No One Wants To Be A Parasitologist

The Shrinking Field of America's Least Favorite Animals

by

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ABSTRACT

Parasites have a bad rap. Most people think of them as scary, gross, or both, but they are also diverse creatures that have evolved in and on every animal and ecosystem on the planet. Parasitism is the most successful way of life for an animal — representing more than 40% of all species — and the wormy and crawly creatures it encompasses are vastly understudied. An increasing volume of research shows that parasites play important ecological functions, from keeping animal populations in check to stabilizing food chains to driving evolution and biodiversity. While parasites can cause horrible human suffering, especially in countries without reliable clean water or sanitation systems, only a fraction of parasites affect humans, with estimates as low as 0.1%.

As climate change and habitat loss threaten animals, so too do they endanger the parasites that live on and inside them. At the same time parasite biodiversity faces shrinkage, the field of parasitology reckons with its own crisis: membership in the American Society of Parasitologists has declined by 76% in the past 50 years, and many of the world's most important parasitologists are elderly or dead. To revitalize the field, parasitologists are charming younger generations with parasite Pokémon cards and stuffed animals and attempting to integrate parasites into global conservation programs. One main question is on parasitologists' minds: How can they convince people to discover, catalog, and understand the world's parasite biodiversity before parasites, the field's leaders, and their valuable knowledge die off?

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In the fall of 1985, Scott L. Gardner found himself standing over his toilet bowl, fishing around in the squishy remnants of his empty bowels with a chopstick.

He had recently returned home from a three-month expedition to Bolivia, where he was studying parasites in wild mammals. His field site near the city of Trinidad had been sparse: a few tents, portable microscopes, and cans of liquid nitrogen to preserve specimens. As he dissected mammals to find the creatures living in their intestines, the site caretaker's pig waddled around, oinking.

When he returned to his graduate school in New Mexico, Gardner felt healthy, but decided to check himself for parasites, like one looks for ticks after a hike. Being trained in the subject, he put a sample of his own feces on a microscope slide. When he looked through the glass, he was shocked: hidden within the brown smear he saw clusters of tiny, light-yellow eggs.

"I'm used to looking at that with regular animals," said Gardner. "But I'm not a regular animal — I'm me!"

Gardner went to the student health center to get treated, his microscope slide in tow as evidence. Sure enough, the doctor confirmed he had contracted *Ascaris*, a pencil-thin parasitic worm that affects more than 1 billion people today. Gardner was prescribed a Vermox pill to stop the worm from absorbing sugar in his body until it died of starvation.

The next morning, he pooped it out — all 12 inches.

Driven by curiosity, Gardner probed around in the toilet until "out came this noodle on a chopstick." He dumped the specimen in a jar and brought it to work, disgusting and fascinating his colleagues.

Today, nearly 40 years later, Gardner is surrounded by noodles in jars at the University of Nebraska-Lincoln's Manter Laboratory of Parasitology, where he serves as curator. Housed in a few modest rooms adjacent to a botanical collection and the floor's only bathroom, the laboratory is the world's largest university collection of parasites. Since 1971, it has been a repository for species from the Nebraska Sandhills to Mongolia's grasslands. Gardner has spent 30 years maintaining and expanding this "bioarchive" and helping biologists around the world access its contents for research.

"You can compare us to a library," said Gábor Racz, the Manter Lab's collections manager. Every week, Racz receives a parasite-filled package from any animal or country imaginable. He spends his days diligently identifying and categorizing its contents, often working long into the evenings, then stopping by the university's recreational center to clear his mind.

Estimating the size of the Manter Lab's collection sounds like an SAT math problem. Heavy metal cases line the walls of a room about the size of a two-car garage. Each case contains three drawers; each drawer holds 100 wooden boxes; each box encloses 100 microscope slides. Rare specimens are stored in a fire- and tornado- proof safe, and poorly preserved ones haphazardly

litter high shelves. A small room across the hall contains tens of thousands of vials, and deep freezers chilling at minus 85-degrees Celsius preserve the DNA of parasites recently collected from the field. “This is not my mess,” Racz grumbled about the chaos, which he took over in 2010, a few years after moving from Hungary.

The lab has around 170,000 cataloged items, but each item doesn’t contain just one specimen. Many parasites are so small or, in the case of worms, so jumbled up, that it’s impossible to count them individually. A single vial can hold thousands of microscopic parasites, bringing the true count of organisms in the collection closer to 17 million — a size Racz estimates doubles every decade.

Faced with such a large volume of specimens, Racz said Gardner is “pretty much driven by passion for this collection.” Aside from a rotating cast of graduate students, the lab is only the two men.

Gardner sports thick aviator glasses with a bright blue strap and various parasite-adorned t-shirts. Each year when he teaches general parasitology to a room full of University of Nebraska undergraduates, he begins the first class with his chopstick horror story. His students groan, giggle, and gag.

At 67, Gardner is an animated instructor, stopping lectures only to silence his phone, which plays the throaty sound of toads mating. His task — to pique young students’ interest in his field — is a daunting one, as parasites’ horrible reputation precedes them. For some, like *Plasmodium* (which causes malaria) and *Trypanosoma* (which causes sleeping sickness), it’s justified due to their devastating impacts on human health. But parasites are also diverse and understudied creatures that have evolved to flourish in every animal and ecosystem on Earth.

