Parasites

part 6, Trematode Tricks

Giant Human Intestinal Fluke

Fasciolopsis buski

Ed Ward MD, Minnesota USA

June 2024

Origins of this article

Since childhood I am fascinated by strange organisms. In my training I gave talks about spotted fevers and the ticks that spread them. I volunteered in West Africa in 2004, treating parasites and other neglected tropical diseases. About a decade ago I started using old microscopes as a hobby, and now I contribute to *Micscape* magazine.

My curiosity makes for long articles divided into parts. Trematode (fluke) biology is discussed now, and eventually I'll relate my own and other true stories about patients with parasites. I have some vintage slides of parasites, allowing me to illustrate a few kinds. I focus on human parasites, but many of my images show parasites of animals

Disclaimers

I am a doctor of 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.

Be skeptical and investigate for yourself if something seems unlikely. You can learn or be fooled on the internet. Science is never finished; it advances by changing models when new evidence accumulates.

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 may 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 worthless $200 parasite cleanse. Serious human parasites are now rare in wealthy nations. Soap, flush toilets, shoes, clean water and cooked food are your best bets against parasites.

Disclaimer to the disclaimer

Immigrants or travelers returning from the tropics and patients on certain medications really could have life threatening parasites, which most US doctors now know little about. Remind the doctor about travel or immunocompromise to lessen the chance of becoming a medical error in these special cases.

Cover page illustration

Fasciolopsis buski is acquired in south Asia by eating aquatic plants containing tiny worm cysts. The adult fluke lives in the human small intestine. This 3.4 x 1.9 cm specimen is about half of maximum size.

Vintage Ward's slide, stained. Photograph with digital camera on a fluorescent small closet light, with milk jug plastic as diffuser, color adjusted.

Other illustrations

If not noted otherwise, photomicrographs are mine, taken with AO/Reichert microscopes with 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 images adjusted for brightness and contrast. Some patient photos of mine from West Africa are also included.

Contents

Parasites

(overall introduction)

Life spreads to every nook and cranny where it can survive, including inside and outside the bodies of animals. The bodies of animals turned out to be comfy and tasty. Evolution produces and adapts many endoparasites (like intestinal worms) and ectoparasites (like lice). Most wild animals have parasites, as did most humans in the past. Most individuals are not harmed, but hosts are sometimes injured by heavy infestation or complications. In poor and tropical areas many people are still harmed and even killed, including about 600,000 annual deaths from malaria. Some ectoparasites also act as vectors to spread bacteria and viruses that cause Lyme disease, encephalitis, plague and other illness. Nearly 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 (helminths), and ectoparasites.

Parasites are most harmful today in 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 may be the majority of animal species in the wild, and the balance of nature might be hurt if we continue to extinct parasite species faster than we can discover them.

Proteocephalus tapeworm head *ex* largemouth bass gut, slide van Cleave, 10X obj., image ~ 1 mm wide

Caligus sp fish louse, ectoparasitic copepod, stitch 4X objective, louse about 7mm long

Part 6 outline

Many different groups of animals have long cylindrical body shapes, and we call them **worms**. Worms that are parasites are called **helminths**. Most helminths are flatworms (tapeworms and flukes) or roundworms. Flatworms occupy an early and important place among animals, and some quickly adopted parasitism. Today I discuss the biology of **trematode flukes** and schistosomes and four especially amazing parasitic adaptations of trematodes.

Taxonomy schemes for Phylum Platyhelminthes

Traditional classification (based on anatomy and lifestyle)

- Class Turbellaria (free living flatworms) — about 6000 species, < 20% of all flatworm species

parasitic

- Class Cestoda (tapeworms) ~5k species
- Class Trematoda (flukes & schistosomes) ~20k species
- Class Monogenea (fish ectoparasites) ~5k species

about 30,000 species, > 80% of all flatworms

Newer phylogenetic classification (based on relatedness; genomic)

- Class Catenulida (only about 100 species, small free living)
- Subphylum Rhabditophora
    - Classes Turbellaria, Monogenea, Cestoda, Trematoda, others
    - “dangling” orders include Rhabdocoela, Polycladida, Tricladida (planaria), many others

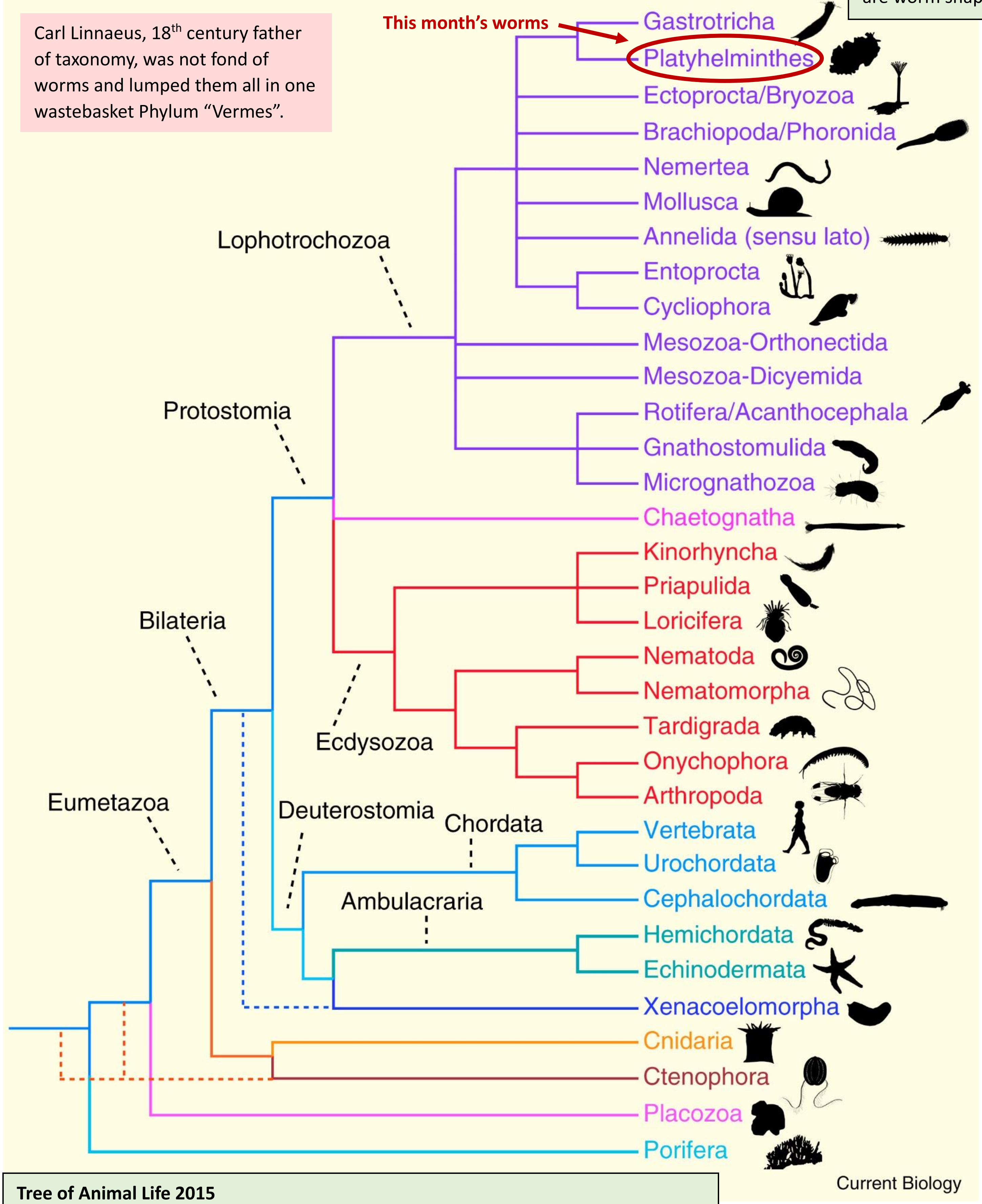
Not discussed yet are other worm parasites: Nematoda, Acanthocephala, etc.

***** if my vocabulary puzzles you too, see a refresher in basic biology concepts and terms here

Worms on a tree of animal life

Note how many animal outlines are worm shaped

Carl Linnaeus, 18th century father of taxonomy, was not fond of worms and lumped them all in one wastebasket Phylum "Vermes".

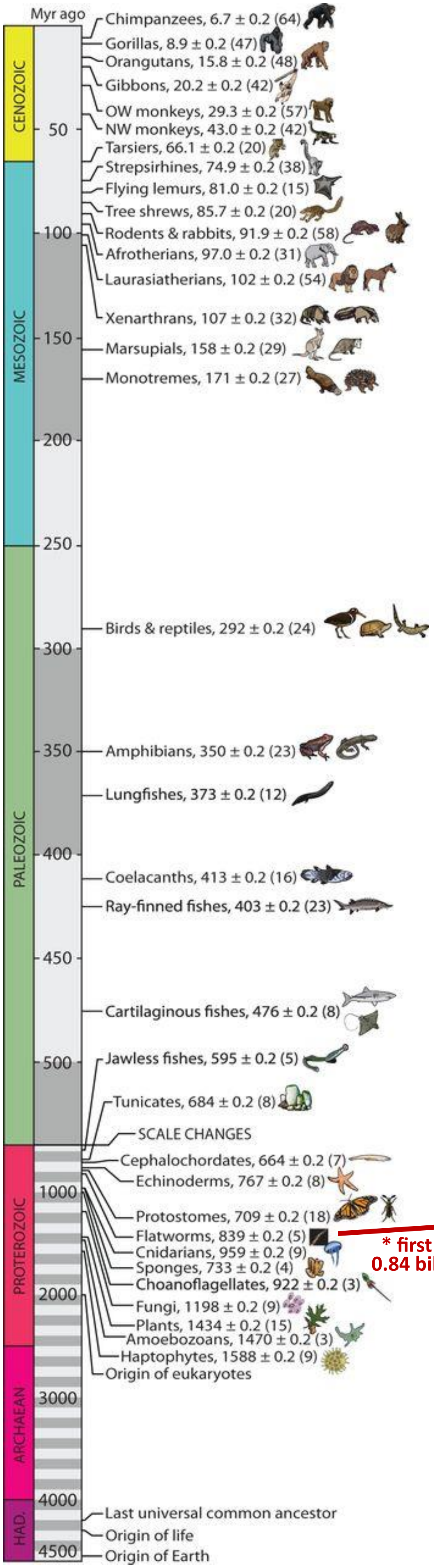


This month's worms

Current Biology

Tree of Animal Life 2015
Best estimate of the phylogenetic relationships of major animal phyla. Major clades are named. Alternative possible positions are indicated by dashed lines. Telford, Budd, Philippe, Phylogenomic Insights into Animal Evolution **Current Biology** 2015

Flatworms on a timeline of life*



*

*** first flatworms**
0.84 billion years ago

Times of diversification of select groups, by genomic clocks

Hedges et al Tree of Life Reveals Clock-Like Speciation and Diversification 2015 **Molecular Biology Evolution**

The 3 major kinds of flatworm are tapeworms, flukes and free living. Tapeworm and fluke vintage slides: *Dipylidium caninum*, 2 pored dog tapeworm slide by JD Mizelle, helminthologist U of Illinois 1930s. Ward's slide of *Fasciolopsis buski*, the "giant human intestinal fluke", this one is about 3.5 cm long.

Tapeworms and flukes have free living cousins, such as this friendly little *Dugesia sp* (or related) planaria, Order Tricladida.
from stream, Red Wing, Minnesota USA,
4X objective, dark field, head ~1.5 mm wide

Worms

You know what a worm is; it's a wriggly tube shaped animal. Being slender and legless is useful for moving through granular substates like dirt. Father of taxonomy Carl Linnaeus lumped all worms together as "Vermes" as they have a similar shape, but we now divide worms among 30 different animal phyla based on body plan and heredity. The biggest 3 phyla of worms are Platyhelminthes, Nematoda and Annelida: flatworms, roundworms and segmented worms.

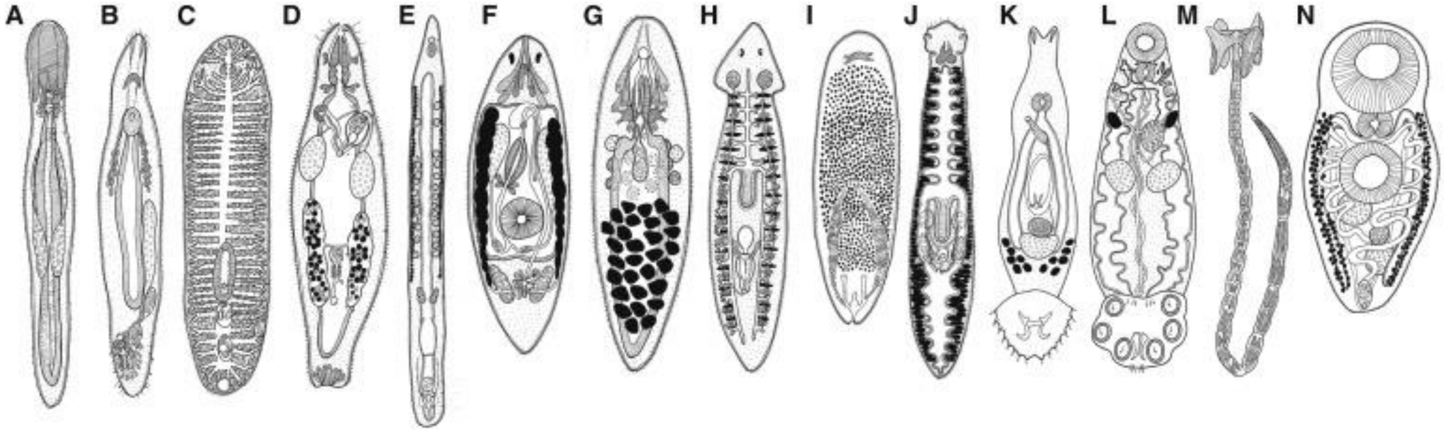
The most classic of all parasites are intestinal worms. Unlike protozoan parasites, these are multicellular animals and the adults are often large enough to be seen without a microscope.

Flatworms get their own phylum, Platyhelminthes. In the evolution of animals, flatworms were the first "regular animals". Unlike shapeless sponges and radially symmetric corals, flatworms have bilateral symmetry (a right and left) and are mobile. Many glide on cilia and some have a pair of simple eyes. You may recall planaria, 1-2 cm long freshwater flatworms that grow back into 2 worms when cut in half. Flatworms have just two "germ layers" during embryologic development and a simple body plan without a true body cavity. Being flat has the advantage of every cell being not too far from the animal's surface, allowing gas exchange (oxygen and carbon dioxide) without needing circulatory or respiratory organs. Flatworms have a simple digestive system with a mouth only (it doubles as anus) often coupled with a very muscular pharynx, and a branched gut to deliver nutrients. The first predators were flatworms, and flatworms were also the first animal group to have lots of members adopt a parasitic lifestyle.

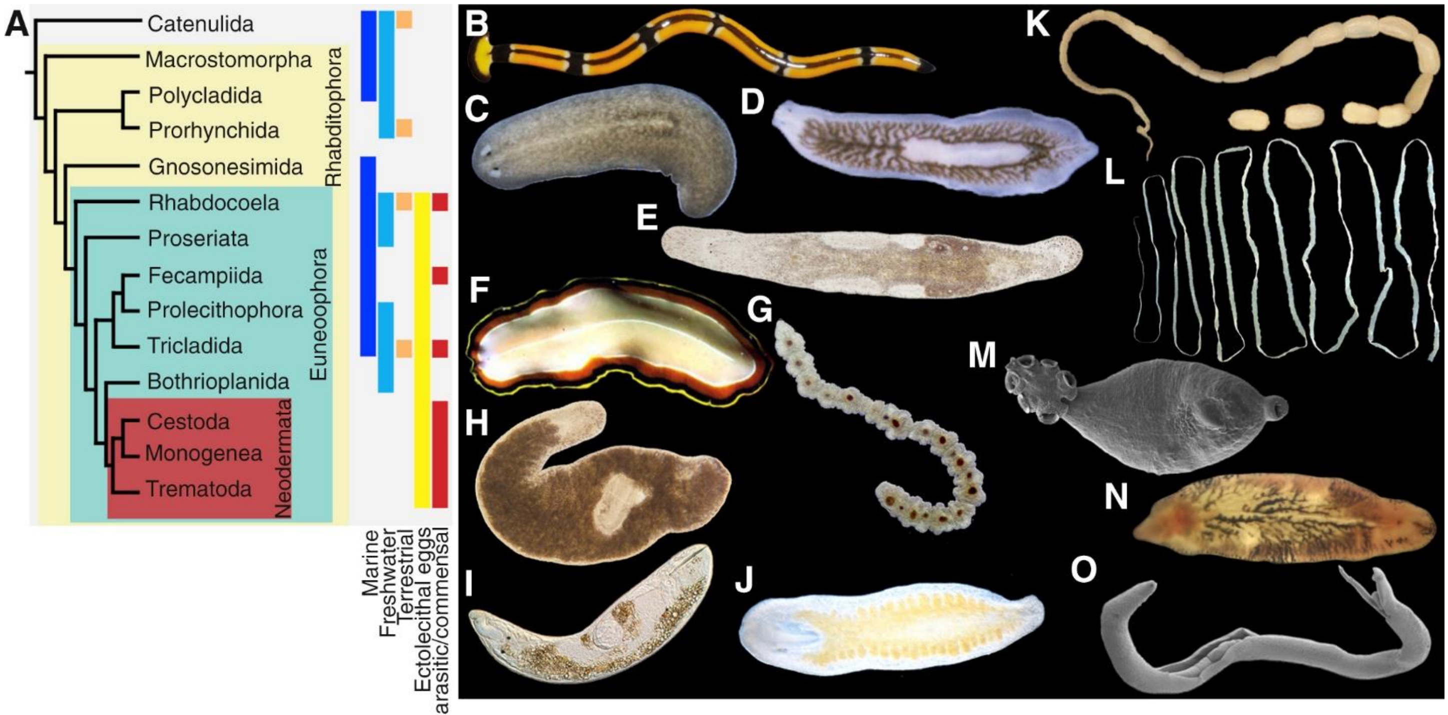
Parasitic worms are also called **helminths**. The most common worms of humans are soil transmitted helminths, and the big three worldwide are all **nematodes**: roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*) and hookworm (*Necator americanus* and *Ancylostoma duodenale*). As many as 2 billion humans may still be infected with soil borne helminths, although most infected individuals don't feel ill. Flatworms are the other big group of parasitic worms, and **most flatworm species are parasites**.

Platyhelminthes is the oldest phyla of worms. Flatworms may have split from other animals about 839 million years ago (per genomic clocks), so they have had more time to evolve than almost all other animals. What did they do with all that time? Some are free living and some developed poisons, but most flatworms became expert parasites. Platyhelminthes is the "most parasitic" of the major phyla of animals. Some are hunters or scavengers, but more than 80% of over 30,000 described species are parasites. Tapeworms are flatworms, and occur around the developing world. In some parts of Africa and southeast Asia the biggest parasite health burden is caused by parasitic blood, liver and bladder flukes. These and other trematodes have come up with amazing life cycle "tricks" during long coevolution with their hosts.

Flatworm Diversity



Selected flatworms (A) Catenulida, (B) Macrostomorpha, (C) Polycladida, (D) Gnosonemisida (Lecithoepitheliata), (E) Proseriata, (F) Rhabdocoela, (G) Prolecithophora, (H) Tricladida, (I) Fecampiida, (J) Bothrioplanida, (K) Monopisthocotylea (Monogenea), (L) Polyopisthocotylea (Monogenea), (M) Cestoda, (N) Trematoda; not to scale, images from J Caira in Littlewood, Waeschenbach, Evolution: A Turn Up for the Worms **Current Biology** 2015



Current Biology

(A) left, modern family tree of the Platyhelminthes. Orders are shown except in Neodermata, for which Classes shown. (B) Land planarian, Tricladida *Bipalium sp*. (C) Freshwater planarian, Tricladida *Schimidtea mediterranea*. (D) Freshwater planarian, Tricladida *Procotyla fluviatilis* (E) Macrostomorpha *Macrostomum ligano* (F) Polycladida *Pseudoceros bimarginatus* (G) Catenulida *Catenula lemnae* (H) Bothrioplanida *Bothrioplana semperi* (I) Rhabdocoela *Gyratrix hermaphroditus* (J) Prorhynchida *Geocentrophora applanata* (K) Dog tapeworm, Cestoda *Dipylidium caninum* (L) Beef tapeworm, Cestoda *Taenia saginata* (M) Monogenea *Protopolystoma xenopodis* (N) Trematoda *Fasciola hepatica* (O) Trematoda *Schistosoma mansoni.* in Collins, J Platyhelminthes **Current Biology** 2017

Free living flatworms Gone Wild

Planaria are friendly freshwater scavengers and biology teacher favorites. A few planaria became terrestrial, and some of those are worldwide invasive species. Many have toxins (they might kill your dog if it ate them), and they hunt native earthworms and land snails.

