PARASITE SOUP: FAITH AND SCIENCE IN THE HISTORY OF PARASITOLOGY

by Jeremy D. Blaschke

Abstract. Popular conceptions of the relationship between science and religion often emphasize the mutual compatibility but segregation of these two authoritative domains. However, along the uncertain border between these two spheres exist many questions that appear to influence and be influenced by both scientific and theological evidence. For biologists, the gruesome details of parasite biology and behavior illuminate a shadow in nature where science and theology must intersect—*did a loving creator God design parasites?* Here, I explore the writings and experiments of the early fathers of parasitology who established and matured a new scientific discipline while deeply integrating their theological beliefs with their scientific investigations. I argue that modern scientists can, and often should, follow in the footsteps of our scientific forefathers and intentionally allow our theological presuppositions to inspire scientific experiments, especially in these important boundary-crossing subjects. In doing so, I believe we may advance scientific understanding of the way reality is by asking unexpected questions and uncover deeper truths about the character of God as revealed in his intricately complex and eternally fascinating creation.

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Parasite Soup

In 1855, a German physician and amateur parasitologist named Friedrich Küchenmeister delivered some home-made soup to condemned prisoners. Hidden within this seemingly gracious offering were numerous parasitic cysticerci—fluid-filled bladder worms destined to develop from their dormant larval states into mature tapeworms inside their human host. A few weeks later, the prisoners were executed and Küchenmeister dissected the corpses, discovering to his morbid delight several small adult tapeworms embedded in the intestinal mucosa of their now deceased host

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(Küchenmeister 1855). This unnerving (and deeply unethical) tale is the story of the first experimental evidence connecting the strange worm-filled globs of "measles" within uncooked pork to the adult *Taenia solium* tapeworm (Cox 2002).

Surprisingly, this result was a *theological* triumph for Küchenmeister as well as a scientific one. He was embroiled in a vigorous dispute with one of the leading parasitologists of the day, Carl von Siebold, regarding chance versus design in nature—a boundary-crossing conflict that influences both science and faith. The details of this debate will be discussed below, but for now, I want to emphasize that Küchenmeister's beliefs about the character of God inspired him to ask novel *scientific* research questions that required him to develop novel experimental methods. As historian of science Farley put it, "A theological accident had produced a new science" (Farley 1972, 123).

To early natural philosophers like Francis Bacon, Carl Linnaeus, and John Ray, who were developing what would become the scientific method and establishing robust traditions of precise observations coupled with repeated experimentation, Küchenmeister's integrated model of science and faith would be expected and applauded (Lindberg and Numbers 1986; Harrison 2009). Many of our scientific progenitors were explicitly inspired to explore creation by their resolute faith in an orderly law-like universe designed to perfection by a Grand Architect (e.g., Ray 1714)—an idea widely popularized by Paley ([1802] 1829) in his *Natural Theology*.

However, this way of practicing science might sound remarkably strange to a modern reader who is heavily influenced by either the now widely criticized Draper-White "conflict-thesis" or the much more commonly held position of NOMA (Nonoverlapping Magisteria) for dealing with the complex relationship of science and religion. In 1997, Harvard paleontologist Gould outlined his famous case for separate domains of authority: "The net of science covers the empirical universe: what is it made of (fact) and why does it work this way (theory). The net of religion extends over questions of moral meaning and value. These two magisteria do not overlap, nor do they encompass all inquiry" (Gould 1997, 4). In this way, Gould argues that science and religion are compatible, and conflict only arises when one domain inappropriately undermines the authority of the other.

Gould wisely recognized the challenges of implementing NOMA in practice, "the two magisteria bump right up against each other, interdigitating in wondrously complex ways along their joint border. Many of our deepest questions call upon aspects of both for different parts of a full answer—and the sorting of legitimate domains can become quite complex and difficult" (Gould 1997, 4). These "border-bumping" issues often generate heated debates among scientists and spread to the public sphere as well. In a thought-provoking paper, philosopher Moritz (2009) discusses

several fascinating examples of these conflicts including debates on the evolution of morality, the metaphysical implications of an expanding universe, and the motivations for stem cell research and disease eradication. Moritz endorses Russell's method of Creative Mutual Interaction as a better description of the relationship between faith and science than NOMA, saying, "This is precisely what we see in the cases described above where theological motivations and presuppositions enter robustly into the history and everyday practice of science" (Moritz 2009, 373).

Building on these arguments, I offer that in almost every subdiscipline of science there exist boundary-crossing concepts that rightly inhabit both magisteria. As such, it is appropriate, even responsible, for religious scientists like Küchenmeister and myself to consider theology when designing experiments to investigate these specific issues. I will illustrate this point through my own experience as a Christian parasitologist and by investigating the remarkable history of my discipline.

The Nature of Science

As a twenty-first-century scientist, I have been trained, at least implicitly, under a NOMA philosophy—to practice my discipline divorced from my beliefs about God. How could my faith possibly affect how I number the bristles on the abdomen of a feather-footed fly (*Trichopoda*) to discern one species from another? What does God have to do with the number of unique host species attacked by the cricket-assassin wasps (*Rhopalosoma*) of West Tennessee? I would not argue that the actual *methods* of science are different because of my faith—I count bristles and monitor wasp populations the same as any other entomologist. However, scientific investigations often begin with curiosity and the questions of science are almost always influenced by *a priori* beliefs about *the way reality is* (e.g., given the evidence at hand, I believe there are at least two species of feather-footed fly in that meadow, or that cricket-assassin wasps are generalist parasitoids rather than specialists). Our initial beliefs then inspire specific scientific hypotheses (e.g., the black morphs and gold morphs of *T. pennipes* will form distinct genetic clades in a phylogenetic analysis). Directed by *a priori* beliefs, a mystery is pursued, an experiment forms, and science emerges.

