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Nature's Criminals

Nature is not without a parallel strongly suggestive of our social perversions of justice, and the comparison is not without its lessons. The ichneumon fly is parasitic in the living bodies of caterpillars and the larvae of other insects. With cruel cunning and ingenuity surpassed only by man, this depraved and unprincipled insect perforates the struggling caterpillar, and deposits her eggs in the living, writhing body of her victim.

—John Brown, in *Parasitic Wealth or Money Reform: A Manifesto to the People of the United States and to the Workers of the World* (1898)

In the beginning there was fever. There was bloody urine. There were long quivering strings of flesh that spooled out of the skin. There was a sleepy death in the wake of biting flies.

Parasites made themselves, or at least their effects, known thousands of years ago, long before the name parasite—*parasitos*—was created by the Greeks.

The word literally means "beside food," and the Greeks originally had something very different in mind when they used it, referring to officials who served at temple feasts. At some point the word slipped its etymological harness and came to mean a hanger-on, someone who could get the occasional meal from a nobleman by pleasing him with good conversation, delivering messages, or doing some other job. Eventually the parasite became a standard character in Greek comedy, with his own mask. It would be many centuries before the word would cross over to biology, to define life that drains other lives from within. But the Greeks already knew of biological parasites. Aristotle, for instance, recognized creatures that lived on the tongues of pigs, encased in cysts as tough as hailstones.

People knew about parasites elsewhere in the world. The ancient Egpytians and Chinese prescribed different sorts of plants to destroy worms that lived in the gut. The Koran tells its readers to stay away from pigs and from stagnant water, both sources of parasites. For the most part, though, this ancient knowledge has only left a shadow on history. The quivering strings of flesh—now known as guinea worms—may have been the fiery serpents that the Bible describes plaguing the Israelites in the desert. They certainly plagued much of Asia and Africa. They couldn't be yanked out at one go, since they would snap in two and the remnant inside the body would die and cause a fatal infection. The universal cure for guinea worm was to rest for a week, slowly winding the worm turn by turn onto a stick to keep it alive until it had crawled free. Someone figured out this cure, someone forgotten now for perhaps thousands of years. But it may be that that person's invention was remembered in the symbol of medicine, known as the caduceus: two serpents wound around a staff.

As late as the Renaissance, European physicians generally thought that parasites such as guinea worms didn't actually make people sick. Diseases were the result of the body itself lurching out of balance as a result of heat or cold or some other

force. Breathing in bad air could bring on a fever called malaria, for example. A disease came with symptoms: it made people cough, put spots on their belly, gave them parasites. Guinea worms were the product of too much acid in the blood, and weren't actually worms at all—they were something made by a diseased body: perhaps corrupted nerves, black bile, elongated veins. It was hard to believe, after all, that something as bizarre as a guinea worm could be a living creature. Even as late as 1824, some skeptics still held out: "The substance in question cannot be a worm," declared the superintending surgeon of Bombay, "because its situtation, functions, and properties are those of a lymphatic vessel and hence the idea of its being an animal is an absurdity."

Other parasites were undeniably living creatures. In the intestines of humans and animals, for instance, there were slender snake-shaped worms later named *Ascaris*, and tapeworms—flat, narrow ribbons that could stretch for sixty feet. In the livers of sick sheep were lodged parasites in the shape of leaves, called flukes after their resemblance to flounder (*floc* in Anglo-Saxon). Yet, even if a parasite was truly a living creature, most scientists reasoned, it also had to be a product of the body itself. People carrying tapeworms discovered to their horror that strips of it would pass out with their bowel movements, but no one had ever seen a tapeworm crawl, inch by inch, into a victim's mouth. The cysts that Aristotle had seen in the tongues of pigs had little wormlike creatures coiled up inside, but these were helpless animals that didn't even have sex organs. Parasites, most scientists assumed, must have been spontaneously generated in bodies, just as maggots appeared spontaneously on a corpse, fungus on old hay, insects from within trees.

In 1673, the visible parasites were joined by a zoo of invisible ones. A shopkeeper in the Dutch city of Delft put a few drops of old rainwater under a microscope he had built himself, and he saw crawling globules, some with thick tails, some with paws. His name was Anton van Leeuwenhoek, and although in

his day he was never considered anything more than an amateur, he was the first person to lay eyes on bacteria, to see cells. He put everything he could under his microscope. Scraping his teeth, he discovered rod-shaped creatures living on them, which he could kill with a sip of hot coffee. After a disagreeable meal of hot smoked beef or ham, he would put his own loose stool under his lenses. There he could see more creatures—a blob with leglike things that it used to crawl like a wood louse, eel-shaped creatures that would swim like a fish in water. His body, he realized, was a home to microscopic parasites.

Other biologists later found hundreds of different kinds of microscopic creatures living inside other creatures, and for a couple of centuries there was no divide between them and the bigger parasites. The new little worms took many shapes—of frogs, of scorpions, of lizards. "Some shoot forth horns," one biologist wrote in 1699, "others acquire a forked Tail; some assume Bills, like Fowls, others are covered with Hair, or become all over rough; and others again are covered with Scales and resemble Serpents." Meanwhile, other biologists identified hundreds of different visible parasites, flukes, worms, crustaceans, and other creatures living in fish, in birds, in any animal they opened up. Most scientists still held on to the idea that parasites large and small were spontaneously generated by their hosts, that they were only passive expressions of disease. They held on through the eighteenth century, even as some scientists tested the idea of spontaneous generation and found it wanting. These skeptics showed how the maggots that appeared on the corpse of a snake were laid as eggs by flies, and themselves grew into flies.

Even if maggots weren't spontaneously generated, parasites were a different matter. They simply had no way of getting inside a body and so had to be created there. They had never been seen outside a body, animal or human. They could be found in young animals, even in aborted fetuses. Some species could be found in the gut, living happily alongside other organisms that were being destroyed by digestive juices. Others could be found

clogging the heart and the liver, without any conceivable way to get into those organs. They had hooks and suckers and other equipment for making their way inside a body, but they would be helpless in the outside world. In other words, parasites were clearly designed to live their entire lives inside other animals, even in particular organs.

Spontaneous generation was the best explanation for parasites, given the evidence at hand. But it was also a profound heresy. The Bible taught that life was created by God in the first week of creation, and every creature was a reflection of His design and His beneficence. Everything that lived today must descend from those primordial creatures, in an unbroken chain of parents and children—nothing could later come squirting into existence thanks to some vital, untamed force. If our own blood could spontaneously generate life, what help did it need from God back in the days of Genesis?

The mysterious nature of parasites created a strange, disturbing catechism of its own. Why did God create parasites? To keep us from being too proud, by reminding us that we were merely dust. How did parasites get into us? They must have been put there by God, since there was no apparent way for them to get in by themselves. Perhaps they were passed down through generations within our bodies to the bodies of our children. Did that mean that Adam, who was created in purest innocence, came into being already loaded with parasites? Maybe the parasites were created inside him after his fall. But wouldn't this be a second creation, an eighth day added on to that first week—"and on the following Monday God created parasites"? Well, then, maybe Adam was created with parasites after all, but in Eden parasites were his helpmates. They ate the food he couldn't fully digest and licked his wounds clean from within. But why should Adam, created not only in innocence but in perfection, need any help at all? Here the catechism seems to have finally fallen apart.

Parasites caused so much confusion because they have life

cycles unlike anything humans were used to seeing. We have the same sorts of bodies as our parents did at our age, as do salmon or muskrats or spiders. Parasites can break that rule. The first scientist to realize this was a Danish zoologist, Johann Steenstrup. In the 1830s he contemplated the mystery of flukes, whose leaf-shaped bodies could be found in almost any animals a parasitologist cared to look at—in the livers of sheep, in the brains of fish, in the guts of birds. Flukes laid eggs, and yet no one in Steenstrup's day had ever found a baby fluke in its host.

They had, however, found other creatures that looked distinctly flukish. Wherever certain species of snails lived, in ditches or ponds or streams, parasitologists came across free-swimming animals that looked like small versions of flukes except that they had great tails attached to their rears. These animals, called cercariae, flicked their tails madly through the water. Steenstrup scooped up some ditch water, complete with snails and cercariae, and kept it in a warm room. He noticed that the cercariae would penetrate the mucus coating the snail's body and shell, drop their tails, and form a hard cyst, which, he said, "arches over them like a small, closely-shut watch glass." When Steenstrup pulled the cercariae out of these shelters, he found that they had become flukes.

Biologists knew that the snails were home to other sorts of parasites as well. There was a creature that looked like a shapeless bag. There was also a little beast they called the King's yellow worm: a pulpy animal that lived in the snail's digestive gland and carried within it what looked like cercariae, all writhing like cats inside a burlap sack. And Steenstrup even found another flukelike creature swimming free, this one not using a missile-shaped tail but instead hundreds of fine hairs that covered its body.

