Contributions

Commentary

A History of the Ecological Sciences, Part 17: Invertebrate Zoology and Parasitology during the 1600s

Scientific research published during the 1600s (see Parts 13–16) expanded considerably beyond the notable amount of research published during the 1500s (see Parts 10–12). Gambuccini published the first treatise on parasitic worms in 1547, but encyclopedic writings by Aldrovandi and Penny compiled separately in the later 1500s were not published until the 1600s (Penny's published by Mouffet). Their broad reference works encouraged investigators in the 1600s to write more narrowly in scope, usually in more detail, and frequently in the new (by the 1660s) scientific periodicals. An adequate contagious theory of disease would not emerge until the later 1800s, but much understanding of the anatomy and life histories of invertebrates was achieved during the 1600s. Hooke's *Micrographia* (1665) inspired several outstanding microscopists to follow his example of investigating microscopic structures.

Felix Platter (1536–1614) was a Swiss student who in 1552 went to study medicine at the University of Montpellier, in France, and wrote probably our earliest first-hand account of student life in a university (Platter 1961, 1976). After receiving there a bachelor of medicine degree, he returned to his native Basel to obtain a doctorate in medicine. He became city physician—in charge of public health and the city hospital—and professor of medicine at the University of Basel. His medical interests were broad, and it was in his textbook on medicine, *Praxeos* (1602–1603), that he first drew a clear distinction between two kinds of tapeworm, and described the broad tapeworm (*Diphyllobothrium latum*) in as much detail as was possible before the microscope. He also described its effects upon its host. His account is translated from the Latin of the 1609 edition by Kean et al. (1978: 653–654). The other tapeworm, which he described in less detail, was probably *Taenia solium* (Grove 1990: 398). Platter's account of scabies and the itch mite is quoted in Latin from *Praxeos* (1625:788) by Hoeppli (1959:46). Platter's textbook was still considered important enough to be translated into English in 1662.

While Platter was an outstanding example of medical progress in the center of Europe, Aleixo de Abreu (1568–1630) achieved modest fame on the fringes of European medicine by writing the first book on tropical medicine (Guerra 1968, 1970). He was Portuguese and studied as an undergraduate at the University of Evora before attending Portugal's only medical school at the University of Coimbra. He practiced medicine in Lisbon for a few years, and in 1594 was appointed physician to the governor of Angola, an important Portuguese colony for exporting African slaves to Brazil. He was also one of three who practiced at the Loanda hospital, the other two being Spanish surgeons. It was there that he gained his first experience with tropical diseases in both the slaves and slavers. In 1603 he became physician to a governor in Brazil for 3 years before returning to Lisbon in poor health. He contracted yellow fever in Angola and apparently amoebiasis in Brazil in 1605. His amoebiasis recurred in 1614 and 1621, and after this last attack he began recording his observations and experiences with tropical diseases, published as *Tratado de las siete enfermedades* (1623). In hopes of a broader audience than Portuguese physicians, he wrote it partly in Spanish and partly in Latin, though he was not a skilled linguist, and there were probably no more than 200 copies printed.

Guerra (1968:59–67) explains the "seven" diseases Abreu discussed as: (1) amoebic hepatitis with abscesses and probable lung and cerebral involvement, (2) renal calculi, (3) malaria and typhoid fever, (4) scurvy, (5) yellow fever, (6) trichuriasis, (7) dracontiasis, and (8) tungiasis. All but the renal calculi and scurvy we now know are parasitic diseases or infections. Guerra also translates important passages on each disease from Spanish or Latin into English and reached the following conclusions: Abreu "gave a full clinical picture of amoebic hepatitis, liver abscess and pulmonary amoebiasis;" his clinical description of semi-tertian malarial fever "is rather short considering his lengthy quotations from Galen, Avicenna and Hippocrates;" his clinical description of scurvy is accurate and concise, and his recommended diet of milk and vegetable syrups is effective; he gave the first complete clinical description of yellow fever, though it was under the heading of "Disease of the worm," since he found the whipworm in the caecum of patients dying of yellow fever, and he described yellow fever as a disease primarily in Africa but also sometimes in Brazil and Lisbon; his description of the whipworm (*Trichuris trichiura*) "contains all the basic pathognomonic elements which make it possible to identify the infestation," though he thought this mild pathogenic helminth caused yellow fever; the Guinea worm (*Dracunculus medinensis* [formerly *Filaria medinensis*]), which he reported from the Mina coast and around the Gulf of Guinea, was "generated" in the legs of men and grew to the size of "a thick fiddle-string," which was extracted very slowly by twisting it around a little stick with care taken not to break it, since that results in many of its young escaping into surrounding tissues and producing "violent local inflammation;" he identified the burrowing flea, chigoe, or jigger (*Tunga penetrans*), as a Brazilian worm or flea that grows in the soles of feet or between toes or under nails, which can be extracted with a pin, but care must be taken not to break it, as that supposedly leads to great damage.

Athanasius Kircher (1602–1680) was the son of a German Catholic Church official, and he became a Jesuit in 1616. He was well educated in humanities, science, and mathematics, and he was a professor at the College of Rome for 8 years (Kangro 1973, Reilly 1974, Godwin 1979, Findlen 2000). His many interests were not mainly biological or medical, but when he went to Rome in 1634, Cardinal Giovanni Carlo gave him a rudimentary compound microscope, perhaps the one drawn in P. Bonanni's *Musaeum Kircherianum* (Rome 1709) which Major reprinted (1939: 119). Kircher mentioned some of what he saw with his microscope in *Ars magna lucis et umbrae* (1646:834), one sentence of which Torrey (1938:253) translates: "I omit here the wonders to be seen in the incubating eggs of birds, in the verminous blood of those sick with fever, and numberless other facts not known or understood by a single physician." A decade later, a "most atrocious and unheard of plague" struck Naples, then Rome (where it killed 15,000), and Kircher courageously worked in a Roman hospital with plague victims and physicians. Now was his chance to go beyond the vague assertions made in 1646. He wrote a new book, *Scrutinium physico-medicum contagiosae luis, quae dicitur pestis* (1658) to explain his new findings. He stated (Section II, Chapter 4, translated by Torrey 1938:255): "...the putrid blood of those afflicted by fevers has fully convinced me; I have found