Parasitism, a relationship between two species where one benefits at the other’s expense, has evolved independently over 220 times in animals alone. It’s the most common animal lifestyle on the planet — accounting for nearly half of all animals — with conservative estimates at 3.5 million species of parasites.

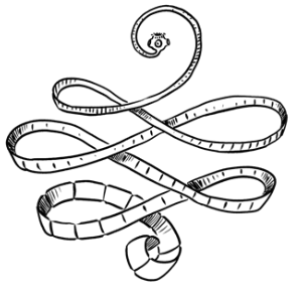
Just as the fascinating and scientifically significant impact of parasites is becoming more apparent, the field of parasitology itself teeters on the verge of endangerment. As climate change and deforestation drive biodiversity losses around the globe, parasitology is confronting a loss within its own field: many of the world’s most important parasitologists are elderly or already dead.

In 1973, the American Society of Parasitology had grown to nearly 1,900 members from its modest start at 320 nearly 50 years earlier. Since then, membership has fallen by 76%, and less than one-third of the remaining members typically attend annual meetings.

It’s a two-sided trend: older parasitologists are retiring or passing away, and new ones are entering the field slowly.

“I started off in this [field] pretty young and I got to know all these people and they’re all expiring,” said Gardner. “It’s so sad. But what can you do, right?”

To entice the next generation of parasitologists, Gardner and his colleagues are confronting a fundamental question: How can they convince the public that parasites are more than just scary?



In filmmaker Bong Joon-ho’s 2019 film *Parasite*, a rich and poor family in Seoul leech off of one another, to gory consequences. The movie won the Academy Award for Best Picture and grossed a quarter of a billion dollars in global sales, bringing the concept of a “parasite” to the fore across cultures. It’s colloquially used to describe needy partners, friends who always ask to borrow money, or coworkers who never contribute their fair share of group work.

But the science of parasites tells a more complex story. Scientists often call them the “dark matter” of the animal world: they’re unseen but incredibly important.

For starters, parasites are wildly diverse. They can be any living thing, from animals and plants to fungi and protozoa. (Viruses and bacteria count as parasites, too, but most parasitologists leave those species to the infectious disease experts.)

The most common parasites are protozoans, but most people think primarily of worms, called helminths. These include flatworms like tapeworms and flukes, nematodes like Gardner’s *Ascaris,* and a small group called the thorny-headed worms. Other common parasites are fleas, lice, and mites, including ticks.

Parasites can have long, segmented bodies; hard outer shells; many tiny legs; suckers, hooks, antennae, bristles, or flagella; or they can be a single, tiny cell.

Parasites are unique in that they are “not linked by a shared ancestry but by a shared lifestyle,” explained Mackenzie Kwak, a parasite ecologist at Japan’s Hokkaido University. Think of it like herbivores: cows and human vegetarians both avoid eating meat, but they are not part of the same family or genus.

What defines a parasite is its reliance on a host species to get energy. Typically, parasites do not explicitly kill their host animals, since that would remove their energy source — not to mention their free shelter and transportation. Sometimes, though, death can be a side effect; the fish tapeworm *Lingula intestinalis* grows so large it changes the buoyancy of the fish it inhabits,

causing the fish to swim closer to the surface, where it is eaten by birds — the eventual host of the worm.

A common quip among parasitologists is that all animals are either parasites or hosts. Some parasites inhabit a single host for their whole life: the tiny crustacean *Anilocra apogonae* lives only in a specific species of cardinalfish, for example. Some parasites have multiple suitable hosts, like the single-celled *Trypanosoma evansi*, which can infect camels, horses, cows, and even humans. Still others rely on different hosts at different stages in their lives, like the liver fluke *Fasciola hepatica*: its larvae live in freshwater snails, then leave the snail to form cysts on aquatic plants, which are in turn eaten by sheep and buffalo.

The parasitic lifestyle is far from freeloading; hundreds of millions of years of evolution have prodded parasites to develop clever tactics for finding and manipulating their hosts. Zombie ants rose to pop culture fame in 2023 with the television series *The Last of Us*, and while the fungal parasite *Ophiocordyceps unilateralis* can't infect humans, its effects do look like mind control. Infected ants mysteriously climb 25 centimeters up the stems of plants and permanently lock in their jaws. This small elevation provides the perfect temperature and humidity for the *Cordyceps* fungus to grow within the ant, eventually bursting out of its body and raining spores onto unsuspecting ants below.

Though not every parasitic lifestyle is as flashy as Cordyceps, many are as effective. Parasites are "almost like Pokémon," said Carrie Cizauskas, a freelance science consultant and trained veterinarian with a background in disease ecology. "They're like these weird little alien creatures that you can be like, 'ooh, this one has these capabilities and this kind of power.'"

Despite people's repulsion, the world of parasites is not a horror show: it's a technicolor field trip from the Magic School Bus. In fact, biologists can use the presence of parasites as an indication of an ecosystem's health, since each species suggests that its specific hosts live nearby. In general, the more parasite species an environment has, the more biodiverse it is.

Research increasingly suggests that parasites play an essential, stabilizing role in complex ecological networks. Their functions can be compared to top predators, like wolves or lions: parasites keep populations in check so host species don't outpace available resources, like food or prime habitat.