? *Dugesia sp* planarian, Red Wing, MN 2008, 2.5X obj. worm about 1 cm long

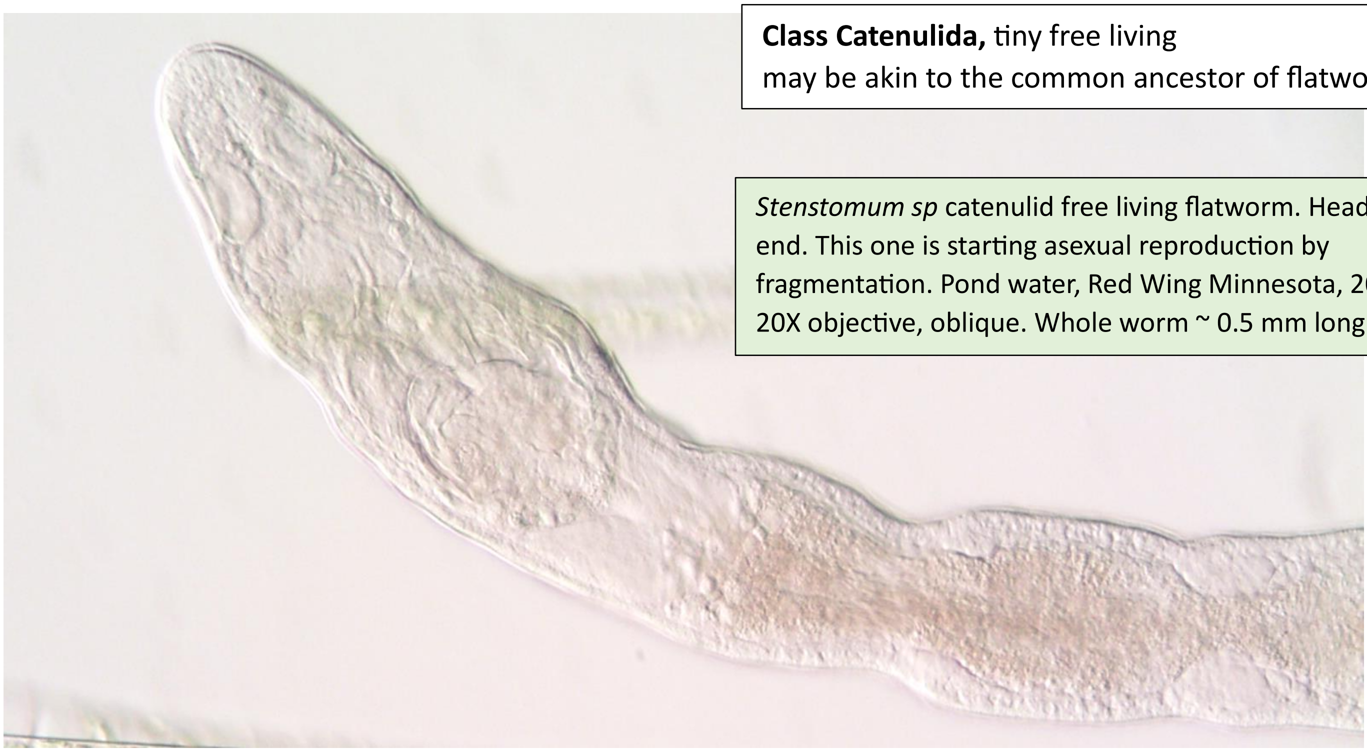
Bipalium kewense invasive land planarian, aka toxic hammerhead worm, can reach 30 cm (1 ft) long, photo B Everson

Polycladid marine worm photo wildsingapore.com

“Penis fencing” flatworms photo reed.edu/A Megana

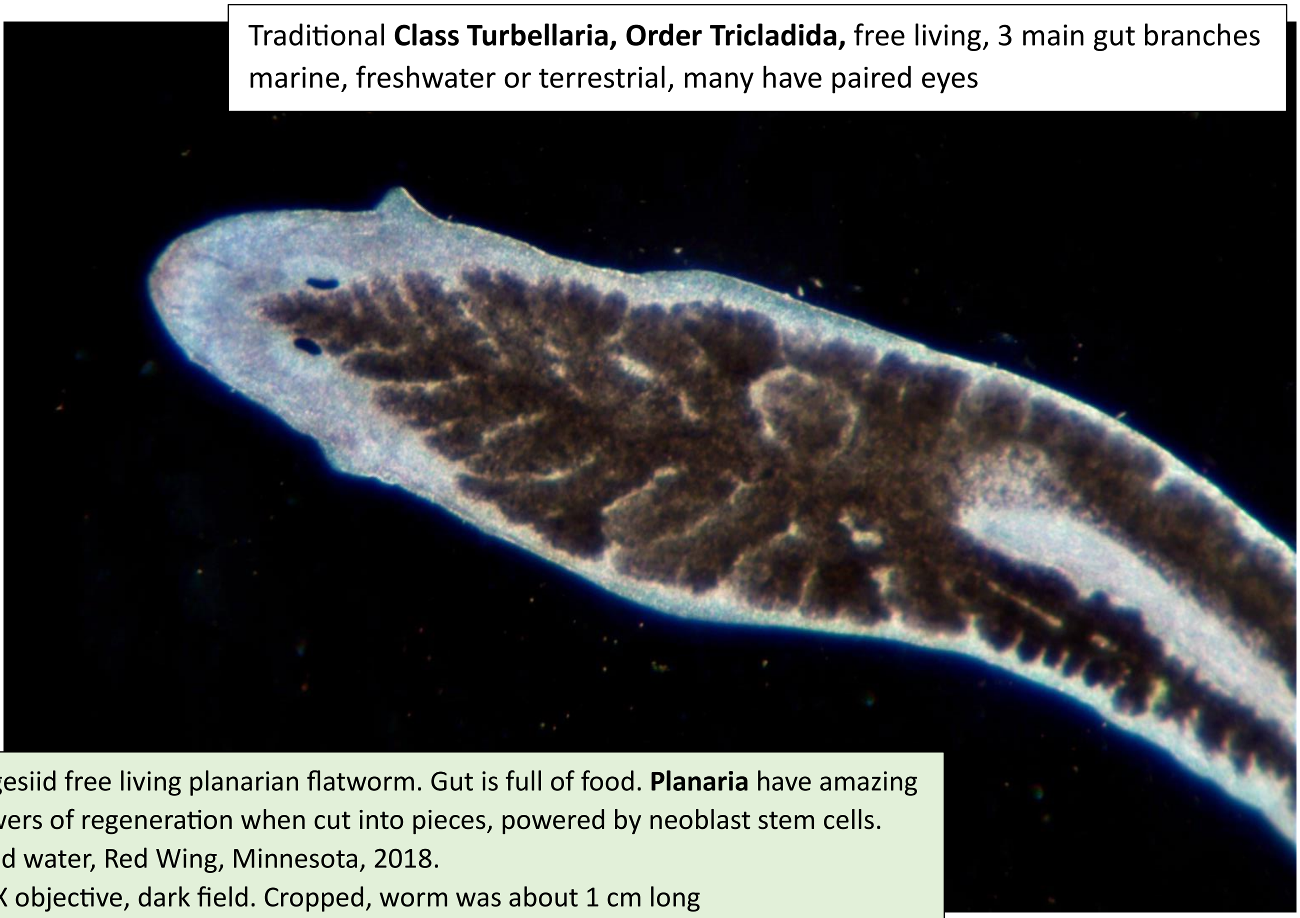
Marine flatworms can be so beautiful as to defy imagination. Many are poisonous and evolved bright colors as a warning to potential predators. Most are hermaphrodites and the 2 bold worms lower right are penis fencing (they are fighting to puncture and inject sperm into each another; be glad human mating is usually less violent).

Examples of major Platyhelminth (flatworm) groups



Class Catenulida, tiny free living
may be akin to the common ancestor of flatworms

Stenstomum sp catenulid free living flatworm. Head end. This one is starting asexual reproduction by fragmentation. Pond water, Red Wing Minnesota, 2018. 20X objective, oblique. Whole worm ~ 0.5 mm long



Traditional **Class Turbellaria, Order Tricladida,** free living, 3 main gut branches
marine, freshwater or terrestrial, many have paired eyes

Dugesiid free living planarian flatworm. Gut is full of food. **Planaria** have amazing powers of regeneration when cut into pieces, powered by neoblast stem cells.
Pond water, Red Wing, Minnesota, 2018.
2.5X objective, dark field. Cropped, worm was about 1 cm long

Taxonomy (traditional scheme, our understanding of flatworm phylogeny is "evolving")

Kingdom Animalia, Phylum Platyhelminthes

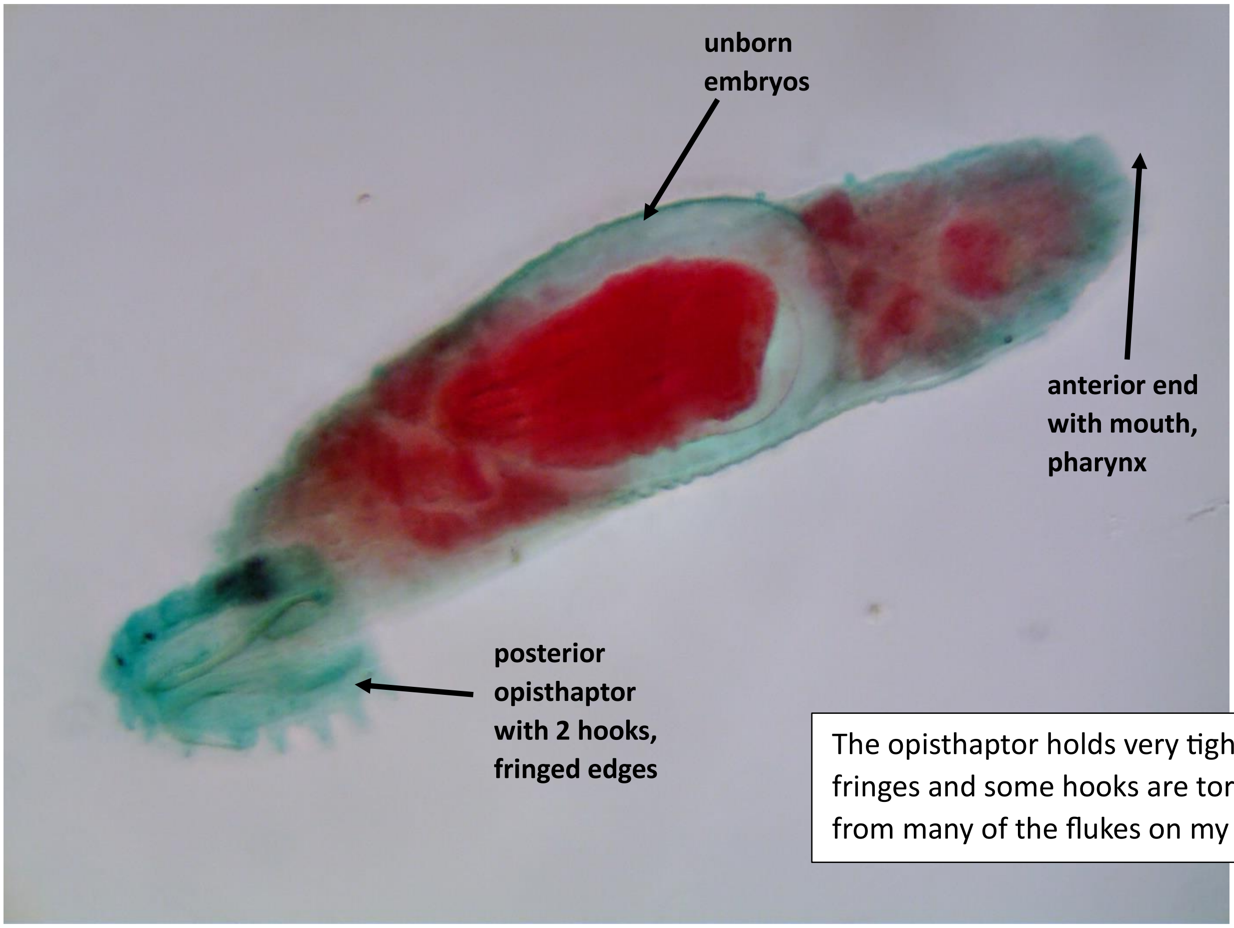
Class Turbellaria (free living flatworms) about 6000 species, < 20% of all flatworm species

parasitic
- Class Monogenea (fish ectoparasites) ~5k species
- Class Cestoda (tapeworms) ~5k species
- Class Trematoda (flukes & schistosomes) ~20k species

about 30,000 species, > 80% of all flatworms

See also proposed flatworm phylogenetic tress on previous and following pages.

Class Monogenea, tiny ectoparasites on skin or gills of a single fish host (none infest humans), most have large posterior hooks and/or suckers for holding on

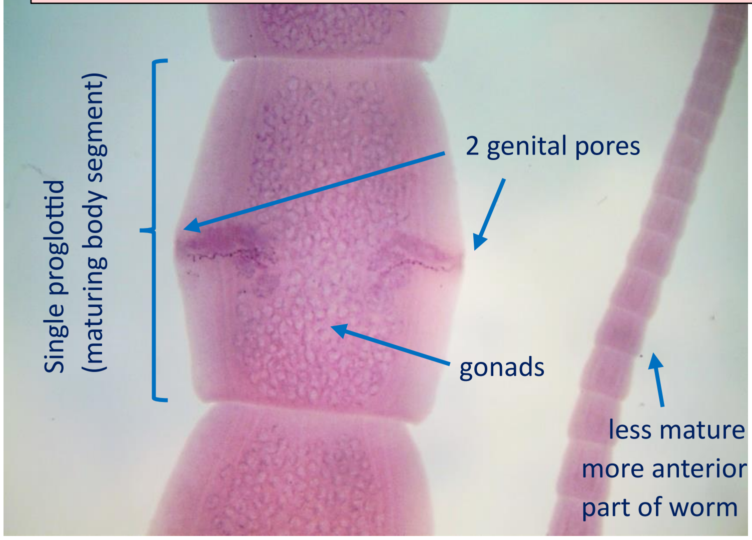


The opisthaptor holds very tight. The fringes and some hooks are torn away from many of the flukes on my slides

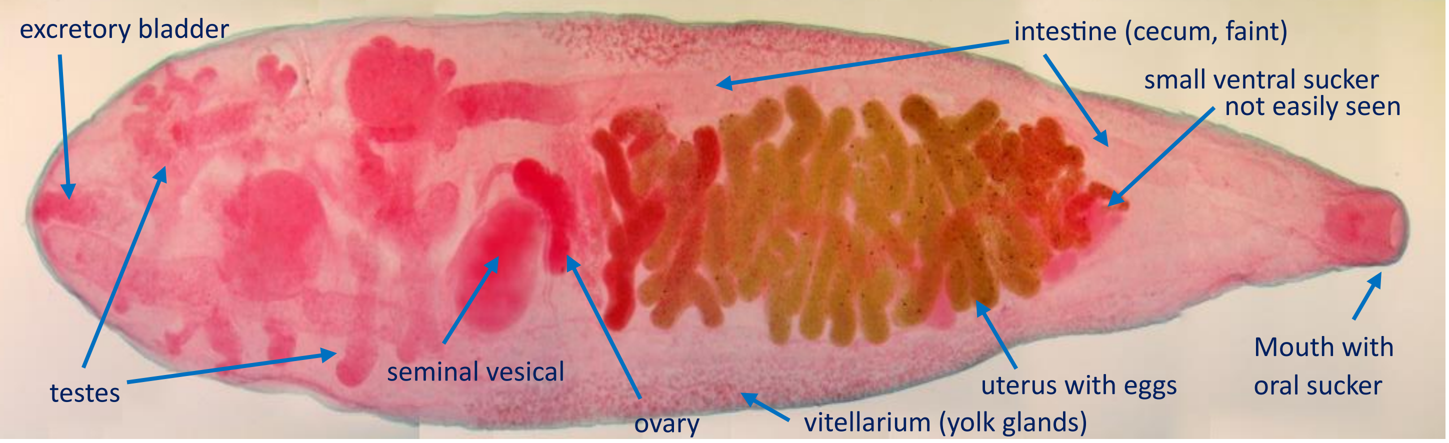
Gyrodactylus elegans monogenean gill fluke of carp and related fish. The large posterior opisthaptor has 2 hooks and a sawtooth fringe that holds the worm in place. Stained specimen. Slide by now defunct Ann Arbor Biology Supply. 20X objective, bright field lighting. Fluke about 0.5 mm long.

Class Cestoda, intestinal parasites, head modified for attachment, body segmented, i.e**. tapeworms**

Dipyllidium caninum aka the two pored dog tapeworm, has a life cycle in fleas and dogs, but human children sometimes eat infected fleas. Adults live in the intestine and pass wriggling "cucumber seed" proglottids in feces. At left: scolex with hooks and 4 suckers, 20X objective, phase contrast, scolex ~0.3 mm wide. Below: two portions of body, 4X objective, larger about 2 mm wide



Class Trematoda, internal parasites with complex life cycles that may involve blood, gut or lungs, i.e. **flukes**
Trematodes are the most numerous of flatworm species and have coevolved very complex life cycles.



Clonorchis sinensis aka the Chinese liver fluke, from vintage Ward's slide, stained. Fluke about 12 mm long, image was stitched using 4X objective

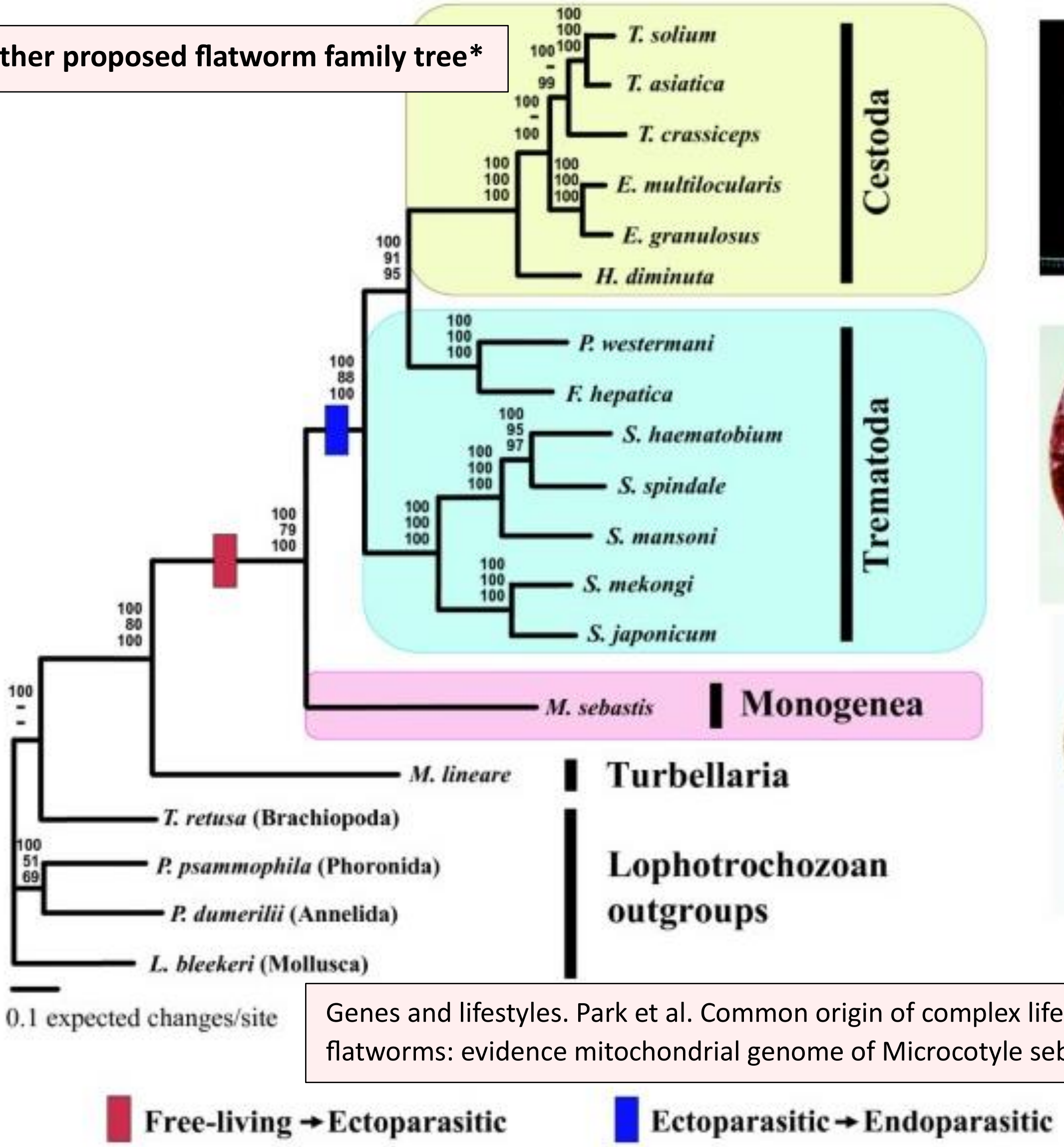
Flukes

Trematodes are also called flukes, as the adults have a flat elliptical shape, like a flounder fish or a leaf. The other parasitic flatworm group, tapeworms, are called “perfect parasites” because of their striking adaptions to living in vertebrate guts. They gave up their own mouth and gut, becoming almost entirely a long string of growing gonads cranking out millions of eggs a day. Trematodes don’t look quite so odd and still have a mouth, but they have just as complex life cycles, if not more so. Not content to live in just intestines, many species live in the blood or true internal organs (if you think topologically, your gut is sort of a channel of the outside world piercing you from mouth to anus a bit like the hole through a donut) and often reek more havoc in the host than well behaved tapeworms. Some blood trematodes, the schistosomes, are second only to malaria in the number of parasitic deaths they cause, mostly in the tropics. Trematodes are highly evolved and adapted to parasitic lives, with their various life stages becoming adept in host anatomy, travelling through bodies guided by smells.

