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Chapter One

Parasites on the Move

It was a long journey that lasted many thousands of generations. From clusters of settlements in what is now Asia, people arrived on foot and in boats, traveling in small family groups, settling for years, and then moving on. Some of these dauntless explorers crossed into North America via the Bering land bridge. During a worldwide glacial maximum period, the cool climate concentrated ice on land, resulting in lower sea levels and exposing a land bridge that made possible new routes for travel. With a resilient spirit, the early peoples left evidence of simple tools like spear points, skin scrapers, and hammerstones. And most certainly, they also brought along parasitic worms that had coexisted with them in their homelands.

The immigrants had no idea they were entering a continent undergoing massive faunal changes. Populations of mammals that had flourished earlier in North America were becoming rare. Within a few thousand years numerous species of large mammals went extinct. It was as if alien ships had scooped up most of the massive mammals from the planet, overlooking the few remnants. A more earthly process was undoubtedly at work—the relentless conversion of the landscape as the continent emerged from a glacial period. Plants on which grazing mammals had depended could no longer grow in the warmer, drier climate. Giant sloths, giant ancient armadillos called glyptodonts, and giant beavers gave way to puny descendants. Fourteen kinds of speedy pronghorn antelopes were survived by one remaining species. Camels, horses, tapirs, mastodons, and mammoths disappeared from their North American ranges. They survived in other parts of the world, but the

American bison remained as this continent's only large herbivore. As their sources of food disappeared, so too did their predators: American lions, saber-toothed cats, and dire wolves were replaced by smaller mountain lions, wolves, coyotes, and foxes.

The fossils of the original Pleistocene fauna are scattered throughout North and South America. These remains outline the story of the first peoples—what they ate, the kinds of tools they created, and how they buried their dead. Archaeological sites throughout the Americas also reveal evidence of the constellation of parasites that accompanied the migrants. Some, like *Enterobius* pinworms, were robust travelers and had no problem surviving in tropical or temperate climates. The incessant partnership between humans and pinworms goes back to a time before the common ancestor of humans and apes. Each human generation passed the parasite on to the next one—like DNA but not like DNA, since the transmission occurred not in the host cells but in the environment as the worm eggs moved among hosts. Pinworms are found in many kinds of primates, the group that includes monkeys and apes, but each species is remarkably specific. One close relative of the human pinworms infects chimpanzees, while others infect gorillas and orangutans. This suggests that different species of pinworms evolved parallel to the relationships of their hosts.

The pinworm, *Enterobius vermicularis*, causes one of the most common kinds of intestinal infection among people living in temperate zones such as North America. Their eggs are easily spread among children and people living in institutions via contaminated clothing, food, and surfaces, and they collect under fingernails and in bedding. Once ingested, the eggs hatch and the juveniles molt to adults, completing their life cycle in humans, their only host. Infection rarely results in serious illness. Because pinworms are relatively host specific, they act as a kind of marker that traces human movements over time. As humans migrated from one area to another, the pinworms came along, leaving traces in coprolites, the fossilized remains of human feces. Even small genetic

