Commentary

A History of the Ecological Sciences, Part 20: Richard Bradley, Entrepreneurial Naturalist

Richard Bradley (1688?–1732) was an Englishman of limited means, who nevertheless devoted his life to botany, horticulture, and natural history. Much of what concerned him we now call ecological subjects. His publications were numerous, often innovative, and popular (Henrey 1975, II:424–454, III:14–18, Edmondson 2002), and they were essential to his livelihood. An example of his innovation is his invention about 1717 of the kaleidoscope, as an aid to formal garden design (Edmondson 2002:187, 204).

Of his early years we only know he had a childhood interest in gardening and that he lived in the vicinity of London (Egerton 2004*a*), a city having many amateur naturalists (Allen 1976:Chapters 1–2). Our earliest evidence of him is a six-page prospectus for a *Treatise of Succulent Plants* (1710, reprinted in Bradley 1964), which he hoped to publish for subscribers; two illustrations included were probably drawn by him. Having no established reputation, he was unable to obtain enough subscribers to publish the book. Yet he clearly made a good first impression, as he attracted several influential patrons. By his time, it would have been very unusual for the Royal Society of London to admit to membership anyone lacking a university education, but there is no evidence he had such an education; nevertheless, Robert Balle proposed him for membership in November 1712, and he was elected a Fellow in December. There is no extant portrait of him; the one Lisney (1960:83) mistakenly published is of a later Richard Bradley.

Bradley's patrons included the affluent apothecary and insatiable collector in all fields of natural history, James Petiver (1663–1718), whom we met in Part 18 (Egerton 2005:309) as John Ray's friend. Petiver had traveled in the Netherlands in 1711 (Allen 2004), and he helped arrange for Bradley to follow his route in 1714, to tour botanical gardens, meet naturalists, and arrange the exchange of biological specimens between collectors in London and Amsterdam. Without Petiver's letter of introduction, it is unlikely that Leeuwenhoek would have seen him when he arrived on 9 May (Egerton 1970*a*:57). Bradley's hope to support himself entirely by exchanging biological specimens between collectors was overly optimistic, and since people who met him assumed he was a physician, he supplemented his income during his 5 months abroad by practicing medicine. He even wrote to Petiver for recipes for medicines for his patients, and Petiver obliged him (Egerton 1970*a*). Bradley also supplemented his income from his Amsterdam trip by drawing insect specimens from Amboina, East Indies, Surinam, and Curaçao, which he saw on display. He sold the drawings after his return to London to another insatiable collector of natural history items, Sir Hans Sloane (1660–1753), whose collections, after his death, became the foundation for the British Museum (MacGregor 1998). Sloane was a royal physician, who became president of the Royal Society after its previous president, Sir Isaac Newton, died in 1727 (De Beer 1975); after Petiver died, Sloane was Bradley's most important patron (Egerton 1970*b*). In 1716 Bradley published two brief articles in the Royal Society's *Philosophical Transactions*. The first was on the anatomy and physiology of an apple tree twig. He did not refer to the publications of the later 1600s on plant anatomy by Marcello Malpighi or Nehemiah Grew. He did clear up a confusion that he said some people had about whether bark is alive, pointing out that outer layers are not and can be removed without killing the tree, but inner layers (= cambium) are alive, containing vessels, and the tree dies if those layers are cut around the tree. He also commented that

"The Seasons of Motion in Plants are the same with those Animals which sleep during the Winter. An Artificial Heat will give Motion to either of these in the Coldest time." (Bradley 1716*a*). His second article (Bradley 1716*b*) described the progression of life on the inner part of a half melon after 4 days: several spots of moldiness appeared and grew every hour for 5 days, when the whole half-melon was covered with green and also a paler-colored vegetation. The green kind appeared to be a fungus with caps filled with ~500 "seeds." The other kind had grass-like leaves and resembled a sort of bullrush that also produced great quantities of "seeds." After 6 days of being covered with mold, the vegetation declined, and disappeared in two more days, leaving stinking water that soon contained small maggots, which grew for 6 days and then laid up in bags for 2 days before becoming flies (Fig. 1). Although Bradley's discussion of mold is briefer and his illustration is less detailed than Robert Hooke's in *Micrographia* (1665:122–131, 1961), Bradley at least found the "seeds" of mold that had eluded Hooke. But here again Bradley failed to cite the book of a predecessor.

