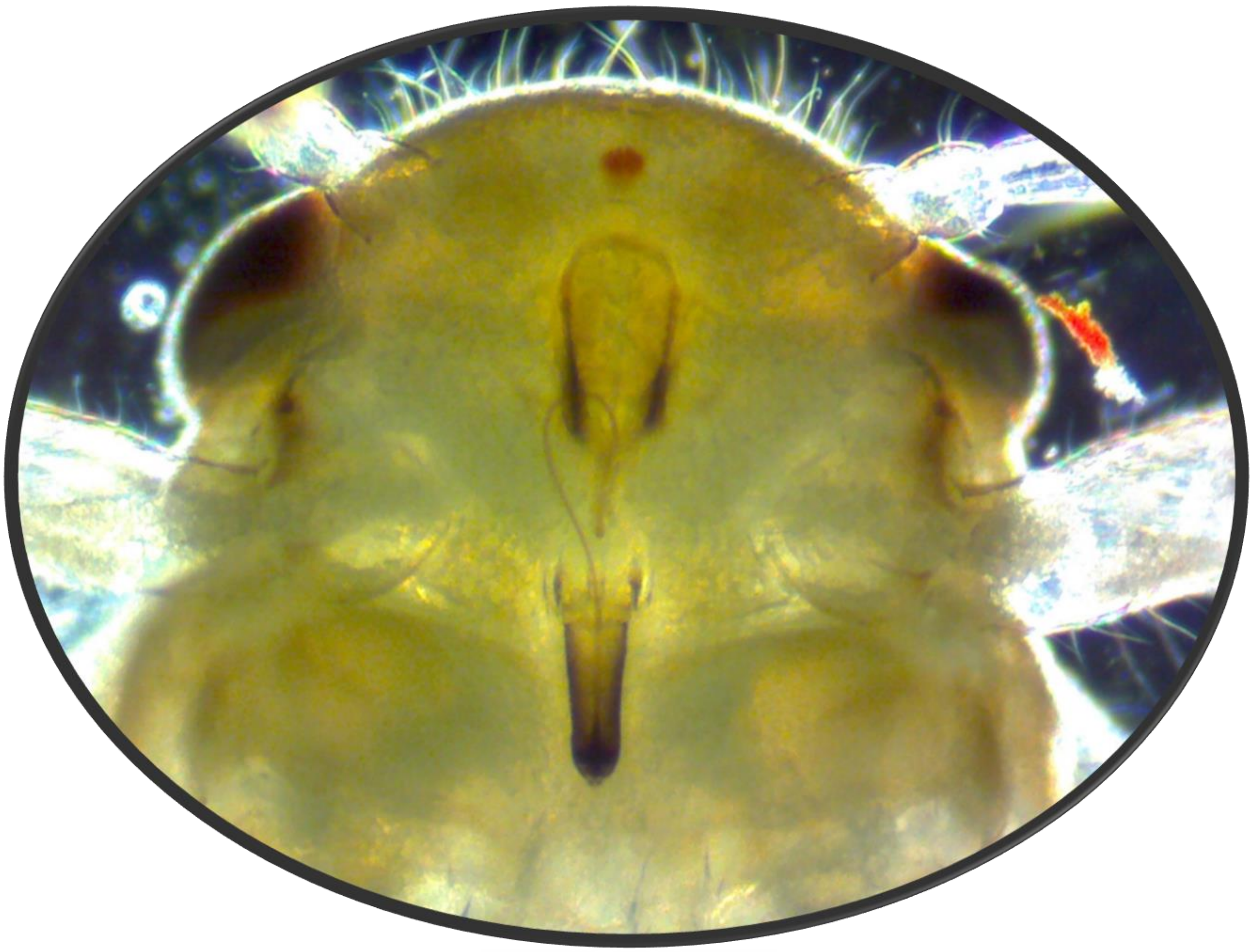
Parasites

part 2

impacts, biology



Ed Ward MD, Minnesota USA

January 2024 *Micscape* Magazine

Origins of this article

I have long been fascinated by weird organisms. During my training I gave talks about Spotted Fever and the ticks that spread it. I had a wonderful experience living in West Africa in 2004, including treating parasites and other neglected tropical diseases. About a decade ago I started using old microscopes as a hobby.

I will continue my introduction to parasites this month; future installments will cover specific parasites. Eventually I'll relate my own and other true stories about patients with parasites. I collect vintage slides of parasites, allowing me to illustrate some kinds. I focus on human parasites, but many of my images show parasites of animals.

Disclaimers

I started out as a little boy and have not fully matured, still thinking creepy crawly things are very interesting.

I am a medical doctor (general internal medicine) but nothing in this article should be used to diagnose or treat medical conditions. Medical Parasitology is a subspecialty full of rare cases and exceptions. The few times I encountered parasites locally, I consulted the US CDC website and the state health department.

If you think you have parasites, consult your doctor. If you live in the USA or Europe having serious parasites is very unlikely, so the doctor will likely dismiss your self diagnosis without testing and offer you $100 of anxiety pills. An alternative healer might happily order $200 of parasite tests and sell you a $200 herbal parasite cleanse you don't need. Serious human parasites are now rare in wealthy nations. Soap, clean water, shoes and indoor plumbing are your best bets against parasites.

Cover page illustration

Hackberry psyllid bug nymph (class Insecta, order Hemiptera) from gall on hackberry tree leaf, Red Wing, MN, USA August 27, 2016. Also called "jumping plant lice" or "hackberry nipple gall makers". Plant parasites, the bugs suck sap with piercing mouthparts (prominent in center of photo) but on occasion they accidentally bite humans (just harmless probing).
4X objective, dark field; bug head about 3.5 mm wide

Other illustrations

If not noted otherwise, photomicrographs are mine, taken with AO/Reichert Microstar or Diastar microscopes with simple USB camera. With a 0.5X reducer (added late 2017) my 2.5X objective images are about 5 mm across, the 4X about 3 mm, 10X about 1.1 mm, 40X about 0.3 mm (300 microns), and 100X about 125 microns. Some patient photos of mine from West Africa are also included.

CORRECTION
My cover illustration for part 1, in December 2023 showed an ixodid tick larva, not a nymph.
The corrected caption is below:

Cover page illustration

Ixodid tick larva (6 legs, nymphs and adults have 8)
family Ixodidae includes deer ticks and dog/wood ticks, the most important hard tick vectors in North America
4X objective, dark field; tick larva about 0.8 mm long
slide is from 1950's and ruined by bubbles in mountant

Contents

Abstract **(global, pertaining to all parasites)**

Life spreads and adapts to everywhere it can survive, including inside and outside the bodies of animals. The bodies of animals turned out to be comfy and tasty. Evolution therefore produces many endoparasites (like intestinal worms) and ectoparasites (such as lice). Most wild animals have parasites, and most humans used to have them. Although most individuals are not harmed, parasites can injure by heavy infestation or by complications. In poor and tropical areas many people are still harmed and even killed, including over 600,000 annual deaths from malaria. Some parasites can also act as vectors to spread bacteria and viruses that cause Lyme disease, viral encephalitis and plague. Almost half of humans still have parasites, most commonly helminths (worms) and hidden toxoplasmosis, but they don't make most of us sick. Members of many different branches of life have sometimes become parasitic: especially protozoans, flatworms, roundworms, and arthropods (including ticks, crustaceans, insects). I will discuss three main kinds of parasites of humans: protozoan parasites, worms, and ectoparasites.

The harms of parasites are highest in the tropical and poor areas of the world. We need to continue life saving efforts to control malaria, worms, and other neglected tropical diseases. Still, most of you reading this need not fear parasites. Anxiety about parasites is far more common than parasitic disease in the developed world. Parasites are also part of the balance of nature, which might be hurt if we continue to extinct parasite species faster than we can discover them.

Proteocephalus tapeworm from large mouth bass, slide H Van Cleave, 10X objective, image ~ 1 mm wide

Ctenocephalides felis, cat flea on opossum, slide L Bircham, 10X objective, image ~ 1 mm wide

Chapter 1, part B Summary

Impacts

Parasites are often small and hidden, but have important impacts on people and nature. The microscopic malaria parasite *Plasmodium* kills more humans than any other parasite, about 600,000 a year, and has shaped history. Intestinal worms can cause malnutrition and anemia, disabling millions of people. Parasites can harm organisms not by causing diseases themselves, but by acting as a vector to spread another pathogen (harmful microorganism). Ticks could give you the bacteria that causes Lyme disease, for example.

Lots of species and Individuals

Multiple species of parasites have been found associated with most animal host species, and parasites likely are the most numerous kinds of animals. When we look closely, all individual wild animals usually have multiple external and internal parasites, as ancient man did also.

Ecosystem Impacts

Parasitic impacts are pervasive and complex. Parasites may balance ecosystems by preventing runaway population growth of consumer species. Some "parasites" may help rather than harm their hosts. Unfortunately, parasites likely are going extinct faster than we can discover them.

Global burdens on humans

Life is not fair and neither are parasites. People in rich nations have largely shed their parasites, but they continue to plague billions of poor people in the tropics, and kill many African children. We are slowly making the human population less wormy.

Biology of Parasites

Strange parasites

Parasites can be up to 10 M (30 feet) long in the case of the broad fish tapeworm, but most are tiny. Some, including the broad tapeworm, live in multiple different hosts during different life stages. Some parasites, such as the arthropod *Sacculina* and the protist *Toxoplasma*, practice parasitic castration or modify host behavior. Parasite bodies, DNA and a few fossils show that they evolved, like the rest of life on earth.

Taxonomy of parasites

Protists, 2 phyla of worms (Platyhelminthes and Nematoda) and Arthropoda give us most of the parasites of animals, even though many phyla have a few parasitic members. The taxonomy of life and especially the classifications of microbes are unfinished works.

Parasite glossary: strange words to describe strange relationships

Parasite an organism that lives in or on another and takes nutrients from the host

Endoparasite lives inside of host

Ectoparasite lives on outside of host

Free living not a parasite; makes food or eats it as a predator/scavenger, does not live inside creatures

Parasite load number of parasites per host (affects potential harm of parasites)

Infestation harboring another animal (worm, arthropod) in or on the body (**infection** is microbes in body)

Host a larger organism that harbors a smaller parasitic (potentially harmful) organism
(smaller organisms helpful to, or neutral for a host are beneficial or commensal, not parasitic)

Definitive host organism that harbors adult (sexually reproductive stage) parasites

Intermediate host organism that harbors immature stages (which may reproduce asexually)

Vector an organism (usually intermediate host) that passes a parasitic organism between hosts

Reservoir a population or community of organisms that can permanently harbor a parasite population

Zoonosis a disease transmitted from animals to people; many parasitic diseases are zoonotic

Parasite life cycle a series of stages through which the parasite grows, reproduces and transmits itself

Monoxenous also known as direct parasitism; life cycle requires only a single host species

Heteroxenous indirect parasitism; life cycle requires definitive host plus one or more intermediate hosts

Direct transmission hosts touch each other (sex counts), passing on a free-living life stage (including skin to skin passing lice) or by ingestion of free-living parasite or eggs (i.e. fecal-oral, by food with contaminated dirt)

Indirect transmission from one host to another through an intermediate host (i.e. a vector such as a tick)

Trophic transmission by eating an organism that contains a parasite (i.e. from prey, or uncooked pork or fish)

Iatrogenic transmission by medical care (i.e. malaria from a blood transfusion or organ transplant)

Parasitoid tiny wasps (some are “fairy flies”) whose larva eat a host from inside, eventually killing it

Hyperparasite a parasite of a parasite; i.e. some parasitoid wasps prey on other parasitoid wasps

Parasitic castration some trematode and arthropod parasites gain added resources by neutering the host

Social parasitism i.e. some butterfly larvae mimic ants in shape and smell and are cared for by ant colonies

Kleptoparasitism i.e. stealing food from another species, as do frigatebirds and hyenas

Brood parasitism i.e. cuckoo birds lay eggs in another species nests, to be raised by host parents

Sexual parasitism i.e. male anglerfish attach to a female and shrink to just tiny sperm-making parasites

Big impacts by tiny parasites

Tiny parasites are a big deal on planet earth. Although mostly hidden they exist in huge numbers of individuals and species. Some can cause direct harm to humans and our domesticated animals. Other parasites serve as vectors for viral, bacterial or parasitic diseases. Some affect the behavior of their hosts (whether that includes people is debated). The impacts of so many parasites in complex ecosystems is huge but largely undiscovered. In some cases parasites can be beneficial (whether that includes people is also debated).

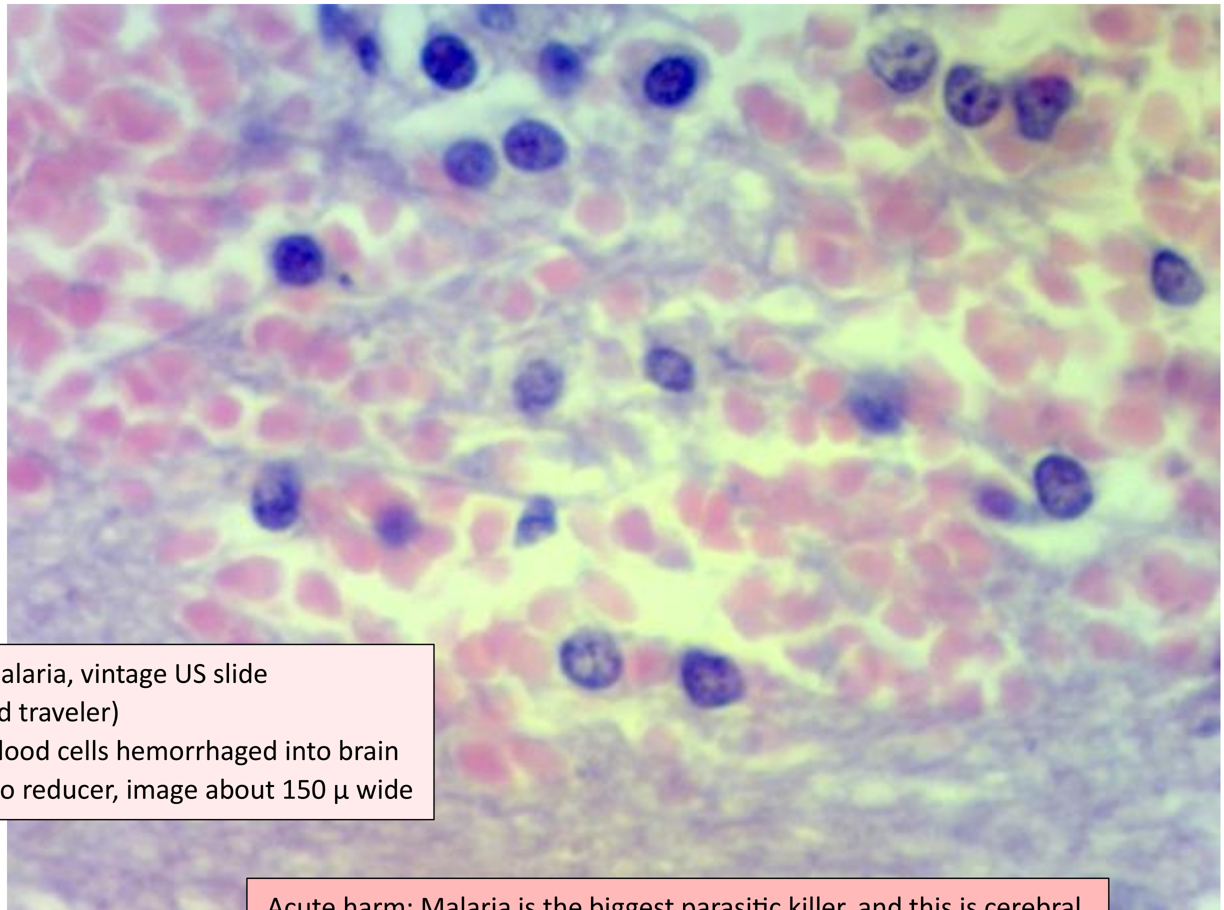
Direct harms to people

Parasites are everywhere and have large total effects even if most individual hosts are not harmed. Organisms move into every environment where they can survive, and after a few adjustments the insides of bigger organisms turned out to be cozy and tasty. A parasite host relationship is at least potentially harmful for the host, although most parasites do little harm.

But a few cases are dramatically harmful, as in *Plasmodium falciparum* causing cerebral malaria and death. Quick death is more typical of bacterial pathogens than of parasites, but protozoans, including *Plasmodium*, were once considered little animals, and thus parasites.

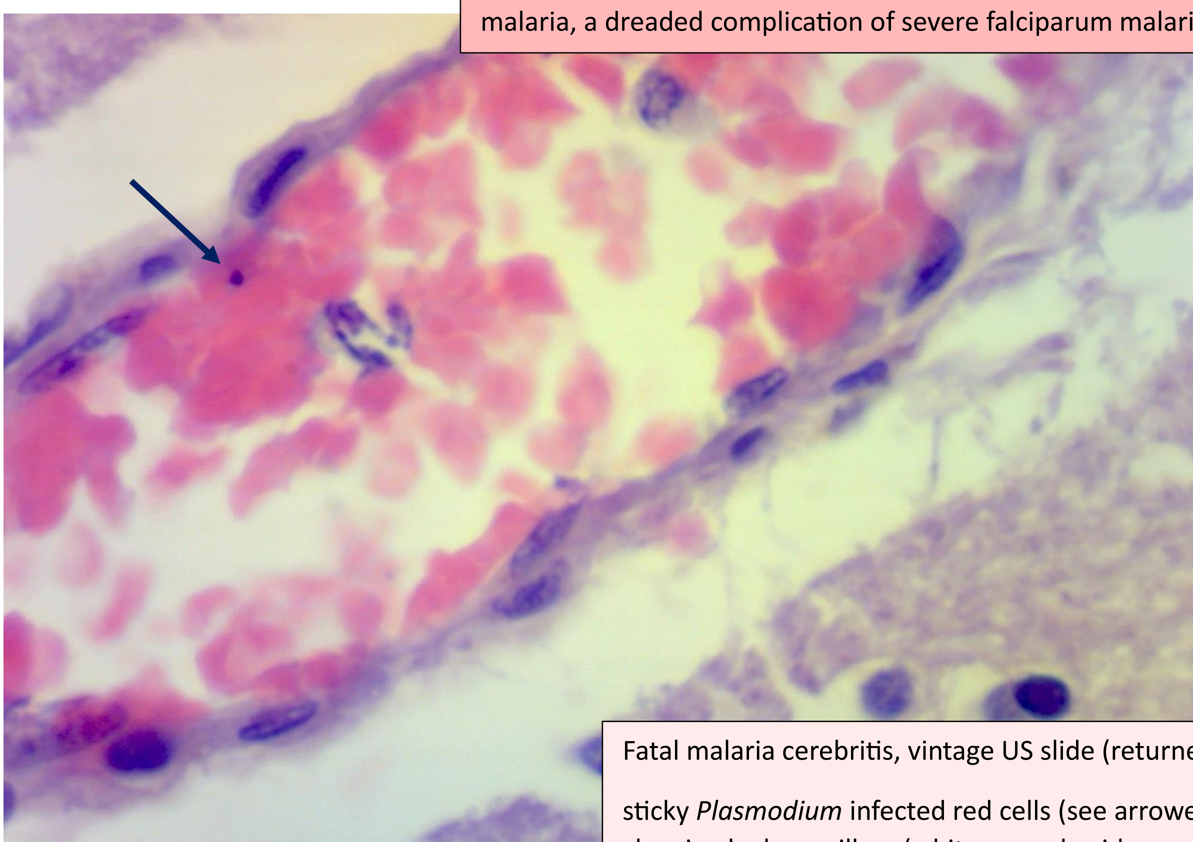
In the case of intestinal worms, little harm is often experienced by most hosts. But some of the about 1.5 billion people that harbor parasitic intestinal worms get sick with abdominal pain, diarrhea, nausea or weakness. A single adult hookworm attached to someone's intestine drinks just 0.2 ml (about 4 drops) of blood a day, but a heavy infestation can lead to 100 ml a day of blood loss. The victim may become anemic, pale, weak and short of breath. Tapeworms and *Ascaris* steal just small amounts of digested food. But if a kid was mildly malnourished before the worm came along, severe malnutrition might ensue, with the child's belly expanding with leaked fluid as lack of protein makes the blood plasma watery. Even the brain is starved and the child may do poorly in school, if they are lucky enough to go to school. When an otherwise survivable bout of pneumonia comes along, a heavily parasitized toddler is more likely to die.

Adult worm parasites usually stay hidden and may turn down the hosts immune system a little to help do so. But their eggs or errant teenagers (larvae) may get stuck in vital organ capillaries, causing blockage and trouble, as in schistosomiasis, which causes the third most parasitic deaths and disability (after malaria and intestinal worms). Adult flukes (flatworm parasites) live in the veins of the colon or bladder. Chronic schistosomiasis (bilharzia), is caused by fibrosis provoked by eggs in the liver, spleen and occasionally the brain or spinal cord. Hydatid disease can occur if larvae of the tapeworm *Echinococcus* end up in the brain, lungs or liver.



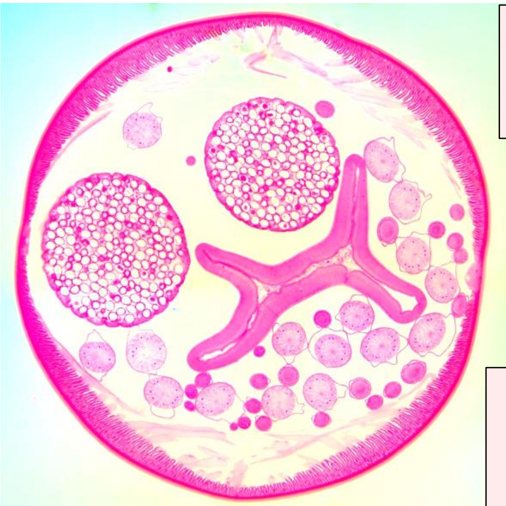
Fatal cerebral malaria, vintage US slide
(likely a returned traveler)
red and white blood cells hemorrhaged into brain
40X objective, no reducer, image about 150 µ wide

Acute harm: Malaria is the biggest parasitic killer, and this is cerebral malaria, a dreaded complication of severe falciparum malaria



Fatal malaria cerebritis, vintage US slide (returned traveler)

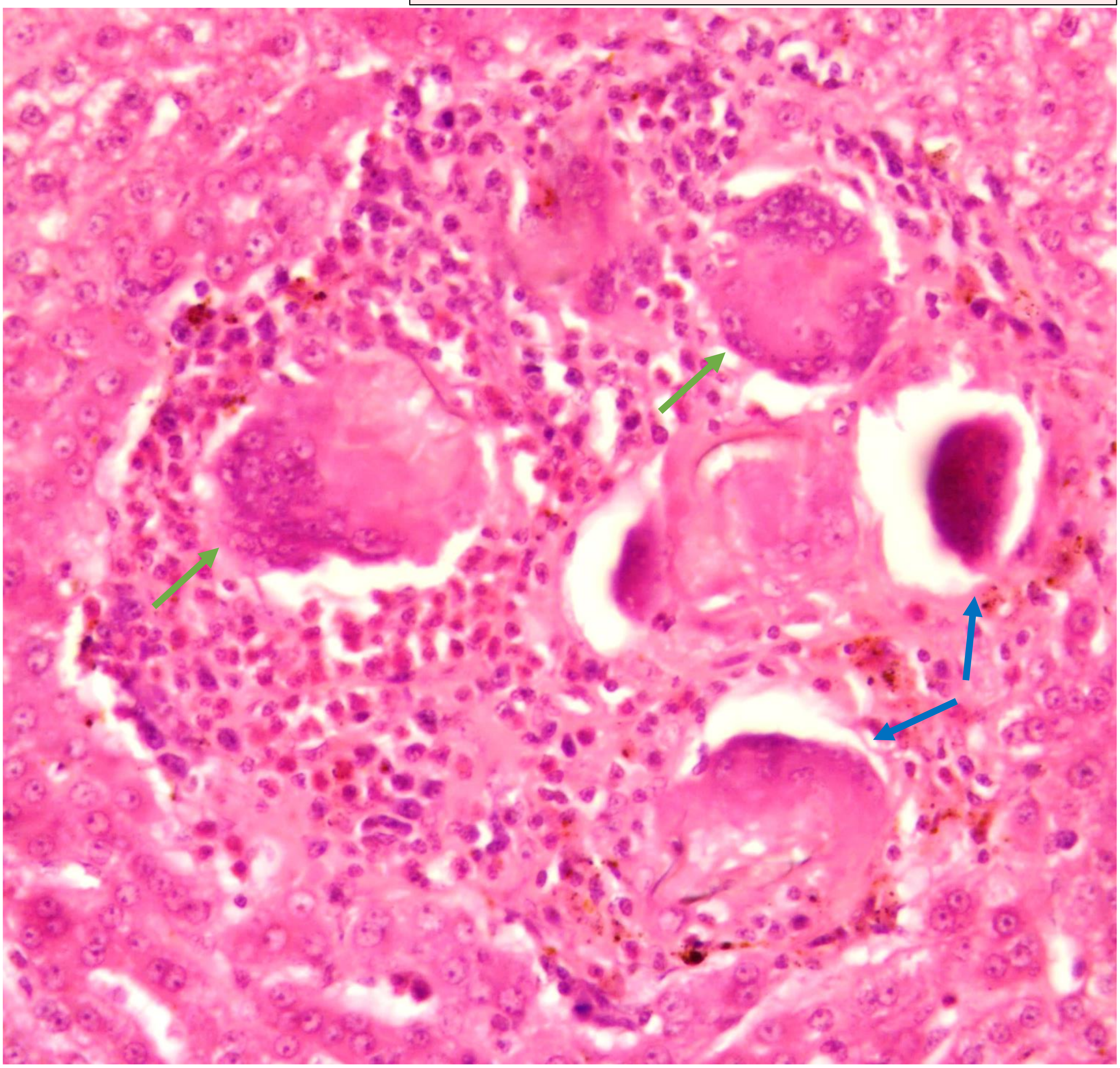
sticky *Plasmodium* infected red cells (see arrowed blue dot)
clogging leaky capillary (white space beside vessel is edema)
100X objective, no reducer, image about 60 microns wide.
Red blood cells are about 5 microns diameter



Left- cross section of female adult Ascaris worm classic vintage educational slide by Turtox stitched with 4X objective, worm about 3 mm dia.