Parasites are also particularly important in food webs. In one study on a California salt marsh published in the journal *Zoology*, removing a single snail species decreased the food web's stability by around 1,000 links between species. It's not that the snail was itself so important, but that it hosted 17 different species of parasitic flatworms, which in turn had hundreds of connections. As Gardner and colleagues wrote in their 2021 book *Parasites: The Inside Scoop*, "Getting rid of all parasites would not make the world a healthier place."

On evolutionary timescales, parasites also drive host species to adapt against them, leading to greater biodiversity. Two groups of the mussel *Mytilus edulis*, for example, evolved different responses against the small, parasitic crustacean *Mytilicola intestinalis* in the southeastern North

Sea. Over time, some mussels grew to tolerate infection and others to resist it, which could potentially lead the mussel to diverge into different species.

Parasites don't only ensure ecosystem health; they have the potential to help human health, too. "No [other] group of organisms has spent so much of their evolutionary time modulating and manipulating our immune systems and our nervous systems," said Kwak. He thinks parasites could reveal new compounds for antibiotics, anesthetics, or immune suppressants. For instance, Kwak suggested looking at ticks for numbing compounds since the creatures have evolved precisely to avoid being felt by the animal on which they're munching.

Despite parasites' ecological and pharmacological importance, research and funding is largely concentrated in the medical and veterinary spheres, on species that negatively affect people and their pets. *Plasmodium*, the single-celled parasite that causes malaria, is easily the most studied parasite on Earth for its impact on human health; advances in such research are vital to saving human life.

Globally, however, at most 4% of parasite species infect humans, and many parasitologists suggest the estimate is closer to 0.1%. Of those, the majority prefer non-human species as hosts (the blood fluke *Schistosoma mansoni*, for example, is better suited to infect rats than humans).

Causing human suffering is far from parasites' whole story. As global biodiversity declines and parasitologists age, revitalizing the field begins with countering the usual narrative of fear.

"It might seem unimaginable that 40 years into the future, we're all gonna look at parasites and be like, 'Oh, so beautiful, so magnificent,'" said Chelsea Wood, a parasitologist at the University of Washington. "But I do think that's what's coming."

Kevin Liévano, a graduate student at the University of Nebraska, has a uniquely stomach-churning origin story when it comes to his interest in parasites.

At the age of eight, he visited his grandmother's house in the mountain town of Zipacón, Colombia for a sleepover. He was excited to see his cousins but couldn't shake his fears about nighttime. In the dark, the forest came alive with the conversations of owls and frogs; Liévano's grandmother told him they were witches.

That night, Liévano awoke to the sound of his little cousin half-gulping, half-choking. Liévano called to him but heard no reply. The house had no electricity, so he lit a candle and turned to the

small boy lying next to him in bed. In the dim glow, he could make out his cousin's nose — and a yellow-white worm dangling out of his nostril.

The next day, Liévano saw more worms on his cousin's pillow and realized that his cousins were "packed with parasites." In retrospect, he theorized that the whole family, who would all recover, had ingested helminth eggs from contaminated food or water. Still, Liévano didn't find the worms nearly as terrifying as witches.

"Most people are like, 'Oh my God, this is gross, I just can't see that,'" said Liévano. "For me, that's something fascinating."

Today, Liévano studies parasites of mammals at the Manter Lab, nearly 3,000 miles from his hometown of Bogotá. Before graduate school, he spent five years working in a veterinary clinic in Bogotá, treating animals from cats to eagles. Part of Liévano's laid back attitude to parasites stems from personal experience at the clinic: he was often their host.

Liévano rattled off his list matter-of-factly. "All kind of worms… fleas, lice, ticks…blood parasites because of the tick bites or mosquitos…Yeah, that's it."

Despite this menagerie of past pests, Liévano is in perfect health. He runs 10 miles per week, dances everything from West Coast Swing to Mambo in the university's dance group, and plays drums in a band. He is also nurturing a parasite-infected bee assassin bug on his desk, lovingly named Little Kevin, after himself.

Liévano believes parasites aren't something to be repulsed by, but something to celebrate as part of life.

"Oh my gosh, I have these inside?" he recalled of the times he learned he had parasites. "Impressive!"

For most Americans, finding or simply learning about parasites is a far more unsavory experience. "The way most people encounter them is in their dog's shit," said Chelsea Wood. "That's not really a thing that's gonna endear itself to you at first blush."

If disgust feels like a natural reaction to parasites, there's an evolutionary reason. Darwin suggested that early disgust-prone humans would have avoided spoiled or dangerous foods — one bad meal could cost them their life and ability to pass on their genes. Disgust may also have kept early humans away from the places parasites thrive, like bodily waste and still water. Avoiding parasitic infections meant survival and the next generation of disgusted humans.

Many other animals, too, have an evolved aversion to being around their own poop. Some, like mandrills, even avoid grooming other monkeys when they can smell that they are infected with parasites.

Despite an evolved aversion to parasites' home turf, humans have been contracting them for millennia. The earliest written documentation of parasitic infections comes from Egyptian

papyrus circa 1500 BC. An ivory comb humans crafted for removing lice was dated to 1700 BC. Scientists found evidence of eggs from a lung fluke in the *Paragonimus* genus in fossilized human feces as ancient as 5900 BC.

"Everybody gets infected or affected with parasites at some point in their lives," said Gardner. Teachers and parents know the nightmare of lice, and hikers are no strangers to ticks. Even today, the amount of *Ascaris* eggs produced annually in infected humans weigh as much as 350 adult blue whales, Gardner and Racz wrote in a 2022 book.

