4. Mr. Darwin's *Researches in Connection with the Earthworm.*

[Abridged from the 'Mark Lane Express.']

For half a century has Mr. Darwin, who is *facile princeps* in his art, patiently observed from day to day, from month to month, and from year to year, the earthworm and its work, and the result of his inquiries is now given to the world.

The earthworm known to zoologists by the name of *Lumbricus terrestris*, exhibits on the exterior of its body a number of close-set transverse grooves dividing it into numerous rings or segments; hence it belongs to the group of animals called Annelids (Latin *Annulus*, a ring). The most anterior segment is small

and conical, there being a depression on its under surface in which the mouth is situated, the vent being at the opposite end of the body. Behind the mouth, the successive rings rapidly reach their average size, while in full-grown worms a part of the body between the twenty-fourth and thirty-sixth rings becomes swollen, is of a different colour from the rest, and is known as the *cingulum* or *clitellum*. The total number of segments varies from 100 to 200, and each is furnished with minute bristles. The whole body is invested by a thin, transparent, but dense cuticle, lined internally by a thick layer of circular muscular bands, inside which is a much thicker coat of muscular fibres arranged lengthwise. With this excellent development of the muscular system worms can crawl backwards as well as forwards, and by the aid of their affixed tails can retreat with extraordinary rapidity into the burrows.

The mouth, which is provided with a little lobe or lip, used for grasping, leads into a muscular pharynx, which reaches back as far as the seventh segment, and which is pushed forward when the animal eats. From this a narrow œsophagus, or gullet, is continued back to the fifteenth segment, and on each side of its lower part there are three pairs of large glands, which secrete a surprising amount of carbonate of lime, and are known in consequence as the calciferous glands; nothing like them is known in any other animal. The gullet opens behind into a crop, which, at the eighteenth segment, is continued into a thickened and muscular gizzard. This latter organ is lined with a smooth, thick, chitinous membrane, and is surrounded by weak longitudinal but powerful transverse muscles. As worms possess no jaws or teeth of any kind, the trituration of the food must be effected, as in birds, chiefly by the gizzard. Grains of sand and small stones, from the twentieth to the tenth of an inch in diameter, may generally be found in the gizzard and intestines, and these probably act like millstones in reducing the food. The gizzard opens into the intestine, which runs in a straight line to the vent. The intestine is infolded lengthwise, thus materially increasing the absorbent surface, at the same time forming a structure which has been aptly described as an intestine within an intestine.

Worms breathe simply through their skin, and they possess colourless blood. There is a nervous system extending through the length of the body, but there are no eyes nor any other organs of special sense, though, as we shall presently see, it may be fairly said of the worm that "he is not such a fool as he looks." The earthworm is hermaphrodite, that is, the two sexes are united in the same individual, the male generative organs being situated in the tenth and eleventh segments, and the female

organs or ovaries in the thirteenth segment. Nevertheless, it is necessary for the production of fertile eggs that two distinct individuals should pair with each other. At ordinary times, during the day they remain in their burrows, but at the pairing season those which inhabit adjoining burrows expose the greater part of their bodies for an hour or two in the early morning. During the process of copulation the two worms get bound together by a tough secretion from the clitellus of each.

Though terrestrial in their habits, earthworms have been known to live for several months completely submerged in water. They are nocturnal, and at night may be seen crawling about in large numbers, but usually with their tails still inserted in their burrows. By the expansion of the tail, aided by the short, slightly reflexed bristles with which their bodies are armed, they hold so fast that they can seldom be drawn out of the ground without being torn into pieces. They are known to leave their burrows on voyages of discovery, and thus to find new sites to inhabit, but it seems unlikely that a worm could again find its burrow after having once left it. When at rest, they remain, as a rule, very near the surface of the ground, apparently for the sun's warmth, and the sharp-eyed thrushes and blackbirds often drag them out and devour them in large numbers.

They are very sensitive to light, especially if bright, and if they are suddenly illuminated at night they retreat into their burrows in a manner highly suggestive of a rabbit dashing into its hole. They are sensitive, also, to temperature, as may be inferred from their not coming out of their burrows during a frost. Of any sense of hearing they are quite destitute; the shrill sound of a whistle and the deep note of a bassoon alike affect them not. But they are peculiarly sensitive to any vibratory motion communicated directly to the medium in which they are; when flower-pots containing earth and worms are placed on a piano and a note struck, the annelids instantly withdraw into their burrows. Their most highly developed sense seems to be that of touch; even a slight puff of air from the mouth causes an instant retreat. The sense of smell is feeble, and is apparently confined to the perception of certain odours of substances on which they feed.