Over 20,000 species of digenean trematodes are known; the biggest class in Platyhelminthes. All are heteroxenous, having complex life cycles with larval stages in at least 1 mollusk intermediate host and adults living in vertebrate definitive hosts. Typical life stages are eggs, then miracidia, sporocysts, rediae, cercariae, metacercaria and adults. The biggest fluke is *Fasciolopsis buski* the “giant intestinal fluke” which can reach 8 cm (3 inches) long. The smallest adult flukes are about 0.5 mm long. Flukes have 2 suckers, an anterior oral (mouth) sucker and a ventral sucker (a few have a third genital sucker). Flukes are hermaphrodites, each individual having both male (testes) and female (ovaries) gonads. (Schistosomes are outliers, differing from other trematodes in having a round cross section and separate male and female sexes). Like tapeworms, the bulk of trematode bodies often becomes egg factories. (Parasitic worms are considered r-selected given they can produce up to millions of eggs per day, but some have decades long adult lifespans).

Having co-evolved with their hosts for hundreds of millions of years, trematodes have learned some amazing tricks. Schistosomes swim through your blood from organ to organ to meet a mate. Host behavior modification has now been seen in many nematode and arthropod parasites and the protist parasite *Toxoplasma* might affect human behavior (discussed in my Jan 2024 posting). But perhaps the most classic old cases of parasite manipulation of host behavior are seen in the trematodes *Dicrocoelium* and *Leucochloridium* manipulating intermediate hosts to promote their being eaten by the definitive host. Some humble trematode parasites have also evolved social behavior, producing a 2 caste system of queens and soldiers reminiscent of ant colonies. And some trematodes can give a host an extra leg!

Another proposed flatworm family tree*



Genes and lifestyles. Park et al. Common origin of complex life cycles in parasitic flatworms: evidence mitochondrial genome of Microcotyle sebastis **BMC Evol Biol** 2007

A rose by any other name gets confusing

Scientific names are more specific than common names. The mountain lion is also called a cougar, puma or Florida panther depending on where you live, but is *Puma concolor* to biologists all over the world.

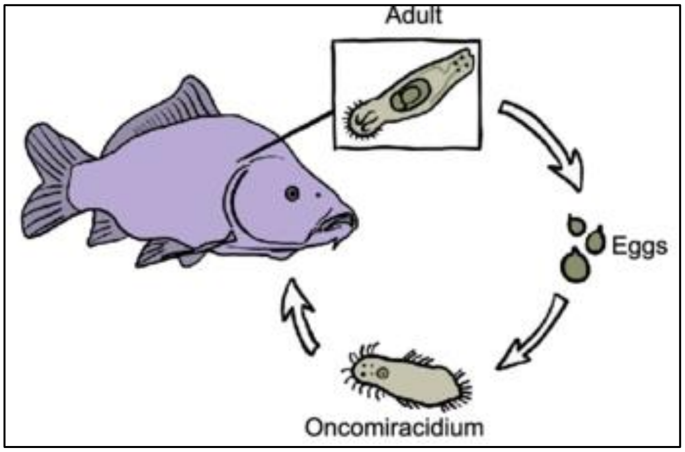
But biologists have their own confusing common language versions of proper biological names.
Class Trematoda are digenean* (aka digenetic) parasitic flukes (not including monogenean flukes). But trematodes (not capitalized)** is sometimes used informally for all fluke shaped flatworms. Monogeneans are fluke shaped but distinct from Trematoda and closer to Cestoda*** by recent phylogenetic study.

*Digenean or digenetic refers to having a life cycle requiring at least two host species, also called heteroxenous or indirect parasitism. Monogeneans complete their life cycle in one host, aka monoxenous or direct parasitism.

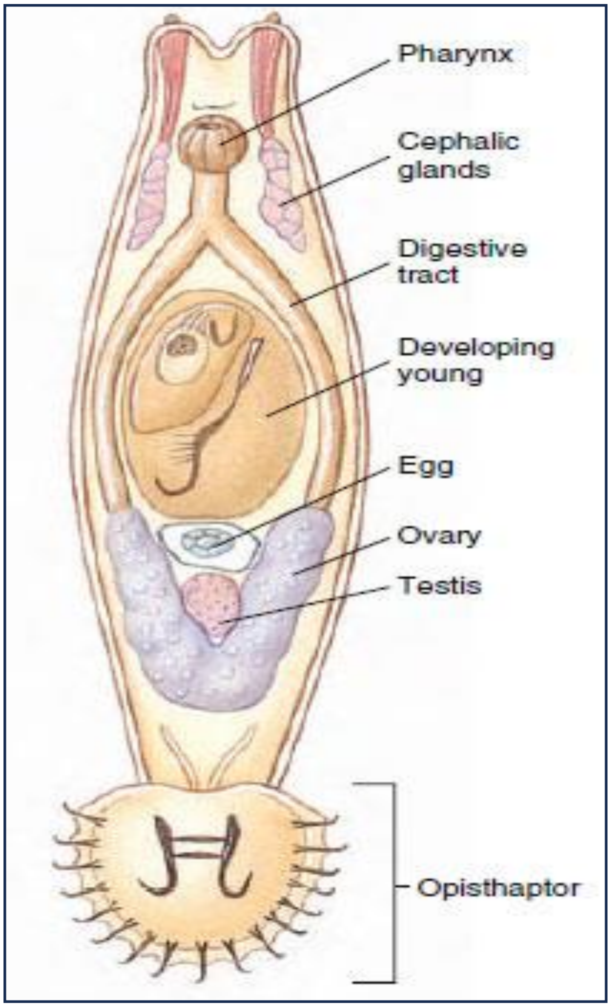
** *Senso lato* means in the broad sense, a made up Latin phrase to describe other made up terms. Biologists make up more Latin and Greek than a medieval priest or even Harry Potter at Hogwarts. Hence my need for glossaries.

***Trematoda comes from Greek for “perforated” (alluding to the suckers looking like holes in the worm) and Cestoda comes from Greek for “girdle” or belt (alluding to tapeworms’ shapes).

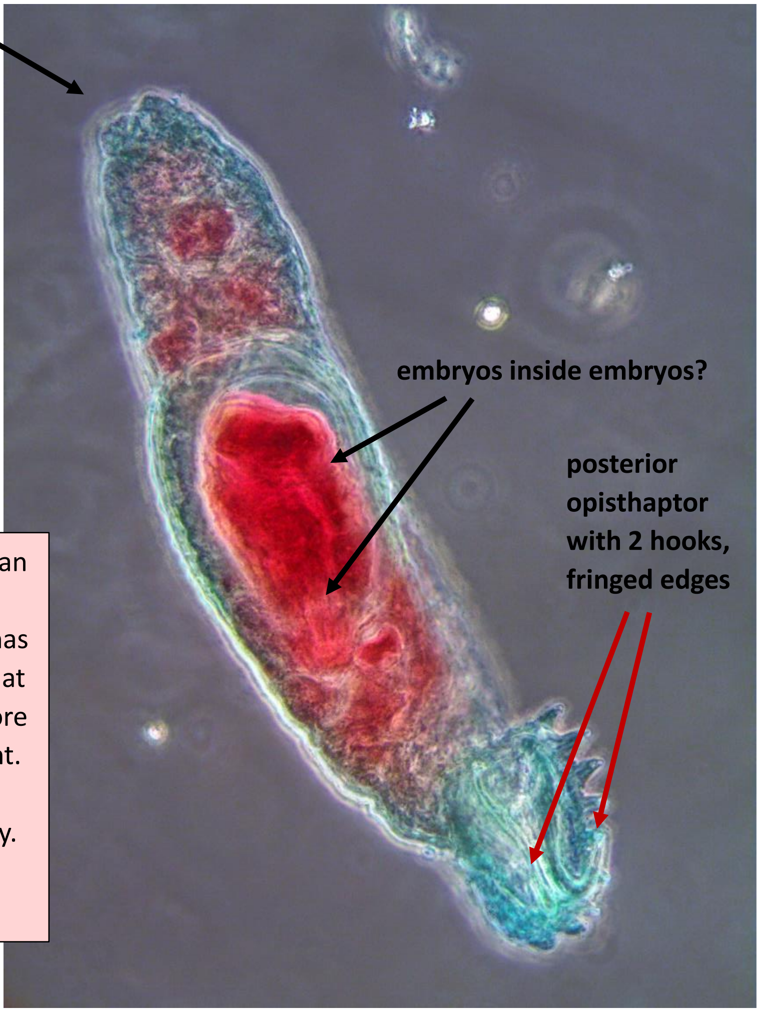
Monogenea is a class of about 5000 known (doubtless more are unknown) species of tiny (mostly less than a mm long) ectoparasitic flukes that mostly live on the skin, gills and fins of marine and freshwater fish. They are directly transmitted parasites, requiring only one host (usually fish but a few live on amphibians or turtles) to complete their life cycle. Monogenea **do not parasitize people** but have sometimes devastated our fisheries, including Norwegian salmon. Although they are fluke shaped, monogeneans are more closely related to tapeworms (cestodes) than to digenean trematodes in recent genomic analyses. Park et al posit monogeneans with their simple monoxenous life cycles are closer in phylogeny to the first parasitic flatworms than are the heteroxenous endoparasitic cestodes and digenean trematodes with vertebrate definitive and invertebrate intermediate hosts. Monogeneans eat mucous or skin cells, and some that live in gills may take blood. All are hermaphrodites and most produce eggs that hatch into motile oncomiracidia, but one very successful order/family, the gyrodactylids, is viviparous (gives live birth to the motile form). *Gyrodactylus* species have embryos inside the embryos inside the embryo, jumpstarting quick life cycles of 1 to 5 days!



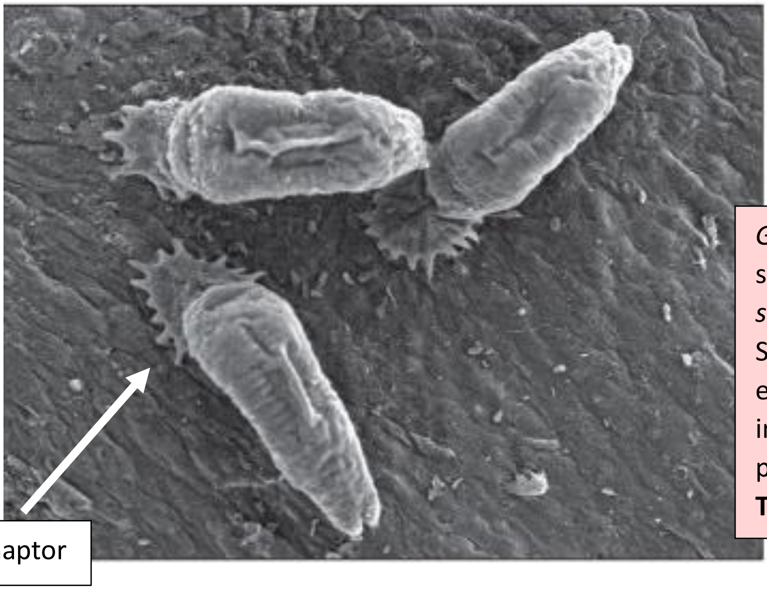
Above- simple oviparous monogenean life cycle, from Grabner et al Parasites and Pollutants **Environmental toxicology and chemistry** 2023



Right- basic anatomy of a dactylogyrid viviparous monogenean showing posterior **opisthaptor** (aka as haptor) for attachment to host, anterior mouth with incomplete (no anus) GI system, bisexual gonads, developing young of multiple generations. Image from eplantscience.com at weebly.com



Gyrodactylus elegans monogenean gill fluke of carp and related fish. The large posterior opisthaptor has 2 hooks and a sawtooth fringe that holds the worm in place. 2 or more nested embryos are often present. Stained specimen. Slide by now defunct Ann Arbor Biology Supply.
20X objective, phase contrast
Fluke about 0.5 mm long.

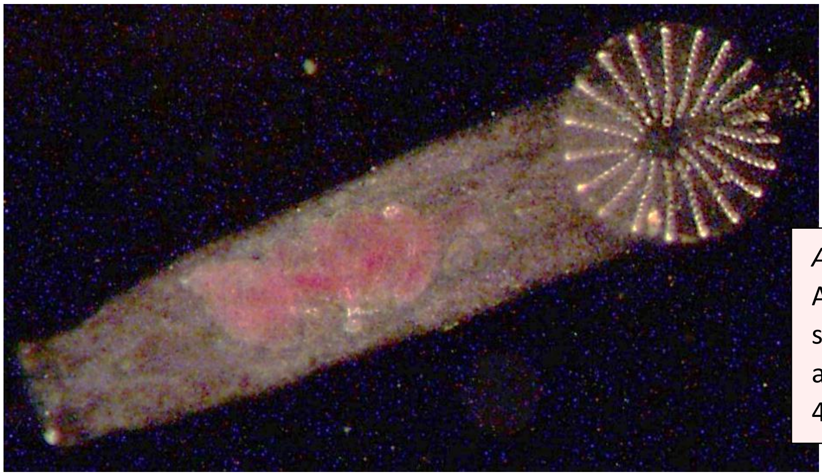


Gyrodactylus salaris infection on skin of Atlantic salmon (*Salmo salar*), important pest in Norway. Scanning Electron micrograph, each worm about 0.5 mm long
image Stentiford er al Policy, phylogeny, and the parasite
Trends in parasitology 2014

3 larger monogenean fish flukes showing a diversity of posterior opisthaptor attachments

Anterior ↔ **Posterior**

Microcotyle sp monogenean trematode, family Microcotylidae, *ex* Sebastodes (rockfish), slide made at Oregon State University USA, c1950s. At about 6 mm long this is one of the largest monogeneans. The attachment haptor at lower right reportedly has 58 hooks in 29 rows. Stitched using 4X objective.



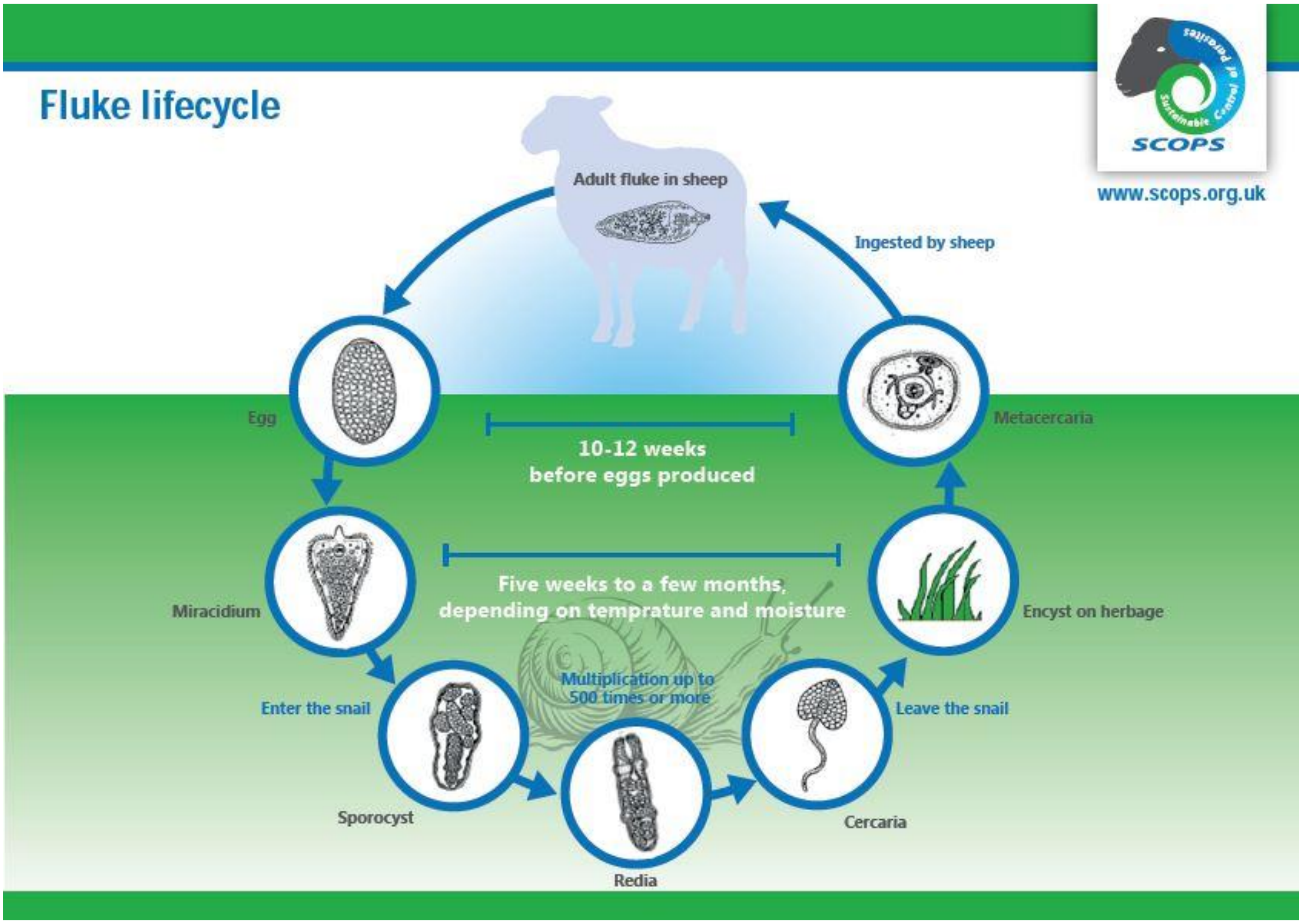
Acanthocotyle pacifica monogenean family Acanthocotylidae. They live on the skin of *Raja sp.* skates. The opisthaptor has many tiny teeth arranged in radial rows FH Wilson 1955
4X objective, dark field, fluke about 3 mm long

Megacotyle trituba monogenean family Capsalidae *ex Sebastodes* sp rockfish Yaquina Bay Oregon USA collected 17-10-1960 by HL Hanson stitched w/ 4X obj., dark field, fluke ~4mm long

Class Trematoda

The largest group of all flatworms is **digenean trematode flukes**, a class of about 20,000 known species, all parasitic. They typically have a flat elongated leaf like shape, with 2 suckers and an outer layer of tegument (once thought to be acellular and now known to be a syncytium of fused cells). They are hermaphrodites with multiple (often 8) life stages in multiple hosts presenting many variations of complex heteroxenous life cycles with vertebrate definitive hosts and 1 to 3 invertebrate (or invertebrate plus vertebrate) intermediate hosts. Flatworms were around for over 300 million tears before gastropods appeared in the early Cambrian 530 million years ago and Devonian lobe-finned fish crawled onto land 375 million years ago. Ever since, trematodes, mollusks and land vertebrates have been co-evolving, with flatworms adapting to us. About 80 million years ago the schistosomes split off from other trematodes. They are oddballs with a different anatomy than other trematodes, and cause the most fatal of trematode diseases. Given that schistosomiasis is such an important human disease I discuss schistosome biology in more detail after discussing the fluke shaped trematodes. Snails are the schistosomes' intermediate hosts and are also involved in each of the cases of amazing host modification I discuss below, and harbor stages of the important trematode flukes of humans.

The ancients saw human tapeworms (which are big and sometimes pooped out) but perhaps not liver flukes, as human dissections were very rarely recorded until modern times. Many parasites were discovered in animals before human counterparts were found. In 1684 the father of parasitology, Francesco Redi, gave a detailed description of an adult fluke he found in a rabbit that was later named *Fasciola hepatica* by Linnaeus in 1758. It is now known as the sheep liver fluke, and ruminates are the usual definitive hosts but it can infect humans. Finding the life stages (as many as 8) and working out complex trematode life cycles (some have 3 intermediate hosts before adult trematodes reproduce sexually in a definitive host) was largely a late 19th and 20th century endeavor. At that time microscopes became very good and academic biology blossomed. *Schistosoma haematobium* was found by German surgeon Theodor Bilharz in an Egyptian autopsy in 1851, and soon shown to cause hematuria. A snail intermediate host was suspected but not proved experimentally until 1915 by Leiper (genomics hastens research today). *Paragonimus westermani*, the human lung fluke, was seen humans by Ringer in 1879. The next year Manson found eggs in sputum and suspected a snail intermediate host, which was proved by multiple Japanese scientists around 1920. The human liver fluke, *Clonorchis sinensis*, was described by McConnell in 1875 and the snail and fish intermediate hosts host were found by Muto and Kobayashi in 1918 and 1915 respectively.