Fig. 1. Guinea worm being extracted by Persian surgeons. Welsch (1674), Plate 63.

it, an hour or so after [blood] letting, so crowded with worms as to well nigh dumbfound me; and I have even been persuaded forthwith that man both alive and dead swarms with numberless but yet invisible little worms…" Wilkinson (1992:27–28) suggests that Kircher might only have seen red blood corpuscles, but if he actually saw worms, S. A. Ewing (*personal communication*) suggests they were likely microfilariae. His discussion was more detailed than in 1646, but not more precise (Reilly 1974:88–95). Nevertheless, he also performed six experiments using a microscope, which Torrey (1938:257–258) translates entirely. Their quality is indicated by the first one: leave a piece of meat overnight in "the lunar moisture," and the next morning one finds that "the putridity drawn from the moon (caused by the moon) has been transformed into numberless little worms of different sizes. . . ." Torrey concludes (1938:271): "The microscope…became, in his hands, less a tool of research than a brand new garnish for ancient modes of thought." The particular ancient thought being defended was spontaneous generation. In *Mundus Subterraneus* (1664–1665) Kircher reported on similar experiments with similar results; for example (translated by Gottdenker 1979: 576, from the 1668 edition):

> *Collect a number of fly cadavers and crush them slightly. Put them on a brass plate and sprinkle the macerate with honey-water. Then expose the plate, as chemists do, to the low heat of ashes or of sand over coals, or even of horse dung; and you will see, under the magnifying power of the microscope, otherwise invisible worms, which then become winged, perceptible little flies and increase in size to animated full-fledged specimens.*

Kircher showed that the use of new instruments did not automatically lead to new conclusions. New concepts could lead either to new conclusions or to new ways to defend old conclusions. The French science philosopher Pierre Gassendi (1592–1655) helped revive the ancient atomic theory of matter, and he used it in his *Syntagma philosophicum* (1658) to discuss spontaneous generation of plants and animals; Adelmann (1966, II, 776–777, 798–816) discusses Gassendi's ideas on this and reprints the Latin text with English translation. He interprets Gassendi's discussion as saying that plants and animals can arise either from live procreation or from atomic seeds (semina) in the earth. Farley (1977:12), to the contrary, thought that Gassendi was refuting the concept of spontaneous generation; I think Adelmann got it right.

The real importance of Kircher's biological work was that it provoked Francesco Redi (1626–1698) to refute his uncritical conclusions. Although both men attended Jesuit schools before going to college, there were significant differences in their backgrounds. Kircher's father was a prominent theologian, Redi's a prominent physician, and in college Kircher's science courses were in physical sciences, Redi's in biology and medicine (Belloni 1975). Redi studied William Harvey's two books on circulation of blood and embryology and absorbed Harvey's clear experimental methods. Redi matched, or exceeded, Harvey's habit of carrying out many experiments and on a wide variety of animals. I know of no other physicians or naturalists during the 1600s who conducted as many biological experiments as they did. Gasking has a good discussion of Harvey's achievements (1970, 3–24), but her account of Redi's work (1970:39–40) is inadequate. Malpighi, Leeuwenhoek, and Swammerdam were equally diligent in their investigations, but probably conducted fewer experiments. Harvey was the pioneer experimenter, and Redi invented the controlled experiment. Redi was a founding member of the Accademia del Cimento (1657–1667) in Florence, inspired by Galileo, who had tutored its patrons, Grand Duke Fernando and his brother, Leopoldo. "Cimento" means experiment, and this academy was the first to explicitly focus on experimentation (Middleton 1971:34, 50–52). As court physician and supervisor of the court pharmacy and foundry, Redi had strong backing for all his researches, including access to animals that died in the court's zoo or were killed on royal hunts (Findlen 1993). Redi did not set out to refute Kircher's claims; rather, he intended to verify them, to produce flies from rotting meat. Once he realized he had to refute rather than verify Kircher's claims, he wanted to find a way to do so that others would find conclusive.

Fig. 2. Francesco Redi.

At first, Redi was content merely to expose a wide variety of dead animals to the air and watch the maggots that developed on them until they turned into pupae, then into adult flies. He kept track of how long the pupa stage lasted, what color it was, and what sort of fly emerged from it, but when he published *Esperienze intorno alla generazione degl' insetti* in 1668, he named none of the flies nor tried to determine if they already had names. He disputed the claims of both Julius Caesar Scaliger, who believed that all flies give birth to maggots, and Honoré Fabri, who believed that flies only lay eggs. Redi speculated (in Bigelow's translation [1909:37]):

> *It is possible (I neither affirm nor deny it) that flies sometimes drop eggs and at other times live worms, but perhaps they would habitually drop eggs if it were not for the heat of the season that matures the egg and hatches it in the body of the fly, which as a consequence brings forth live and active worms.*

Some flies are ovoviviparous, but without knowing the species being observed we cannot know whether he sometimes failed to find eggs laid and only saw maggots after they hatched. Despite his lack of interest in the names of flies, his *Experiments on the Generation of Insects* (Italian 1668, English 1909) is well illustrated, though only two of them are of flies; most of the rest are of parasites, not scavengers. He gladly acknowledged that the Grand Duke's generosity enabled him to obtain Signor F. Pizzichi's services to draw the illustrations (Redi 1909:95). But identifying insects was not Redi's primary concern. He wanted to disprove spontaneous generation, and to do so he devised what we call a controlled experiment (Redi 1909:34):

> *One day a large number of worms, which had bred in some buffalo-meat, were killed by my order; having placed part in a closed dish, and part in an open one, nothing appeared in the first dish, but in the second worms had hatched, which changing as usual into egg-shape balls* [pupae], *finally became flies of the common kind.*

Then it occurred to him that skeptics might complain that the closed dish inhibited spontaneous generation, so he devised another experiment in which meat in a vase was covered with "a fine Naples veil," and the vase was placed in "a frame covered with the same net" which exposed the meat to the air without exposing it to flies. He found no worms in the meat, "though many were to be seen moving about on the net-covered frame" (Redi 1909:36–37). A further argument against spontaneous generation of flies was the fact that females have ovaries, which in the case of green flies, contain as many as 200 eggs. His conclusion was that dead animals do not produce worms.