In turn, science is capable of disclosing small pieces of reality—the way things really are—and thereby directly support or contradict one's initial presuppositions. Primary beliefs often agree with reality as revealed through a particular experiment (cricket assassin wasps do appear to be generalists: Miller, Benefield, and Lounsbury 2019). Other times, they do not (unfortunately, there were not two species of feather-footed fly in that meadow). When *a priori* beliefs about the reality of nature are challenged by scientific results, a fascinating interplay occurs. How strongly held are those initial beliefs? How robust was the scientific analysis? Perhaps the

number of species of feather-footed fly is of little consequence. On the other hand, maybe it is and perhaps with more specimens or a different analysis of genetics or morphology, I might someday discover evidence confirming the existence of that elusive second species of feather-footed fly. This nuance in how science and belief interact is extremely important when analyzing evidence in boundary-crossing questions.

Sometimes, experimental evidence is overwhelming enough to call into question even the most significant of one's *a priori* beliefs, as I will examine below in the history of parasitology and spontaneous generation. Other times, a scientist is so convinced of the veracity of their opinions, they will spend decades investigating new paths, designing new experiments, and wrestling with contradicting data as they strive for vindication (e.g., Alfred Wegener on continental drift or Lynn Margulis on endosymbiosis). Thus, science represents a perpetual dialogue between one's *a priori* beliefs and the results of their experiments, each of which evolves in relation to the other. No experiment is formed naked of underlying presuppositions, and very few beliefs can withstand the gradual accumulation of overwhelming contradicting evidence. Why then, should we not intentionally allow some of our most significant beliefs about reality—our theological presuppositions—to direct our scientific investigations of that very reality?

The Problem of Parasites

One of my most tightly held beliefs is that reality was ultimately crafted by a loving creator. Pressing in on this belief is my professional expertise in parasitoid behavior and evolution. Parasitoids are insects that lay eggs on or in other creatures. After hatching, the parasitoid larvae slowly consume the host alive. Darwin famously wrote about these beasts to his devout Christian friend Asa Gray: "I cannot persuade myself that a beneficent and omnipotent God would have designedly created the Ichneumonidae with the express intention of their feeding within the living bodies of Caterpillars" (Darwin [1860] 2020, 3rd par.).

Having studied some of these ichneumonid wasps myself, I have great sympathy for Darwin's struggle. My scientific investigations of the way reality *is* present extraordinary challenges to my expectations of the way nature *should be* if it were created by a loving God. My experiments explore what and how—I am constantly perplexed by the *why*. This is a significant boundary-crossing concern. Keeping these magesteria separate as Gould suggests seems impossible; they clearly overlap in significant ways. On the surface at least, it appears I must choose between two mutually exclusive options: parasites are disturbingly harmful entities that cause net damage to creation *or* God is a careful, loving, and sovereign designer.

For millennia, great philosophers have wrestled with the dilemma of justifying the existence of a loving God given the reality of suffering in nature. In the last 100 years or so, theodicies have struggled to keep pace with the terrible mountain of scientific evidence that has exposed a brutal nature far more vicious than we once imagined. Myriads of parasites take control of the mind of their hosts (Libersat, Delago, and Gal 2009; Gal and Libersat 2010), castrate their hosts (Baudoin 1975; Lafferty and Kuris 2009), and manipulate host behavior to seek out their own predators or drown themselves (Thomas, Schmidt-Rhaesa, and Martin 2002; House, Vyas, and Sapolsky 2011). Social groups of animals are plagued by heart-wrenching siblicide (Mock, Drummond, and Stinson 1990) and infanticide (Hrdy 1979), intrafamilial cannibalism (Fox 1975), and violent forced copulations (Clutton-Brock and Parker 1995; Knott and Kahlenberg 2007). Not only are the incidences of what philosophers term "natural evil" (e.g., Rowe 1996) more abundantly recognized, but the emotional and mental capacity for nonhuman animals to suffer as a consequence of these cruelties is becoming more obvious (e.g., Gregory 2008; Linzey 2013).

None of the studies cited above were conducted with the express intention of providing pertinent data to the theological problem of natural evil, yet the implications are readily apparent. Theists must now contend with more and greater evil than before. Are scientists of faith simply destined to wait for the philosophers to arrive at a satisfactory solution or can we also contribute to this important discussion through our own discipline—not as philosophers but as scientists? In other words, *can science pursue theodicy?* Philosophy relies on science to discover facts about nature—wholesome or grotesque as they may be. I offer that philosophy in turn can and should direct scientific investigations in pursuit of particular evidence in favor of one theological explanation or another. Specifically, I suggest that theistic-minded parasitologists should intentionally use their scientific expertise to generate novel data pertinent to the persistent boundary-crossing theological problem of parasites.

To make this case, I will review three representative debates that significantly shaped the history of parasitology while modeling this mutually beneficial relationship between science and theology: Bloch versus Drummond on design and chance in parasite infections, Vallisnieri versus Andry on the ultimate source of parasite eggs, and Küchenmeister versus von Siebold on the existence of "stray" tapeworms. I will then briefly discuss the nineteenth-century rift that bifurcated natural philosophy into two distinct disciplines (science and theology) and ultimately resulted in the modern scientific practice of experimentation without direct reference to underlying presuppositions. Finally, I consider how we may return to the early interdisciplinary origins of parasitology by intentionally allowing our *a priori* beliefs about God to direct specific scientific investigations. In

doing so, I believe we may advance scientific understanding of the way reality is by asking unexpected questions and uncover deeper truths about the character of God as revealed in his intricately complex and eternally fascinating creation.

The Doctrine of Design, Heterogenesis, and Parasite Biology

Before engaging with the detailed debates among these early parasitologists (16601860), establishing some context is necessary. The paradigm most natural historians of the time were operating within relied on the doctrine of design which stated that every natural event required a cause and every cause flowed from a divine purpose (Aquinas 1964, 1.116.1; Lüthy and Palmerino 2016). It was through the apparent design in nature that the existence of God was all but assured. In the words of Ray, this truth made discovering the works of God in creation part of the regular "business of a Sabbath-day" (Ray 1714, 170). And as the British popularizer of natural theology Paley described it: "there cannot be design without a designer; contrivance, without a contriver; order, without choice; arrangement, without anything capable of arranging; subserviency and relation to a purpose, without that which could intend a purpose; means suitable to an end, and executing their office in accomplishing that end, without the end ever having been contemplated, or the means accommodated to it" (Paley [1802] 1829, 10).