Taken in perspective, human parasitic infections in the developed world are far less of a threat today than at any other point in history. Access to clean water is likely the number one reason: washing your hands and food are the first steps to parasite prevention. When people do get infected, antiparasitic drugs, surgical procedures, and an immune-strengthening diet (think: raw garlic and pomegranates) are readily available cures.

As parasite infections have decreased, parasites have also fallen off the radar of western countries. Medical schools often no longer mandate parasitology classes, with such courses falling into small concentrations like tropical medicine or infectious disease. Parasitology classes are only offered at universities with dedicated faculty, and high school courses are practically non-existent in the U.S. (not one person interviewed for this article had taken one). Only veterinarians are still required to learn parasitology in their training.

"Increasingly, I don't experience or encounter parasitology very much, certainly at the undergraduate level," said Kwak. "Even at the graduate level, it's very rare."

Wood shared Kwak's concerns, calling undergraduate biology programs "bereft of parasites."

"Somehow, we're giving people full-on degrees in biology when they don't know anything about a plurality of animal life," she said, emphasizing that parasites represent upwards of 40% of all animal species.

Without parasite exposure during their education, many parasitologists stumble into the field by accident. Some, like Wood, feel lucky to have found their way in during their undergraduate years.

Though she originally wanted to be a marine biologist, Wood settled for working in an estuarine parasite lab at a nearby university when her college didn't have any offerings. Her initial response was, fittingly, disgust, but she eventually "fell completely in love with the worms."

"I realized that there was this whole sub-world, this whole alternate dimension that was present in nature and in all the animals that I had been interested in since I was little," Wood said. "It was sort of like waking up from the Matrix."

Others, like Chenhua Li, a parasitologist who now works in biotech, had never even heard of parasitology before her graduate studies in the field. "English is not my native language," she explained of her experience researching western graduate programs while living in China. "I

didn't recognize parasitology as a word, but it started with a 'P-A' and ended with 'ology,' so I mistook that word as 'pathology.'"

After her initial shock, Li ended up loving the field and pursuing a PhD.

If budding biologists rarely learn about parasitology, established ones, too, often don't consider parasites in their research.

Utah State University ecologist Sara Weinstein worries that ecologists often exclude parasites from studies on ecosystems and animals where parasites play crucial roles. It's easier to focus on the larger organisms in an ecosystem, like trees and mammals, leaving parasitologists to disentangle the effects of creatures that are small or out of sight.

"Instead of saying parasite research has to be this standalone project," Weinstein suggested, more ecologists could think about their work as "an ecosystem-level project," — that is to say, include the little guys.

Carrie Cizauskas, the veterinarian-turned-science consultant, thinks that part of the parasite oversight comes from how the scientific community shares ideas. "There's huge, huge gaps in how scientists talk to each other," they said. "Medical doctors and veterinarians read completely different literature than do ecologists and naturalists and conservationists."

Cizauskas feels this gap tends to siphon parasites into their own small field, despite how these organisms are, by definition, members of other biological systems.

Many parasitologists see a plainer reason that their creatures aren't widely studied: they're not that cute. Research suggests that since humans evolved to care for our young, we are drawn to baby-like features in other animals: big eyes, round cheeks, and stubby limbs, for example. This tendency has led to remarkably streamlined ideas of which animals count as cute, and which ones are icky. There's even a German word for it: *Kindchenschema*, which literally translates to "baby schema."

In the late 1960s, cuteness benefitted a different set of hated animals: apex predators. Wolves were villains in fairy tales, notorious for harming ranchers' livestock, and the subject of U.S. government-sponsored extermination programs. In 1973, however, wolves were added to the Endangered Species Act and the public slowly began to appreciate them for their ecological value to food chains. It helped that wolves look cuddly.

Unfortunately for parasites, said Kwak, they are "not nearly as charismatic" as big predators. They don't have dedicated exhibits at zoos, nor stuffed animals representing them in gift shops. And, he emphasized, parasites aren't simply unsightly — they're oftentimes plain invisible. Some parasites can only be seen with a microscope, and many make their living literally *inside* other creatures.

"You don't see a tapeworm walking down the street," said Sarah Orlofske, a parasitologist at the University of Wisconsin-Stevens Point. "Most students have seen a bird, maybe they've seen a

lizard, maybe they've seen a snake. But unless you're, like, really keen on mosquitoes and ticks, most students don't interact."

If you can't see the parasites, Orlofske continued, you "don't relate to them" — and won't study them. In her career, she has mentored over 80 biology undergraduates; only two of them initially came to her wanting to study parasites.

Medical improvements, decreases in parasite education, and parasites' struggle in the vanity department have created an unfortunate confluence: parasitology is a shrinking field, with few new scientists to fill in the gaps.

When Mike Kinsella graduated in 1969 with a PhD in parasitology from the University of Montana, he struggled to find a faculty position where he could discover new species of parasitic worms. He ended up back in school for pharmacology, then worked as a pharmacist for two decades to pay the bills. Upon retiring, though, Kinsella realized his love for worms hadn't faded.

For the past 30 years, Kinsella has been a stay-at-home parasitologist, identifying species for zoos, wildlife biologists, and fellow parasitologists from the comfort of his home desk in Missoula, Montana. Every week, he opens his mailbox to find packages of worms from different countries and host animals. Then he gets to work with two modest microscopes and volumes of parasite reference books. In total, Kinsella has described over 30 new species, published more than 200 papers, and had 20 species named after him.

