Commentary

A History of the Ecological Sciences, Part 18: John Ray and His Associates Francis Willughby and William Derham

John Ray (1623–1705) was the greatest naturalist and natural theologian of his time. He was assisted early in his career by patron, student, and zoologist Francis Willughby (1635–1672), and late in his career by cleric, natural philosopher, and natural theologian William Derham (1657–1735), who became his literary executor. Ray had a number of other associates who also contributed to his work, especially Martin Lister, Tancred Robinson, and Hans Sloane, all of whose roles are described in Charles E. Raven's encyclopedic biography of Ray (1942). Ray was the first naturalist to emphasize that natural history must be founded on an ability to identify plant and animal species, yet systematics was never the goal of his studies. His interest in natural theology encouraged his investigation into how nature works. Although his adult life was something of a struggle, he was nevertheless a constantly productive naturalist who produced numerous publications (Keynes 1951). The cumulative impact of his work was a major contribution to the Scientific Revolution during the 1600s (Levine 1983).

Ray (spelled Wray until 1670) came from modest circumstances: his father was a blacksmith and his mother a herbal healer. He absorbed her love of plants and religion. Little is known of his childhood, but if he had not been an excellent student, he would never have been admitted to Cambridge University. Arriving in 1664, he prepared for the ministry but showed a strong interest in botany and zoology. Since there were no courses offered in natural history, he joined a group of scholars who dissected animals to study comparative anatomy of vertebrates, and he published the first county flora in England, using as a model Gaspard Bauhin's flora of Basle, Switzerland. Raven (1942:81) described Ray's *Catalogus plantarum circa Cantabrigiam nascentium* (1660) as

> *a small octavo volume suitable for the pocket, is certainly an unpretentious . . . work. Few books of such compass have contained so great a store of information and learning or exerted so great an influence upon the future; no book has so evidently initiated a new era in British botany.*

Fig. 1. John Ray (Ray 1717).

Ray studied Cambridgeshire plants for 6 years before beginning work on the book and then took 3 years to complete it. In deference to the assistance of three friends (named in Ray [1975:24] including Willughby; a letter in Thompson [1974:112] illustrates that assistance), he did not even put his name on the title page. In an age still burdened with polynomials, correlating Cambridgeshire plants with those described in books on British and Continental plants was a demanding task, yet he found and identified 558 species, listed alphabetically, only one of which, a sedge, is of uncertain identity today. Fortunately, Ray's herbarium survives and is in Britain's Natural History Museum (Walters 1981:6–14).

Ray's *Catalogus* is directly relevant to ecology in his accurate recording of places where each species are found—bogs, woods, meadows, riverbanks. More important, he includes biological observations and conclusions. Under ash tree (*Fraxinus excelsior*) he explained the correlation between growth rings seen in a tree stump and the age of the tree, a study at the interface between ecology and physiology (Ray 1660:55; translated by Ewen and Prime, Ray 1975: 64–65):

> *The rings which are seen in the trunks and boughs of trees when cut crossways show more openly in the wood of this tree than in others. These rings in trees growing in the tropics are equidistant all round and have the heart of the tree in the true centre as Gassendus* tom 2. *P.178. observed in the wood of the Brazilian acanthus. In other regions situated either to the south or to the north they are expanded towards the equator and are contracted in the regions facing the pole so that the hearts are always found to be eccentric . . . .*
>
> *1. The age of a tree or branch is disclosed by the number of rings, unless the tree has stopped growing, the number of rings equals the number of years. 2. Normally the inner rings are closer together owing to pressure, probably in trees of great girth and growing old, the outside rings may be narrower through lack of vigour. 3. The pith is compressed as the tree ages; this is evident in the Elder. 4. The wood is harder and darker in the inner rings than in the outer, certainly never lighter . . . . 5. The tops of the trees have fewer rings and the inner rings of the trunk can be seen drawing to a point as they rise; the pattern thus formed is called in English* [he wrote in Latin] *the "grain of the tree". 6…my opinion is that so long as the tree is alive, it adds a new ring, even if it is a narrow one, every year; the age of a tree cannot be determined because its inside decays and the external rings become too narrow to count.*