This reasoning seemed so universally appealing that when discussing the possibility of denying design in nature the physician Carmichael wrote: "It is scarcely possible to conceive, that opinions [opposing design] can find an asylum in any rational mind; even the last remnant of reason that sticks to a maniac would intuitively reject them" (Carmichael 1818, 94). Even the famous antichurch rationalist, Voltaire, recognized the obvious design in creation as indicating an ultimate Creator: "Every work which shows us means and an end, announces a workman; then this universe, composed of springs, of means, each of which has its end, discovers a most mighty, a most intelligent workman. Here is a probability approaching the greatest certainty…To affirm that the eye is not made to see, nor the ear to hear, nor the stomach to digest—is not this the most enormous absurdity, the most revolting folly, that ever entered the human mind?" (Voltaire 1824, 323; 334).

Evidence for design was discovered everywhere in abundance, from the wings of butterflies to the physiology of the human heart. Every animal and structure was formed by God with purpose to fulfill its duties happily and without ceasing. No significant change occurred to a species' morphology or habits over time, no species ever went extinct, and chance was nowhere to be found in the sovereign workings of nature. These *biological*

hypotheses flowed from *theological* presuppositions about the character of God and what may be derived from that character: namely, that chance was discordant with the existence of God. Every effect had a cause and that cause was God's beneficent design.

Another foundational, if highly contentious, philosophy during the early-modern period was that of spontaneous generation or heterogenesis—the idea that living things may emerge from living or once living tissue (not to be confused with abiogenesis—life arising from inorganic matter). Fungi were seen to generate from decaying organic matter and parasites were thought to arise from intestinal secretions or lymphatic tissue just as a seed or fruit was produced according to the unseen internal laws of a plant.

The famous maggot-exclusion experiments conducted by Redi (1668) should have spelled the end for heterogenesis as an explanation for the source of living things. Redi demonstrated that fly larvae only arise from meat that has had previous contact with adult flies. Prevent the adults from laying eggs on the meat and no adult flies will be generated spontaneously from the meat itself. While heterogenesis was dismissed as the solution to insect origins, parasites were still a mystery. Their small size, inaccessible habitats, and complex multihost life cycles allowed parasites to persist as one of the last bastions of evidence in favor of spontaneous generation for almost 200 years after Redi's experiments. I offer a brief outline of one such life cycle below to demonstrate the complexity these early scientists were attempting to unravel.

Among the first complete life cycles to be fully deciphered was that of the pernicious beef tapeworm, *Taenia saginata*. This infamous creature begins its adult life by attaching itself to the intestines of its human host with a spiny sucker-adorned scolex. As the tapeworm grows and matures, segments called proglottids begin to form posterior to the scolex creating an ever-increasing chain of segments that can reach a disturbingly enormous length (>10 m!). Predigested nutrients stolen from the host are readily absorbed through the tapeworm's outer layer of skin which operates like an inside-out intestine. Eventually, each proglottid will develop testes *and* ovaries. Sexual reproduction occurs between adjacent proglottids of the same tapeworm or with another individual inhabiting the same host. Fertilization occurs inside the proglottid which now swells with maturing embryos encased in hardened shells. Bursting with hundreds of eggs, the gravid proglottid separates from its parent and is washed away with feces outside the host into the external environment.

Once in the open air, the gravid proglottids are capable of voluntary movement and will wriggle and squirm as they release their infective eggs into the grass. If a hapless bovine happens to wander along, it may ingest hundreds of microscopic eggs as it leisurely enjoys a grassy meal. Inside the intestines of the cow, the eggs hatch and tiny tapeworm larvae burrow

out of the intestine into skeletal muscle tissue. Now in a warm and safe location, the tapeworm larvae transform into *cysticerci*—fluid filled sacs of worms that give the meat a knobby distorted appearance. When an unlucky human eats that "measly" beef without thoroughly cooking it, the cysticerci are able to survive the hostile gauntlet of stomach acid and reach the small intestine intact. Hidden within the cysticerci is an invaginated scolex which now unfurls and deeply embeds itself within the intestinal mucosa of its final host. The tapeworm has found its final resting spot and will spend the next several years pilfering nutrients from its host, prodigiously producing proglottids, and generating thousands upon thousands of infective eggs.

The extraordinary journey of *T. saginata* is surely one of the most complicated life histories of any living thing. We have inherited this hard-won knowledge from the fathers of parasitology, Redi, Vallisnieri, Küchenmeister, and hundreds of others who labored for *centuries* to unravel the persistent mystery of intestinal worms. Tapeworms are remarkable creatures who reproduce sexually as adults and, in some species, asexually as larvae. Their eggs are microscopic and found nowhere near the adults. They require two completely different hosts to survive and within these hosts their habits and morphologies are vastly different. Working with rudimentary microscopes, no conception of such radical metamorphosis, and fighting an uphill battle against proponents of heterogenesis, the first parasitologists were mired in an experimentally challenging and theologically controversial discipline.

What is especially inspiring about this fascinating period of history is how often these scientists wove their philosophical beliefs into their experiments. For many of them, their beliefs about the character of God or how nature *must be* if created by God, directed which experiments were conducted and how the results of these experiments were interpreted. They discovered truths about nature and about God by allowing these two disciplines to interact in an intentional and robust way.

Bloch versus Drummond

In the early eighteenth century and continuing through the mid-nineteenth, the newly burgeoning discipline of parasitology revealed a complex narrative that significantly stressed the established philosophy of natural theology. Here were creatures that appeared to generate themselves at random from all sorts of organisms and whose existence seemed antithetical to a kind and loving designer. Two main ideologies developed during these debates on the generation of worms (Farley 1972; Grove 1990). The *internalists* represented the traditional belief that worms developed spontaneously from within human tissue itself (i.e., heterogenesis),

while the *externalists* advocated for some form of "seed" apart from the host that would eventually develop into a parasite once located within an appropriate host.