Feeding as they do on various materials, it is natural to assume that they possess some sense of taste, however unrefined. They are very fond of cabbage-leaves, and are found to prefer the green to the red variety; as a rule, when leaves of the cabbage, horse-radish and onion were offered together, the onion-leaves were always preferred. Of the leaves of the cabbage, lime-tree, parsnip, virginian creeper, and celery, those of the last-named

were always eaten first. But the leaves of the carrot and wild cherry are in greater favour than any of those already mentioned. Sage and thyme always, and mint nearly always, were refused.

Earthworms are very timid, but Mr. Darwin doubts whether they suffer as much pain when injured as they seem to express by their contortions. Judging by their eagerness for certain kinds of food, they must enjoy the pleasure of eating. Their sexual passion is strong enough to overcome for a time their dread of light. They pass the winter either singly or rolled up with others into a ball at the bottom of their burrows. As they are much more easily excited at some times than at others, their nervous condition must vary with circumstances. One of their strongest instincts is the plugging up of the mouths of their burrows with various objects, such as dead leaves and stones; even very young worms act in this way. In this work, moreover, they exhibit a certain degree of intelligence, a fact which surprised Mr. Darwin more than anything else connected with worms.

As regards food, worms are omnivorous. They swallow an enormous quantity of earth, out of which they extract any digestible matter it may contain. Half-decayed leaves, leaf-stalks, flower-stalks, and fresh leaves are consumed. These vegetable products are dragged to a depth of from one to three inches down the burrows, and are then moistened by a fluid secreted by the worms, and if the leaves are fresh, or nearly fresh, this fluid kills and discolours them. The secretion appears to resemble the digestive fluid poured by the pancreatic glands into the stomach of the higher animals. It seems highly probable that the calciferous glands, to which reference has already been made, serve to neutralise more or less completely the acids generated by the half-decayed leaves.

Mr. Darwin tested the intelligence of worms by some simple yet ingenious experiments, the object of which was to determine whether they exercised any power of discrimination in their method of seizing leaves and other objects which they wished to drag to their burrows. They grasp such things in the mouth, and it was clearly demonstrated that, as a rule, they took hold of the end which would with least difficulty enter the burrow. Leaves are dragged into the burrows, not only for plugging them up and so preserving warmth, nor yet only for food, but also for lining the upper part or mouth of the hole. Hundreds of such plugged burrows may be seen in many places, especially during autumn and early winter. If leaves, leaf-stalks, sticks, &c., are not obtainable, the worms often cover up the mouths of their burrows with stones, which they arrange in little heaps. The

work of closing the burrows is usually performed at night, and worms appear to dislike leaving their burrows open.

Worms excavate their burrows in two ways—by pushing away the earth on all sides, and by swallowing it. A worm placed on loose mould was observed to bury itself in between two and three minutes; the stretched-out and attenuated anterior extremity of its body was inserted into a little crevice or hole, and then the pharynx was pushed forward, driving the earth away on all sides. In an experiment in which compact, well-pressed earth was used, the worm was nearly twenty-six hours burying itself. It went in head first, swallowing the earth, and ejecting it as a casting at the other end of its body. Whenever a worm burrows to a depth of some feet in undisturbed, compact ground, it must form its burrow by swallowing the earth, for it is incredible that the ground could yield on all sides to the pressure of the pharynx when pushed forwards within the worm's body.

The burrows extend down perpendicularly, or a little obliquely, and their walls are lined or cemented over with earth which has been passed through the animal's body. This lining strengthens the walls, and, perhaps, saves the body of the worm from being scratched. The burrows, then, are not mere excavations, but are rather tunnels lined with cement. When a worm comes to the surface to eject earth, the tail protrudes, but when it collects leaves its head must protrude. Therefore, says Mr. Darwin, "worms must have the power of turning round in their closely fitting burrows; and this, as it appears to us, would be a difficult feat."

