Biology of Macroparasites

Grant Foster

Learning Outcomes For this Week

1. **Understand the definition of "macroparasite" and the diverse set of taxonomic and life-history strategies it can encompass. (Eg. simple vs complex life cycle, trophic transmission)**
2. **Explain why biological features of macroparasites make us model them differently than microparasites (total number, aggregation, intensity, environmental stages, long sublethal infections, continual reinfection)**
3. **Be able to explain each piece of and modify the basic macroparasite model**
4. **Articulate under which conditions macroparasites can cause population cycles in hosts**
5. **Be able to articulate where we can find macroparasite (both on earth and in the environment)**
6. **Explain why macroparasites are a risk to human health, and common pathways of human macroparasite infection**
7. **Be able to explain what aspects of a disease system is described by prevalence, intensity, and the frequency distribution of parasites in a host**

What is a Macroparasite?

Macro = Large!

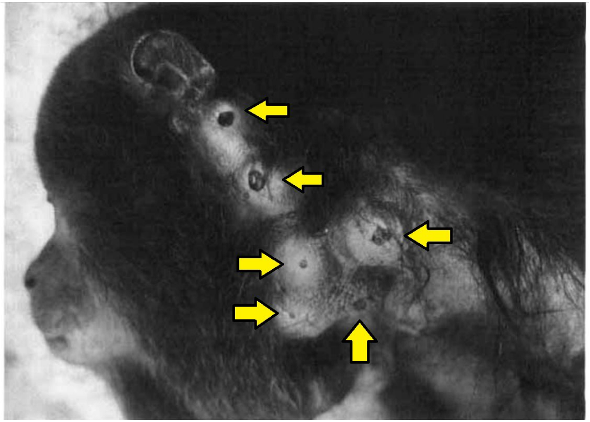
Life history strategy used by multiple groups!

Arthropods

- Chelicerate (ticks, mites)
- Insects (bot flies, fleas, lice)

Most are ectoparasites, with some exceptions

- (lung mites, bot flies)



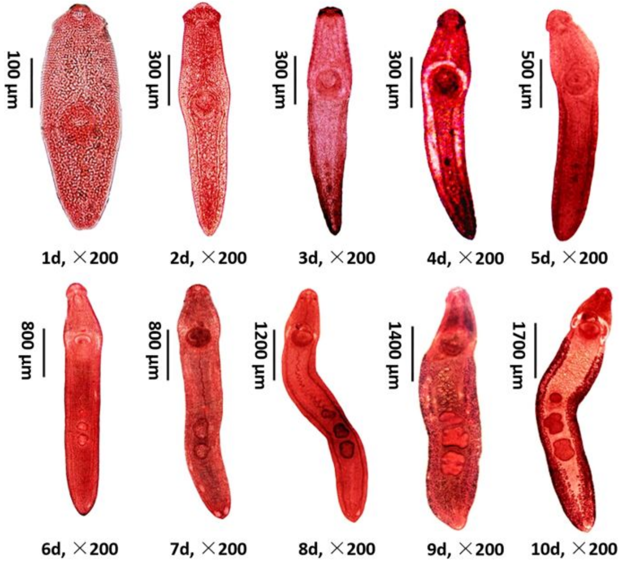
What is a Macroparasite?

Helminths are generally macroparasites

Cestodes

Trematodes

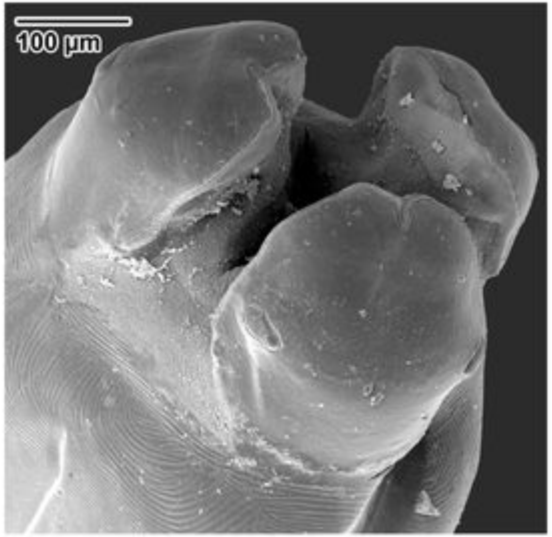
Nematodes



Macroparasite Life Cycles

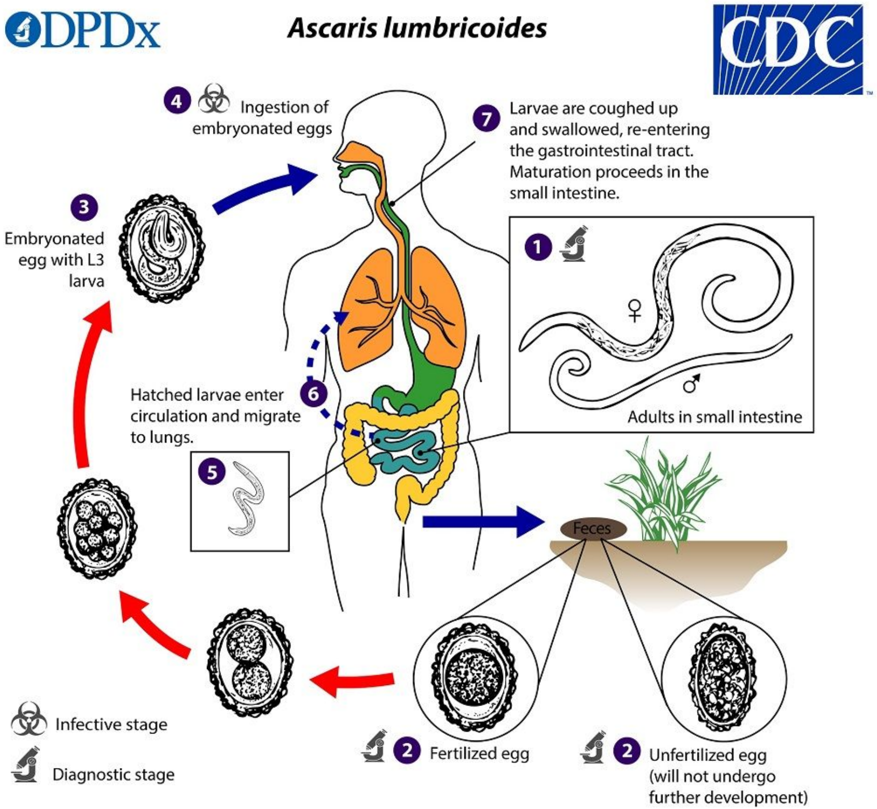
Ascaris lumbricoides (Nematoda)