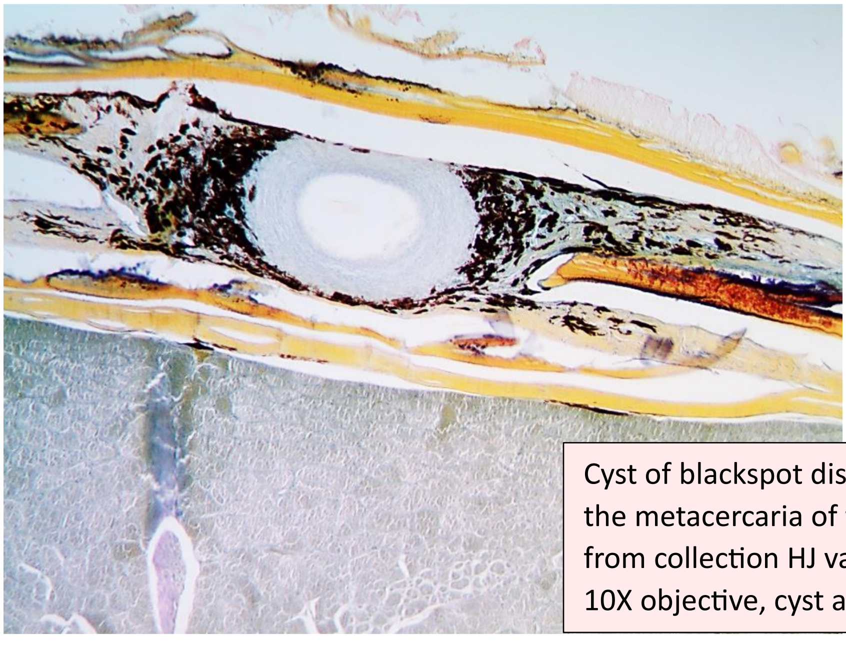


A digenean trematode life cycle. *Fasciola hepatica*, the sheep liver fluke, has just 2 hosts, a mollusk (intermediate) and a vertebrate (definitive) host (many flukes have additional hosts). Stages: 1. egg 2. miracidium 3. sporocyst 5. redia 6. cercaria 7. metacercaria 8. adult fluke.
from Sustainable Control of Parasites (SCOPS) a UK sheep farmer organization

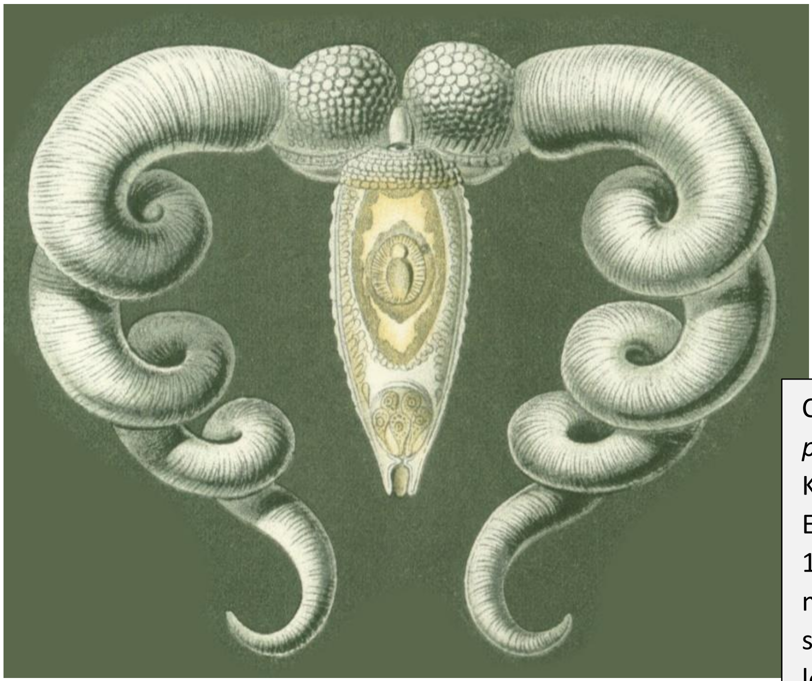
Life stages of some Trematoda

Eggs of *Ichthyocotylurus variegatus* a trematode parasite of fish. Slide L Bircham collection, 10X objective, eggs are big, ~ 0.4 mm

Miracidia of *Fasciola hepatica* (swimming dispersal stage hatches from egg), Ward's slide. 40X obj., cropped, ~ 130 microns long

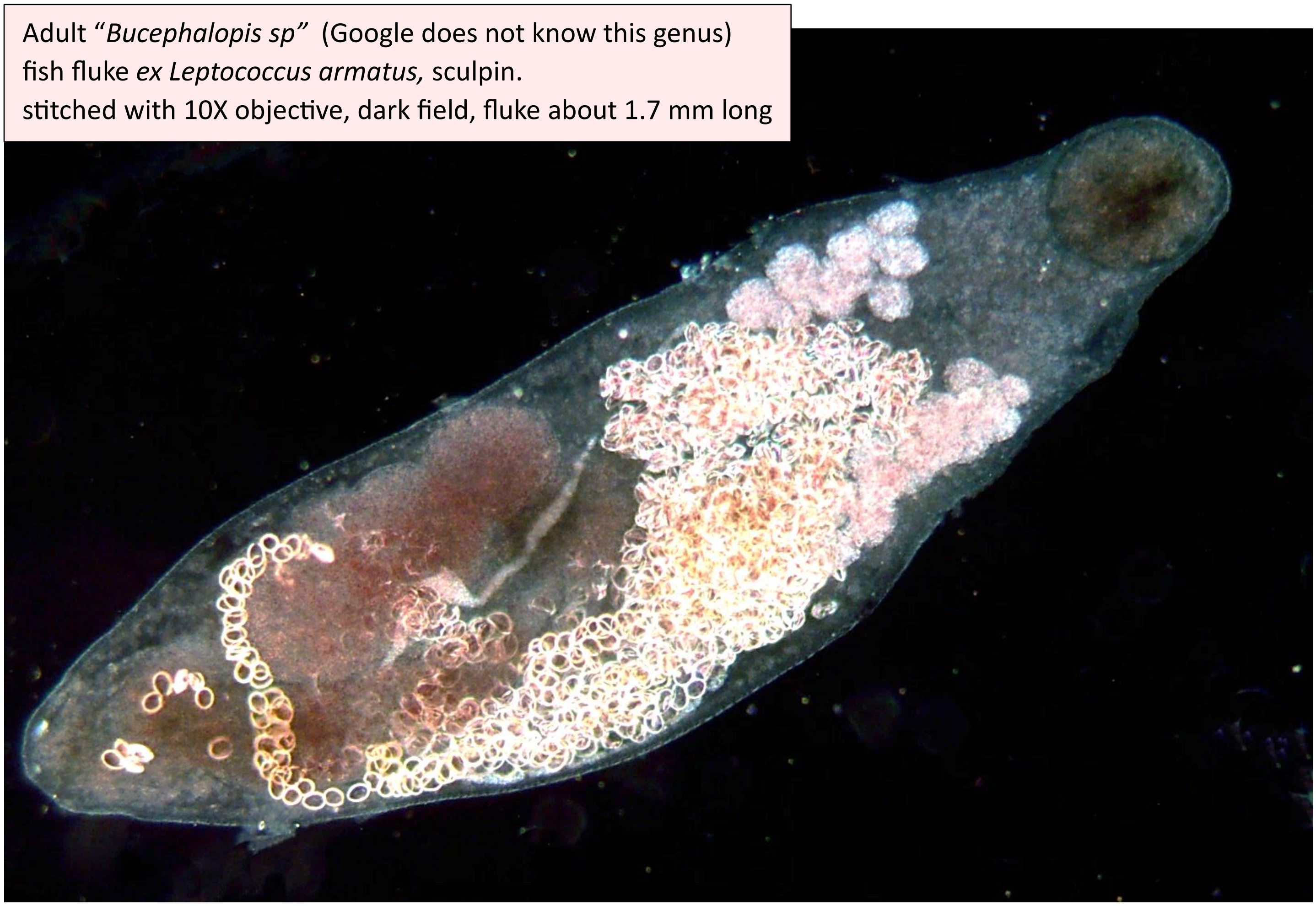


Cyst of blackspot disease showing disrupted minnow skin;
the metacercaria of trematode fluke is missing, Ann Arbor slide from collection HJ van Cleave (was at U of Illinois 1911 to 1953)
10X objective, cyst about 0.2 mm, image about 1.1 mm wide

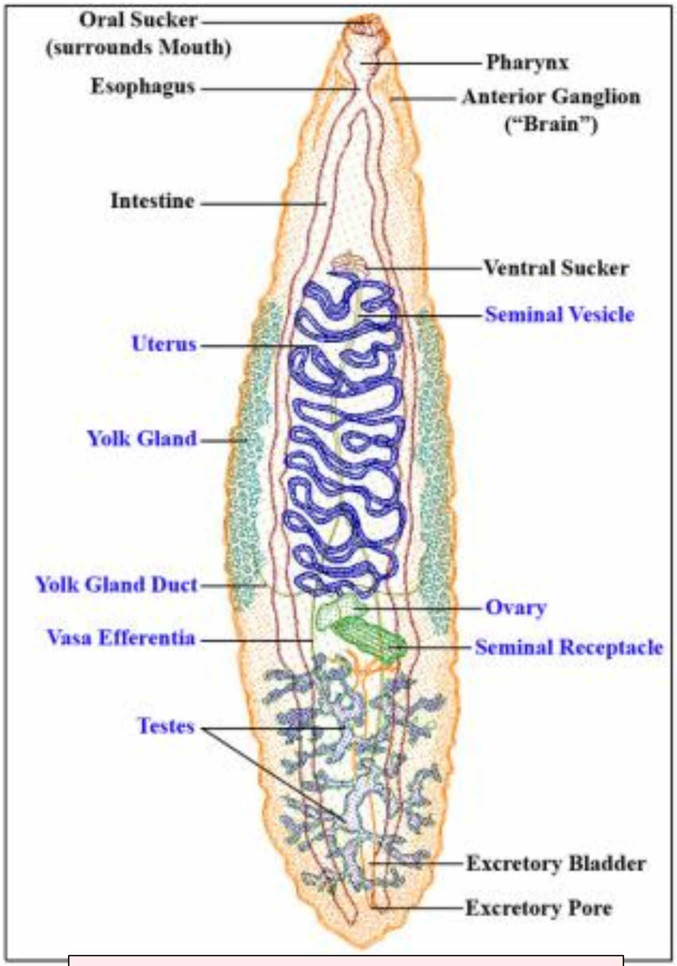


Cercaria larva of the trematode *Bucephalus polymorphus* drawn by flawed genius Ernst Haeckel in Kunstformen der Natur 1904, image Wikipedia. Elaborate “horns” are tails, body ~ 0.25 mm long. 19th and early 20th century field naturalists with microscopes pieced together most of the parasite life stages and cycles we know now. Cercariae don’t always look like tiny tadpoles with single or forked tails. *Bucephalus polymorphus* cercariae drift as plankton.

Adult “*Bucephalopis sp”* (Google does not know this genus)
fish fluke *ex Leptococcus armatus,* sculpin.
stitched with 10X objective, dark field, fluke about 1.7 mm long

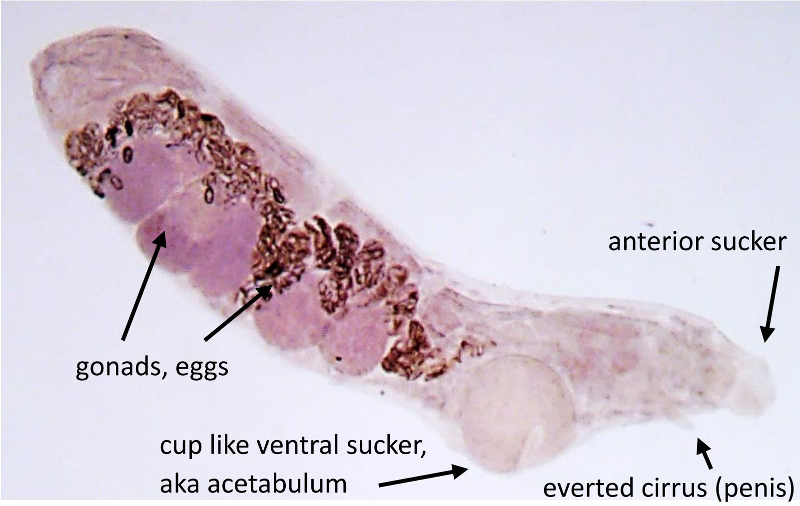


Anatomy: digenean trematodes typically have flat, long, leaf shaped bodies. Most have anterior and ventral suckers. Like other helminths, much of their (hermaphroditic) bodies are comprised of various reproductive organs. Thin small bodies allow good gas exchange, so respiratory and cardiac systems are not needed.



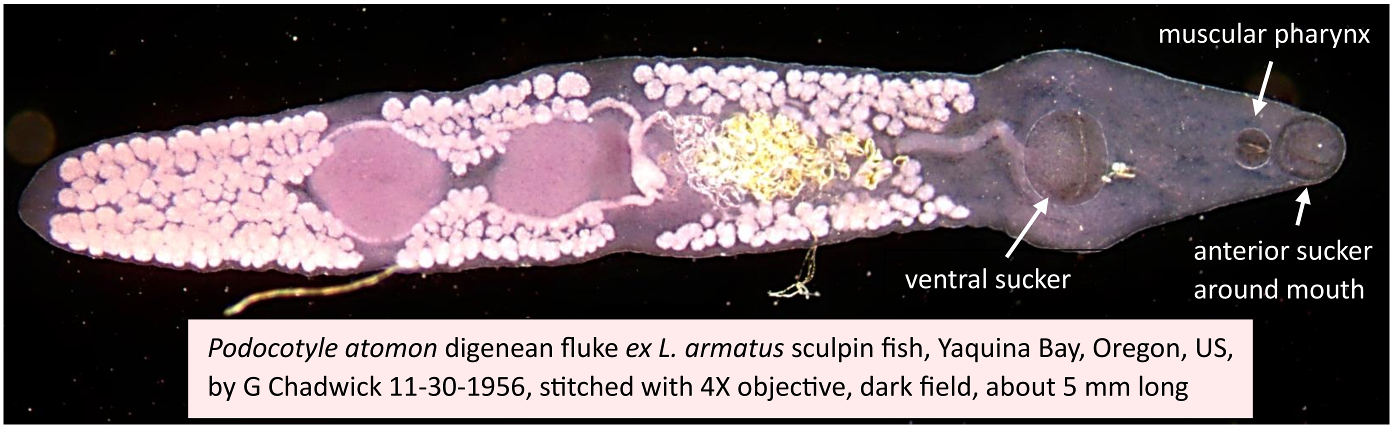
Digenean trematode anatomy diagram from Al-Emarah et al researchgate.net labelled parts above visible on slide at right

Clonorchis sinensis adult Chinese liver fluke *ex* liver of man, slide Oregon State University, USA 4X obj. dark field, stitched, fluke ~ 1.2 cm long



Genolinea sp. fish fluke ex *Leptocottus armatus* (sculpin) stomach, collected Yaquina Bay, Oregon by SE Swedberg on 11-9-1957
4X objective, cropped, fluke about 2 mm long

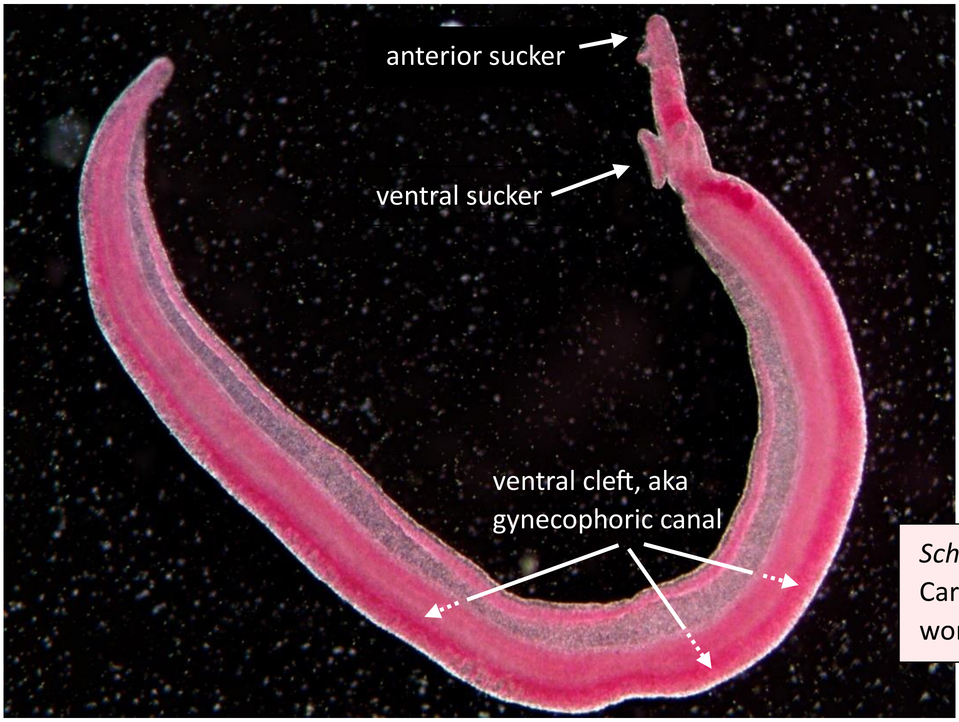
More examples of digenean trematodes (aka Class Trematoda)



Podocotyle atomon digenean fluke *ex L. armatus* sculpin fish, Yaquina Bay, Oregon, US, by G Chadwick 11-30-1956, stitched with 4X objective, dark field, about 5 mm long

Paramphistomum sp ex ruminate stomach, collected in Africa, Dr. A Renz; stitch with 4X objective, dark field, fluke about 3 mm long

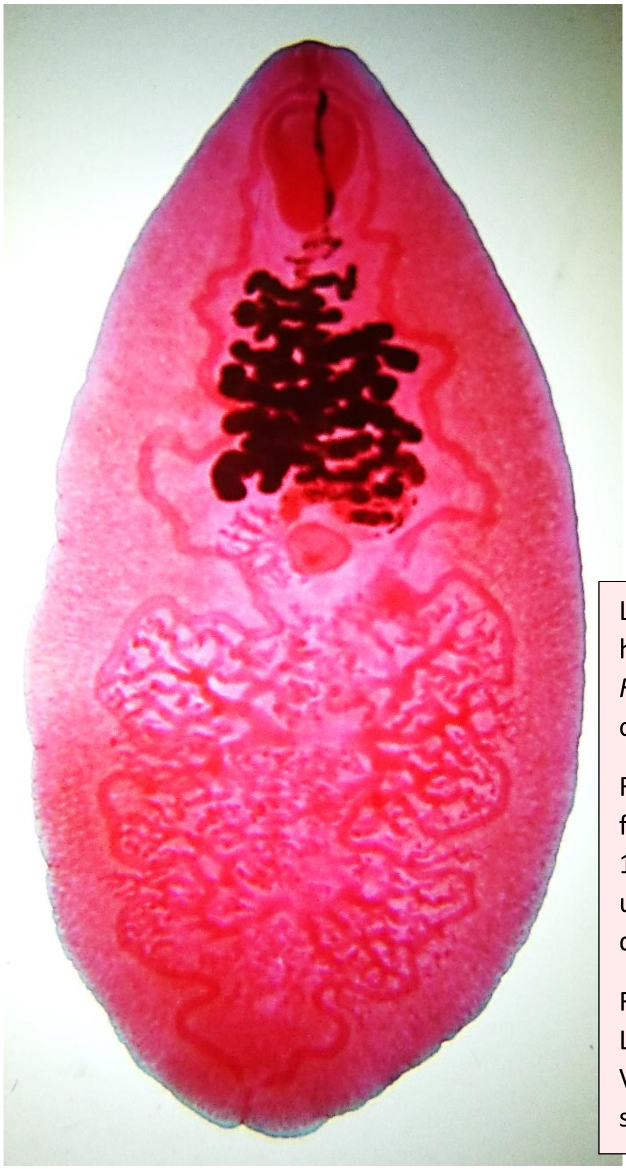
Trematodes ("perforated" in Greek) are named because ttheir sometimes cup shaped suckers can look like holes

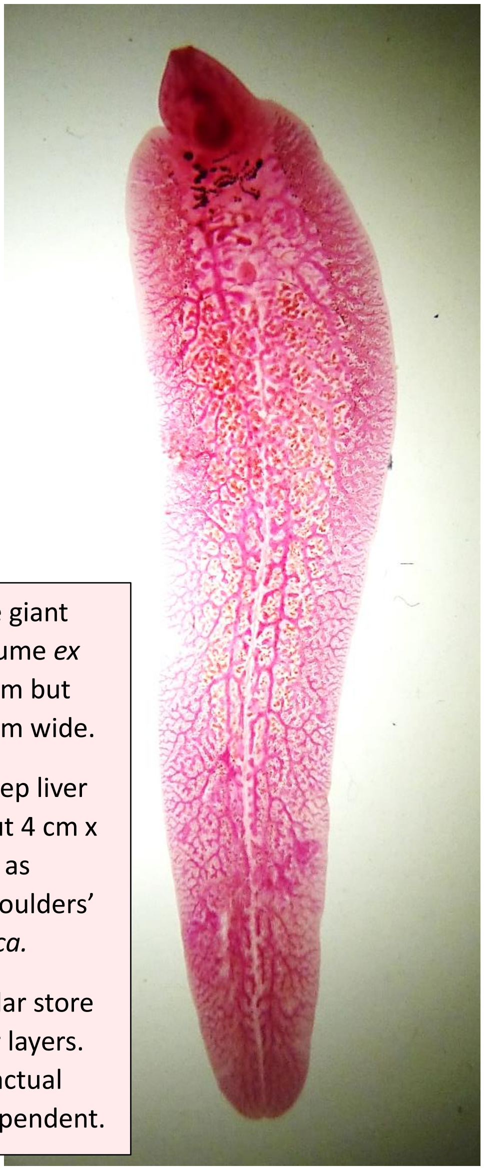


Schistosomes are odd trematodes with round instead of flat bodies (more typically worm like, although males have a V-like cross section). Schistosomes ("split body") are named for the male's deep ventral cleft that holds a female worm for a lifetime together in a human vein.