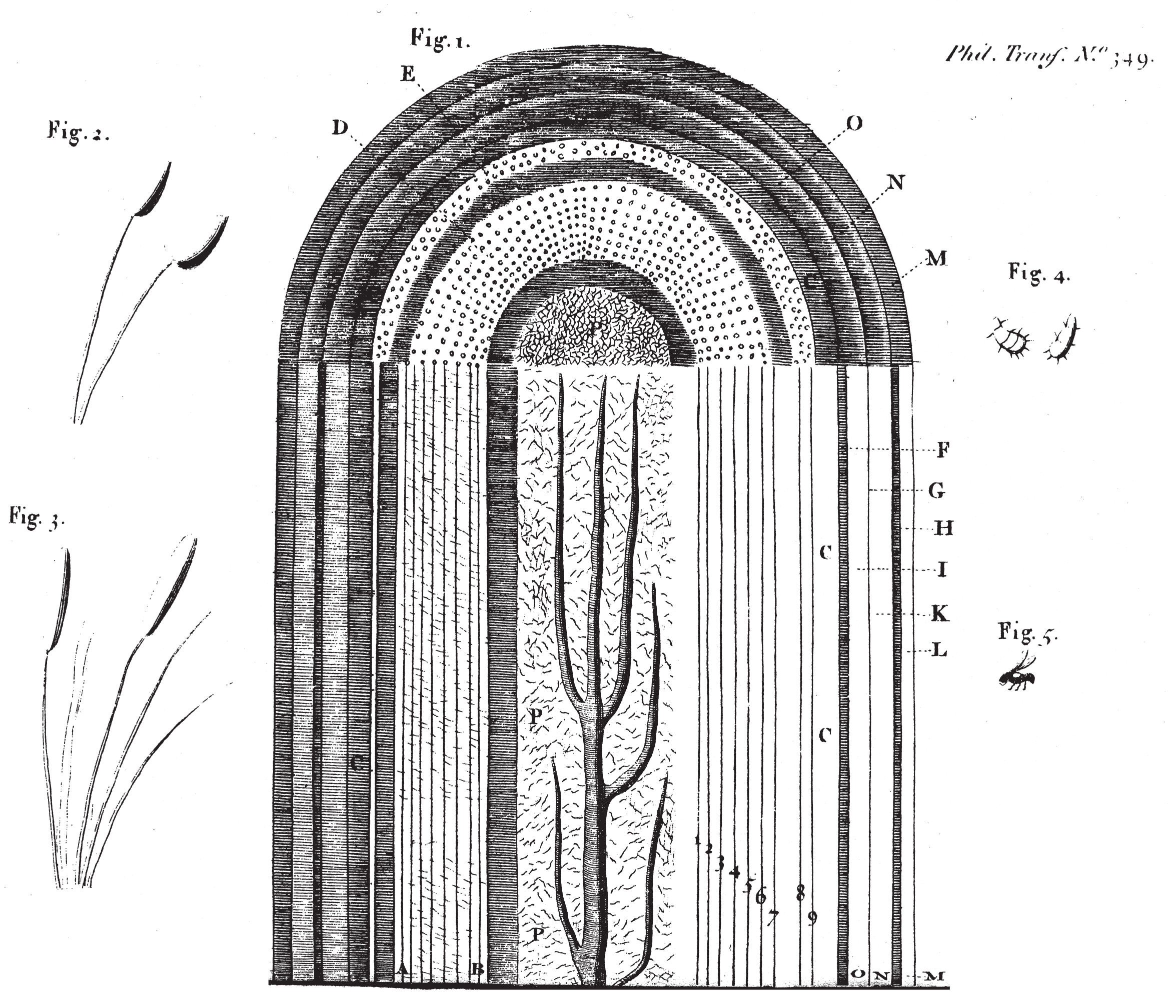

Fig. 1. Illustration for Bradley's 1716 articles: his Fig. 1 is an enlarged section of an apple twig (for 1716*a*); his Fig. 2 is green mold, Fig. 3 is pale bull-rush like vegetation, Fig. 4 shows maggots, and Fig. 5 is a fly (for 1716*b*).