Ray wrote this 5 years before Hooke announced his discovery of plant cells in *Micrographia*, and since Ray clearly did not examine tree rings under a microscope, he could not explain exactly how the rings grew. Under hops (*Humulus lupulus*) he observed (Ray 1660: 91, translated by Ewen and Prime, Ray 1975:81) that "The hop and probably other twining plants follow the course of the sun, that is they twist from east through south to the west never in the reverse direction. . . ." Under elm tree (*Ulmus procera*) he recorded how the growth of trees in the open isinfluenced by prevailing winds (Ray 1660:180; translated by Ewen and Prime, Ray 1975:126):

> *From the shape of a tall tree growing in the open air it is possible to say from what quarter of the heavens the stronger and more prevalent winds are accustomed to blow in any particular locality. Thus trees growing near the sea point to the east because those parts of the country are particularly exposed to frequent gales.*

He also explained some animal uses of various species. Under hemlock (*Conium maculatum*) he reported (Ray 1660:34; translated by Ewen and Prime, Ray 1975:54) that he had dissected the crop of a bustard (*Otis tarda*) and "found it stuffed with hemlock seeds;

there were only four or five grains of corn mixed with them. So even at harvest the bird leaves corn for hemlock." If Ray hoped this observation on food preference might help save bustards from farmers' ire, it seems unsuccessful—the last bustard was killed in Britain in 1835. Under deadly nightshade (*Atropa belladonna*) he commented (Ray 1660:157–158; translated by Ewen and Prime, Ray 1975:114) that snails and slugs commonly eat it despite its poison. (He added that these animals are hermaphroditic.)

His longest note under any plant is not about the plant itself but about its habitual insect pest. The discussion is under rape (*Brassica rapa*) and wild turnip (*B. napus*), where he reported (Ray 1660:134; translated by Ewen and Prime, Ray 1975:102) that "Caterpillars born on brassica have taught us that a close relationship exists between these stocks as the leaves of rape are eaten no less greedily that those of brassica although they scorn many other plants that we have offered them as food." He raised 10 or so of these caterpillars in a wooden box at the end of August 1658 and inadvertently discovered insect parasitism, but without fully understanding it (Ray 1660:134–138; translated by Ewen and Prime, Ray 1975:103):

> *Seven of them proved to be viviparous or vermiparous; from their backs and sides very many, from thirty to sixty apiece wormlike animalcules broke out; they were white, glabrous, footless and under the microscope [perhaps only a magnifying glass] transparent. As soon as they were born, they began to spin silken cocoons, finished them in a couple of hours, and in early October came out as flies, black all over with reddish legs and long antennae, and about the size of a small ant. The three or four caterpillars which did not produce maggots changed into angular and humped chrysalids which came out in April as white butterflies.*

He also described a case of parasitism of *Rosa canina* by the rose bedeguar (*Rhodites rosae*), and commented on previous authors' observations on the subject (Ray 1660:139–140; translated by Ewen and Prime, Ray 1975:105):

> *Sometimes a smooth hairy lump grows on the stalks of...*[Rosa canina]. *If you cut open this gall, you will find it packed with small white maggots; this is on the evidence of* Bacon nat. hist. cent.6 exp.562. Spigel isag. lib. 1, cap.10. Moufet. Theat insect. lib.2, cap.20. . . . *Spiegel, Moufet and Aristotle* (Arist. Lib.5. hist. cap.19) *say that beetles are borne from these maggots*....[but] *the maggots which lie hidden in the gall during the winter come out in the month of May the following year in the form of flies; their shape and proportion are like those of winged ants; their size is a little smaller . . . . Some of these flies are armed with a sting or spike protruding from the tail but others altogether lack this, so this probably makes a distinction between the sexes.*

Raven (1942:102–103) points out that some of Ray's observations on insects published in this first book were extended in his last book, *Historia insectorum* (1710); for example, he expanded his observations on insect galls in it on pages 259–260.

