A History of the Ecological Sciences, Part 2: Aristotle and Theophrastos

If Plato founded ethics, his pupil Aristotle (384–322 BC) invented logic and sponsored, if he did not entirely write, treatises that qualify as fully fledged science. Aristotle's father, Nicomachos, was a Greek physician at the Macedonian court at Pella, and Aristotle grew up as a friend of Prince (later King) Philip II. Aristotle probably intended to follow in his father's footsteps, but that option ended with his father's death. Civil war broke out, life at court became precarious, and his guardian sent Aristotle at age 17 to Athens, where he studied at the Academy for 20 years, if tradition is correct. After Philip II began conquering the Greek states, Aristotle left Athens in 347 BC (probably because of anti-Macedonian agitation) and served three years as Philip's agent in Assos, on the Asia Minor coast. He became a friend and advisor to its ruler, Hermeias, who gave Aristotle his daughter in marriage. At Assos, Aristotle assembled a group of scholars and ran some sort of school. Also, he frequently visited Mytilene on the island of Lesbos. Either he met Theophrastos of Eresos (c.371–c.287 BC) there, or possibly Theophrastos was one of the scholars who joined Aristotle's group in Assos. When Persians captured and executed Hermeias for treachery, Aristotle fled to Lesbos and stayed for about a year. Then he returned to Pella, possibly with Theophrastos. Aristotle persuaded Philip to rebuild Stagira, Aristotle's home town, which Philip had destroyed during his conquests. Aristotle remained at Pella for seven years, probably involved in diplomatic work for Philip, until Philip was assassinated in 336. Much later, a legend arose that Aristotle had returned to Pella to become tutor to Philip's son, Alexander III. It is too good a story to die, but there is no evidence for this claim until three centuries later. After Philip's assassination (since Alexander and his mother benefited, they may have been involved), several Greek states rebelled, believing that a new 20-year-old king could not hold together Philip's empire. However, Alexander swiftly suppressed the revolts, and he made an example of Thebes: he destroyed it and enslaved everyone who was not slaughtered. Athens had planned the revolt, yet Alexander allowed it to submit without punishment. That surprising fact has been attributed to Aristotle's presumed intervention. Perhaps he convinced Alexander that a flourishing Athens was much more valuable to Alexander than a destroyed one. The clincher was Aristotle's plan to open his own school there, the Lyceum, where he could train administrators for Alexander's empire and where he could monitor Athenian politics.

There are striking differences between the teachings of the Academy and the Lyceum, which are usually attributed to Aristotle's position as an independent thinker. No doubt he was, but he also confronted a different world from Plato's. Whereas the Academy trained a ruling class for small city-states, the Lyceum faced the challenge of training administrators for a vast, little-known empire. The deductive methodology of the Academy seemed insufficient. Nevertheless, the *Aristotelian Corpus*, which is much longer than Plato's *Dialogues*, contains a paradox: the philosophical treatises that explain scientific method are deductive, whereas the actual scientific treatises—especially the biological ones—are inductive. One way to explain this is to assume that Aristotle wrote the deductive treatises before he founded the Lyceum in 335, and that he wrote the inductive treatises afterwards. If a contradiction between deductive instructions and inductive practice were the only problem, this explanation might suffice. However, there are also small contradictions within the treatises. The usual explanation of this is that the treatises were lecture notes, and that as the years passed, first Aristotle, and then his successors, made minor changes. Supposedly, Aristotle's contributions were the more intelligent portions, and the less intelligent contradictions were by his successors. This solution is unsatisfactory. There seem to have been two different versions of these treatises, which an editor later blended.