Regrettably, Redi did not quit while he was ahead, but went on to argue a contrary hypothesis for the origin of insect parasites inside fruits. He acknowledged that "Gassendi thinks that worms breed in the pulp of fruits owing to the insemination of the flowers by flies, bees, mosquitoes, etc., their seeds [fertilized eggs] afterwards developing with the fruit, becomes worms" (Redi 1909:91). Yet Redi favored two other ways: either the worm gnaws its way into the fruit or else the "same soul or principle which creates the flowers and fruits … is the same that produces the worms of these plants" (Redi 1909:92). He was alert to the distinction between insects found embedded in fruit and insects that bore into fruit from the outside. He ridiculed Pietro Andrea Mattiuoli for claiming that oak-galls produce spiders, worms, and flies. Redi claimed to have opened more than 20,000 galls in 3 or 4 years and never found any spider inside one unless there was an opening into which it crept to hide (Redi 1909:70–71). If Redi's claim was accurate, he may have held the record for the most galls opened until Alfred C. Kinsey, who claimed to have opened a million, in the years 1917–1936 (Jones 1997:209). Redi also disputed Kircher's assertion in *Mundus subterranus* that "the mulberry tree produces the silkworm, on being impregnated with the seed of any chance animal, which penetrates the substance and the juices of the tree," since he had repeatedly attempted to verify this and had failed (Redi 1909:109–113). In 1693, after others had undermined his hypothesis of plant souls creating gall insects, Redi admitted that his pen (or imagination) had run out of control (Gottdenker 1979:579).

Redi's *Esperienze* continued with a fairly brief discussion of two endoparasites in mammals, the liver worm of sheep and a head worm in deer, both of which had been discussed by earlier authors. He gave the earliest illustrations of both, and he disputed Aristotle's claim (*History of Animals*:506a 27–30) that deer worms are found in all deer and never more than 20 per deer. Redi found them in 9 of 10 deer that he dissected, and the number per deer ranged from 20 to 39

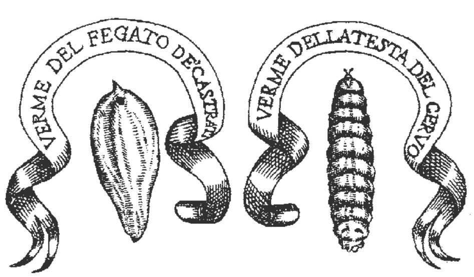

Fig. 3. Sheep liver worm (*Fasciola hepatica*) and deer head worm (*Cephenomyia rufibarbis*). Redi 1668:190; 1909:116

(1909:116–118). The book ends with illustrations and brief descriptions of a wide variety of ectoparasites from an equally wide variety of animals. He rejected Aristotle's belief that the eggs of fleas never produce any offspring (*History of Animals*:539b:12–13), and Redi concluded that "every kind of ant has its special variety" of parasite (Redi 1909:119–121, Bodenheimer 1931). This claim could only be substantiated if he could identify different species of ants and their parasites, but he failed to name any of them. Most likely, a number of these ectoparasites were illustrated here for the first time, but his casual description of the plates makes it rather difficult to distinguish a few of them. (Bodenheimer [1928–1929:II:355–356] and Guiart [1898:439] offer some identifications.) Here is an example of his casual descriptions (Redi 1909: 123): "lice found on the bustard, resembles greatly the long-bodied ones of the falcon, plate I."

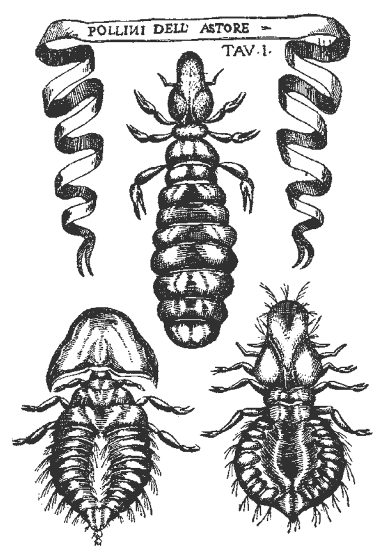

Fig. 4. Lice in Redi's plate I (1909:127).

Redi returned to the problem of endoparasites in his *Osservazioni intorno agli animal viventi che si trovano negli animali viventi* (1684) and gave descriptions adequate enough for Guiart (1898:434–439) to assign modern scientific names to about 75 of them, found in almost as many host species. Hydatid cysts and other bladderworms had been described since antiquity, but Redi first recognized them as parasites rather than as abnormal growths. He studied them in the mesentery and in the peritoneal cavity of a hare and saw some of them move (probably *Cysticercus pisiformis* [Grove 1990:320–321, Kean et al. 1978: 563]). He saw similar cysts in a martin. He raised the question of whether they might be worm eggs, and he boiled some of the liquid from the cysts to see if it coagulated like the white of a vertebrate egg, and since it did not, he doubted they were eggs. Redi's publications were often reprinted (Prandi 1941) and inspired others to undertake similar investigations, and also inspired Kircher's reply of criticisms in his book on Noah's Ark (1675; see Beier 1973:89). There are 39 volumes of Redi's manuscripts preserved in Florence, and Bacchi (1982) has published some of his notes on experiments, mostly from the 1680s.