After sending his catalogue of Cambridgeshire plants to the printers (in Cambridge and London), Ray and Willughby took their first extended field trip, to northern England and the Isle of Man, which is equidistant between northern England and northern Ireland. The friends decided to compile natural histories of British plants and animals, and since Willughby's stronger interest was in animals, he would do them and Ray would do the plants. Before returning to Cambridge, Ray visited Thomas Brown at Norwich in August and they botanized along the Norfolk coast. Ray and Willughby's collaboration was very productive, though Willughby never got beyond the note-taking stage before his death at age 37 in 1672. In 1658, 1661, and 1662 Ray went on field trips without Willughby into other parts of Britain.

Fig. 2. Francis Willughby (Allen 1951).

Ray had trained for the ministry and was ordained, and he had intended natural history to be only an avocation. However, in 1662, after the Restoration, a Royalist Parliament passed a law requiring all ministers to sign a loyalty oath, and Ray, a Puritan, felt it violated his religious belief. His refusal to sign ended his clerical career, and his avocation became his life's work. In 1663 he and Willughby left on a 3-year trip to Western Europe to collect observations, specimens, and illustrations and to visit professors at several universities and a few unaffiliated naturalists (Ray 1673, Raven 1942:112–140, Allen 1951:419–422). This experience enabled the partners to broaden the scope of their studies beyond Britain, first to western Europe and later to the rest of the world known to Europeans.

In 1660, the 25-year-old Willughby had become a founding Fellow of the Royal Society of London—which happened at that young age only because he came from the nobility. In 1667 Ray was elected a Fellow, and in 1669 Willughby and he sent in "Experiments concerning the Motion of Sap in Trees, Made this Spring by Mr. Willughby and Mr. Wray," which the Society published in its *Philosophical Transactions*. Willughby had returned from the Continental trip before Ray and had begun these experiments himself (Welch 1972:76). Their experiments were exploratory, without a hypothesis, in a Baconian manner. Although Raven (1942:188) admitted that they made no fundamental discovery, he thought that this was "the first systematic attempt to study the physiology of a living plant and thus opened up a new field of research and gave a new direction to botany." In claiming such priority for Ray, however, Raven failed to consider the studies before 1669, discussed in Part 14 (Egerton 2004:210), though Raven may be right about these experiments stimulating studies by others. Botanist and historian Agnes Arber (1943) cited other examples in which Raven slighted other botanists while praising Ray. More recently, however, Morton (1981:210) followed Raven's example in claiming Ray as "the founder of plant physiology, even though his original contributions were modest." He based his judgment largely on the discussion of plant physiology in Volume 1 of Ray's *Historia Plantarum* (three volumes, 1686–1704); this is generally considered Ray's greatest scientific treatise. Ray was the first naturalist to pay special attention to the distinction between species, and he wrote his first essay on the subject in 1672 (published in 1757 and reprinted in Ray 1928:77–83). His later expression of his species concept in *Historia Plantarum* was long standing (Ray 1686:Volume I; translation by E. Silk, in Mayr 1982:256–257):

> *After a long and considerable investigation, no surer criterion for determining species has occurred to me than the distinguishing features that perpetuate themselves in propagation from seed. Thus, no matter what varia-*

tions occur in the individuals or the species, if they spring from the seed of one and the same plant, they are accidental variations and not such as to distinguish a species . . . . Animals likewise that differ specifically preserve their distinct species permanently: one species never springs from the seed of another nor vice versa.

In a different context, Ray explained, "I reckon all Dogs to be of one Species, they mingling together in Generation, and the Breed of such Mixtures being prolifick" (Ray 1717:21). Ray made important contributions to the classification of plants (Stevenson 1947, Sloan 1972, Morton 1981:201–203, 228–229, Stearn 1985–1986:113–117), including drawing a distinction between herbaceous Monocotyledons and Dicotyledons in his Methodus Plantarum (1682). Ray is often credited with being first to make this distinction (Raven 1942:195, Morton 1981:203, 228–229), but Mayr (1982:163) cites four predecessors. Although Ray was able to obtain funds to publish illustrations in the treatises on ornithology (from Emma, Willughby's widow) and ichthyology (from the Royal Society), both of which carried Willughby's name as author, he was unable to obtain funds for plates of the different species for his own books on plants (Henrey 1975:127–134, 266–269).