Most common macroparasite of humans

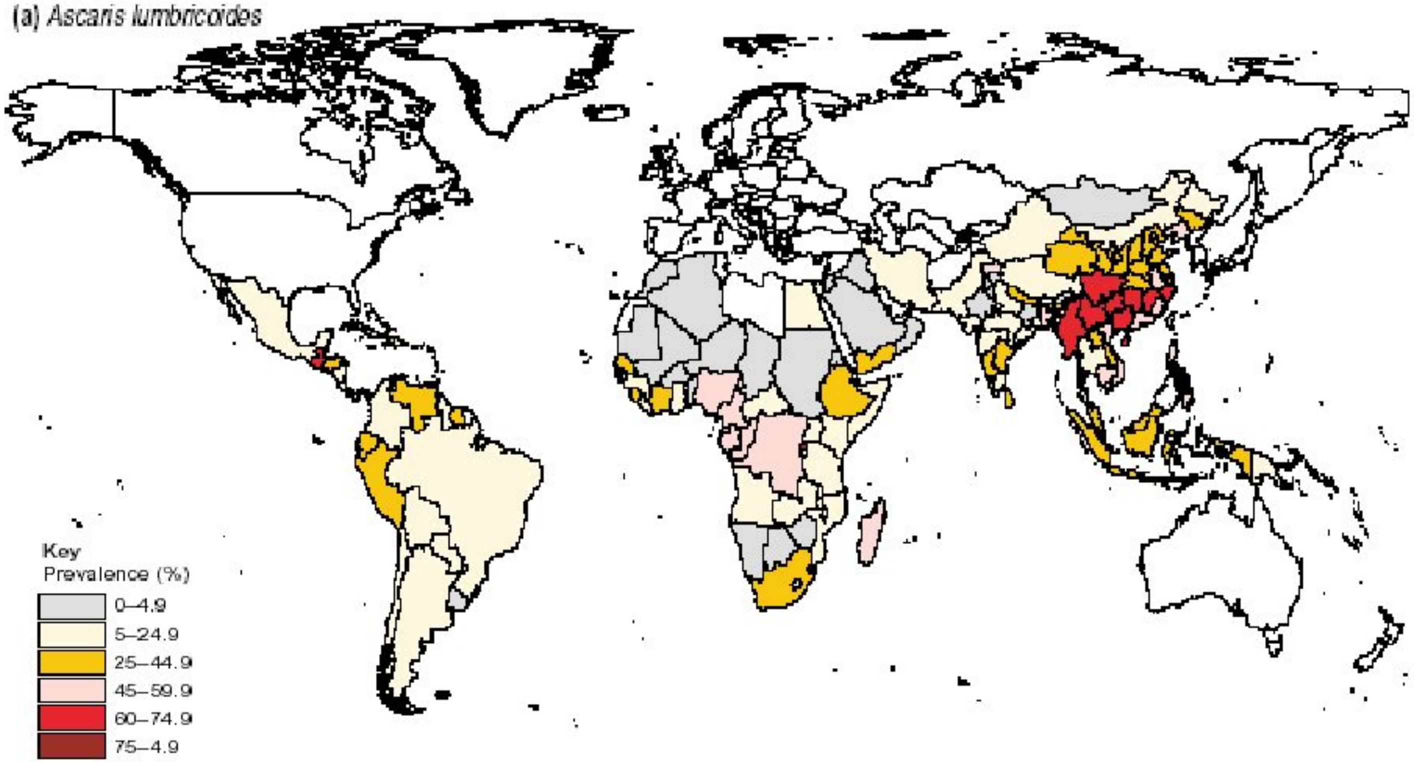


- > 1 billion people infected worldwide
- inhabit intestines
- females produce ~200,000 eggs per day
- Adults live for 1-2 yrs

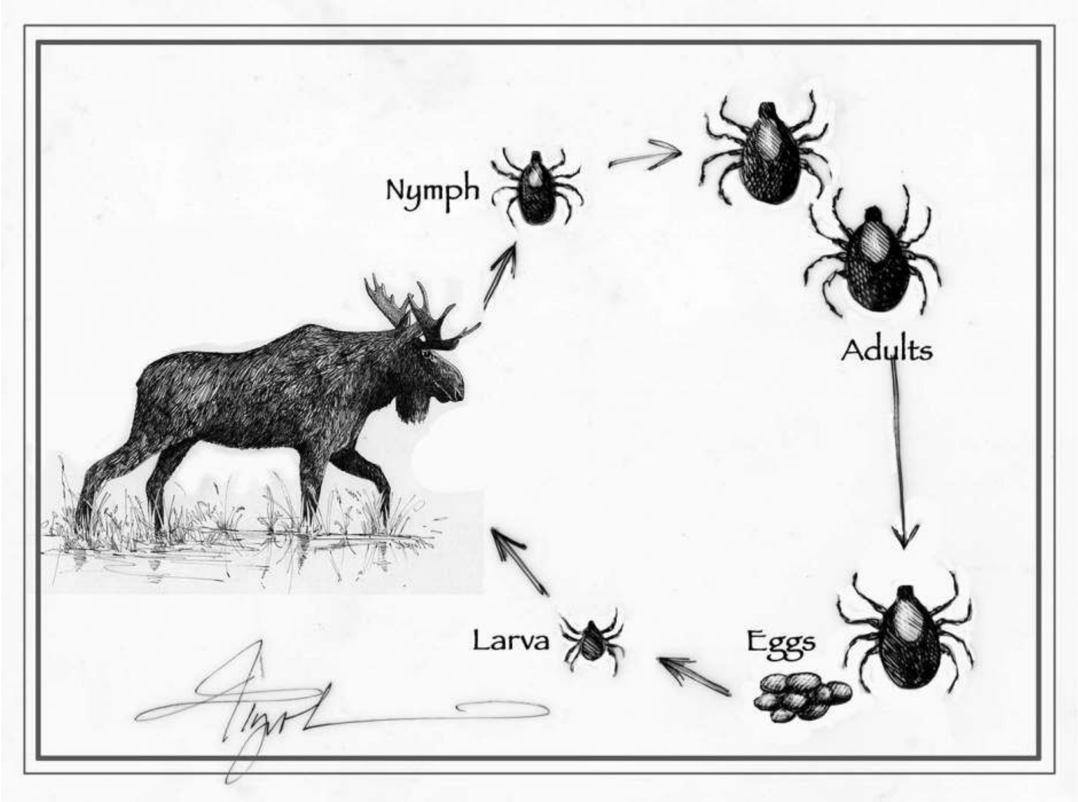
Simple (Direct) Life Cycle



Global distribution of *Ascaris*



Simple (Direct) Life Cycle



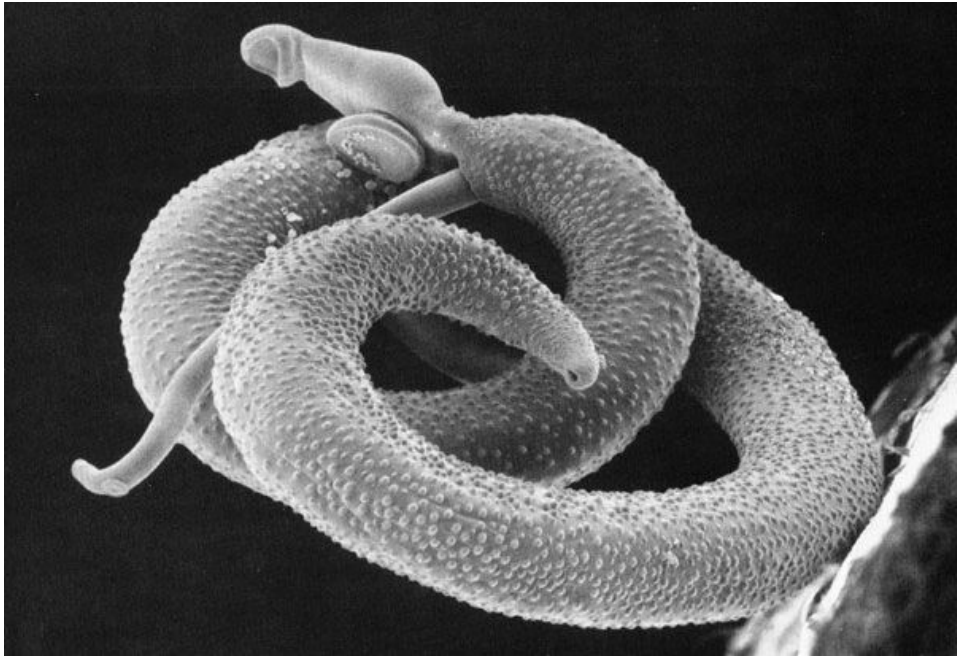
“Winter tick” or “Moose tick”
Dermacentor albipictus

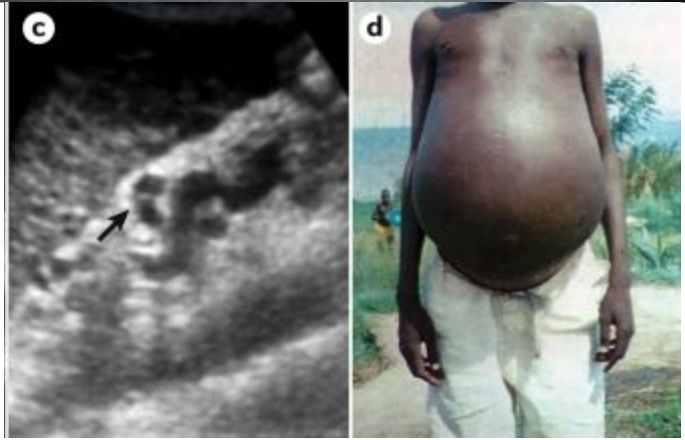
Feeds on one moose through all stages, unlike many other species