Kinsella runs his personal parasitology lab, which he calls HelmWest — Helm for the helminth worms he studies, and west for its residence in Montana — all out of pocket. He washes and reuses slides 200 times and asks colleagues to send him chemicals when he can't purchase his own. His wife, ever supportive, only "draws the line at dissecting things in the living room," Kinsella said, acknowledging that she'll sometimes let small mammals slide.

Despite this bare-bones set up, Kinsella is one of the world's leading experts on parasitic worms — and one of the only people scientists can send their specimens to for identification. He's also 83.

"When I'm gone, I don't know if there's anybody left that can do what I do," he said.
Since parasite varieties are so numerous — there are an estimated half a million species of nematodes alone — many parasitologists are the only, or one of the only, experts on a specific

group. When these scientists pass, their intricate understanding of how to classify and connect species goes with them.

This problem isn't only anecdotal; a 2022 study published in the *International Journal for Parasitology* found that a large proportion of finding and describing new parasite species over the past two decades has been done by a handful of productive scientists. These individuals are mostly in the later stages of their careers, with little turnover to younger scientists — a fact that, according to the authors, is "putting the whole field at risk of collapse."

Importantly, this trend is not the case for subfields like disease ecology or parasite ecology, which concern themselves more with what parasites do rather than what they are. But while tenure-track positions and conferences for these disciplines increase, the work of discovering, naming, connecting, and cataloging species is petering out.

Nowadays, if Kinsella has a question, the community of scientists he can consult has dwindled. He finds his basement filling up with new species he has not been able to identify.

Tyler Achatz, a young parasitologist at Middle Georgia State University, echoed Kinsella's concern. "Honestly, at this point, we hope every time we look at our worms that it's not going to be new," he joked about finding new species. "If it's new, you have to do all that work."

But parasite diversity is vast and still largely unexplored. Achatz, an assistant professor, found two new species on his first day exploring by his university's cross-country track. During his PhD, he described 26 new species and identified the existence of at least 50 others.

Being in a shrinking field has forced Achatz into the fire early in his career. He feels equal parts happy and worried that his expertise is already in demand.

"Unless people step up and start filling that gap, the knowledge is gonna get lost," he said.

For Gardner, who has described around 50 new parasite species in his career (and has had three named after him), the main problem isn't knowledge, but time. With so much curation and teaching work on his plate, his species identification takes a backseat. Gardner estimates that there are thousands of new but un-described species in the Manter Lab's collection — a number that would be astonishing in fields like mammalogy or ornithology.

And that number keeps increasing. Many parasitologists bequeath their private collections to the Manter Lab upon their deaths, keeping the Lab's collection steadily growing. The system lays bare how Gardner is losing colleagues while gaining the work they leave behind.

"Gábor and I are trying to do the best we can, but there's no way to actually do it," said Gardner, who estimates that the work of maintaining the collection would be best suited to 10 people. "The task is daunting and time is short."

Sustaining an archive the size of the Manter Lab is far from easy. The most comparable parasite collection in size — the U.S. National Parasite Collection, run by the U.S. Department of

Agriculture — was subsumed in 2013 by the Smithsonian Institute due to "preservation purposes." Its 20 million specimens joined the Smithsonian Museum of Natural History's Department of Invertebrate Zoology, which today has about 70 million specimens, including the parasite collection.

Consolidating parasite collections can be beneficial — it increases the safety of rare specimens and streamlines the process to borrow items — but it also reduces jobs in an already narrow field and increases work volume for the scientists who remain. Also, added Racz, consolidating collections makes it harder for local or less well-funded scientists to access specimens that once resided close by.

The Smithsonian Institute is a government-run collection, rendering it somewhat more stable than that of a university-run collection like the Manter Lab. In 2003, Gardner was a vocal advocate for the Manter Lab when the University of Nebraska defunded the institution under which the collection was housed. Gardner's persistence persuaded the University to maintain the collection and find it new funding sources.

Despite the significance of the Manter Lab (Gardner and Racz have stopped short of assessing the collection for insurance, valuing a single host animal with parasites at $150 to $500), Racz said money is "always in limbo." Their university funding only covers day-to-day operations; Gardner relies on grant applications to support projects like digitizing the collection or going into the field for research.

"The Manter Lab doesn't receive the kind of funding it needs, and it's not just from the University of Nebraska" said Judy Diamond, a curator at the University of Nebraska State Museum and a frequent collaborator with Gardner and Racz. "They put their hearts into maintaining and growing the collection," she said. "They won't be deterred from their work."

But Gardner's colleagues, like Kinsella, worry what will become of the Manter Lab when Gardner eventually retires. "He's been the one behind building that collection and keeping it going," said Kinsella. "I wonder if once he's gone, whether the university is going to have the commitment to it."

On a slushy January afternoon, Racz bee-lined past wooden planks to the elevator of the University of Nebraska State Museum. The ground level was closed for remodeling and an unfortunate discovery of asbestos, and Racz wasn't of the mind to dilly-dally.

When he stepped out onto the 4th floor, a white-haired museum employee greeted him warmly. She had been sitting down after a day of classroom field trips but was eager to tell Racz about a child's response to the parasite exhibit.