We do not know what portions of the *Aristotelian Corpus* were by Aristotle. He headed the Lyceum for only a dozen years, until Alexander died in 323; Aristotle then fled Athens because he was viewed as a Macedonian spy. Theophrastos, his successor, headed the Lyceum for three dozen years. It seems likely that philosophical treatises attributed to Aristotle and to Theophrastos are actually written by them, but the popular image of Aristotle as both a brilliant philosopher and a diligent biologist is questionable. The best evidence that he was a biologist is that much of the information on marine biology comes from Lesbos, where he had spent a year. But Theophrastos had grown up there and may have gone back for visits; thus, we cannot know which one (or both?) collected these data. What we do know is that Aristotle was a philosopher, diplomat, and founder of the Lyceum, and that the biological treatises came from the Lyceum. Theophrastos might have had as much or more to do with them as Aristotle, and at any rate, an undetermined number of other scholars were also involved. Later, the zoological treatises were attributed to Aristotle and the botanical treatises to Theophrastos, even though they are similar in organization, style, and outlook. Both sets contain descriptive *Historia* and also causal treatises: *Generation of Animals*, *Parts of Animals*, and others for animals, and *De Causis Plantarum* for plants.

The zoological treatises discuss more than 500 species of animals, and the botanical treatises discuss more than 500 species of plants, which is an impressive range of knowledge. The information is often more reliable than that of Herodotos, although the Lyceum still accepted second-hand reports, including some from Herodotos' *History*. In neither the zoology nor the botany is the treatment species by species. Rather, there is a comparative treatment of groups of species according to anatomy, physiology, reproduction, and habits. Ecological observations abound, yet the *Aristotelian-Theophrastan Corpus* developed the concept of physiological teleology to replace the providential ecology of Herodotos and Plato. Instead of explaining reproductive rates of prey species as being higher than those of predator species because they were designed that way to prevent predators from exterminating their prey, the Lyceum explained reproductive rates as a function of physiological necessity. A mouse can produce more young per pregnancy than can an elephant because there is little matter to organize in a mouse embryo and much matter to organize in an elephant embryo. Physiological necessity was compatible with the Lyceum's development of teleological explanations and its rejection of the randomness of the atomic theory of Leukippos (flourished 435 BC) and Democritos (flourished 410 BC). Although some phenomena might appear random, such as when and where rain falls, the Lyceum believed that natural phenomena have purposes. Rabbits reproduce rabbits, not cats or rats, and all organs have definite functions: eyes see what to eat, teeth chew food, stomachs digest food. The ecological relevance of teleological explanation is seen in this account of differences among birds (*Parts of Animals*, 694a16–694b3, Peck translation):

> *The same bird never possesses both spurs and talons, and the reason is that Nature never makes anything that is superfluous or needless. Spurs are of no use to a bird that has talons and can fly well: spurs are useful for fights on the ground, and that is why certain of the heavy birds possess them, while talons would not be merely useless to them but a real disadvantage: they would stick in the ground and impede the birds when walking. And in fact all crook-taloned birds do walk badly, and they never perch upon rocks... . This state of affairs is the necessary result of the process of their development. There is earthly substance in the bird's body which courses along and issues out and turns into parts that are useful for weapons of offence. When it courses upward, it produces a good hard beak, or a large one; if it courses downwards it produces spurs on the legs or makes the claws on the feet large and strong. But it does not produce spurs and large claws simultaneously, for this residual substance would be weakened if it were scattered about.*

Similarly, deer lack upper incisor teeth because they have antlers (*P.A.* 663b35–664a8). Herodotos's story about lion reproduction was explicitly dismissed, although he was not named as the source (*Historia Animalium*, 599b2–12, Peck translation):

The story which is told about the lioness losing her uterus in parturition is nonsense, and was made up to account for the scarcity of lions,

> [which] *are not found in many places—in the whole of Europe it occurs only in the tract of country between the rivers Acheloös and Nessos. The lioness' cubs are so small when born that at two months they can barely walk. Lions in Syria bear five times: five the first time, then one fewer each succeeding time; after that they bear no more.*

However, the credibility that the Lyceum gained by dismissing Herodotos' story it lost by accepting the inaccurate Syrian report.