Can have huge burdens (50k+), can contribute to huge mortality of calves. Burden positively associated with warming summers

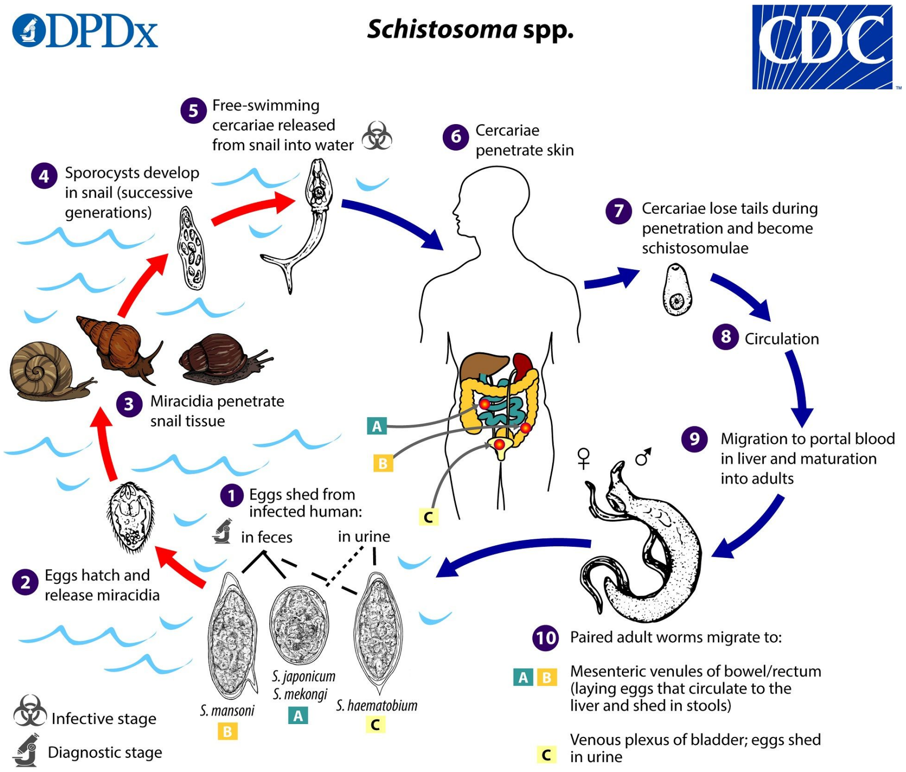
Complex (indirect) life cycle

Schistosoma (blood flukes)

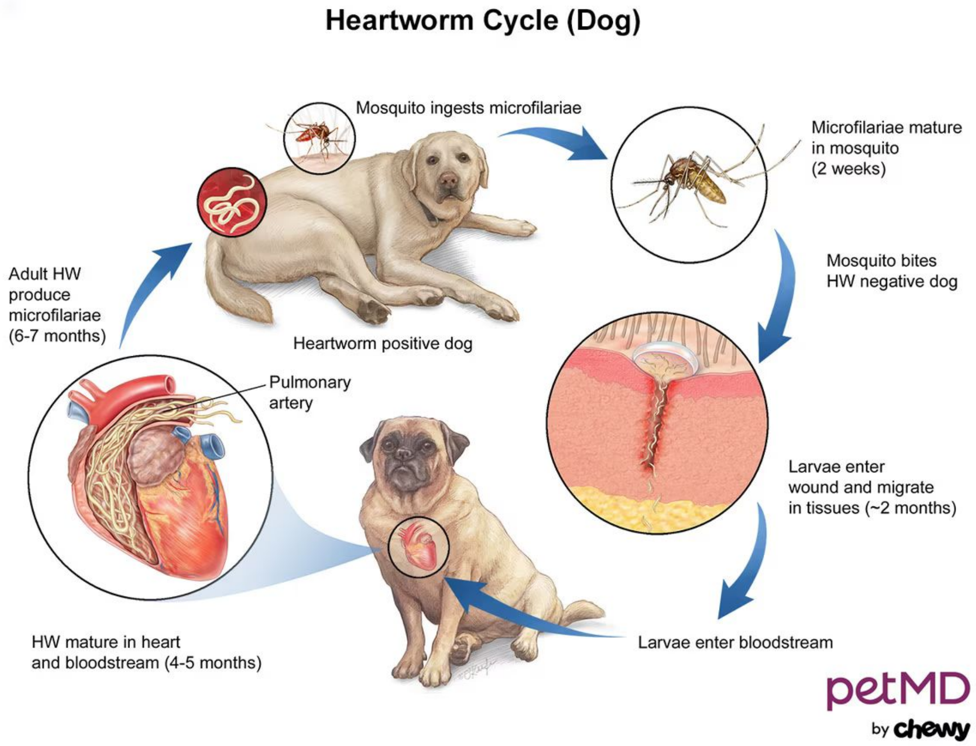




Complex (Indirect) life cycle

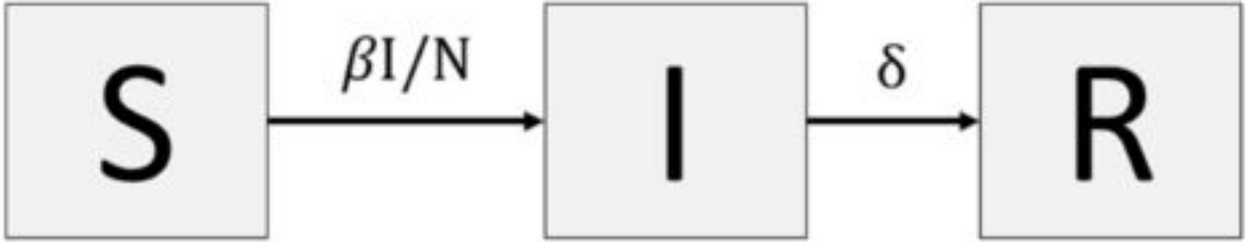


Complex (Indirect) life cycle



Reminder: Our Basic Microparasite Model

A. Classical SIR model



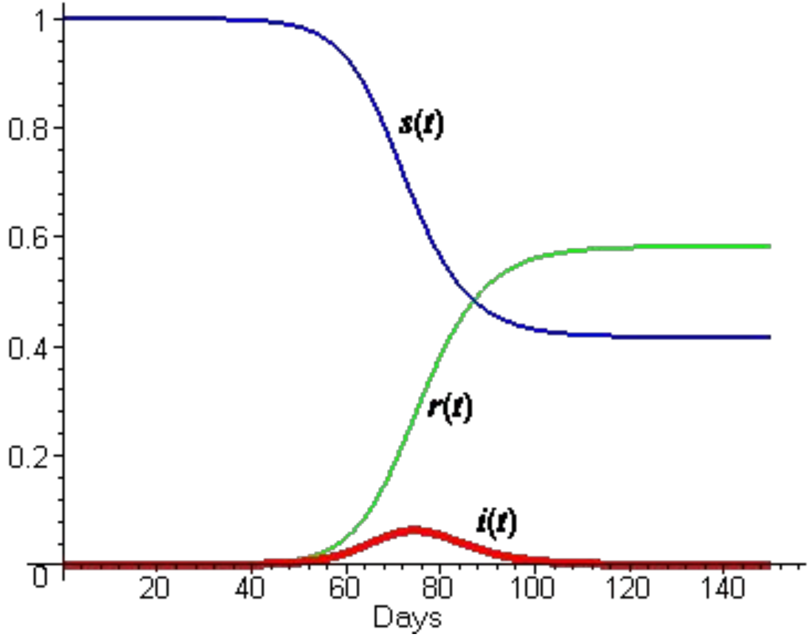
Equation

$$\frac{dS}{dt} = -\frac{\beta IS}{N}$$

$$\frac{dI}{dt} = \frac{\beta IS}{N} - \delta I$$

$$\frac{dR}{dt} = \delta I$$

Why would we need to think about macroparasites differently than microparasites?



Why would we need to think about macroparasites differently than microparasites?

Distributions and aggregation

Why might keeping track of the number of parasites explicitly matter?

