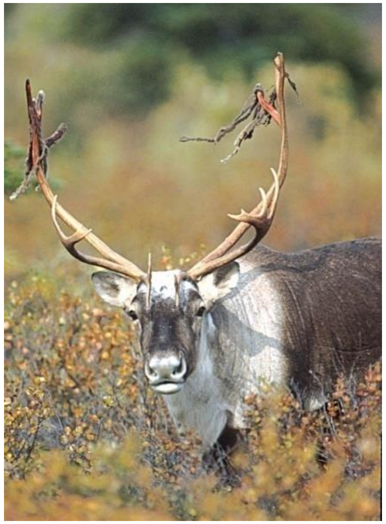
Parasitism

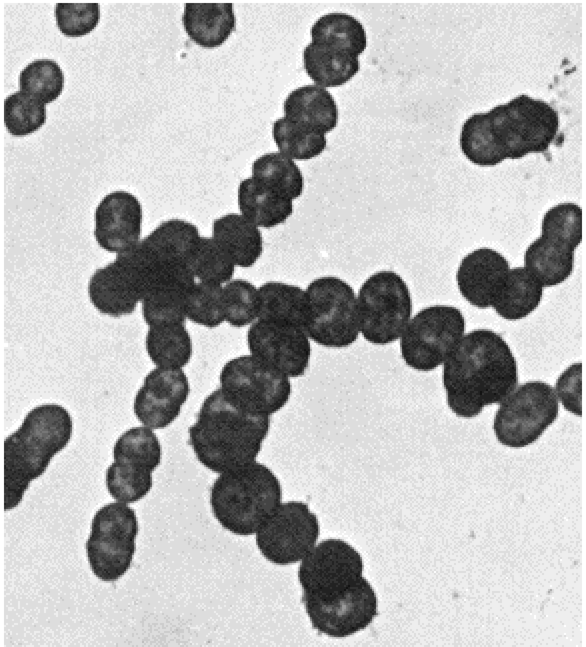
Hypoderma tarandi
(Warble fly)



Caribou

The world is full of parasites

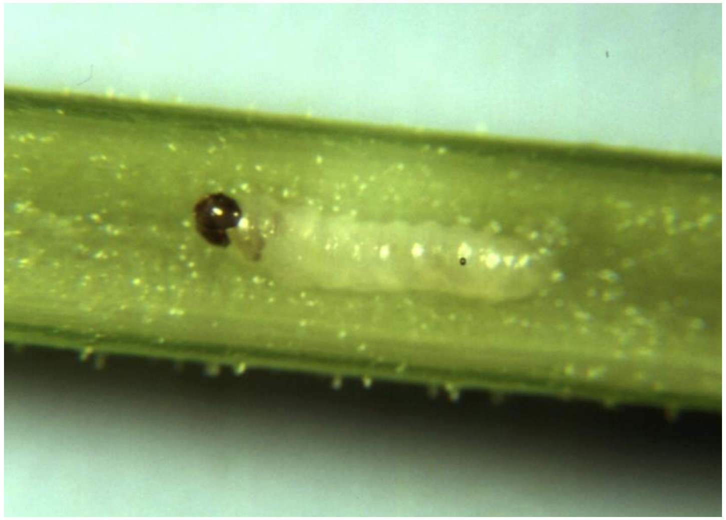
Influenza



Streptococcus pyogenes

The world is full of parasites

Greya piperella



The world is full of parasites

Castilleja miniata
(Indian paintbrush)

The world is full of parasites

Arceuthobium abietinum
Dwarf mistletoe

Witches' brooms
(fungus)

Parasites come in two flavors

Microparasites – Generally single celled, extremely numerous, and multiply directly within the host. Because most are intracellular they become deeply caught up in the intimacies of cell metabolism and antibody reactions.

- Viruses
- Bacteria
- Protozoans

Macroparasites – Generally multicellular, less numerous than microparasites, and grow and multiply outside of the host. Most are extracellular.