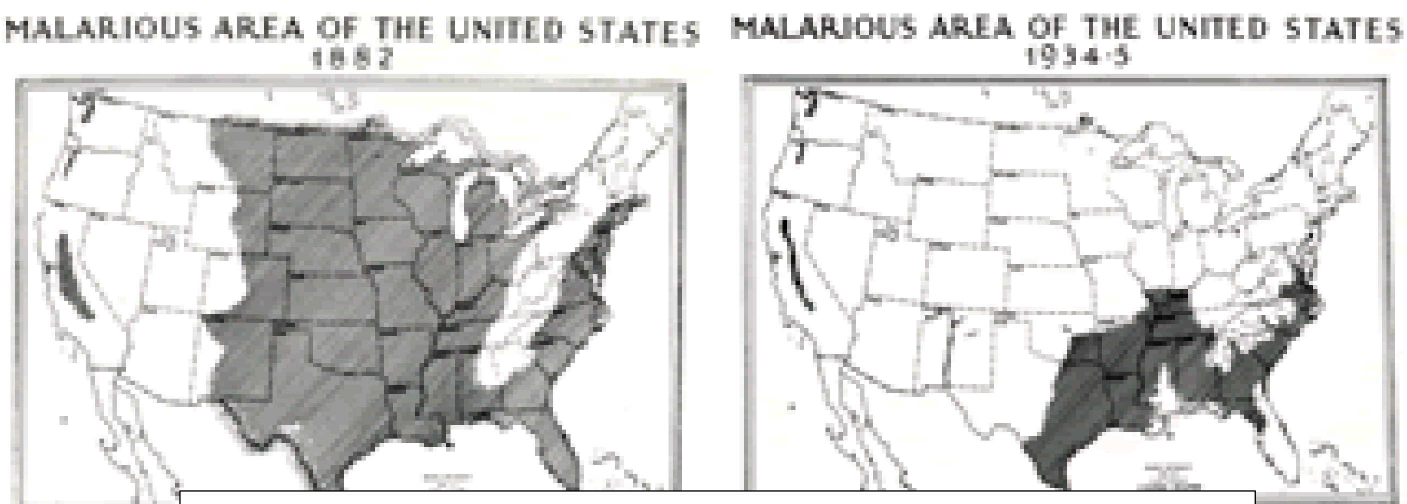
Slow harms: Worms can cause malnutrition or anemia, and chronic schistosomiasis can cause organ failure

Below- *Schistosoma japonicum* in human liver, Army Medical School slide, circa 1950's. The whole granuloma with several degenerate eggs (blue arrows) and multinucleate giant cells (green arrows) is about 300 microns wide. Stitched using a 40X objective



Historical parasite impacts

Over *Homo sapiens'* about 300,000 year history most humans harbored intestinal worms and lice. Although harmful human parasites have been largely eliminated from economically developed regions today, malaria and other parasites have killed kings and shaped history. Crowded, unsanitary conditions in medieval times may have created peak human parasitosis. From childhood until his death in 1799, US founding father George Washington suffered from repeated bouts of malaria (and he probably suffered even more from his doctor's archaic treatments). Malaria and yellow fever (parasite and viral infections transmitted by mosquito) were strong rebel allies in American wars for independence. During US Revolutionary war campaigns in the Carolinas and Virginia, 1780-81, and in the Haitian Revolution, 1791-1804, European soldiers were felled in vast numbers by their lack of immunity. Up to 80% of French soldiers in Haiti died of malaria or yellow fever. Malaria also boosted the value of new trans-Atlantic slave acquisitions, as adult native Africans were even more immune than those slaves born and raised in the rice farming swamps of southeastern US states; US born slaves more often died when they got malaria. Malaria was widely endemic in the US for two centuries, resulting in numerous and especially childhood deaths until many of the swamps were drained by the late 1800's, shrinking the malarial areas to mostly the southeast. Eventually the use of pesticides, especially DDT, officially eliminated malaria from the U.S. in 1952 (rare domestically acquired cases of malaria still occur today in Florida).



Maps of malaria transmission in the USA 1882 and 1935   images from WHO and CDC

Historically, the southeast US also had rampant endemic hookworm, acquired from walking barefoot on contaminated dirt and resulting in chronic severe anemia. Industrialist John D Rockefeller thought "southern laziness" came from the parasite and his foundation worked to successfully eliminate it from the US between 1900 and 1950 with education and sanitation.

More mechanisms of direct harm by parasites

Parasites sometimes eventually cause deaths, even though most of the time they are stealing so little material that the host is little affected. The evolutionary pressure on the parasite is to survive and make babies, not to sicken or kill. Parasites generally move to somewhere the host can't see or feel them, otherwise you might pick them off. Mosquitoes use their needle-like 6 mouth parts (including a pair of saw like maxillae) to inject a numbing agent (how kind of them, as evolution selected for those that didn't get swatted). After a parasite gets established, sickness (disease) follows in a minority of cases by several mechanisms. We discussed some of the direct harms previously. Sometimes the number of parasites per host (parasitic load) becomes so great as to cause anemia or malnutrition. Sometimes intestines or bile ducts get blocked by masses of worms, or parasites end up a particularly sensitive organ (like the brain, causing seizures). Sometimes inflammation and fibrosis imitated by the host's immune system fighting the parasite causes vessel blockages (including strokes) and/or organ failure (like liver cirrhosis, blindness, or heart or lung failure). Mosquitoes or other vectors might give you a pathogen such as West Nile Virus or a parasite such as a malaria sporozooite. Hyperparasite wasps are a special kind of parasite called parasitoid, meaning their host eventually always dies (the wasp larvae slowly consume the insides of host, which dies just as they pop out), a form of delayed predation. Luckily, acquiring a serious parasitic disease is quite rare in Northern Europe and the United States, where a lot of *Micscape* readers live*.

***** You can still be harmed by an ectoparasite indirectly passing along a serious pathogen causing Lyme disease, anaplasmosis, viral encephalitis, and other serious infections. These pathogen caused diseases are not discussed here. They occur everywhere. If you develop rash or fever after being exposed to ticks or mosquitoes, see a doctor.

Parasites as vectors

Sometimes another life form uses a parasite for its own purposes. Many parasites have complex life cycles that take them inside the body of several different animals. This can be useful to germs. **Organisms that transfer an infectious agent from one animal to another are called vectors**. Blood feeding arthropod ectoparasites are commonly vectors. The infectious agent can be a virus, bacteria, protozoa or an animal parasite. Most of the associations between vector and pathogen are species or genus specific (i.e. only *Anopheles* species mosquitoes spread malaria). Most but not all vectors are arthropod ectoparasites that pass on blood borne pathogens, sometimes after the pathogen takes a life cycle step inside the vector.

Example Vector Borne diseases (not all **parasitic**)

Disease	Type of vector	Type of pathogen
	Arachnid Arthropods:	
Crimean-Congo fever, tick encephalitis	**Ticks**	virus (pathogen)
Lyme, borreliosis, tularemia	**Ticks**	bacteria (pathogen)
Scrub typhus	**Mites**	bacteria
	Insect Arthropods:	
Dengue, Zika, West Nile, yellow fever	**Mosquitoes**	virus
Malaria	**Mosquitoes**	protozoan **parasite**
Lymphatic filariasis	**Mosquitoes**	nematode **parasite**
Sandfly fever	**Biting flies**	virus
Sleeping Sickness	**Tsetse Fly**	protozoan **parasite**
River blindness	**Black flies**	nematode **parasite**
Epidemic typhus	**Body Lice**	bacteria
Plague	**Fleas**	bacteria
Chagas disease	**Reduviid bug**	protozoan **parasite**
	Mollusks:	
Schistosomiasis	Freshwater snails	flatworm **parasite**
Angiostrongyliasis	Freshwater snails	nematode **parasite**

Most of the vectors and some of the diseases are parasites, as shown in **bold**

Snails are free-living, but the biting arthropod vectors are **ectoparasite** or **micro-predator** parasites

Ixodes scapularis, black legged aka deer tick, adult female, removed after brief attachment to my wife on 17 May 2013. In US is vector of Lyme disease and anaplasmosis bacteria, babesiosis protist parasite, and Powassan virus
slightly cropped, 4X objective, tick about 3 mm long

Aedes albopictus Asian tiger mosquito, male, Rankin County Mississippi, USA, April 21 2012. Invasive in the US, his female partner is a vector for dengue, chikungunya and zika viruses and *Dirofilaria* (dog heartworm).
stitched with 4X objective, body + head about 4mm long

Harms to other animals

Not all parasitic harms are direct or involve humans. Most parasite species infest nonhuman animals. Your dog might be sickened by intestinal roundworms or tapeworms, by heartworms (*Dirofilaria immitis* roundworms acquired from mosquito ectoparasites) or by mites causing mange. Your cat might get sick from coccidian dysentery (severe, often bloody diarrhea), intestinal worms or fleas. Our livestock from farmed fish to chickens to pigs to cattle also have lots of parasites. Some of those parasites of pets and farm animals are zoonoses that can be passed to people. Even those that can't hurt people directly can cause sickness and death in our companion and food animals. Virchow's 150 year old ideas of One Health (animal disease affects humans) remains true today. The 1 billion poor humans dependent on raising livestock for a living are particularly vulnerable to parasites harming their animals.

Various stages in the complex lifecycle of the coccidian parasite *Isospora felis* (arrows) damaging cat intestine. slide from Johns Hopkins School of Hygiene, circa 1950 20X objective, image about 550 microns across

Numbers of parasite species

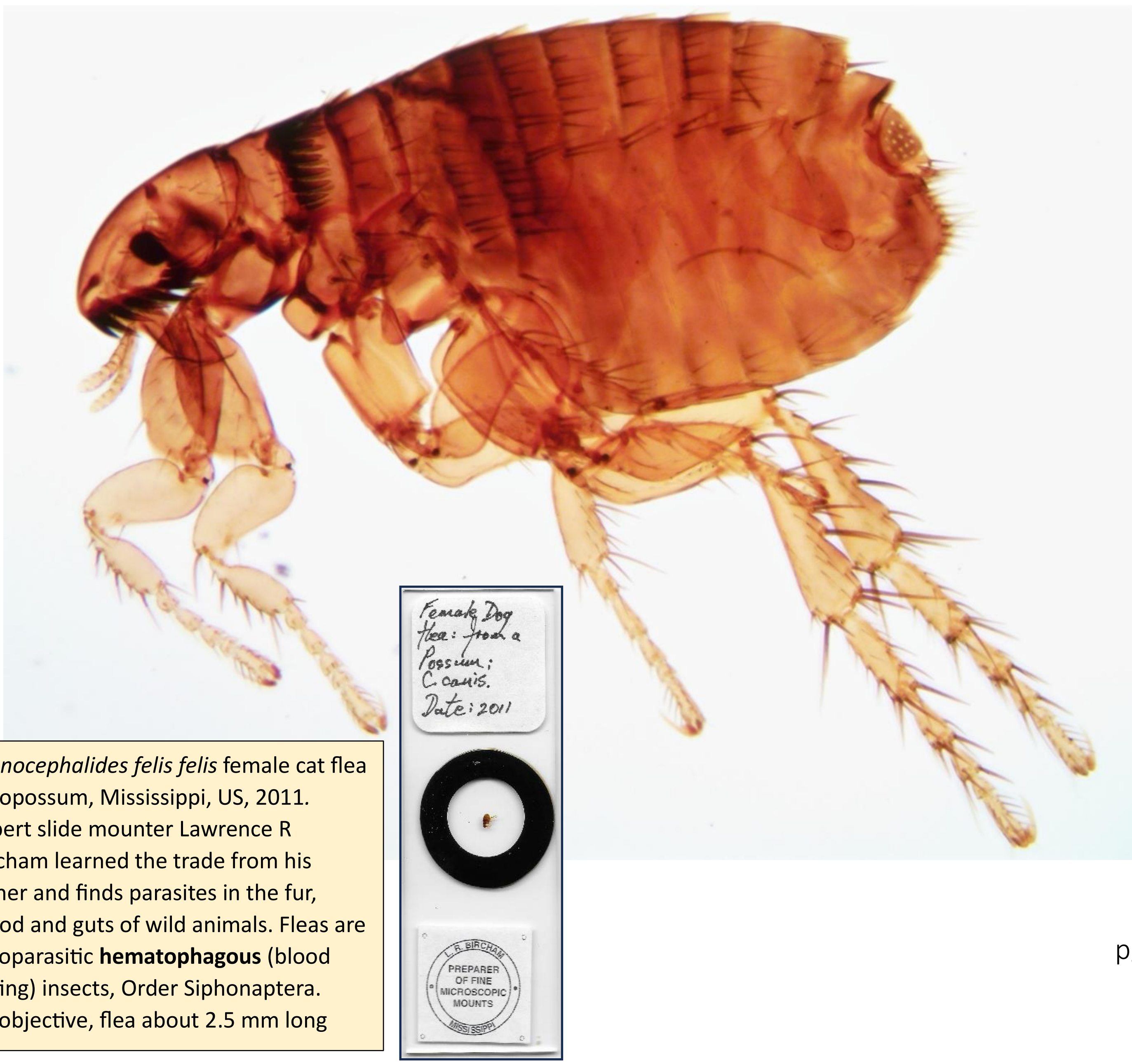
After millions of generations passing body to body, most parasites become highly specialized for certain spots in or on specific hosts, generating new parasite species, and sometimes new life stages. Almost 500,000 species of parasites (internal worms and external lice are the most numerous kinds) made up about 40% of 1.2 million known extant (living) animal species tallied about 2018 (a 2022 paper thinks we are up to about 2.2 described total animal species). Half a million is an undercount resulting from our own ignorance. One 2020 review estimated only 5-15% of helminth parasite species of vertebrates have been named. Much more is undiscovered than is known. Most species are tiny living things still awaiting official discovery. So far about 400 species of worm and protozoan parasites that infest humans have been found, and about 100 seem to infest exclusively our *Homo sapiens* bodies (which appeared on the plains of Africa only about 300,000 years ago). Our parasite research is anthropocentric and more broadly each species of mammals and birds is found to harbor about 10 species of flatworms and nematodes. Likely a majority of animal species will eventually turn out to be parasites.

Nature fills every niche, in many surprising ways. If we included all organisms that live in or on animals while causing harm, numbers would be even bigger. The line between parasite infestations and pathogenic infections is fuzzy. Parasites often live with you for a long time; pathogens often hurt or kill you quickly. Still, the line between parasite and disease pathogen is somewhat arbitrary. Although all viruses and some bacteria parasitize the inside of cells and may or may not cause disease, they are often called pathogens (because they can cause acute and often severe or fatal disease) while a "typical" parasite is stealthy and the host may show no or few signs of infestation (or might become malnourished or might get sick when a vital organ becomes blocked by inflamed worms). Some viruses, such as Herpes zoster (aka the chickenpox and shingles virus) persist in humans for the rest of their lives after infection, a very parasitic and symbiotic thing to do. But we don't count viruses when we think of parasites. There is no simple way to usefully define what a parasite is, without adding a long list of exceptions. In this paper I will move towards discussing the "classic" endoparasites and ectoparasites that are protozoans or animals living in or on other animals. Counting even protists as parasites is partly an artifact of biologists wrongly thinking protists were single celled animals ever since Leuwenhoek called them "animicules" (little animals) in the late 1600's, a mistake finally corrected in the late 1900's. Still, many protozoan parasites have morphologic adaptations (such as the apicomplexan apparatus for entering cells) and complex life cycles with distinctly different protozoan life cycle stages inside different host organisms, all of which is typical of parasites. Later I'll describe classic parasites in three groups:

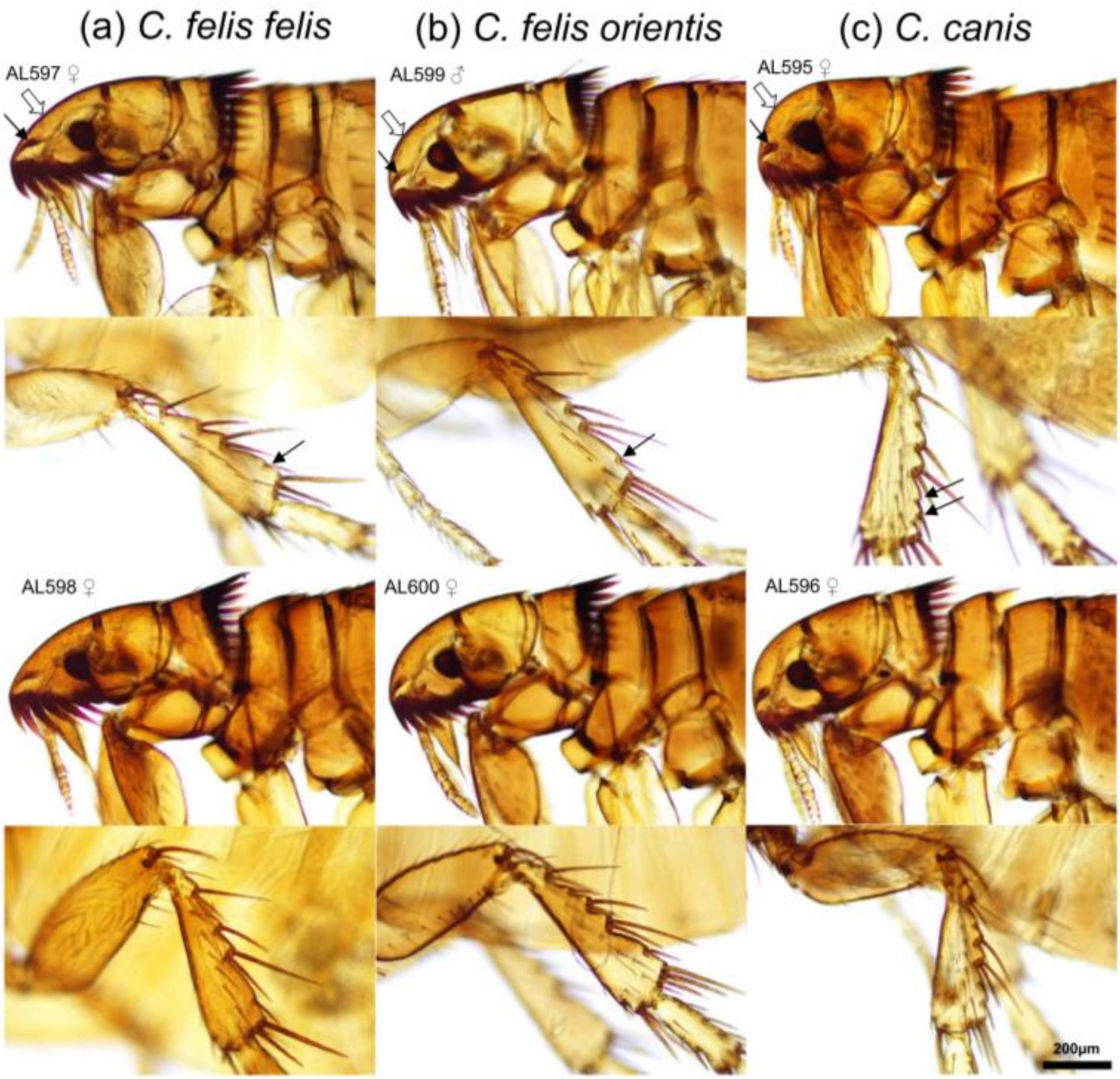
1. Protist parasites 2. Helminth (wormlike) parasites 3. Ectoparasites.

Numbers of individual parasites

Earlier I discussed that most animal species will probably turn out to be tiny parasites. It is possible most individual animals will also turn out to be parasites (although tiny free-living nematodes, mites and copepods are super abundant). Lawrence Bircham found 42 individuals of 3 species of ticks on a single roadkill mink in Mississippi USA. Parasites may not be obvious at first, but upon careful examination (fine comb through fur, organ by organ autopsy, look at gut contents, blood smear and serology for hidden parasites) nearly all individual wild vertebrate animals will be found to harbor multiple parasites, even though most host animals do not appear to be sickened by the parasites. Like a skilled pick-pocket thief, many parasites are adapted to steal food without the host even noticing. Most commonly found in wildlife are various sorts of intestinal worms and external mites and lice, which most humans also harbored in the past. Microfilaria in blood and parasite eggs in feces are also common. Some wild animals live in the equivalent of human extreme poverty, malnourished and flea ridden.



Ctenocephalides felis felis female cat flea on opossum, Mississippi, US, 2011. Expert slide mounter Lawrence R Bircham learned the trade from his father and finds parasites in the fur, blood and guts of wild animals. Fleas are ectoparasitic **hematophagous** (blood eating) insects, Order Siphonaptera. 4X objective, flea about 2.5 mm long

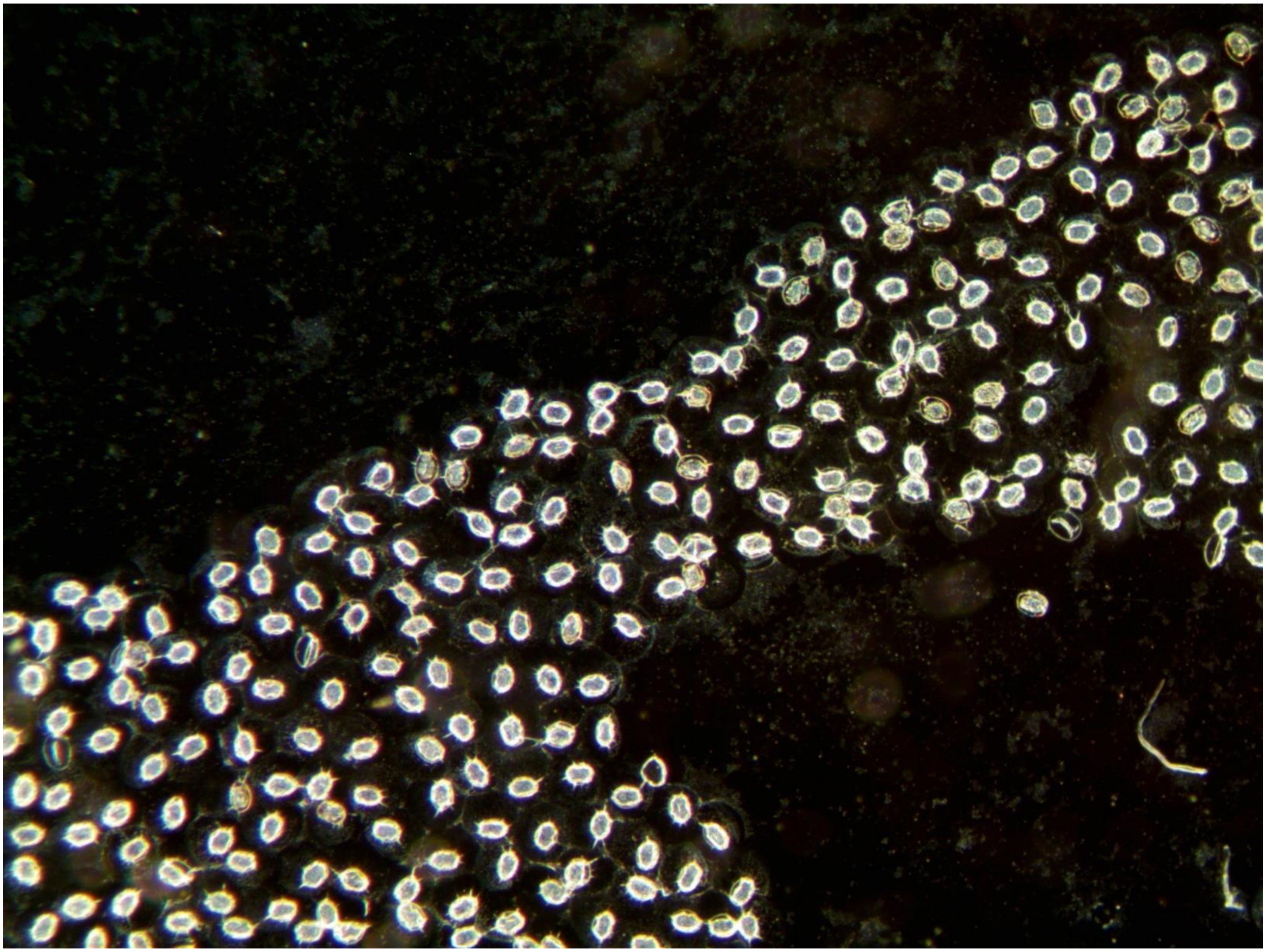


Diagnostic features to distinguish "cat fleas" from "dog fleas", from Hii et al. The authors were careful in their identification of *Rickettsia* carrying fleas in India, and they did DNA trees for the fleas and the *Rickettsia* bacteria they found on dogs. Identifying small arthropods can be challenging. Lawrence R Bircham is an accomplished amateur slide maker who has discovered and co-authored scientific monographs on new mite species, yet I think the flea shown on the previous page is a *C. felis* cat flea, not a *C. canis* dog flea as he labeled it. The two flea species look similar, and a majority of fleas found on dogs worldwide are actually cat fleas.

Opossums carry various fleas, including *Ctenocephalides spp.* vectors of *Rickettsia typhi* the cause of murine typhus which occasionally causes human illness. *R. typhi* in Texas in the southern US used to be carried by rats and their *Xenopsylla* fleas (eventually vanquished by DDT). Now "mouse" typhus is more often harbored by opossums (*Didelphis virginiana*) and *Ctenocephalides* "cat" fleas.