Distributions and aggregation

Prevalence: – proportion of population affected (for micro- and macroparasites)

Intensity: mean number of parasites per infected host (# parasites / # infected hosts)

These are two really common metrics of population-level infection burden! What might they be missing?

Reminder: Distributions and aggregation

Most hosts harbor just a few parasites

A few hosts often harbor a lot!

One method of describing aggregation is by fitting a negative binomial distribution

Dispersion parameter of k

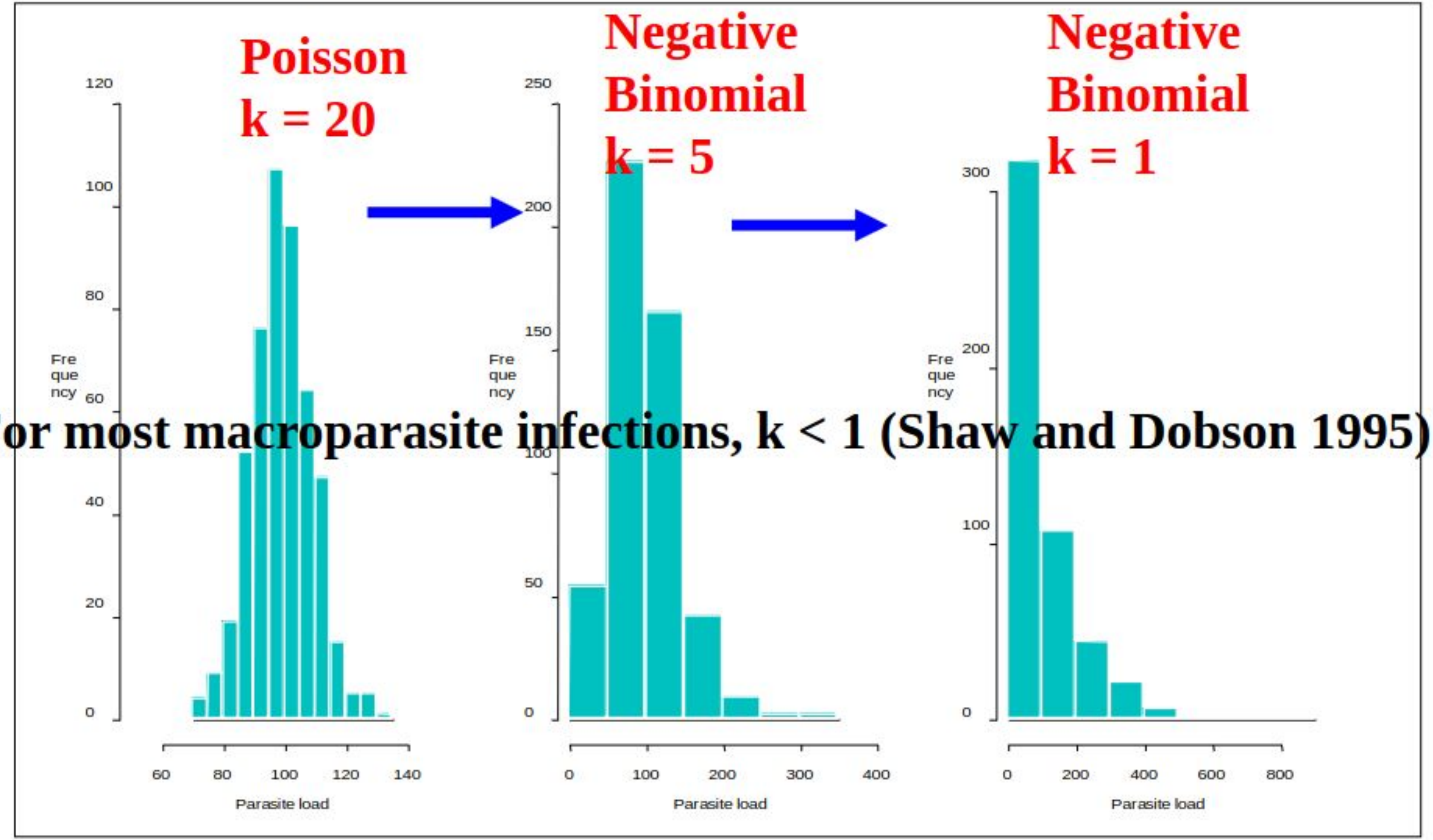
- Poisson (random): $s^2 = m$
- Negative binomial (aggregated) defined by: $s^2 = m + m^2/k$
- k = dispersion parameter

- When k is large (> 20), distribution becomes random

- Poisson (random): $s^2 = m$
- Negative binomial (aggregated) defined by: $s^2 = m + m^2/k$
- k = dispersion parameter

- When k is large (> 20), distribution becomes random
- When k is small (approaches or falls below 1), distribution is aggregated

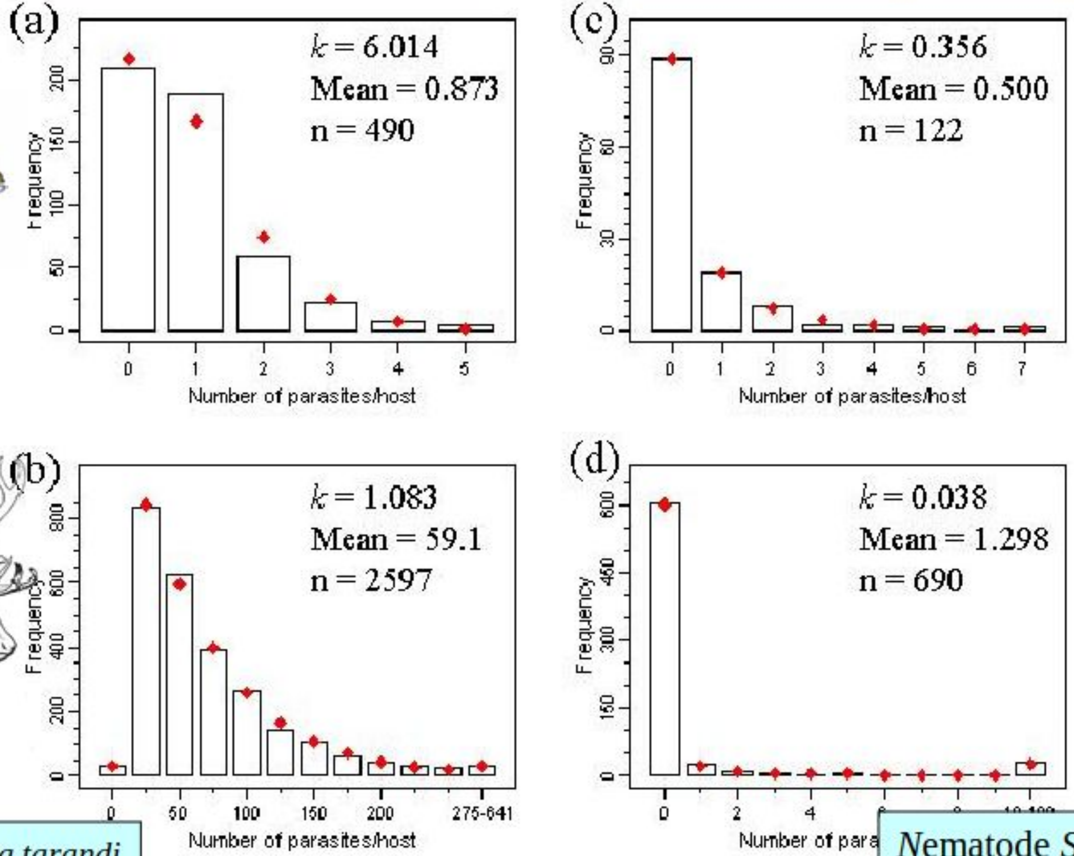
In all cases, mean = 100

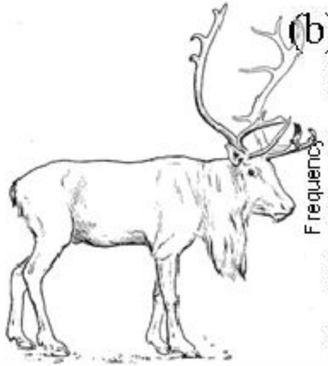


For most macroparasite infections, k < 1 (Shaw and Dobson 1995)