"Someone asked what the giant snakeskin was," she recounted, referring to a 100-foot long model tapeworm suspended from the ceiling. "And I said, 'It's a parasite from a whale.' And he said, 'What's a parasite?'"

When the University of Nebraska State Museum began renovating in 2017, Garder and Racz spent a year designing a permanent parasite exhibit aimed at the public. The plastic model of a whale tapeworm is one element; pull-out drawers of taxidermied host animals, a simple microscope with an oversized wheel of specimens, and a 10-foot touchscreen table for interactive games round out the room. On one wall, snug in a jar, sits Gardner's chopstick-scooped *Ascaris*.

The exhibit's goal is simple: to introduce the public to parasites that are more fascinating than fearsome. With children and students, specifically, the hope is that they might follow a budding interest in parasitology to a career in it, giving the field a boost a few years down the line.

Wood hopes introducing children to the world of parasites "will spark some folks' imaginations about career paths that are not dolphin training, but instead learning about what's inside of dolphins."

It's a tactic shared by parasitologists around the country. At the University of Georgia, a program called EcoReach sends scientists to classrooms and science fairs to engage students in ecology topics including parasites. At the University of Wisconsin-Stevens Point, Orlofske runs a museum event that has kids comb out glitter from stuffed animals' fur to mimic ticks. Wood is publishing a children's book in fall of 2024 called "Power to the Parasites." Cizauskas, who is also an illustrator, is designing a parasite coloring book featuring scientific descriptions of the creatures on each page.

Li sells packs of parasite Pokémon cards that highlight creatures with unique qualities. Notable cards include *Toxoplasma gondii* (a parasitic protozoan that boasts "Mind Control" since it attracts its rodent host to the smell of cat urine, where the rat spreads it to felines) and *Leucochloridium paradoxum* (a flatworm touting "Mimicry" by pulsating rapidly inside snails to attract birds searching for worms).

"Not only dinosaurs are cool," said Li, who also commissions monthly parasite comics and has created a parasite personality quiz taken by 5,000 people.

Still others, like science illustrator Mona Luo, want to capture public interest by subverting people's parasite expectations altogether. Her goal is to make the creatures "so beautiful that people don't have time to think about how disgusted they are."

Luo (who provided the illustrations for this thesis) is known among parasitologists for her pun-filled parasite Valentine's Day cards. "The idea of parasites is really romantic because it's like an intimate relationship between two creatures," she said. This year, Luo received a personal

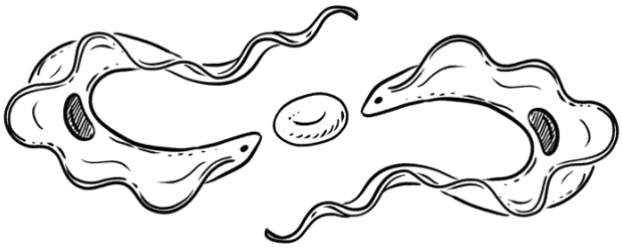
request to design the logo for the 100th anniversary of the American Society of Parasitologists, for which she chose a postcard-style drawing of five parasites posing in front of the mountains in Denver, Colorado where this year's meeting will be held.

Luo's dream project is a poetry-filled coffee table book with a "sumptuous and decadent" parasite drawing for each letter of the alphabet.

"There is a lot of value in trying to cut these negative associations people have," said Supraja Rajagopal, the coordinator of EcoReach, about parasites. They hope EcoReach can "get that idea in kids' heads when they're younger that this isn't bad, this thing isn't gross, or icky."

The Manter Lab has also dipped their toe into unlikely parasite paraphernalia. By Racz's desk sits a cardboard box of parasite stuffed animals featuring cartoonish lice, ticks, and the protozoan that causes Chagas disease. They're leftovers from outreach events at the State Museum, and Gardner tosses extras to students who answer questions correctly in class.

"I think you can cuddle up to tapeworms, too," said Gardner.



Sparking children's interest in parasites is one front in the quest to revitalize parasitology. But its effects won't be felt for decades. That's a problem given the more universal threats facing parasitology: climate change and habitat loss.

As warming temperatures, variable weather patterns, and deforestation impact host species' habitats, the parasites on and inside them will also feel the effects. For every animal threatened with extinction, parasitologists say that several parasites will go extinct with it, depending on how many used the animal as a host. Some studies estimate that as many as a third of parasites may be endangered.

"Parasites face a double threat," wrote Kwak, Wood, and colleagues in 2020 in the journal *Biological Conservation*. "They are directly vulnerable to extinction due to anthropogenic factors like climate change or invasive species, and indirectly vulnerable through coextinction."

Many of these extinctions will be silent, since we don't know the parasite lived in its host to begin with. Out of the millions of parasite species, only two have been assessed for the Red List, an inventory of threatened species maintained by the International Union for Conservation of Nature (IUCN).

In fact, parasites are still largely framed as threats to conservation: a 2011 study also published in *Biological Conservation* found that 72% of English language conservation biology textbooks did not mention parasites or portrayed them negatively.

Kwak, who serves as the co-chair of the IUCN's Parasite Specialist Group, is on a mission to put parasites positively on the radar of global conservation movements. On Japan's lush Amami Ōshima island, he is leading the first ever conservation program for a parasite: the Ryukyu rabbit tick, *Haemaphysalis pentalagi*. To do so, Kwak and his team are studying the Ryukyu rabbits, a dark-furred species that lives only on Amami Ōshima and its neighboring island, Toku-no-Shima. By learning about the rabbit's threats, as well as breeding a captive population, they will in turn conserve the tiny tick species that lives exclusively in these rabbits' fur.