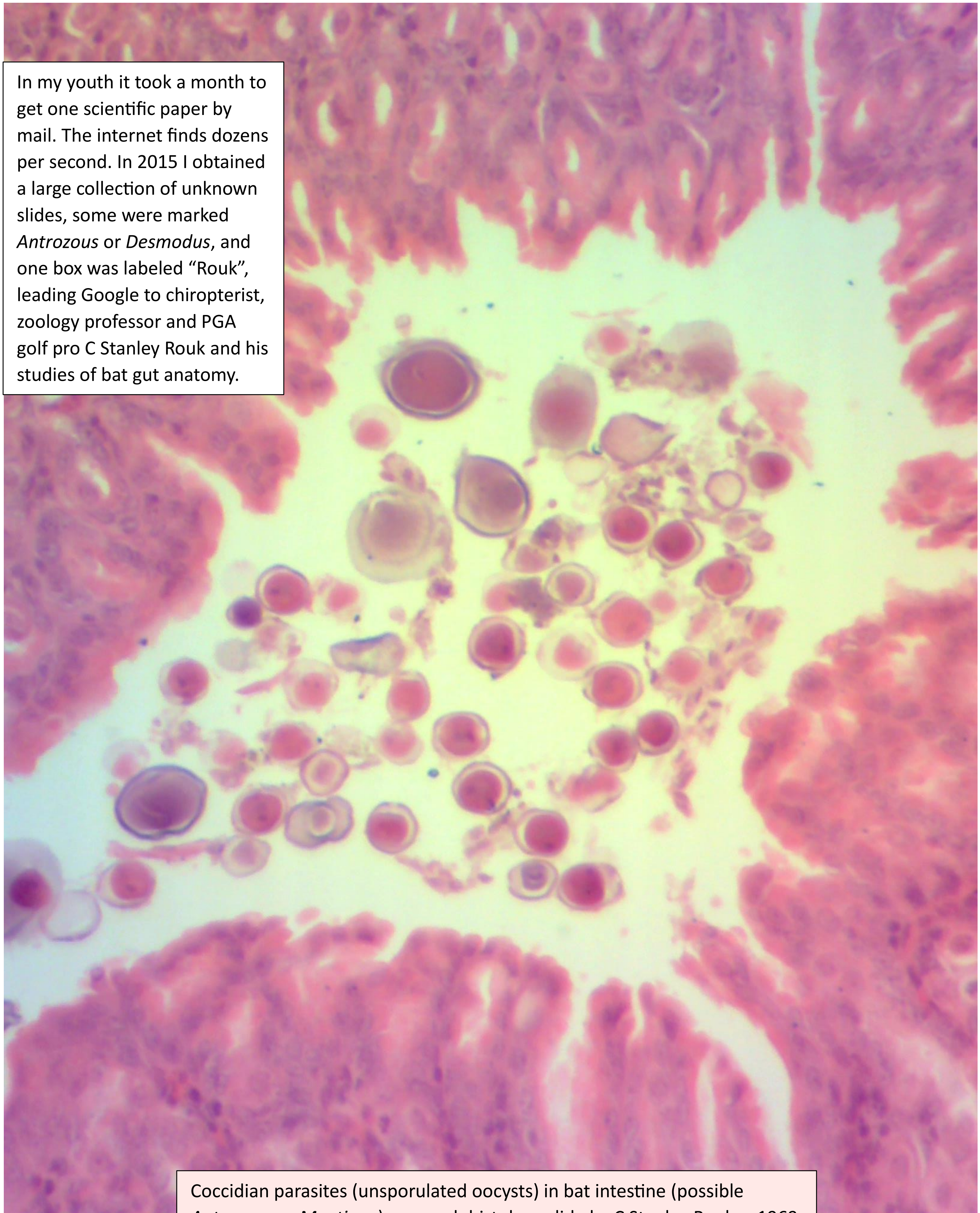
Wild animals with worm parasites, slides by L R Bircham in Mississippi, USA. Philosophers and biologists debate whether wild animals suffer from hunger and fear of being preyed upon. These might be offset by affection from mates and other positive feelings. Most wild animals carry parasites, but still appear overall healthy.

Above 2 nematode worms from opossum gut. Photomicrograph stitched with 2X objective; red stained worm about 2 cm long. Below, 2 different nematode microfilaria in raccoon blood, likely *Dinofiliaria sp* on left and *Brugia sp* on right. 40X objective, image about 300 microns across. The microfiliaria larvae are about 100 & 200 µ long.



Examining an animal for parasites can include a rectal exam and scanning feces under a microscope.
Eggs of *Porcephala sp* a 'tongue worm' (Pentastomida are very odd worm like arthropod parasites)
in unstained feces of black tailed rattlesnake (*Crotalus molossus*) from Russell, Kansas, USA, date unknown.
Slide made by L R Bircham of Rankin County, Mississippi, USA.
4X objective, darkfield, image ~ 3 mm across, individual eggs about 50x40 microns, in clear sacs twice as big.

In my youth it took a month to get one scientific paper by mail. The internet finds dozens per second. In 2015 I obtained a large collection of unknown slides, some were marked *Antrozous* or *Desmodus*, and one box was labeled “Rouk”, leading Google to chiropterist, zoology professor and PGA golf pro C Stanley Rouk and his studies of bat gut anatomy.



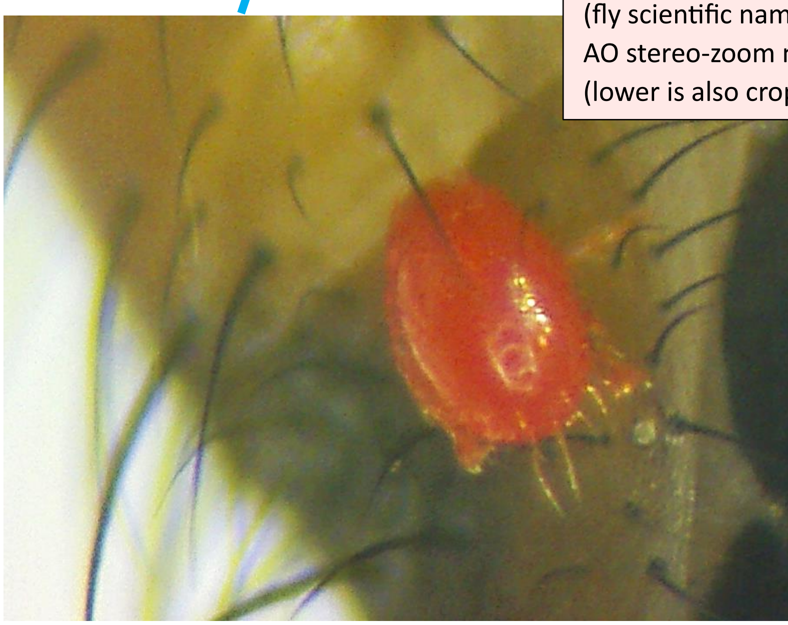
Coccidian parasites (unsporulated oocysts) in bat intestine (possible *Antrozous* or *Myotis sp*), research histology slide by C Stanley Rouk, c 1969 10X objective, image about 0.6 mm tall, large oocysts up to about 80 μ dia.

Effects on ecosystems

Humans and our livestock now constitute 96% of the mass of all mammals, but there is still a big world of wild animals, most of them invertebrates. And they also have parasites. About half of all insects in the world are infected with *Wolbachia*, a rickettsial intracellular bacterium in myriad symbiotic relationships with insects, some harmful, some beneficial. If a *Wolbachia* hurts a mosquito carrying malaria, that could help the warm blooded host animals that might have been otherwise given malaria. Parasites can be prey. Some birds pick off and eat ectoparasites of mammals. It's a worm eat worm world. Some aquatic annelid worms eat parasitic trematode worms that emerge from freshwater snails. Interactions between parasites and hosts in natural ecosystems are hard to predict. By definition, hosts of parasites are often harmed, but there are many exceptions. One acanthocephalan (spiny head worm) parasite that harms its fish host in clean water becomes beneficial in some polluted environments, as it can concentrate lead to a level 2700X that in host fish. Without parasites holding them back, some animals can become plagues. Invasive species may thrive if their new territory doesn't have the parasites that held them in check in their home range. Sometimes a parasite can be used to control an invasive pest (but sometimes they jump to other unexpected hosts with disastrous effects). An invasive grey squirrel is conquering the immune naïve UK native red squirrel population in part with the aid of a severe pox virus the invader carried with it.

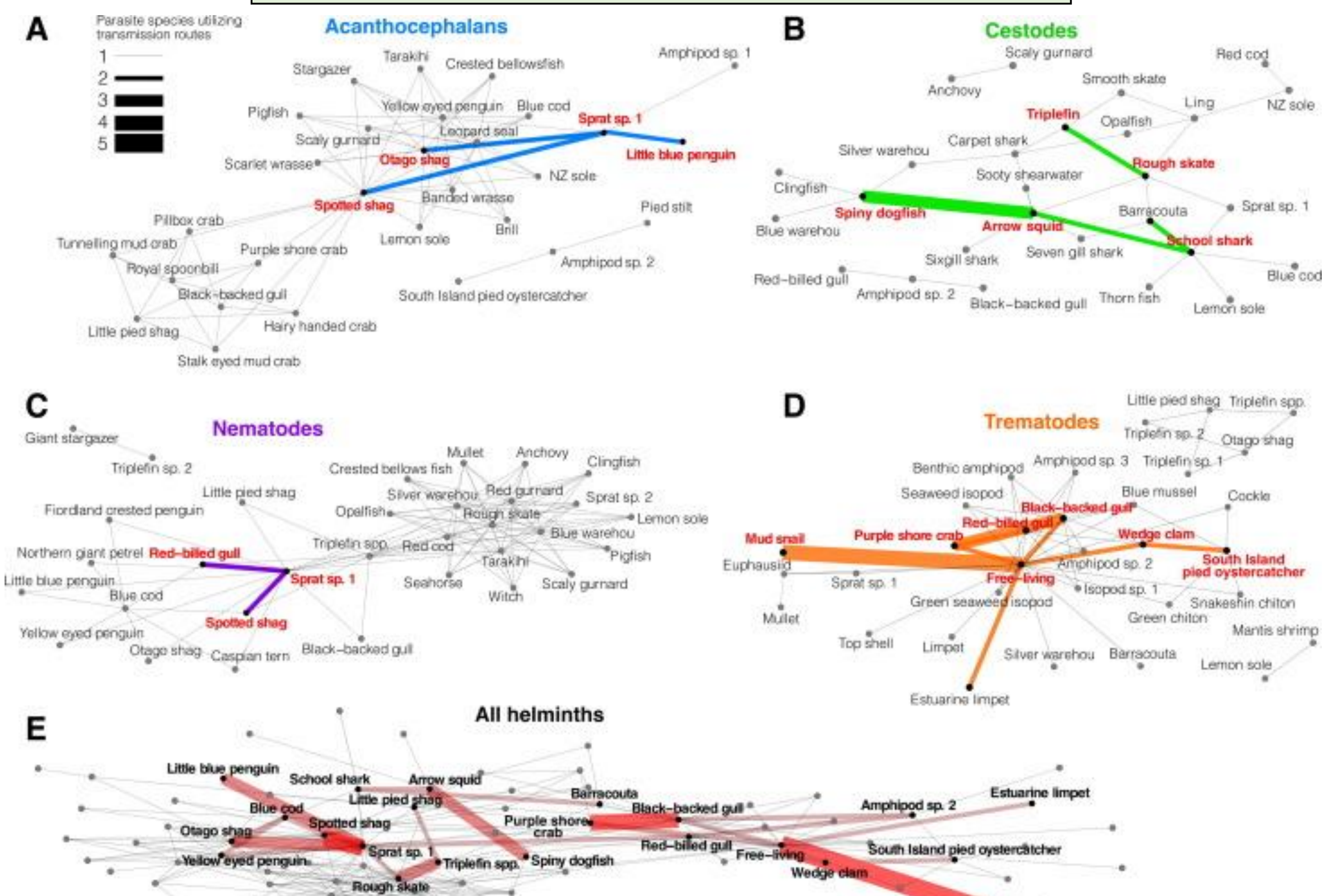
Healthy ecosystems are full of hidden parasites that help maintain the balance of nature. Parasitic apicomplexan protists are the most numerous eukaryote species in rainforest soil and may drive the high arthropod complexity we see there. Parasites can change host fitness and behavior, causing decline or growth in host populations, thus affecting trophic interactions, food webs, competition and biodiversity. Parasites are key players in shaping ecosystems, but man has recently become a key disrupter in many places, slashing forests to grow oil palms or cattle. Anthropogenic climate change might cause decline in fish parasites with complex life cycles, the resurgence of malaria in parts of China and allow the reduviid bugs that spread Chagas disease to move further into the southern US. Old parasites are often lost and new ones come into disturbed spots, but we don't know which parasites we will find tomorrow.

The full number of different parasites in the complex webs of nature is unknown, and perhaps even unknowable. All that scientists have learned is a miniscule fraction of total reality. New parasite species are almost certainly going extinct faster than we can discover them. When we intervene in nature man is blindly playing God, yet humans have to manipulate nature in order to survive. Man is a part of nature, not separate from it. It seems reasonable to try to work with the patterns of nature rather than push against them, as best we can with our always imperfect scientific knowledge.

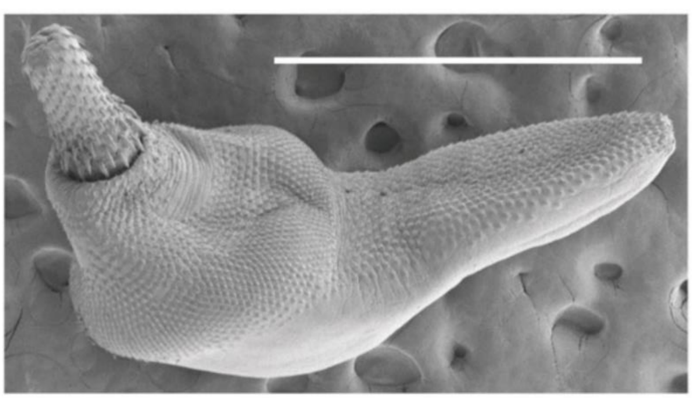


Is a pest of a pest our friend? Red mites on housefly *Musca domestica* (fly scientific name by Linnaeus, 1758)
AO stereo-zoom microscope at 0.7X objective power above, 3X below (lower is also cropped)

The real world is far more complex than our complicated models of it



Parasite circles of life in 35 species of helminths (parasitic worms) using 289 transmission pathways between 57 hosts in a marine ecosystem in New Zealand. 59 new larval stages were found. Jerusha Bennett, Bronwen Presswell and Robert Poulin state: “Parasitic helminths exhibit remarkable diversity in their life cycles, although few parasite species have their whole life cycles resolved.” Identifying organisms in nature has been greatly advanced by “DNA barcoding” and other modern techniques. Still all the hard scientific work done by this team and many other heroic “mircrobe hunters” since Robert Koch and Louis Pasteur first discovered germs about 150 years ago deserves our praise and celebration.



Acanthocephalan (a worm-like parasite evolved from rotifers) *Profilicollis novaezealandensis* “ex” (which means ‘from” to parasitologists) royal spoonbill bird, from Bennet et al

SEM (electron micrograph), helminth about 2 mm long (bar 1000 microns)

Global human burdens of parasites

Being a part of nature, man is affected by parasites. We fancy ourselves "above" the animals but we are apes, and we carry the parasites of animals. Infestation with intestinal worms was essentially universal among humans until recently, most commonly *Ascaris*, hookworms and whipworms. The Merck veterinary manual says the same for our canine friends: "Dogs can become infected with many different parasites, but the 'unholy trinity' of roundworms [also called ascarids by vets], hookworms, and whipworms are among the most common". Worms may or may not make individual humans sick, but they weaken human populations if the infestations are heavy. Malaria, a mosquito carried protozoan, takes more human lives than any other parasite but has been slowly yielding to control efforts over the past two centuries. Malaria (mostly *P falciparum*) killed over 1 million people annually 20 years ago but that was reduced to an estimated 619,000 deaths (mostly in African children) and infected about 247 million people worldwide in 2021 per the WHO. While general sanitary improvements associated with economic development often reduces intestinal parasitism, vector borne parasites like malaria often require specific eradication efforts. Historically, 19^{th} century Europe was ahead of the Americas in reducing the burden of malaria and other parasitic diseases.

The WHO, an organization with high scientific standards, recommends mass deworming every 6 to 12 months in poor villages in tropical countries with a high prevalence of soil transmitted intestinal worms (helminths). It makes sense that it would improve kids' nutritional and maybe educational status, but that has been difficult to confirm with good human trials. The Cochrane Collaboration, the grand-daddy of evidence based medicine was unable to find strong evidence for any proven benefit of mass deworming in reviews in 2015 and 2019.

Although deworming is of uncertain value, clean water and improved sanitation have multiple knock on benefits beside reducing the transmission of intestinal helminth parasites. Most human parasites persist in the "global South". In the late 1990s it was estimated 3.5 billion people, about 60% of all humans at the time, had intestinal worms. Around 2019 the World Health Organization estimated 1.5 billion, or about 25% of people still had worms.

It’s a wormy world at my house

Intestinal helminth slides from various collections
top- collected by unknown educator, about 1950’s
middle- slides made by L R Bircham, Mississippi, US
bottom- collection by H J van Cleave, U of Illinois

Slow progress against parasites of the global poor

Human bodies are slowly becoming less wormy and protist filled. Neglected Tropical diseases (NTDs) include parasites that affect billions, and kill or cripple some patients. Not all neglected diseases are parasites. The slow growing hard to treat bacterial pathogen *Mycobacteria tuberculosis* is still causing active infection in only about 10 million people today and is alive but latent (causing no illness) in about 1.8 billion, mostly poor people. Even 100 years ago when TB was a leading cause of death in the western world, it harmed the poor much more often than the rich. Rudolph Virchow, the late 19th century father of pathology called TB a "social disease". HIV/AIDS is a viral disease acquired largely by particular social groups.

About 1.7 billion people still suffer from NTDs today. The US government spends about $0.1 billion a year on NTD's (a pittance considering it spent $766 billion on defense in 2022, and total US health spending was about $4500 billion the same year, half from the government). Despite our wealth in the West, we do not on balance give any economic aid to the developing word. Since about 1980 the net flow of money is from the poor to the rich nations. Some academics and Africans have proposed an end to all foreign aid, coupled with also ending all economic exploitation. Worm and protozoan parasites affecting poor people in the tropics continue to be relatively neglected. The biggest funder of efforts is The Global Fund to Fight AIDS, Tuberculosis and Malaria, started 2 decades ago by seed money from US billionaires Bill and Melinda Gates, and recently spending about $4 billion a year. The fund now has public and private funding from 80 countries, although donors don't always follow through on their pledges. Sweden for example has sometimes withheld its donation because of proven financial corruption in some recipient nations. Even without consistent adequate funding, international efforts have managed to reduce malaria, TB and HIV death rates in the past few decades.

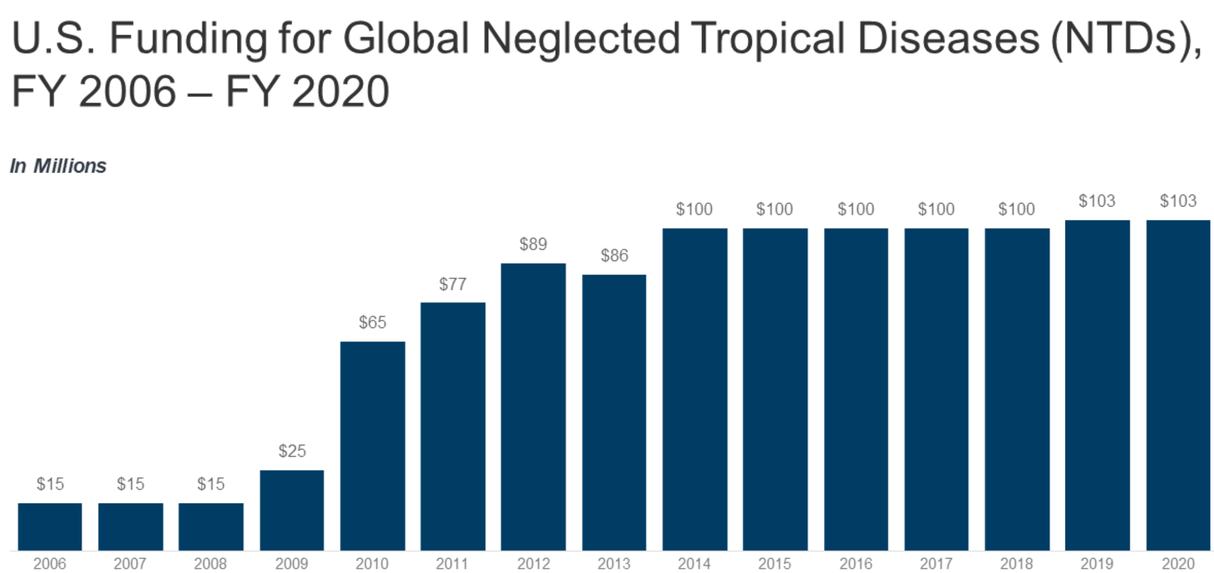
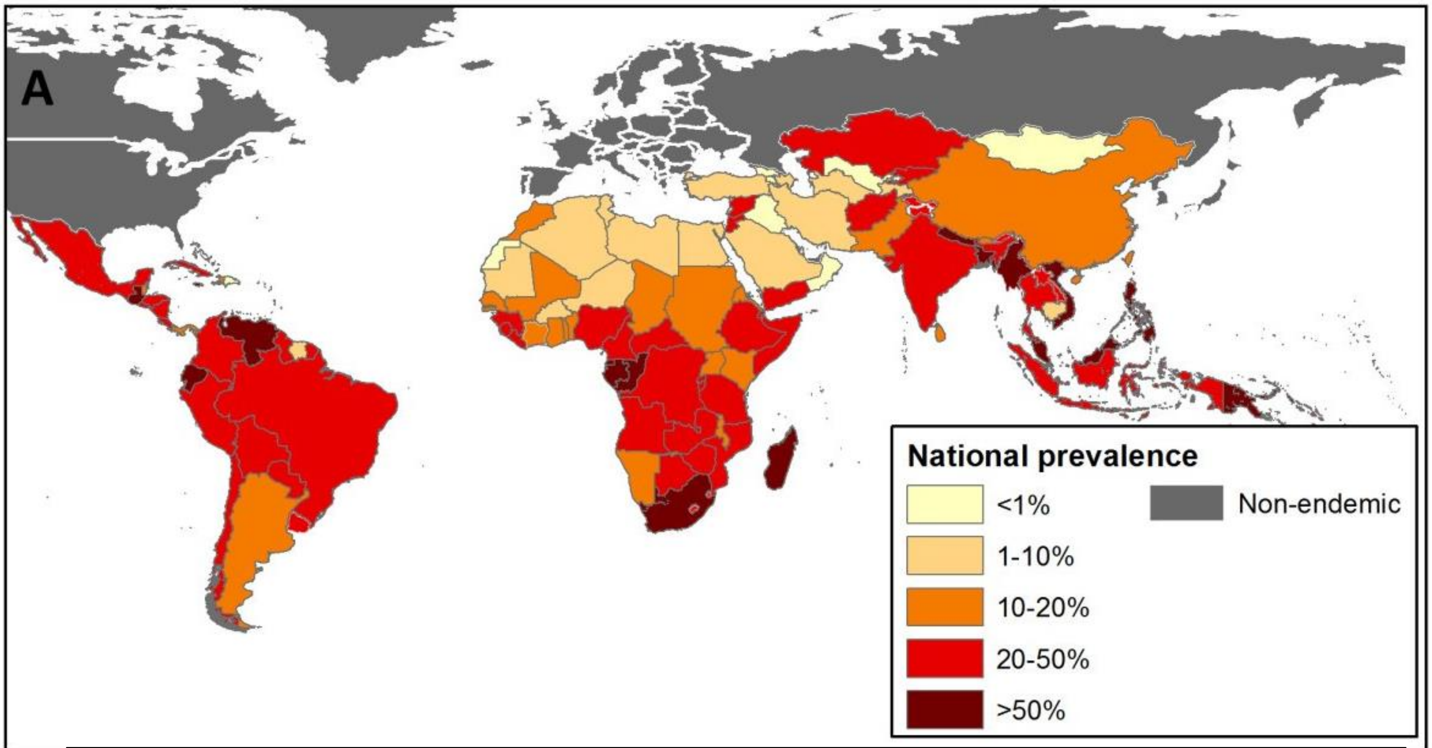


Chart by Kaiser Family Foundation shows $0.103 billion US government spending on NTDs in 2020. This was 1/ 41240 or 0.0024% of total US health care spending in 2020. On this graph with US NTD spending being 2 inches high, total US health spending would be 6873 feet or 1.3 miles high.