Tapeworm *Triaenophorus nodulosus* in Perch *Perca fluviatilis*,

Nematode *Porrocaecum ensicaudatum in* Common Starling *Sturnus vulgaris*

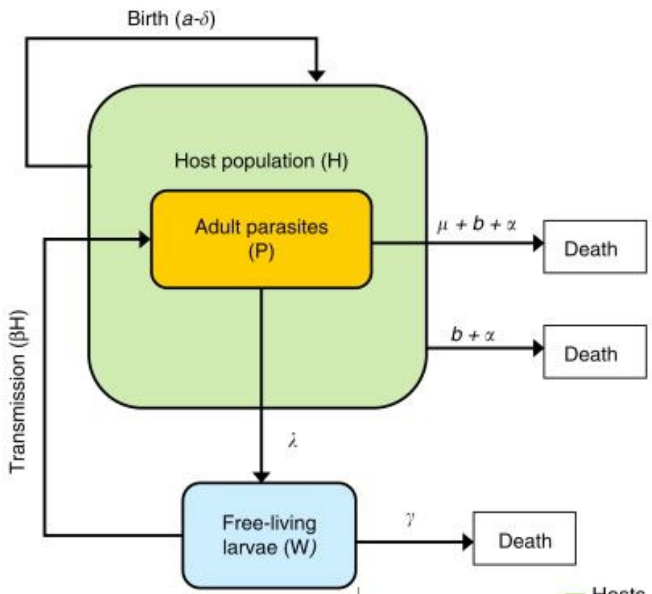




Warble fly *Hypoderma tarandi* in Reindeer *Rangifer tarandus*

Nematode *Spiroxys japonica in* Frog *Rana nigromaculata*

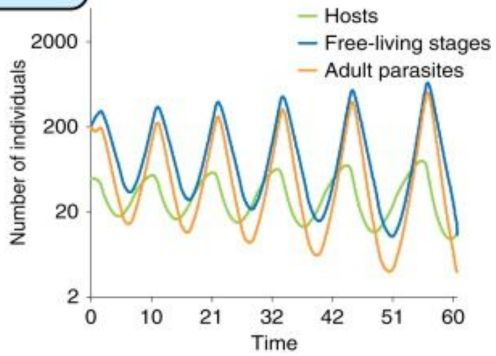
Let’s look at a macroparasite model…

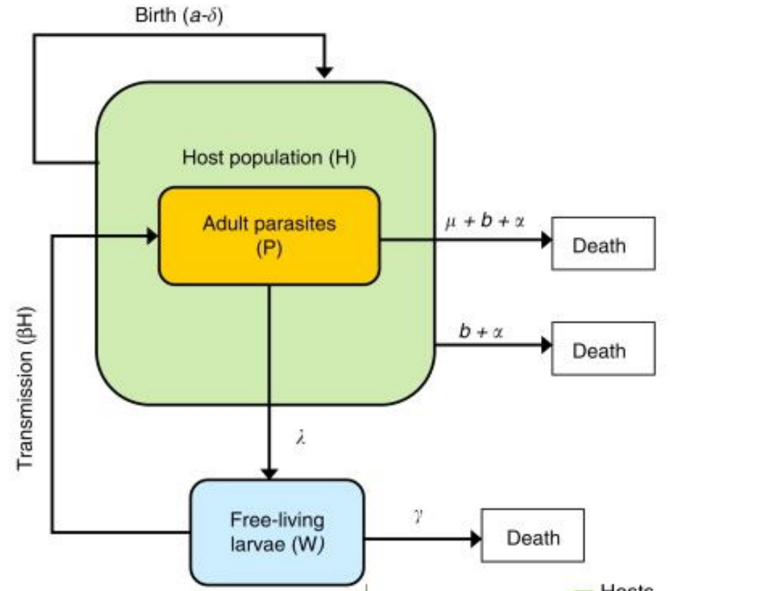


$$\frac{dH}{dt} = (a-b)H - (\alpha + \delta)P$$

$$\frac{dP}{dt} = \beta WH - (\mu + b + \alpha)P - \alpha \frac{P^2}{H}\frac{(k+1)}{k}$$

$$\frac{dW}{dt} = \lambda P - \gamma W - \beta WH$$





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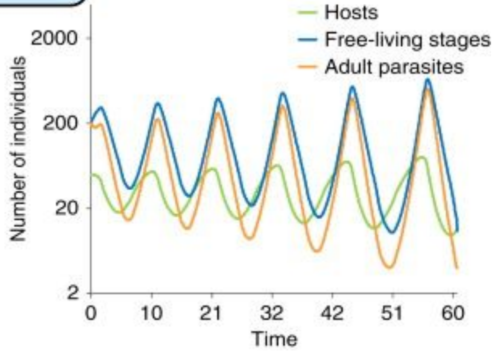

How do would you translate the following pieces of information into "equation speak"? (assume your dt is in units of days)

1. Adult parasites shed an average of 137 larvae per day
2. Parasite larvae (W) persist in the environment for an average of 2 weeks.
3. There is no parasite-induced reduction in host fecundity

R0 of the macroparasite model

Remember the definition of R0 for the microparasite model?

For macroparasites: *Number of adults parasites (P) produced per parasite during its lifespan (assuming a newly introduced parasite in a population of uninfected hosts)*

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R0 of the macroparasite model

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Gross reproduction = λβH

Life Expectancy = 1/Parasite Death Rate

$$R_0 = \frac{\lambda \beta H}{\text{Parasite Death Rate}}$$

R0 of the macroparasite model

R0 = Gross Reproduction x Life Expectancy

Gross reproduction = λβH

Life Expectancy = 1/Parasite Death Rate

$$R_0 = \frac{\lambda \beta H}{\text{(Parasite Death) (Loss of Larval Worms)}}$$

R0 of the macroparasite model

$$R_0 = \frac{\lambda \beta H}{(\mu + b + \alpha)(\gamma + \beta H)}$$

Death inside host

Background host death

Parasite-induced mortality

R0 of the macroparasite model

$$R_0 = \frac{\lambda \beta H}{(\mu + b + \alpha)(\gamma + \beta H)}$$

Decay of larvae in environment

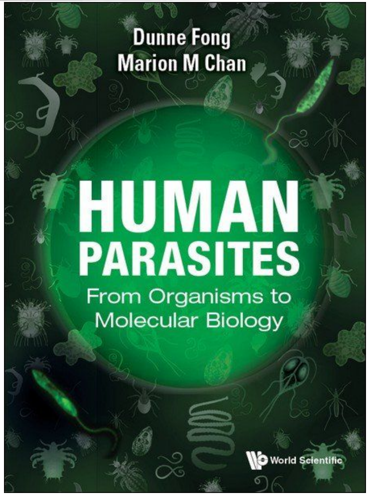
Larvae "lost" to transmission

Shifting Gears: Burden of Macroparasites on Human Health

TABLE V. Transmission strategies. (++) = very important, (+) = important, (–) = relatively important, N = number of species.

Mode of transmission	Example	Transmission efficiency	Importance of human density	Prevalence >5% or widespread N	Morbidity–mortality N
Direct, passive egg/cyst/spore	Whipworm	Low	++	31*	13*
Direct, active search	Hookworm	↓	++	17	12
Direct, contact	Lice	↓	+	10	7
Vectored	Leishmaniasis	↓	–	26	19
Trophic transmission as predator host	Lung fluke	High	–	48*	20*

* *Toxoplasma gondii* included in both categories.



(Numbers from Kuris, 2012).