Giacinto Cestoni (1637–1718) was a pharmacist in Leghorn, Italy, who came to know Redi because Duke Fernando summered in Leghorn and Redi accompanied him. In 1680 Cestoni and Redi began to correspond, and after Redi died, Cestoni corresponded with Antonio Vallisnieri (Belloni 1971). Cestoni's special interest was insect reproduction, and through his skill with a microscope he eventually discovered the viviparity and parthenogenesis of aphids. He collaborated with a physician from Leghorn who was a disciple of Redi, Giovan Cosimo Bonomo (1666–1696), who served as a physician to Fernando's successor son, Cosimo III (Faucci 1931, Belloni 1970). Cestoni and Bonomo described the life history of the itch mite, *Sarcoptes scabiei*. Bonomo sent his manuscript to Redi for comments and he rewrote it before publishing it under Bonomo's name (Bonomo 1937*a*). Remarkably, Bonomo's original manuscript has survived and is translated into English (Bonomo 1937*b*). We have already seen that Thomas Mouffet described the itch mite in 1634 and 1658 (Egerton 2004:29), but although Mouffet's account was adequate, it was inadequately publicized. When Bonomo's work was belatedly summarized in the *Philosophical Transactions of the Royal Society* (Bonomo 1703), no one protested that an Englishman had already published this discovery. Bonomo's account was more detailed (16 pages) than Mouffet's, and it was a separate publication, not buried in a reference encyclopedia on insects. Bonomo and Cestoni uncovered details about the mite's life history, means of infection, and effective vs. ineffective treatments. However, Bonomo made two errors of observation, one minor and one major. His minor error was reporting that the mite has six legs instead of eight (it does have six in the larval stage only), and his major error was reporting that the mite is almost always found within the "Watery Pustules," whereas it is never found in them (as Mouffet knew). Friedman (1937:19–20) thinks that the reason Bonomo's discovery was not accepted by the medical world, despite its prominent publication and translation into Latin and German and its summary in English, was because when others examined the pustules they did not find the mite. After Bonomo's death at age 30 and Redi's death at about age 71, Cestoni described the life history of the flea (Cestoni 1699). Robert Hooke had published a more spectacular illustration of an adult flea than Cestoni's, in *Micrographia* (1665), but Cestoni published six illustrations of the life cycle and discussed the means of transmission to new hosts. Cestoni also wrote to Vallisnieri in 1710 that he, not Bonomo, had discovered that scabies was caused by a mite (Cestoni 1940–1941:586–587). Actually, peasant women pointed out the cause to Bonomo, and Cestoni learned about it from a dictionary compiled by the Accademia della Crusca, of whom Redi was the most prominent member (Bonomo 1937*b*:159–160).

The second half of the 1600s was a golden age of microscopy (Petit and Théodoridès 1962:Chapter 13, Beier 1973:89–91), initiated primarily by Hook in 1665, and picked up by Malpighi, Swammerdam, and Leeuwenhoek, though Malpighi had already used a microscope to discover capillaries in a frog's lungs in 1661. Marcello Malpighi (1628–1694) was a remarkable scientist–physician who mainly studied anatomy and physiology of vertebrates (Adelmann 1966, Belloni 1974, Malpighi 1975, Bertoloni Meli 2000) but the Royal Society of London persuaded him to write a monograph on silkworms (1669), which is discussed, with some of his illustrations, by Bodenheimer (1928–1929, I:329–333; see also Adelmann 1966, index in V, 2452). Malpighi discussed and illustrated the silkworm's reproductive system, which helped undermine the notion that insects reproduce by spontaneous generation. (If they do, why do they have reproductive organs? [Garden 1691, Farley 1977:10–11]). He wrote on plant galls in the second part of his *Anatome Plantarum* (1679). He believed the galls were stimulated by the insects that laid eggs on the plant where the gall developed. He discussed galls on a variety of plants, with a comparable variety of insect parasites (Bodenheimer 1928–1929, I:334–337; Adelmann 1966, index in V, 2390; Bertoloni Meli 1997:280). In 1691 Filippo Buonanni attacked him for his claim that insects cause plant galls, and Malpighi replied in detail in his *Opera postuma* (1697, I:77–80, cited from Adelmann 1966: I:393).

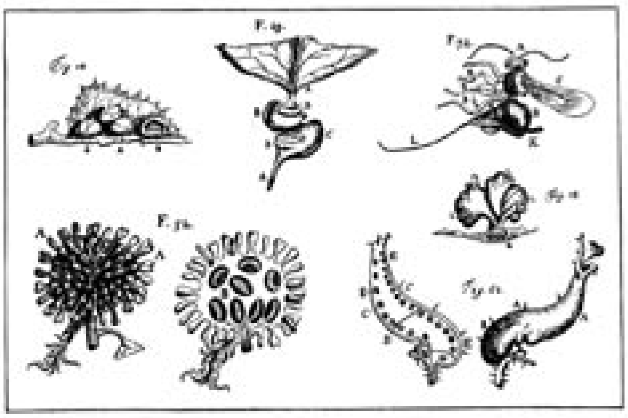

Fig. 5. Plant galls, some in cross section showing insect larvae inside (Malpighi 1679). (From Bodenheimer 1928–1929, who gives the illustrated gall insect identifications at I:334 and a longer list at II:357–359.)

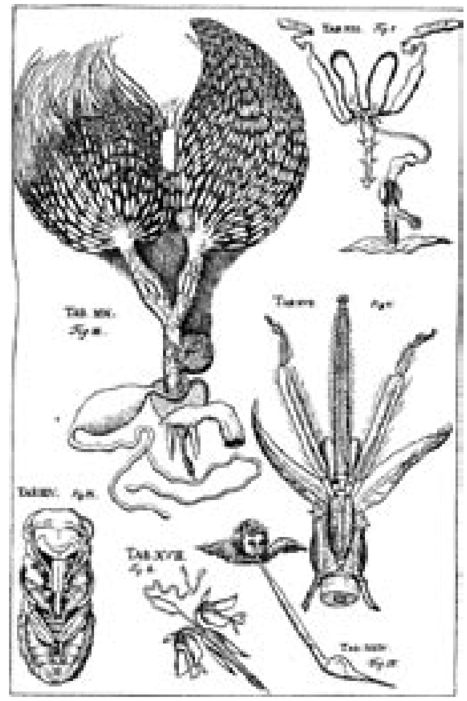

Fig. 6. Illustrations of the honey bee from *Biblia Naturae*, showing both male and female reproductive systems and Swammerdam's technique of blowing dyed liquids into tracheae to aid dissection (from Bodenheimer 1928–1929).