In 1780, the Danish Royal Society of Copenhagen offered a prize essay contest on the much-debated topic of parasitic beginnings. Second prize went to Johann Goeze, a German pastor and amateur parasitologist who was making a name for himself with precise observations of the internal anatomy of tapeworms. Another German, Bloch won first prize for his clear and concise essay detailing 12 proofs that parasitic worms "are destined by nature to live only in other animals" (Bloch 1782, 84). The significance of this point was that the presence of worms in intestines or brains was not *accidental*. There were no free-living forms of tapeworms that burrowed into hosts the way parasitoid insect larvae did. There were in fact, no known free-living *anything* (adults, larvae, eggs, and so on) that indicated an external source of infection. Both essays made reasonable and compelling cases for the spontaneous origin of worms.

The historian Farley describes the strength of their arguments in favor of internalism: "In the lawful, ordered, mechanical world of the eighteenth century, such parasites could not possibly arrive at these precise locations by chance, they had to be generated there. No other conclusion was possible" (Farley 1989, 51). Bloch also considered the biogeography of parasites as another significant proof of their spontaneous generation. Unlike many contagions of the day like smallpox or plague, parasite infections did not seem to have epicenters. Each village, town, and city had infected people whose neighbors remained uninfected. Infections could be found in the old and the young—significantly, even among the unborn still in their mother's womb! Given the widespread geographical disparity in location of parasite hosts and lacking at the time the concept of intermediate hosts which may swim, fly, or be carried far away from their origin of infection, Bloch justifiably reasoned that each infection must arise within the host itself rather than pass from host to host (see also Bremser 1819). Importantly, Bloch arrived at this conclusion with considerable input from his theology. What seemed to be the alternative to internalism—that hosts were *randomly* infected by some invisible external mechanism operating without reason—went against Bloch's conception of a divinely governed and orderly natural world devoid of random chance.

According to Bloch and allies, God's design of parasites inhabiting human intestines meant that their existence must be *necessary* for the harmony of nature. Bloch considered this an illustration of the Divine Architecture of the universe: "These same worms, I say, seem to be placed expressly in our interior, to prove that we are destined to nourish animals in our turn, as they nourish us" (Bloch 1782, 83). In this way, his response to the problem of evil was to attribute intentionality and *purposeful design* to even the disgusting and harmful in creation. Notice especially that he

chose this path instead of advocating for a greater role for chance to play in God's design of nature. This antagonism to chance was one of the most consistent features of the debates on the origin of worms. Interestingly, it was a perceived overreliance on chance in nature by the internalists that caused many scientists to favor externalism instead.

Observing the same evidence of apparently random infection as Bloch and other internalists, the externalists were concerned that spontaneous generation required nature to be rife with random accidents and uncaused effects (Farley 1972). If tapeworms naturally arose from within human intestines, why was not every human host to one? How could the effect "life," arise uncaused from tissue? The externalist Priestley reasoned by analogy that since heterogenesis had been disproven in most life forms, it could not occur in any life forms. To suggest otherwise opposed the doctrine of design: "all changes that take place contrary to the observed analogy of nature must be events without a cause; and if one such event can take place, any others might, and consequently the whole system might have had no superior designing cause; and if there be any such thing as atheism, this is certainly it" (Priestley 1809, 129).

Drummond, Professor of Anatomy and Physiology in Belfast, recognized in parasites exquisite morphologies that indicated to him the clear mark of design. He presented a powerful design-based argument against the internalist position by pointedly detailing the complex internal structures and precise adaptations of parasites that he saw as "perfect and admirable" (Drummond 1841, 103). Similar in motivation to Bloch, but with opposite conclusions, Drummond argued that *internalism* relied on chance: "In considering the formation of any animal, we cannot move a step without reference to an all-powerful architect; in every structural part, in every function, in every action, in every instinct of such animal, we perceive so great a degree of contrivance, creative power and wisdom, that the conviction is forced upon us that these cannot be the work of chance" (Drummond 1841, 104).

After beautifully presenting the complexities of functional mouths, complex integuments, and internal systems discovered in various intestinal parasites, Drummond sarcastically offers that the logical end point of internalism would be that parasites somehow know the future before they even exist:

> [I]t must be evident that the effused lymph or clot has the power of metamorphosing itself not only into a worm, but into a worm of either sex, as it may choose to determine; and it is equally obvious, that two clots must consult together in order to determine into what species they shall by mutual agreement become transformed. This must be absolutely necessary; there must be a predetermined arrangement between the two; for without this millions of males might be formed without one

> corresponding female, and millions of females be condemned to live and die in single blessedness (Drummond 1841, 107).

Drummond and his externalist allies routinely used the doctrine of design to counter their worry that internalist philosophy allowed for an incipient atheistic attack against the purpose-filled creation of natural theology. By the time Drummond was writing, externalists had been diligently pursuing the invisible connecting "germs" they believed *must* exist without much success for over 150 years. Their perseverance over the decades was grounded on the strength of their theological convictions rather than empirical evidence.

As represented by Bloch and Drummond, both internalists and externalists were inspired by their theological convictions to pursue experiments that would substantiate their scientific positions. For the internalists, they required a counter to the devastating uncaused effect critique. This motivated them to research potential mechanisms by which a parasite may naturally emerge from human tissue. By studying diet, age, and many other health-related variables, they uncovered important features of human anatomy, physiology, and development. For their part, the externalists were inspired to search for that ephemeral infecting spore and the path it traveled from one host to another. This led to numerous discoveries of new species, insights into diverse ecosystems, and technological inventions designed to observe the microscopic world.

Interestingly, the design arguments espoused by both camps ultimately proved untenable as chance was eventually acknowledged to have a tremendous influence in natural processes. Current theologians tend to rescue the providence of God in nature by defining *ontological* chance as categorically different than *epistemological* chance and by invoking secondary causes rather than denying the existence of randomness altogether (e.g., Reeves 2015). The presuppositions of Bloch and Drummond reveal that discovering truth about reality is not always contingent on the veracity of one's motivating presuppositions. Even if our presuppositions prove incomplete or invalid in the future, they can still inspire novel research questions and advance our knowledge of reality if they are allowed to direct scientific investigations in the present.