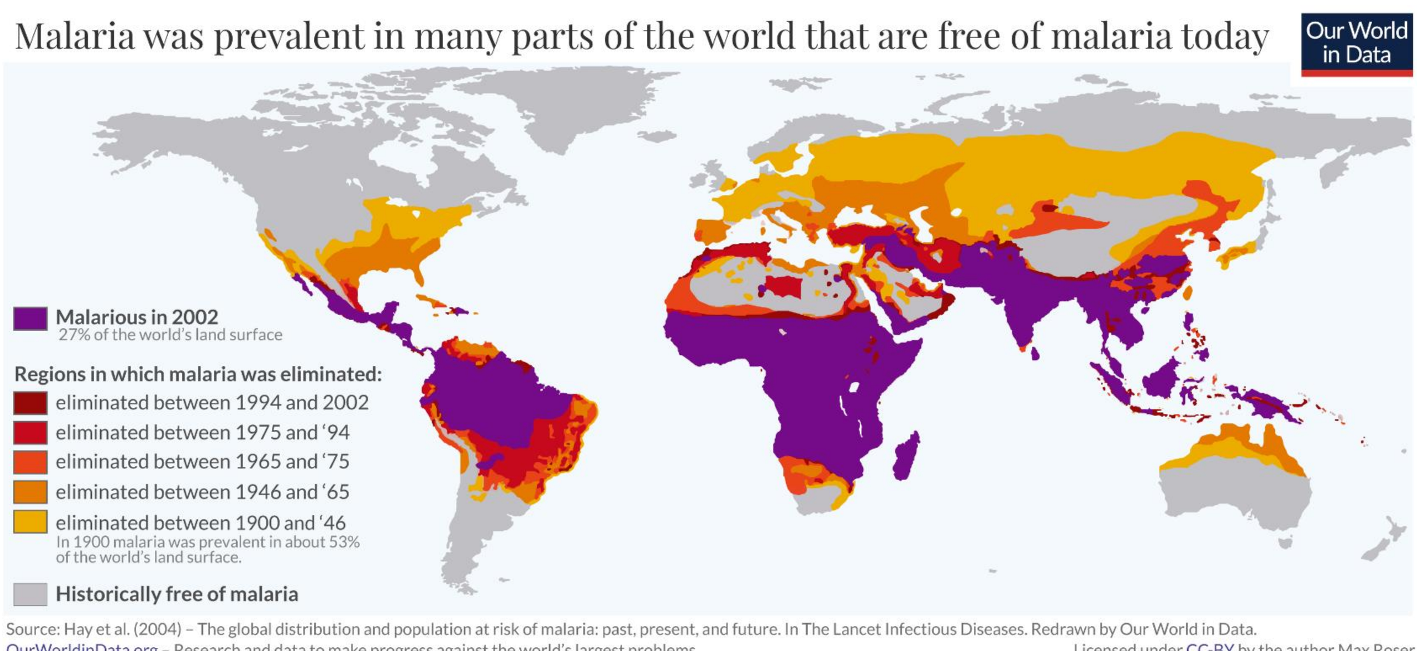


Prevalence of soil transmitted helminth human infestation in 2010. Malaria and other parasitic and neglected tropical diseases have a similar distribution. Image Pullan, Smith, Jasrasaria et al in Parasites Vectors 2014

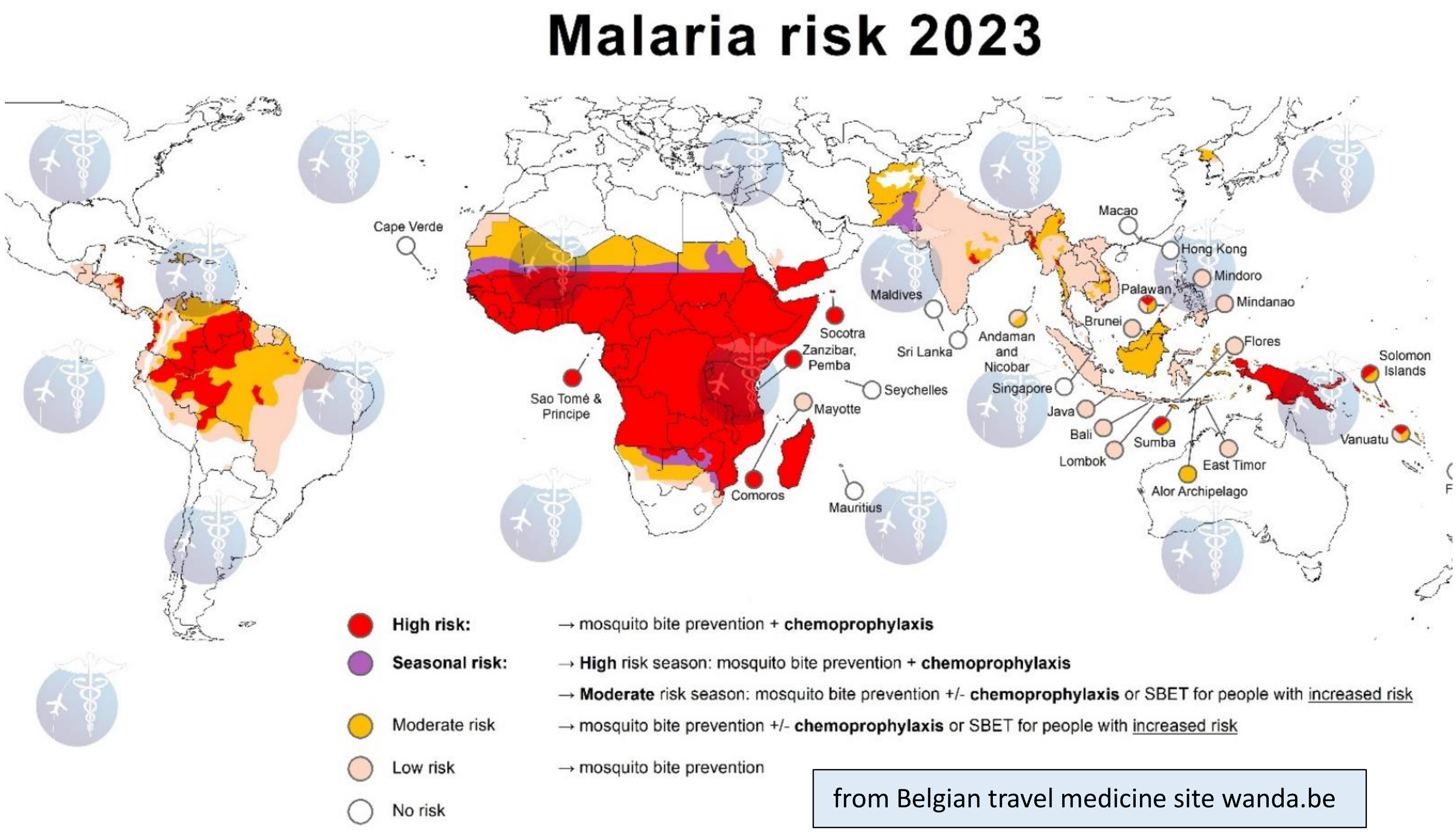
Malaria still kills more people than any other parasite, but international efforts using mosquito control, insecticide treated bed nets, and prompt drug treatment of cases of falciparum malaria have yielded results. In the 190's malaria killed about a million people a year in tropical Africa and southeast Asia, but fell to a low of 586,000 in 2015 and still killed 608,000 in 2022 (see the WHO World malaria report 2023), mostly children in Africa. The gradually successful fight against HIV/AIDS by the global healthcare community goes hand in hand with fighting parasites. With weak immune systems people with untreated HIV (human immunodeficiency virus) progress to AIDS (acquired immunodeficiency syndrome) and are at risk for extra severe parasitic infections caused by *Leishmania, Strongyloides, Toxoplasma, Cryptosporidium* and others. With drug treatment HIV patients are not cured, but their immune systems are strengthened so they can live long, healthy lives. About 38 million people live with HIV, a number that continues to climb, as 1.3 million people got infected in 2022, a new low. Annual HIV deaths peaked at 1.89 million in 2004, and were down to about 600,000 in 2022. Another NTD success story is dracunculiasis, a particular unpleasant parasitic infection that results in a 1 meter long "Guinea worm" emerging from victim's legs. Human cases have dropped from about 3.5 million in 1986 to only 13 cases worldwide in 2022 thanks to eradication efforts in Asia and Africa. It is hoped dracunculiasis (and also polio virus) might be wiped out completely some day in the future, like smallpox virus was in 1977.

Reliable numbers for the total number of human parasite infestations today are be hard to find. Per WHO, in the year 2000 about 3.5 billion people, 60% of all humans, had intestinal worms and 2 billion, 1 in 3, had protozoan parasites. By 2010 the WHO estimated about 440 million people were infected with hookworm, 820 million people were infected with Ascaris, and 460 million with whipworm. Burdens of disease can be estimated by tallying disability (sickness and loss of function) caused by disease. In 2010 the WHO attributed 5.2 million DALYs (disability adjusted years of life lost) to three 3 soil acquired helminths (parasitic worms), with hookworm anemia causing the most disability. An additional 3.3 million DALYs from schistosomiasis (liver and bladder flukes), 2.8 million DALYs from lymphocytic filariasis (worms in lymph vessels) and 0.5 million DALYs from onchocerciasis (river blindness) were also tallied by the WHO report. About 2019 the WHO estimated human worm carriage was down to less than 50% and 1.5 billion people had protozoan parasites, down to about 1 in 5 people. That included 1.8 billion latent carriers of toxoplasmosis, 500,000,000 infected with amoebic dysentery, 300 million new malaria infections per year, 180 million new cases of vaginal trichomoniasis yearly, 8 million people with American trypanosomiasis (Chagas disease), and 1.3 million new cases of leishmaniasis per year.

A few recent estimates have human worm carriage down to as little as 1 billion, or 1 in 8. I am optimistic. Despite everything that is wrong in the world, human lifespan continues to rise globally (after a temporary setback from the COVID virus, which luckily evolved quickly to get along better with humans). Unfortunately, global doesn't mean everywhere. US life expectancy went down every year 2016 to 2022, largely driven by overdoses, alcoholism and suicide in working class whites, so called "deaths of despair."



When you feel down and need a dose of evidenced based optimism about the state of our world (economics, health, wellbeing) go to the Our World in Data and most of the time you'll feel better.



from Belgian travel medicine site wanda.be

Malaria still matters a great deal if you live in or travel to many places in the tropics. Your travel itinerary also matters. Travelling to the rural countryside is usually riskier than staying at a fancy hotel in the capital city. Consult a travel doctor a month before you travel. You might get medicine to prevent malaria (chemoprophylaxis) or SBET (Standby Emergency Treatment for Malaria). If you have a fever in the first few months back home, see a doctor and tell them where you travelled.

Privileged to be parasite-free

Most people reading this article don't need to worry much about parasites personally, as they are probably living in privileged times and places.

Since the origin of *Homo sapiens* in Africa about 300,000 years ago, most people harbored potentially harmful parasites in and on their bodies. Lice and intestinal worms were nearly universal. Then a combination of industrial and social revolutions starting almost 300 years ago greatly improved health and comfort for most people today. If you are reading this then it is likely you have safe water and food supplies, shoes, indoor plumbing, window screens, floor boards and a solid roof, all diminishing the chances of worms burrowing into your feet or being swallowing in contaminated water, and of exposures to mosquitoes and reduviid bugs. Good living standards, scientific research and public health measures have probably eliminated the most significant human parasites from your part of the world.

Great strides continue to made fighting parasites and poverty in the world. The WHO estimates intestinal worm infestations dropped from 60% to 25% of all humans so far in this century. Global median annual income more than doubled between 2000 and 2019 from $1325 to $2759 (with the mean about $12000 in 2019, and yours is likely higher). Global life expectancy increased 6+ years between 2000 and 2019 from 66.8 to 73.4 years average (even as life expectancy in the US began to decline during the same timeframe).

But the global gains in well being are far from being evenly distributed. Severe inequalities make averages (means) deceptive when almost half of the world's total wealth is held by the top 1%, and the bottom half divvies up just 0.74%. Most people are poor and live in the "majority world" (a newer term for what we also call the third or developing world) and they are still lacking in money, health and governance. Without all the luxuries we take for granted, the parasites they suffer from are just a small part of the unfair miseries (wars, famines, and imprisonment without trial if they complain about the dictator) borne by the powerless majority. 4.3 billion people live in 95 countries under authoritarian regimes today.

Its normal to feel bad about this sorry state of affairs. For some readers the best way to worry about parasites is by helping out people with parasites who have little way to help themselves. You might consider a charitable donation to Oxfam, Against Malaria Foundation or Deworm the World.

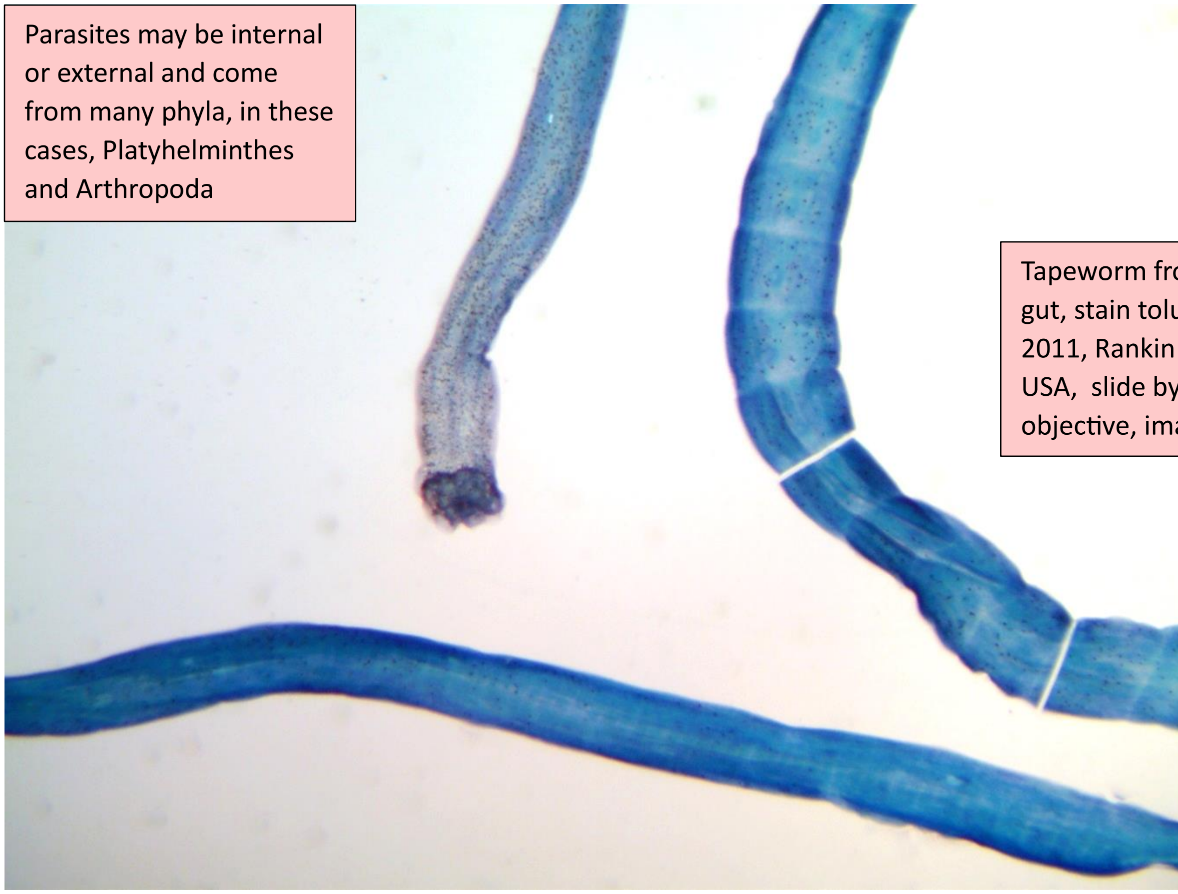
It's also perfectly fine to feel grateful for the cosmic lottery you've won. Average *Micscape* readers are often males in rich European or North American countries. You likely know a European language and have computers and microscopes. You may be privileged by your race, gender, citizenship (in a former colonial power), and your political and economic systems. You were likely born in a country with the full modern liberal package: democracy, good schools, free speech and press, universal health care (not in US) and private property. You weren't born in medieval times, living an average 30 miserable years with lice and worms. And be extra thankful you weren't reincarnated this time around into a caterpillar being hormonally manipulated and eaten alive from the inside by dozens of parasitoid wasp larvae.

Trichodina sp. a ciliate protist ectoparasite of hydra (tentacle at left) and sometimes of fish and clams. The ciliates clean up like little Roombas, and might be commensals but are usually considered parasitic. Specimen from pond in Red Wing, Minnesota, USA on 29 Nov 2019. 40X objective, cropped; the ciliates are about 50 microns in diameter.

Biology of Parasites

Evolution has crafted many ways to be a parasite. Endoparasites live inside the host animal and derive nutrition from it. **Ectoparasites** live on the outside of the host, often with claws that grab hairs, blood sucking mouthparts or other adaptations. Lice, fleas and some mites are obviously adapted for living their lives on or in skin. Ticks are adapted to find hosts with organs to sense heat, vibrations and chemicals (smells), and then to crawl to a hidden spot to engorge with blood for a few days. Mosquitoes and other biting flies don't live on or in a host, even though they nourish themselves by quickly stealing blood. These flies (order Diptera) are micro-predators and are variably counted as parasites by different authorities. Bot fly larva live in the host's skin, subcutaneous tissue or ears and may be considered proper parasites.

Parasites may be internal or external and come from many phyla, in these cases, Platyhelminthes and Arthropoda



Tapeworm from wild opossum gut, stain toluidine blue, May 2011, Rankin County, Mississippi, USA, slide by L R Bircham, 4X objective, image ~ 3 mm wide

Tick *Ixodes cookei* from wild skunk, Feb 2011, Rankin County, Mississippi, USA, slide by L R Bircham, 4X obj., darkfield, image ~ 3 mm wide

Endoparasites are blind in the dark, but still find their way. Parasites navigate by smells (chemical signals), currents, vibration, warmth and wetness. Consider *Ascaris,* a big (up to 30 cm, 1 foot long) roundworm that was carried by a third of humans until recently. *Ascaris* larvae find their way from intestine to portal veins, through the liver and heart to lung capillaries, into the bronchi, up to the throat, down through the stomach to the intestines where they become adults and make eggs that will pass out in the poop. *Ascaris* has better anatomy skills than a first year medical student with the standard 100 billion neurons in his head. Yet *Ascaris* has just a simple ring of perhaps 200 neurons for a brain and a simple (aka direct or **monoxenous**) life cycle, consisting of just one host. Every parasite has a definitive host animal where adults live and have sex. Parasites with complex (aka indirect or **heteroxenous**) life cycles also have one or more intermediate hosts that sometimes act as a vector, shuttling them between hosts.

Parasite life cycles and behaviors

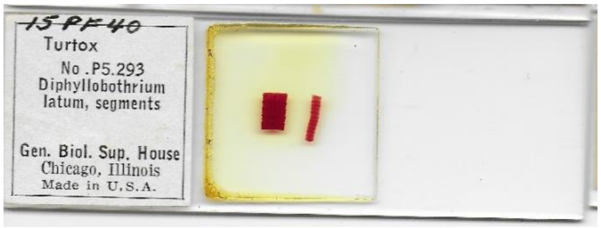
Many parasites transform into different stages inside different hosts and vectors. A parasite's life cycle stages may look as unrelated as a caterpillar to a butterfly. In the days before DNA analysis, it sometimes took decades to figure out that some little spots in the blood were actually the same species as blobs in the liver and worms in the gut of three different animals. I've included many of the CDC's parasite life cycle charts in this article. Most charts represent the accumulated knowledge gained by of generations of researcher working for many decades before another life cycle puzzle was solved. Each chart summarizes a wealth of hard won knowledge that can benefit the wellbeing of humankind, the best kind of science.

Some parasites have simple lifestyles and some have surprising ones. Parasites found many ways to spread themselves between hosts. At least a half a million species are parasites of parasites, also known as hyperparasites. Most but not all hyperparasites are parasitoids that eventually kill the host. *Sacculina* is a castrating parasite that manipulates the sex hormones and gender behaviors of the host. The protist *Toxoplasma* also modifies host behavior. How much that includes the 3 billion or so humans who are infected by it is a subject of ongoing debate and research. We find some parasites and their behaviors unusual and cruel, but parasites are just part of nature, playing roles created as species and ecosystems evolved.

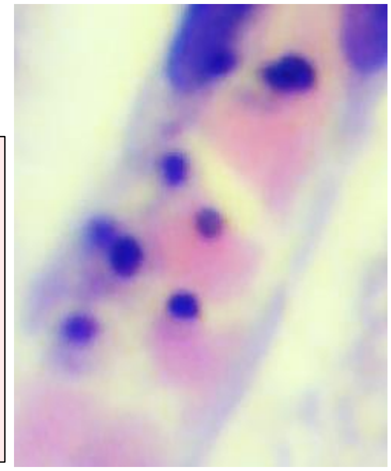
Big and small human parasites

The broad fish tapeworm *Diphyllobothrium latum* can reach almost 15 meters (50 feet) long and be 2 cm wide. It coils to fit into your intestine. On the other hand, the merozoites (red blood cell stage) of malaria parasite *Plasmodium falciparum* is about 1.5 microns long, about the same length as prokaryotic E coli, about 10 million times longer than the broad tapeworm. Any guess which is deadlier? (The little guy is).

Big and small below-
segments of the broad “fish” tapeworm (man is the definitive host). Slide shown about life size, depending on your monitor. Whole worm can be 10 to 15 meters long.



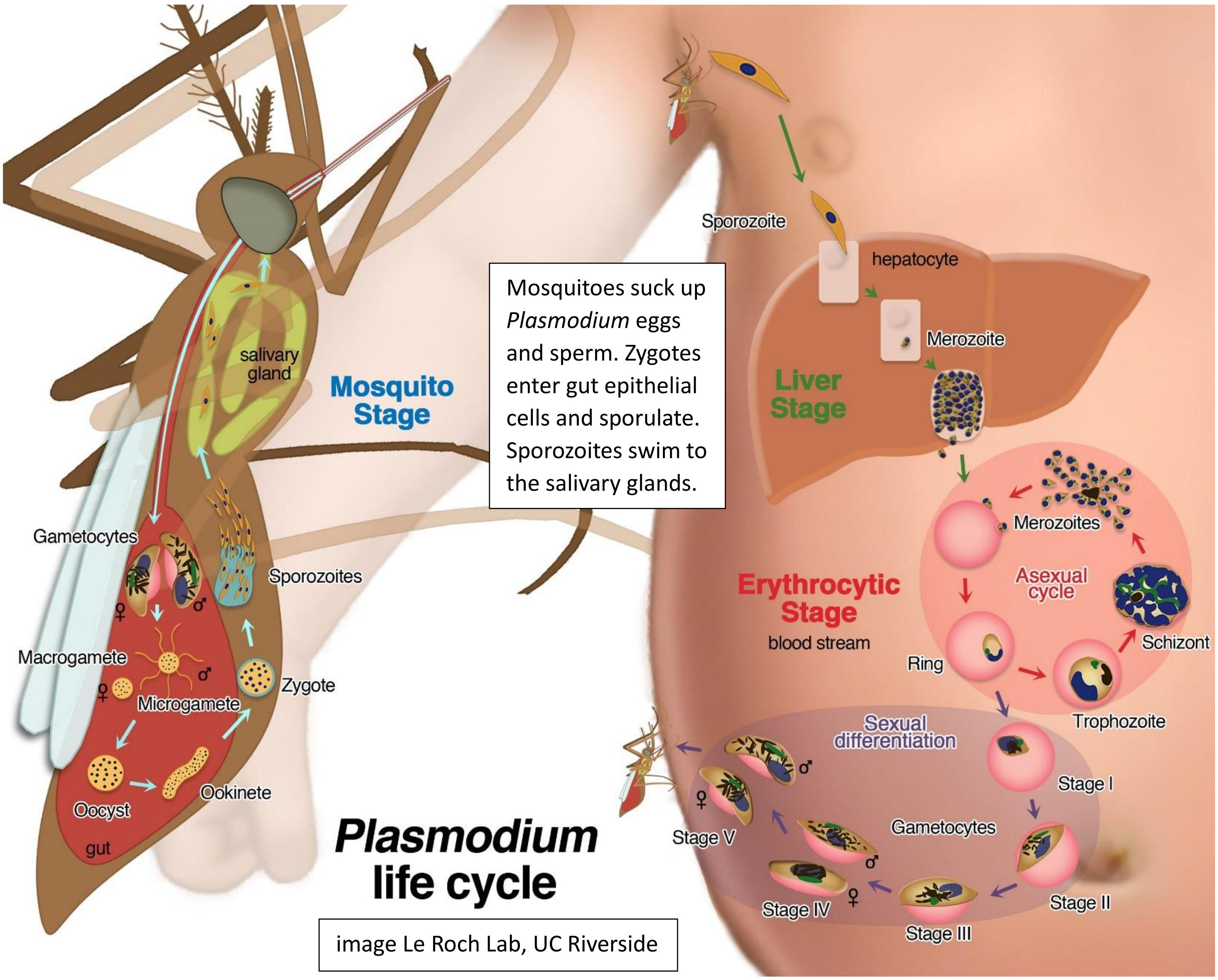
Big and small right-
Plasmodium falciparum merozoites; the blue dots are the blood stage of the parasite, about 2 microns, inside 5 micron red blood cells.
Slide of cerebral malaria.
40X objective, cropped, ‘enlarged’



Parasite transmission

There are many variations on parasitism. Parasites may have very different life stages, and all have to get around somehow. All parasites seem a bit strange to us, and as we say in the US, some of them are real doozies in the unusual ways they survive and disseminate themselves among different hosts. Spreading themselves around is commonly done by some kind of **direct contact**, such when an animals rub against each other sharing lice, or they eat food contaminated by parasite eggs in the dirt (the soil borne **fecal-oral route**). Many, like the malaria parasite, are **transmitted by a vector** such as a blood sucking tick or fly. Some parasites are **trophically transmitted** (up the food chain) when a prey organism contains a stage of the parasite, as when an infected rat passes *Toxoplasma* on to the cat that eats it. Some parasites can be **transmitted vertically** from an infected mother to her unborn children. And some can be **transmitted iatrogenically** through medical technology, as when a transplanted liver contains the hidden trypanosome parasite that causes Chagas disease. Some nematodes like *Ascaris* require just one host species (**monoxenous**) and spread by directly passing their eggs to another individual host. Adult parasitic worms may live in their host’s gut for years, hanging on with hooks or suckers and gradually using organic material from host’s digested food to make millions of eggs that pass out of the host anus. Many other parasites require one or more intermediate hosts (**heteroxenous**) for life stages to mature into the next. In many cases that mosquito or snail (among other animals) can also become a **vector** passing the parasite to the next host.

Life cycles of parasites can be very convoluted, travelling from organ to organ inside hosts, reproducing asexually and sexually in different hosts, and at some stage leaving a host (often sneaking out as eggs in feces or as a stage in blood taken by a blood eating vector) to propagate itself. The many adaptations evolved by most parasites over many millions of years have left many adapted to only one or two host species (**stenoxenous**), and most vertebrates have their own specific species of malaria, coccidia and hookworms. But a few parasites are host generalists (**euryxenous**) capable of infesting hundreds of species, such trypanosomes and *Toxoplasma*. But many of these indiscriminate infestations are a dead end for the parasite. *Toxoplasma* still requires a feline gut to have sex and make oocytes to be passed in feces. There are many buts and many butts involved when you describe parasite life cycles.



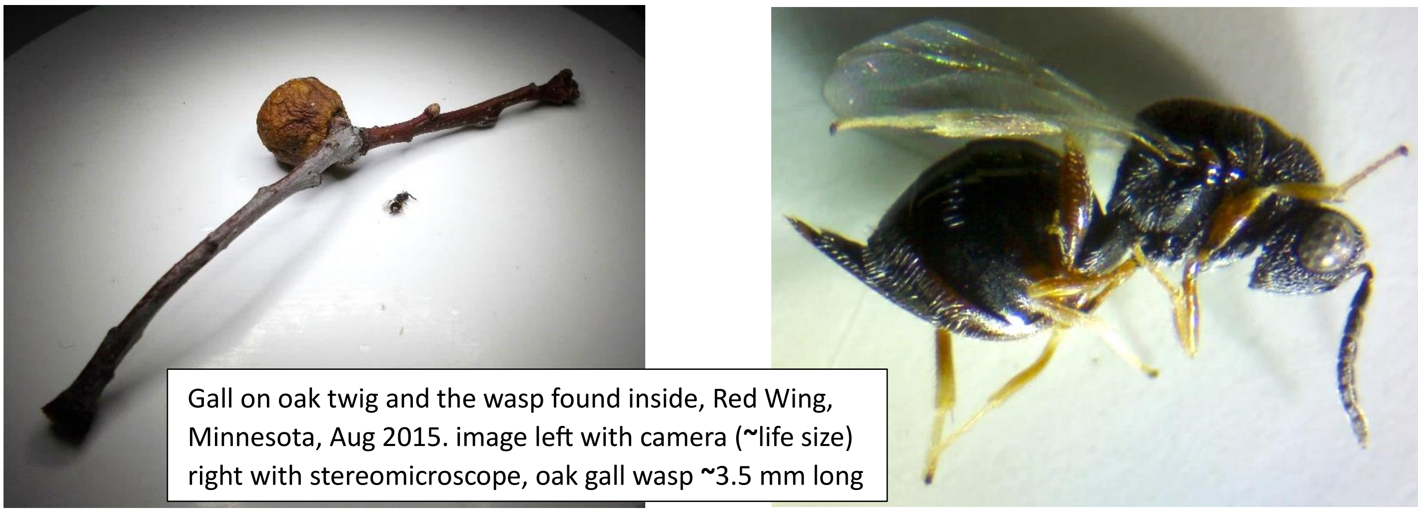
Mosquitoes suck up *Plasmodium* eggs and sperm. Zygotes enter gut epithelial cells and sporulate. Sporozoites swim to the salivary glands.

image Le Roch Lab, UC Riverside

It took decades of work by scientists of many nationalities to work out the life cycle of *Plasmodium*. The malaria parasite is dependent on specific anopheline mosquito hosts. The last US mosquitoes capable of transmitting malaria were controlled with DDT, a triumph for public health. Unfortunately, an unseen second order effect was DDT weakening the eggshells of fish eating birds, nearly eliminating the bald eagle (our national bird) from the continental US.