Looking at all these organisms swimming through the water and through the snails—organisms that in many cases had been given their own Latin species names—Steenstrup made an outrageous suggestion. All these animals were different stages

and generations of a single animal. The adults laid eggs, which escaped out of their hosts and landed in water, where they hatched into the form covered in fine hairs. The hair-covered form swam through the water and sought out a snail, and once it had penetrated a snail, the parasite transformed itself into the shapeless bag. The shapeless bag began to swell with the embryos of a new generation of flukes. But these new flukes were nothing like the leaf-shaped forms inside a sheep's liver, or even the finely haired form that entered the snail. These were the King's yellow worms. They moved through the snail, feeding and rearing within them yet another generation of flukes—the missile-tailed cercariae. The cercariae emerged from the snail, promptly forming cysts on the snail. From there they somehow got into sheep or another final host, and there they emerged from their cysts as mature flukes.

Here was a way that parasites could appear inside our bodies with no precedent: "An animal bears young which are, and remain, dissimilar to their parent, but bring forth a new generation, whose members either themselves, or in their descendants, return to the original form of the parent animal." Scientists had already met the precedents, Steenstrup was saying, but they couldn't believe that they all belonged to the same species.

Steenstrup would eventually be proved right. Many parasites travel from one host to another during their life cycles, and in many cases they alternate between different forms from one generation to the next. And thanks to his insight, one of the best cases for spontaneous generation in parasites fell apart. Steenstrup turned his attention from flukes to the worms that Aristotle had seen living in cysts embedded in pig tongues. These parasites, called bladder worms at the time, can live in any muscle in mammals. Steenstrup suggested that bladder worms were actually an early stage in the development of some other worm not yet found.

Other scientists noticed that bladder worms looked a bit

like tapeworms. All you had to do was cut off most of the tapeworm's long ribbony body, and tuck its head and first few segments inside a shell, and you had a bladder worm. Maybe the bladder worm and tapeworm were one and the same. Maybe they were actually the product of tapeworm eggs that had made their way into the wrong host. When the eggs hatched in this hostile environment, the tapeworms couldn't take their normal path of development but grew instead into stunted deformed monsters that died before they could reach maturity.

In the 1840s, a devout German doctor heard about these ideas and was outraged. Friedrich Küchenmeister kept a little medical practice in Dresden, and in his free time he wrote books on biblical zoology and ran the local cremation club, called Die Urne. Küchenmeister recognized that the idea that bladder worms were actually tapeworms certainly sidestepped the heresy of spontaneous generation. But it then fell into another sinful trap—the idea that God would let one of his creatures wind up in a monstrous dead end. "It would be contrary to the wise arrangement of Nature which undertakes nothing without a purpose," Küchenmeister declared. "Such a theory of error contradicts the wisdom of the Creator and the laws of harmony and simplicity put into Nature"—laws that even applied to tapeworms.

Küchenmeister had a more pious explanation: the bladder worms were an early stage in the natural life cycle of the tapeworm. After all, the bladder worms tended to be found in prey—animals such as mice, pigs, and cows—and the tapeworms were found in predators: cats, dogs, humans. Perhaps when a predator ate prey, the bladder worm emerged from its cyst and grew into a full tapeworm. In 1851, Küchenmeister began a series of experiments to rescue the bladder worm from its dead end. He plucked out forty of them from rabbit meat and fed them to foxes. After a few weeks, he found thirty-five tapeworms inside the foxes. He did the same with another species of tapeworm and bladder worm in mice and cats. In 1853, he fed

bladder worms from a sick sheep to a dog, which soon was shedding the segments of an adult tapeworm in its feces. He fed these to a healthy sheep, which began to stumble sixteen days later. When the sheep was killed and Küchenmeister looked in its skull, he found bladder worms sitting on top of its brain.

When Küchenmeister reported his findings, he stunned the university professors who made parasites their life's work. Here was an amateur out on his own, sorting out a mystery the experts had failed to solve for decades. They tried to poke holes in Küchenmeister's work wherever possible, to try to keep their own ideas about dead-end bladder worms alive. One problem with Küchenmeister's work was that he sometimes fed the bladder worms to the wrong host species and the parasites all died. He knew, for example, that pork carried a species of bladder worm, and he knew that the butchers of Dresden and their families often suffered from tapeworms called *Taenia solium.* He suspected that the two parasites were one and the same. He fed *Taenia* eggs to pigs and got the bladder worms, but when he fed the bladder worms to dogs, he couldn't get adult *Taenia.* The only way to prove the cycle was to look inside its one true host—humans.

Küchenmeister was so determined to prove God's benevolent harmony that he set up a gruesome experiment. He got permission to feed bladder worms to a prisoner about to be executed, and in 1854 he was notified of a murderer to be decapitated in a few days. His wife happened to notice that the warm roast pork they were eating for dinner had a few bladder worms in it. Küchenmeister rushed to the restaurant where they had bought the pork. He begged for a pound of the raw meat, even though the pig had been slaughtered two days earlier and was beginning to go bad. The restaurant owners gave him some, and the next day Küchenmeister picked out the bladder worms and put them in a noodle soup cooled to body temperature.

The prisoner didn't know what he was eating and enjoyed it so much he asked for seconds. Küchenmeister gave him more

soup, as well as blood sausage into which he had slipped bladder worms. Three days later the murderer was executed, and Küchenmeister searched his intestines. There he found young *Taenia* tapeworms. They were still only a quarter of an inch long, but they had already developed their distinctive double crown of twenty-two hooks.

Five years later, Küchenmeister repeated the experiment, this time feeding a convict four months before his execution. Afterward he found tapeworms as long as five feet in the man's intestines. He felt triumphant, but the scientists of his day were disgusted. The experiments were "debasing to our common nature," said one reviewer. Another compared him to some doctors of the day who cut the still-beating heart out of a just-executed man, merely to satisfy their curiosity. One quoted Wordsworth: "One that would peep and botanise/Upon his mother's grave?" But no doubt was left that parasites were among the strangest things alive. Parasites were not spontaneously generated; they arrived from other hosts. Küchenmeister also helped discover another important thing about parasites that Steenstrup hadn't observed: they didn't always have to wander through the outside world to get from one host to another. They could grow inside one animal and wait for it to be eaten by another.

The last possibility still left for spontaneous generation was represented by the microbes. That was shortly put to rest by the French scientist Louis Pasteur. To make his classic demonstration, he put broth in a flask. Given enough time the broth would go bad, filling with microbes. Some scientists claimed that the microbes were spontaneously generated in the broth itself, but Pasteur showed that the microbes were actually carried in the air to the flask and settled into it. He went on to prove that microbes weren't just a symptom of diseases but often their cause—what came to be known as the germ theory of infection. And out of that realization came the great triumphs of Western medicine. Pasteur and other scientists began to isolate the par-

ticular bacteria that caused diseases such as anthrax, tuberculosis, and cholera and to make vaccines for some of them. They proved that doctors spread disease with their dirty hands and scalpels and could stop it with some soap and hot water.

With Pasteur's work, a peculiar transformation came over the concept of the parasite. By 1900, bacteria were rarely called parasites anymore, even though, like tapeworms, they lived in and at the expense of another organism. It was less important to doctors that bacteria were organisms than that they had the power to cause diseases and that they could now be erased with vaccines, drugs, and good hygiene. Medical schools focused their students on infectious diseases, and generally on those caused by bacteria (or later, by the much smaller viruses). Part of their bias had to do with how scientists recognize causes of diseases. They generally follow a set of rules proposed by the German scientist Robert Koch. To begin with, a pathogen had to be shown to be associated with a particular disease. It also had to be isolated and grown in pure culture, the cultured organism had to be inoculated into a host and produce the disease again, and the organism in the second host had to be shown to be the same as that inoculated. Bacteria fit these rules without much trouble. But there were many other parasites that didn't.

Living alongside bacteria—in water, soil, and bodies—were much larger (but still microscopic) single-celled organisms known as protozoa. When Leeuwenhoek had looked at his own feces, he had seen a protozoan now called *Giardia lamblia*, which had made him sick in the first place. Protozoa are much more like the cells that make up our own bodies, or plants or fungi, than they are like bacteria. Bacteria are essentially bags of loose DNA and scattered proteins. But protozoa keep their DNA carefully coiled up on molecular spools within a shell called the nucleus, just as we do. They also have other compartments dedicated to generating energy, and their entire contents are surrounded by skeleton-like scaffolding, as with our cells. These were only a few of many clues biologists discovered that

showed the protozoa to be more closely related to multicellular life than to the bacteria. They went so far as to divide life into two groups. There were the prokaryotes—the bacteria—and the eukaryotes: protozoa, animals, plants, and fungi.