Schistosoma mansoni adult male, Carolina slide. 4X obj., dark field, worm about 1 cm long long

Big Flukes





Left- *Fasciolopsis buski* is the giant human intestinal fluke, presume *ex Homo*. This one is 3.3 x 1.9 cm but can be 7.5 cm long and 2.5 cm wide.

Right- *Fasciola hepatica*, sheep liver fluke, presume *ex Ovis*, about 4 cm x 1 cm; perhaps stretched out as usually about 3 x 1.5 cm; 'shoulders' distinguish it from *F. gigantica.*

Flukes photographed on dollar store LED closet light with diffuser layers. Vintage slides below about actual size, 3 inch long, monitor dependent.

Standard 3 inch microscope slides (and their fluke specimens) shown about actual size, depending on your monitor

Vintage parasite microscope slides
I have been lucky to acquire a few collections of old parasite slides (sometimes a box of 100) on eBay in the US. One collection came by way of a former grad student of a late Professor of Zoology at the Univerisity of Illinois, USA, and past president of the the American Society of Parasitology, Harley Jones van Cleave (b1886-d1953). Another set came from a modern amateur expert slide maker, the now elderly LR Bircham, state of Mississippi, USA, who learned mounting in balsam from his father. Other boxes with parasite slides from biologic supply houses (Ward's, Turtox, others) and/or made at universities appear to have been teaching collections of unknown educators or students. Parasites are popular with teachers to demonstrate morphology, evolution and ecology in fascinating ways.

Some slides of HJ van Cleave, University of Illinois parasitology teaching collection

Select parasitology slides from LR Bircham, most specimens collected, mounted by him

Great slides that came along with toy quality Edmund microscope; suspect an educator kept their circa 1960s childhood microscope

Select slides in a circa 1950 Bakelite box, appear to be university teaching slides

Schistosomes are weird but deadly trematodes. Other trematodes are hermaphrodites and flat but schistosomes have separate male and females, and are round in cross section. The genus *Schistosoma* probably arose in Asia about 80 million years ago as their ancestors moved from bird to rodent hosts, then they spread to Africa and eventually to our human ancestors.

Few worms are monogamous, but schistosomes pair off for life and go a step further: **female and male schistosomes cuddle together for life**. A female worm lives permanently in the deep ventral gynecophoric cleft of a male, a position called *in copula*. They live embraced together inside human veins, mating and producing eggs for up to 40 years together.

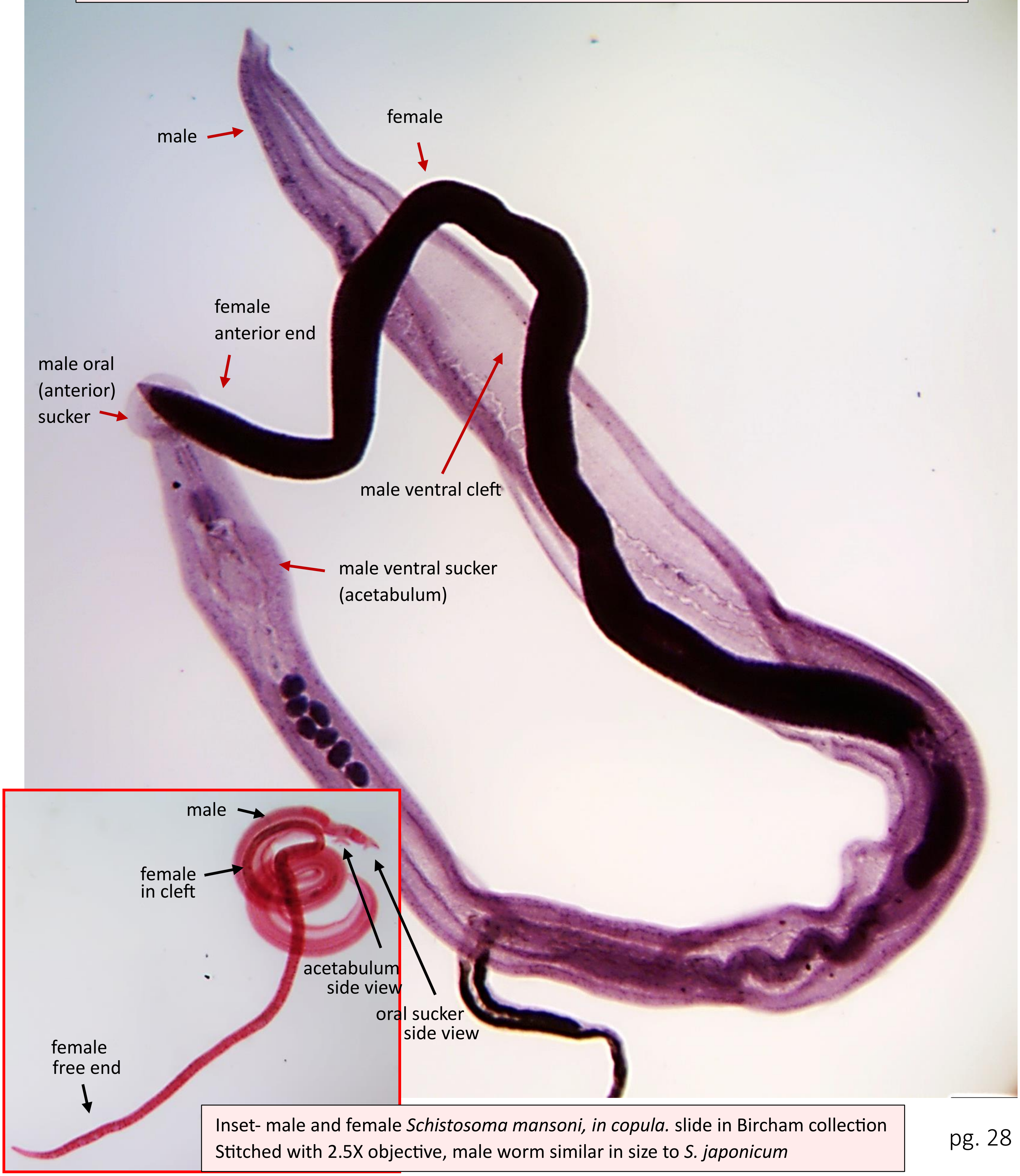
An old parasitology joke:

"How do a male and female schistosome find each other?" Answer: "Delightful".

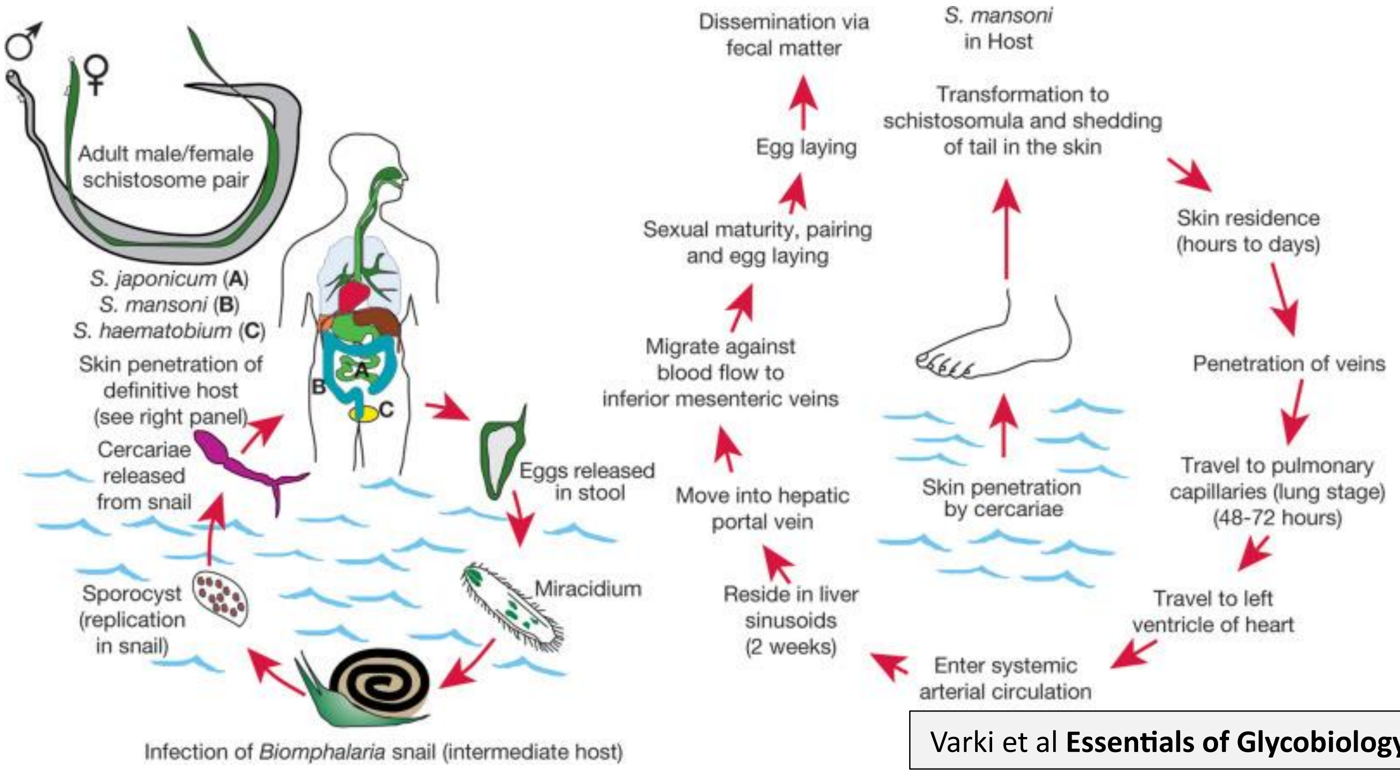
A scientific answer includes epic journeys inside the human body. Most trematodes live in the gut or bile ducts but schistosomes are "blood flukes" and adults live in blood vessels. The cercaria stage burrows into our skin and is carried by veins through the right heart to the lungs. The cercaria transforms into a slender schistosomulum that can pass through capillaries (the smallest vessels) then back through the left heart and arteries into the body. It favors getting into the vessels that go to the liver. If the larva ends up somewhere else it can slip through capillaries and ride back through the heart and lungs for more chances to find its destination. Once in the liver portal liver veins schistosomula grow into adult worms. Adults find mates and make their way back into veins around the colon or bladder (depending on species). There the copulating couple lives out their lives, producing spined eggs that can penetrate into the lumen of the intestine or bladder to be passed out in feces or urine, to find a snail so their circle of life can continue. We sacrificed thousands of hamsters and mice working out these migrations. Later, we sequenced the genomes of *Schistosoma mansoni* (2009), and *S. haematobium* and *japonicum* (2016). The parasites' 3.6 million base pair genome is about 1/10 the size of yours. The "anatomy skills" of schistosomes likely use olfaction ("smelling" different biochemicals) and detection of vibrations, temperature and light/dark differences (their genome suggests they have these capabilities). Genes have also shown *Schistosoma* has many of the same neuroendocrine chemicals that humans use, including cortisol, thyroid hormone and follicle stimulating hormone (a female sex hormone). There may even be a schistosome cell receptor weakly analogous to that for oxytocin, the "love hormone" involved in mother-child bonding in mammals. So maybe embracing schistosomes really do find each other to be delightful.

But schistosomes are not delightful for humans. Some eggs exit our bodies but many get stuck in liver and lungs. Errant eggs cause intense inflammation and fibrosis that can lead to hepatic cirrhosis, pulmonary hypertension and bladder cancer. Schistosomes continue to infect over 200 million people and **cause about 200 thousand deaths annually**, mostly in Africa.

Male and female *Schistosoma japonicum, in copula* (copulation, a lifetime activity for them), great Ward's slide Stitched using 2,5X objective, the image is about 5 mm across and the male is about 1 cm long

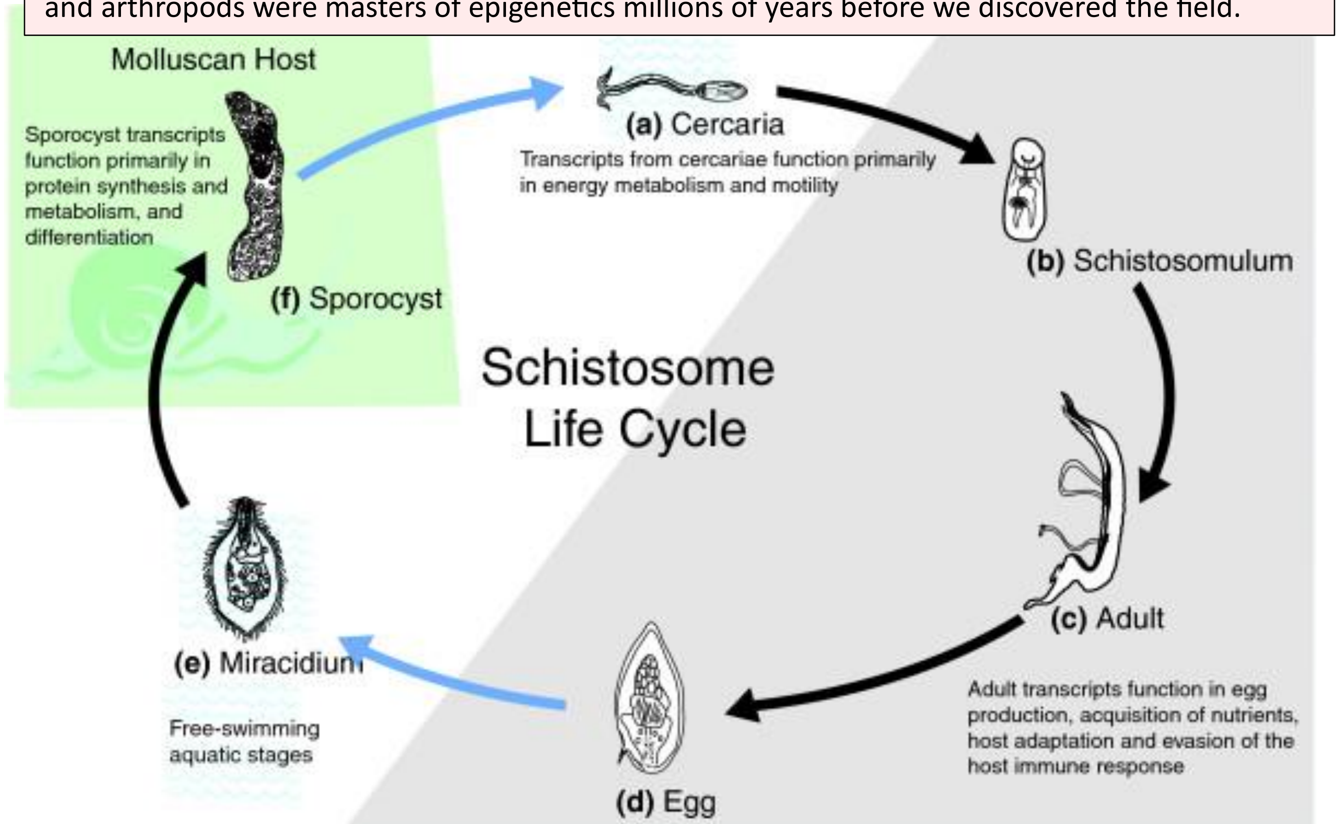


Inset- male and female *Schistosoma mansoni, in copula.* slide in Bircham collection Stitched with 2.5X objective, male worm similar in size to *S. japonicum*



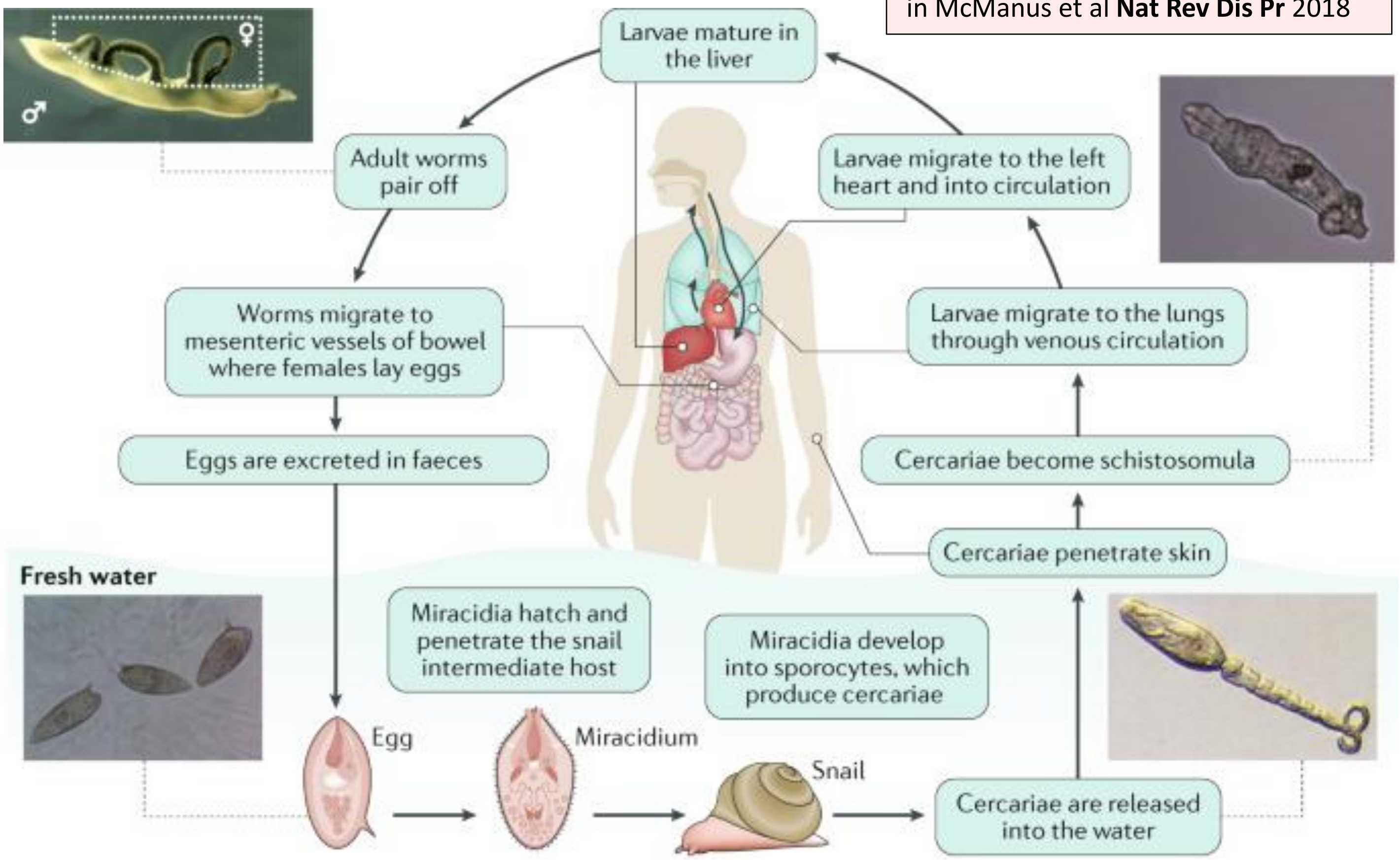
Varki et al **Essentials of Glycobiology** 2022

Life cycle of *Schistosoma sp*. in snails and humans is complex as they are highly co-evolved. Navigating inside hosts, parasites must recognize (smell) various biomolecules.
Different (metamorphic) life stages transcribe the same genome in very different ways. Flatworms and arthropods were masters of epigenetics millions of years before we discovered the field.