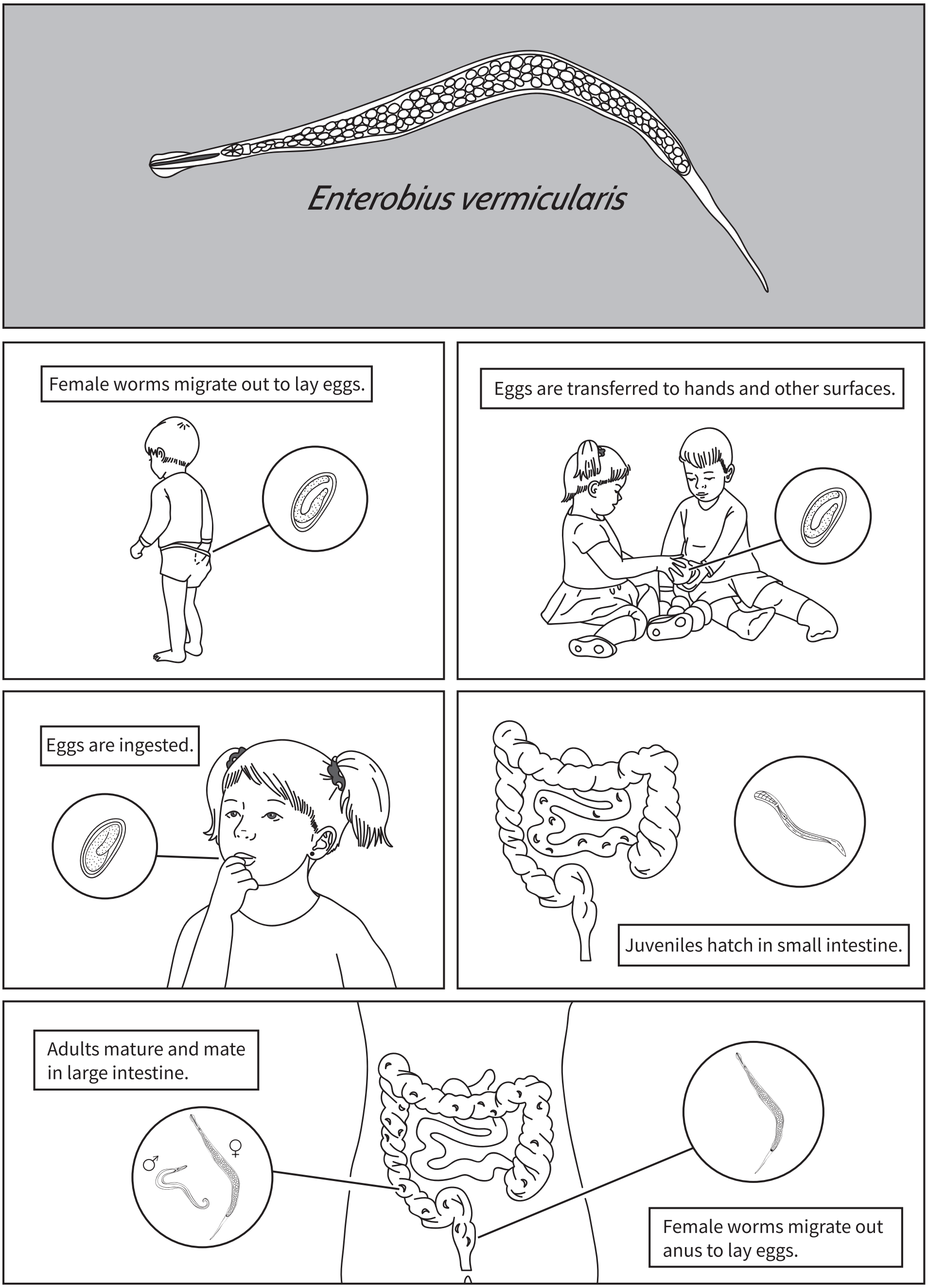

Figure 1. *Enterobius vermicularis* lifeline. Illustration by Brenda Lee.

differences within the same species of pinworm give clues to human movements. It turns out that the pinworms that accompanied people who migrated across the Bering land bridge to North America show genetic differences from those that accompanied other migrants. These differences aren't enough to consider the pinworms different species, but they do indicate that people traveled to the New World by multiple routes—some by land from Asia and some apparently by boat from Micronesia and beyond.

Many other parasites migrated with early humans from their origin in Africa to other regions, including the American tropics. Early archaeological sites in the Western Hemisphere reveal evidence of several parasites, including the large nematode *Ascaris lumbricoides* and the whipworm *Trichuris trichiura*. One species in particular—the human hookworm, *Ancylostoma duodenale*—is choosey about where it lives and reproduces, since its eggs and larvae don't tolerate a cold and dry climate. These worms probably accompanied ancient settlers who arrived in Latin America via other routes than the Bering land bridge, because it is unlikely the free-living stage of the juveniles could have survived through the Siberian cold.

Some parasite species are particular about having only humans as their definitive host. Others are opportunistic and settle for any large mammal. Of the 400 or so parasite species that infect people, most—as many as 70%—use humans only as incidental hosts. The fluke *Schistosoma mansoni* is an example of a parasite that uses humans incidentally, since it also readily infects chimpanzees, baboons, and rats. Dog and cat hookworms can be passed to humans—the tiny juveniles burrow into skin and cause infections—but fortunately the parasites don't reproduce inside people.

As people migrated, they carried parasites from their homelands, and during their travels, they picked up new ones. As they put down roots in larger and larger settlements, both kinds of parasites—those specific to human hosts and those acquired from other animals—were offered new opportunities for transmission. The settling of human populations into large stable aggregations allowed for more robust transmission of infectious diseases caused by viruses and bacteria, and it also enabled parasites to have more lasting and sometimes deadly impacts.