Many protozoa, such as the amoebae grazing through forest floors, for instance, or the phytoplankton that turn the oceans green, are harmless. But there are thousands of species of parasitic protozoa, and they include some of the most vicious parasites of all. By the turn of the century, scientists had figured out that the brutal fevers of malaria weren't caused by bad air but by several species of a protozoan called *Plasmodium*, a parasite that lived inside mosquitoes and got into humans when the insects pierced the skin to suck blood. Tsetse flies carried trypanosomes that caused sleeping sickness. Yet, despite their power to cause disease, most protozoa couldn't live up to Koch's rigorous demands. They were creatures after Steenstrup's heart, passing through alternating generations.

Plasmodium, for example, enters a human body through a mosquito bite as a zucchini-shaped form known as a sporozoite. It travels to the liver, where it invades a cell and there multiplies into forty thousand offspring, called merozoites—these are now shaped like a grape. Merozoites pour out of the liver and seek out red blood cells, where they make more merozoites. The new generations burst out of the cells and seek out more blood cells. After a while, some of the merozoites produce a different form—a sexual one, called a macrogamont. If a mosquito should take a drink of the host's blood and swallow a blood cell with macrogamonts in it, they will mate inside the insect. The male macrogamont fertilizes the female one, and they produce a round little offspring called an ookinete. The ookinete divides in the mosquito's gut into thousands of sporozoites, which travel to the mosquito's salivary glands, there to be injected into some new human host.

With so many generations and so many different forms, you can't raise *Plasmodium* organisms simply by throwing them in a

petri dish and hoping they'll multiply. You have to get male and female macrogamonts to believe that they're living in the gut of a mosquito, and once they've bred, you have to make their offspring believe they've been shot out of the mosquito's mouth and into human blood. It's not impossible to do, but it took until the 1970s, a century after Koch set up his rules, for a scientist to figure out how to culture *Plasmodium* in a lab.

Parasitic eukaryotes and parasitic bacteria were pushed further apart by geography. In Europe, bacteria and viruses caused the worst diseases, such as tuberculosis and polio. In the tropics, protozoa and parasitic animals were just as bad. The scientists who studied them were generally colonial physicians, and their specialty became known as tropical medicine. Europeans came to look upon parasites as robbing them of native labor, of slowing down the building of their canals and dams, of preventing the white race from living happily at the Equator. When Napoleon took his army to Egypt, the soldiers began to complain that they were menstruating like women. Actually they had been infected with flukes. Like the flukes Steenstrup had studied, these were shed by snails and swam through water looking for human skin. They ended up in the veins in the abdomens of the soldiers and pushed their eggs into their bladders. Blood flukes attacked people from the western shores of Africa to the rivers of Japan; the slave trade even brought them to the New World, where they thrived in Brazil and the Caribbean. The disease they caused, known as bilharzia or schistosomiasis, drained the energy of hundreds of millions of people who were supposed to build European empires.

As bacteria and viruses occupied the center of medicine, parasites (in other words, everything else) were spun out to the periphery. Specialists in tropical medicine went on struggling against their own parasites, often with a staggering lack of success. Vaccines against parasites failed miserably. There were a few old cures—quinine for malaria, antimony for blood flukes—but they did only a little good. Sometimes they were so

toxic that they caused as much harm as the disease itself. Meanwhile, veterinarians studied the things living inside cows and dogs and other domesticated animals. Entomologists looked at the insects dug into trees, the nematodes that sucked on their roots. All these different disciplines became known as parasitology—more of a loose federation than an actual science. If anything held together its factions, it was that parasitologists were keenly aware of their subjects as living things rather than just agents of disease, each subject with a natural history of its own—in the words of one scientist at the time, "medical zoology."

Some actual zoologists studied this medical zoology. But just as the germ theory of disease was changing the world of medicine, they were reckoning with a revolution of their own. In 1859, Charles Darwin offered a new explanation for life. Life, he argued, hadn't existed unchanged since Earth's creation but had evolved from one form to another. That evolution had been driven by what he named natural selection. Every generation of a species was made up of variants, and some variants fared better than others—they could catch more food or avoid becoming food for someone else. Their descendants inherited their characteristics, and with the passing of thousands of generations, this unplanned breeding produced the diversity of life on Earth today. To Darwin, life was not a ladder rising up to the angels or a cabinet filled with shells and stuffed animals. It was a tree, bursting upward with all the diversity of the species on Earth alive today and long past, all rooted in a common ancestry.

Parasites fared as badly in the evolutionary revolution as they had in the medical one. Darwin contemplated them only in passing, usually when he was trying to argue that nature was a bad place to try to prove God's benevolent design. "It is derogatory that the Creator of countless systems of worlds should have created each of the myriads of creeping parasites," he once wrote. He found that parasitic wasps are a particularly good antidote to sentimental ideas about God. The way that

the larvae devoured their host from the inside was so awful that Darwin once wrote of them, "I cannot persuade myself that a beneficient and omnipotent God would have designedly created the Ichneumonidae [one group of parasitic wasps] with the express intention of their feeding within the living bodies of Caterpillars."

Yet, Darwin was downright kind to parasites compared with the later generations of biologists who carried on his work. Instead of benign neglect, or even mild disgust, they felt outright scorn for parasites. These late Victorian scientists were drawn to a peculiar, now debunked form of evolution. They accepted the concept that life evolved, but Darwin's generation-by-generation filter of natural selection seemed too random to account for the trends they saw in the fossil record that had lasted millions of years. They saw life as having an inner force driving it toward greater and greater complexity. To their mind, this force brought a purpose to evolution: to produce the higher organisms—vertebrates such as us—from the lower beings.

One influential voice for these ideas belonged to the British zoologist Ray Lankester. Lankester grew up with evolution. When he was a boy, Darwin came to his family's house and told him stories about riding a giant tortoise on a Pacific island. When Lankester became a man, he had a giant frame and a puffy, vaguely Charles Laughton–like face. As an Oxford professor and the director of the British Museum he carried Darwin's theory forward with what seemed at times like sheer bodily power. He made the people around him feel small in both size and mind; he reminded one man who met him of a winged Assyrian beast. Once King Edward VII offered him some tidbit of scientific knowledge while paying him a royal visit, and Lankester bluntly replied, "Sir, the facts are not so; you have been misinformed."

To Lankester, Darwin's theory had brought a unity to biology as impressive as that in any other science. He had no pa-

tience for doddering dons who looked at his science as a quaint hobby. "We are no longer content to see biology scoffed at as inexact or gently dropped as natural history or praised for her relation to medicine. On the contrary, biology is the science whose development belongs to the day," he declared. And its understanding would help free future generations from stupid orthodoxies of all sorts: "the jack-in-office, the pompous official, the petulant commander, the ignorant pedagogue." It would help carry human civilization upward, as life itself had been striving for millions of years. He laid out this view of the biological and political order of things in an essay he wrote in 1879, titled "Degeneration: A Chapter in Darwinism."

The tree of life you find described in that essay isn't the wild bush of Darwin. It's shaped like a plastic Christmas tree, with branches sticking out to the side from a main shaft, which rises to higher and higher glories until it reaches humans at the top. At each stage in the rise of life, some species abandoned the struggle, comfortable with the level of complexity they had achieved—a mere amoeba, sponge, or worm—while others kept striving upward.

But there were some drooping branches on Lankester's tree. Some species not only stopped rising but actually surrendered some of their accomplishments. They *degenerated*, their bodies simplifying as they accommodated themselves to an easier life. For biologists of Lankester's day, parasites were the sine qua non of degenerates, whether they were animals or single-celled protozoa that had given up a free life. To Lankester, the quintessential parasite was a miserable barnacle named *Sacculina carcini*. When it first hatched from its egg, it had a head, a mouth, a tail, a body divided into segments, and legs, which is exactly what you'd expect from a barnacle or any other crustacean. But rather than growing into an animal that searched and struggled for its own food, *Sacculina* instead found itself a crab and wiggled into its shell. Once inside, *Sacculina* quickly degenerated, losing its segments, its legs, its tail, even its

mouth. Instead, it grew a set of rootlike tendrils, which spread throughout the crab's body. It then used these roots to absorb food from the crab's body, having degenerated to the state of a mere plant. "Let the parasitic life once be secured," Lankester warned, "and away go legs, jaws, eyes, and ears; the active, highly gifted crab may become a mere sac, absorbing nourishment and laying eggs."

Since there was no divide between the ascent of life and the history of civilization, Lankester saw in parasites a grave warning for humans. Parasites degenerated "just as an active healthy man sometimes degenerates when he becomes suddenly possessed of a fortune; or as Rome degenerated when possessed of the riches of the ancient world. The habit of parasitism clearly acts upon animal organization in this way." To Lankester, the Maya, living in the shadows of the abandoned temples of their ancestors, were degenerates, just as Victorian Europeans were pale imitations of the glorious ancient Greeks. "Possibly we are all drifting," he fretted, "tending to the condition of intellectual Barnacles."