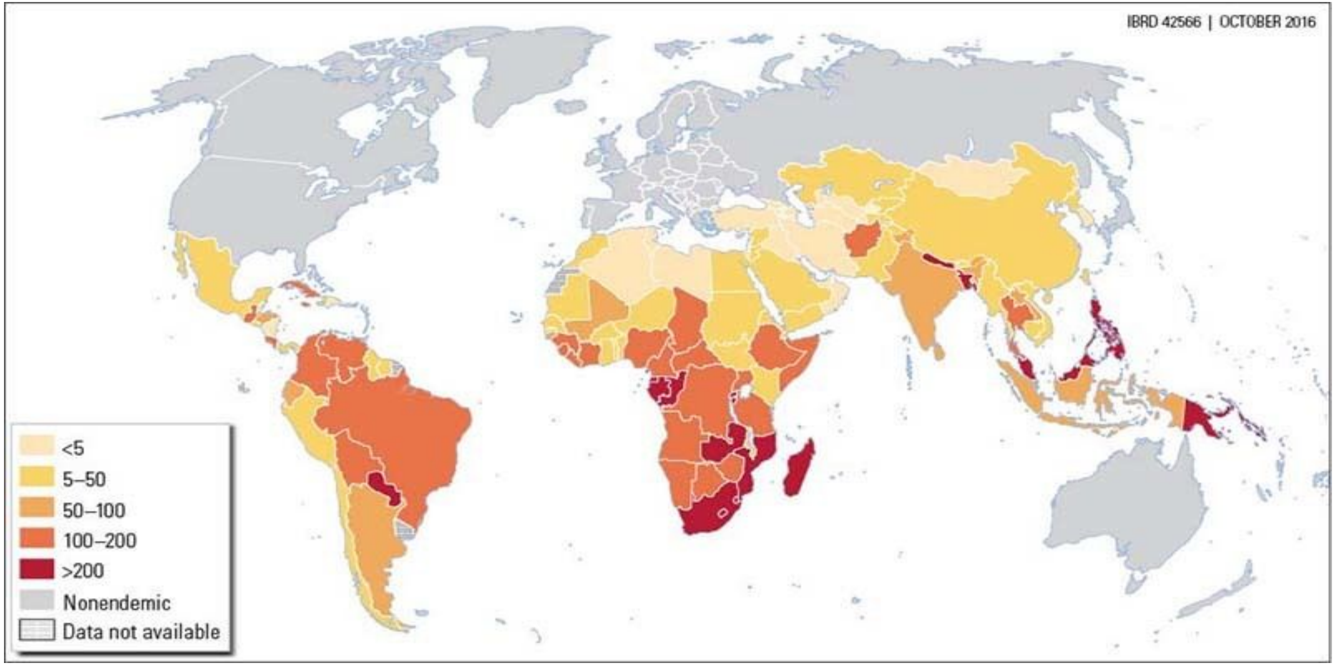
Helminth Infections are a major burden on many tropical developing countries

Table 1
The major human helminthiases and their global prevalence and distribution

Disease	Major etiologic agent	Global prevalence	Regions of highest prevalence
Soil-transmitted nematodes			
Ascariasis	*Ascariasis lumbricoides* (roundworm)	807 million	Developing regions of Asia, Africa, and Latin America
Trichuriasis	*Trichuris trichiura* (whipworm)	604 million	Developing regions of Asia, Africa, and Latin America
Hookworm	*Necator americanus*; *Ancylostoma duodenale*	576 million	Developing regions of Asia, Africa, and Latin America (especially areas of rural poverty)
Strongyloidiasis	*Strongyloides stercoralis* (thread worm)	30–100 million	Developing regions of Asia, Africa, and Latin America (especially areas of rural poverty)
Filarial nematodes			
LF	*Wuchereria bancrofti*; *Brugia malayi*	120 million	Developing regions of India, Southeast Asia, and sub-Saharan Africa
Onchocerciasis (river blindness)	*Onchocerca volvulus*	37 million	Sub-Saharan Africa
Loiasis	*Loa loa*	13 million	Sub-Saharan Africa
Dracunculiasis (guinea worm)	*Dracunculus medinensis*	0.01 million	Sub-Saharan Africa
Platyhelminth flukes			
Schistosomiasis	*Schistosoma haematobium*; *Schistosoma mansoni*; *Schistosoma japonicum* (blood flukes)	207 million	Sub-Saharan Africa Sub-Saharan Africa and Eastern Brazil China and Southeast Asia
Food-borne trematodiases	*Clonorchis sinensis* (liver fluke); *Opisthorchis viverinni* (liver fluke); *Paragonimus spp.* (lung flukes); *Fasciolopsis buski* (intestinal fluke); *Fasciola hepatica* (intestinal fluke)	>40 million	Developing regions of East Asia
Platyhelminth tapeworms			
Cysticercosis	*Taenia solium* (pork tapeworm)	0.4 million (Latin America only)	Developing regions of Asia, Latin America, and sub-Saharan Africa

Distribution of DALYs for Soil-Transmitted Helminth Infections, per 100,000 Population

Disability-Adjusted Life Year



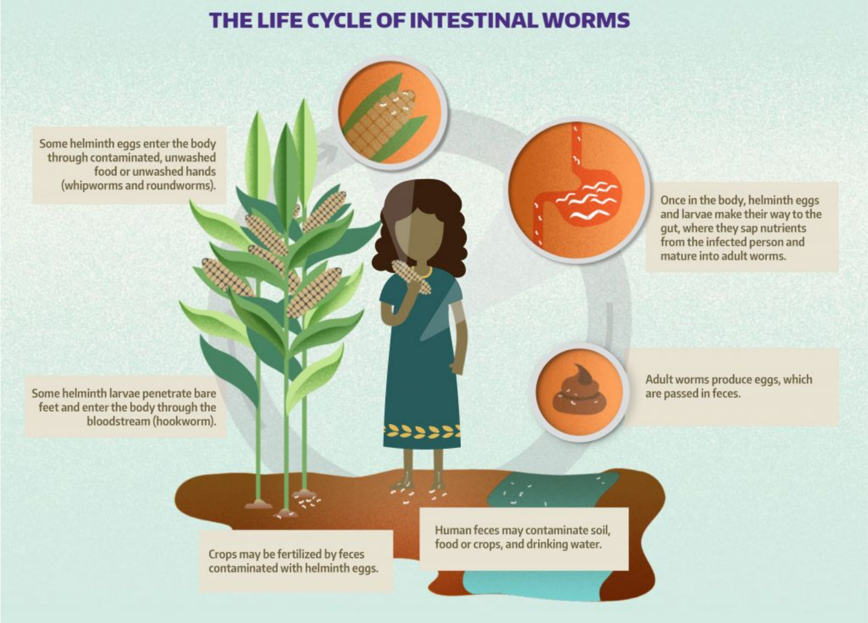
https://www.ncbi.nlm.nih.gov/books/NBK525254/figure/pt3.ch13.sec3.map2/

Transmission Pathways of soil-transmitted helminths

Infective stages released through feces, which can contaminate soil of water

Infection can occur through

- Contamination of uncooked fruits or vegetables
- Contaminated water
- Direct with contaminated soil



Intervention Strategies: How do we target helminthic diseases?

Collectively we often treat “soil transmitted helminths” under an umbrella due to common coinfections, and because many helminths respond to similar treatments

Distribution of anthelmintics - (Albendazole, Levamisole, Mebendazole, etc).

- Multiple distribution/targeting options
  - All individuals/community-wide
  - Target particular at-risk or highly transmitting groups
  - Target based on infection status/intensity

Rapidly effective, but confer no lasting immunity (fast reinfection)

Risk of anthelmintic resistance (Avramenko et al., 2020).

Intervention Strategies: How do we target helminthic diseases?

Education Programs

- Informing on transmission pathways
- Emphasizing the importance of personal hygiene and sanitization practices to prevent transmission
- Can be community-wide education programs, or implemented into existing schools

Can be helpful in some contexts (Gyorkos et al., 2013 found that education programs significantly reduced burden four months after antihelminthic)

However, in many impoverished areas, the problem is resources-not knowledge.

"Deprived communities understand the importance of the safe disposal of fecal matter and of wearing shoes, but poverty often hinders the construction of latrines and the purchase of shoes." (Mascarini-Serra, 2011)

Intervention Strategies: How do we target helminthic diseases?

