were drawn to his clear and vigorous prose—and his surprising conclusions.

Darwin described the volume of soil that earthworms swallow and eject as castings, or earthworm manure, and he reported that an acre of garden soil could contain more than 50,000 earthworms and yield 18 tons of castings per year. He studied earthworms' ability to bury objects of every sort—from handfuls of chalk scattered on the ground to Roman ruins that had, he believed, been preserved for archaeologists by an industrious earthworm population. Most of all, though, he credited worms with the transformation of the soil itself: "Their chief work is to sift the finer from the coarser particles, to mingle the whole with vegetable debris, and to saturate it with their intestinal secretions . . . no one who considers the facts . . . will hereafter, as I believe, doubt that worms play an important part in nature."

At the time, people thought Darwin's estimates grossly inflated and his claims exaggerated. No scientist before him had taken such an interest in the creatures living underfoot. Earthworms were still considered largely a garden pest that damaged plant roots and spoiled clean green lawns with their castings. At best, they were thought to provide some small service by perforating the earth and allowing water to penetrate. At least one reviewer of Darwin's early papers insisted that worms were too small and weak to carry out the massive movements of soil to which Darwin assigned them. Another critic dryly observed, "In the eyes of most men . . . the earthworm is a mere blind, dumb, senseless, and unpleasantly slimy annelid. Mr. Darwin undertakes to rehabilitate his character, and the earthworm steps forth at once as an intelligent and beneficent personage, a worker of vast geological changes, a planer down of mountainsides . . . a friend of man."

Darwin wasn't deterred by the criticism. "The subject may appear an insignificant one," he admitted, "but we shall see that it possesses some interest." He could hardly restrain himself before laying out his central thesis—and remarkable conviction—that "all the vegetable mould over the whole country has passed many times through, and will again pass many times through, the intestinal canals of worms." It's a stupendous achievement for a blind and deaf creature with no spine, no teeth, and a length of only two or three inches. Scientists of the day could scarcely credit the idea, and they were quick to express their skepticism. Darwin had heard the criticisms before, in response to the paper he had presented to the Geographical Society, and he did not waste the opportunity to both refute his critics and remind them whom they were up against. After all, he'd fought most of his life to win acceptance for his theory of evolution, and he saw parallels between his work on evolution and his work with worms.

A scientist looking back over Darwin's work wrote that "the key to his genius

was the ability to stretch his imagination to encompass geological time—thousands of years, thousands of centuries." Darwin understood that tiny, incremental changes in the environment could bring about the evolution of a species. This same approach led him to understand that, over time, soil could be transformed through the efforts of earthworms.

"Here we have an instance," Darwin wrote of his detractors, "of that inability to sum up the effects of a continually recurrent cause, which has often retarded the progress of science, as formerly in the case of geology, and more recently in that of the principle of evolution." A French scientist who disagreed with his conclusions about the abilities of earthworms was dispatched with the calm statement that the Frenchman "must have thus argued from inner consciousness and not from observation," for Darwin's own observations bore out the truth. The power of earthworms came not from their individual but from their collective strength. It's a surprisingly egalitarian conclusion to reach about the worms, and it could come only from a man who had both great vision and great affection for the creatures themselves.

Among today's earthworm scientists, Darwin is a kind of touchstone, a muse. He looked below ground with real interest and treated the dark earth as the mysterious, unexplored territory that it is. He lived at an exciting time for scientists: In every corner of the world, exotic plants and birds and fossils awaited discovery. But he chose to seek out the earthworm. We know now that Darwin merely glimpsed the potential power of worms. For example, his estimate that more than 50,000 worms could inhabit an acre of soil was in fact quite low; scientists have shown the figure to be one million. Earthworms in the Nile River valley can deposit up to 1,000 tons of castings per acre, which helps to explain the astonishing fertility of Egypt's agricultural land. As Darwin had only begun to suspect, earthworms pass the top few inches of soil through their guts every year. This makes them beings to be reckoned with, a force for change in more ways than even he could have guessed.