An uninterrupted flow from nature to civilization meant that biology and morality were interchangeable. People of Lankester's day took to condemning nature and then using nature in turn as an authority to condemn other people. His essay inspired a writer named Henry Drummond to publish a best-selling screed, *Natural Law in the Spiritual World*, in 1883. Drummond declared that parasitism "is one of the gravest crimes in nature. It is a breach of the law of Evolution. Thou shalt evolve, thou shalt develop all thy faculties to the full, thou shalt attain to the highest conceivable perfection of thy race—and so perfect thy race—this is the first and greatest commandment of Nature. But the parasite has no thought for its race, or for its perfection in any shape or form. It wants two things—food and shelter. How it gets them is of no moment. Each member lives exclusively on its own account, an isolated, indolent, selfish, and backsliding life." People were no different:

"All those individuals who have secured a hasty wealth by the chances of speculation; all children of fortune; all victims of inheritance; all social sponges; all satellites of the court; all beggards of the market-place—all these are living and unlying witness to the unalterable retributions of the law of parasitism."

People had been referred to as parasites before the late 1800s, but Lankester and other scientists gave the metaphor a precision, a transparency, that it never had before. And it's a short walk from Drummond's rhetoric to genocide. Listen to how closely his line about the highest conceivable perfection of a race meshes with these words: "In the struggle for daily bread all those who are weak and sickly or less determined succumb, while the struggle of the males for the females grants the right or opportunity to propagate only to the healthiest. And struggle is always a means for improving a species' health and power of resistance and therefore, a cause of its higher development." The author of these words wasn't an evolutionary biologist but a petty Austrian politician who would go on to exterminate six million Jews.

Adolf Hitler relied on a confused, third-rate version of evolution. He imagined that Jews and other "degenerate" races were parasites, and he took the metaphor even further, seeing them as a threat to the health of their host, the Aryan race. It was the function of a nation to preserve the evolutionary health of its race, and so it had to rid the parasite from its host. Hitler probed every hidden turn of the parasite metaphor. He charted the course of the Jewish "infestation," as it spread to labor unions, the stock exchange, the economy, and cultural life. The Jew, he claimed, was "only and always a parasite in the body of other peoples. That he sometimes left his previous living space has nothing to do with his own purpose, but results from the fact that from time to time he was thrown out by the host nations he had misused. His spreading is a typical phenomenon for all parasites; he always seeks a new feeding ground for his race."

Nazis weren't the only ones to burn the brand of parasite on their enemies. To Marx and Lenin, the bourgeoisie and the bureaucrats were parasites that society had to get rid of. An exquisitely biological take on socialism appeared in 1898, when a pamphleteer named John Brown wrote a book called *Parasitic Wealth or Money Reform: A Manifesto to the People of the United States and to the Workers of the World.* He complained of how three-quarters of the country's money was concentrated in the hands of 3 percent of the population, that the rich sucked the wealth of the nation away, that their protected industries flourished at the people's expense. And, like Drummond or Hitler, he saw his enemies precisely reflected in nature, in the way parasitic wasps live in caterpillars. "With the refinement of innate cruelty," he wrote, "these parasites eat their way into the living substance of their unwilling but helpless host, avoiding all the vital parts to prolong the agony of a lingering death."

Parasitologists themselves sometimes helped consecrate the human parasite. As late as 1955, a leading American parasitologist, Horace Stunkard, was carrying on Lankester's conceit in an essay published in the journal *Science*, titled "Freedom, bondage, and the welfare state." "Since zoology is concerned with the facts and principles of animal life, information obtained from the study of other animals is applicable to the human species," he wrote. All animals were driven by the need for food, shelter, and the chance to reproduce. In many cases, fear drove them to give up their freedom for some measure of security, only to be trapped in permanent dependency. Conspicuous among security-seeking animals were creatures such as clams, corals, and sea squirts, which anchored themselves to the ocean floor in order to filter the passing sea water for food. But none could compare with the parasites. Time after time in the history of life, free-living organisms had surrendered their liberty to become parasites in exchange for an escape from the dangers of life. Evolution then took them down a degenerate path. "When other food sources were insufficient, what would be

easier than to feed upon the tissues of the host? The dependent animal is proverbially looking for the easy way."

Stunkard was only a little coy about how this rule of parasites could apply to humans. "It may be applied to any group of organisms, and is not intended to refer merely to political entities, although certain implications may be in order." With its complete surrender of its liberty, the parasite had entered the "welfare state," as Stunkard put it—with hardly a tissue of metaphor dividing the tapeworm and the New Deal. Once parasites gave up their freedom, they rarely managed to regain it; instead, they channeled their energies into making new generations of parasites. Their only innovations were weird kinds of reproduction. Flukes alternated their forms between generations, reproducing sexually in humans and asexually in snails. Tapeworms could produced a million eggs a day. How could Stunkard have had anything but fast-breeding welfare families in mind? "Such a welfare state exists only for those lucky individuals, the favored few, who are able to cajole or compel others to provide the welfare," he wrote. "The well-worn attempt to obtain comfort without effort, to get something for nothing, persists as one of the illusions that in all ages has intrigued and misled the unwary."

Writing in 1955, Stunkard represented a dying gasp of the old take on evolution. As he was attacking food-stamp parasites, his fellow biologists were unceremoniously dumping the whole foundation of his scientific view. They discovered that every living thing on Earth carries genetic information in its cells in the form of DNA, a molecule in the shape of a double helix. Genes (particular stretches of DNA) carried the instructions for making proteins, and these proteins could build eyes, digest food, regulate the creation of other proteins, and do thousands of other things. Each generation passed its DNA to the next, and along the way the genes got shuffled into new combinations. Sometimes mutations to the genes turned up, creating new codes altogether. Evolution, these biologists realized, was built

on these genes and the way they rose and fell as time passed—not on some mysterious inner force. The genes offered up rich variety, and natural selection preserved certain kinds. From these genetic ebbs and flows new species could be created, new body plans. And since evolution was grounded on the short-term effects of natural selection, biologists no longer had any need for an inner drive for evolution, no longer saw life as a plastic Christmas tree.

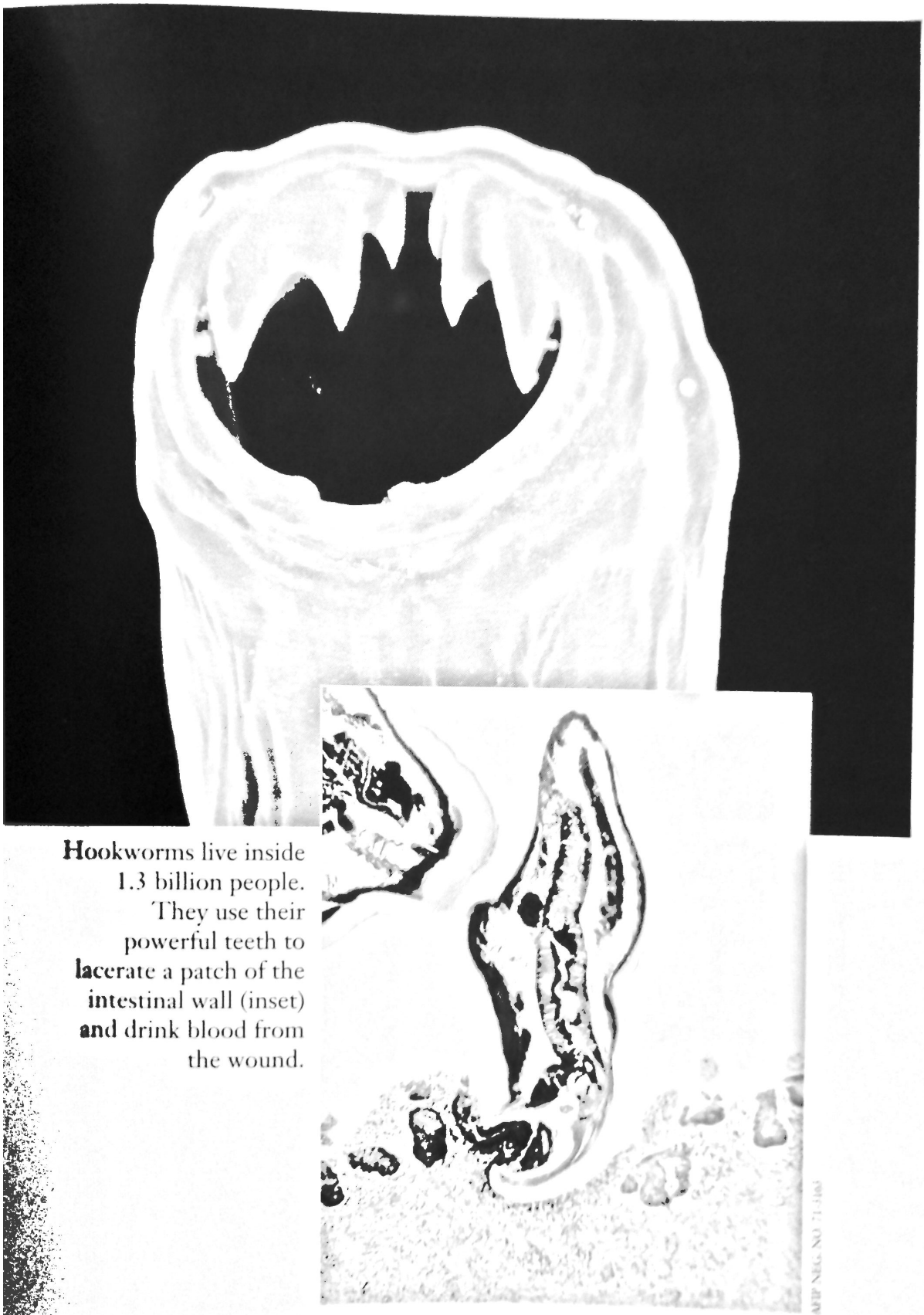
Parasites should have benefited from this change of scientific heart. They were no longer the backward pariahs of biology. Yet, well into the twentieth century, parasites still couldn't escape Lankester's stigma. The contempt survived both in science and beyond it. Hitler's racial myths have collapsed, and the only people who still believe in eradicating social parasites are at the fringes, among the Aryan skinheads and the minor dictators. Yet, the word *parasite* still carries the same insulting charge. Likewise, for much of the twentieth century, biologists thought of parasites as minor degenerates, mildly amusing but insignificant to the pageant of life. When ecologists looked at how the sun's energy streamed through plants and into animals, parasites were nothing more than grotesque footnotes. What little evolution parasites experienced was the result of being dragged along by their hosts.