These articles bolstered Bradley's reputation and helped pave the way for publication of his *History of Succulent Plants,* which appeared in five installments or "decades" (1716–1727), with 10 accounts and illustrations in each decade (all reprinted in Bradley 1964). He copied one illustration from Commelin and Commelin's *Horti Medici Amstelodamensis* (1697–1701) but probably drew the rest himself, from live plants (see Fig. 2). This was the first treatise on succulent plants, and the world journal on succulents plants is now named *Bradlea* (Rowley 1983). That publication was Bradley's only contribution to descriptive botany.

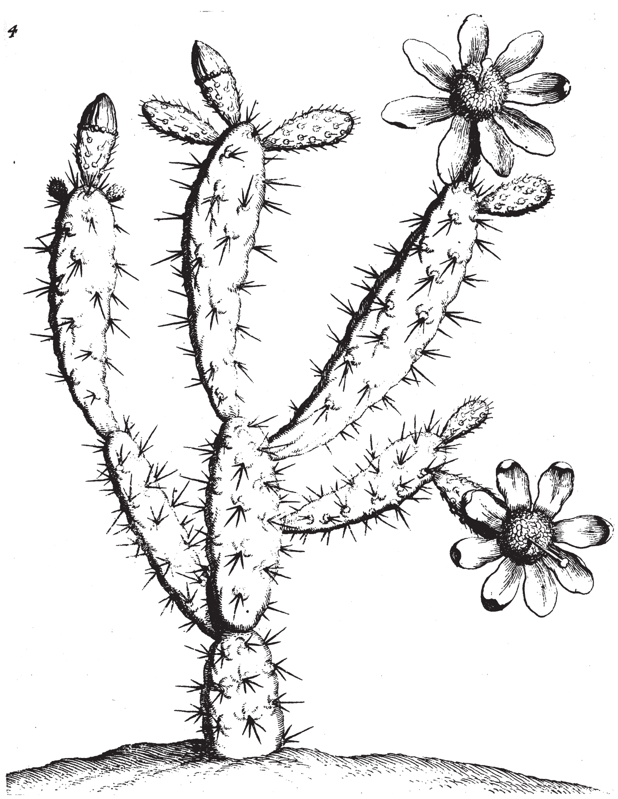

Fig. 2. Pinpillow, or Minion Prickley Pear (*Opuntia curassavica*), Bradley 1716–1727, No. 4, 1964. This was also one of the illustrations in his 1710 prospectus.

He was more interested in the life of plants than their descriptions. For example, he was interested in the sexuality of plants, which Nehemiah Grew, when discussing flowers, had suggested in *The Anatomy of Plants* (Grew 1682:171, Roberts 1929:62–64). In 1694, Professor Rudolph Jakob Camerer at the University of Tübingen conducted experiments to demonstrate this, and reported it in *De Sexu Plantarum Epistola* (Roberts 1929:12–15). Bradley learned of this discovery from Robert Balle, who had sponsored his admission into the Royal Society. Bradley conducted experiments on tulips to confirm it, and in the first edition of *New Improvements of Planting and Gardening* (Bradley 1719–1720:22–23, Zirkle 1935:115) he reported the accidental hybridization of yellow and black auriculas in a garden. In 1719 he reported the first intentional hybridization, done by Thomas Fairchild, who crossed a carnation (*Dianthus caryophyllus*) and a sweet william (*Dianthus barbatus*) (Bradley 1719–1720, Roberts 1939:62–65). Bradley also speculated that if two "vermicules" (sperm) entered a plant ovum, "we shall find two foetus under the same covering, or else a monstrous double foetus joined together." (Bradley 1721:106). Ritterbush (1964:97) commented that this conjecture "indicated a rare insight into questions of generation and a promise which Bradley fulfilled by the virtuosity of his speculations on plant generation."