Vallisnieri versus Andry

In his *Letters to a Young Naturalist*, Drummond (1831) responds to the claim made by some natural historians that female ostriches are uncaring mothers who often lay an excess of eggs which they are unable to cover and so are destined for death. Drummond's natural theology claimed that animal mothers were beacons of the paternal love of God for us—there could be no uncaring mothers in nature. Therefore, the supernumerary eggs found in ostrich nests must be beneficently and intentionally laid

by mother ostriches because they were vital to the nourishing of ostrich chicks (he postulated that the extra eggs were in some way different than fertilized eggs). Drummond describes the alternative as promoting regular occurrences of "errors" in nature, which he considered "abhorrent to everything we know of her ways" (Drummond 1831, 61). He summarizes this view of natural theology: "We everywhere find design in the works of creation, and every thing tending to produce some good end; and I must still impress upon your mind, that any contradiction to this is only apparent, and that did we understand its real nature, it would be found a perfection, in place of an error" (Drummond 1831, 62–63).

While Drummond was not discussing parasites specifically, he represents well the typical response to perceived challenges to beneficent design—they can only be due to our ignorance. Poor design cannot be found in nature. The same problem of randomness and waste in nature, particularly in regard to parasite eggs and offspring, became a significant source of conflict among proponents of externalism. As we know now, parasites like tapeworms or liver flukes possess some of the most extraordinary reproductive potential of any living thing. An adult *T. saginata* tapeworm may contain over 37 million eggs in its proglottids at any given time (Schapiro 1937) while liver flukes can generate over 4,000 eggs per worm per day (Kim, Choi, and Bae 2011). Such massive productivity is necessary as each egg has only a minute chance of completing the complicated circuit of life that nature has predestined for it. Drummond would not approve.

In the early eighteenth century however, these facts had not yet been uncovered, and externalists, who were convinced that life can only arise from some sort of seed, had to rely heavily on philosophy rather than scientific evidence to support their position *contra* spontaneous generation. Continued failure to decipher this great mystery led to a division within the externalist camp itself, once again due to the specter of chance in nature. Some, like Nicholas Andry, dean of medicine at the University of Paris, advocated for an external *environmental* source of parasite eggs, which infected their hosts through food, water, or air. Andry describes his position as follows: "Worms breed in the bodies of men and other animals, by means of a seed that enters there, in which those worms are enclosed…there is nothing in Nature, into which the seeds of insects [i.e. parasites] may not insinuate itself, and that a great Quantity of them may enter into the body of Man, as well as into those of other Animals, by means of the Air and Aliments….they likewise enter the Flesh very often by the outside….the skin is full of cavities" (Andry [1700] 1701, 8).

New descriptions of what appeared to be abundant eggs inside each tapeworm proglottid seemed to support Andry's environmental externalism. However, other externalists struggled with the philosophical ramifications of the newly discovered egg-filled uteri of parasites and the

disparity in number between eggs and adults. Were the eggs to be released haphazardly—without *purpose*—into the environment in hopes of chance infection? According to these thinkers, if God created tapeworms to inhabit human intestines, then human intestines would be the destiny of each tapeworm egg—God makes no accidents.

To escape the theological menace of a chance and wasteful creation as well as explain the disproportionate abundance of parasites in children, many externalists found refuge in *vertical transmission*. One of the most influential of these proponents was Vallisnieri, an Italian physician and naturalist who was among the first advocates for rigorous experimentation in biology. Vallisnieri proposed that parasite "seeds" are passed from parents to their offspring through the placenta, lactation, or initially through sexual intercourse (Vallisnieri [1713] 1721; Bremser 1819). Indeed, seminal fluid seemed to be full of tiny worm-like creatures that could potentially grow to enormous sizes within their destined host (de Gols 1727). In this way, there never occurred an accidental infection and eggs were never wastefully deposited in the environment. Parasites were always and only discovered in the exact habitat for which God had created them.

Preformation was another popular idea during this time. Malebranche, building on ideas from St. Augustine and others, described preformation as: "all the bodies of men and beasts, which shall be born or produced till the end of the world, were possibly created from the beginning of it" (Malebranche [1673] 1694, 14). In this view, Eve—the mother of all living—contained in her ova all the forms of all humans that were ever to be. Vallisnieri ([1713] 1721) applied this concept to human parasites in a *double preformation* theory that extended the origin of worms to the original human couple as well. Accordingly, Vallisnieri's own parasites came from his mother and hers from her mother and so on, all the way back to Eve.

However, by solving the philosophical difficulty related to random infection and wasted eggs in this way, Vallisnieri encountered yet another theological problem, one which his contemporary LeClerc described as "The most difficult Question…yet to be discussed, to wit, From whence the first Seed of Worms is derived" (LeClerc [1715] 1721). The problem was that Adam and Eve were created *good*, and suffering from parasites seemed incompatible with that concept. Vallisnieri described the problem and some potential solutions: "It is not reasonable to suppose that God would have placed the first worm in [Adam's] body, forasmuch as Man in this state of innocence was to be free of all kinds of diseases….But if on the other hand, after the lapsed state of Adam, we allow that worms were formed by God…. a greater difficulty will arise….for….it will follow that God made a new creation of worms, which is contrary to Holy Writ; since God hath taught us, that before Man was made, all other animals were created" (Vallisnieri [1713] 1721, 35051).

Vallisnieri rejects two ideas. The first is that God would have created Adam and Eve with harmful parasites, the second is that God would create parasites afresh after the Fall. His thought-provoking solution was that parasites were created within Adam and Eve but had a *positive* role in the original design of creation: "Adam could support and feed these insects [= parasites] which had a mind to live together quietly and friendly, as we may say; if anything superfluous remained, that they might eat…and would not transgress their bounds or eat holes through the sides of the gut . . . but would rather by gently licking the parts and by healing them, do their host a kindly office. . . . But this happiness of Adam was but of short continuance, for disobeying God, all things were suddenly changed; so that these worms were made the Ministers of Divine Justice and raised an insurrection upon him" (Vallisnieri [1713] 1721, 35253).