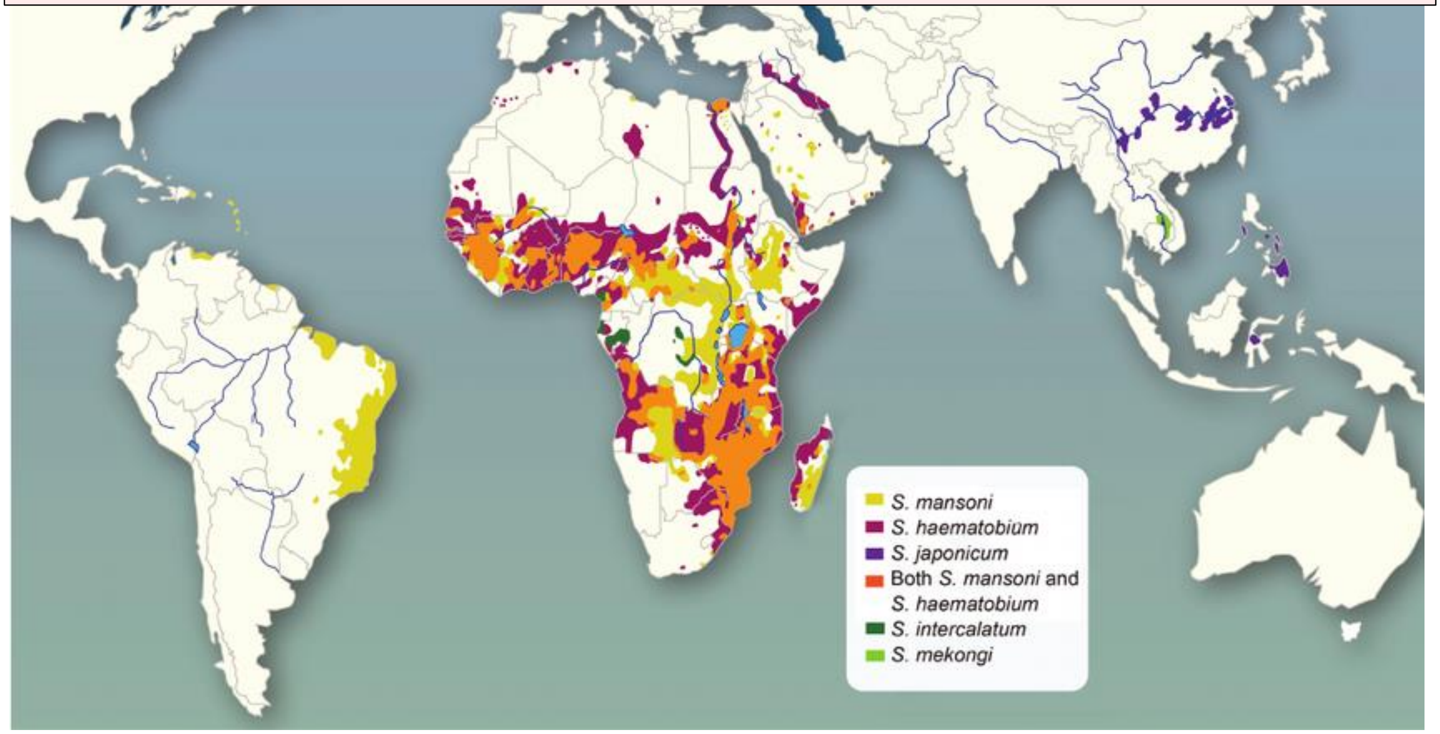


Jolly et al Gene expression adaptation of a helminth parasite to different niches **Genome biology** 2007

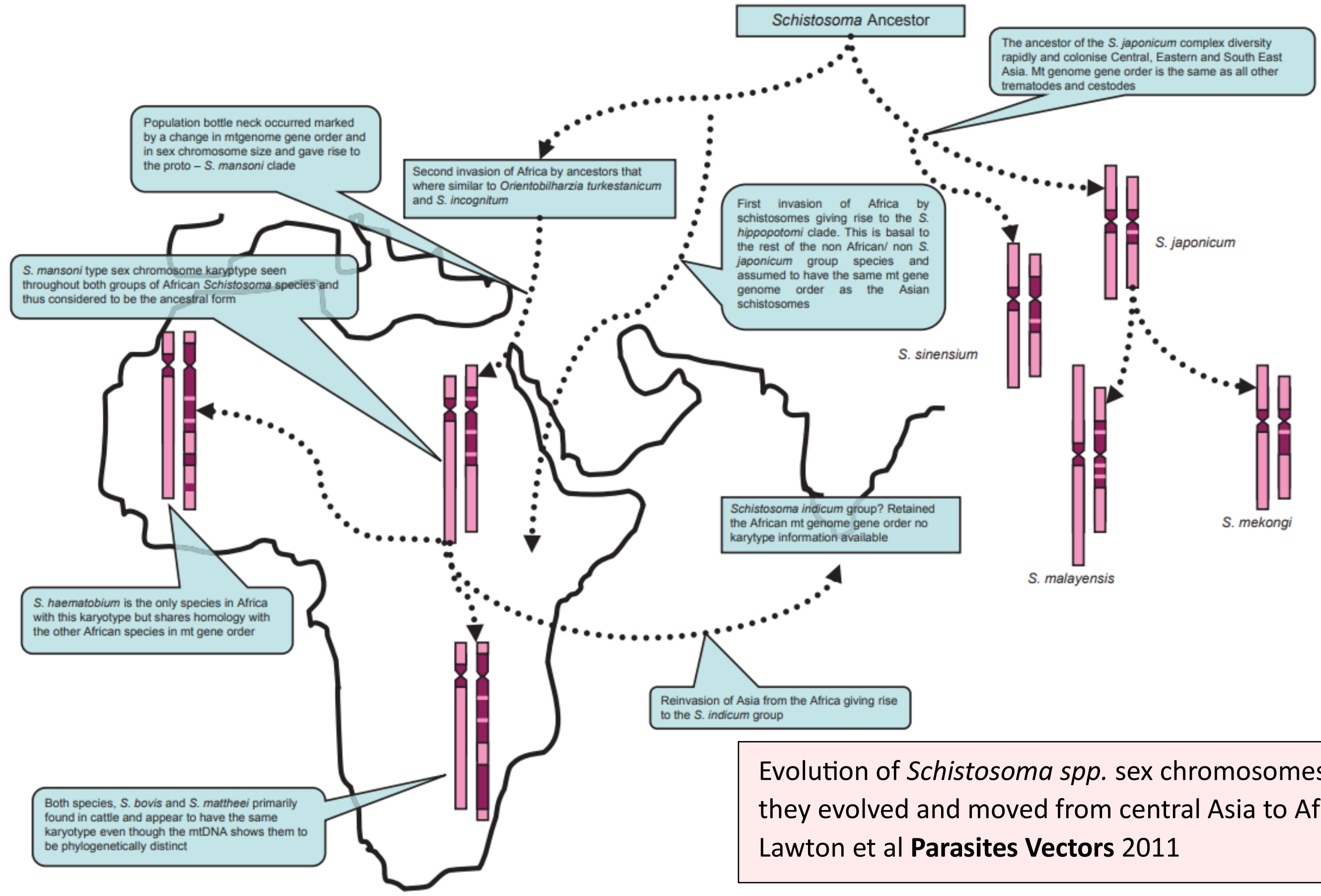
Life cycle of *Schistosoma mansoni*
in McManus et al **Nat Rev Dis Pr** 2018



Schistosoma spp. originated in Cretaceous age Asia but human schistosomes are now mostly found in tropical Africa.
Map in Weerakoon et al **Clin Micro Rev** 2015, adapted from Gryseels et al **Lancet** 2006



Each group of human parasites has its own **evolutionary ancestry** story. *Homo sapiens* is a newcomer on the tree of life, arising just 0.3 million years ago. Our parasites originated in nonhuman animals first, then moved into and adapted to our ancestors, then to us.



The ancestor of the *S. japonicum* complex diversity rapidly and colonise Central, Eastern and South East Asia. Mt genome gene order is the same as all other trematodes and cestodes

Population bottle neck occurred marked by a change in mtgenome gene order and in sex chromosome size and gave rise to the proto – *S. mansoni* clade

Second invasion of Africa by ancestors that where similar to *Orientobilharzia turkestanicum* and *S. incognitum*

First invasion of Africa by schistosomes giving rise to the *S. hippopotomi* clade. This is basal to the rest of the non African/ non *S. japonicum* group species and assumed to have the same mt gene genome order as the Asian schistosomes

S. mansoni type sex chromosome karyptype seen throughout both groups of African *Schistosoma* species and thus considered to be the ancestral form

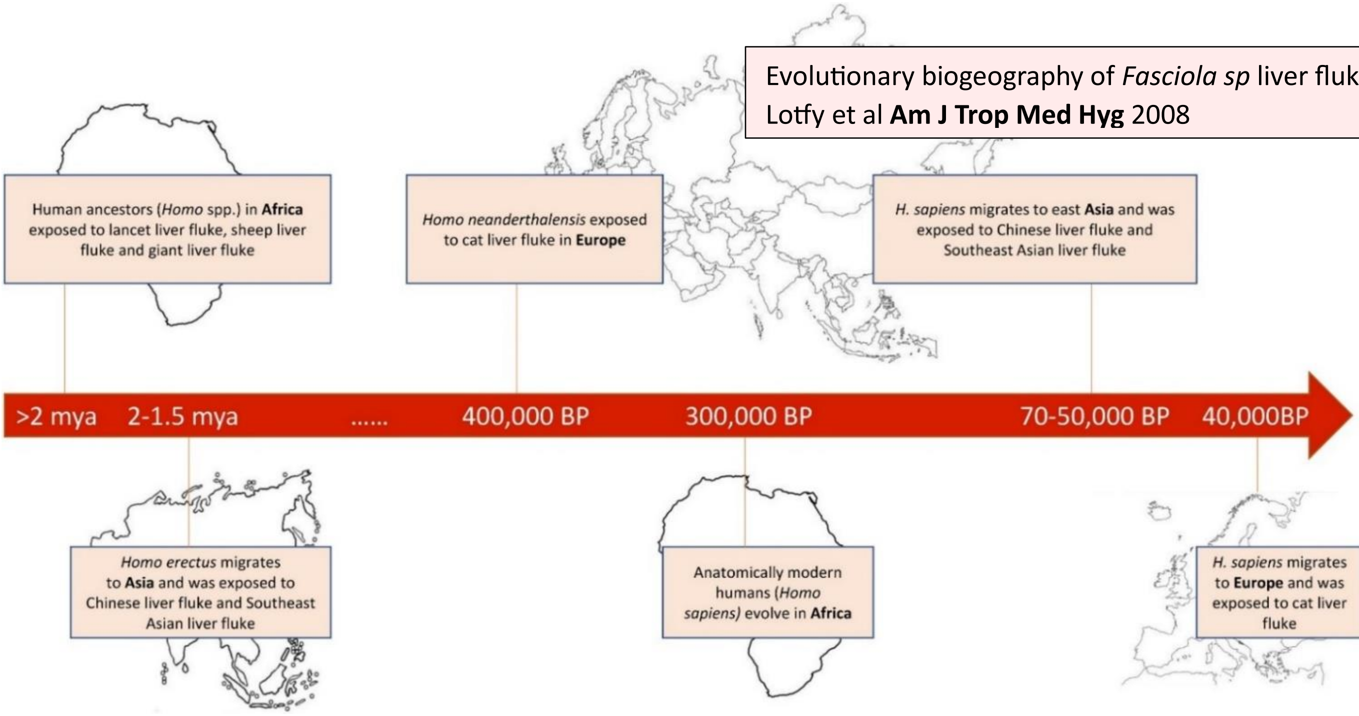
Schistosoma indicum group? Retained the African mt genome gene order no karytype information available

S. haematobium is the only species in Africa with this karyotype but shares homology with the other African species in mt gene order

Reinvasion of Asia from the Africa giving rise to the *S. indicum* group

Both species, *S. bovis* and *S. mattheei* primarily found in cattle and appear to have the same karyotype even though the mtDNA shows them to be phylogenetically distinct

Evolution of *Schistosoma spp.* sex chromosomes as they evolved and moved from central Asia to Africa
Lawton et al **Parasites Vectors** 2011



Human ancestors (*Homo* spp.) in **Africa** exposed to lancet liver fluke, sheep liver fluke and giant liver fluke

Homo neanderthalensis exposed to cat liver fluke in **Europe**

H. sapiens migrates to east **Asia** and was exposed to Chinese liver fluke and Southeast Asian liver fluke

Homo erectus migrates to **Asia** and was exposed to Chinese liver fluke and Southeast Asian liver fluke

Anatomically modern humans (*Homo sapiens)* evolve in **Africa**

H. sapiens migrates to **Europe** and was exposed to cat liver fluke

Evolutionary biogeography of *Fasciola sp* liver flukes.
Lotfy et al **Am J Trop Med Hyg** 2008

Four very Tricky Trematodes

Trematodes Gone Wild part 1, *Dicrocoelium* creates suicide ant zombies

Parasite induced color and behavior changes to promote predation of an intermediate host was first described in an acanthocephalan parasite of the common amphipod *Gammarus* by Hindsbo in 1972. Parasite modification of host behavior has now been seen in over 100 parasite-host interactions and is probably very common. A classic case is ***Dicrocoelium dendriticum****.* The lancet liver fluke of sheep was discovered in 1819 but its life cycle in snails and ants was not discovered until the 1950s, by naturalist Wendell Krull. Sheep pass eggs in feces that are eaten by snails, and the parasite goes through several snail organs and 3 stages to become cercaria coughed up in tiny mucous balls (land snails have a tiny respiratory pore if you look carefully). The snail mucous is eaten by ants, and the cercaria migrate to the ant's abdomen and some to the brain olfactory lobe and encyst as metacercaria. The infested ant keeps going to its day job at the colony but is induced to follow temperature and light changes each afternoon and break away from the rest of its ant colony and to climb up high in grass and hold on all night with its jaws. *Dicrocoelium* manipulates the ant to risk its life every evening but lets it return to the colony before the heat of the next day. Eventually the suicidal zombie ant gets eaten by a grazing ruminant, passing *Dicrocoelium* into its definitive host, where it will mature and live in the bile duct, making eggs, completing a complex life cycle of 3 hosts and 6 parasite life stages. In rare cases humans eat food contaminated by infested ants and become a dead end in the trematode's life cycle.

(red arrows show dispersal stages)

Ovis aries about 1.5 m
University of Wisconsin

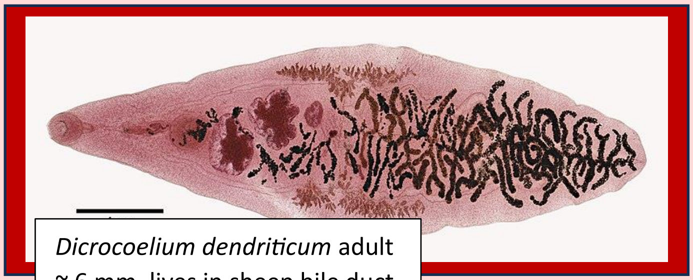
eggs

Cochlicopa lubrica
~6 mm, Wikipedia

cercaria

Formica sp ant ~8 mm
D Colwell londonntd.org

metacercaria

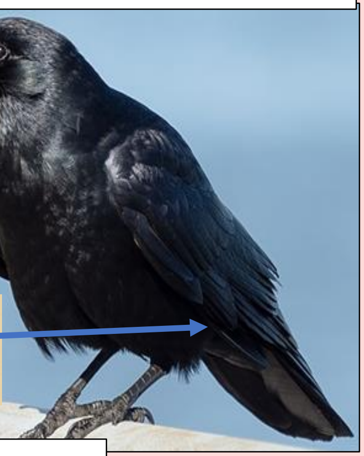


Dicrocoelium dendriticum adult
~ 6 mm, lives in sheep bile duct
Wikimedia, Peabody museum

Trematodes Gone Wild part 2, *Leucochloridium* makes disco dancing blind eunuch zombie snails

Some trematode parasites modify both the body and mind of a host to perpetuate their parasitic life cycle. Flukes in the genus *Leucochloridium* require the bird definitive host to eat part of the snail intermediate host to keep their beautiful little circle of life going. *Leucochloridium* manipulation of snails was questioned in 1835 and later proven by modern research. Snails think bird shit is tasty. Thus, worm eggs can enter the snail, then multiply by cloning and pass through multiple life stages in the snail culminating in a fiendishly designed apparatus delivering a deluxe Pez dispenser of parasite technology: a multicolored pulsating broodsac full of hundreds of teenage worms. Not content with only a sporocyst apparatus that can comprise up to 40% of the snail's biomass, the parasite also induces the infested snail to crawl further than normal, upwards on foliage into the light, where the pulsating broodsac can put on a good show for the birds. A bird sees a tasty "maggot" perched on a snail and swoops down and snips the broodsac (and eyestalk) off the snail, which often survives. Not content with just turning a third of the snail's mass into parasite mass, and manipulating its tiny brain, *Leuchochloridium* has a third evil parasite trick up its sleeve. It often castrates the snail. This frees up resources that would have gone towards snail eggs and often prolongs the snail's life so the sporocyst apparatus can repeatedly deliver new pulsating broodsacs into eyestalks that grow back. Nature can seem cruel, but there is no intention of good or bad by the worm or the snail. It's just the amazing adaptive result of hundreds of millions of years of coevolution of flatworms and mollusks.

Corvus ossifragus, fish crow, Wikimedia



Worm eggs in bird feces are eaten by snail

Succinea putris, Wikimedia

Adult fluke lives in bird cloaca

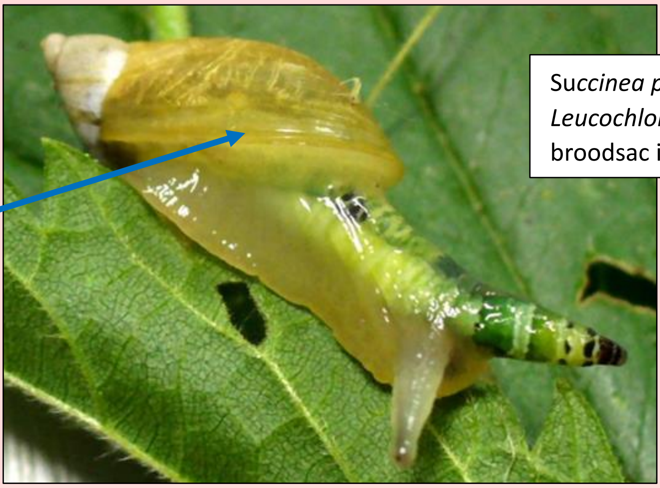
Miracidia hatches from egg, bores into snail hepatopancreas, develops into tree like sporocyst, clones many cercaria which migrate into a broodsac, encyst as metacercaria

2 mm adult *Leucochloridium,* above, 1 mm metacercaria below. Drawings, Wikimedia

Broodsac eaten by bird, metacercaria develops into hermaphrodite adult

1 metacercaria, hundreds stacked in each broodsac

Leucochloridium sporocyst apparatus with broodsacs ex snail, Usmanova 2023



Succinea putris with *Leucochloridium paradoxum* broodsac in eyestalk, Wikimedia

GIF of *Leucochloridium paradoxum* broodsacs infesting *Succinea putris* land snail photo Guilles San Martín

This GIF is at reanimateobjects.tumblr.com/tagged/Leucochloridiidae

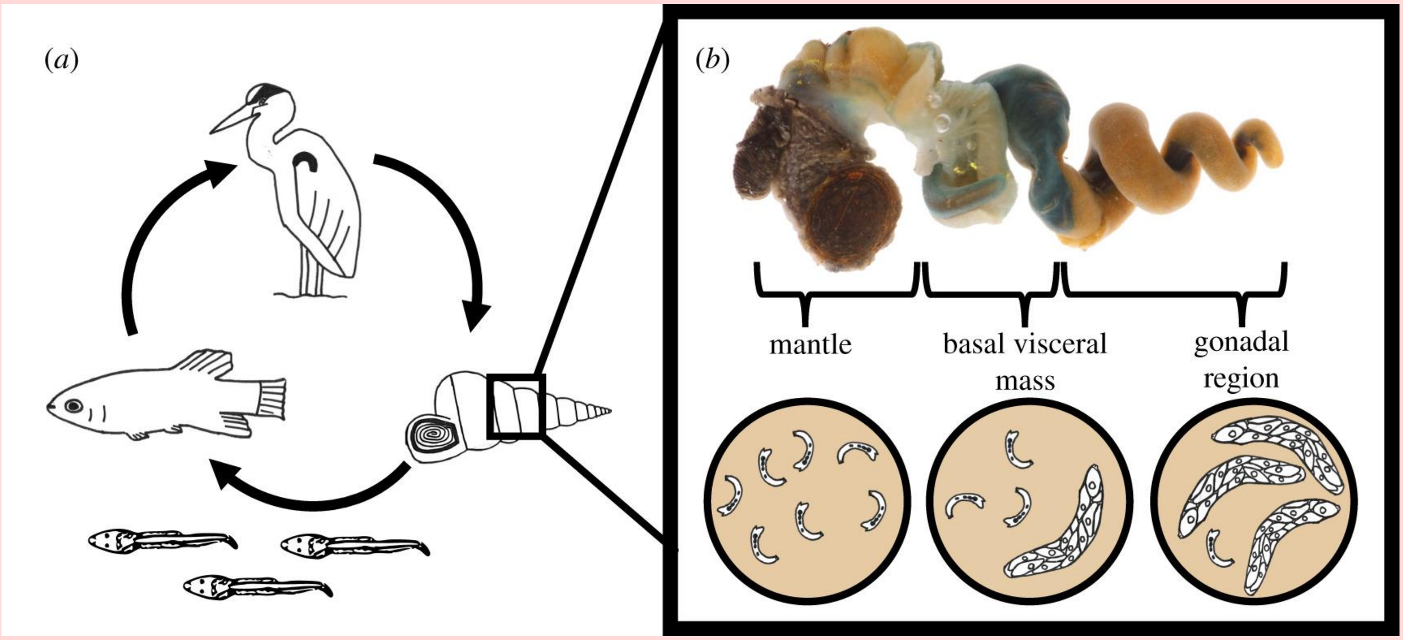
if the GIF animations don't play, see *Leocochloridium* at allyouneedisbiology, Wired or YouTube