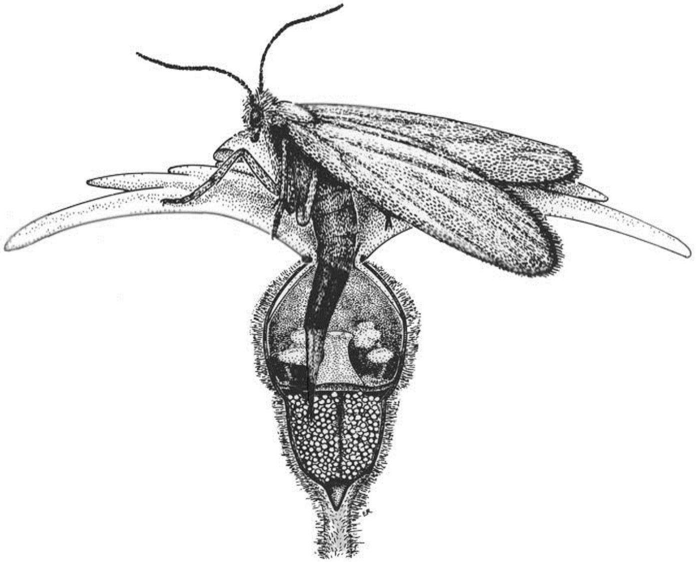
- Fungi
- Helminth worms
- Phytophagous insects

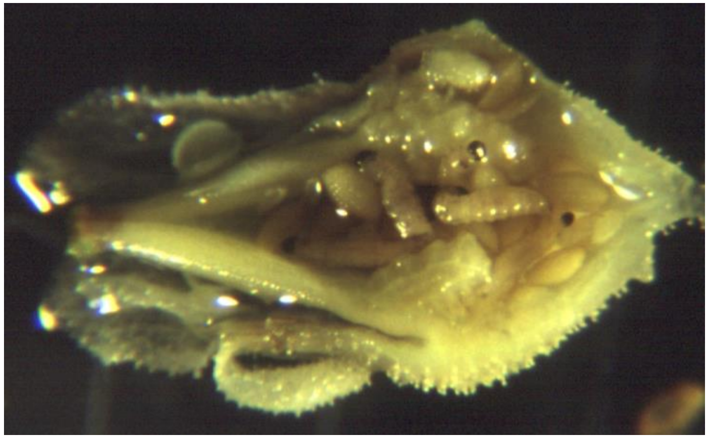
Parasites are generally highly specialized

- **The majority of parasites have a very narrow ecological niche using only one or two host species**

- **This extreme specialization occurs because of the inherent difficulties of being a parasite**