Jan Swammerdam (1637–1680) was the son of a wealthy Amsterdam apothecary who had a private collection of "rarities" from the East and West Indies. Swammerdam followed in his father's footsteps by making his own collection of insects, and he took his collection to the University of Leiden in 1661, where it impressed fellow medical students and faculty (Schierbeek 1967, Lindeboom 1975, 1982, Winsor 1976, Fournier 1990). Although he received his MD in 1667, he practiced biology, not medicine, though his anatomical and physiological studies on mammals had medical implications. Swammerdam was first to systematically study the morphological changes in insect life cycles, and he classified different species according to their life cycle patterns. He made his own instruments for his dissections and drew finer anatomical details in his illustrations than anyone else. In his history of comparative anatomy, Cole (1944:270) calls Swammerdam "perhaps the greatest comparative anatomist of the seventeenth century." He published some of his insect studies, beginning with *Historia insectorum generalis, ofte, algemeene verhandeling von bloedloose dierkens* (*General account of bloodless animalculae,* 1669, summarized by Schierbeek 1967: 143–149), which described development of different kinds of insects, argued that the pupa was not an egg but another stage of development, that plant galls result from eggs laid by insects, and that parasitic "worms" found in caterpillars were offspring of other insects. When he died of malaria 5days after his 43rd birthday, he left many manuscripts, which Hermann Booerhave finally published in Dutch and Latin on facing pages, entitled *Bybel der Natuure, Biblia naturae, sive historia insectorum* (three volumes, 1737–1738). Cole (1944:272) calls it "one of the outstanding classics of the literature of zoology." A German translation appeared in 1752 and English and French translations in 1758. Miall (1969:174–199) provides a good overview of Swammerdam's achievements;

Locy (1925:244–248) quotes Booerhave's account of Swammerdam's techniques; and Bodenheimer (1928–1929, I:343–366; II:361–362) reprints part of Swammerdam's text in German translation. However, the portrait both Locy and Bodenheimer publish as Swammerdam is misidentified (Parker 1937). Both Swammerdam and his readers were fascinated by the life history of the mayfly—which he described in 1675 (Swammerdam 1681)—since the adult lives for only one day, during which it breeds. In 1778, Benjamin Franklin wrote a brief essay, "The Ephemera," after he had been shown in France "numberless skeletons of a kind of little fly, called an ephemera, whose successive generations, we were told were bred and expired within the day," and he also saw adults which he said seemed to be "engaged in conversation" (cited from Franklin 1987:922–924). Not only is Franklin's essay still being reprinted, so is Swammerdam's account (Rook 1964:127–137).

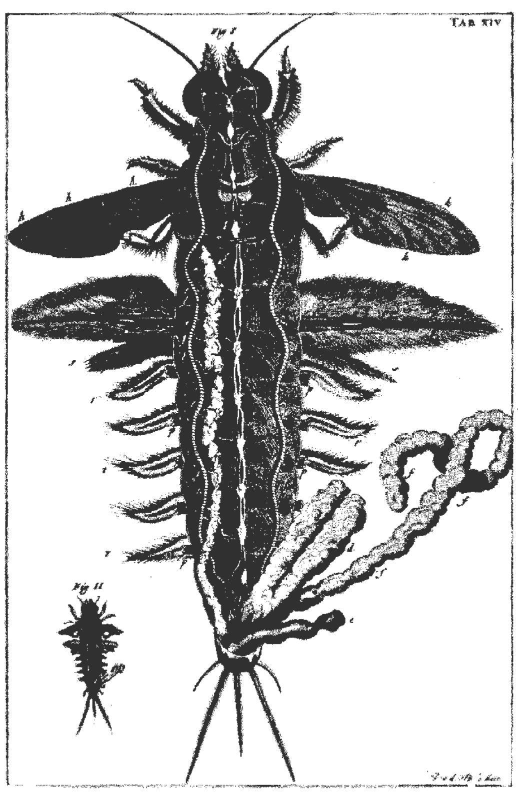

Fig. 7. Dissection of male nymph mayfly (Swammerdam also published a drawing of a dissected female nymph, reproduced in Cole 1944:283). From Swammerdam 1757.

A younger contemporary of these microscopists was English physician Edward Tyson (1651–1708). He was from the upper middle class and studied anatomy, natural history, and botany at Oxford University, 1667–1677, where he earned three degrees, before obtaining his MD degree from Cambridge University in 1680 (Williams 1976, Guerrini 2004). He settled in London and became a prominent member of the Royal Society. Most of Tyson's anatomical investigations were on vertebrates, but he also wrote three articles for the Royal Society on worms parasitic in mammals. Tyson had learned from Vesalius' book that anatomical studies require good illustrations as well as verbal descriptions. His study (1683*b*) of roundworms (*Ascaris lumbricoides*), which he called *Lumbricus teres*, contained the first illustration of dissected internal parasites, showing male, female, and eggs—no fewer than 1000 of the latter being his estimate. (Almost all of this article is reprinted by Kean et al. (1978:346–349), though the Latin quotations are rendered in English and footnote citations are omitted.) He believed they reproduced sexually within the intestine, but he had no idea how they got there. Redi described and illustrated this worm in the following year, but Cole (1944:212) judged Redi's "does not compare favourably with that of his predecessor."