Soon after Willughby's death in 1672, Ray turned to producing Willughby's *Ornithology*, which was a memorial to his patron and became the beginning of modern ornithology. Although he placed Willughby's name alone on the title page as author, Ray's contribution to the book was as much or more than Willughby's careful notes and collected illustrations (many from their European tour). This point is seen in an extract from Ray's letter on various birds to Martin Lister, 1 October 1667 (Ray 1928:113–115 [in Latin], Raven translation 1942:315):

Your observation of the Green Woodpecker corresponds with my own of the Black and both the Spotted Woodpeckers and the Wryneck. I once got out of the crops of these birds on dissection larvae as big as my small finger. The muscles and tendons by which they shoot out and retract their tongues deserve curious study.

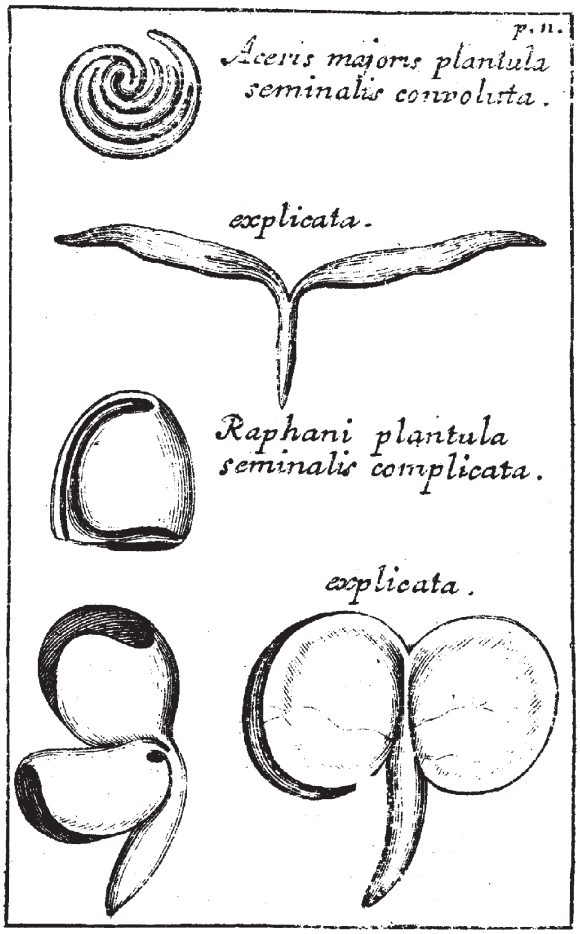

Fig. 3. This drawing of sycamore and radish seeds from Malpighi's *Anatomy of Plants* (1675) is reprinted in Ray's *Methodus Plantarum* (1682) and *Historia Plantarum* (1686).

Although Ray initially published the *Ornithology* in Latin (1676), 2 years later he published an enlarged English version. Two modern histories of ornithology (Stresemann 1975:43–45, Walters 2003:38–40)

stress the importance of these authors' new classification of birds, and Ray performed the same service in 1693 for quadrupeds (Petit and Théodoridès 1962:317–320). Raven (1942:308–338) provides the most details on the *Ornithology*'s production and contents; Hall (1951:18–30) quotes the classification, human bird-hunting techniques, and the dodo; and Miall (1912:103–111) presents a briefer overview than Raven and more natural history extracts than Hall.