The inherent difficulties of being a parasite





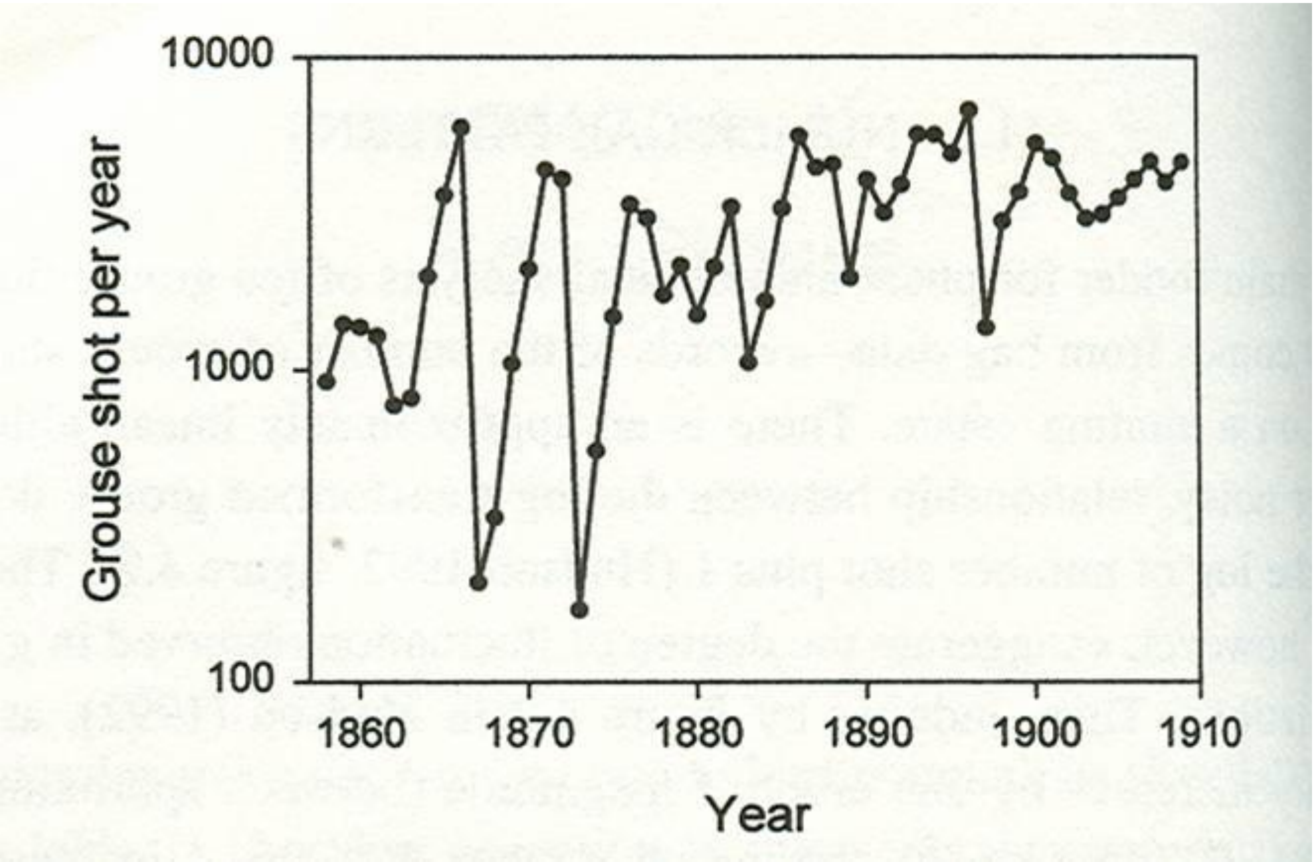
Can parasites regulate host population density?

A case study in Red Grouse in Scotland

Lagopus lagopus scoticus
(Red Grouse)

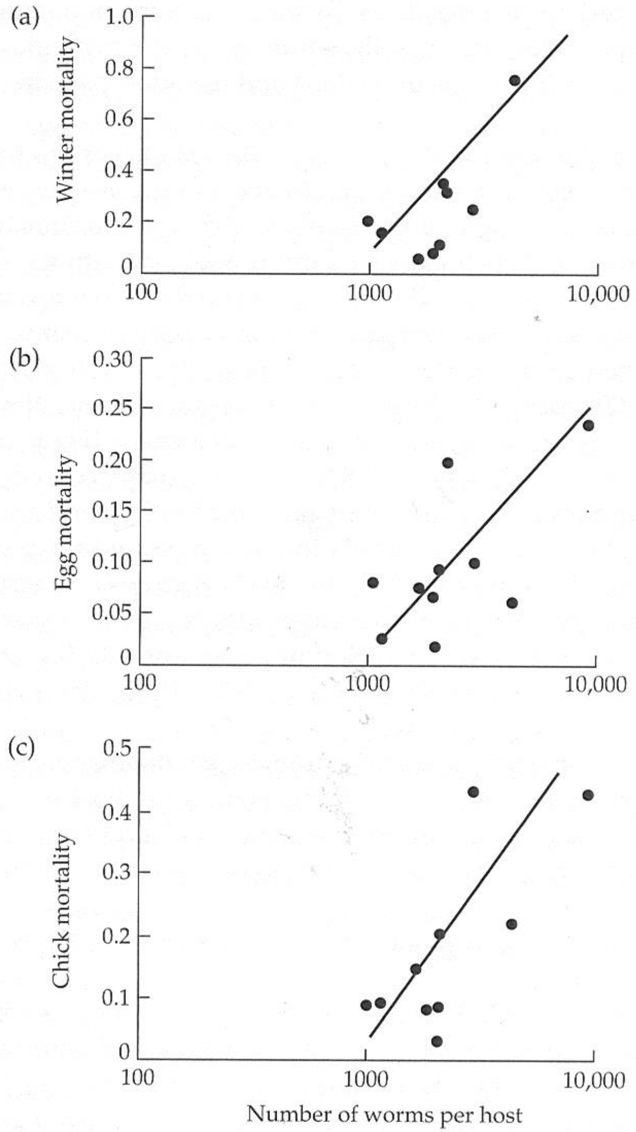
Trichostrongylus tenuis
(nematode)