Tyson had more trouble understanding tapeworms (1683*a*). His illustrations were good, but limited to external morphology. He did identify, describe, and illustrate the head of a tapeworm from a dog (now called *Taenia pisiformis*), which was about 5 feet long. This discovery helped him to reject the common belief that it was not a single worm but many linked together. He also described and illustrated a tapeworm from a young man about 20 years old that was 24 feet long and had 507 segments. However, Tyson thought the genital pores were mouths and he failed to study the internal anatomy of the proglottids. Since he knew of no free-living worms resembling them, and since he failed to find reproductive organs, he could not understand how they arose. In 1687 Tyson spoke at a meeting of the Royal Society on "Hydatides in animalls are a sort of living creatures." He described these cysticerci (as they are now called) as "bladders about the size of a pigeon's egg that he had found in

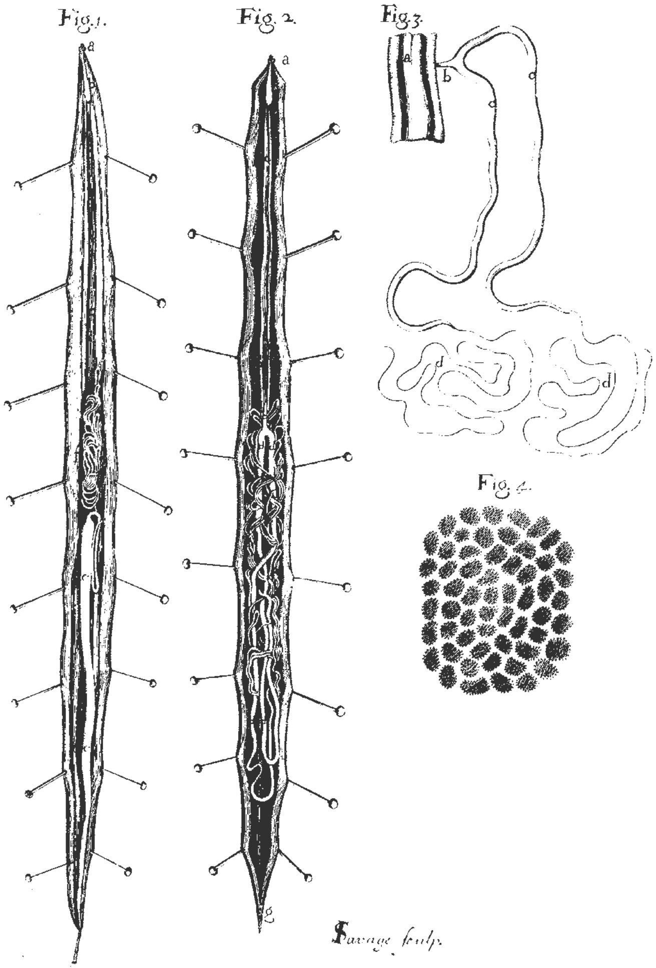

Fig. 8. (1) Male worm opened: (a) three lips, (b) esophagus, or gullet, (ccc) large intestine, (d) penis, (ee) vesicula seminalis, (f) testis; (2) female worm opened: (a) mouth, (b) gullet, (ccc) intestine, (dddd) vagina uteri, (e) the two cornua uteri, (fff) spermatick vessels, (g) anus; (3) genital parts of female: (a) pudendum or foramen as it appears outside the skin, (b) vagina uteri, (cc) the two cornua uteri, (dd) spermatick vessels; (4) eggs as viewed by the microscope (Tyson 1683*b*).

the peritoneal cavity of a gazelle brought back from Aleppos" [now Halab, Syria] (Grove 1990:321). His talk was recorded in the unpublished *Journal Book of the Royal Society* and was finally published in the *Philosophical Transactions* in 1691. He guessed that these cysts (now called *Cysticercus tenuicollis*) were embryos of worms, and they resembled cysts he had found in human patients. He did not, however, discover that these cysts are a stage in the life cycle of a tapeworm. A German physician, Philipp Jacob Hartmann (1648–1707), independently found similar cysts in a goat in 1685 and identified it as a worm, and 3 years later he found the same kind of cysts in a pig (Grove 1990:321, 362–363, 800; Kean et al. 1978:619–620, 627), and in 1694 similar ones in a dog and a mouse (Hoeppli 1959:477).

During the 1600s, naturalists and physicians conducted more detailed studies on invertebrates than had ever been made before, and many of these studies were on parasites. Many such studies described the internal organs, including sex organs, and such studies cast doubt on the spontaneous generation of invertebrate animals. Those studies were supported by Redi's invention of the controlled experiment, which he used to show that scavenger flies do not arise spontaneously. And although Redi was confused about the origin of gall insects, Malpighi and Swammerdam showed that they also arose from sexual reproduction. There was good progress made in understanding the life cycles of insects. Lindeboom (1975:14) argues that modern entomology began with the appearance of three books in 2 years: Redi's on generation of insects (1668), Malpighi's on silkworms (1668), and Swammerdam's on the anatomy and physiology of insects and other arthropods (1669). There was some progress in understanding the anatomy of some internal parasites, but their ultimate origin remained a mystery. By the later 1600s, investigations had become numerous enough that nearly simultaneous independent discoveries were being made (Sticker 1926).

John Ray (1623–1705) was among the greatest naturalists of his time, and he made important contributions to entomology and parasitology that will be discussed in Part 18 of this history. Antoni van Leeuwenhoek (1632–1723), a Dutchman who knew Swammerdam, conducted and published microscopic studies on a wide range of plants and animals for a half-century; he will be the subject of Part 19. Since Govard Bidloo's work on liver flukes is associated with Leeuwenhoek, it also will be included in Part 19.

The prominent French professor of medicine Nicholas Andry (1658–1742) published the first edition of his *De la generation des vers dans le corps de l'homme* in 1700, which was a climax of parasitology in the 1600s and the starting point for parasitology in the 1700s. Andry's book will be discussed in a future part of this history.

Literature Cited

Abreu, A. de. 1623. Tratado de las siete enfermedades, de la inflammacion universal del higado, zirbo, pyloron, y riñones, y de la obstrucion, de la satiriasi, de la terciana y febre maligna, y passion hipocondrica. Pedro Craesbeeck, Lisbon, Portugal. Cited from Guerra 1968.

Adelmann, H. B. 1966. Marcello Malpighi and the evolution of embryology. Five volumes. Cornell University Press, Ithaca, New York, USA.

Bacchi, W. 1982. Su alcune note sperimentali inedite di Francesco Redi. Annali dell'Instituto e Museo di Storia della Scienza di Firenze **7**:35–56.

Beier, M. 1973. The early naturalists and anatomists during the Renaissance and seventeenth century. Pages 81–94 *in* R. F. Smith, T. E. Mittler, and C. N. Smith, editors. History of entomology. Annual Reviews, Palo Alto, California, USA.