Even in 1989, Konrad Lorenz, the great pioneer in animal behavior, was writing about the "retrograde evolution" of parasites. He didn't want to call it *degeneration*—that word was perhaps too loaded by Nazi rhetoric—and so he replaced it with "sacculinasation," after *Sacculina*, Lankester's backsliding barnacle. "When we use the terms 'higher and lower' in reference to living creatures and to cultures alike," he wrote, "our evaluation refers directly to the amount of information, of knowledge, conscious or unconscious, inherent in these living systems." And according to this scale, Lorenz despised parasites: "If one judges the adapted forms of the parasites according to the amounts of retrogressed information, one finds a loss of infor-

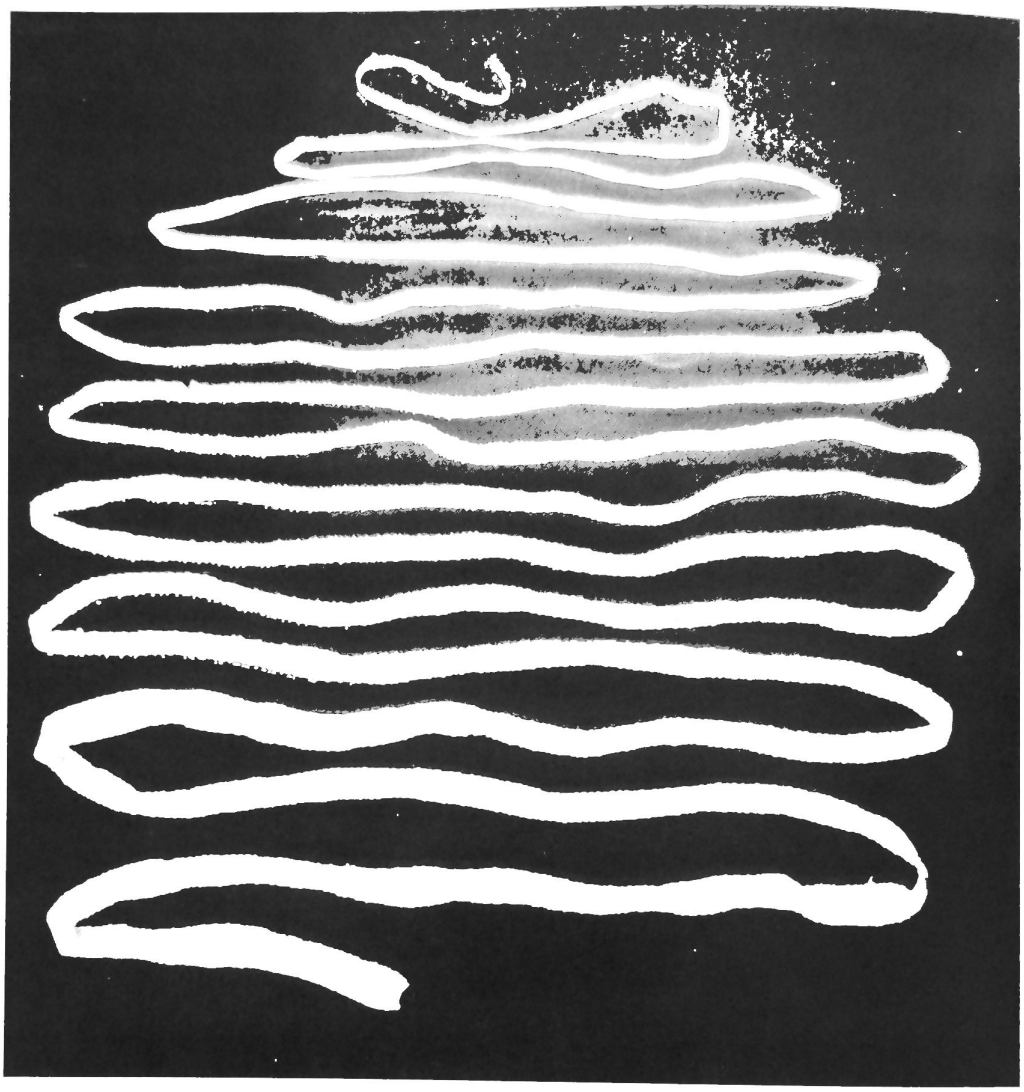
mation that coincides with and completely confirms the low estimation we have of them and how we feel about them. The mature *Sacculina carcini* has no information about any of the particularities and singularities of its habitat; the only thing it knows anything about is its host." Much like Lankester 110 years earlier, Lorenz saw the only virtue of parasites as a warning to humans. "A retrogression of specific human characteristics and capacities conjures up the terrifying specter of the less than human, even of the inhuman."

From Lankester to Lorenz, scientists have gotten it wrong. Parasites are complex, highly adapted creatures that are at the heart of the story of life. If there hadn't been such high walls dividing scientists who study life—the zoologists, the immunologists, the mathematical biologists, the ecologists—parasites might have been recognized sooner as not disgusting, or at least not merely disgusting. If parasites were so feeble, so lazy, how was it that they could manage to live inside every free-living species and infect billions of people? How could they change with time so that medicines that could once treat them became useless? How could parasites defy vaccines, which could corral brutal killers like smallpox and polio?

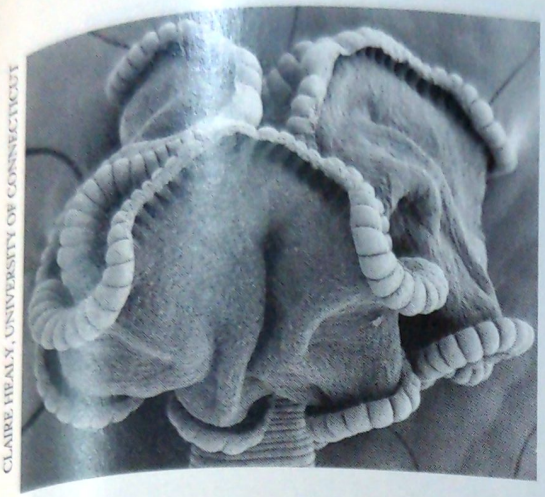
The problem comes down to the fact that scientists at the beginning of this century thought they had everything figured out. They knew how diseases were caused and how to treat some of them; they knew how life evolved. They didn't respect the depth of their ignorance. They should have borne in mind the words of Steenstrup, the biologist who had first shown that parasites were unlike anything else on Earth. Steenstrup had it right in 1845 when he wrote, "I believe that I have given only the first rough outlines of a province of a great terra incognita which lies unexplored before us and the exploration of which promises a return such as we can at present scarcely appreciate."



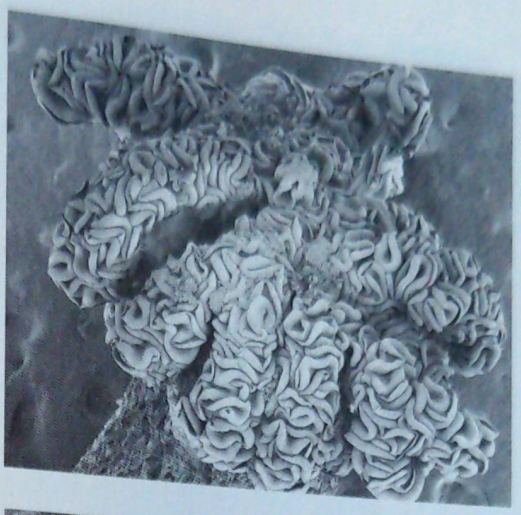
Hookworms live inside 1.3 billion people. They use their powerful teeth to **lacerate** a patch of the **intestinal** wall (inset) **and** drink blood from the wound.