Trematodes Gone Wild part 3, Fluke queens and Clone wars

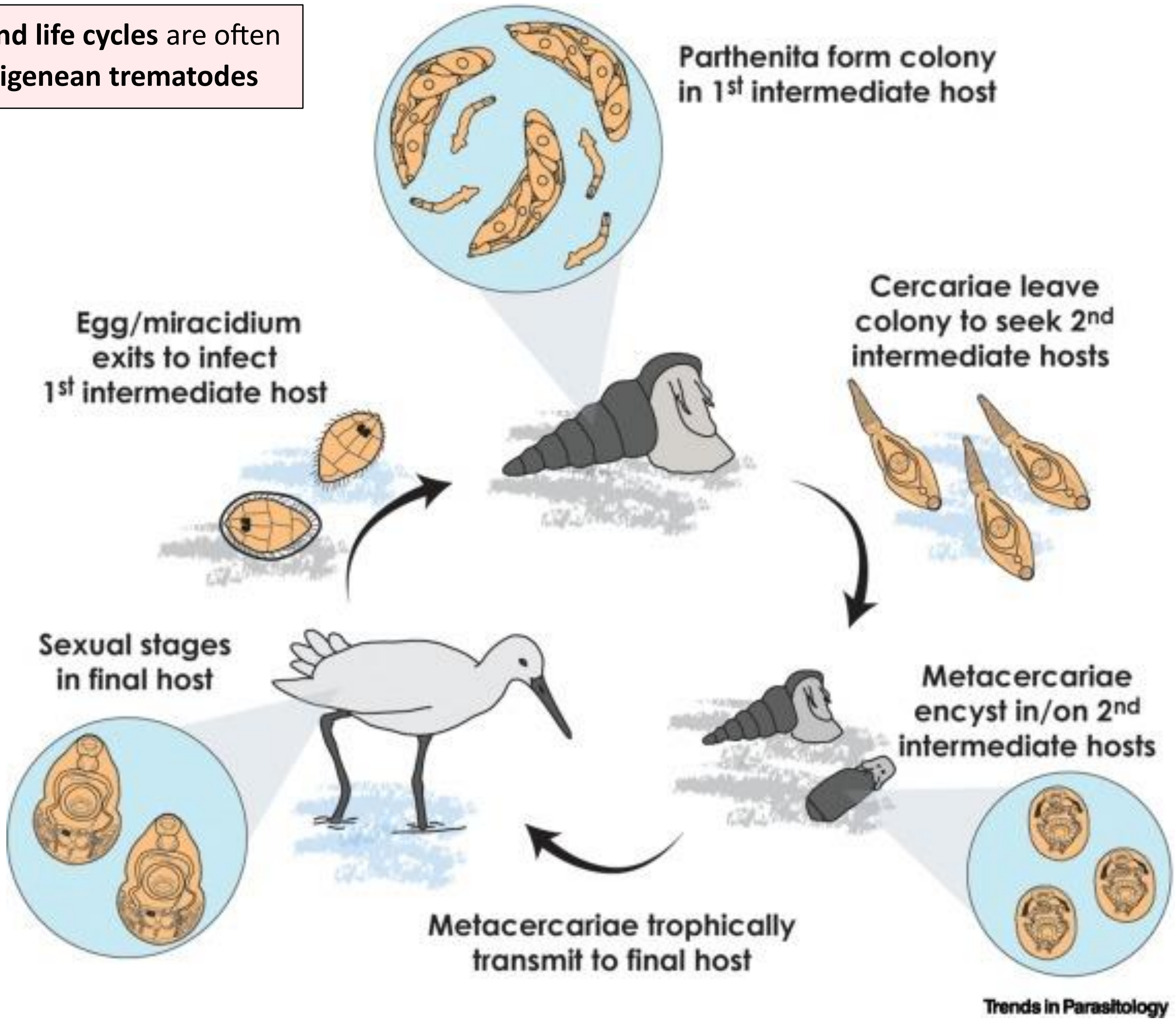
Left image- large reproductive redia (“queen”) with developing cercariae inside, and a much smaller nonreproductive redia (‘soldier’) of *Himasthla* sp. B. Queen about 1.6 mm long and soldier about 0.5 mm. image from R Hechinger in Newey et al

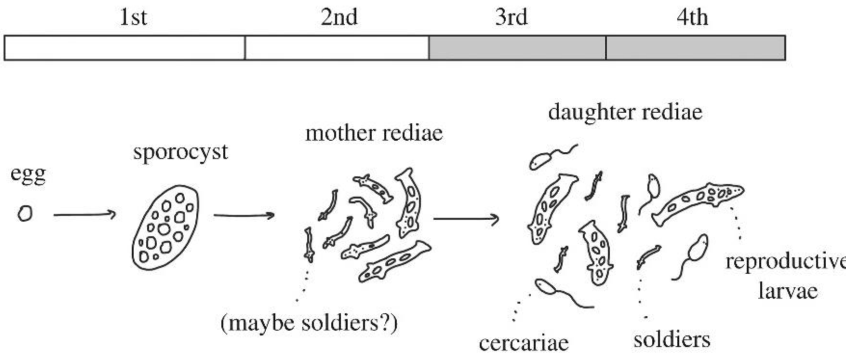
Illustration below- (a) trematode life cycle. A larva infects a snail and clonally produces a colony of soldier and reproductive rediae. Cercariae leave the snail and encyst on/in second intermediate hosts. The cysts are transmitted to wetland bird final hosts by predation. (b) trematode colony dissected from snail. The mantle and basal visceral mass are invasion areas, with soldiers and reproductives produced in the gonadal region. by Resetarits et al.

Marine trematode sporocysts and redia often reproduce asexually (parthenogenesis, cloning) for several generations, producing a sizable colony of worms (about 2000 redia) inside a mollusk secondary host. The colony might live in an infested snail for a decade, and is worth defending. Some trematodes have become true social animals, with colonies of clones divided into defensive and reproductive castes. Although they are genetically identical clones, the small (but strong mouthed) “soldiers” are often 30 or more times less massive than the “queens”. The soldiers recognize colony members but vigorously attack trematodes from other colonies, whether of the same or of different species. The colony can quickly make more soldiers and less queens if threatened by the presence of competing trematodes nearby. Division of labor by caste has been found in 15 trematode species in 3 families and may be common. The first discovery of castes in flatworms in 2011 was a surprise, as previously eusocial behavior was mostly known from termite, bee and ant colonies. As with eusocial trematodes, social insect colonies are comprised mostly of clones. (The one possibly eusocial mammal, the odd naked mole rat is nonclonal, having long lived, closely related female and male workers living with a single reproducing queen in a hypoxic underground colony.)



Life stages and life cycles are often complex in **digenean trematodes**





upper illustration: a social trematode life cycle with 2 intermediate hosts Hechinger **Trends Parasitology** 2023

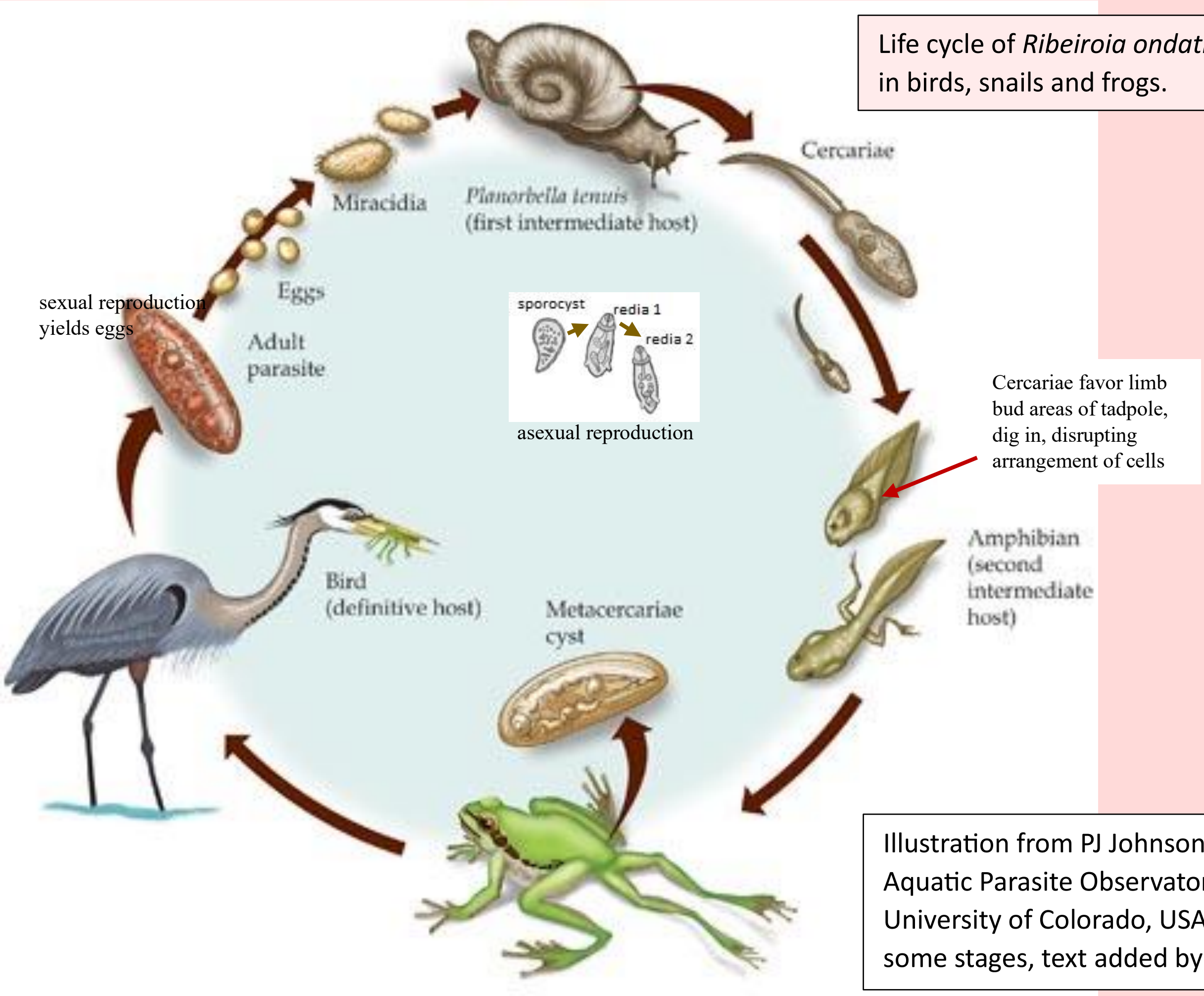
left: multi-generation polyembryonic larval asexual reproduction in *Himasthla* Whyte **Biology Letters** 2021

Life cycle of a trematode with 2 aquatic intermediate hosts. This includes social trematodes such as *Himasthla* or *Philophthalmus sp*. Eggs in bird feces yield miracidia that infect snail first intermediate hosts. 'Parthenitae' are produced by clonal parthenogenesis in a sporocyst and then in 1 or more generations of reproductive redia. The resulting redia colony may also make soldiers, and it clones cercariae which disperse by swimming to become metacercaria in or on a second intermediate host, invertebrate or vertebrate (commonly snails, mussels, crabs or fish). After the second intermediate host is eaten by a vertebrate final host the metacercaria becomes a sexual adult fluke.

Smaller *Himasthla* sp. B soldier left, defending its colony by attacking the larger reproductive redia of a different trematode, *Parorchis acanthus*. Note dispersive tailed cercaciae and next generation redia inside the reproductive. Darkfield illumination, magnification unknown, but most *Himasthla* soldiers are about 0.5 mm long extended. image R Hechinger at phys.org press release regarding Resetarits et al, Social trematode standing army size 2020

Trematodes Gone Wild part 4, giving a host a leg up (not in a good way)

In 1995 kids on a fieldtrip to a local pond in Minnesota USA were shocked to find lots of badly deformed frogs. After considering pollution and other causes university researchers zeroed in on a trematode parasite and in 1999 Johnson and colleagues showed experimentally cercariae of *Ribeiroia ondatrae* cause leg deformities in frogs. Other suspected causes, including nutrient and pesticide runoff (pond #1 was adjacent to a corn field) and reduced biodiversity boost *Ribeiroia* populations and thus increase frog limb deformities. Extra, deformed or missing limbs are caused when cercariae burrow into a tadpole's developing limb bud. Deformed legs make it harder for tadpoles to swim and frogs to hop, boosting the chance they are eaten by a heron and thus complete the fluke's lifecycle.



Life cycle of *Ribeiroia ondatrae* in birds, snails and frogs.

Illustration from PJ Johnson, Aquatic Parasite Observatory, University of Colorado, USA. some stages, text added by me

Frogs and salamanders are threatened not only by parasites but by deforestation, pollution, pandemic chytrid fungal infection and climate change. The US Geological Survey estimates US amphibian populations are declining at 3.8% per year. With "compound interest" in 20 years amphibians may disappear from half the places they now live. The 2010 International Union for Conservation of Nature (IUCN) Red List found 24% of amphibian species are endangered worldwide. Few species of insects are officially endangered, largely because we don't care enough about insects to keep track. Most entomologists think we are causing an" insect apocalypse". Insect populations may have declined 50% in the past 40 years. Some experts debate this, as populations boom and bust, but a halving of bug populations agrees with multiple surveys finding an approximately 2% per year decline. **Insect, fish and amphibian population crashes** may be a canary in the coal mine warning that we have hurt mother nature so badly we humans could be the next to be hurt. There are 8 billion humans and about 10 quintillion insects on earth. If we keep halving insect and amphibian populations, who knows the consequences to the balanced ecosystems that support human life?

Limb deformities in frogs caused by the trematode *Ribeiroia ondatrae*
top Pacific treefrog *Pseudacris regilla,* bottom Plains leopard frog *Rana blairi*

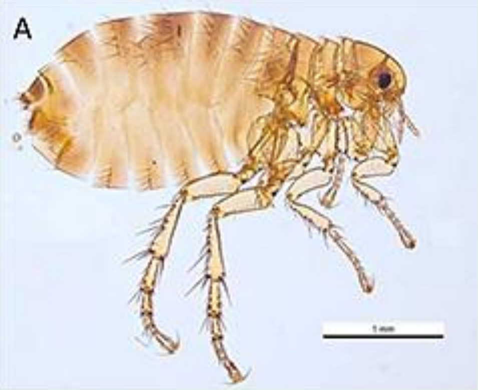
Deformed frogs don’t jump as well, so are more likely to be eaten by a heron. For millions of generations, cercariae of *Ribeiroia ondatrae* that (at first blindly) burrowed into the limb bud spots of tadpoles were a little more likely to pass their genes to the next generation. So over time the parasites became powerful disrupters of frog leg development.

Photos from Johnson Laboratory and Aquatic
Parasite Observatory, University of Colorado, USA

Linnean Taxonomy

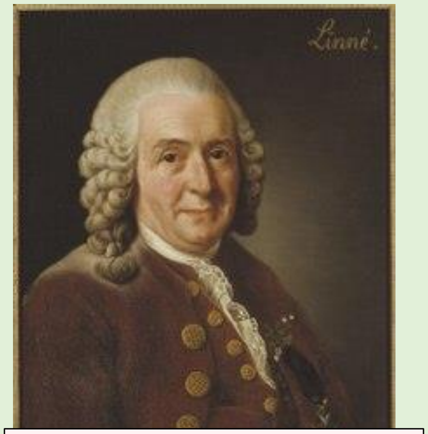
Taxonomy is the science of classifying organisms. Swedish genius Carl Linnaeus (b1707-d1778) set up the system scientists still use today (with modifications) in his *Systema Naturae* in 1735. His system is a hierarchy of different sized groups from Kingdom down to species, and an individual species is referred to by a binomial name that includes genus and species, i.e. *Homo sapiens*. Linnaeus classified organisms according to obvious physical characters. Naming and classifying organisms gave Darwin a head start when he did his work one century later. Modern taxonomy usually classifies organisms into ranked groups based on their evolutionary ancestry (a literal family tree). Many but not all taxonomic groups are clades, all the descendants of a common ancestor. We break that rule sometimes because some subgroups seem distinct (birds are in a clade with dinosaurs, and insects are in a crustacean clade). We have also added more levels to taxonomy, particularly at the top levels after late 20th century biochemical and DNA methods allowed us to better see distinctions between microbes. There are just 2 domains: Prokarya (bacteria and archaea) and Eukarya (everything else). Taxonomy continues to change as science gets more data. There are 4 or 5 eukaryotic kingdoms in most schemes now days: Protozoa, (Chromista), Plantae, Fungi, Animalia.
An example of modern classification, that of the human flea, an animal first named by Linnaeus:

bar 1 mm, K Walker Museum Victoria



Domain	Eukarya
Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta
Order	Siphonaptera
Family	Pulicidae
Genus	Pulex
Species	irritans
Binomial	*Pulex irritans*

named by Linnaeus in 1758



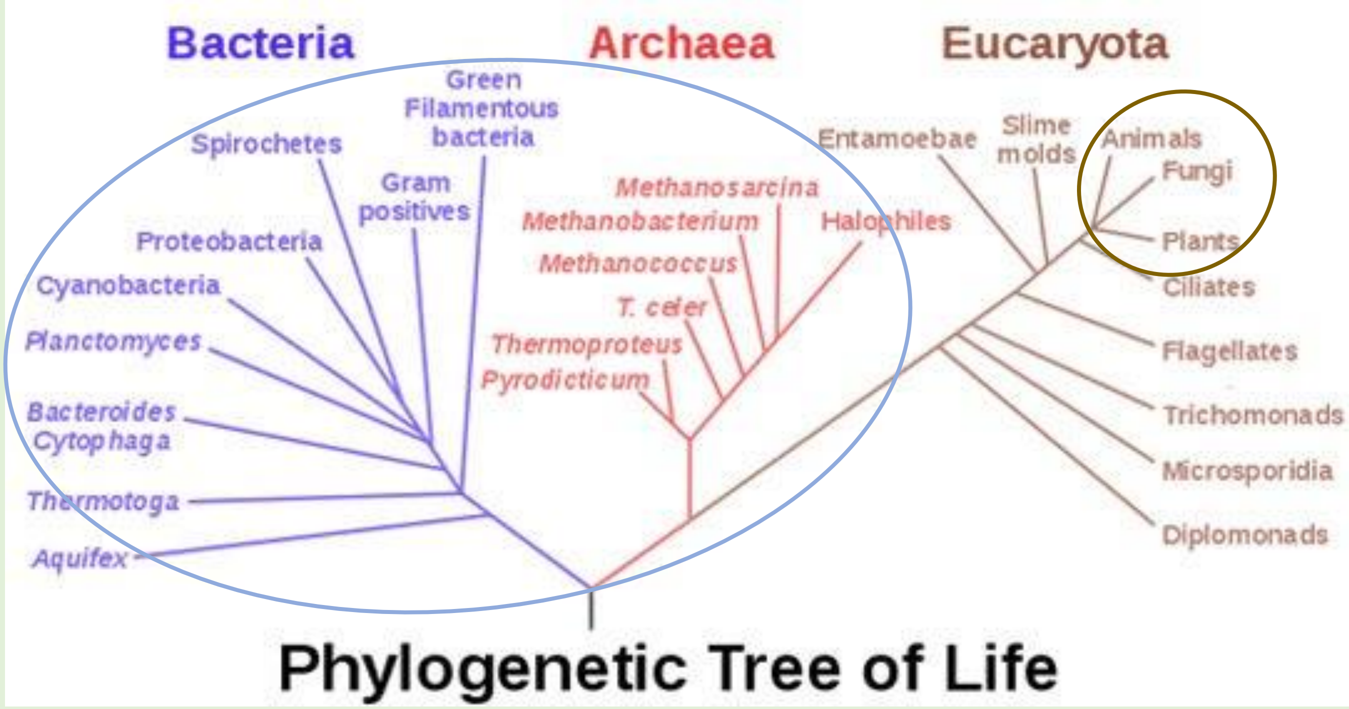
Linnaeus 1775 by Roslin, wikipedia

Evolution explains a lot

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 known fossils were fewer and the mechanisms of inheritance were unknown (Czech monk Gregor Mendel discovered the laws of genetics in pea plants in the 1860's but no one knew it for decades). Evolution is now 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 data) central theory in biology that makes sense of puzzling new evidence from research, like 5 legged frogs and the COVID virus changing to be less deadly. I see evolution in action in the hospital as bacteria continually evolve to be resistant to the most used antibiotics.