The fact that Bradley's *History of Succulent Plants* came out in separate "decades" during several years may have given him the idea of establishing the first British horticultural periodical (Roberts 1939), *A General Treatise of Husbandry and Gardening* (Fifteen issues, 1721–1723 and collected into three volumes, 1721–1724). In the second issue, he published a report from a Dr. Bury of Compton, who asserted that moors or heaths could be improved by first burning the land and then adding salt and lime (Bradley 1721–1724, I:100–101). The item following Bury's report was an abstract from the Royal Society's *Philosophical Transactions* of experiments conducted by de la Prime, which found that seeds soaked in various kinds of salts did not usually germinate as quickly or as consistently as seeds that had not been soaked. Bradley apparently felt more confident about de la Prime's conclusions than about Bury's, because in the next issue he cautioned that land flooded with salt water needed to be cleansed before planting. Bradley knew that although many crops deplete land fertility, clover improves it (Bradley 1721–1724, II:50), and he remarked upon the luxuriant crops grown upon land that formerly held a rabbit warren (see below).

Bradley seems to have agreed with two of his correspondents, B. S. and S. C., that (in the words of S. C.)

> *Plants have a considerable Share of Nourishment, which they draw from the Air, by way of their Leaves and Bark, as well as from the Earth and Water by means of their Roots* (Bradley 1721–1724, III:50).

B. S. reached his similar conclusion after carrying out, at Bradley's suggestion, Jean Baptiste Van Helmont's classical growth experiment (Bradley 1721–1724, I:35–40; on Van Helmont's experiment, see Egerton 2004*b*:209). A prominent agricultural author, Jethro Tull (1674–1740), blamed Bradley for "being the chief, if not only Author, who has publish'd this phantasie" of plants deriving some nourishment from air (Tull 1733:22).

In Bradley's book, *The Gentleman and Gardeners Kalendar, Directing What Is to Be Done Every Month* (1718; third edition 1720), he summarized the usual climate for each month over several decades, but in his *General Treatise* he summarized the weather for the past month only. This is his report for October 1721 (Bradley 1721–1724, II:54).

> *The Wind for the greatest Part of the Month was Westerly, and the Weather generally fair in the Day time, but frequent Rains in the Night; towards the End we had pinching Frosts, which discharged the Trees of their Leaves.*

An unseasonably cold night in late spring, or an unusually long drought, might be the main factor in explaining why a certain species produced few flowers or fruit during a year. Bradley also recognized the desirability of collecting precise data on weather, and for 2–7 June 1721 he published data collected at 3-hour intervals (excepting midnight until 9:00 am) from a barometer, hygrometer, and thermometer, along with indications of weather (clear, rainy, cloudy) (Bradley 1721–1724, I:260). He gave instructions for constructing barometers and thermometers at a time when these instruments were still novel and not standardized (Bradley 1721–1724, I:217–219, 246–254). His own came from John Patrick, a prominent manufacturer of such instruments (Middleton 1964:112, 120, 355, 376, and 1966:60–61).

Following the severe winter of 1728–1729, Bradley wrote a book on it. He reported that a mole-catcher had predicted the winter's severity from finding moles buried a foot deeper in the ground than usual. Bradley postulated that moles had buried deeper to find earthworms, which might be sensitive to impending weather conditions because of their "Structure and tender Disposition" (Bradley 1729:9). He may not have realized that moles hibernate, but he did discuss hibernation of tortoises. The severe weather forced Ruffs to winter as far south as London (normally not south of Norfolk and Suffolk) and snipe and geese south to Essex, Bedfordshire, and Buckinghamshire; sheep and cattle died late in the winter; plants from South Carolina died, and others flowered 4–6 weeks later than usual (Bradley 1729:10–21). Bradley published a number of articles on how to grow plants in artificially heated conditions, including how to build and use greenhouses (Bradley 1721–1724, I:176–183; III:133, 142). He gave instructions on how to raise Pineapple, among other species, in a greenhouse, describing how much water and light were needed to produce flowers and fruit.