Tapeworms, reaching up to sixty feet long, are the biggest parasites that live in humans.



CLAIRE HEALY, UNIVERSITY OF CONNECTICUT



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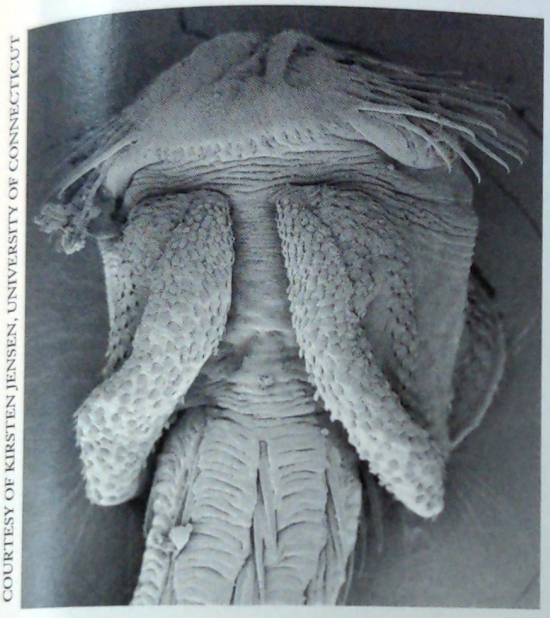

COURTESY OF KIRSTEN JENSEN, UNIVERSITY OF CONNECTICUT

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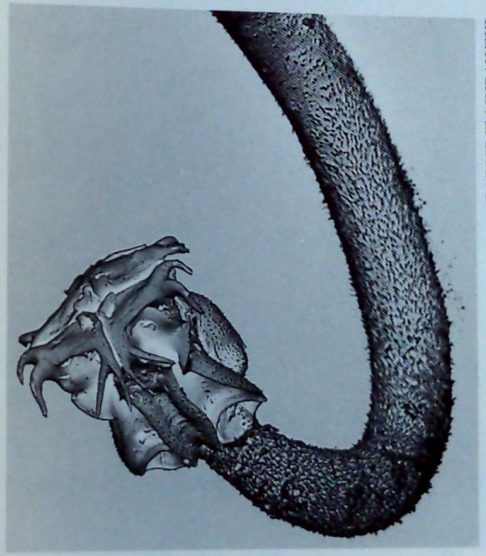

DARLYNE MURAWSKI

DANIEL BROOKS

There are 5,000 known species of tapeworm that live in various animals, and probably many thousands more still await discovery. Each one has a head specially adapted for lodging itself in its host's body.

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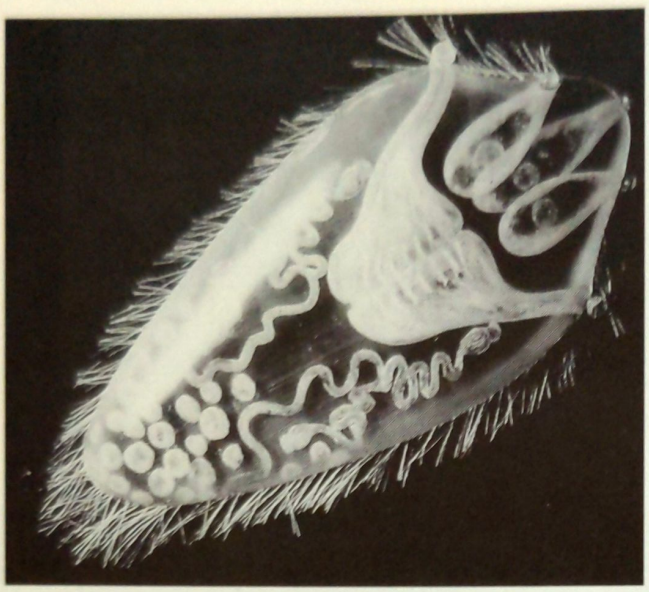
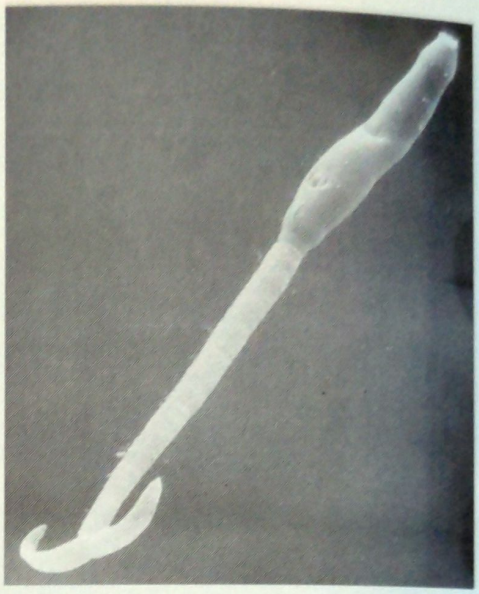
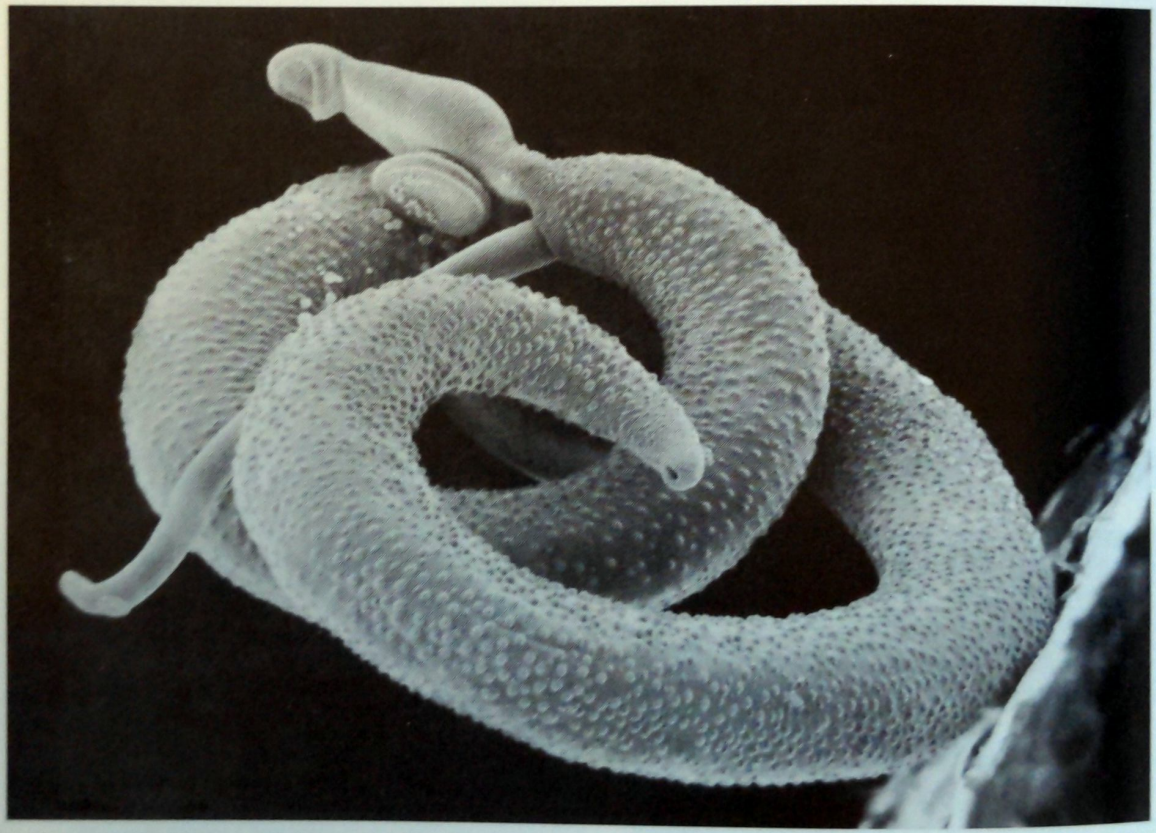




MING WONG



Schistosoma (also known as the blood fluke) infects more than 200 million people. *Top left:* Its eggs hatch in fresh water and the young parasite seeks out a snail. *Top right:* Inside the snail, the parasite passes through several generations before producing a missile-shaped stage called a cercaria. *Bottom:* The cercaria then penetrates human skin and becomes an adult that finally ends up in the veins of its human host.