Thus, Vallisnieri combined his scientific beliefs about externalism and vertical transmission with his theological beliefs about God's goodness, beneficent design, and the impact of the Fall to create an inventive solution to a complex problem. His remarkable conclusion was that God must have created parasites within the bodies of Adam and Eve at the instant of their creation. However, because of the suffering wrought by these creatures in the present, their very nature must have been *different* in the past. This was quite an extraordinary, even prescient, claim for a time when species were seen as immutable.

This idea sparked intriguing discussions among parasitologists about the state of Adam and his potential parasite companions. de Gols speaks cautiously but optimistically about Vallisnieri's suggestion, agreeing that: "And as the Perfection of the great World is, that it is fill'd with various Inhabitants, why therefore may not this little World [i.e. the human body] have Variety too? It will not be so injurious to the first Parent, to say, That his Body might have been an Hospital of various and wonderful kinds of Insects; which, while he was innocent, ought not to contribute to his Destruction, but make him more complete, and yield him Honour: Nay, they might do him a great Kindness" (de Gols 1727, 6869).

LeClerc is more critical, offering that the "paradoxical" ([1715] 1721, 354) opinion of Vallisnieri may apply well to certain parasites like *Taenia* or *Ascaris*, but what about lice? Would lice also be made inhabiting Adam's hair? Arguing a 100 years later from the internalist position, Bremser applied LeClerc's critique even more fully to include all human parasites—flukes, tapeworms, nematodes, and arthropods—and decried such an Adam as a "wahre Wurmnester" (true worm nest)—a host to hundreds of parasite species at once (Bremser 1819, 30). Bremser offered a perceptive, but what he considered paltry, potential solution: all parasites—tapeworms, roundworms, and flukes included—could have arisen from one or a few common ancestors. However, he concludes by saying that anyone who could believe such a ridiculous notion "would not, in

consequence, regard a man to be devoid of his sense who believed that any animal, an elephant, for example, would after a time become the father of whales, lions and kangaroos" (Bremser 1819, 30). Ironically, just such a ridiculous notion would supplant all these various theories on the ultimate origin of parasites a mere forty years after Bremser wrote this (Darwin 1859).

The debate between Andry's environmental externalism and Vallisnieri's double preformation reveals how intertwined philosophy and biology once were. Andry's position eventually proved correct, but was reliant on philosophy until the biology caught up. As a result, environmental externalism languished for 150 years. Vallisnieri was so convinced of his theological beliefs that he was willing to consider ideas that were unusual, even heterodox, at the time. I cannot help but imagine how differently the dialogue between faith and science may have played out if evolutionary theory had emerged in the early eighteenth century from Christian ideas about the biological consequences of the Fall rather than Darwin's ultimately agnostic *Origin of Species*.

Küchenmeister versus von Siebold

The triumph of externalism finally occurred in the 1850s, which proved to be one of the most transformative decades in scientific history. By now, all the individual components of a parasite's life cycle had been discovered: adults, eggs, and various larval stages. However, these forms were so distinctive they were often considered unique types of creatures rather than intermediate stages within a single complex life cycle. For tapeworms like *T. saginata* specifically, this meant that the adult tapeworms and larval bladder worms (cysticerci) were routinely described as separate species entirely. The cysticerci themselves were considered by most scholars to be among the best evidences for heterogenesis as they were unique creatures that appeared in muscle and connective tissue where they seemed to have no hope of escaping.

One of the most prominent parasitologists of the day was the German zoologist von Siebold who had trained under the great "Linnaeus of parasitology" Karl Rudolphi. von Siebold considered the numerous and varied cysticerci found in animal muscle tissue (which we now know belong to numerous and varied genera and species of tapeworms) to belong to a single species: *Taenia serrata*. According to von Siebold, when larvae *T. serrata* wandered into an unnatural host, they would "remain immature and undergo dropsical degeneration" (von Siebold 1844, 640). In other words, the "stray" larvae would balloon with liquid and fade from existence in their dead-end host. The morphological differences between cysticerci specimens from various hosts were explained as a consequence of their host's physiology or the age of the parasite rather

than inherent differences between species of tapeworm. Importantly, this interpretation of the biological facts meant that tapeworm larvae, and by extension any other animal, could be discovered where they were *not designed by God to be*.

Such a notion greatly disturbed our old friend Küchenmeister. Küchenmeister, who studied parasitology and theology and wrote books on biblical zoology in his spare time, vehemently rejected von Siebold's *scientific* hypothesis for *theological* reasons (Farley 1972). According to Küchenmeister, the idea of stray creatures "contradicts the wisdom of the Creator and the laws of harmony and simplicity put into Nature" (1853, 19) and was "contrary to the wise arrangement of Nature which undertakes nothing without a purpose" (1853, 11–12). There could be no stray creatures or developmental dead-ends. Consequently, the many types of cysticerci must *not* all be the same species. No creature could be destined to perish as globs of diseased mush inside an improper host.

Another prominent parasitologist, Steenstrup ([1842] 1845) had recently published his transformative research on the life cycle of parasitic flukes using his theory on the Alternation of Generations—the idea that parents and offspring may differ dramatically in morphology and habitat. Küchenmeister used this explanatory framework to propose that each unique morphospecies of cysticerci represented an immature stage of an enormous variety of tapeworm species, each one with a unique host. The cysticerci then escape their muscle-bound fate when their host was eaten by another animal. Thus, the cysticerci were not pathological stray animals exhibiting poor design, but were located exactly where the wisdom of God had directed them to be so the adults in turn could find themselves in their own perfect habitat: the intestines of another host. If true, Küchenmeister's hypothesis would also provide compelling evidence that parasites were not spontaneously generated inside their host—in contrast to the status quo which was supported at this time by over 200 years of research by Europe's most esteemed scholars. Farley describes Küchenmeister's predicament: "He was not only taking issue with all the great names of that period, such as von Siebold, Dujardin, and van Beneden, but also with the empirical evidence at their disposal. To do this obviously required a deep commitment, the type of commitment that comes from deeply held religious views" (Farley 1972, 121).