In the *Ornithology*, Chapter 3, "Of the generation of birds," our authors disagreed with William Harvey's belief (1651, exercise 29) that some hen eggs only come into existence after copulation. They thought (Willughby [and Ray] 1678:10–16) that hens are born with all the eggs in their ovaries that they ever lay. They cited five cases of longevity that seemed credible to them: a goose and a pelican had each been kept for 80 years; a pigeon had lived 22 years and had bred until its last 6 months; a linnet lived 14 years, and a goldfinch 23 years. When pigeons raise two young, Willughby wondered whether they were of opposite sexes; Ray replied that they usually are but sometimes are not.

Aristotle's *Historia Animalium* (600a15) claimed that swallows do not migrate in winter as other birds do, but hibernate, and naturalists revived this belief from the 1500s to the 1700s. Willughby and Ray (1678:212, quoted in Raven 1942:328) doubted this: "To us it seems more probable that they fly away into hot countries, viz. Egypt, Aethiopia etc." Their many natural history observations of ecological interest are illustrated in these six examples:

Lapwing (*Vanellus vanellus*) (Willughby [and Ray] 1678:308, quoted in Miall 1912:109–110):

> *It builds its nest on the ground, in the middle of some field or heath, open and exposed to view, laying only some few straws or bents under the eggs, that the nest be not seen. The eggs being so like in colour to the ground on which they lie, it is not easy to find them though they lie so open. The young, so soon as they are hatcht, instantly forsake the nest, running away, as the common tradition is, with the shell upon their heads, for they are covered with a thick down, and follow the old ones like chickens. They say that a lapwing, the further you are from her nest, the more clamorous she is, and the greater coil she keeps; the nearer you are to it, the quieter she is, and less concerned she seems, that she may draw you away from the true place, and induce you to think it is where it is not.*

Fig. 4. Plate from Willughby [and Ray] (1678).

Blackbird (*Turdus merula*) (Willughby [and Ray] 1678:191, quoted in Miall 1912:111):

The blackbird builds her nest very artificially with outside of moss, slender twigs, bents and fibers of roots, cemented and joined together with clay instead of glue, daubing it also all over withinside with clay. Yet doth she not lay her eggs upon the bare clay, like the mavis, but lines it with a covering of small straws, bents, hair, or other soft matter, upon which she lays her eggs, both that they might be more secure and in less danger of breaking, and also that her young might lie softer and warmer.

Honey-Buzzard (*Pernis apivorus*) (Willughby [and Ray] 1678:72, quoted in Raven 1942:327):

It builds its nest of small twigs, laying upon them wool and upon the wool its eggs. We saw one that made use of an old Kite's nest to breed in, and that fed its young with the nymphae of wasps: for in the nest we found the combs of wasps' nests and in the stomachs of the young the limbs and fragments of wasp-maggots. There were in the nest only two young ones, covered with a white down, spotted with black. Their feet were of a pale yellow, their bills between the nostrils and the head white. Their craws large, in which were Lizards, Frogs etc….This bird runs very swiftly like a Hen. The female as in the rest of the Rapacious kind is in all dimensions greater than the male.

Dipper (*Cinclus cinclus*) (Willughby [and Ray] 1678:149, quoted in Raven 1942:327–328):

It frequents stony rivers and water-courses in the mountainous parts of Wales, Northumberland, Yorkshire etc. That I (J.R.) described was shot beside the river Rivelin near Sheffield in Yorkshire: that Mr Willughby described near Pentambeth in Denbighshire in North Wales. It is common in the Alps in Switzerland, where they call it Wasser-Anzeil. It feeds upon fish, yet refuseth not insects. Sitting on the banks of rivers it now and then flirts up its tail. Although it be not web-footed, yet will it sometimes dive or dart itself quite under water. It is a solitary bird, companying only with its mate in breeding time.

Cormorant (*Phalacrocorax carbo*) (Willughby [and Ray] 1678:330, quoted in Raven 1942:328):

. . . on the rocks of Prestholm Island near Bearmaris we saw a Cormorant's nest, and on the high trees near Sevenhays in Holland abundance . . . . besides this we have not known or heard of any whole-footed bird that is wont to sit upon trees, much less build its nest upon them.