DICKSON DESPOMMIERS

Trichinella, the cause of trichinosis, is an exceptional parasite: an animal that lives like a virus. Its larvae penetrate individual muscle cells and coil up inside, taking control of the muscle's DNA in order to make the cells a more comfortable home.

LENNART NILSSON/ALBERT BONNIERS FORLAG AB

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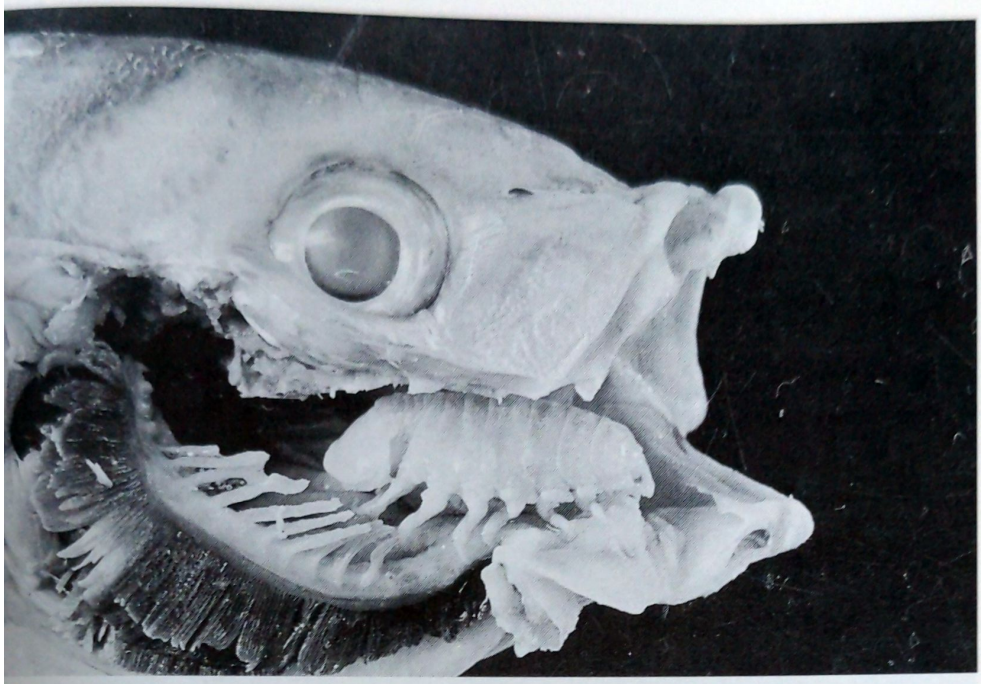
DAVID ROOS

Top: The single-celled parasite *Plasmodium falciparum* causes malaria. Here a new generation of the parasite bursts out of a red blood cell. *Bottom left:* Another single-celled parasite, *Trypanosoma brucei*, is the cause of sleeping sickness. *Bottom right: Toxoplasma gondii* (shown here nestled inside a host cell) is one of the most successful parasites on Earth: in some regions of the world, 90 percent of people carry it in their bodies.



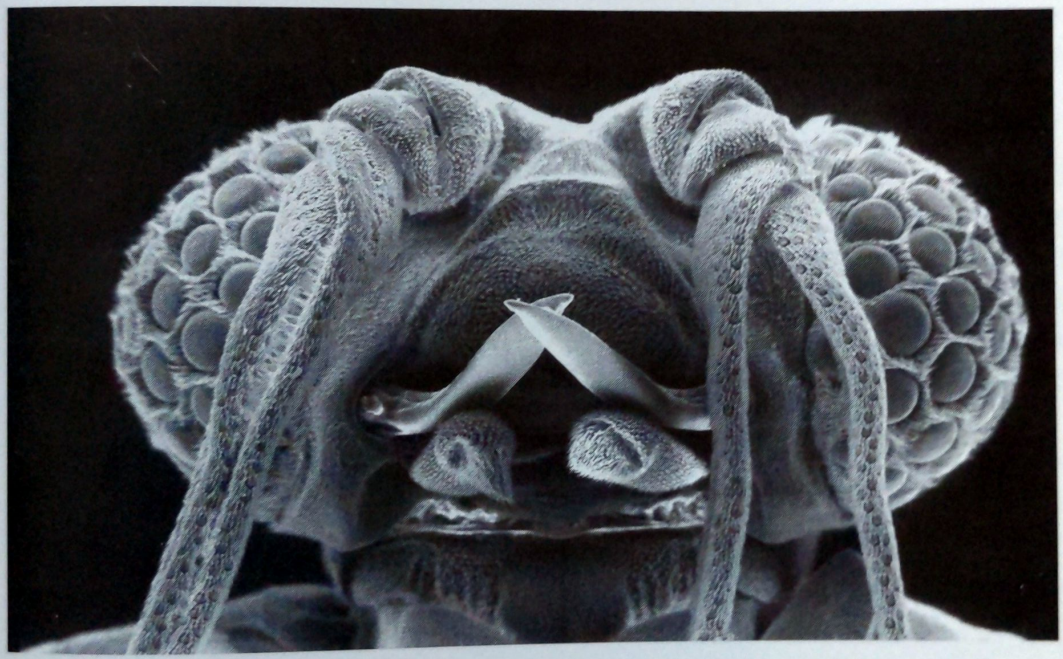
Parasites often choose very particular—and peculiar—places to live. This crustacean invades a fish's mouth, devours its tongue, and takes the tongue's place. It then acts like a tongue; the fish can use it to grip and swallow prey.

GEORGE BENZ, SOUTHEAST AQUATIC RESEARCH INSTITUTE, AND JEFF BRASWELL, DUPONT

Another choosy parasite is the crustacean *Ommatokoita elongata*. It lives only in Greenland sharks, which roam underneath the Arctic ice. Moreover, *Ommatokoita* lives only in their eyes, anchoring itself in the eyes' jelly with its specially adapted legs.

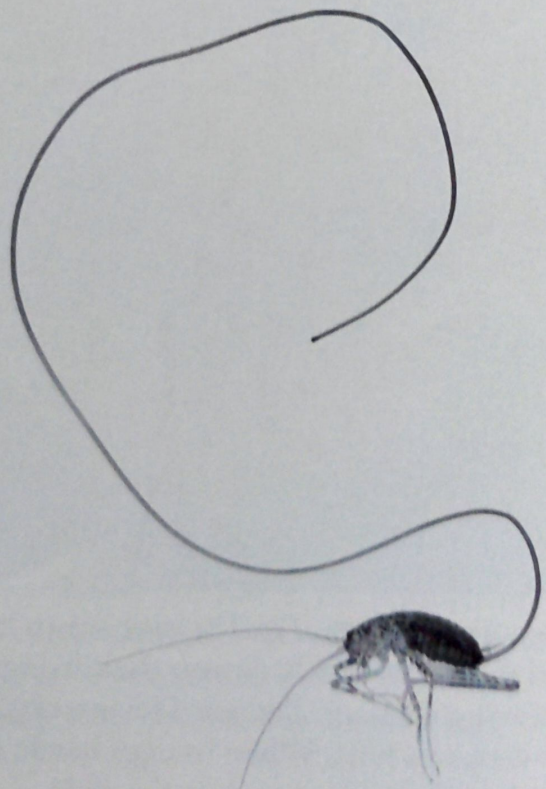
PHOTO BY MARIANNE ALLEYNE AND NANCY BECKAGE

ELKE BUSCHBECK, BIRGIT EHMER/CORNELL UNIVERSITY



Insects are masters at parasitizing other insects. *Top:* Parasitic wasps lay their eggs inside caterpillars, and the larvae slowly devour their living hosts before crawling out and weaving cocoons. *Bottom:* The insect *Xenos peckii* makes non-parasitic paper wasps its host. When its eggs hatch, the female stays inside, devouring its hosts' sex organs, while the male burrows out and flies to another wasp to find a mate. As an adult, the male has only a few hours to live; as a result, it has evolved remarkable eyes to help find a mate. It has 100 miniature eyes, each of which is equipped with its own retina, able to form a full image of its own.