Upon careful reflection Darwin's theory seems inevitable. People create different kinds of pigeons and other animals through selective breeding. Nature does much the same thing. Darwin saw there is a struggle in nature for organisms to survive and produce offspring. It is observed that all organisms come from the reproduction of parent organisms, that there are differences between individuals in a group (i.e. some are faster or slower) and that parents make imperfect copies of themselves (we now know genes are shuffled and may mutate). 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 new 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 is no designer, just the results of how natural life processes work out based on chemistry, physics and maths.

Most life is prokaryotic: Bacteria and Archaea, very tiny, no nucleus, on left. All multicellular organisms are in the small brown circle on the right. Between are Protists, bigger than bacteria, but mostly microscopic, nucleated single celled life. Carl Woese used ribosome RNA data for his 1990s tree.



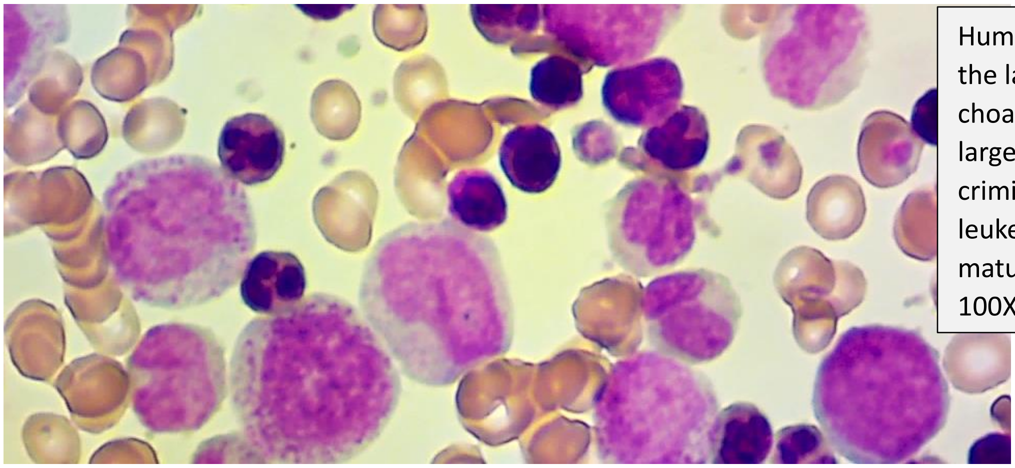
Cell Theory and the Theory of Evolution

These 2 great ideas are the foundation of modern biology and underlie scientific agriculture and healthcare. Both theories arose in mid19th century Europe and are reproven a million times daily in applications around the world. (Soviet biologist Lysenko rejected Darwinism 1930s-60s as capitalist, worsening famines in Russia and Mao’s China.)

As atoms make up matter, cells are the basic unit of all life. Robert Hooke saw tiny boxes in cork with his microscope in 1665, calling them “cells”. German scientists Theodor Schwann and Matthias Jakob Schleiden had better microscopes and in 1838 proposed all plants and animals are made up of cells. The multi-talented Rudolph Virchow completed the basic cell theory in 1855 by proclaiming all cells come from preexisting cells, in Latin *“omnis cellula e cellula.”*

Around the same time, a humble genius In England solved the mystery of why we have so many different kinds of animals and plants. In 1859 Charles Darwin published *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. Evolution is so logical it is inevitable. Living beings copy themselves, but often slightly imperfectly. In the struggle to live and breed some individuals can run faster or are otherwise favored. So the next generation comes from survivors that are a little different. Some populations get split up by barriers. Over deep time (life on earth is about 3.8 billion years old) a single cell divided zillions of times and became all the amazing life on the planet today, from bacteria to *Paramecium* to mushrooms to trees 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 worked out, explainable by chemistry and physics.

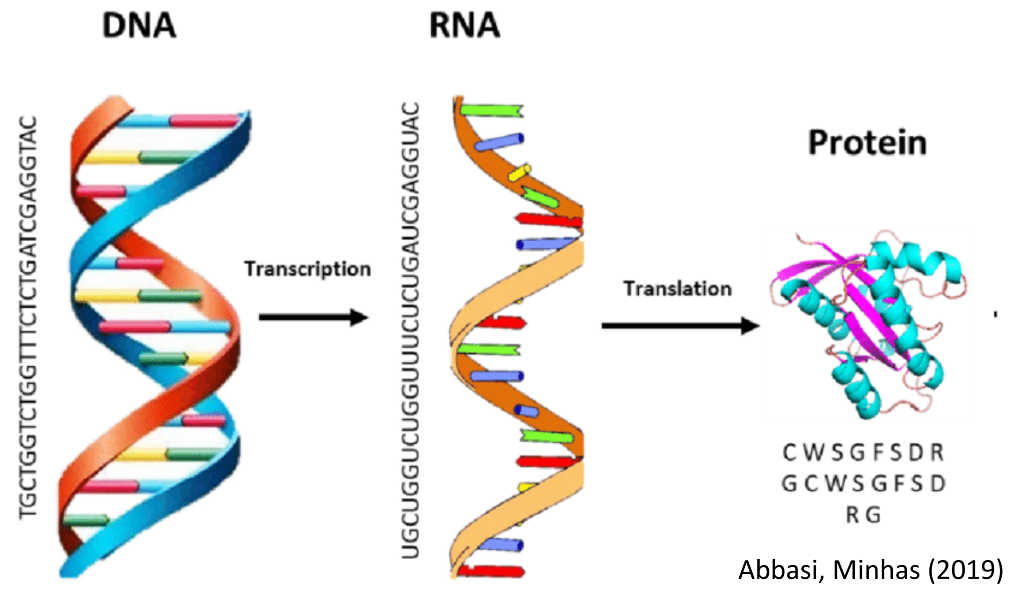
Run the evolutionary clock backwards and eventually you get to the first living cell. Every cell in every being is a direct descendant of that single cell (if life arose more than once, the others got wiped out long ago). Everything alive today uses variations of the same DNA and protein biochemistry of our common ancestor cell. That first very tiny cell grew and split into 2 daughters. They also split into 2 and so on. Thanks to exponential math they filled the oceans. Some learned to make food from sunlight, producing oxygen as a toxic waste. After billions of generations there were many different kinds of cells and one day one gobbled up another as lunch, but the lunch didn’t die. The “lunch” became mitochondria, finding a nice new place to live and paying rent with high energy molecules. Naked DNA got organized into chromosomes inside a nucleus and life was off to do bigger things. With extra stored information, daughter cells could be different than each other yet still programmed to cooperate with each other. Multicellular life was born: bodies made of thousands or millions or eventually trillions of cells. Inside your body is a wonderland. It’s like a bustling city with skyscrapers and highways and factories populated by 35 trillion resident cells. All those cells came from 1 cell formed when your mom and dad had sex. And those sex cells came in turn from earlier and earlier cells. We have a massive convoluted family tree, all the way back to the first bacterial cell at a steaming hot, sulfurous deep sea vent 3.8 billion years ago. During all those years there were only a few great leaps; most of the changes were tiny and incremental (but added up over time). You, *Homo sapiens*, might be one of the great leaps, or not. You have the abstract reasoning required for complex language and math, leading to civilization and eventually to modern technologies powerful enough to destroy the planet or to create a paradise on earth. Please choose the latter.



Human blood cells, distant descendants of the last universal common ancestor and of choanoflagellate protozoa. In this case the large purple cells belong to a dangerous criminal gang (suspect chronic myelogenous leukemia with many large blasts and smaller maturing neutrophils, 1950’s hospital slide) 100X oil obj, cropped, RBCs about 7 µ wide

The central dogma of molecular biology: DNA ⇨ RNA ⇨ protein

Czech monk Gregor Mendel worked out laws of inheritance in pea plants in the 1860s. In the early 20th century chromosomes and their gene subunits were studied extensively in *Drosophila* (fruit flies). Chemists found the most important chemicals in cells seemed to be a myriad of different proteins (polymers of amino acid building blocks) that made up cell structures and carried out complex chemical reactions. In 1953 Watson and Crick (after seeing Rosalind Franklin's data) solved the puzzle of the helical shape of the DNA (deoxyribonucleic acid) molecule. Armies of scientists figured out how life works on a molecular level: the **central dogma** of biology. Information in DNA is *translated* into mRNA, which leaves the nucleus and is *transcribed* into a unique protein by ribosomes (very complex nanomachines consisting of protein and special RNA). Based on the physics of water solutions, each protein self folds into a unique 3D shape that lets it do its job. The human genome was first sequenced in 2003. It is mind boggling. Each of your 200 very different types of cells contains the same complete blueprint for a human. An amazing system of **epigenetic** chemical signals turns genes off and on as needed so the single cell fertilized egg inside your mom could develop into the unique 35 trillion cell mass that is you. Epigenetics also means genes are not destiny. Much more ill health is caused by poverty and social discrimination than by genes. Parasitic diseases show this pattern, becoming mostly relegated to poor people not getting much of the wealth created by modern technologies.



Abbasi, Minhas (2019)

Genomics has been a boon to biology research in the past 50 years. We can now explore evolutionary relationships through DNA trees, clone and genetically manipulate cells and animals, and can sequence the whole transcriptome (all the mRNA) of human cells to see what genes they are using (and which are silent).

Mirroring society, scientists have long been racist and thought discovering genes proved their case. Linnaeus did not include dark skinned peoples in *Homo sapiens*. A century ago most anthropologists were "**scientific racists**" (a pseudoscientific oxymoron) and eugenicists who believed blacks would corrupt human bloodlines (a belief repeated by Hitler and a recent US president). Racism is pervasive, but **scientifically, race does not exist**. **Race is a social construct.** Some 19th and 20th century US state laws said people with 1/8 or even "one drop of black blood" were black. Yes, you can sometimes guess the ancestry of a person from skin color, but DNA tests show you are often wrong. Virchow tried to divide 19th century German school kids into racial groups using scientific measurements but he couldn't: variation within each group was bigger than the difference between purported racial groupings.

Parasite glossary

Parasite an organism that lives in or on another, taking nutrients that would have benefited the host (many viruses, bacteria and fungi fit the definition but we usually call them acute pathogens instead)

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

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

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

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 often 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 stages through which the parasite grows, reproduces and transmits itself in 1 or more hosts

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

Heteroxenous aka **digenean** or **indirect**; life cycle requires one or more additional 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. predation, or via uncooked meat)

Iatrogenic transmission by medical care (i.e. from 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

Kleptoparasites steal food from other species, i.e. frigatebirds and hyenas

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

Brood parasitism raised by parents of another species, i.e. cuckoo birds lay eggs in another species’ nests

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

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

Carcinogenic parasite increases cancer risk; some blood flukes can cause bladder, bile duct or liver cancer

Parasite and Biology glossary part 2

Aberrant Host	one that cannot support parasite development aka a dead end host
Accidental Host	not the usual host, but can support parasite development (with or without dispersal)
Paratenic Host	an accidental intermediate host that may be able to pass on the parasite
Autoinfection	transfer of new parasite stage within one host, as occurs with some nematodes and flatworms
Hyperinfection	repeated autoinfection leading to high parasite load and dissemination beyond usual infected organs (i.e. in the nematode *Strongyloides* runaway hyperinfection can be fatal)
Cestodes	tapeworms; parasitic flatworms with bodies like a segmented ribbon, no mouth
Trematodes	flukes; parasitic flatworms with bodies shaped like a narrow leaf
Cloaca	single opening of reproductive, GI and urinary systems (in most vertebrates except mammals)
Coprozoic or Coprophagous	living in or eating feces; organisms typically harmless and pass through if ingested
Cyst	**(**organism in) a resistant membrane or wall, can be a parasite dispersal stage
Dispersive stage	form of organism that travels by swimming or drifting in water, or inside a motile host
Endemic	means a disease is native to a particular place, typically cases occur much of the time
"ex"	came from indicated host (i.e. *ex Homo sapiens* denotes specimen removed from a human)
Exotic	a non-native species; if a nuisance or harmful then called an **invasive** species
Facultative/Opportunistic Parasite	lives a free living or a parasitic life cycle, depending on opportunities
Filaria	a family of insect transmitted nematodes that live in host lymph and blood
Filariform larva	infectious stage of many parasitic nematodes, may penetrate skin and go to internal organs
Genotype	the genetic (DNA) code of an organism **Phenotype** is the observable appearance
Phylogeny	hereditary and evolutionary relationships of different groups (**Taxonomy** mostly follows it)
Gravid	filled with eggs, as in a mature (female or hermaphrodite) nematode, or a tapeworm proglottid
Helminth	any parasitic worm (and sometimes used more broadly for any worm)
Hologonic	having a single sex (female) colony; **or** gonads with germ cells throughout, i.e. *Strongyloides*
Hydatid Cyst	cysts within cysts of larval *Echinococcus* sp. tapeworms, causes hydatid disease in organs
Instar	life stages in arthropods and nematodes, defined by molting
Oviparous	produces eggs **Viviparous** gives birth to formed, often motile young
Prokaryote	tiny cells without nuclei (bacteria, archaea) **Eukaryote** has nucleated cells, all other life
Senso lato	(describes a taxonomic group) in a broad sense **Senso stricto** in a strict sense
Syncytium	smaller cells fused into a multinucleate cell, i.e. helminth tegument, muscle fibers, infection

Sex Glossary (because sex is more complicated than I remembered)

Reproduction and sex can be accomplished in many confusing ways. With variations, the birds and the bees inherited sex from protists: eggs and sperm fuse to become the next generation. Sex has big advantages over splitting in half: by reducing what is passed on to a single cell most parasites are given the slip, and by combining genetic information from two parents, variation is boosted so evolution has more to select from.

Asexual Reproduction- genetic material is passed from only 1 parent to the next generation.

Binary fission- most cells pinch in 2 during mitosis, a few multicellular organisms also divide evenly
Budding- creating a growing bubble or blob that cleaves off, as in yeast and hydra
Fragmentation- metazoan (multicellular animal) dividing into many parts, as in some free living flatworms
Vegetative propagation- many plants and some animals (sea squirts) grow new individuals from runners
Sporogenesis- creation of small resistant forms as in ferns, moss, many fungi (by mitosis or meiosis)
Sporulation- in apicomplexan protists the oocyst nucleus divides by meiosis to form 8 haploid sporozoites
Merogeny- protist merozoites undergo additional rounds of asexual reproduction (i.e. erythrocytic cycle)
Sporocyst- trematode miracidia nucleus divides stepwise to form multiple germ balls which each become a redia, that may undergo another round of asexual reproduction before making multiple cercariae
Polyembryony- a single zygote becomes multiple identical clone embryos. Trematode sporocysts and redia are polyembryonic, as are social insect workers and armadillos (always identical quadruplets). Via differences in gene expression genetically identical clones become phenotypically different castes.
Parthenogenesis- development from an unfertilized egg, common in bdelloid rotifers, nematodes, social insects, rare vertebrates ("virgin births" are known in zebra sharks, boa constrictors Komodo dragons, turkeys). Parthenogenesis in flowering plants is apomixis (clonal seed production).
Clones- asexual processes may create multiple genetically identical copies (phenotypes vary in some cases)

Sexual Reproduction- gametes derived from 2 parents join to become a single celled zygote which develops into an organism or organisms. Because of its advantages sex is common among bacteria (by conjugation and environmental gene acquisition) and eukaryotes (gamete based sex).

Mitosis- standard eukaryotic cell division with 2 copies of each chromosome to both diploid daughter cells
Meiosis- Two sets of cell divisions create gametes with segregation of chromosomes into haploid sets
Diploid- full set of chromosomes from mom and dad (46 in most people, 23 pairs inc. 2 sex chromosomes)
Haploid- half set of chromosomes; found in gametes (4 in fruit flies, 23 in man, 39 in dog, 52 in carp)
Somatic cell- almost all cells in body, diploid, divide by mitosis
Germ cell/germ line- haploid gametes and those diploid cells that will become gametes
Gametes- sex cells: female egg/ovum and smaller motile (in higher animals) male sperm
Zygote- the single cell formed by fusion of gametes, i.e. the fertilized egg
Types fertilization- 1.conjugation 2. external fertilization 3. internal fertilization 4. alternation of generations
Alternation of generations- diploid and haploid every other generation; obvious in corals and "lower" plants; in "higher" plants and animals only tiny gametes are haploid
Hermaphroditic- aka monoecious; both sex gonads in one individual (same time or sequential), common in plants and invertebrates; some can self-fertilize but others mate with another hermaphrodite
Unisexual- aka dioecious or gonochoric ; separate sexes, individuals are male or female
Gender- a human social construct, not always the same as biologic sex

(I am now an honorary biology professor, having succeeded in making sex boring.)

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 a privileged place in a privileged time.

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 clean 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 bites by infected mosquitoes or reduviid bugs. **Better living standards, scientific knowledge and public health measures eliminated the most significant human parasites from most developed nations.**

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 6.6 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 denounce the dictator) borne by the powerless majority. **Most people (4.3 billion) live in 95 countries under authoritarian regimes today**.

Some people may feel sad 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. You weren't born in medieval times, living 30 miserable years with lice and worms. 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 imperial power), and by your political and economic systems. **You likely enjoy the full modern wealthy liberal package: democracy, good schools, free speech and press, private property, strong currency, universal health care** (except US).

Left-
Mitchell, a malnourished parasite infested West African boy at a *Medicines sans Frontiers* clinic, Liberia, 2004

Right-
Irena, a *Micscape* contributor from Russia

Parasites US doctors should know about (but may not)

Because most harmful parasites have been eliminated from rich countries, doctors in the United States learn very little about parasites during their training. Most doctors know about (but may forget are protozoan parasites) vaginal ***Trichomonas*** infections and diarrhea caused by ***Giardia*** or ***Cryptosporidium***. The first two are treated with a common antibiotic, and most US doctors have never prescribed an anti-parasitic drug, unless maybe for a **scabies** mite skin rash. Perhaps 60 million people in the United States have asymptomatic latent toxoplasmosis, but that condition is not treated.

Cutaneous larva migrans and **swimmer's itch** are harmless rashes after swimming or wading in contaminated water. They are caused by larval hookworms or schistosome cercariae penetrate your skin, but aren't serious because you are a dead end host for dog, cat, or duck parasites.

One intestinal helminth is still endemic in the United States, the nematode ***Enterobius vermicularis***, also called **pinworm**. It is most common in daycare age kids and although not harmful it can cause severe rectal itching and can recur after treatment. 20 to 40 million Americans may have pinworms, although many have no itching. There are shameful cases of doctors laughing at patients who thought they had intestinal worms when they really did have pinworms. Pinworm is diagnosed by an old fashioned "scotch tape" test and a microscope (not something that most providers can order from the lab) and can be treated.

It is true that in developed nations real symptomatic helminth infections are rarer than patients with a false belief that worms are migrating through their body (about 2 to 27 per 100 thousand people per year in studies of delusional parasitosis). Because sometimes the patient is right, it might be prudent to do a CBC with differential (looking for eosinophilia, which is much more common with allergies than parasites). 3 stool specimens for microscopic examination for parasite eggs and select serology tests might be indicated if a patient has risks for parasites.

Immigrants to the U.S. from developing countries, **travelers** returning from the tropics, and patients who are **immunosuppressed** by disease or medications are prone to parasitic infections. Very rarely Americans got parasites from food prepared by immigrant cooks, or produce that came from Latin America. Travelers can have various parasitic hitch hikers. Many parasitic infections (Chagas disease, schistosomiasis) require years of reinfections before they cause illness, so a brief vacation is low risk. A very serious acute infection in returned travelers is falciparum malaria. Most years in the United States about 2000 people have malaria, and 7 of them died in 2018. Some of these victims came back from vacation in the tropics, some were immigrants returning from visiting family back home, and a very few cases were acquired in the southern U.S. or from blood transfusions. If you run a fever after returning from a trip to the tropics see a doctor and emphasize that you were in the tropics and could have malaria. Special blood smears and serology tests can diagnose malaria. Unfortunately, many US doctors lack training about parasites. If you do not think the doctor has diagnosed you correctly, seek another opinion. If you slowly get ill with intestinal or nonspecific symptoms after foreign travel and have reason to think it is parasitic, see your primary doctor if you trust them. Or consider going to a travel medicine clinic as they know more about parasitic diseases than most U.S. healthcare providers. People with weak immune systems caused by cancer treatments, HIV infection or some arthritis drugs are more susceptible to all infections, viral, bacterial and parasitic. Even with infection they may not run a fever or feel very sick.

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Micscape is a high quality website hosted in the UK and made great by amateur contributors from around the globe. *Micscape* Magazine always has lots of good information for hobby microscopists wanting to learn more about how to do it yourself.

For 2024 I offer *Micscape's* readers a series of articles about parasites, illustrated in part from my slide collection.

I am incurably curious about parasites and keep thinking I should know more. I had fun learning about amazing adaptations by trematodes, and I look forward to discussing trematode human diseases next time. 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. Don't be freaked out by parasites. They are everywhere in nature, but seldom cause harm to humans in the developed world, with a few exceptions.

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

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