Hyperparasites

Parasites are not immune to parasites. Oak gall wasps are common 5 mm long parasites who inject eggs into the plant. The eggs hatch into larvae that stimulate extra plant tissue, creating protective round growths on oak leaves and twigs, before pupating and eventually popping out of the gall as an adult wasp to start the cycle anew. 2 mm hyperparasite wasps lay their eggs in gall wasps where they grow and develop into adults. And hyperparasites can have parasites. A 5 species deep symbiosis involving different species of hyperparasite gall wasps was discovered: hyperparasites of hyperparasites of hyperparasites of wasp parasite of plants.



Gall on oak twig and the wasp found inside, Red Wing, Minnesota, Aug 2015. image left with camera (~life size) right with stereomicroscope, oak gall wasp ~3.5 mm long

There are about a half million (and growing with new discoveries) species of parasitoid wasps, more than all the other wasps, bees and ants put together. Luckily for us, most parasitoid wasps are very tiny (many are microscopic) and they do not attack people. A few large wasps are also parasitic on insects or spiders. For example the obviously named cicada killer and tarantula hawk wasps. The latter is the state insect of the US state of New Mexico. The striking blue wasp with orange wings could almost qualify as a state bird, being 6.5 cm (2.5 inches) long with a 1.2 cm (1/2 inch) stinger! I used to live in New Mexico and a few times I saw a big wasp carrying off a huge spider. The adult female paralyzes a tarantula with a sting, carries it off (she is a strong flyer), lays a single egg on it, and seals the unfortunate giant spider in a burrow for its baby to eat the spider from the inside.

The wasp larva avoids eating vital organs, to prolong the shelf life of its big meal. Because the spider is doomed to die in a few weeks, the tarantula hawk is a **parasitoid**: a parasite that always kills its host. Big *Pepsis grossa* is in superfamily Vespoidea, which also contains yellow jackets and other commonly seen social wasps, which it closely resembles.

A tarantula Hawk, *Pepsis grossa,* and its about to be baby food larder.
approximately life size, depending on your computer monitor
image J Cowles, Johns Hopkins U. Press

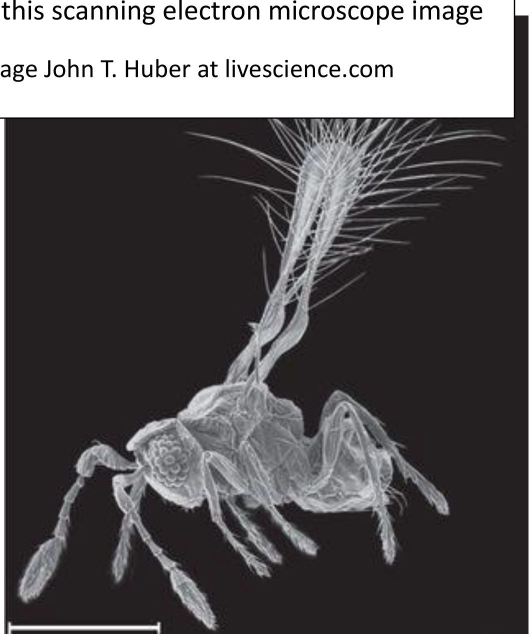
“Fairyfly” parasitoid wasp walking on a 2018 pond water sample. Note wasp is only slightly bigger than *Ceriodaphnia* “water fleas” and a copepod nauplius larva.   4X objective, image about 3 mm wide, wasp head plus body about 0.8 mm (800 µ) long, magnified about 35X total on the page, depending on monitor

Parasitoids

Luckily, most parasitoid wasps are less than 2mm long. Tiny parasitoids abound, with family Chalcididae alone having a half million species (more than all other kinds of wasps). Chalcidid wasp larvae mostly parasitize insects, spiders, mites and nematode worms. The smallest are called fairyflies (their non-membranous wings are brush-like, as at a tiny scale air is more viscous) and the smallest of those is 0.13 mm long, the smallest known adult insect. If you have seen a caterpillar with dozens of tiny white protrusions then you likely saw the pupae of parasitoid wasps. Females inject a young caterpillar with eggs, which hatch and slowly eat the caterpillar from the inside, eventually popping out to pupate. The larvae avoid eating vital organs, and they may manipulate hormones, stopping the caterpillar from going through metamorphosis so the host lives longer and becomes unnaturally large before finally being eaten to death. When scores of larvae of parasitoid wasp *Glyptapanteles* emerge and spin cocoons on the back of the host caterpillar, 2 larvae remain behind inside. They manipulate the host nervous system so the caterpillar defends the now visible pupae from attackers with new violent wriggling behaviors. Nature does whatever works to propagate successful species.

Tinkerbella nana is a fairyfly discovered in Costa Rica in 2013. Its body is 0.13 mm long in this scanning electron microscope image

image John T. Huber at livescience.com

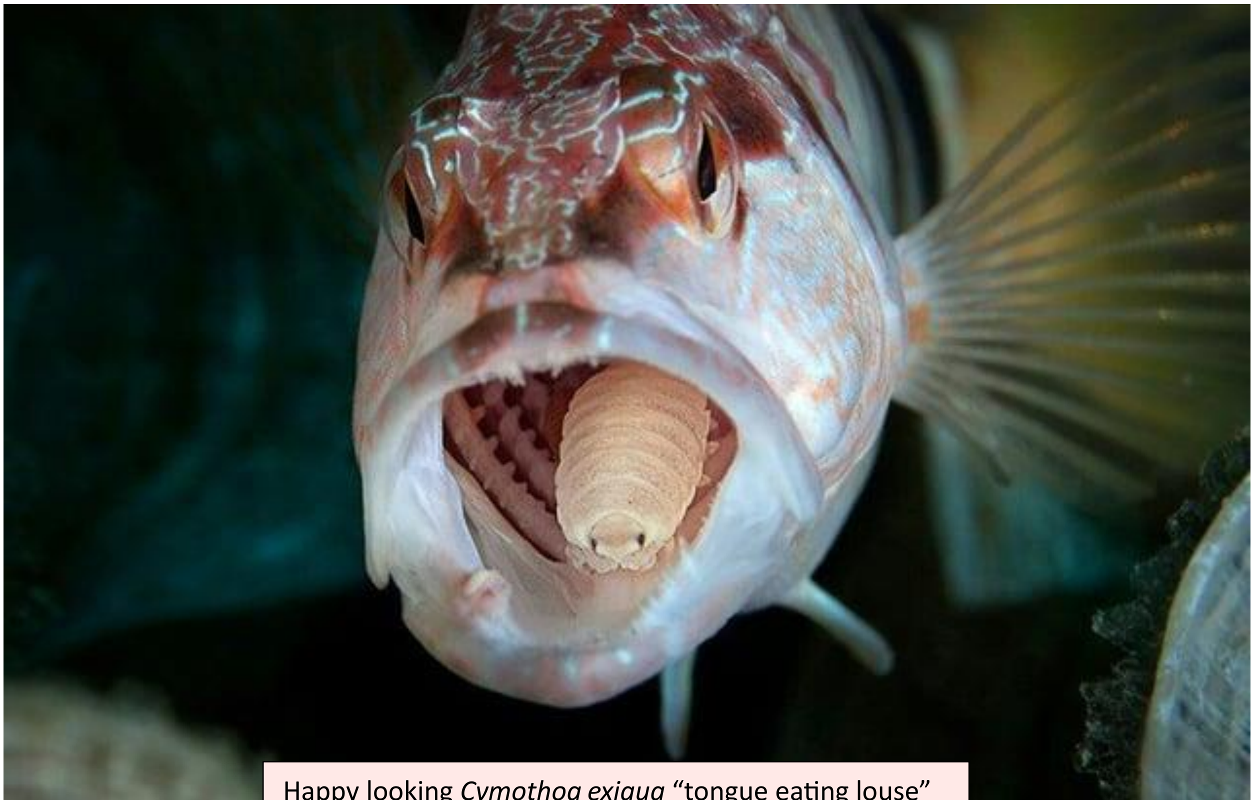


Fairyfly parasitoid wasp, 2018 pond water sample. 10X objective, LED epi lighting, polar background wasp head+body about 0.8 mm (800 µ) long

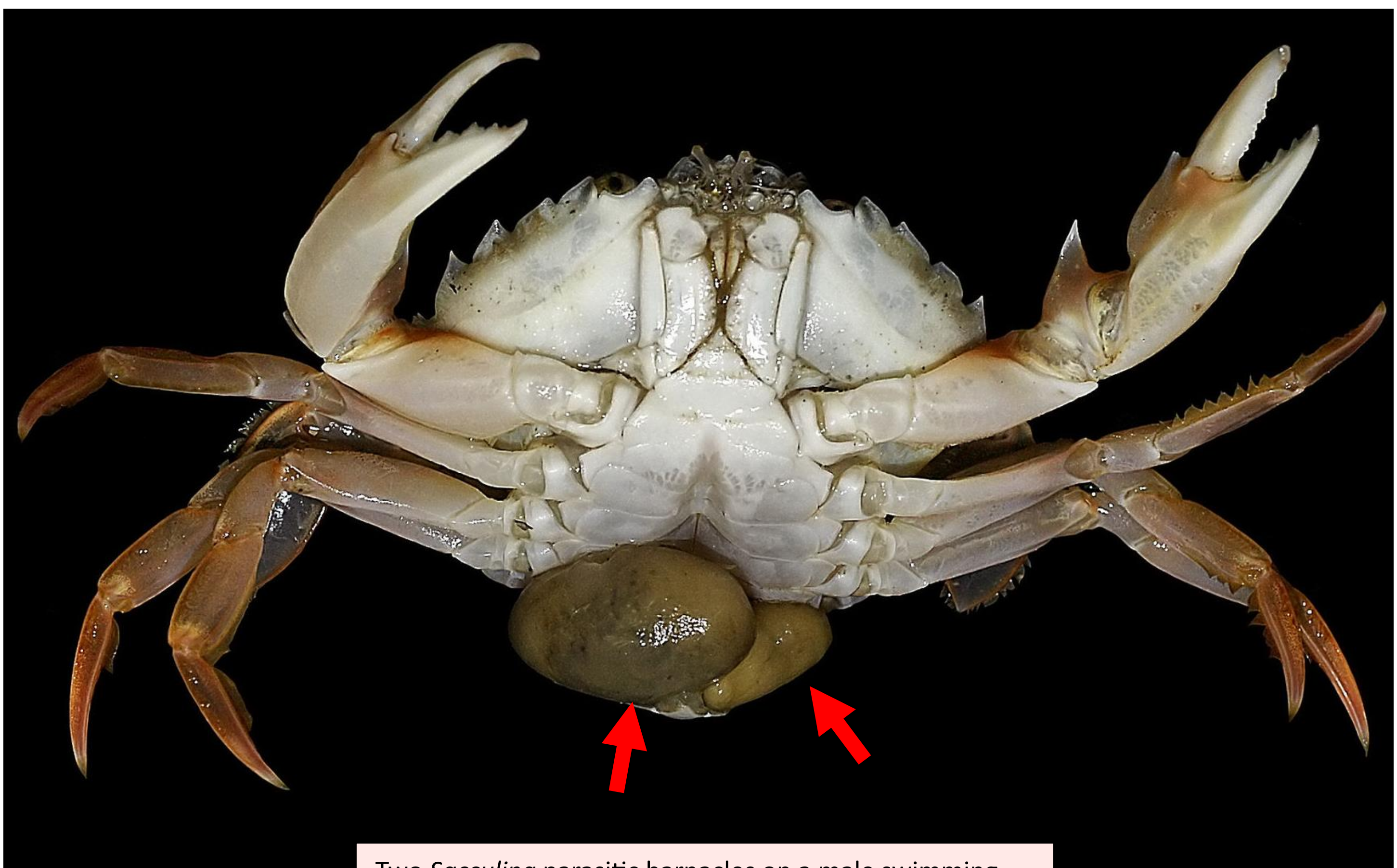
Sacculina and other oddballs

Parasites look odd, often having jettisoned unneeded body parts like eyes and mouths in order to live more efficiently. But some parasite bodies and lives are extra strange. *Cymothoa exigua ,* a parasitic isopod crustacean, lives in the mouth of a fish, replacing the fish's tongue. It uses its front claws to sever blood vessels to the fish's tongue, which then shrivels and falls off to leave a spot for the growing parasite. This "tongue eating" parasite is not to be confused with the long soft bodied pentastomid "tongue worms" like *Linguatula* and *Armillifer* that parasitize the upper respiratory tracts (mostly, larvae may go astray) of some vertebrates. Tongue "worms" are not related to true worms but are revealed by their sperm and DNA to be highly modified arthropods. They are named for the adult body being tongue shaped, and not to be confused with tongue residing *Gongylonema*, a rare 10 cm nematode worm that can infest the human tongue. Again, parasitology is a field of nooks and crannies full of exceptions and oddities. For a small sampling of shockingly odd parasites, browse the Parasite of the Day website.

***Sacculina,* a parasitic barnacle**, is one of the strangest of all parasites. Barnacles, stuck to rocks and posts in oceans everywhere are already a bit strange. They are not closely related to mussels (mollusks), corals or other sessile marine animals, but are actually crustaceans, relatives (nightmarish ones in this case) of crabs, the host of *Sacculina*. The parasite is named for its strange roundish sack shaped body, which sends out root like-like fibers into the host. Its anatomy is definitely strange, lacking the exoskeleton and jointed legs that define proper arthropods. And its parasitic behavior involves castrating and manipulating its host's behavior to the parasite's advantage. The *Sacculina* lifecycle begins with female barnacle larva swimming free until they find a nice crab, then latching on to the crab's genital area. *Sacculina* destroys the genitals, castrates the crab and grows there, while sending out root like fibers wrapping around the crab's internal organs and nerves. It induces the release of female crab hormones, turning a male crab to female if needed, and encouraging egg minding behavior. These host crabs usually take good care of a brood sac egg mass but now instead groom and defend the female *Sacculina* parasite, which forms a few small receptacles in her body. Male barnacle larvae plug into the receptacles and then wither down to just testes, the only part a male is really needed for. This process in the male *Sacculina* is an example of **sexual parasitism,** as if **castrating parasitism** wasn't kinky enough by itself. Barnacle sex then creates a new generation of parasitic castrating larvae ready for release. Finally, the sometimes formerly male now "mother" crab climbs up a rock and shoots the larvae out of a fake brood sac, waving her claws and delusionally wishing her babies a good life as they drift off into the current. Nature can seem cruel to us. Or maybe she has a dark sense of humor. Nature can be very beautiful, then take a life in the next moment. But nature is above our moral judgement.



Happy looking *Cymothoa exigua* “tongue eating louse” in the mouth of its host fish. image from Reddit



Two *Sacculina* parasitic barnacles on a male swimming crab from Belgian coast, by Hans Hillewaert, at Wikipedia

Wonderful drawing of Sacculina carcini adult female parasitizing the crab Carcinus maenas, showing sac like body under the host tail and indicating network of branching internal fibers penetrating throughout the crab's body.
image at Wikipedia, isolated from plate 57 (Cirrepedia, aka barnacles) in Ernst Haeckel's *Kunstformen der Natur* (1904).

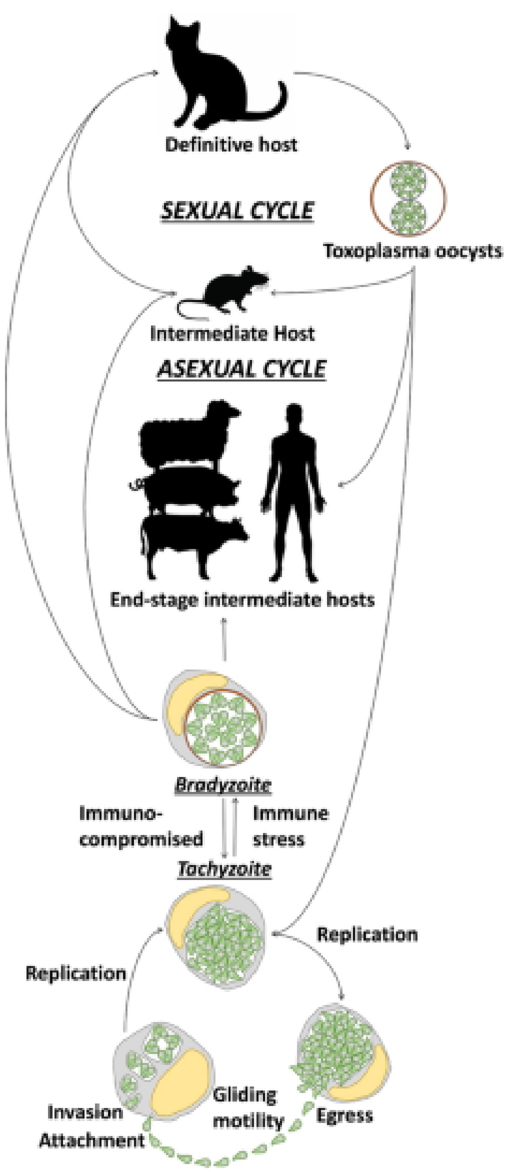
Parasite mind control?

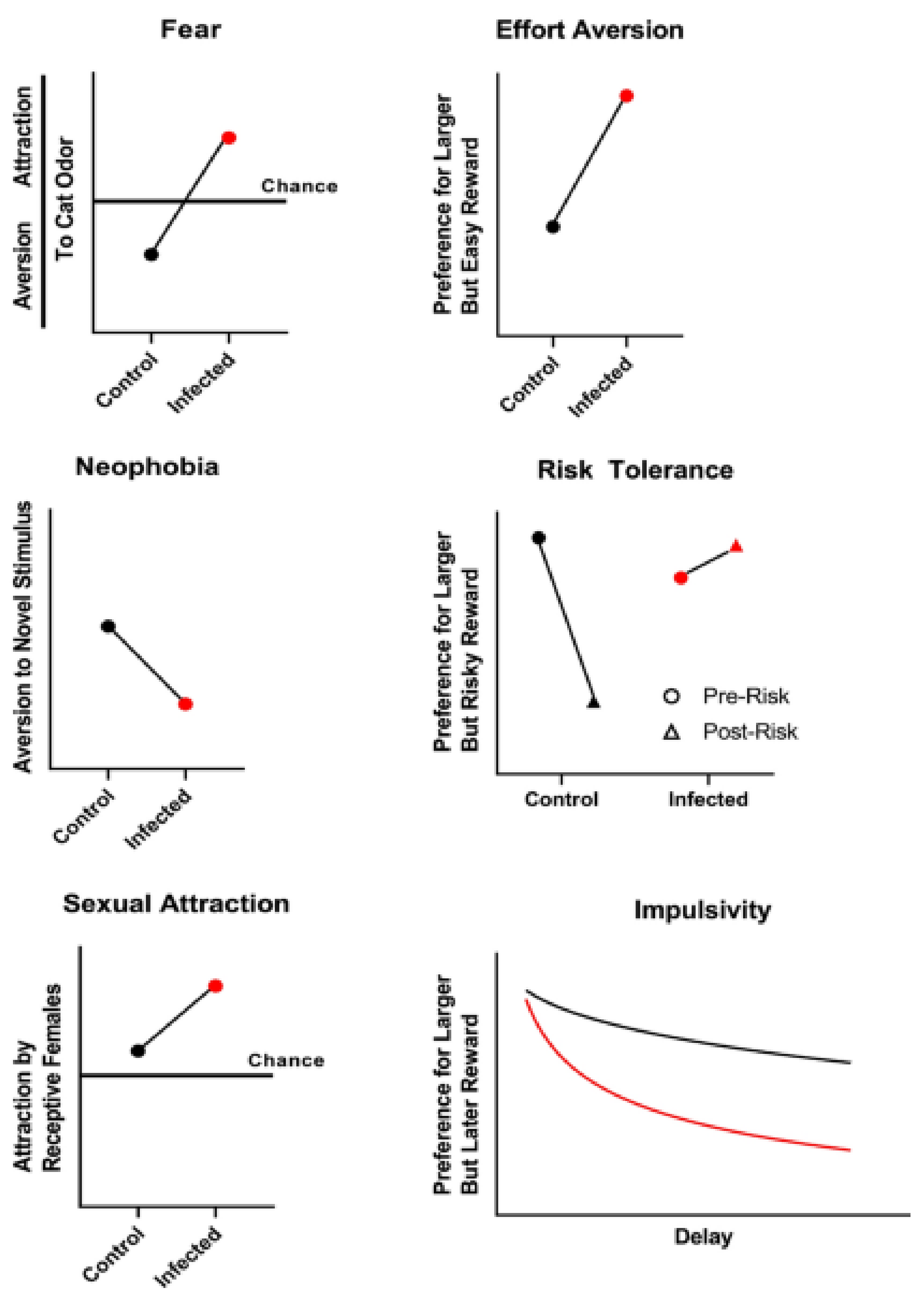
Sacculina is not unique in modifying the behavior of a host. It is a trick that can aid the spread of parasites, so evolution performs it. We saw that parasitoid wasps sometimes also castrate and manipulate their host's behavior. Other host behavior manipulating parasites include *Cordyceps* fungi and *Toxoplasma* protists. The former is turning humans into zombies in a popular TV show, but luckily the real *Cordyceps/Ophiocordyceps* is harmless to people. It is a nightmare for ants and other insect hosts. The parasitic fungus infects the ant's brain and compels the ant to climb high up on a plant before bursting out of the ant's head as a miniature mushroom to spread its spores more widely. The lancet liver fluke *Dicrocoelium dendriticum* pulls a similar trick on ants. The parasitic flatworm has a life cycle in snails, ants, cows (and rarely people). The metacercaria stage in ants compels them to climb up into grass, boosting the chance of being eaten by a cow and thus perpetuating the parasite life cycle. (The flatworm *Leucochloridium* infests snails and creates a colorful pulsating display in the eyestalk to entice a bird to eat the snail). *Plasmodium* is the genus of 4 species of protozoan parasites that cause human malaria. *Plasmodium* synthesizes volatile terpenes affecting our red blood cells, boosting production of carbon dioxide and body odor aldehydes, thus making human hosts smell more attractive to the *Anopheles* mosquito vector, boosting the spread of malaria.

A rose by any other name… follows certain rules

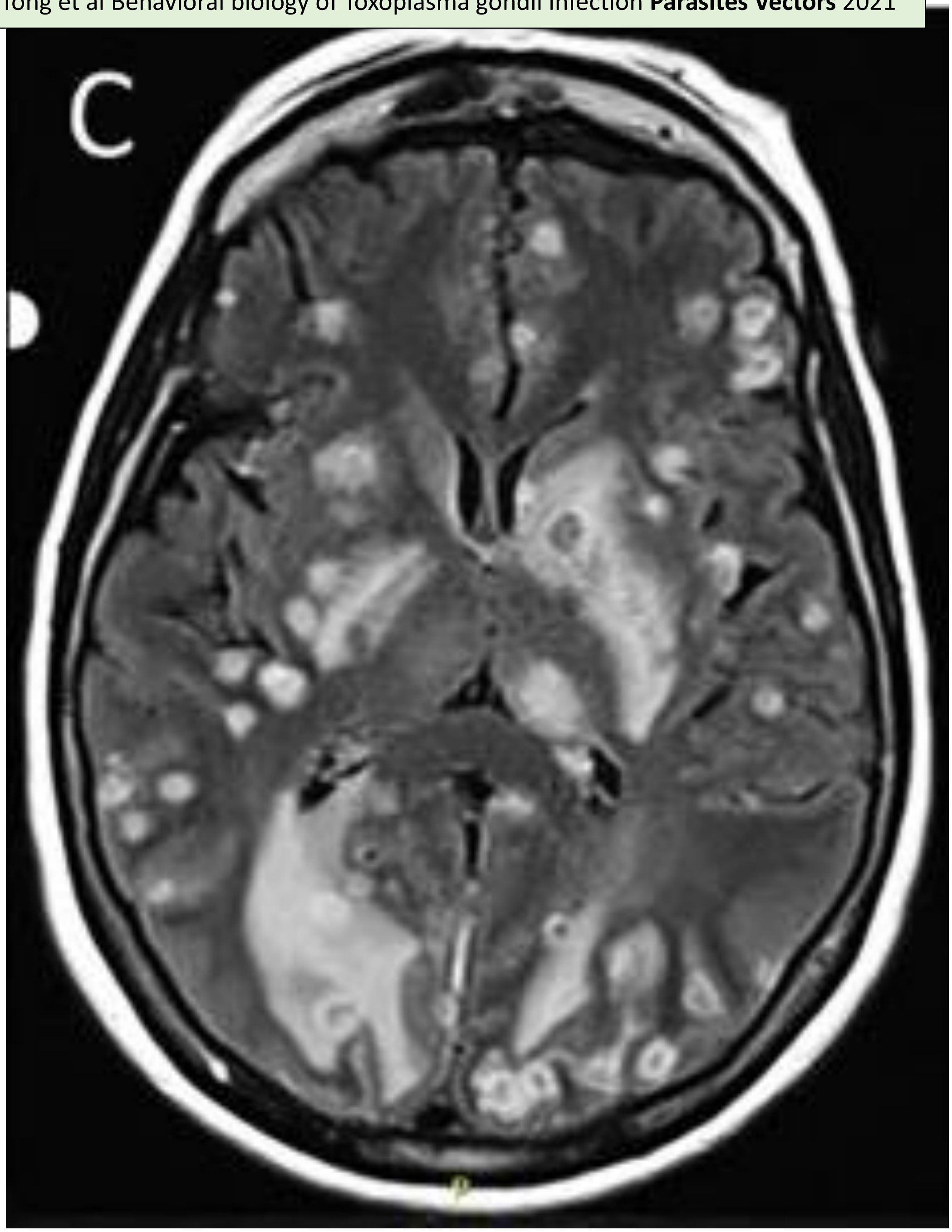
Note *Toxoplasma gondii* is the name of the protozoan parasite that causes the disease toxoplasmosis, and there many similar parasite/disease pairings. (But malaria was named as a disease long before the causative organism was discovered. *Plasmodium* parasites cause malaria.) Thank 18th century Swede Carl Linnaeus for the hierarchical (Latin names for higher and lower ranked groups) taxonomy system we still use today, with slight modifications. Genus and species, the smallest two ranks, are used to designate 1 or more closely related organisms. Proper names are usually italicized and the genus name is capitalized. Sometimes the discoverer's name and year of discovery is included. For example, *Plasmodium falciparum* Welch 1897 (named at Johns Hopkins) causes the worst malaria. *P. vivax* usually causes milder illness (if meaning is clear, the genus may be abbreviated to a capitol letter followed by a period). *Plasmodium sp.* designates a single unknown species, and *Plasmodium spp.* designates more than one unknown species. I often get lazy and just write *Plasmodium* when referring to one or multiple known species in the genus.