Over the past 100 years, earthworm scientists (called oligochaetologists, after Oligochaeta, the taxonomic class in which earthworms fall) have come to quantify what farmers have always known: that worms, through their actions, substantially change the earth. They alter its composition, increase its capacity to absorb and hold water, and bring about an increase in nutrients and microorganisms. In short, they prepare the soil for farming. They work with humans to extract a life from the land. They move the earth. What a remarkable accomplishment for a creature weighing only a fraction of an ounce.

An earthworm travels through the soil, pushing some particles aside and ingesting others. Although its food choices may look alike to the casual observer, the worm is actually sorting through the soil in search of tiny bits of decaying organic matter, which it will swallow along with some clay or sand particles. It builds a permanent burrow as it goes. At night it rises to the surface of its burrow, ejecting a small mound of castings around the entrance. It searches for food,

tugging leaves, pine needles, and other detritus into its burrow. This simple routine is enough to endear it to the farmer or gardener. On its nightly forage for food, it acts like a small, very efficient plough.

The body of an earthworm is perfectly designed for life underground. Sight is unnecessary in the subterranean world; a sensitivity to light is all the worm needs to avoid straying out of its habitat. Lungs are not much use in the tight confines of a burrow; instead, the earthworm breathes through its skin, taking in oxygen and expelling carbon dioxide, relying on damp conditions to help it absorb the oxygen in the same way that the damp interior of a mammal's lungs facilitates the passage of air into its body. The earthworm's shape allows it to be an extraordinary vessel for soil—the perfect container for holding, transporting, and transforming earth.

"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 earth-worms," wrote Darwin. Although he studied many aspects of the earthworm's biology and behavior, the august scientist was especially intrigued by its ability to sift the earth. He watched worms emerge from their burrows at night and draw in twigs and leaves or even drag small stones over a gravel walk until they formed a pile at the mouth of the burrow. He crept on the ground and unplugged enough of these burrows to know that the worms rested just inside, their heads readily visible just below the surface. Were they hiding from predators? Trying to keep rainwater out? Perhaps they were just protecting themselves from the cold night air. Whatever the reason, this nightly gathering of materials and systematic drawing in of leaves and plugging of burrows was certain proof of their unlikely physical strength and engineering abilities.

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If a person were to pull leaves or twigs into a hole, Darwin reasoned, he would grab the object by its narrowest end and pull it in. If the object was long and skinny like the hole itself—say, a twig or stem—he would probably pull the thickest, heaviest end in first. Surely, instinct alone could not account for the manner in which a worm selected material for its burrow. Intelligence, Darwin declared, had to be the guiding factor. When the worms reached for fallen leaves and twigs around their burrows, they selected the best material available. They evaluated, they experimented, they made decisions. Let me say that again: They made decisions—actual decisions—after trying several alternatives and choosing the one that seemed best for the situation. This is perhaps the most surprising revelation in Darwin's book. Although earthworms had undoubtedly been making such decisions for centuries, they found a new and unlikely advocate in Charles Darwin, who had the time, the resources, and the scientific

methodology to prove that what earthworms did was more than mere chance.

I thought of Darwin and his worms when I was out in the garden digging a new vegetable bed for three dozen asparagus crowns. The earth was damp but not muddy, just right for planting. I pushed a pitchfork into the soil and leaned back on the handle just enough to raise the tines of the fork and disturb the ground. My days of double digging—of scooping out the top layer of earth and the one beneath it, filling in the trench with compost, and placing a mixture of soil and compost on top—are over. The soil is an intact system, a community of microorganisms that lives and breathes, and it will function best if I don't disturb it too much.

Once the ground was loosened, I spread a layer of compost on top. The microbes—the bacteria, the protozoa, the fungi—could work their way into the earth gradually, and the earthworms would rise to the surface and take the compost back down with them. I pulled apart the soil with a hand spade and created a narrow trench down the center of the bed to bury the asparagus crowns. A layer of compost went in the bottom, and then I pulled the crowns out of the box, and spread the roots so they straddled the compost. I knocked enough dirt back into the trench to cover the crowns, but a shallow depression remained. I planned to fill it in slowly over the next few months as the first asparagus shoots appeared. The extra soil around the newly formed shoots would make them pale and tender, and at the same time provide enough nutrients to encourage them to grow tall and robust.