Though usually found near the surface of the earth, worms have been observed to burrow as deep as six or eight feet. The castings—and these it must be remembered come both from earth swallowed in burrowing and from that eaten as food—are generally piled up round the mouth of the burrow, and are not infrequently tunnelled through in an oblique manner to enable the worm to get rid of further castings when the pile has risen to some little height. In some countries these castings reach as much as three to six inches high, with a diameter of two to three inches, and a weight of from one to three ounces. As all earthworms pass a greater or less quantity of earth through their system in the course of life, the total effect cannot be insignificant; indeed, it is stupendous, as we shall see when we discuss the remaining part of Mr. Darwin's work.

The amount of earth brought up by worms from beneath the surface of the soil and afterwards spread out more or less completely by the rain and wind may be judged by two methods—by the rate at which objects left on the surface are buried, and

more accurately by weighing the quantity of earth brought up in a given time.

As an example of the first method the following may be taken :—In the spring of 1835, a field which had long existed as poor pasture, and was so swampy that it trembled slightly when stamped on, was thickly covered with red sand, so that the whole surface appeared at first bright red. Two and a half years afterwards holes were dug in the field, and the sand was found to form a layer at the depth of three-quarters of an inch from the surface. In 1842 fresh holes were dug, and then the red sand formed a distinct layer 2 inches beneath the surface or 1½ inch beneath the turf; so that, on an average, one-fifth of an inch of mould had been annually brought to the surface by the industry of the earthworm. On a totally different soil, namely, on the chalk soils of Kent, Mr. Darwin found that the fine earth accumulated on the surface at about the same rate as in the case already given, that is, at an average rate of 0·2 to 0·22 of an inch per annum. But he observes that on the Kentish chalk, when a ploughed field is first laid down in grass, the mould accumulates at a much slower rate. The rate also must become very much slower after a bed of mould several inches thick has been formed; for the worms then live chiefly near the surface, and burrow down to a greater depth, so as to bring up fresh earth from below only during winter when the weather is very cold, and during summer when it is very dry.

Another interesting case mentioned by Mr. Darwin is that of a narrow path extending across his lawn, which, in 1843, was paved with small flagstones, set edgeways, but on which worms threw up many castings, while weeds grew thickly between them. For some years the path was weeded and swept, but ultimately weeds and worms prevailed, and the gardener ceased to sweep, merely mowing off the weeds as often as the lawn was mown. The path soon became covered up, and after several years no trace of it was left. On removing, in 1877, the thin overlying layer of turf, the small flagstones, all in their proper places, were found covered by an inch of fine mould.

As bearing on this same subject, Mr. Darwin adds: "Farmers in England are well aware that objects of all kinds, left on the surface of pasture lands, after a time disappear, or, as they say, work themselves downward. How powdered lime, cinders, and heavy stones can work down, and at the same rate, through the matted roots of a grass-covered surface, is a question which has probably never occurred to them."

Worms are very partial to the shelter of stones, and when a stone of large size and irregular shape is left on the surface of the ground, it rests, of course, on its more protuberant parts, but

worms soon fill up with their castings all the hollow spaces on the under side. As soon as the hollows are filled up, the worms eject the earth which they have swallowed beyond the circumference of the stones, and so the surface of the ground gets raised all round the stone. As the burrows excavated directly beneath the stone collapse after a time, the stone sinks a little. In this way boulders, which at some far-away time have rolled down on to a meadow, are always somewhat imbedded in the soil, and when removed, leave an exact impression of their lower surfaces on the underlying fine mould. But if a boulder is so huge that the earth beneath remains dry, such earth will not be inhabited by worms, and the boulder will not sink into the ground. Stones that have "sunk" in the way here described may be seen in plenty on the commons near Tunbridge Wells. The point here discussed is of some practical importance to ordnance surveyors, as the beach-stones, marked with a broad arrow, which they fix in the ground as a record of their levels, may in time become false standards.

Hensen calculated that the number of worms found in a garden was equivalent to 53,767 per acre, and that this number would weigh 356 lbs., taking the average weight of a worm as 1 gram (i.e. between 15 and 16 grains). In a corn-field the worms would, according to Hensen, be about half as numerous.