***Toxoplasma gondii* is another behavior modifying protozoan parasite**, and is hosted definitively by cats (feline intestines are where it reproduces sexually, although it is also found in over 30 species of birds and over 300 species of mammals). Some reviewers call *Toxoplasma* the world's most successful parasite, as it infects 30 to 50% of the human population, mostly in a latent state. Humans can acquire "toxo" from undercooked meat or from cat feces. An estimated 40 to 60 million Americans and maybe 2.5 to 4 billion people worldwide have toxoplasmosis, based on blood test surveys. Getting toxoplasmosis sometimes causes a brief flu-like illness. The parasite can bore from cell to cell into anywhere in the body but goes especially to the brain and eyes. In most people our immune system walls off the parasite in microscopic cysts soon after infection. People with positive serology mostly have asymptomatic latent infections (although whether these patients are all truly asymptomatic is now debated) and toxo seldom causes serious medical illness except in pregnant women (it is especially dangerous to an unborn child) and in immunocompromised people. Humans are a dead end intermediate host for the parasite. Its main life cycle is through cats and their rat and bird prey that pick up toxo eggs from soil. It seems clear *Toxoplasma* modifies host rat behavior, making them act bolder and drawn to cat urine. These behaviors increase the chance of the rat being eaten by a cat, completing the trophic transmission step in the *Toxoplasma* lifecycle.





Life cycle of *Toxoplasma gondii* on left.   Some putative host behaviors on the right.
-Tong et al Behavioral biology of Toxoplasma gondii infection **Parasites Vectors** 2021



MRI of infected human brain. Disseminated cerebral toxoplasmosis in a 63 y.o. lady immunocompromised by aggressive treatment of chronic lymphocytic leukemia. The multiple small round and ring lesions are active toxoplasmosis disease, not to be confused with the invisible microscopic cysts of latent infection.

image Xu, J, et al **Journal of Clinical Neuroscience** 2018

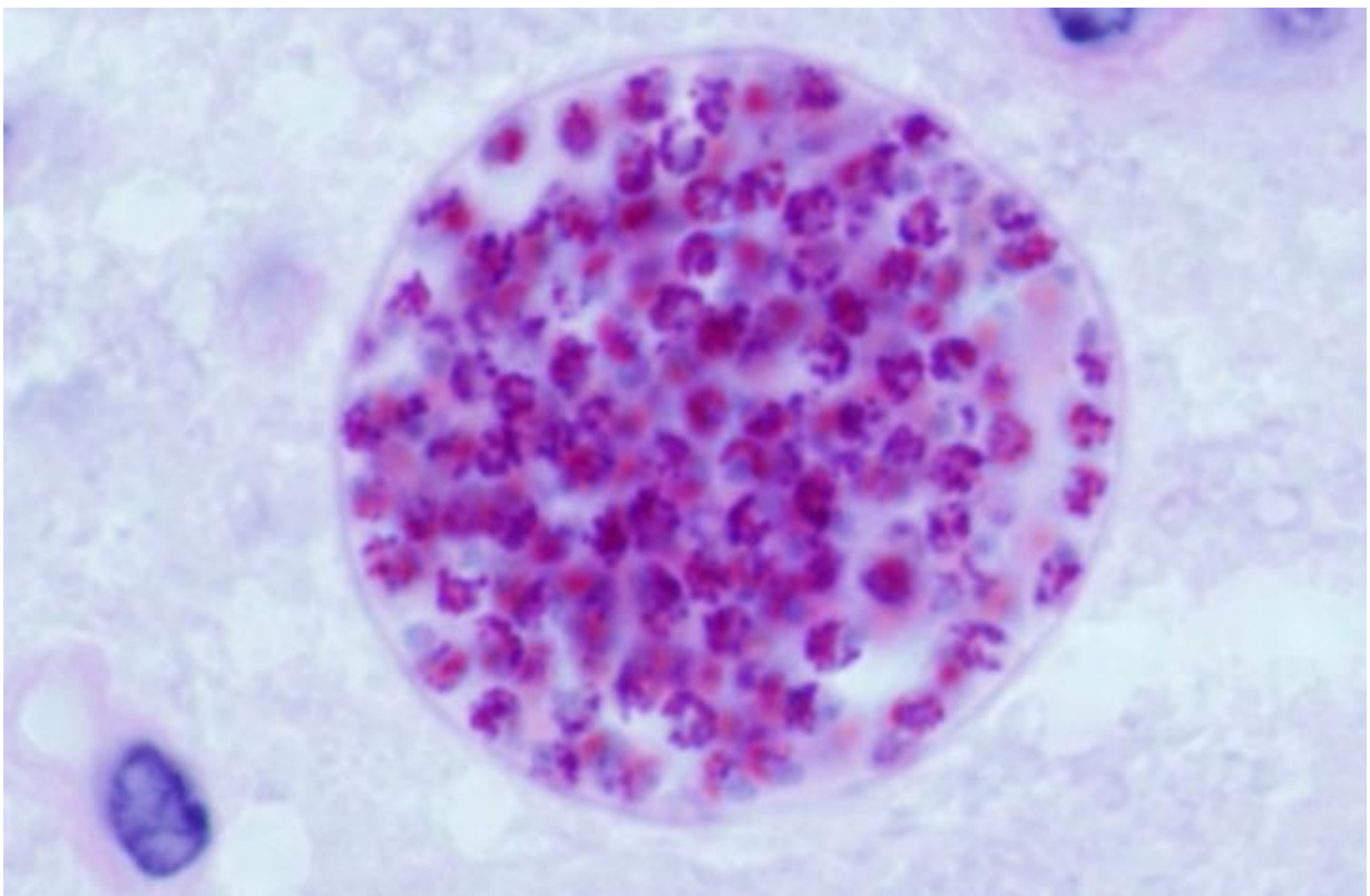
I recall a very similar CT scan that surprised me in medical school in 1987. My 30 y.o. lady with AIDS (most patients were men at that time, and we had no cure) suddenly started seeing things and acting paranoid. I thought she had a psychotic break until I saw the CT scan. As I recall we started empiric treatments for abscess, fungus and *Toxoplasma*, but to no avail. Toxoplasmosis was confirmed by autopsy.

A big question is how much latent toxoplasmosis affects human behavior. Given rodent data, I had wonder if some “cat ladies” don’t mind the smell of cat piss because of toxoplasmosis, but I was otherwise initially skeptical about big claims for *Toxoplasma* changing human behavior. Many association studies are reported but maybe interesting positive ones are more likely to be published, such as latent *Toxoplasma* infection being correlated with entrepreneurship in Danish women. Maybe the studies fail to fully control for cat owners being different than the general public. Some studies found photos of men and women with latent toxoplasmosis both appear more attractive to strangers. Multiple studies link toxoplasmosis carriage to many common psychological and neurologic disorders. *Toxoplasma* carriage has been linked to increased risk of schizophrenia, attention deficit disorder, anxiety, depression, suicide, bipolar disease, OCD, intermittent explosive (rage) disorder and also with autism, epilepsy, Parkinson’s disease, Alzheimer’s dementia, headaches, frailty in the elderly and fatal traffic accidents. A 2023 paper found an unadjusted odds ratio (OR) of 2.35, and an adjusted OR of 2.24 (95% CI: 1.61–3.12) for schizophrenia in latent toxoplasmosis patients. Many seemingly well done meta-analyses of dozens of studies claim toxoplasmosis is an underappreciated cause of mental illness, especially schizophrenia, with toxo conferring about double relative risk. Another 2023 paper estimated 21.4% of cases of schizophrenia and 27.3% of cases of bipolar disorder could be caused by toxoplasmosis. A 2022 review found 66 papers linking toxoplasmosis weakly or strongly to schizophrenia and concluded the next step should be anti-parasitic drug trials, not further association studies. One old study claimed that a recent symptomatic *Toxoplasma* infection in two kids caused obsessive compulsive disorder, and the symptoms improved after anti-parasitic drug treatment (or was it just time?). Many non peer reviewed sources and PhD theses propose elaborate theoretical mechanisms of causation and make big claims.

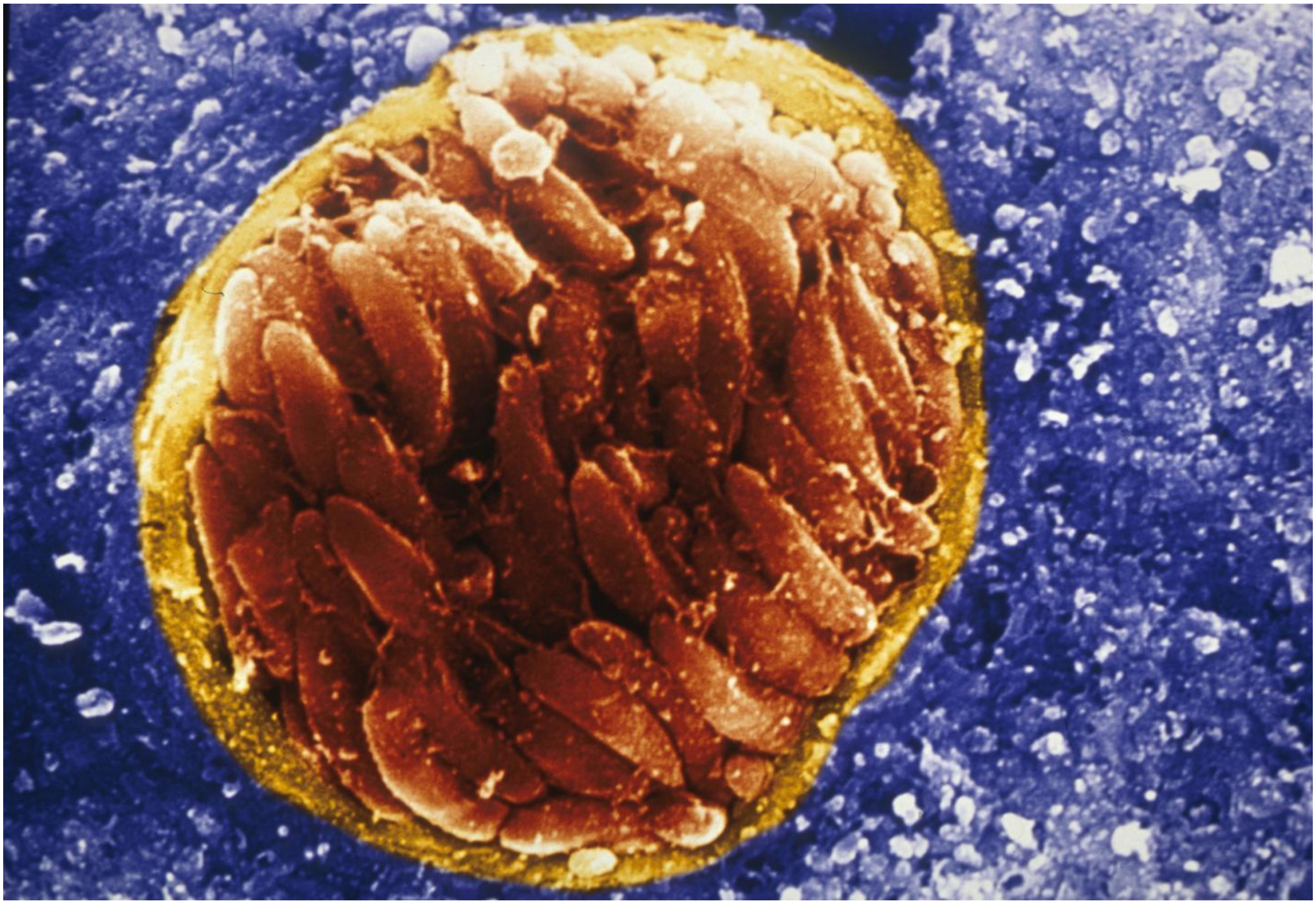
To me the claims seem to be too plentiful (could a parasite really contribute to almost every kind of neuropsychiatric disease?) and the evidence too shaky to be accepted in full at this time. I tend to agree with some skeptical reviewers who note that when studies known to be of lower quality (and thus more subject to uncontrolled bias) are eliminated, the estimated risks for neuropsychological disease are smaller or disappear altogether. I note the study of attractiveness published 23 comparisons between infected and noninfected subjects and just 3 parameters (less facial asymmetry, lower mass and BMI) were different to $P < 0.05$ in a study of 213 subjects and controls; 20 of the comparisons they made did not pan out. Even if some small minority of results seem statistically significant in large survey studies, many of the differences would be too small to notice in real life. Psychology research has a known crisis in the reproducibility of its results. This is an area I am not expert in, and after reviewing multiple papers I am still not completely sure what to think. We don’t need to decide today. Much research on the putative behavioral effects of latent toxoplasmosis is still ongoing.

Even if links to neuropsychiatric diseases are not yet well proven, the latent *Toxoplasma* hypothesis does have good biological plausibility, and most (not all) of the behavioral data in mice is consistent. The parasite has a gene for tyrosine hydroxylase, an enzyme in dopamine synthesis. Boosting dopamine in the brain near *Toxoplasma* cysts might make the host bolder (although animal experiments with a mutant strain not making the enzyme still showed host behavior effects). *Toxoplasma* can also increase testosterone levels, and increases the proportion of male births in hosts. Some of the parasite's microscopic cysts are in important brain areas related to avoidance behavior including the amygdala, and those cysts cause variable inflammation in the brain. Hormones and brain lesions do have effects on behavior, but I have not completely given up on free will. Biological and social factors of course change the odds of making certain decisions, yet I think we all still make our own choices. Some people, such as millions of celibate nuns and priests, are able to make choices contrary to hormonal influence.

It remains an open question whether toxoplasmosis is a big influence on human behavior.



Toxoplasma gondii cyst full of resting bradyzoites, in mouse brain. Light microscopy, details unknown (suspect 100X objective). Compare with SEM and TEM electron microscopy images following pages. image obtained from Wikipedia



Toxoplasma gondii cyst full of resting bradyzoites, in mouse brain. Scanning Electron Micrograph, original David Ferguson, image from AAAS Eureka Alert regarding 2016 article by Coccaro et al on aggression and *Toxoplasma* in Journ Clin Pysch

Transmission Electron Microscopy *Toxoplasma gondii* in lung of a bar-shouldered dove. Two tachyzoites enclosed in parasitophorous vacuolar membrane (pvm). Conoid (co) at top, micronemes (mn), rhoptries (ro), and nucleus (nu).
Rigoulet et al 2014 Toxoplasmosis in a bar-shouldered dove (Geopelia humeralis) from the Zoo of Clères, France. **Parasite** 21, 62, image at Wikipedia

Speculation on evolution of parasites

The grand pageant of wonderful life forms is due to the miracle of evolution. It seemed obvious to people in the past that God specially created every plant and animal for its own special spot in nature. Consider how perfectly designed a tapeworm seems for living in your intestine. It has no eyes, no mouth, no intestines. It doesn't need them, living in the dark in a sluggish current of digested food in your intestine. Not just parasite bodies, but their life cycles seem designed. Some tape worms live 4 different life stages in copepods (tiny crustaceans), small fish, big fish and human intestines. Surely nature must have a design, a plan, a creator. But as Darwin worked out, nature, with its struggles for life is its own designer. A few hundred million years ago a flatworm was eaten by a fish that didn't chew well, and the lucky worm lived and made baby worms. The worms that survived were likely to be just a little bit different than those average worms who did not, and because of heredity their babies were like the parents, but sometimes also a little bit different (genes are passed on but also shuffled and can mutate). A few of the babies also survived being eaten, as did some of their babies and so on. Over millions of generations, the worm's bodies were changing to be adapted to being eaten by fish. Eventually some of the immature stages survived being eaten by copepods and some survived when a human ate raw fish. After millions of years, some random luck and the above random survival of better adapted variants, we now have today's adult broad fish flatworm appearing custom made for our intestine, with eggs and larval stages perfectly at home in copepods and fish. Yet there was no designer, just the logical results of how natural biological processes worked out, based on chemistry, based on physics, based on maths.

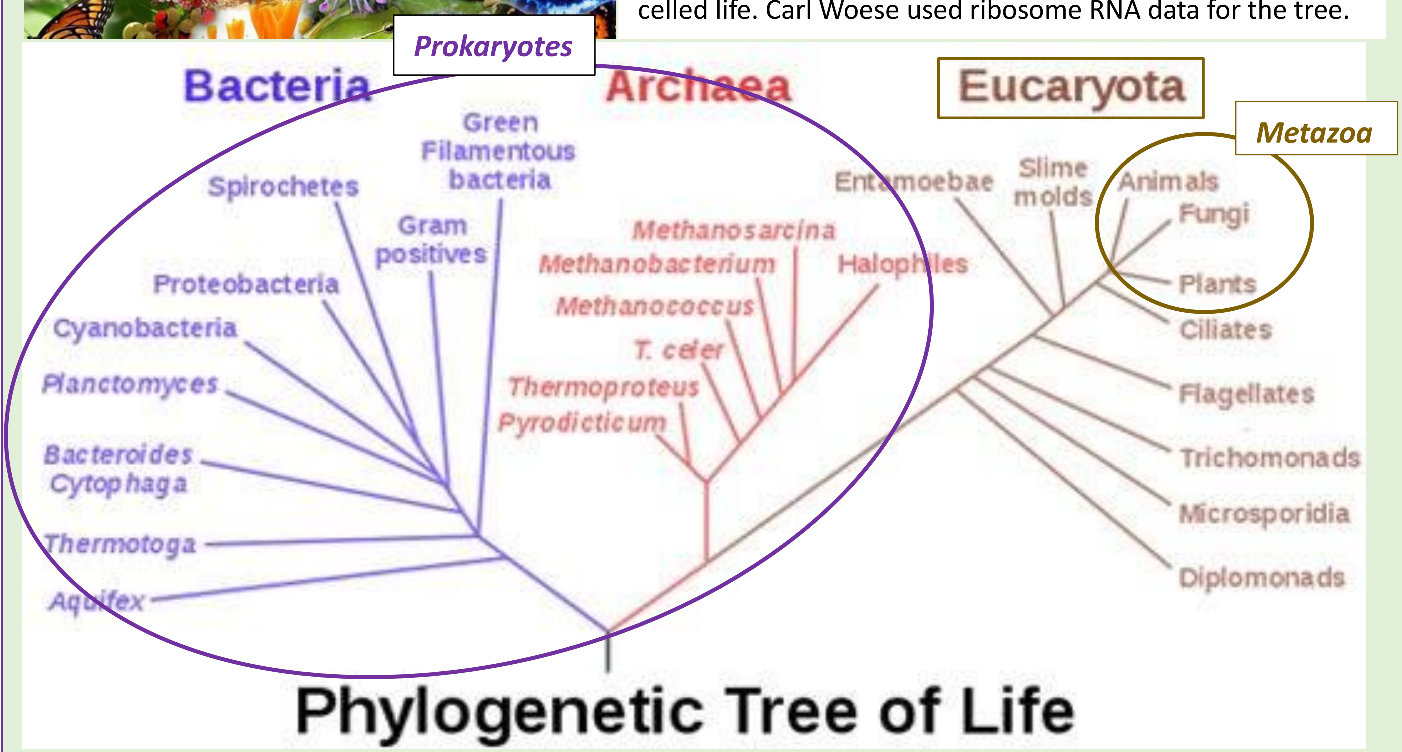
Although fossil parasites are few and far between until the last ice age (yesterday in geologic time), morphology comparisons and genome studies infer evolutionary relations among various parasites and their hosts. Because modern man is so recent, we have been able to infer the origins of some of our parasitic lice hitchhikers. Abundant evidence shows parasites must have independently evolved over and over again when organisms found the inside or outside of other animals habitable. Over time the morphology, physiology and sometimes the life stages of parasites adapt to maximize survival. Sometimes this results in convergence of traits (helminth gut parasites derived from different phyla are usually worm-like and share many traits) but sometimes evolution is divergent. The parasitic barnacle family Rhizocephala, which includes the bizarre *Sacculina* (see above under odd and mind control) certainly struck out on its own. The adults don't look like a barnacle or any other arthropod, being reduced to a sac like body and the root like fibers it grows throughout the host's body. Apart from its nauplius and cyprid larval stages, *Saculina* doesn't look at all like any other animal.

Basics of Evolution

In 1859 evolution was a new theory, laid out in clear, logical and humble detail by Charles Darwin in his book *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. Darwin had gathered thousands of his own and others' observations about the varieties of life, but at that time fewer fossil links were known and the mechanism of inheritance was unknown (Czech monk Gregor Mendel discovered the laws of genetics in pea plants in the 1860's, but no one knew it). Today, evolution is a proven fact: millions of new bits of evidence show life slowly evolved into a myriad of different forms on planet earth. Evolution remains a powerful and changing (all science is subject to modification by additional information) central theory in biology that makes sense of new evidence from biologic and medical research. I see evolution in action in the hospital as bacteria evolve to be resistant to commonly used antibiotics, and the COVID-19 virus evolved to be more docile inside us.

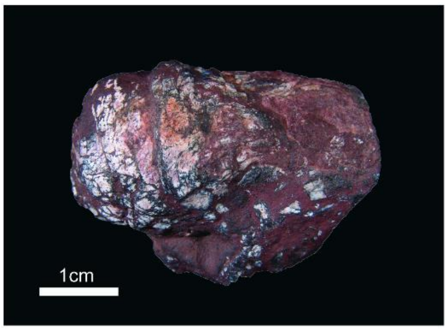
Darwin's theory is amazing in that upon careful reflection it seems inevitable. People create different breeds of dogs, pigeons and other domesticated animals through selective breeding. Darwin showed nature does much the same thing. It can be observed that all organisms come from the reproduction of previous organisms, that there are differences between individuals in a group (i.e. some are faster or slower) and that parents reproduce imperfect copies of themselves (we now know genes are shuffled and sometimes mutate). Darwin noticed that there is a struggle in nature for organisms to survive and produce offspring. In real circumstances (gazelles being chased by cheetahs for example) survival is not just random but favors certain bodily abilities (i.e. running faster) so the next generation comes from selected (faster) surviving parents and so each generation becomes slightly adapted in particular ways. Over deep time (the earth is now known to be about 4.55 billion years old) a single cell became all the amazing life on the planet today, from bacteria to *Paramecium* to grass to mushrooms to worms to you. Every living thing becomes fined tuned for its way of life, making life look like it was designed. Yet there was no designer, just the logical results of how natural life processes (based on chemistry, physics and math) worked out.

Most life is prokaryotic: very tiny, no nucleus, the Bacteria and Archaea, on left. All Metazoans (multicellular organisms) are in the small circle on right. Between are Protists, bigger than bacteria, but mostly microscopic, nucleated single celled life. Carl Woese used ribosome RNA data for the tree.