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There were easily a few dozen earthworms inhabiting the newly dug asparagus bed. Each worm holds less than a teaspoon of earth in its body as it moves through the soil. In a day, it will eat about a third of its body weight in soil, maybe more. This doesn't sound like much, but even Darwin's conservative estimates showed that over the course of a year, a healthy earthworm population can move almost 20 tons of soil per acre.

I leaned against my shovel, calculating that I had spread about 30 pounds of compost over my asparagus bed. Over the next year, I could expect earthworms to add another 30 pounds of castings around the roots of the plants. If conditions are right, they'll supply another 30 pounds—maybe more—the following year, and the year after that. These asparagus crowns will produce for more than 20 years. In that time, if the earthworms flourish, they'll contribute about 600 pounds of nutrient-rich

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castings to this small space, taking care of my vegetable bed far more efficiently than I ever could.

Darwin is responsible for putting these kinds of thoughts in my head. My gardening chores take significantly longer now that I slow down to count worms, now that I sit in the garden path, chin in hand, calculating the volume of castings. I have slowed down, it seems, to Darwinian time. He had that luxury in his later days; he could spend hours out in the fields around his house, watching earthworms, collecting their castings, guessing how they spent their time once they vanished from sight.

He also had the good fortune to know scientists around the world, and these colleagues regularly sent him specimens and castings in the mail. He carefully weighed and cataloged them, made a note about the area where they were collected, and organized the results into tables. Thanks to Darwin's meticulous approach, the data in his work remain, even today, some of the best ever gathered about earthworm activity. He wrote this in his autobiography: "I think that I am superior to the common run of men in noticing things which easily escape attention, and in observing them carefully."

There's no doubt that he took pleasure in his work. He had a genuine fondness for the worms and seemed to enjoy the painstaking effort that his research required. I like to think that his study of their habits was a daily delight in his old age. One biographer wrote that Darwin "became in the end what he had always been in his heart, almost a part of nature himself, a man with time to lean on a spade and think, a gardener." I imagine him as a dabbler, a homebody, a man who explored his most intimate surroundings with both deliberation and wonder. In the waning years of his life he was sometimes weak and infirm, but that merely turned the attention of his scientific mind away from the wider world and toward his home, his garden, and the earth.

The approaches he used to evaluate earthworms were, by then, classic Darwinian methods. Throughout his career, he took an ingenious, almost playful approach to experimentation. Like most naturalists he was a tinkerer, interested as much in nature's minutiae as in its grandeur. He liked the inner workings, the tiny springs and gears of the natural world. Perhaps he felt that nature's true power rested there, in the movement of pebbles and seeds, and in the commerce of ants and worms.

OLD AGE MERELY TURNED THE ATTENTION OF HIS SCIENTIFIC MIND TOWARD HIS HOME, HIS GARDEN, AND THE EARTH.

Think of him in his laboratory, with his notebooks and specimens. One day he becomes interested in the mechanism that allows climbing vines to climb, and he ties small weights to the tendrils of plants to see how they respond. The weights hang on the vines like miniature Christmas-tree ornaments, forcing the plants to reveal their tricks. He marvels at plants whose leaves roll tightly shut after dark. How could a plant act so deliberately, with such intent? He forces the leaves open so that they cannot close at night, hoping to lay bare the plants' secrets.

And when the old man turns his attention to worms, picture him stealing outside on wet mornings to pull leaves out of burrows and observe how they had probably been tugged inside. He gathers a handful of pine needles and scatters them around the burrows to see how the

worms will handle them. Eventually, his curiosity about the worms' mental capacity leads him to cut out irregularly shaped paper triangles, set them among active burrows, and then chart the number of times the triangles are drawn in by the apex, the middle, or the base.