Sanitation and Personal Hygiene

- Construction of latrines, toilets, sewer, water treatment systems
- Can help meaningfully reduce endemicity of helminth infections in humans

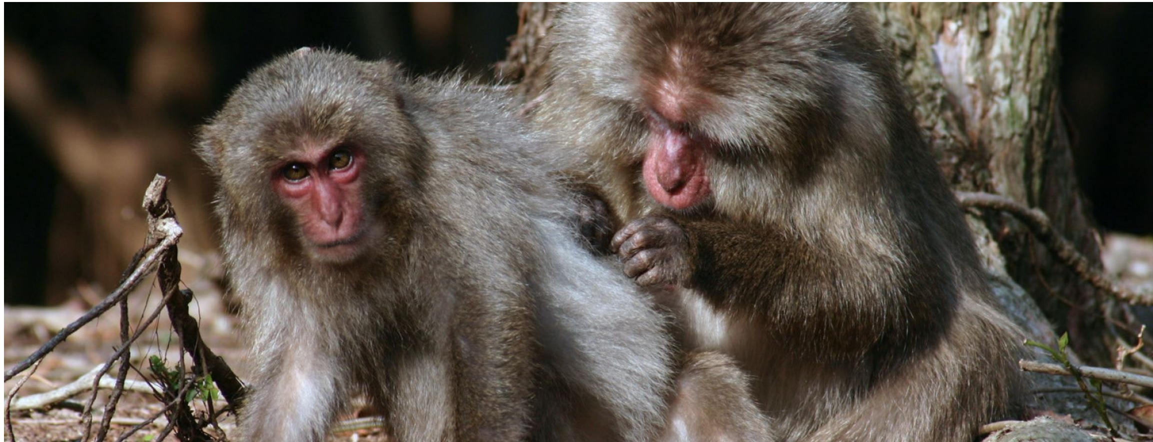
- Can be expensive
- Often require more community or governmental-level organization, as less is up to individual control
- At a community-level, sanitation may not meaningfully reduce transmission until coverage is high (Mascarini-Serra, 2011).

Intervention Strategies: How do we target helminthic diseases?

Vaccination?

- Not yet - it's a tough problem
- Helminths are quite good at evading host immune responses
- Many have stage-specific expression of antigens-
    - We've yet to identify proteins expressed across all life stages suitable to be a vaccine candidate for any STH (Wong, 2020).

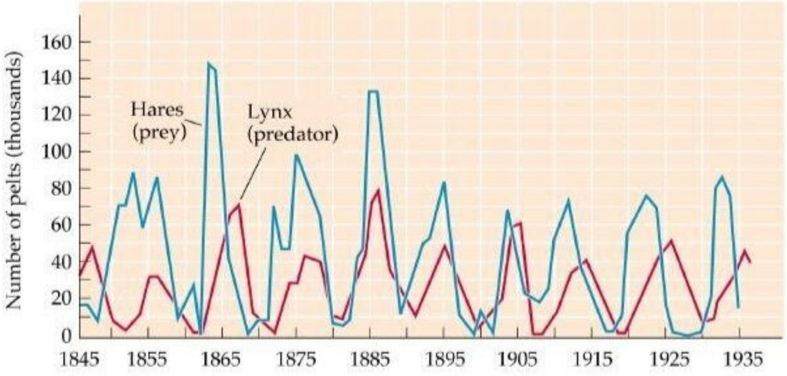
Macroparasites in Wildlife Populations:

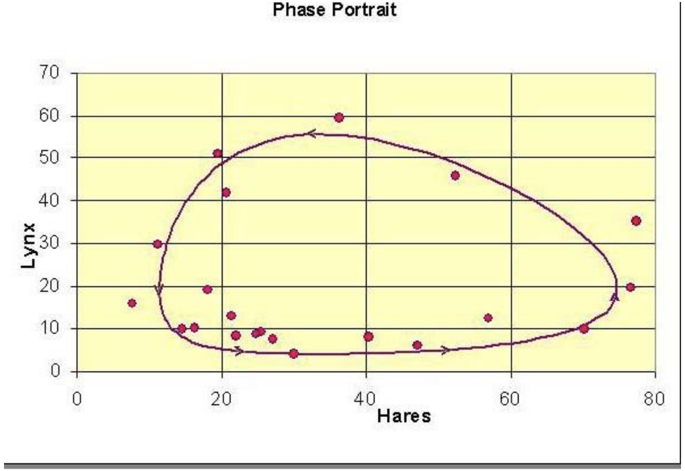


Can parasites cause population cycles?

One of the common features of classic predator-prey models is the presence of regular population cycles

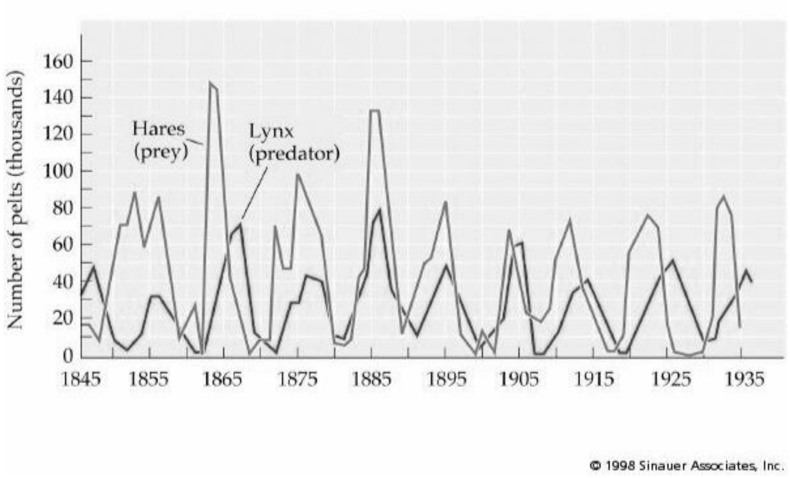
Due to the combination interdependence of predator and prey growth rates and lagged time effects

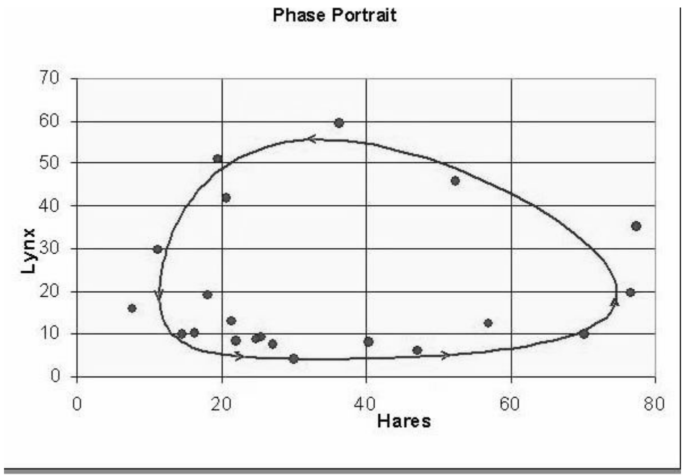




Can parasites cause population cycles?

Can parasites cause similar cycles?

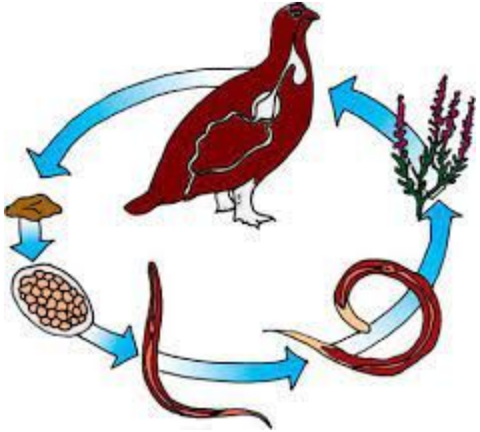




Can parasites cause population cycles?