Bradley provided several discussions on the quantity, value, and rate of agricultural production, which resemble our modern concept of ecological productivity. The modern concept focuses on three factors: (1) standing crop (biomass), (2) production rate, and (3)

Fig. 3. Pineapple (*Ananas sativus*). Bradley 1721–1724, III:206. He copied the main figure from Commelin and Commelin (1697–1791, Plate 57), and added figures C and D.

material removed. Bradley addressed the second of these in his *New Improvements of Planting and Gardening* (1719–1720:59–71), where he urged his countrymen to raise more trees because England's forests were seriously depleted. He explained what he thought was the most profitable way to manage forest land, including when to remove timber, and he charted expenditures and profits for the 9th, 17th, and 25th years after planting. In *A Philosophical Account of the Works of Nature* (1721) he discussed elm seed production and oak weight increase. His inspiration here was an article by Denis Dodart (1634–1707), "Sur la multiplication des corps vivans considerée dans la fecondité des plantes" (1703), which Bradley translated fairly completely. Dodart used the phrase "une progression géometrique croissante," which Bradley translated as "*A Geometrical Progression of Growth*" (Bradley 1721:110). But one of Bradley's readers, R. Bosworth, was dissatisfied with his account and requested further clarification of the rate at which trees grow. After further reading and pondering, Bradley concluded that the rate of growth would be about the same as the rate of money invested at 5% annually (Bradley 1721–1724, II:71), which is a compound interest rate of increase, a reasonable estimate (Blackman 1919, Egerton 1969:396–401). Bradley addressed the first and third factors in our modern concept of ecological productivity (standing crop and material removed) in articles on family vegetable gardens and vineyards. In both cases, his concern was how close the plants should be planted in order to conserve space and yet maximize yield, and he cautioned: "The Neglecting to contrive a due Succession of Crops [is a mistake]; for in that Case, we may lose half the Profit of our Ground, which ought never to lie idle." (Bradley 1721–1724, III:6).

He also discussed the productivity of cattle, sheep, rabbits, poultry, and fish, and he generalized on the quality of different foods (Bradley 1719–1720, Part 1:29):

> *I am of Opinion that the* Salts . . . *in* Flesh, Fruit *and* Herbs *are the same, only differing in the Proportions of their Quantities; that is, one Pound Weight of* Flesh *may perhaps contain twice as many* Salts *as the like Weight of* Grain *or* Seed*, and one Pound of* Grain *twice the Salts as may be found in a Pound of* Herbs *or* Grass*.*

The word "salt" had no precise chemical meaning at the time, but he clearly thought that meat has more food value than grain, and grain more than herbs or grass.

He quoted letters to him from farmers, for example, on how many cows were raised per acre and how much milk they produced, but he received the most information on raising rabbits. He discussed achieving maximum production in both small-scale and large-scale rabbit warrens. In a small warren, shelters had to be provided, males had to be chained to prevent them from destroying the young, and the rabbits had to be fed with imported food. He calculated that during a year, two males, twenty females, and their offspring would consume 48 bushels of bran @ 3 pence per bushel, 12 bushels of oats @ 16 shillings per quarter, and 6 trusses of hay @ 1 shilling per truss. In addition to bought feed, "The rude Cabbage Leaves, the Turnep-tops, the Carot-tops, and the Weeds which too frequently annoy a Garden, will make up to them what is necessary" (Bradley 1721–1724, II:355). The returns upon this investment were at least six broods per year, but at Hammersmith, breeders achieved nine or ten broods per year by only allowing a doe to raise five young. However, he calculated that 20 females breeding six times a year and raising five young per brood, would produce 600 young, which could be sold when a month old for sixpence each. Deducting the two pounds and two shillings for the bought food, this left a profit of 12 pounds and 18 shillings. Besides which, "Intrails of the Rabbets will always be of Use to your Fish" (Bradley 1721–1724, II:356).