Aristotelian writings apparently contain the earliest extant discussions of age determination and longevity in animals. The data come from observations on both domestic and wild species, although there is more on the former. Some breeds of dogs reportedly live only 10 years, others 15, and some people credited Homer's claim that Odysseus's dog died in its 20th year. In addition, data came from actual experience with particular dogs, "A dog's age [can be] told by inspecting its teeth: young dogs have sharp, white teeth, older dogs black blunt ones" (*H.A.* 575a11–13). Teeth were also used to age horses, supplemented as they aged by checking the cheeks, which were pulled away from the jaw. Reportedly, one horse had lived 75 years and a mule 80 years (*H.A.* 578a). Hunters determined the age of stags by their antlers: spikes appeared in the second year, antlers bifurcated when they appeared in the third year, trifurcated in the fourth year, and so on until the sixth year; after that, age was estimated by the number and wear of teeth (*H.A.* 611a31–b5). There was also information on age of sexual maturity, gestation periods, and number of young produced at one time—all correlated with physiological constraints rather than with the need for survival.

Animal plagues were both surprising spectacles and serious threats to livelihood and food supply. When a plague of mice or voles struck field crops, they left little for the farmer, despite his fumigating, digging them out of the ground, and turning swine loose on them. *Historia Animalium* reported an ecological cause for their disappearance: "Rain is the only thing which can control their attacks—and then they disappear with speed" (580b 25–27). The causes of the plagues were unknown; however, there were some physiological reports that seemed relevant: "There is a place in Persia where when a female mouse is cut open the female embryos are seen to be pregnant. Some people say, indeed stoutly maintain, that, if they merely lick salt, mice become pregnant, without any copulation" (580b 28–581a 1). Locust plagues could also be understood as resulting from the interaction of reproductive factors and climate (556a 8–13).

Historia Animalium has a number of accounts of parasites: deer have maggots living in their heads; lice and fleas lay eggs that do not hatch, for adults arise spontaneously from putrefying matter or excrement; the itch-mite forms under the skin of people who have a great deal of moisture in the body, and some people have been killed by it; balliros and tilon fish develop intestinal worms at the time of the dog–star; dogs with rabies can transfer it to other animals by biting them; when hounds have worms they eat standing grain; cuckoos lay eggs in other bird's nests. The relationship between tiny white crabs and pinna was known, without it being clear whether it was parasitic or commensal.

Ancient Greeks did not understand plants as well as they did animals because their knowledge of physiology and reproduction was quite limited. They knew that some species do best in sunlight and others in shade, but they did not understand the function of leaves. Nevertheless, the botanical writings contain abundant ecological observations, interpreted by physiological necessity. *Enquiry into Plants* and *De Causis Plantarum* both assumed that plants draw nutrition from soil, water, and winds. They had learned from Mesopotamia that dust from male date palm flowers must be shaken over the female flowers before fruit will develop (*Enquiry*, *De causis* II.9.15). Greek assumptions that some other tree species also have sexes was based upon the fact that female trees bear fruit and male trees do not. This awareness did not lead to a general understanding of sex in plants or of pollination. The Lyceum also knew that fig fruits do not grow unless small insects are present to cause caprification (*Enquiry* II.8.2, *De causis* II.9.5); and that mistletoe and *Viscum* grow on other plants, which was compared to the situation of pinna and its white crabs, and the cuckoo laying eggs in other birds' nests (*De causis* II.17.8-10). There was mention of birds eating berries and depositing the seeds elsewhere, where they grow, and this was compared to jays and other birds burying acorns in the ground, yet no generalizations emerged. Insect galls attracted enough interest to be described on various plant species, but their cause remained unknown. Other discussions with ecological content include species distributions, both in habitat and in geographical range. Some aquatic species are found in the seas, others in lakes or streams. Some land species grow in marshes, others in rocky soil, others in rich soil, some in shade and others in open fields, some on mountains and others in lowlands. There is information on seasons of flowering and fruit, and information on propagation. Concerning longevity, it is reported that aquatic plants, like aquatic animals, are shorter-lived than terrestrial species, and that cultivated plants do not live as long as wild ones (*Enquiry* IV.13.1). There are reports on long-lived trees, but use of tree rings for dating them was unknown. There is much more practical information on plants than on animals in the zoological volumes. This includes uses of different kinds of woods and raising food crops in *Enquiry*. More than half of *De causis* is devoted to agriculture. These works also include information on insect infestations of both crops and trees. In both the plant and animal works, the possibility of some insect and small plant species arising spontaneously was accepted.