Puffin (*Puffinus puffinus*) on the Isle of Man (Willughby and Ray 1678:333, quoted in Raven 1942:328):

The old ones early in the morning, at break of day, leave their nests and young and the island itself and spend the whole day in fishing in the sea…so that all day the island is so quiet and still from all noise as if there were not a bird about it. Whatever fish or other food they have gotten and swallowed in the day-time, by the innate heat or proper ferment of the stomach is (as they say) changed into a certain oily substance (or rather chyle) a good part whereof in the night-time they vomit up into the mouths of their young, which being therewith nourished grow extraordinarily fat.

The story of Willughby [and Ray]'s *Historia Piscum* (1686) is similar to that of the *Ornithology*: it was a joint effort, with editor Ray contributing more than Willughby. The latter had left fewer notes on fish than on birds, and Ray supplemented them by soliciting information from his naturalist colleagues (Raven 1942:339–370). The resulting volume contained many fewer natural history observations of ecological

interest than the bird volume, no doubt because fish behavior is more difficult to observe than bird behavior. Miall (1912:112) pointed out that the fish volume depended heavily upon previous books by Rondelelt, Belon, Salviani, Gesner, and Marcgraf, and therefore "It cannot be said that this is a very important contribution to natural history." Even the observation from *Historia Piscium* that Miall mentioned, about sharks having the mouth on their bottom side as a provision of nature to ensure safety of other fish and to prevent sharks from dying from gluttony, is actually repeated from Aristotle's *De Partibus Animalium* (696b24–33, quoted in Egerton 1973:328–329). Nevertheless, two historians of ichthyology thought highly of this work. Cuvier in 1828 wrote (Simpson translation 1995:71):

> *Ray and Willughby had the honor of being the first to write an ichthyology in which the fishes were clearly described according to nature and classified based on characteristics drawn only from their structure, and in which their natural history was finally rid of all passages from ancient writings…*

More recently, Jordan wrote (1905:390) that "The basis of classification was first fairly recognized by" Ray and Willughby in *Historia Piscium*, which brought "order out of the confusion left by their predecessors." Their treatise described 180 species directly from nature and described 240 more from other authors' works. There was no later English edition.

In 1690 when Ray, age 63, began work on his *Historia Insectorum*, his health was already in decline. However, we saw above in notes to his Cambridgeshire catalogue of plants (1660) that he had an early interest in insects, the persistence of which is illustrated in this extract from his letter to Lister on 17 July 1670 (Ray 1718:69, quoted from Salmon 2000:252):

> *This summer we found here the same horned* Eruca [caterpillar], *which you observed about Montpelier, feeding on* Foeniculum [Seseli] tortuosum. *Here it was found on common Fennel: It has already undergone the first change into a* Chrysalis*, and we hope it will come out a* Butterfly *before winter.*

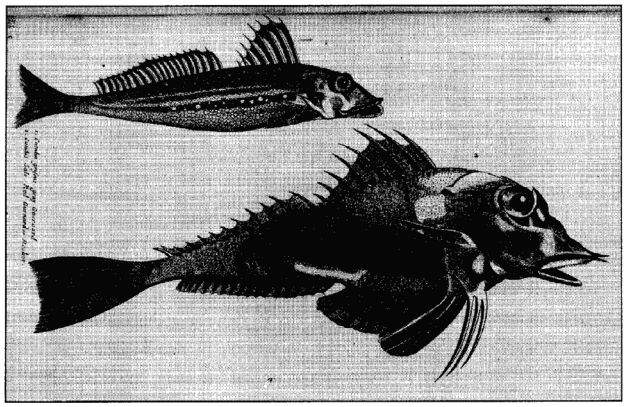

Fig. 5. Top: Flying gurnard (*Cephalacanthus volitans*); bottom: sea-robin (*Prionotus evolans*). Willughby [and Ray] 1686: Plate 13.