The large-scale warren he described was 700 acres, and the summer food grew in the warren itself. Although William Gilbert's North Wiltshire land was considered some of the most barren in England, after the warren was removed and it was plowed, it produced some of the most luxuriant grain in England. Bradley attributed this unusual fertility to "the Soil being render'd fine by the working of the Rabbets, and also from the large Share of Vegetative Salts, proceeding from the Dung and Urine which by plowing were regularly mix'd, and thereby render'd fruitful." (Bradley 1721–1724, III:30–31). However, Bradley neglected to consider that the importation of hay and hazel twigs for winter food was rather similar to adding fertilizer to the soil. This warren was stocked with 8000 rabbits, which Gilbert thought produced about 24,000 offspring annually. There was some loss due to accidents, poachers, weasels, polecats, foxes, and diseases, but Bradley provided no data on the extent of the loss.

His information on fish productivity included an informal controlled experiment. A friend stocked three ponds with small carp. One pond was at the bottom of a hill, and its fish grew half again larger than those in the other two ponds, apparently due to what washed off the hill into the pond during rains. The two remaining ponds had different bottoms, and the fish in the pond with a clay bottom grew larger than those in the pond with a gravel bottom (Bradley 1721–1724, II:92–93). Bradley himself raised fish in pans (natural depressions), and he gained some insight into which fish could be raised together and which could not. He saw eels, flounders, and silver pence bury in the mud at the bottom and snatch young fish swimming by, and eels, flounders, and perch were the only fish that could survive with pike (Bradley 1721–1724, II:349–350). Although pike and eels ate frogs, he warned (Bradley 1721–1724, II:345):

> *In the Spring Season, when Frogs and Toads begin to appear, suffer as few as possible in your Carp Ponds, but destroy them before they spawn, so that they and their Generation perish at once; for whether these horrid Animals do Mischief or not to the Carps, by poisoning of them, as is reported, they certainly rob the Carps of great Part of their Food.*

If one raised pike and perch, the pond should contain roach and dace for their food, and water weeds "for their Shelter and Nourishment; for where there are Water-weeds, there will also be Water-Insects, which help the Feed of Fish" (Bradley 1721–1724, II:351). On a pond with large pike, however, one could not also raise ducks, because pike eat ducklings. According to Bradley's calculations, fish ponds yield a very good yearly profit.

Despite Bradley's advice to kill frogs so they do not "rob" carp of food, he did believe in the balance of nature (the concept remained unnamed until Linnaeus [Egerton 1973]). When a plague of caterpillars erupted on farms west of London, "Some Farmers imagin'd that the Birds which were there in great Flocks had eaten the Leaves of their *Turneps*, and [farmers] contriv'd all Means possible to destroy" the birds. However, Bradley convinced them that "the Birds were rather Friends than Enemies, and came there to feed upon the *Caterpillars*, which were in such great Numbers, that each *Turnep-Plant* had not less than a thousand upon it…"(Bradley 1719–1720, Part 3:58). Some ancient farmers had already known this (Aelianus, Book 3, Chapter 12). In *A Philosophical Account of the Works of Nature* (1721:159), Bradley generalized that "all Bodies have some Dependance upon one another; and that every distinct Part of Nature's Works is necessary for the Support of the Rest; and that if any one was wanting, all the Rest must be out of Order." On 13 August 1723, Bradley's correspondent, S. C., provided data supporting Bradley's earlier assertion that birds help farmers by eating insects (Bradley 1721–1724, III:87):

> *I lately observ'd a couple of Sparrows who had Young Ones, and made twenty [feeding] Turns each per Hour; and reckoning but 12 Hours per Day, let us compute what a number of those Vermin were destroy'd by that Nest alone.*
>
> *40 Caterpillars per Hour.*
> *<u>12</u> Hours of feeding per Day.*
> *480 Caterpillars destroy'd per Day.*
> *<u>7</u> Days suppos'd between Hatching and Flight.*
> *3360 Caterpillars destroy'd by one Nest alone in one Week.*

S. C. felt this was a conservative estimate, since he thought most birds feed young 14 or 15 hours per day.

He further observed that the amount of fruit harvested was greater in regions where birds were not molested, and that birds thought to be eating blossoms and buds were actually searching for insects.