Some scholars collected information from farmers, fishermen, hunters (or sometimes indirectly, as for example, from Xenophon's *On Hunting*), and others who had experience with the natural world. Scholars on Alexander's expedition of conquest sent back information and possibly plants, and the information was organized and conclusions drawn. This is definitely full-fledged science; yet a modern reader may wonder whether the intellectual organization, and even some of the interpretations, were not in place before much data was acquired.

The conjecture and refutation that Karl Popper found among some early natural philosophers pretty much disappeared at the Academy, and reappeared at the Lyceum in a weak form, mainly as history of science: this is what early natural philosophers believed, this is why we disagree, and this is what we believe instead. In addition, Theophrastos did question the extent of the teleological principle in his *Metaphysics* by asking what is the purpose of tides and male nipples; and he questioned whether fire is really the same sort of element as earth, air, and water in *De Igne*. And Strato—third head of the Lyceum and the earliest known experimentalist—questioned aspects of Aristotelian physics in his (lost) treatise, *On Motion.* However, these reservations were of too limited scope in comparison to the comprehensiveness of Aristotelian theory for their skeptical comments to constitute refutations.

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Why Are My Brilliant Research Findings Not Utilized in Ecology Textbooks?

You and your colleagues have worked diligently for several years to complete an important ecological study. You have published the results in a high-impact ecology journal, and have received favorable comments from other scientists in your discipline, and good feedback when you have given talks at national and international meetings. But when a new ecology textbook comes out, your research is not highlighted as an example to students of the next generation, and you are disappointed. Why might this happen?

I have just finished revising my *Ecology* book for the fifth edition. In the process, I have read or scanned about 6000 articles in the ecology literature. Of these I have selected 425 articles published since 1995 to illustrate and explore ecological concepts in population, community, and ecosystem dynamics. From this experience, I can give you a partial and biased answer to your question: Why was my research not selected for use in this particular ecology textbook?

There are at least three hypotheses to explain this lack of selection: (1) This ecology textbook is clearly hopeless and should not be adopted by any right-thinking college professor. This hypothesis may well be correct, but it suffers somewhat from the "shoot-the-messenger" syndrome, and I will have to evaluate it later when the market reports of book sales come in. (2) Your research is clearly hopeless and ought not to be included in any textbook because it does not illustrate any ecological concept clearly, or its results were inconclusive. I will reject this hypothesis because if you have read this far, the explanation clearly does not apply to your research. And, in general, there is much excellent research that is not reported in textbooks. (3) Your research is excellent, but was not reported in a way that will attract the attention of textbook writers. It is this third hypothesis that I wish to explore here, and I propose that it is, in most cases, the explanation for your problem.

A textbook writer has at most one or two paragraphs, or one figure or one table, to report your findings. Often it may be less: one sentence and one table or figure. I suggest an exercise to illustrate the textbook writer's dilemma. Read a paper in *Ecological Monographs* (for example) that is not directly in your field of expertise, and try to extract a 1–2 sentence summary of findings reported in this paper, along with one figure to illustrate the key results. You will find you cannot do this for most papers because the authors have not provided a succinct abstract or a summary diagram to illustrate their findings. Now go back and look at *your* key papers and see if you have done the same thing.

You may well argue that scientific papers are written to impress one's peers and associates, not to communi-