Darwin was enormously thorough about his research. Since this was to be his last book, he seemed determined that it document every element of earthworm life correctly. He did not pull a *few* leaves out of burrows, he pulled 227—and reported that 181 of them, or 80 percent, had been drawn in by their tips. The others had been drawn in by their bases or seized in the middle, causing them to crumple once inside the burrow. The image of the elderly scientist pulling 227 leaves out of burrows and cataloging them to prove the intelligence of earthworms in his backyard is amusing, even surprising, but he did not stop with the leaves. He went on to reconstruct pine needles by breaking them apart and rejoining the pieces at the base using glue or thread. He intended to prove that worms knew to drag the needles into their burrows by the base, where the pieces had been rejoined, rather than by one end, which would surely result in a needle's getting stuck midway. He wanted to demonstrate that the worms were not acting simply out of instinct, because of a pine needle's particular taste or feel. He created 271 of these artificial pine needles, observed that 85 percent of them were drawn in by their bases, and noted that worms were slightly more likely to draw pine needles in by the base if they were held together with thread rather than with glue, which might have smelled or tasted unpleasant to the worms. He wondered whether the worms naturally avoided the sharp points of pine needle ends and chose the base because it was rounder. To test this, he carefully trimmed off the sharp ends and found that worms drew the needles in by the base regardless.

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For the paper triangle experiment, he did not simply cut a few triangles and leave them lying around. He cut 303 triangles of various sizes, coated them with fat to keep them from going limp in the night dew, and established some baseline data by drawing triangles into small tubes using tweezers to determine the most efficient method that he would employ if he, rather than the worms, were given this task. He chose the apex of a triangle, as opposed to the middle or the base. Even working with this unfamiliar material, the worms drew the paper triangles in by their apexes 62 percent of the time. Darwin went on to observe that the triangles pulled by their apexes had been drawn in cleanly, with very little evidence of fumbling around or trial-and-error effort first. "We may therefore infer," he wrote, "—improbable as is the inference—that worms are able by some means to judge which is the best end by which to draw triangles of paper into their burrows."

One of Darwin's most extraordinary qualities was his ability to recognize when a scientific question could not be answered because of the limitations of the science of his day. He knew, for instance, that during his lifetime, no significant progress would be made on the question of how life began. Near the end of his days he wrote to a colleague, "You expressed quite correctly my views where you said that I had intentionally left the question of the Origin of Life uncanvassed as being altogether ultra vires [beyond the powers] in the present state of knowledge." The same could be said of Darwin's insight into the role of earthworms in the soil. The technology that would allow scientists to understand the complex relationships among soil microbes, plants, and earthworms would not be advanced for several more decades.

When *The Formation of Vegetable Mould* was published, the idea that an earthworm might possess enough intelligence to judge how best to pull objects into its burrow was novel indeed. No scientist had paid as much attention to this seemingly trivial matter as Darwin did, or devoted so many pages of published work to it. But even he could not grasp the importance of the earthworm's impact on the soil ecosystem. The relationship between the microscopic world of soil and the macroscopic ecology—between the earthworms and other visible creatures that inhabit the earth—was still largely a mystery.

At the beginning of the fourth chapter of *The Formation of Vegetable Mould*, Darwin wrote this: "Archaeologists are probably not aware how much they owe to worms for the preservation of many ancient objects. Coins, gold ornaments, stone implements, &c, if dropped on the surface of the ground, will infallibly be buried by the castings of worms in a few years, and will thus be safely preserved, until the land at some future time is turned up." He went on to describe the excursions he or his son William took to excavation sites around England, including a farm in Surrey where Roman ruins were found, an abbey in Hampshire destroyed by Henry VIII, and the ruins of a Roman villa in Gloucestershire. He reported that worms had burrowed into the old stone walls, undermined foundations, and generally deposited a layer of castings that permitted grass and other plants to grow. After examining the sites of several ancient ruins, he concluded that the actions of earthworms "would ultimately conceal the whole beneath fine earth."

In some ways, Darwin thought of worms as historians, covering the remains of one civilization and preparing the earth for the next. But earthworms can hardly be considered sneaky in their concealment; anyone who has ever watched a worm knows that it goes about its work in the most matter-of-fact manner. It's only carrying out the natural order of things, folding the ruins of a farm, a city, or a society into the lower strata of the earth. When our civilizations end, and when we as individuals die, we don't ascend, not physically. We descend. And the earth rises up to meet us. ❑