What set Küchenmeister apart from many of his peers was his willingness and creativity in pursuing scientific evidence for his theological presuppositions. In 1851, he crafted a plan to test his theory. Küchenmeister fed dozens of tapeworm cysticerci found in rabbit muscle tissue to several foxes, the natural predators of rabbits, and after a few weeks recovered several small adult tapeworms in the foxes' intestines. He experimented again a few years later (1853) with a different species of tapeworm and host and achieved identical results, and then again a few years after that

with the infamous (and unethical) parasite soup experiment (1855). These phenomenal discoveries sparked a flurry of feeding experiments on various species of cysticerci and potential hosts which advanced parasitology more in a decade than in the previous 50 years combined (Leuckart 1863; Naunyn 1863; Oliver 1870). von Seibold repeated many of these experiments and recovered the same results, yet still maintained his theory on dropsical degeneration for several more years. Küchenmeister continued his research demonstrating the continuity of cysticerci and adult tapeworm for many species and eventually showed experimentally the connection between eggs and cysticerci as well.

The complete life cycle of tapeworms, and the resultant mortal blow to the heterogenesis of parasites, was uncovered by an amateur parasitologist operating under inspiration from his beliefs about the nature of God. Through his controlled experiments, Küchenmeister was able to show scientifically what his theology had indicated would be true about the natural world. To summarize, Kuchenmeister began with the theological presupposition that God creates every creature to live in its proper place and the biological observation that some cysticerci seem to be trapped in a dead-end state of being, existing *not* in their proper place. He then applied his theology to the biological problem at hand by arguing that this discrepancy is only apparent—the cysticerci are meant to be in muscle tissue as they are immature stages of tapeworms, and then generated a testable scientific hypothesis (if I feed cysticerci to a prey animal's natural predators, I will find tapeworms in the predator's intestines). Küchenmeister allowed his theology to inspire and shape his scientific research and, as a consequence, he is now considered the founder of experimental helminthology.

The Collapse of Natural Theology

During the time of Küchenmeister's exciting discoveries, the broadly accepted paradigm of natural theology was being radically challenged as the scientific enterprise initially crafted by Christian philosophy continued to reveal nature as inadequately, even malevolently, designed. Natural theologians like Vallisnieri and Drummond made valiant attempts to counter the increasing evidence of the influence of chance in nature, but by the time of Küchenmeister's experiments, it was clear that chance and waste *were* abundant in nature, parasitic infections contingent and seemingly without divine purpose. Furthermore, investigations into animal anatomy exposed numerous vestigial organs and inefficient physiology (Haeckel 1876) and parasitoid insects were described consuming their prey from the inside out in gruesome fashion (e.g., Rennie 1830). Finally, Darwin (1859) transformed chance into a great force by which the emergence of new species could arise through random variation and natural selection. In doing so, Darwin helped topple the already teetering doctrine of design by

providing an agnostic explanation for apparently intentional design in nature (although see Gray [1860] 1963 for an immediate defense of design plus natural selection).

With the nearly universal acceptance of chance as an integral feature of nature a rift tore open between science and religion. Chance, as the antithesis of providence, had been excluded under the reign of natural theology and many people reasoned therefore that with its ascendancy, the doctrine of design had been refuted. Indeed, Ayala considered Darwin's greatest discovery to be an explanation for "design without designer" (2007, 8572). Darwin provided the template for explaining the human hand, the vertebrate eye, and all the wonders and beauty of the natural world as gradual accumulations of beneficial traits selected from within a canvas of random variation and differential survival. However, scattered abundantly along the evolutionary wayside are disastrous mutations, mass extinctions, and the emergence of malevolent creatures like parasites—"the design of organisms is not intelligent but imperfect and, at times, outright dysfunctional" (Ayala 2007, 8573). This twofold critique of the doctrine of design—that nature was built on chance and that flawed "design" was rampant—was too effective a foil for natural theology to remain coherent. By the turn of the century, mainstream natural history had veered dramatically away from the "feeble philosophy" of natural theology (Gillespie 1987, 1) and toward scientific naturalism which has characterized the modern discipline of science ever since (Gould 1994).

Within parasitology, the conversation largely shifted to concerns over theodicy. Drummond and Küchenmeister were correct about the apparent ingenious design of a tapeworm's biology and life history. But if they were right that God designed tapeworms as they are, where they are, and to do what they do, how could God be *good*? How could a loving God create destructive organisms like parasites using such a random and wasteful process as evolution? There were, and are, no complete answers to that question. Consequently, 160 years after Darwin, parasitology (and science in general) receives negligible input from theology. Science is considered authoritative on questions related to parasite biology, origins, and diversification, while theology is left to muse on *why* parasites exist and arose in this or that way. Rarely, if ever, do theological presuppositions direct scientific hypotheses as they once did.

Recapturing the Theo-Scientific Philosophy of Early Parasitology

The spontaneous generation controversy was among the most complex and long-lasting scientific debates in the early modern age. While certainly not everyone was an ardent natural theologian like Küchenmeister or

Vallisnieri (there were many influential atheistic scientists especially among the French rationalists), there were very few thinkers who failed to discern how inseparable their philosophy was from their scientific hypotheses. Each scientist analyzed the current biological data, contributed their own observations and experimental evidence, and at the same time interpreted the murky details of parasite biology within their own philosophical paradigm. The lessons for us today are threefold.