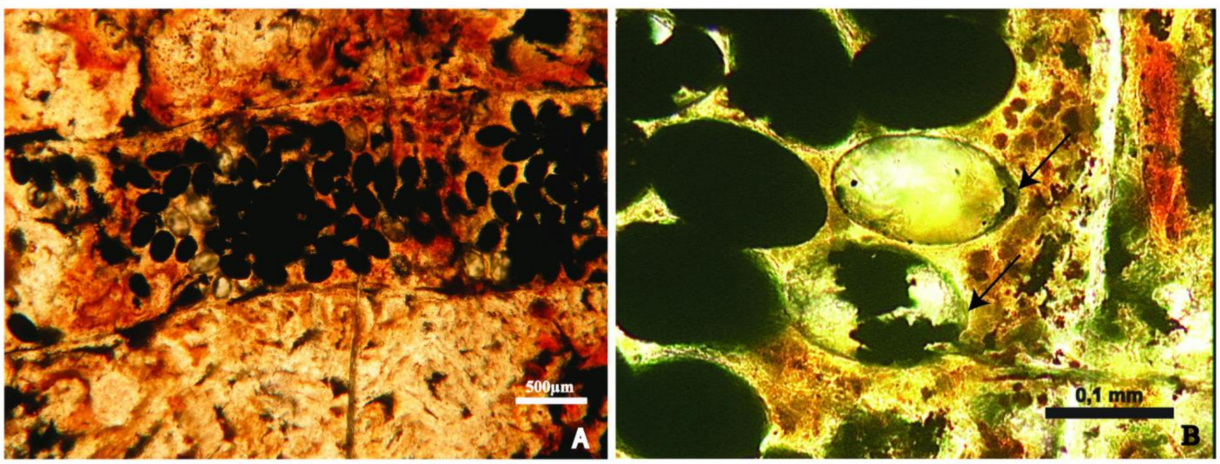


Little rock hard data on parasite evolution

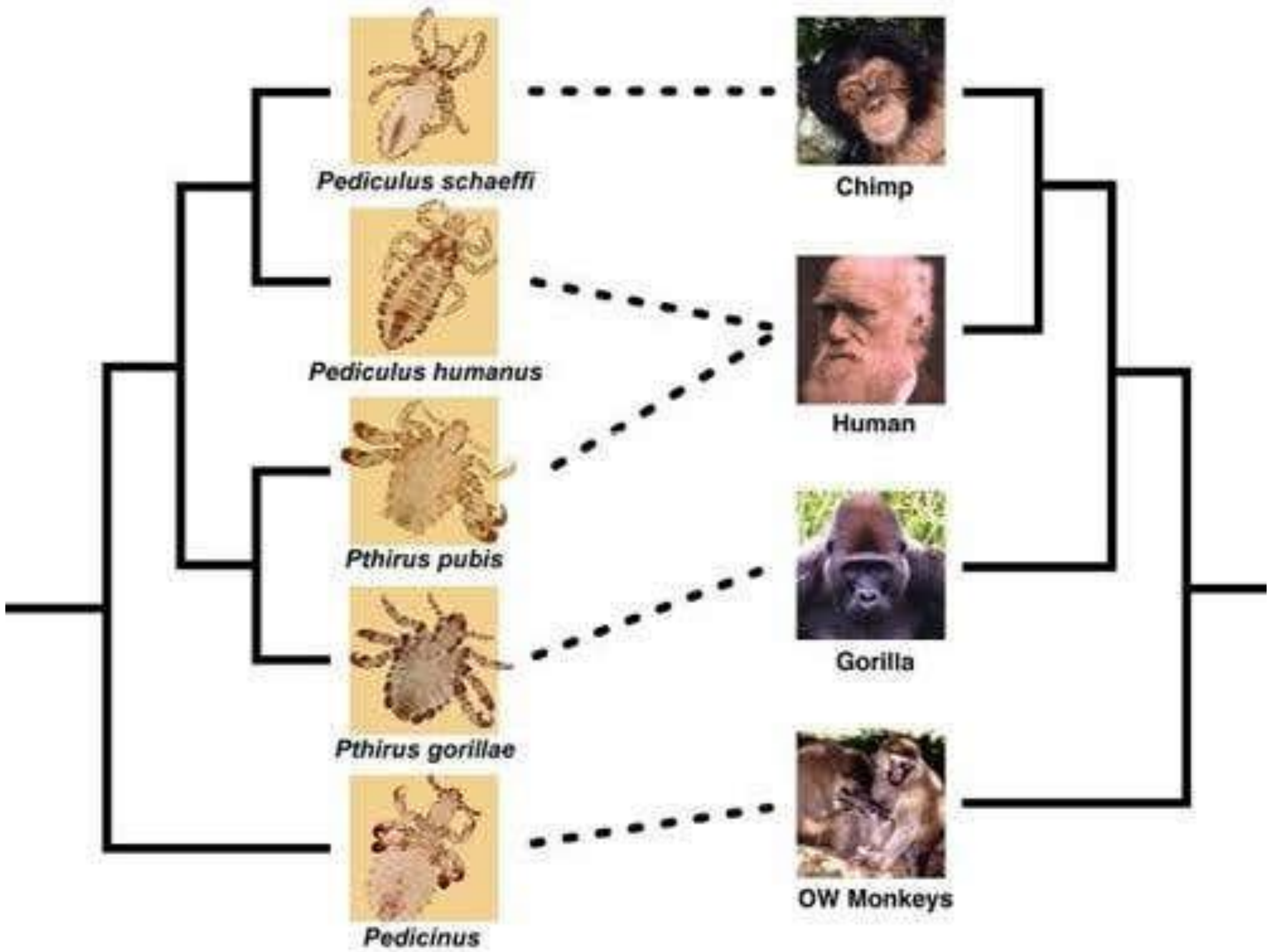
We don't have many really old fossil parasites. But ice age mummified mammals show lice in their hair and worms in their guts. Nematode and horsehair worms and parasitic insects are seen in 100 to 110 million year old Burmese amber. Nematode and unidentified eggs were found in a 200 million year old reptile coprolite. Tapeworms started infesting vertebrates before 270 million years ago, based on eggs in Permian shark poop from Brazil. The oldest known parasite fossil is ectoparasite tube worms on a brachiopod shell, from 510 million year old Cambrian Period rocks in China. The worms were kleptoparasiting (competitively stealing food from the host), so shells infested with tube worms were smaller on average.



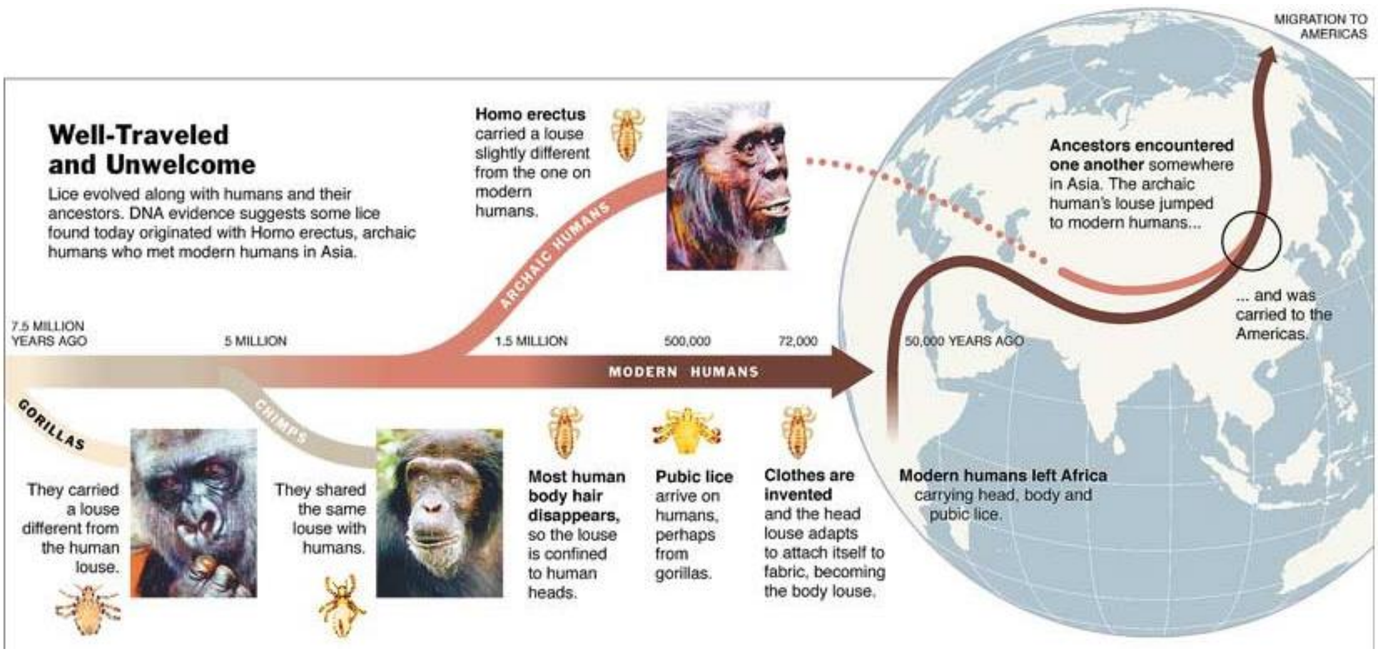
Shark fossil poop, about life size left, sections about 20X and 200X below. Dentzien-Dias et al Tapeworm Eggs in a 270 Million-Year-Old Shark Coprolite. **PLoS ONE** 2013 The fossils date from the Permian Peroid, before the biggest animal extinction event in earth's history.



Brachiopod ***Neobolus wulongqingensis*** with tube worms on shell. (bar = 2 mm) image Zhang et al. An encrusting kleptoparasite-host interaction from the early Cambrian. **Nature Commun** 11, 2625 (2020).



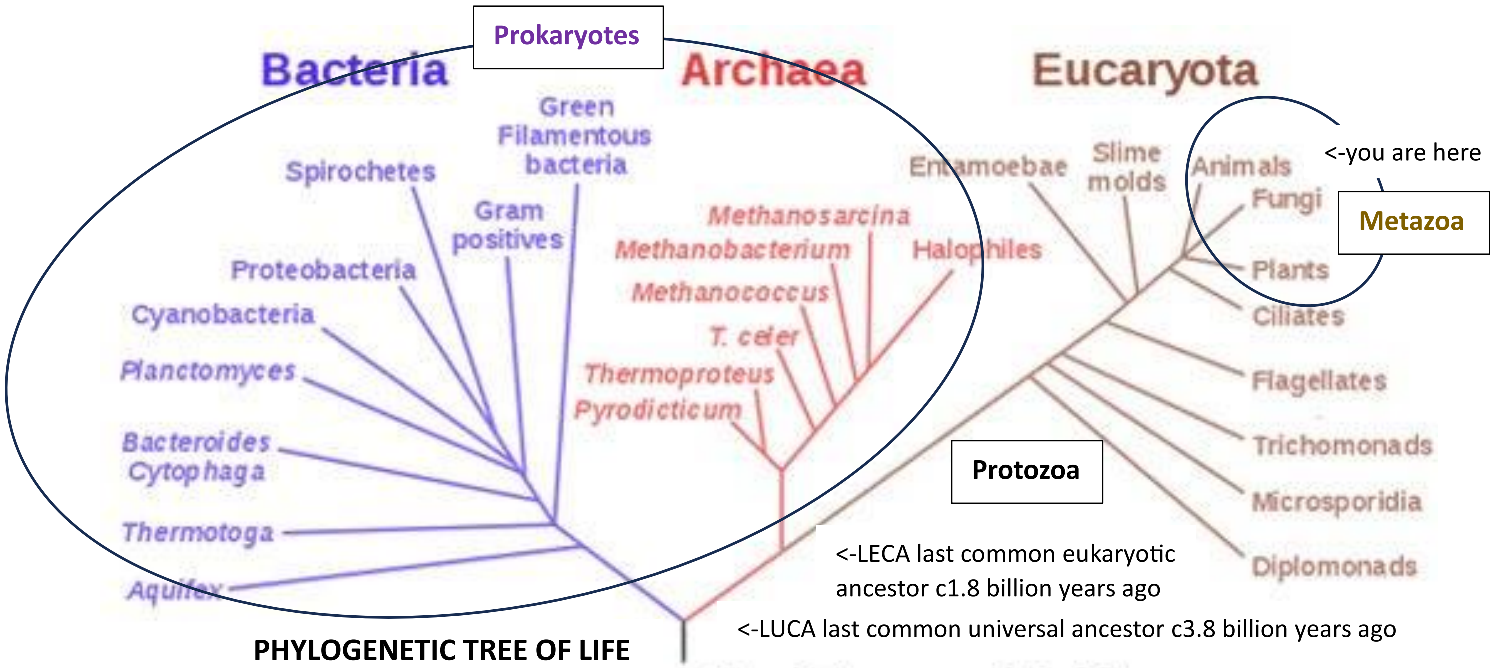
Proposed phylogeny of lice of man and some of our relatives. from Reed, Light, Allen, Kirchman. Pair of lice lost or parasites regained, 2007, retrieved at Research Gate



Lice travelled and evolved with our pre *Homo sapiens* ancestors. from Nicholas Wade, What a Story Lice Can Tell, **New York Times** October 5, 2004, retrieved at headlice.org Human body lice may be an example of animals adopting to human technology (clothes).

Taxonomy of all life, and of parasites

Parasitic lifestyles have evolved many times in many branches of life. An overview of all life shows most types of organisms are microbes (so small as to need a microscope to see clearly). These microbes were also the first life, with bacteria and archaea probably appearing almost 4 billion years ago, soon after the young earth's surface cooled down. Bacteria got a big head start. The first primitive animals came along only about 0.8 billion years ago.



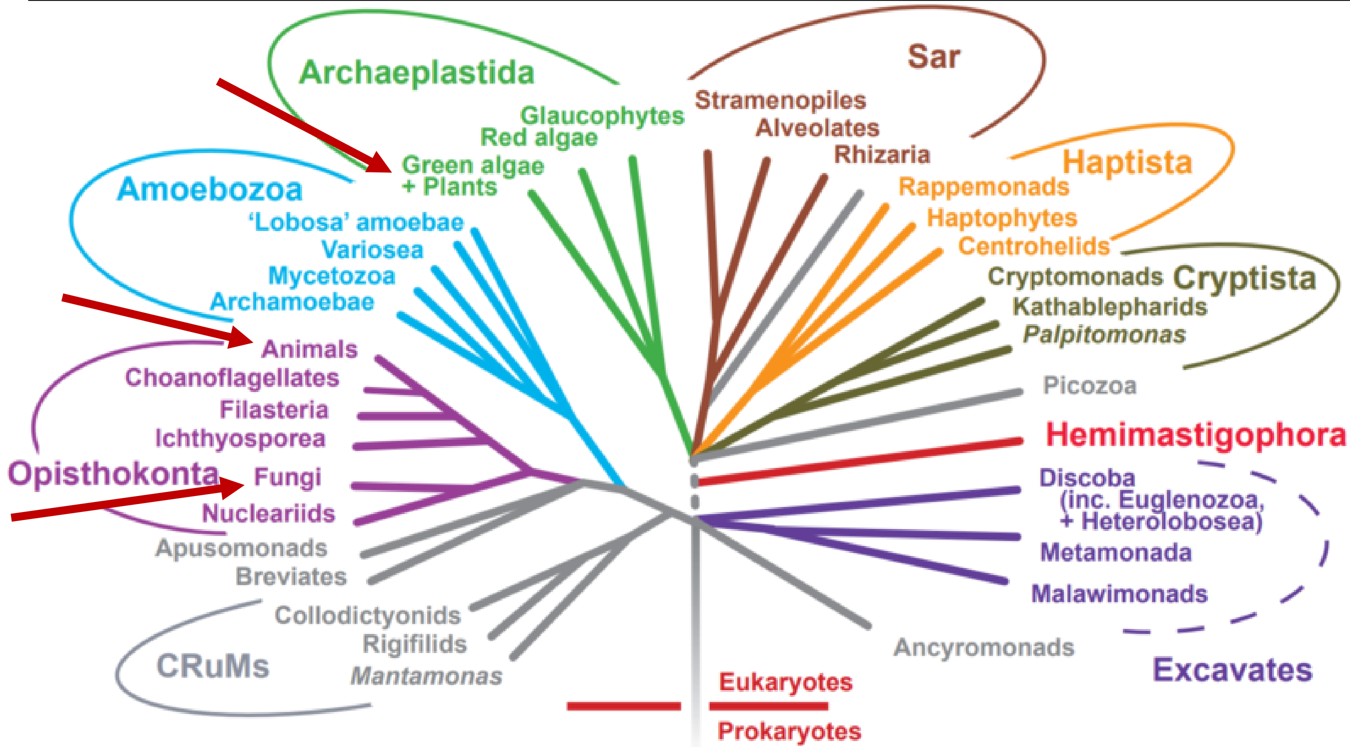
PHYLOGENETIC TREE OF LIFE

Most life is prokaryotic, left, very tiny, no nucleus. Multicellular organisms are in the small circle upper right. "In between" are diverse single celled organisms we call protists. rRNA tree C Woese and NASA Astrobiology, E Gaba 2006.

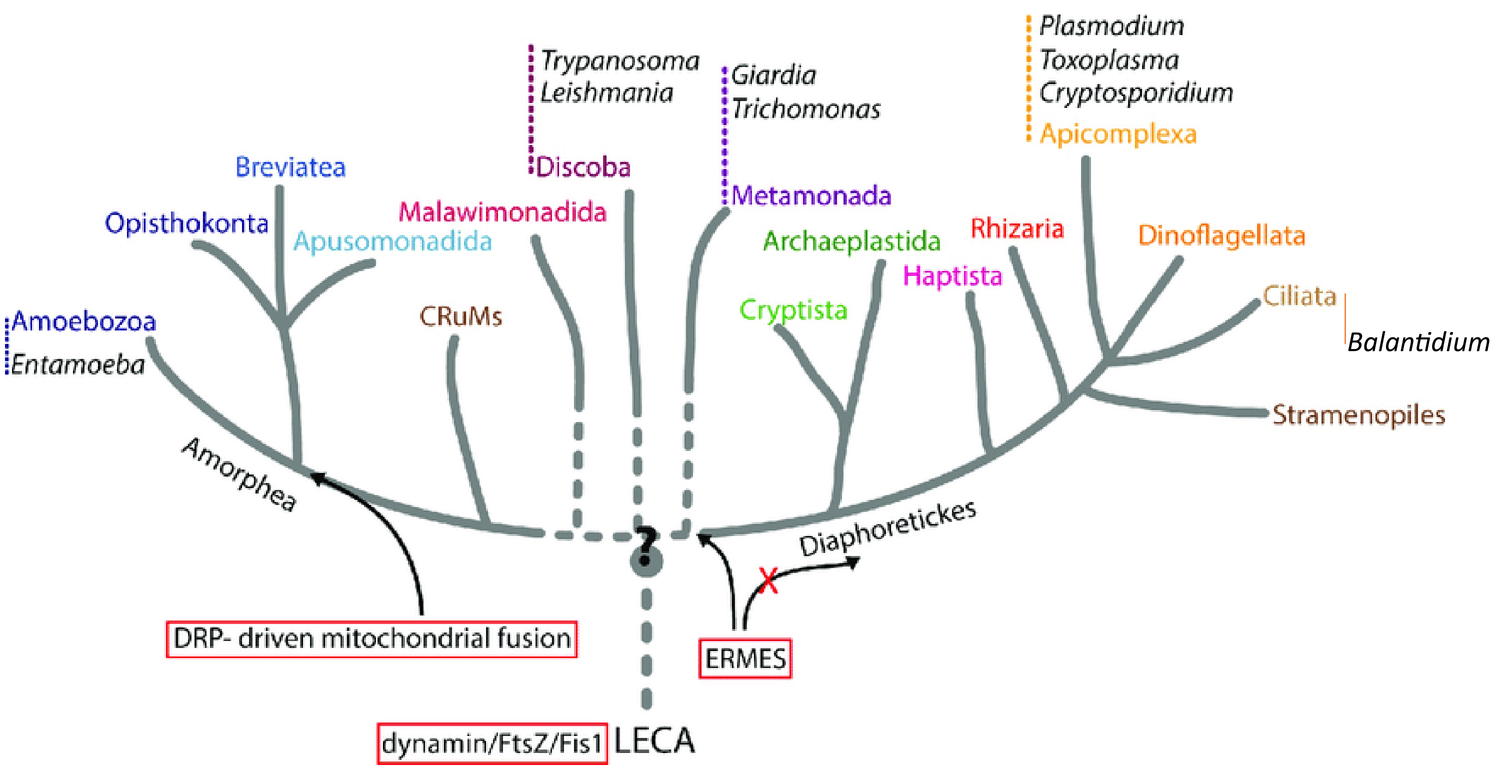
Prions and viruses (not on the tree as are nonliving, nanoscopic protein or protein/nucleic acid bits), bacteria, protists (aka protozoa) and fungi are the mostly microscopic groups that have some members acting as disease (acute illness) causing pathogens of animals and plants. Broadly defined, these same microbial groups, along with some animals, have some species that have become parasites (except, strangely no archaea have been shown to be pathogenic.) As noted before, historically we often define parasites more narrowly as those protists and animals that live in or on animals, taking nutrients and thus hurting the host a little bit.

Trees of life have been redrawn repeatedly over my lifetime, and science will never be completely finished. The phylogeny of protists has been particularly messy. Classic groupings of protozoans by appearance, i.e. amoebas, ciliates, flagellates, etc. were not all confirmed by genetics. In terms of biomolecules, the animals, fungi and plants are closely related to some protists (including choanoflagellates), so they appear on family trees like additional groups of protists. Different authors draw many different trees of Protist/Eukaryote Life.

A non-hierarchical interpretation of the phylogeny of protists. Ciliates and Apicomplexans are in the big SAR-alveolate clade. Excavates are not a clade. Red arrows indicate the 3 classic metazoan kingdoms; all other groups are protists   Alastair Simpson, Dalhousie University, Aug 2020, image Wikipedia



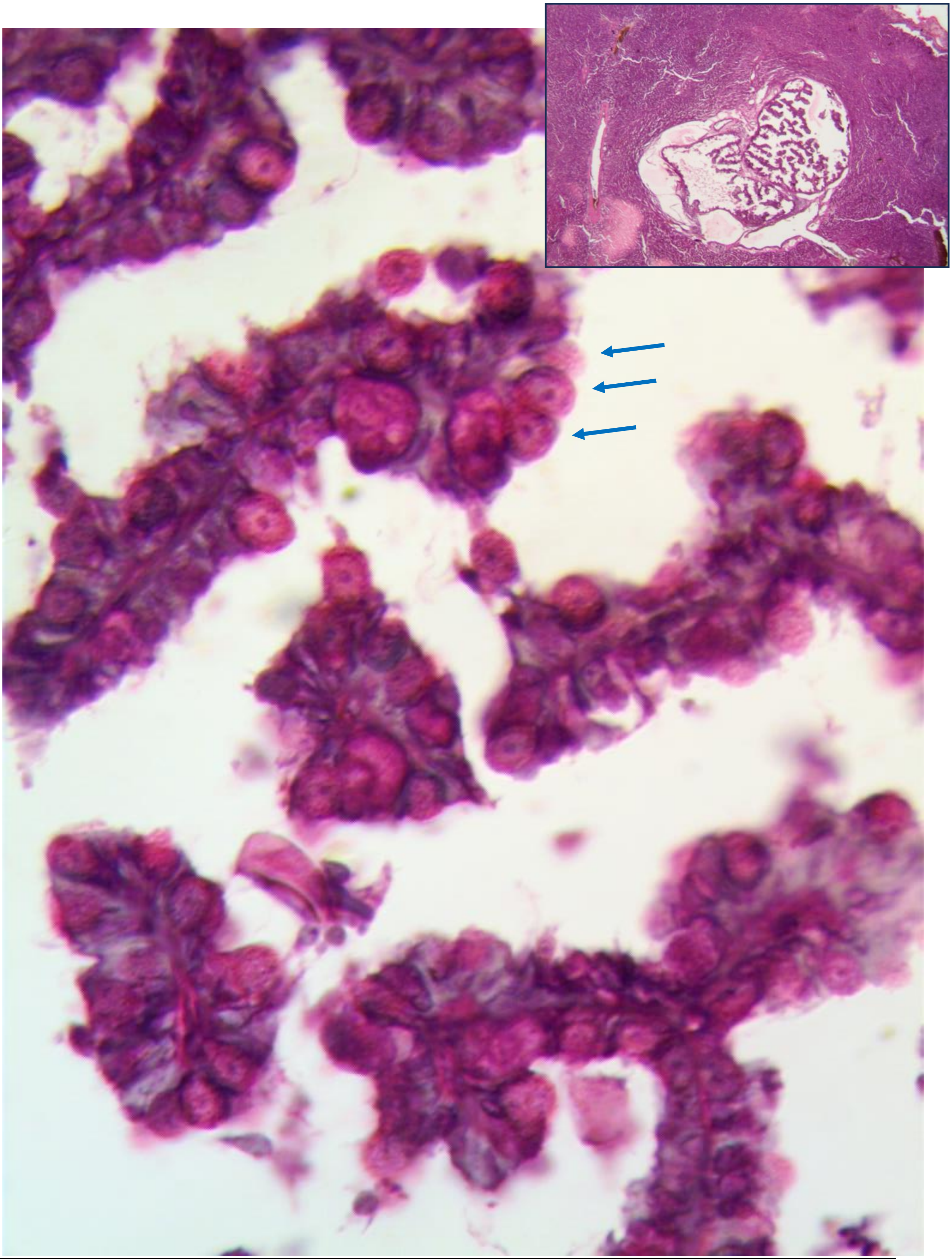
Phylogeny of Eukaryotes, treated as 8 supergroups



Place of some protist parasites in a different Eukaryotic/Protist tree of life

LECA last eukaryotic common ancestor. Dynamin/DRP, ERMES are intracellular membrane processing complexes. I added Balantidium. Voleman et al 2019 Mitochondrial dynamics in parasitic protists PLoS Pathogens

Protists look like tiny animals. Free living ciliates *Paramecium* (right) and *Spirostomum* are bigger than most microbes (slow swimming 1 mm "worms" seen by naked eye) and seem curious about their surroundings (simple innate behaviors). Old marsh water, Red Wing, MN, USA, December 2016. 10X objective without reducer, circular oblique lighting with extreme chromatic aberration (phase like effect) from using old AO 34mm parfocal phase objectives on a newer 410 microscope. Image about 450 microns wide, *Paramecium* about 250 microns long.



Protist parasite *Eimeria stiedae*, rabbit coccidiosis with cystic destruction of liver by proliferating coccidia (arrows) slide Johns Hopkins Sch Hygiene Protozoology c 1950s, main 40X obj., image about 230 microns wide; inset 4X obj.

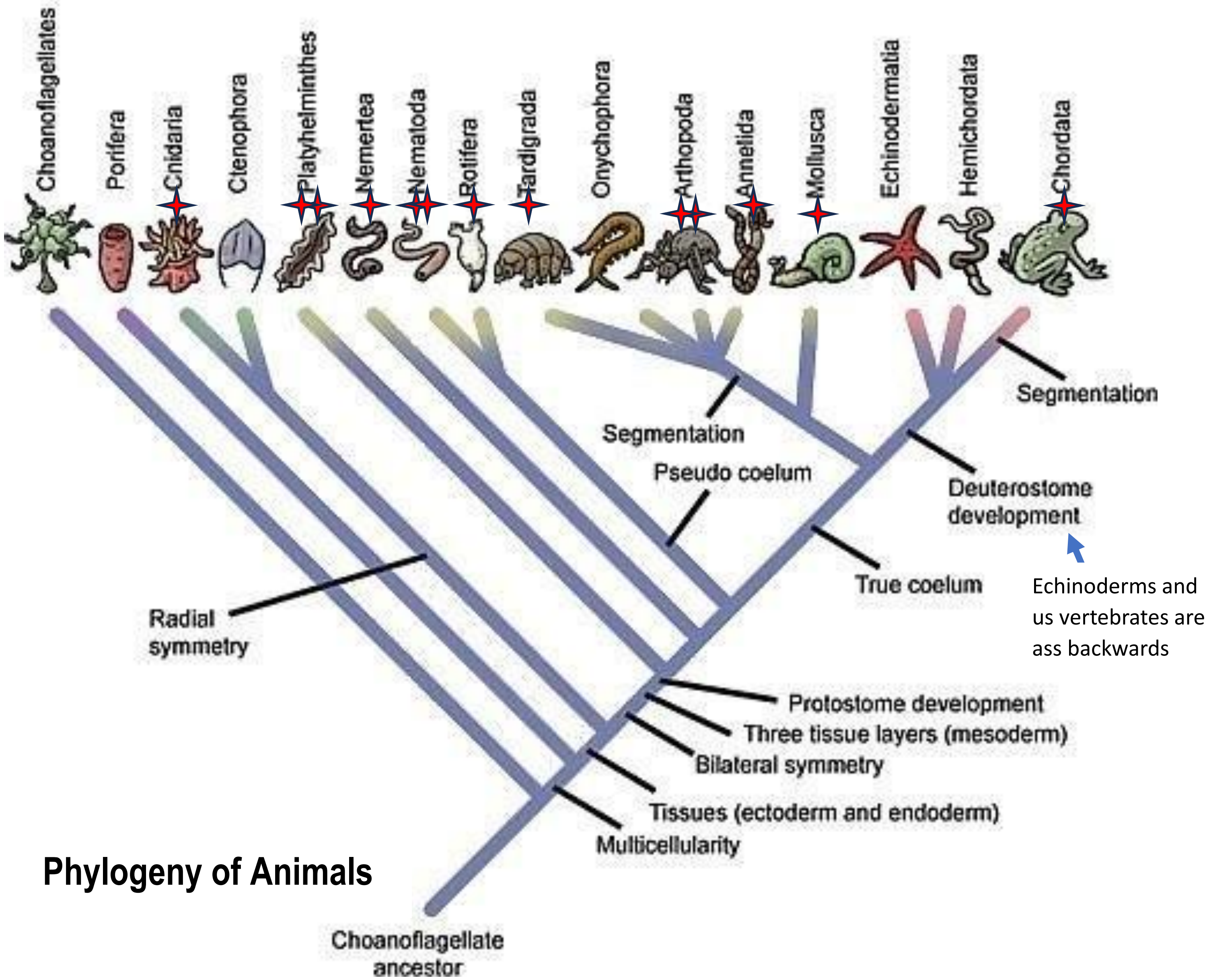
A few of the protozoan human parasites are similar to what you see in pond water. There are enteric (intestinal) amoebas (*Entamoeba*) and ciliates (*Balantidium*). Fatal amoebic meningitis can result when (luckily rare) *Naegleria* amoeba from warm freshwater go up the nose. Discobans (named for discoid mitochondrial cristae) are flagellates like green freshwater *Euglena*, also have amoeboid and cyst forms, and include the agents of African sleeping sickness and Chagas disease (2 *Trypanosoma* species) and of Leishmaniasis.