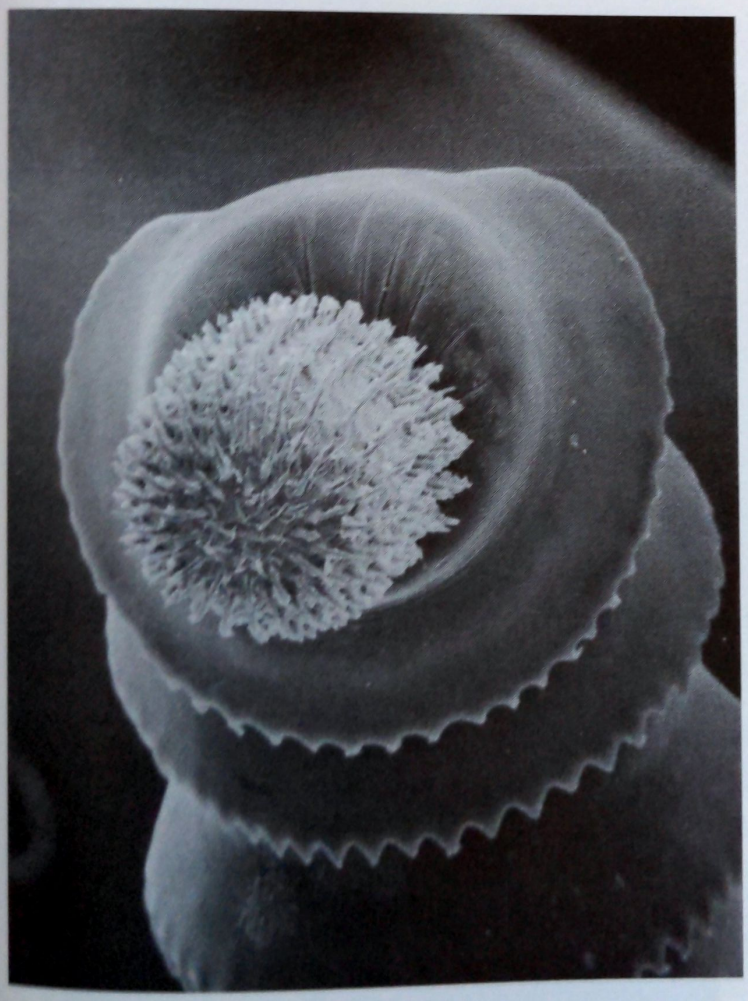
CHARLES AND FANNY BREWER-CARÍAS



ANDREAS SCHMIDT-RHAESA

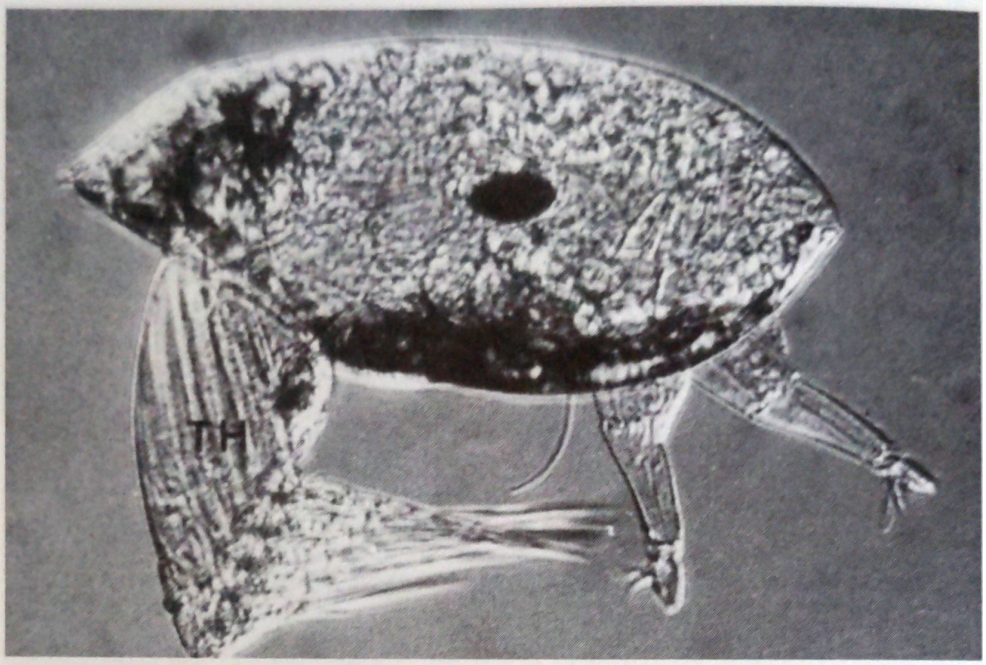
Once a parasite has used up its host, it needs to escape. *Top:* A fungus emerges from an ant. *Bottom:* A worm-like parasite called a nematomorph escapes its cricket host.

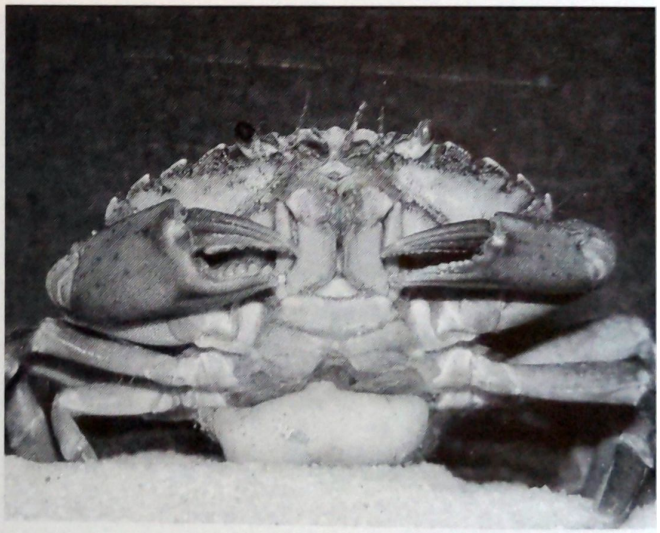
THOMAS DUNAGAN

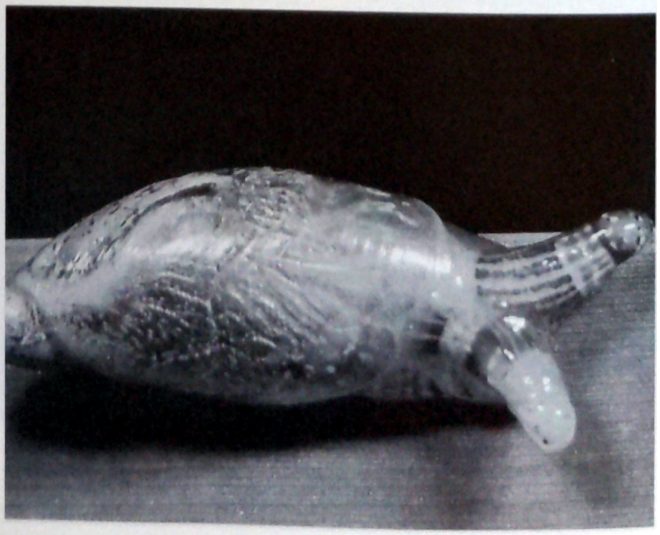


THOMAS DUNAGAN

Thorny-headed worms, like many parasites, live in two or more hosts during their life. Many of them live initially in insects or crustaceans and then move into predators such as birds. To get into these predators, the parasites make their intermediate hosts stupid and foolhardy—and thus easily preyed upon.







Top: The parasitic barnacle *Sacculina carcini* invades crabs and fills up their entire body with a network of roots. It forms a sac full of larvae where the crab's own egg pouch should be *(middle)*, and it forces the crab to care for its young. *Bottom:* Snails can also be horrifically victimized when they are infected with the fluke *Leucochloridium paradoxum*. The parasite's final hosts are birds. To get their attention, the parasite climbs into the snail's transparent tentacles. The striped flukes, which can be seen through the tentacles, look like caterpillars, and they catch the eye of hungry birds.

DAVID KJAERGAARD

Cuckoos are a special sort of parasite—they don't live inside other animals, but they steal parental care. They lay their eggs in the nests of other bird species and trick the foster parents into rearing them. Here a reed warbler contemplates the giant cuckoo nestling that has taken its own offspring's place.

Only a few parasites of humans are on the verge of eradication. *Top:* For centuries people have extracted guinea worms from their legs by gently spooling them onto sticks. Public health campaigns have driven down guinea worms to less than 100,000 cases a year and are on the verge of eradicating the parasite altogether. *Bottom:* In 1998 a new campaign was launched to wipe out elephantiasis, caused by microscopic worms that block lymph nodes.

AFIP NEG. NO. N-50807

PHOTO BY MICHAEL A. HUFFMAN

Parasites sometimes make mistakes, and the results can be lethal. *Top left:* Normally, tapeworms first mature in a cyst in intermediate hosts such as cows or pigs before they move on to humans. But if their eggs should end up in a human body, they will go ahead and form a cyst anyway, often in the brain. *Top right:* A botfly laid its eggs on a boy's head, and one of the larvae penetrated his brain. *Bottom:* Hosts have had to evolve ways to fend off the ever-present threat of parasites. Chimpanzees eat medicinal plants to fight off invaders.

FOX/EVERETT COLLECTION

EVERETT COLLECTION

Hollywood has a healthy respect for the sophistication and cunning of parasites. *Top:* In the television show *The X-Files*, a fungus attacks people in the same way that some real fungi attack insects. *Bottom:* In the *Alien* movie series, a creature fashioned after parasitic wasps plants its young in the chests of human hosts.