Among the instances illustrative of the weight of earth brought up by worms, Mr. Darwin gives the following: "In a field at the bottom of a valley in the chalk, a square yard was measured at a spot where large castings abounded. These castings, which retained perfectly their vermiform shape, were collected, and weighed, when partially dried, 1 lb. 13½ oz. This field had been rolled with a heavy agricultural roller 52 days before, and this would certainly have flattened every single casting on the land. The weather had been very dry for two or three weeks before the day of collection, so that not one casting appeared fresh or had been recently ejected. We may therefore assume that those which were weighed had been ejected within, we will say, forty-five days from the time when the field was rolled. I had examined the same part of the field shortly before it was rolled, and it then abounded with fresh castings. Worms do not work in dry weather during the summer, or in winter during severe frosts. If we assume that they work for only half the year—though this is too low an estimate—then the worms in this field would eject during the year 83·37 pounds per square yard; or 18·12 tons per acre, assuming the whole surface to be equally productive in castings. As this enormous weight of earth would pass through the intestines of the worms, its fertility would necessarily be greatly increased. In three other cases the observed or

calculated weights of the ejecta per acre per annum were found to be 14·58, 7·56, and 16·1 tons respectively.

"Supposing the annual castings to be strewn over the ground in a layer of uniform thickness, the accumulation of mould in a period of ten years was calculated in five examples of different kinds of soil to attain respective depths of 2·2, 1·9, 2·1, 2·2, and 0·83 inches.

"The problem concerning the weight of earth which each worm on an average ejects every year on the surface of the soil is hardly capable of direct solution, but on the moderate assumption that 26,886 worms, more or less, live on an acre of old pasture land and throw up annually 15 tons of earth per acre, then each worm must annually eject 20 ounces."

No one, urges Mr. Darwin, who considers the facts now given —on the burying of small objects and on the sinking of great stones left on the surface—on the vast number of worms which live in a moderate extent of ground—on the weight of the castings ejected from the mouth of the same burrow—on the weight of all the castings ejected within a known time on a measured area, will hereafter doubt that worms play an important part in nature.

Abundant evidence is quoted as to the part worms have played in the burial and concealment of several Roman and other old buildings in England, notably those of Abinger in Surrey, of Beaulieu Abbey and Silchester in Hants, of Brading in the Isle of Wight, of Chedworth in Gloucestershire, and of Wroxeter (Uriconium) in Shropshire. The floors, halls, and passages have been undermined by worms, and the walls, wherever their foundations do not lie at a great depth, have been penetrated and undermined by worms, and have consequently subsided. The unequal subsidence thus caused probably explains the great cracks which may be seen in many ancient walls, as well as their inclination from the perpendicular.

The disintegration of the particles which compose the earth and the denudation or laying bare of the land by the removal of these disintegrated particles to lower levels are operations in which worms play a very noteworthy part. The dark colour and fine texture of vegetable mould is largely due to the action of worms. Rocks are disintegrated by the humous acids of decaying vegetation, and it appears that similar acids are generated within the bodies of worms, while their action is facilitated by the continued movement which the particles of earth undergo through the action of worms. Even the triturating process to which moderately small fragments of stone are subjected in the gizzards of worms must have an important ameliorating effect on the soil. There is good evidence,

observes Mr. Darwin, that on each acre of land which is sufficiently damp and not too sandy, gravelly, or rocky for worms to inhabit, a weight of more than ten tons of earth annually passes though their bodies and is brought to the surface. The result for a country of the size of Great Britain, within a period not very long in a geological sense, such as a million years, cannot be insignificant; for the ten tons of earth has to be multiplied first by the above number of years, and then by the number of acres fully stocked with worms; and in England, together with Scotland, the land which is cultivated and is well fitted for these animals has been estimated at above 32 million acres. The product is 320 million million tons of earth.

Though the work of earthworms is chiefly manifested in the little towers or castings which they build up outside their burrows, yet, paradoxical though it may seem, the general effect of their labours is to reduce inequalities and to level the ground. The finest particles of earth are washed completely away from castings, particularly from those on inclined surfaces; and whenever castings get dry and dusty they become the sport of the winds, so that sooner or later they get transported to lower levels. There is no better illustration of this than that afforded by the gradual, though certain, disappearance of the furrows and ridges from fields that were formerly ploughed, but have for a long period been in pasture.

How efficiently the worm assists the cultivator of the soil is a point on which Mr. Darwin lays no light stress. 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.

Mr. Darwin's concluding words are a simple tribute to the industry of the earthworm. "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 earthworms. 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 doubtful 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."