It's "two for the price of one conservation," said Kwak. If successful, his study will help prove that parasite conservation is easy and cheap — if the parasites aren't significantly harmful, just don't remove them from the host species you're already saving. For the amount of money spent to save one or two large mammals, said Kwak, you could save "a thousand [parasite] species, many of which probably have much more significant value to ecosystems."

Extinction is not in store for every parasite species; some may thrive in a warmer world. This can be a major public health concern, as warmer, wetter regions — perfect habitats for mosquitos and ticks — expand into previously cooler ranges. Changing climates may also alter the behavior of host animals, making them more suited to contracting or transmitting parasites. In warm temperatures, for example, some insect species that carry the Chagas-causing parasite reproduce earlier in their lives, which could potentially spread the parasite faster.

With vastly different hosts, lifecycles, and habitats, predicting the future of parasites is messy, if not impossible. But Wood sees existing evidence suggesting that climate change and habitat loss will harm far more species than they help.

Worryingly, little of what we do know concerns species beyond the heavy hitters on human health. With those species, "we have fuck-all of a clue what's happening," said Wood.

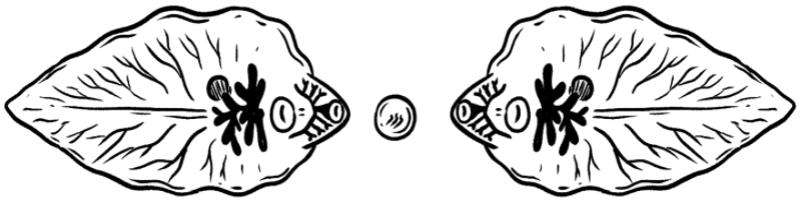
Parasitologists find themselves in an accelerating race: to catalog the world's parasite biodiversity faster than it disappears — and before their own community goes, too. This is called the taxonomic impediment.

"We're obliterating biological diversity on the Earth as fast as we can," said Gardner. "There's not enough people who will take those [species] and describe them and understand what they are before they're gone."

Scientists often argue that one of the strongest arguments for studying biodiversity is that we don't know what any species might reveal, be it the missing puzzle piece to an evolutionary question or a new ingredient for a life-saving drug. With parasites, we could learn which threatened species are keeping ecosystems ever-so-gently in balance, or which ones might evolve to be future human killers.

We also might not, and there are plenty of scientists committing their lives to ticks and worms simply because they like them.

“There's so much biodiversity everywhere, you know, right under [our] feet, even in the city, even in [our] own bodies, potentially,” said Cizauskas. “And that stuff is just as important as, say, a panda.”



One day in the Manter Lab, Gardner and Racz went downstairs to an unassuming storage room. Cardboard boxes lined the walls in stacks sometimes six tall. Each one had the same name printed on it in black Sharpie: Rausch.

When Gardner’s uncle Robert L. Rausch, a famous parasitologist, passed away, Gardner and his wife took it upon themselves to pack up his home. Rausch’s personal possessions went to Gardner’s cousins. What remained of his extensive collection of parasites, microscopes, and scientific images was stuffed into 100 boxes and driven halfway across the country to Nebraska.

Each week, Gardner and Racz agreed, they would bring one box upstairs to the main collection and unpack it. It’s since been four years.

“I would never have been a parasitologist if it hadn’t been him coming to our farm and teaching me,” said Gardner about his uncle. Integrating Rausch’s collection into the Manter Lab is, in many ways, cementing his legacy in parasitology — a legacy to which Gardner has similarly devoted his life.

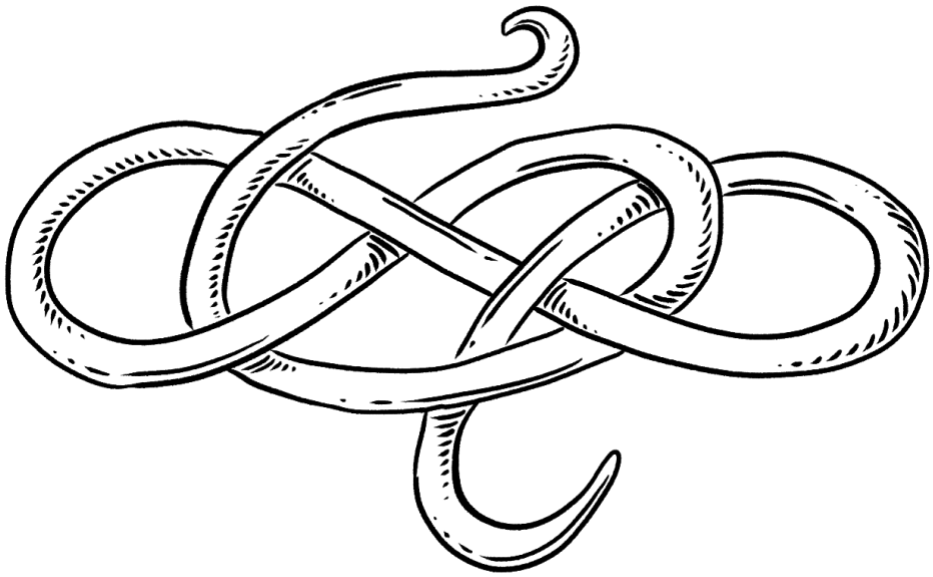
Even as he nears 70, Gardner moves through the collection with sprightliness and resolve. Each day, his son, a freshman at the University of Nebraska-Lincoln, comes by the Lab. The pair shares lunch together at the same large table that has new scientific papers and old German parasitology textbooks strewn about on its surface. Racz will pull up a chair, as will Liévano — a rag-tag, amicable bunch, surrounded by a ceaseless clutter of parasites to catalog and papers to file.