Study system: Red Grouse (*Lagopus lagopus scoticus*) in Northern England

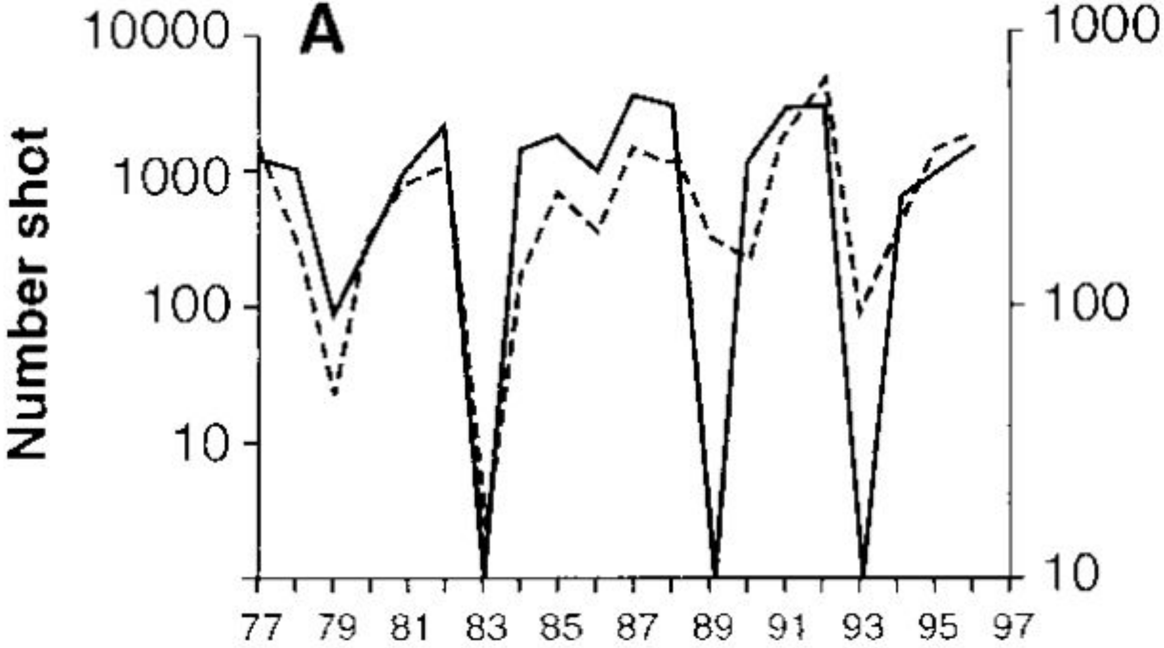
Infected by the nematode *Trichostrongylus tenuis*



Can parasites cause population cycles?

We have well-resolved population data from hunting records

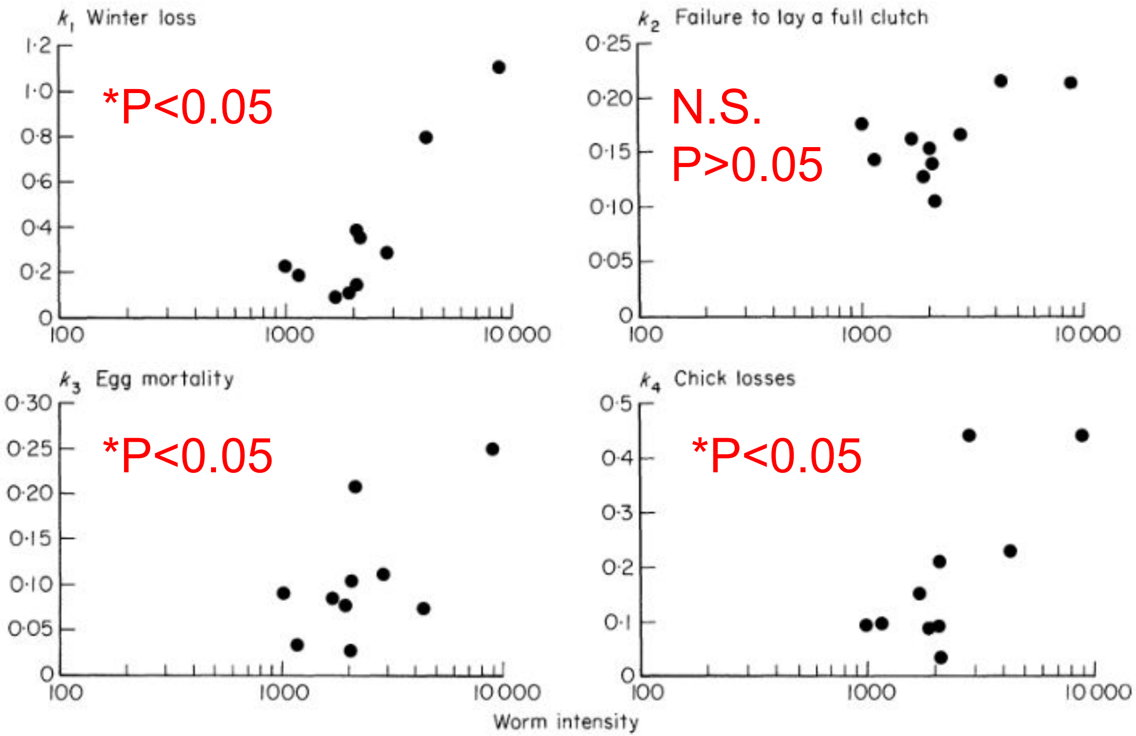
Hosts do cycle, but is it due to parasites?



Can parasites cause population cycles?

Do parasites affect host demography?

Yes!



Can parasites cause population cycles?

Does host population size affect parasite demography?

Yes!

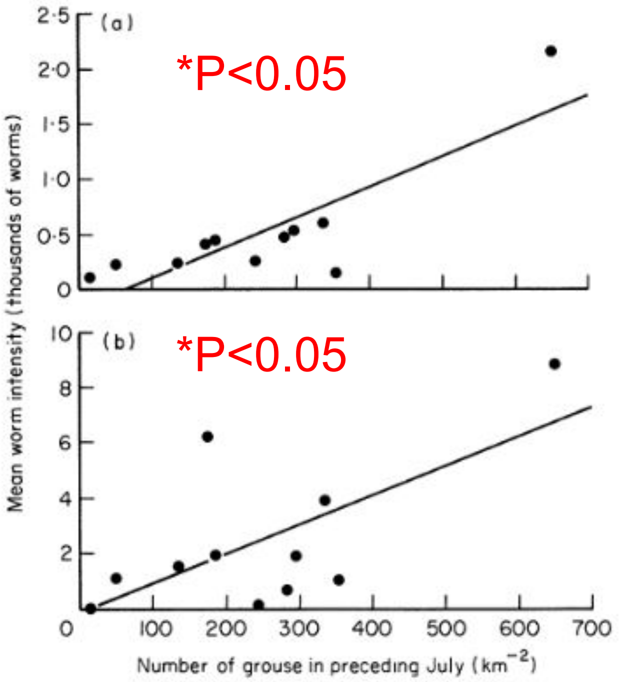


Fig. 2. Increase in parasite burden during (a) summer and (b) winter infection periods in relation to density of grouse in the preceding July.

Can parasites cause population cycles?

Does removing parasites dampen host cycles?

Experimentally treated subsets of host populations with anthelmintic

Found that removing parasites dampened cycles!

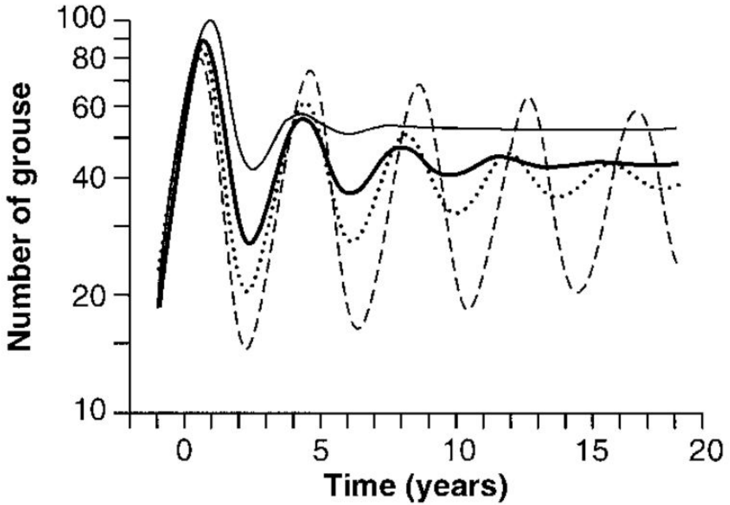


Fig. 3. The influence of treatment on the cycling of grouse populations. Changes in the number of grouse are shown in relation to the proportion of grouse treated. No treatment, dashed line; 5%, dotted line; 10%, thick solid line; and 20%, thin solid line.

What can we take away?

1. **Understand the definition of "macroparasite" and the diverse set of taxonomic and life-history strategies it can encompass.**
2. **Explain why biological features of macroparasites make us model them differently than microparasites**
3. **Be able to explain each piece of and modify the basic macroparasite model**
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Sources

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