Metamonads and apicomplexans seem odd protists. Metamonads are mostly free living flagellate protists that no longer have mitochondria, a strange adaptation. They get their energy anaerobically, but mostly tolerate oxygen. It is debated how close they are to stem eukaryotes, and whether they are excavates. *Giardia* and *Trichomonas* are extracellular parasites in the intestine and vagina respectively, causing diarrhea or vaginitis.

Apicomplexans are alveolates (the A in the SAR clade, also including the ciliates and dinoflagellates). But apicomplexans are almost all parasitic intracellular parasites, named for their conical apical complex used for host cell entry. Apicomplexans have no flagella, except their spermatozoa. Apicomplexans include *Plasmodium* causing malaria, *Toxoplasma* causing toxoplasmosis (a form of coccidiosis, not to be confused with fungal coccidiomycosis), *Cryptosporidium* is a coccidia causing cryptosporidiosis diarrhea (not to be confused with fungal cryptococcosis), *Babesia* causing babesiosis, and *Cyclospora* causing cyclosporiasis.

Leaving protists behind, we finally get to parasitic animals. Classic parasites are endoparasites living inside or ectoparasites living on the outside of animals. **Endoparasites** include helminths (‘worms”) living in the gut or other internal organs of host animals. Classic **ectoparasites** are mites, ticks, fleas, lice and parasitic (bot) flies that attach or burrow into the skin and stay a while. With bodies adapted for attachment to feathers, fur or skin and specialized feeding, they are often quite interesting under the microscope. Many ectoparasites live their whole lives on the host, but most ticks attach for just a few days. Some animals are parasites by stealing resources from other animals, but have just a fleeting or no attachment at all. **Micropredator** examples are blood eating mosquitoes (pregnant females only) and some biting flies (which are insects/ arthropods), and leeches (annelids, related to earthworms) which feed quickly then fly or swim away. There are even **hematophagous** (blood eating) mammal parasites: the 3 species of vampire bats. A few animals have developed other parasitic behaviors without living in or on the host. Some steal food or parental care, such as hyenas or cowbirds, i.e. **kleptoparasites** or **brood parasites**. Some insects are **social parasites**. Some ants and bees live in the colonies of related species, being taken care of by the workers there. A few butterfly larvae (i.e. of the Large Blue Eurasian butterfly) mimic ant larva in shape and smell, gaining care in an ant colony.

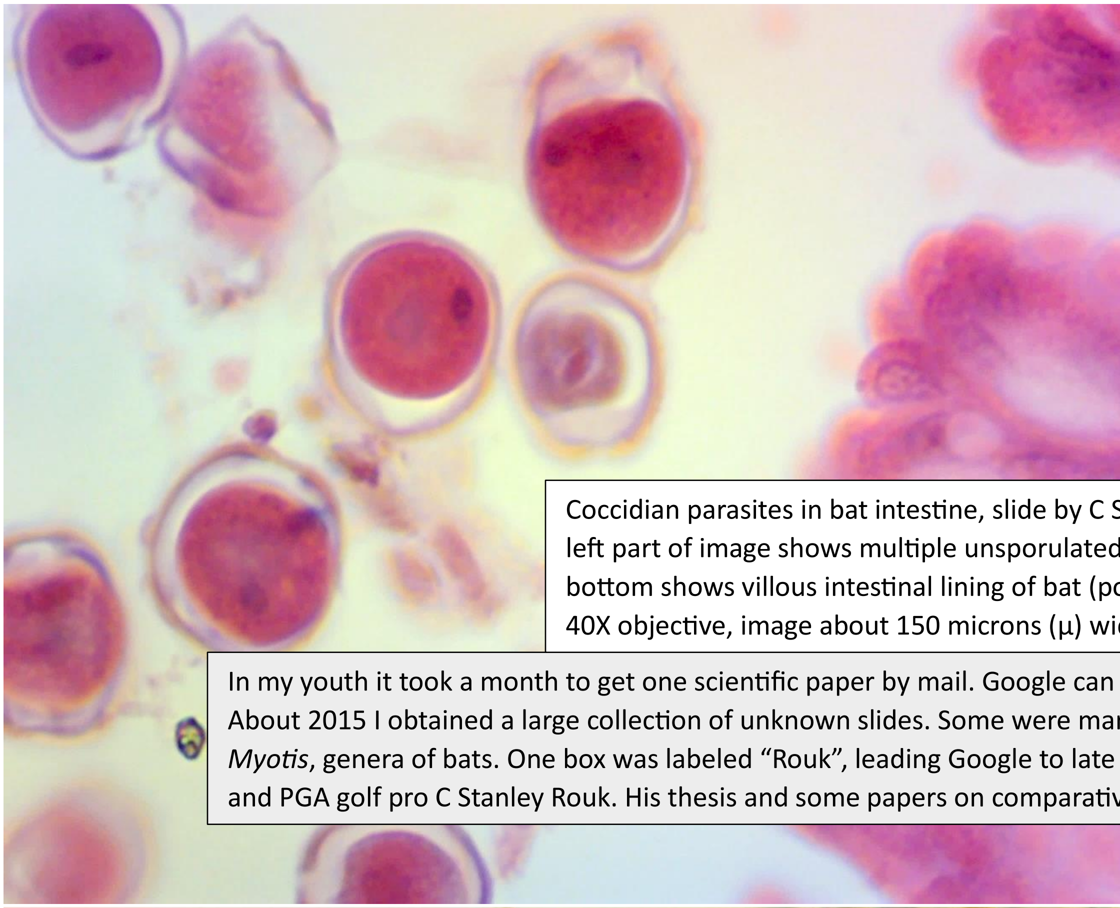
University of California researchers found animals in 15 phyla (about half of animal phyla) have independently evolved to become parasites at least 223 times, including a few jellyfish, rotifers, tardigrades, rare fish, and lots of helminths and arthropods (the latter are very good at speciation, constituting about 80% of all animal species). Most parasites infest nonhuman animals and many are marine, but I will focus especially on human parasites here.



Added stars designate animal phyla with parasitic species: some parasitic species

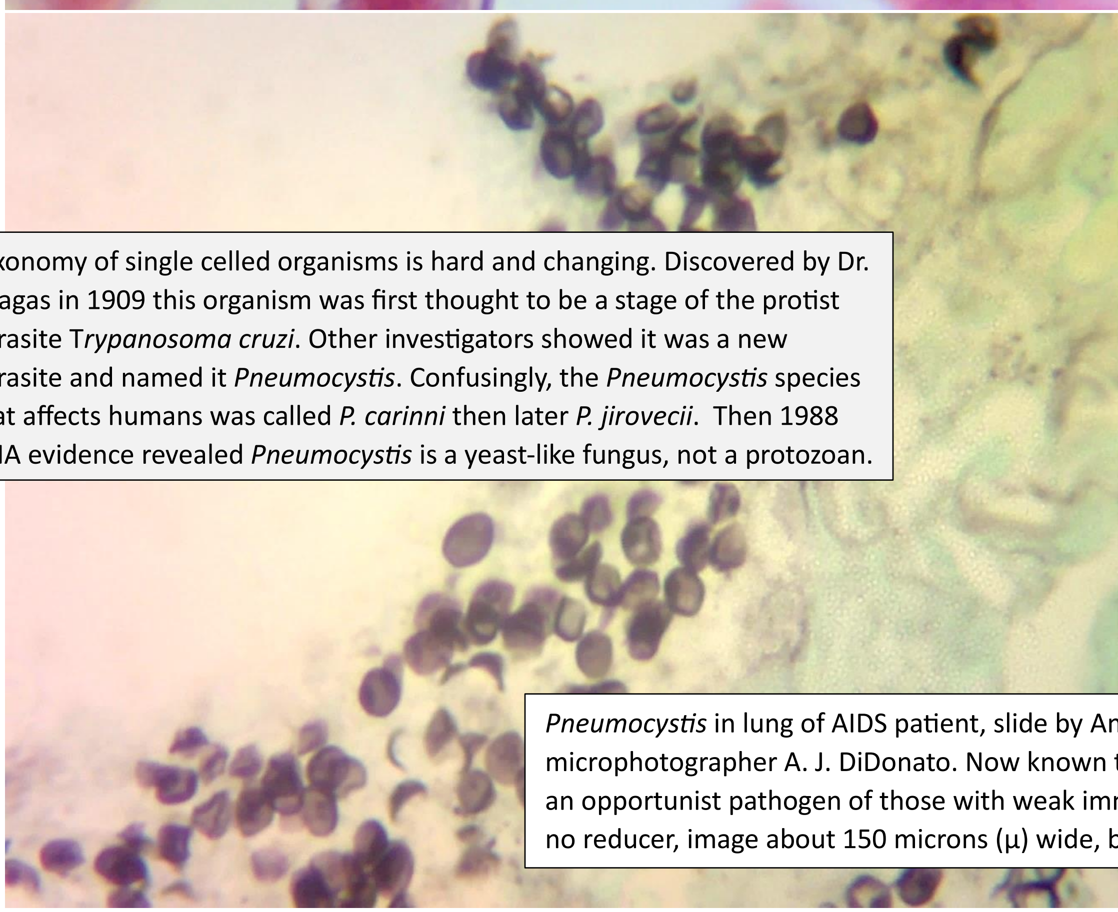
many parasitic species

Siddika Arshi, Towhidul, Towhidul, Rumman. Constructing a Fully Ranked phylogenetic Constraint Tree using Monophyletic Group, Crown Group and Relative Age Constraints. 2016 **Int J Sci Research**, at Research Gate



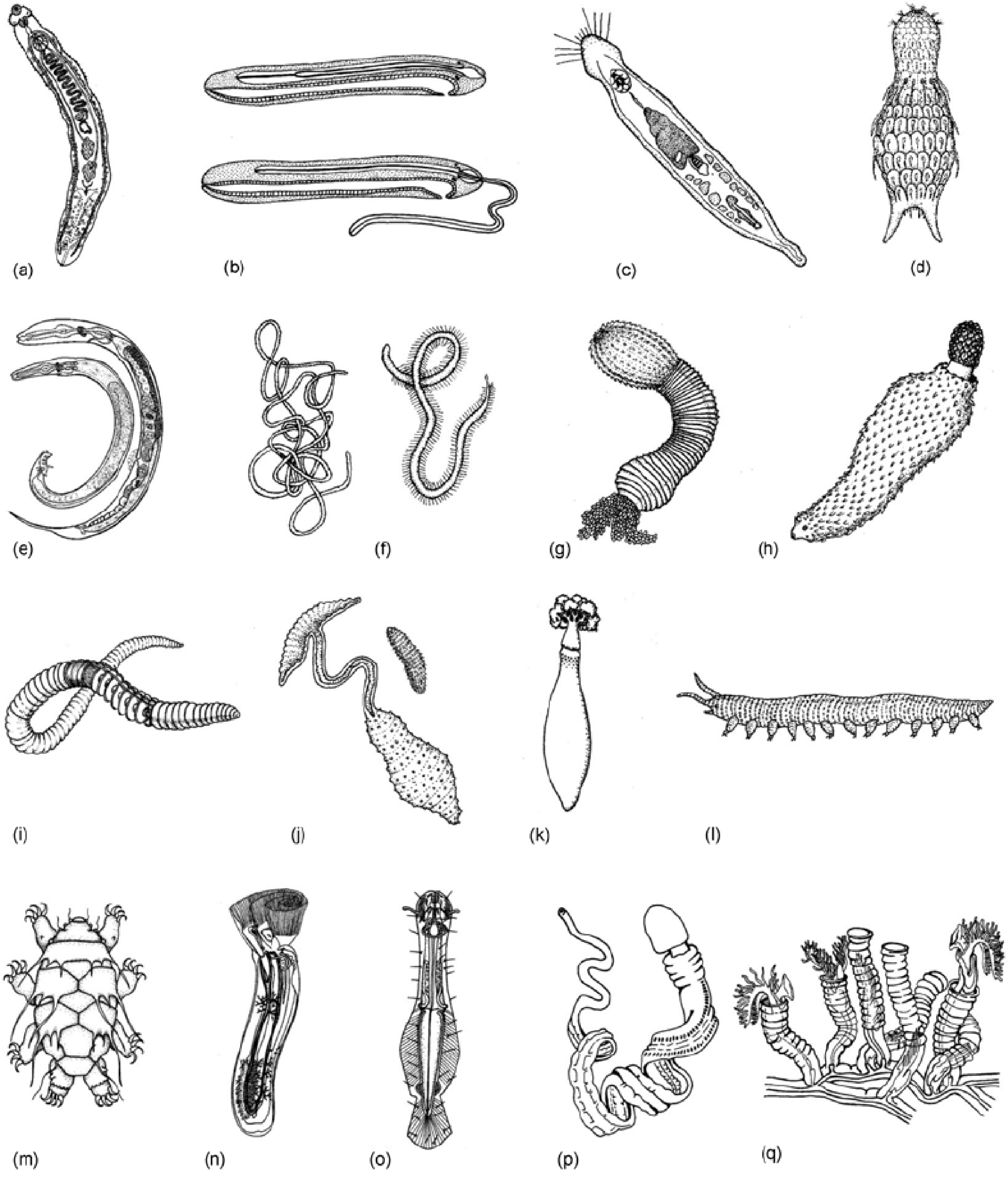
Coccidian parasites in bat intestine, slide by C Stanley Rouk, circa 1969
left part of image shows multiple unsporulated oocysts in gut lumen
bottom shows villous intestinal lining of bat (possibly *Antrozous* or *Myotis sp*)
40X objective, image about 150 microns (µ) wide, oocysts up to about 30 µ

In my youth it took a month to get one scientific paper by mail. Google can now find dozens per second. About 2015 I obtained a large collection of unknown slides. Some were marked *Antrozous, Desmodus* and *Myotis*, genera of bats. One box was labeled "Rouk", leading Google to late chiropterist, zoology professor and PGA golf pro C Stanley Rouk. His thesis and some papers on comparative bat GI anatomy are on-line.



Taxonomy of single celled organisms is hard and changing. Discovered by Dr. Chagas in 1909 this organism was first thought to be a stage of the protist parasite T*rypanosoma cruzi*. Other investigators showed it was a new parasite and named it *Pneumocystis*. Confusingly, the *Pneumocystis* species that affects humans was called *P. carinni* then later *P. jirovecii*. Then 1988 DNA evidence revealed *Pneumocystis* is a yeast-like fungus, not a protozoan.

Pneumocystis in lung of AIDS patient, slide by American slide maker and microphotographer A. J. DiDonato. Now known to be a fungus, *Pneumocystis* is an opportunist pathogen of those with weak immune systems. 40X objective, no reducer, image about 150 microns (µ) wide, black cysts 5-8 microns in diam.



Bag of worms: 16 phyla with mostly tubular bodies. (a) Platyhelminthes; (b) Nemertea; (c) Gnathostomulida; (d) Gastrotricha; (e) Nematoda; (f) Nematomorpha; (g) Priapulida; (h) Acanthocephala; (i) Annelida; (j) Echiura; (k) Sipuncula; (l) Onychophora; (m) Tardigrada; (n) Phoronida; (o) Chaetognatha; (p) and (q) Hemichordata: (p) acorn worm; (q) pterobranchia. From Ma, Hou, Baines, Phylogeny and evolutionary significance of vermiform animals from the Early Cambrian Chengjiang Lagerstätte. 2010 Science China Earth Science. 53. 1774-1783

References

Andrews KT Fisher G, Skinner-Adams T Drug repurposing and human parasitic protozoan diseases **Int J Parasitol Drugs Drug Resist** 2014 Aug; 4(2): 95–111.

Arrow KJ et al, Institute of Medicine (US) Committee on the Economics of Antimalarial Drugs; Saving Lives, Buying Time: Economics of Malaria Drugs in an Age of Resistance. Washington (DC): National Academies Press (US); 2004. 5, A Brief History of Malaria.

Ashour D, Othman A, Parasite-bacteria interrelationship **Parasitol Res** 2020 Oct;119(10):3145-3164.

Attias, Teixeira, Benchimol, et al. The life-cycle of Toxoplasma gondii reviewed using animations. **Parasites Vectors** 13, 588 (2020) (animations available on You tube)

Avise, Hubbell, Ayala, editors. **In the Light of Evolution**: Volume II: Biodiversity and Extinction. Washington (DC): National Academies Press (US); 2008. 4, Homage to Linnaeus: How Many Parasites? How Many Hosts

Barry-Jester AB How a Big Pharma Company Stalled a Potentially Lifesaving Vaccine in Pursuit of Bigger Profits **Propublica** online 2023 Oct 4

Bennett, Presswell, Poulin, Tracking life cycles of parasites across a broad taxonomic scale in a marine ecosystem, **International Journal for Parasitology** Vol 53, Iss 5–6, 2023, Pages 285-303

Briquet S, Marinach C, Silvie O, Vaquero C Preparing for Transmission: Gene Regulation in Plasmodium Sporozoites **Frontiers Cellular and Infection Microbiology** 2021, vol 10

Carlson, Dallas, Alexander, Phelan, Phillips. What would it take to describe the global diversity of parasites? **Proc. R. Soc. B.** 2020: 28720201841

Carrillo-Bustamante, Costa, Lampe, et al Evolutionary modelling indicates that mosquito metabolism shapes the life-history strategies of *Plasmodium* parasites. **Nature Commun** 2023 14, 8139

Carter R, Mendis KN. Evolutionary and historical aspects of the burden of malaria. **Clin Microbiol Rev.** 2002 Oct;15(4):564-94

CDC Centers for Disease Control, parasite homepage at cdc.gov/parasites/index.html; good source of information: search or use alphabetic list for details on specific parasites

Chakrabarti, Wood, et al, The case for preserving parasites, WBUR **On Point radio show**, 24 Aug 2023, wbur.org/onpoint/2023/08/24/week-of-wonder-the-case-for-preserving-parasites

Cox FEG, History of Human Parasitology **Clin Microbiol Rev.** 2002 Oct; 15(4): 595–612.

Dos Santos Pacheco et al Evolution, Composition, Assembly, and Function of the Conoid in Apicomplexa, 2020 August**Trends in Parisitology** vol 36, iss 8, p688-704

Flegr J, Prandota J, Sovičková M, Israili ZH. Toxoplasmosis--a global threat. Correlation of latent toxoplasmosis with specific disease burden in a set of 88 countries. 2014 Mar 24 **PLoS One**. 2014;9(3):e90203.

Garnham PCC Discovery of Malaria Parasites and of their life cycles **Hist. Phil. Life Sci**. 1988 (10) 93-108

GBD 2019 Diseases and Injuries Collaborators, Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. 2020 Oct 17 **Lancet** vol 396 iss 10258 p 1204-1222

Goddard, J, Bircham, L and Robbins RG. New tick (Acari: Ixodidae) records from a mink, Neovison vison (Schreber), in Mississippi, U.S.A. **Systematic and Applied Acarology** 2012 Aug 17 (3), 251-253

Król G, Tomaszewska A, Wróbel G, et al. Toxicity of parasites and their unconventional use in medicine. **Ann Agric Environ Med**. 2019;26(4):523-531

Hii et al Evidence for a specific host-endosymbiont relationship between 'Rickettsia sp. genotype RF2125' and Ctenocephalides felis orientis infesting dogs in India, 2015 March **Parasites & Vectors**

Hopkins et al, Environmental Persistence of the World's Most Burdensome Infectious and Parasitic Diseases, **Front Public Health** 2022 Jul 8;10:892366. doi: 10.3389/fpubh.2022.892366.

Hossain M, Kennedy KJ, Wilson HL, et al. Human Neural Larva Migrans Caused by *Ophidascaris robertsi* Ascarid. 2023 **Emerging Infectious Diseases**. 29(9):1900-1903.

Lawrence, Jasper sells helminths at autoimmunetherapies.com. A 2009 **ABC news** story "Allergy Desperation: I'll Take a Parasite, Please" alerted the FDA and Lawrence moved to UK

Leung FH, Watson W. The parasite that wasn't: a case of mistaken identity. **Can Fam Physician**. 2011;57(10):1145-1147.

Lu VM, Saad AG, Shah AH. Histologic Anatomy of Neurocysticercosis. **JAMA Neurol**. Published online October 23, 2023.

Milne, G, Webster, J, Waker M, Toxoplasma gondii: An Underestimated Threat? **Trends Parasitology** Dec 2020 Vol 36, Iss 12, 959-969

Mohyuddin, Laffon, Teixeira, et al, Toxoplasma gondii IgG Serointensity Is Positively Associated With Frailty, 2023 **Journals of Gerontology**: Series A

Mushegian AR. Are There 1031 Virus Particles on Earth, or More, or Fewer? **J Bacteriol.** 2020 Apr 9;202(9)

National Research Council (US); Avise, Hubbell, Ayala editors. **In the Light of Evolution: Volume II**: Biodiversity and Extinction. (Wash DC): National Academies Press (US); 2008. 4, Homage to Linnaeus: How Many Parasites? How Many Hosts? At ncbi.nlm.nih.gov/books/NBK214895/

Noushin Emami et al. A key malaria metabolite modulates vector blood seeking, feeding, and susceptibility to infection. **Science** 2017 355,1076-1080

Parise, Hotez, Slutsker, Neglected Parasitic Infections in the United States: Needs and Opportunities **Am.J.Trop.Med.Hyg.,**90(5),2014,pp.783–785 doi:10.4269/ajtmh.13-0727

Perkins, S, Leung, T "Parasite of the Day" at dailyparasite.blogspot

Preston, D. & Johnson, P. (2010) Ecological Consequences of Parasitism. **Nature Education Knowledge** 3(10):47

Pullan, R, Smith, J, Jasrasaria, R et al. Global numbers of infection and disease burden of soil transmitted helminth infections in 2010. **Parasites Vectors** 7, 37 (2014)

Racaniello, V, Despommier, D, Griffin, D "This Week in Parasitism" podcast at microbe.tv

Reed, Light, Allen, Kirchman. Pair of lice lost or parasites regained: The evolutionary history of Anthropoid primate lice. **BMC biology** 2007, 5. 7. 10.1186

Ritchie, S, No, having a cat doesn't increase your risk of developing schizophrenia, I News, 7 Dec 2023 at inews.co.uk

Sender, Fuchs, Milo, Revised Estimates for the Number of Human and Bacteria Cells in the Body. **PLoS Biol** 2016 Aug 19;14(8)

Shinoda, Kenta, et al, Nematode ascarosides attenuate mammalian type 2 inflammatory responses. **Proceedings of the National Academy of Sciences** 119.9 (2022): e2108686119.

Sircar et al Raccoon Roundworm Infection Associated with Central Nervous System Disease and Ocular Disease — Six States, 2013–2015. **MMWR**. Morbidity and Mortality Weekly Report. 65 (35): 930–933. doi:10.15585/mmwr.mm6535a2. PMID 27608169.

Tong, Pavey, O'Handley et al. Behavioral biology of Toxoplasma gondii infection. **Parasites Vectors** 14, 77 (2021)

Weinstein SB, Kuris AM, Independent origins of parasitism in Animalia. **Biol Lett.** 2016 Jul;12(7):20160324. doi: 10.1098/rsbl.2016.0324. PMID: 27436119; PMCID: PMC4971171.

Windsor DA, Most of the species on Earth are parasites. **Int J Parasitol.** 1998 Dec;28(12):1939-41. doi: 10.1016/s0020-7519(98)00153-2. PMID: 9925276.

Wood, Welicky, Preisser, A reconstruction of parasite burden reveals one century of climate-associated parasite decline. **PNAS** Jan 9, 2023 120 (3).

World Health Organization, Soil-transmitted helminth infections, **WHO**, 18 January 2023 at who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections

Xu, J, et al, Disseminated cerebral toxoplasmosis in a patient with chronic lymphocytic leukemia **Journal of Clinical Neuroscience** 2018, Vol 50, 127-128

Micscape always has lots of good information for amateur microscopists wanting to learn more about how to do it yourself.

For 2024 I offer *Micscape's* readers a series of articles about parasites.

I am incurably curious about parasites and keep thinking I should know more. The internet makes it easy to learn more, so my articles are always longer than I intended at first.

Just look at the interesting pictures if you want. I do recommend the discussion starting on page 25 of how relatively tiny amounts of Western spending have helped lower the burdens of tropical diseases in people who can't afford their own public health measures. I am an optimistic person and very grateful to be living in an economically developed nation, as I discuss in "Parasite Privilege" on page 31.

Some people are real experts and know much more than I do on these subjects. I would be pleased to have any mistakes or misunderstandings corrected.

I am Ed Ward in the state of Minnesota, USA.
Your comments are always welcomed, my email is eward1897 AT gmail DOT com

Published in the January 2024 edition of Micscape Magazine www.micscape.com