As a computer science major, Gardner’s son has been revamping the Manter Lab website for a more modern look. He hopes it will draw more people to click through and learn about the parasites his dad loves so much.

Gardner doesn't mind that his son isn't following in his footsteps, though he makes sure to let him know the door is open if he ever changes his mind. "He's a great biologist," Gardner said proudly.

After about 20 minutes together, Gardner will get up and move on to another task in the laundry list that keeps the Manter Lab functioning. When asked if he has thought about retiring, Gardner gave a tired chuckle.

"I have too much to do," he said.



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INTERVIEWS

Date of first interview included.

Achatz, Tyler. Assistant Professor in the Department of Natural Sciences at Middle Georgia State University. Zoom Interview. 18 Dec. 2023.

Berkhout, Boris. Researcher at the University of Amsterdam. Zoom Interview. 20 Oct. 2023.

Blaylock, Reginald B. Research Professor and Assistant Director of the Thad Cochran Marine Aquaculture Center at the University of Southern Mississippi; President of the American Society of Parasitology. Email Communication. 9 May 2024.

Bowers, Alison. Research Associate in the Stanford Doerr School of Sustainability at Stanford University. Zoom Interview. 30 Jan. 2024.

Bush, Sarah. Professor in the School of Biological Sciences at the University of Utah. Phone Interview. 11 Dec. 2023.

Cizauskas, Carrie. Scientific Consultant; Illustrator. Zoom Interview. 19 Jan. 2024.

Couch, Lee. Secretary/Treasurer of the American Society of Parasitology. Email Communication. 14 Mar. 2024.

Diamond, Judy. Professor in the University Libraries Department; Curator of the University of Nebraska State Museum at the University of Nebraska-Lincoln. In-Person Interview. 23 Jan. 2024.

Doña, Jorge. Postdoctoral Researcher at the University of Illinois. Zoom Interview. 16 Nov. 2023.

Gardner, Scott. Professor of Biological Sciences; Curator of the Manter Laboratory of Parasitology at the University of Nebraska-Lincoln. Zoom Interview. 12 Dec. 2023.

Hopkins, Skylar. Assistant Professor in the Department of Applied Ecology at North Carolina State University; Co-Chair of the IUCN SSC Parasite Specialist Group. Zoom Interview. 17 Nov. 2023.

James, Peter. Associate Professor in the Department of Environmental Health at Harvard University. Zoom Interview. 23 Oct. 2023.

Kinsella, Mike. Parasitologist. Zoom Interview. 19 Dec. 2023.

Kwak, Mackenzie. Research Fellow at Hokkaido University; Co-Chair of the IUCN SSC Parasite Specialist Group. Zoom Interview. 15 Nov. 2023.

Lafferty, Kevin. Marine Ecologist for the U.S. Geological Survey; Principal Investigator and Adjunct Faculty at UC Santa Barbara. Zoom Interview. 23 Oct. 2023.

Li, Chenhua. Founder and President of the Global Parasitologist Coalition. Zoom Interview. 31 Jan. 2024.

Liévano, Kevin. Graduate Student in Biological Sciences at the University of Nebraska-Lincoln. In-Person Interview. 23 Jan. 2024.

Luo, Mona. Science Illustrator. Zoom Interview. 9 Jan. 2024.

McKenzie, Valerie. Associate Professor in the Department of Ecology and Evolutionary Biology at the University of Colorado Boulder. Zoom Interview. 18 Dec. 2023.

Masud, Numair. Research Associate at Cardiff University. Zoom Interview. 25 Oct. 2023.

Orlofske, Sarah. Associate Professor; Curator of Animal Parasites at the University of Wisconsin-Stevens Point. Zoom Interview. 19 Dec. 2023.

Phillips, Anna. Research Zoologist and Curator of Clitellata and Parasitic Worms at the Smithsonian National Museum of Natural History. Email Correspondence. 10 May 2024.

Poulin, Robert. Professor in the Department of Zoology at the University of Otago. Zoom Interview. 9 Nov. 2023.

Racz, Gábor. Collections Manager of the Manter Laboratory of Parasitology at the University of Nebraska-Lincoln. In-Person Interview. 22 Jan. 2024.

Rajagopal, Supraja. Graduate Student in the Odum School of Ecology at the University of Georgia. Zoom Interview. 11 Dec. 2023.

Tkach, Vasyl. Professor of Biology at the University of North Dakota. Zoom Interview. 20 Dec. 2023.

Tomamichel, Megan. Graduate Student in the Odum School of Ecology at the University of Georgia. Zoom Interview. 10 Nov. 2023.

Weinstein, Sara. Assistant Professor of Biology at Utah State University. Zoom Interview. 11 Dec. 2023.

Wood, Chelsea. Associate Professor in the School of Aquatic and Fishery Sciences at the University of Washington. Zoom Interview. 8 Nov. 2023.