Belloni, L. 1970. Giovan Cosimo Bonomo (1666–1696). Dictionary of Scientific Biography **2**:291.

Belloni, L. 1971. Giacinto Cestoni (1637–1718). Dictionary of Scientific Biography **3**:180–181.

Belloni, L. 1974. Marcello Malpighi (1628–1694). Dictionary of Scientific Biography **9**:62–66.

Belloni, L. 1975. Francesco Redi (1626–1697/1698). Dictionary of Scientific Biography **11**:341–343.

Bertoloni Meli, D., editor. 1997. Marcello Malpighi: anatomist and physician. Olsckhi, Florence, Italy.

Bertoloni Meli, D. 2000. Marcello Malpighi (1628–1694). Pages 388–390 *in* Encyclopedia of the scientific revolution from Copernicus to Newton. W. Applebaum, editor. Garland, New York, New York, USA.

Bodenheimer, F. S. 1928–1929. Materialien zur geschichte der entomologie bis Linné. W. Junk, Berlin, Germany.

Bodenheimer, F. S. 1931. Zur Frühgeschichte der Erforschung der Insektenparasitismus. Archiv für die Geschichte der Mathematik und Natur Wissenschaften und der Technik **13**:402–416.

Bonomo, G. C. 1703. An abstract of part of a letter from Dr Bonomo to Signior Redi, containing some Observations concerning the worms of humane bodies. By Richard Mead. Royal Society of London Philosophical Transactions **23**:1296–1299 + 4 figures facing 1291.

Bonomo, G. C. 1937*a*. Osservazioni intorno a'pellicelli del corpo umano. Facsimile of the 1687 edition printed by P. Matini, Florence, Italy. Medical Life **44**:43–60.

Bonomo, G. C. 1937*b*. A translation of Bonomo's manuscript letter to Redi. Translated by R. Friedman. Medical Life **44**:156–164.

Cestoni, G. 1699. A new discovery of the origin of fleas, made by Signior D'iacento Cestoni of Leghorn. Royal Society of London Philosophical Transactions **21**:42–43 + plate facing 41.

Cestoni, G. 1940–1941. Epistolario ad Antonio Vallisnieri. Edited by S. Baglioni. Reale Accademia D'Italia, Rome, Italy.

Cole, F. J. 1944. A history of comparative anatomy. Macmillan, London, UK.

Egerton, F. N. 2004. A history of the ecological sciences, part 12: invertebrate zoology and parasitology in the 1500s. ESA Bulletin **85**:27–31.

Farley, J. 1977. The spontaneous generation controversy from Descartes to Oparin. Johns Hopkins University Press, Baltimore, Maryland, USA.

Faucci, U. 1931. Contributo alla storia della scabbia. Rivista di Storia delle Science mediche e Naturali **22**:153–170, 198–215, 257–371, 441–475.

Findlen, P. 1993. Controlling the experiment: rhetoric, court patronage and the experimental method of Francesco Redi. History of Science **31**:35–64.

Findlen, P. 2000. Athanasius Kircher (1602–1680). Pages 349–350 *in* Encyclopedia of the scientific revolution from Copernicus to Newton. Garland, New York, New York, USA.

Fournier, M. 1990. The book of nature: Jan Swammerdam's microscopical investigations. Tractrix **2**: 1–24.

Franklin, B. 1987. Writings. Edited by J. A. L. Lemay. The Library of America, New York, New York, USA.

Friedman, R. 1937. Giovan Cosimo Bonomo: the 250th anniversary of his discovery of the parasitic nature of scabieis. Medical Life **44**:3–42.

Garden, G. 1691. A discourse concerning the modern theory of generation. Royal Society of London Philosophical Society **16**:474–483.

Gasking, E. 1970. The rise of experimental biology. Random House, New York, New York, USA.

Godwin, J. 1979. Athanasius Kircher: a renaissance man and the quest for lost knowledge. Thames and Hudson, London, UK.

Gottdenker, P. 1979. Francesco Redi and the fly experiments. Bulletin of the History of Medicine **53**: 575–592.

Grove, D. I. 1990. A history of human helminthology. C. A. B International, Wallingford, UK.

Guerra, F. 1968. Aleixo de Abreu [1568–1630], author of the earliest book on tropical medicine describing amoebiasis, malaria, typhoid fever, scurvy, yellow fever, dracontiasis, trichuriasis and tungiasis in 1623. Journal of Tropical Medicine and Hygiene **71**:55–69.

Guerra, F. 1970. Aleixo de Abreu (1568–1630). Dictionary of Scientific Biography **1**:25–26.

Guerrini, A. 2004. Edward Tyson (1651–1708). Oxford Dictionary of National Biography, Oxford, UK.

Guiart, J. 1898. Francesco Redi, 1626–1697. Archives de Parasitologie **1**:420–441.

Hoeppli, R. 1959. Parasites and parasitic infections in early medicine and science. University of Malaya Press, Singapore.

Hooke, R. 1961. Micrographia: or some physiological descriptions of minute bodies made by magnifying glasses, with observations and inquiries thereupon. Reprinted from the 1665 edition published by Jo. Martyn and Ja. Allestry for the Royal Society, London, UK. Dover, New York, New York, USA.

Jones, J. H. 1997. Alfred C. Kinsey: a public/private life. W. W. Norton, New York, New York, USA.

Kangro, H. 1973. Athanasius Kircher (1602–1680). Dictionary of Scientific Biography **7**:374–378.

Kean, B. H., K. E. Mott, and A. J. Russell. 1978. Tropical medicine and parasitology: classic investigations. Two volumes. Cornell University Press, Ithaca, New York, USA.

Kircher, A. 1646. Ars magna lucis et umbrae. Rome, Italy. Cited from Torrey 1938.

Kircher, A. 1658. Scrutinium physico-medicum contagiosae luis, quae dicitur pestis, quo origo, caussae, signa, prognostica pestis nec non insolentes malignantis naturae effectus… Mascardi, Rome, Italy.

Kircher, A. 1668. Mundus subterraneus. Amsterdam, The Netherlands. Cited from Gottdenker 1979. Bulletin of the History of Medicine **53**:575–592.