First, from Vallisnieri, we can learn to think imaginatively, outside the usual paradigms, and contemplate ways our theology may be correct given what we know about the natural world and vice versa. Second, from Küchenmeister, we can learn to apply our imaginative ideas to the actual practice of science, the observations, experimentations, and data analyses—if *this* is true about God and nature, how might I discover it? Third, from Drummond and Bloch, we can learn humility and grace. Different philosophers and scientists bring unique biases to these challenging questions and we should not be surprised when the same evidence is interpreted accordingly. Each of these thinkers contributed significantly to parasitology while at the same time actively wrestling with the interplay between their theology and science. None of them were ultimately correct in both their philosophy and biology. Consequently, I should acknowledge that my own understanding of the natural world is incomplete and I most likely believe things about the character or purposes of God that are inaccurate. Importantly however, I will not know which is which until I explore *together* God and nature more completely.

As a parasitologist and Christian, I recognize the importance of the philosophical underpinnings of my scientific investigations. Like Küchenmeister, Vallisnieri, and Drummond, I am fascinated by the intricate activities of parasites and inspired to explore nature by the many unanswered questions about parasite biology, behavior, and history. And like them, I am aware of how the facts of natural history can support, exclude, or put tension on certain theological beliefs. Is there a way for twenty-first-century scientists to follow the path of the early modern natural theologians, or are we destined to keep our passion for nature and our passion for God separate?

Perhaps a way forward may open when we realize that scientific research begins motivated by diverse influences. Of all the wonderful mysteries and intriguing unknowns in the universe, why do scientists study the specific things we study? In my experience, scientific research is a highly contingent process. I often study the systematics of parasitoid insects because that is what my minute sliver of scientific expertise rests in, a fact that hinged on the specific university, advisor, and funding I enjoyed during graduate school. Therefore, when I contemplate research, exploring the systematics of phasiine flies is at the forefront of my mind. However, motivation for

research can arrive from multiple avenues. Experiments are chosen based on past experience and research inertia, but also personal curiosity about a serendipitous observation, noble intentions for the good of all mankind, or simply on what will garner any funding whatsoever. I recommend adding something significant to this list of influences for the Christian scientist specifically: how does the proposed research contribute to broader conversations about the existence, character, and/or purposes of God?

To be clear, I am not arguing that explicit theological presuppositions will improve the formulation of scientific hypotheses, but rather that theological presuppositions may inspire *completely new* hypotheses which can then be rigorously tested as all scientific hypotheses are. Numerous boundary-crossing points of friction exist within many scientific disciplines between Christian theology and the current understanding of the world as revealed by that discipline. Christian physicists, neuroscientists, and geneticists have to wrestle with questions about the active character of God in history, the existence of an immaterial soul, and genetic determinism, respectively. For parasitology, the tension lies in issues of theodicy (how could a loving God create parasites). If theology shapes a significant portion of one's identity, it should influence every decision we make—including our choice about which scientific experiments to pursue professionally. If we must do science (and we must!), let us investigate questions that contribute to both knowledge *and* faith whenever possible. Are parasites good or bad? How much does our genome influence our behavior? Do non-human animals have minds? Does God act in the physical world?

Answers to questions such as these require scientific investigation of the way reality is coupled with philosophical interpretations of those facts. Of course, many research programs seem to have little or nothing to offer the "big questions" in life (e.g., how many species of feather-footed fly exist). But if we are thoughtfully investigating nature as the handiwork of God, I believe every bit of knowledge we gain has the potential to reveal profound truths about its creator. As revealed in the history of parasitology, scientific understanding is built slowly, tiny egg by tiny egg. While I apply this integrated model of theology and science to the narrow field of Christian parasitology below, I believe the same principles can be applied to other scientific disciplines and the significant theological debates found within them.

Parasite biology tends to divide Christians into at least two general groups: those who have embraced the standard model of evolutionary history and therefore accept the existence of parasites before the existence of humans, and those for whom the perceived theological costs of doing so would be too great and so advocate for a recent, post-Fall diversification of parasites. Each of these groups maintains distinct philosophical

presuppositions that are unavoidable. I suggest that we (Christian parasitologists and scientists in general) can and should allow these presuppositions to direct at least some of our scientific investigations.

For those who believe parasite evolution has been a constant feature of life's history, the greatest theological challenge is to the perceived goodness of God. Parasites are intuitively "evil" creatures and chance processes seem counter to divine providence. To put the question worth pursuing simply, are parasites and random processes really *that bad*? Perhaps there exist deeper truths in nature about God's character or purposes that require further investigation to discover—our intuitions may be incorrect. Such presuppositions could inspire scientific research exploring the potential *positive* role parasites may play in maintaining health of host populations, increasing biodiversity of ecosystems, or connecting trophic levels within complex food webs. If God created parasites as an intentional component of his designed creation, philosophers would greatly benefit from scientists helping discern specifically *how*.

For those who believe our intuitions about parasites are correct—that a good God would not have declared his creation "very good" as it swarmed and writhed with parasites, those presuppositions can also inspire scientific research. As with the internalist versus externalist debate, the same experiments are often performed by scientists with opposite philosophical foundations who are all seeking objective truth. If parasites do *not* play a positive role in the lives of their hosts or the biodiversity and overall health of their ecosystems, science is capable of quantifying *how* harmful parasites actually are. In addition, believing *a priori* in a post-Fall emergence of parasites leads to a more specific avenue of research. How likely is it that the many hundreds of thousands of parasite species have diversified in only a few thousand years? From what kinds of creatures do parasites arise? Is parasitism a privation of mutualism? The evolutionary history of each lineage of parasites can be explored scientifically using phylogenetics, biogeography, and ancestral state reconstruction to begin answering these questions.

Regardless of one's philosophical leanings, these questions are worth pursuing. According to Moritz, "the overlap of boundary lines—when viewed in light of the history and philosophy of science—is understood as integral to how progressive research normally advances in both science and theology" (Moritiz 2009, 363). By investigating boundary-crossing questions, we may not only discover more about the intricately complex world we inhabit, we may also learn valuable truths about the one who made it all and designed us with the curiosity and ability to seek answers to difficult questions. In this pursuit, we might reclaim some of the lost wisdom and practices of the early natural philosophers and reunite our scientific endeavors with our beliefs about the character of our Creator.

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