Ray also published a note on ants in 1671. Willughby's notes available to Ray were not limited to insects, but included worms and other invertebrates. As usual, Ray solicited and received help from other naturalists, and he used Lister's observations on spiders and beetles. For this project he was also aided by his wife, Margaret, and their four daughters—Margaret, Mary, Catharine, and Jane—who collected insects around their Black Notley home. In gratitude, he named several newly discovered butterflies and moths after his daughters. On 29 May 1693 his wife made an important discovery concerning a moth which Raven thinks was probably *Pachys betularia* (Ray 1710:177, Raven translation 1942:395):

> *It emerged out of a stick-shaped geometer caterpillar: it was a female and came out from its chrysalis shut up in my cage: the windows were open in the room or closet*

where it was kept, and two male moths flying round were caught by my wife who by a lucky chance were into the room in the night: they were attracted, as it seems to me, by the scent of the female and came in from outside.

Raven suggests that this was probably the first record of insect pheromones (though Raven did not use that term).

James Petiver (1663–1718) was Ray's only significant predecessor in naming British insects. He was a London apothecary (pharmacist) and nature collector who published on insects from 1695 until 1717 (Allen 2004, Stearns 1952, Salmon 2000:103). He and Ray were friends, not competitors, and he provided valuable assistance. In 1660 when Ray reported caterpillars producing flies instead of butterflies when chrysalises opened in the spring, he had been unsure how to interpret his observations. By the time he wrote *Historia Insectorum*, however, he understood (Ray 1710:114, translated by Raven 1942:104):

I think that the ichneumon wasps prick these caterpillars with the hollow tube of their ovipositor and insert eggs into their bodies: the maggots are hatched by the warmth of them, and feed there until they are full grown: then they gnaw through the skin, come out, and spin their cocoons.

There was no English edition of *Historia Insectorum* either. However, Bodenheimer (1928–1929:I, 486–494; II, 412–427) provided a German translation of extracts and also modern identifications of insects Ray discussed.

In addition to the ecological observations scattered through Ray's numerous natural histories, he also emphasized interactions among plants and animals in a more coherent way in his very influential book on natural theology, *The Wisdom of God Manifested in the Works of the Creation* (1691). The idea that one can learn about God by studying his creation arose among the ancient Greeks, and there were two basic arguments: (1) that the lives of plants and animals are designed to intertwine in ways to preserve the balance of nature, and (2) that the structure and function of the organs of the human body are designed to enable humans to flourish. The most famous discussion from antiquity of the former argument is in *De Natura Deorum* by Cicero, a first century BC Roman (Glacken 1967:54–61, Egerton 1973:30). Discussion of the latter argument is in several writings by the Greek physician Galen, in the 100s AD. In a very comprehensive survey of the history of natural theology, Neal C. Gillespie (1987) argues that there were few original contributions to the subject since Cicero and Galen until Ray, and that Ray made the most important contributions down to the time when the whole subject was challenged by Darwin's *Origin of Species* (1859). Glacken (1967:415–442), Raven (1942:452–478), and Zeitz (1994) essentially agree. Although I think Matthew Hale's *Primitive Origination of Mankind* (1677) was a more substantial contribution to the subject than Gillespie recognized (Egerton 2005), there is no doubt about the overwhelming importance of Ray's book on natural theology.

Ray had expressed his strong skepticism of spontaneous generation of animals in a note published in 1671, and that skepticism remained in his later writings. Arguments that he accumulated over the years were explained in *The Wisdom of God* (cited from the seventh edition, 1717:298–326, 1977). Another of Ray's concerns was the possible extinction of species. Since antiquity, it had been argued that all species are endowed with effective means of preservation (Egerton 1973). If any species actually became extinct, it could reflect against God's omnipotence or creative wisdom. Particularly worrisome were large fossil ammonites. Only the much smaller chambered nautilus had ever been found alive. Ray (1692:19–124) did not take a dogmatic stand, but pointed out that much of the world remained unexplored by European naturalists. In a posthumous essay, "Mr. Ray of the Number of Plants," (in Derham 1718:344–351), he also argued against the origin of new species or the extinction of

previously existing species. Although he could not prove that species do not become extinct, he could emphasize their means of survival. This was another theme that went back to antiquity (Egerton 1973), and Ray (1717:110–146, 1977) marshaled the usual evidence along with a few new examples, including Lister's observation that swallows, like chickens, will continue laying eggs if previous eggs are removed from the nest daily (until 19 were laid), and Ray's own observation about woodpeckers' tongues being designed to extract insects from the trunks of trees or limbs.