Lindeboom, G. A. 1975. A short biography of Jan Swammerdam (1637–1680). Pages 3–34 *in* The letters of Jan Swammerdam to Melchisedec Thévenot, with English translation. Swets and Zeitlinger, Amsterdam, The Netherlands.

Locy, W. A. 1925. The story of biology. Garden City Publishing, Garden City, New York, USA.

Major, R. H. 1939. Athanasius Kircher. Annals of Medical History Series 3, **1**:105–120.

Malpighi, M. 1675–1679. Anatome plantarum, cui subjungitur appendix. Two volumes. J. Martyn, London, UK.

Malpighi, M. 1975. The correspondence. Edited by H. B. Adelmann. Five volumes. Cornell University Press, Ithaca, New York, USA.

Miall, L. C. 1969. The early naturalists: their lives and work (1530–1789). Reprinted from the 1912 edition, Macmillan, London, UK. Hafner, New York, New York, USA.

Middleton, W. E. K. 1971. The experimenters: a study of the Accademia del Cimento. Johns Hopkins Press, Baltimore, Maryland, USA.

Parker, G. H. 1937. A spurious portrait of Swammerdam. Quarterly Review of Biology **12**:206–209.

Petit, G., and J. Théodoridès. 1962. Histoire de la zoologie. Hermann, Paris, France.

Platter, F. 1602–1603. Praxeos seu de cognoscendis praedicendis praecavendis, curandissque affectibus homini incommodantibus tractatus tertius et ultimus. Two volumes. Conradi Waldkirchü, Basel, Switzerland.

Platter, F. 1662. A golden practice of physick. Translated by A. Cole and N. Culpepper. P. Cole, London, UK.

Platter, F. 1961. Beloved son Felix: the journal of Felix Platter, a medical student in Montpellier in the sixteenth century. Translated and introduced by

Seán Jennett. Frederick Muller, London, UK.
Platter, F. Tagebuch (lebensbeschreibung) 1536–1567. Edited by Valentin Lötscher. Schwabe, Basel, Switzerland.
Prandi, D. 1941. Bibliografia delle opere di Francesco Redi. Libreria Nironi et Prandi, Reggio-Emilia, Italy.
Redi, F. 1668. Esperienze intorno alla generazione degl' insetti. Piero Matini, Florence, Italy.
Redi, F. 1684. Osservazioni intorno agli animali viventi che si trovanto negli animali viventi. Piero Matini, Florence, Italy.
Redi, F. 1909. Experiments on the generation of insects. Translated by M. Bigelow. Open Court Publishing, Chicago, Illinois, USA.
Reilly, C. 1974. Athanasius Kircher, S. J., master of a hundred arts. Edizioni del Mondo, Rome, Italy.
Rook, A., editor. 1964. The origins and growth of biology. Penguin Books, Baltimore, Maryland, USA.
Schierbeek, A. 1967. Jan Swammerdam (12 February 1637–17 February 1680): his life and works. Swets and Zeitlinger, Amsterdam, The Netherlands.
Sticker, G. 1926. Zur Parasitologie um das Jahr 1700. Sudhoff's Archiv für die Geschichte der Medizin **18**:72–92.
Swammerdam, J. 1669. Historia insectorum generalis, ofte, algemeene verhandeling van de bloedeloose Dierkens. Van Dreunen, Utrecht, The Netherlands.
Swammerdam, J. 1681. Ephemeri vita, or the natural history of the ephemeron. English translation by Edward Tyson of Swammerdam's 1675 Amsterdam edition: Ephemeri vita afbeeldingh van's menschen leven… London, UK.
Swammerdam, J. 1737–1738. Bybel der natuure, Biblia naturae, sive historia insectorum. Two volumes. Edited by H. Boerhaave. In Dutch with Latin translation by H.D. Gaubius. I. Severinus, Leiden, The Netherlands.
Swammerdam, J. 1978. The book of nature. Translated by T. Flloyd. Reprint of the 1758 London edition. Arno Press, New York, New York, USA.
Théodoridès, J. 1966. Les grandes etapes de la parasitologie (suite et fin). Clio Medica **1**:185–208.
Torrey, H. B. 1938. Athanasius Kircher and the progress of medicine. Osiris **5**:246–275.
Tyson, E. 1683*a*. *Lumbricus latus*, or a discourse read before the Royal Society of the joynted worm, wherein a great many mistakes of former writers concerning it, are remarked; its natural history from more exact observations is attempted; and the whole urged, as a difficulty against the doctrine of univocal generation. Royal Society of London Philosophical Transactions **13**:113–144 + plate facing 113.
Tyson, E. 1683*b*. *Lumbricus teres*, or some anatomical observations on the round worm bred in human bodies. Royal Society of London Philosophical Transactions **13**:154–161 + plate facing 153.
Tyson, E. 1691. *Lumbricus hydropicus*; or an essay to prove that hydatides often met with in morbid animal bodies, are a species of worms, or imperfect animals. Royal Society of London Philosophical Transactions **16**:506–510 + plate facing 491.
Welsch, G. H. 1674. Exercitationes de vena medinensi, ad mentem ebnsinae sive de dracunculis veterum. Theophili Goebelli, Augsburg, Germany.
Wilkins, L. 1992. Animals and disease: an introduction to the history of comparative medicine. Cambridge University Press, Cambridge, UK.
Williams, W. C. 1976. Edward Tyson (1650/1651–1708). Dictionary of Scientific Biography **13**: 526–528.
Winsor, M. P. 1976. Jan Swammerdam (1637–1680). Dictionary of Scientific Biography **13**:168–175.

Acknowledgments

I thank for their assistance Anne-Marie Drouin-Hans, Université de Bourgogne, Jean-Marc Drouin, Muséum National d'Histoire Naturelle, Paris, and Sidney A. Ewing, College of Veterinary Medicine, Oklahoma State University, Stillwater, Oklahoma.

Frank N. Egerton
Department of History
University of Wisconsin-Parkside
Kenosha WI 53141
E-mail: frank.egerton@uwp.edu