In *A Philosophical Account of the Works of Nature*, Bradley (1721) estimated that a codfish's roe contains about 1,000,000 eggs, and following the example of Aristotle (*Historia Animalium*, 567b:1–3) and Matthew Hale (1677:208), he speculated on the time needed for cod to increase to a volume equivalent to the size of the earth—about 1000 years. Since this never happens, he concluded that (Bradley 1721:60)

> *...the more Enemies a Fish has to itself and its Encrease, so Nature has taken Care to provide it with such a Capacity of encreasing, or propagating its Species, that there is a due Allowance to make good all Losses that may happen.*

Another aspect of the balance of nature is what we call ecological diversity. We have seen previously that John Ray gave examples of insects eating only one species of plant, and that William Derham carried this idea to such an extreme that he overlooked the possibility of competition between species (Egerton 2005). Bradley, on the one hand, cited examples of flexibility in animal diets—horses' normal diet is grass but they eat grain, dogs eat meat, but will eat fruit, and snails seem to eat any plant (Bradley 1719–1720, Part 1:29; Part 3:71)—but on the other hand, he cited many examples of insects that specialize in eating only one plant (Bradley 1719–1720, Part 3:58–74). He was also aware of insects that feed on plants having ichneumon fly parasites. He generalized (Bradley 1719–1720, Part 3:60–61):

> *...it may be these Insects which prey upon others, are not without some others of lesser Rank to feed upon them likewise, and so to Infinity; for that there are Beings subsisting, which are not commonly visible may be easily demonstrated...in a* Microscope*.*

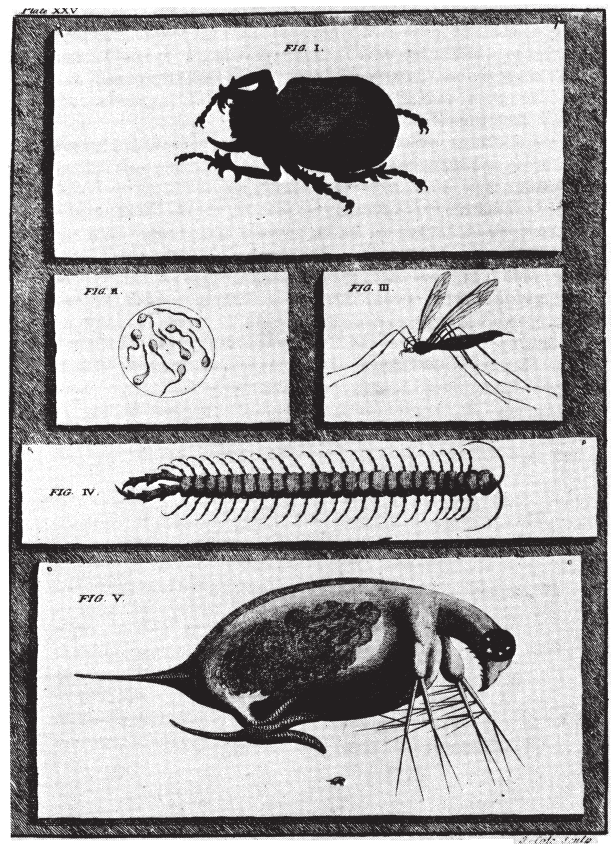

Fig. 4. Bradley 1721*a*, plate 25. Although Bradley sought connections between plants and animals in the text of *A Philosophical Account of the Works of Nature*, he did not present plants and animals in the same illustrations. His FIG. I, bull-beetle; FIG. II, animalcula in semine masculine; FIG. III, adult gnat; FIG. IV, centipede from the West Indies; FIG. V, monoculus found in Thames water, with microscope.