Human migrations have occurred throughout history. Sometimes invaders set out to distant lands to extract resources by conquering peoples, like the Spanish conquistadors in the sixteenth century, overpowering locals with their germs and weapons. But most people migrate because they are displaced—by war, by the collapse of their food supply, by infectious disease, and sometimes by racism and prejudice. The 300 years beginning in the 1600s mark an especially dark period in human history as more than 7 million people were forcibly sent from their homes in Africa to serve as slaves in the New World. The Portuguese, English, French, Spanish, Dutch, and Danish built slave economies throughout the Americas and other parts of the globe. People were captured from vast regions across Africa: first from what is now Senegal, Gambia, Angola, and Congo, and then from Togo, Benin, Nigeria, Mozambique, and Madagascar, and across the continent. From inhuman conditions on transport ships, slaves disembarked in the West Indies, Mexico, Colombia, and Brazil, and then were forced to work in forests, fields, mines, and homes.

Slave traders created inhuman conditions that enabled the movement of parasites with enslaved Africans. The parasitic protists that cause malaria, such as *Plasmodium falciparum*, probably originated in Africa, since they are closely related to those that infect other primates there. Throughout the course of the slave trade, different species and various lineages of *Plasmodium* from throughout Africa were introduced to the Americas. But Africans weren't the only source of the parasite. Analysis of DNA from at least three South American tribes suggests that there were earlier migrations to the New World from Australasia, since these tribes appear to share ancestry with Indigenous populations from Australia and Melanesia. One can imagine that at least one form of the malaria parasite could have arrived at South America before the European-driven slave trade.

The first enslaved Africans to arrive in the English colonies in Virginia may have been kidnapped from a Portuguese slave ship at around 1619. During the next years, hundreds of thousands of people from Africa were sold and traded to work on plantations. In the American colonies, enslaved Africans were highly prized in malaria-prone regions because they seemed to tolerate the disease better than Europeans. Some, in fact, carried a genetic mutation from their African homeland that limited the survival of the malaria-causing parasites by changing the configuration of hemoglobin in red blood cells. This mutation is called sickle cell disease, and it has been passed on through generations of survivors. The mutation still occurs in modern people living in areas where malaria no longer occurs; the mutation causes blood cells to reduce the amount of oxygen they carry, and under certain conditions the disease can be fatal.

Some parasites migrate with their hosts and then move comfortably from person to person in the new environment. Others require a suitable intermediate host in order to thrive. The intermediate host doesn't have to be the same species as that from the place of origin, since a close relative can serve as suitable replacement. The parasitic trematode flatworm, *Schistosoma mansoni*, probably first arrived in the Americas in people kept in the holds of slave ships. In Brazil, these flukes found acceptable intermediate hosts in local snails closely related to those in Africa. And the parasites flourished, continuing to infect people throughout the Americas wherever the snails and people lived together. The slave ships also brought the nematode, *Onchocerca volvulus*, that causes African river blindness. The presence of a blackfly host closely related to those in Africa enabled the parasite to naturalize in the New World.

Forced migrations continue to occur throughout the world, and the inhuman conditions of slave ships have been replaced by the squalor of refugee camps. In 2021, more than 80 million people were forcibly displaced from their homes. Two-thirds are currently from five countries: Syria, Afghanistan, South Sudan, Burma, and Somalia. When people from different regions are compelled to live in close quarters for long periods of time, their parasites are subjected to new intense selection pressures. By allowing the substandard sanitary conditions of refugee camps to persist, the international community empowers a witches' brew of microbes and parasites to spread well beyond the camps themselves.

When the first migrants came to the New World, they could not have known that gradual changes in climate had been reshaping the ecological landscape for millennia. The giant mammals that so dominated the Pleistocene landscape were in sharp decline. Over time, as these migrants became the first Americans, they adapted to live with the animals that remained, such as the vast herds of bison, that would sustain growing human populations in the plains. Colonialism changed all of that, first by subjugating Native peoples and then by decimating the herds of animals they had relied on. The colonists asserted their culture throughout the landscape, dominating the ecology with expansive human developments. Years later, this process has put into motion the conditions for much more rapid changes in global climate than the Earth has experienced throughout human history. And parasites are giving the first clues to how those changes will impact everyone on the planet.

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