A somewhat newer question, or at least newly answered (Ray 1717:368–373, 1977), was why there are multitudes of noxious insects. First, because it displays the riches of the power and wisdom of God. Second, because insects are eaten by other animals, many individuals are needed to prevent their extinction. Third, because insects are important food for birds, fishes, and various quadrupeds. Among his examples is an implicit food chain. Derham had, using a microscope, studied "those vastly small animalcula" (zooplankton), and found that they were food for small insects, which Ray had just said were eaten by fish, and of course he knew that people ate fish. Fourth, God can use noxious insects when he wishes to punish wicked persons or nations. Since it was known that insect pests are much worse in some places than in others, one may wonder why Ray did not conclude from his fourth point that wicked people are attracted to areas with many insect pests and virtuous people are not. That thought was "beyond the radar" of natural theologians, including Ray.

William Derham was a clergyman in Upminster, a town near London, which occupation left him with ample time to pursue his scientific studies (Atkinson 1952, Knight 1971, Smolenaars 2004). He became a Fellow of the Royal Society in 1702 and published 46 articles in its *Philosophical Transactions*, 1698–1735, many of them concerning the weather at Upminster. His justification for a clergyman engaging in scientific studies was that they provided material for his own two books on natural theology, *Physico-Theology* (1713) and *Astro-Theology* (1715), both of which were very popular and went through many editions and translations into other languages. Derham was bound to cover some of the same ground as Ray, but Derham also had new information and new perspectives (Glacken 1967:421–424). He provided a new synthesis of animal and human demography (Egerton 1967:135–144), and he had a larger store of knowledge of them than had Matthew Hale 36 years earlier (Egerton 2005). Derham seems to have first actually used the word "balance" in a discussion of the balance of nature (Derham 1716:171, 1977): "Thus the Balance of the Animal World is, throughout all Ages, kept even, and by a curious Harmony, and just Proportion between the increase of all Animals, and the length of their Lives, the world is through all Ages well, but not overstored." In discussing human demography, he drew upon the studies by John Graunt and later authors. He saw (1716:177, 1977) the tendency of births to be more numerous than deaths as

> *an admirable Provision for the extraordinary Emergencies and Occasions of the World; to supply unhealthful Places, where Death out-runs Life; to make up the Ravages of great Plagues, and Diseases, and the Depredations of War and the Seas; and to afford a sufficient number for Colonies in the unpeopled Parts of the Earth.*

He suggested that some of these calamities might be punishment for wickedness and also "wise Means to keep the Balance of Mankind ['s population] even. . . .

Ray had defended the wisdom of having mountains as providing a variety of abodes for a variety of species of plants and animals. Derham generalized this argument to explain that the diversity of soils and climates of the earth provide the needs for the large variety of existing species. In his chapter, "Of the Food of Animals," he further observed (1716:180–215, 1977) that animal species have special kinds of food, and

also special anatomical features that enable them to obtain it, such as the long bills of woodcocks, snipes, and curlews, which they use to extract worms from the soil. It would have been difficult to make his argument for what we call ecological diversity had Derham chosen omnivorous species as examples; that is one limitation to his argument, and his neglect of competition between species is another. Perhaps a focus on the wisdom of creation diverted attention from these aspects of species interactions.

Thus, natural theology had limitations as a paradigm for understanding the living world. However, as a motivator for natural history studies, it played an important role in the thinking of European and American naturalists from the 1600s into the 1800s. John Ray and his associates, Francis Willughby and William Derham, provided the guidance and inspiration for many of these studies.

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