This last thought was one of several that led Bradley to support the idea of animate contagion as a cause of disease (Williamson 1955:45–51). We saw in Part 12 (Egerton 2004*b*) that Girolamo Fracastoro had defended the idea of contagious germs (1546), but for him the germs were chemical atoms. Neither Fracastoro nor anyone else had established a contagion theory, and by 1720 the idea had few supporters (Winslow 1943:Chapter 8). Bradley noticed that easterly winds were frequent in March and that (Bradley 1719–1720, Part 3:54):

> Caterpillars *generally attend these Winds, chiefly infecting some one sort of Tree more than another … from which Observations I think we may draw the following Inferences, either that the Eggs of those Insects are brought to us by the* Easterly Winds*; or that the Temperature of the Air, when the Easterly Winds blow, is necessary to hatch those Creatures, supposing their Eggs were already laid upon those infested Parts of the Trees the preceding Year.*

To the objection that east winds were not warm enough to hatch insects, he replied that the existence of insects in Norway, Iceland, and other cold regions showed that insects do not necessarily need much heat to hatch. Meanwhile, plague, which had wandered through Europe in fits and starts since 1347, struck Marseilles, France in 1721. Bradley responded with a little book, *The Plague at Marseilles Considered*, in which he reported that by 20 October, about 60,000 had died of it there (Bradley 1721*b*:3). Reasoning that winds that blow insect infestation might do the same for plague, and using data from previous London plagues, he predicted that the Marseilles plague would subside in the winter (Bradley 1721*b*:xii), and since insects are specific in their food, he suspected that diseases that attack one race of people might not attack other races (Bradley 1719–1720, Part 3:93). Bradley also knew that the streaked condition in tulips could be transmitted by grafting, and the Rev. John Laurence (or Lawrence), another horticultural author (Gilmour 1965), had found the same condition in jasmines: when a bud from a yellow jasmine was grafted onto a plain jasmine, after several years the whole tree would have leaves striped with yellow. Laurence spoke of grafting as "inoculation"(Laurence 1714:41). Bradley argued that the situation was analogous to giving a smallpox inoculation, and that the striped effect in tulips and the yellow effect in jasmines was due to the spread of a distemper from the infected plant material through the healthy plant (Bradley 1721–1724, I:202–203 and III:98). We now know that the striped effect in tulips is caused by a virus (Hall 1929:104–106). However, Bradley did not believe all diseases were caused by living beings; for example, he attributed an epidemic among chickens to poor ventilation of their coop (Bradley 1721–1724, III:68–69).

In 1724 Bradley became the first professor of botany at Cambridge University (Walters 1981:15–29), but since the position carried no salary, he was too busy publishing his books to do much teaching. He did not manage to publish "A Course of Botanical Lectures Explaining Principles of Vegetation," (1725) which still exists in manuscript in the Cambridge Botany School Library, but he reworked the material for his *Ten practical discourses concerning Earth and Water, Fire and Air, as They Relate to the Growth of Plants* (1727). He did publish *A Course of Lectures upon the Materia Medica, Ancient and Modern* (1730), in which he discussed the need for a physic garden at Cambridge. His rival and successor as professor of botany at Cambridge, John Martyn, wrote a facetious review of it, saying it was "obliging" of Bradley to publish the book since only three or four students had heard the lectures (Williamson 1961:365).

Bradley lived a precarious economic existence and died in his mid-40s. At a time when many naturalists were content to name, describe, and classify species, he was an enterprising, open-minded naturalist who succeeded in disseminating his many and diverse thoughts on how plants and animals live and interact. His writings contain some vagueness and mistakes, but as a whole, his contributions advanced natural history in a direction that ultimately led to ecology.

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