Red grouse and nematode parasites



Could observed fluctuations in grouse density be due to the parasite?

Evidence suggests that the parasite has strong negative effects



But do these negative effects regulate grouse population densities?

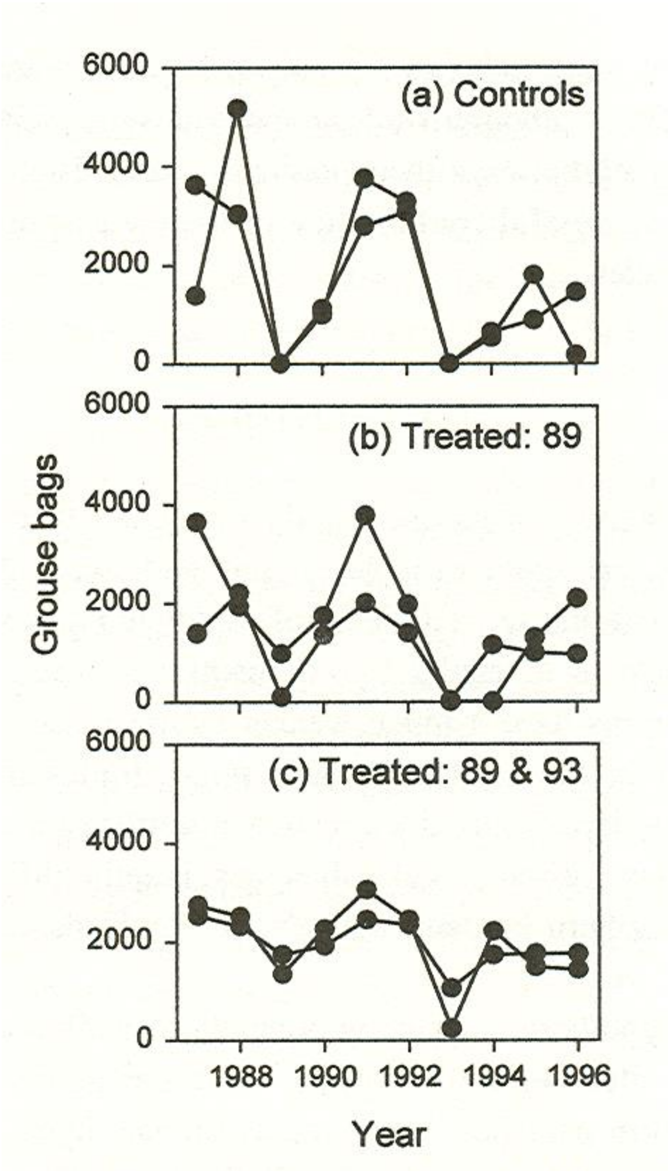
An experimental test

(Hudson et. al. 1998)

Scottish Moor

- Selected 6 independently managed moors
- 2 untreated controls
- 2 treated with anti-parasite drugs in 1989
- 2 treated with anti-parasite drugs in 1989 and 1993

Experimental results



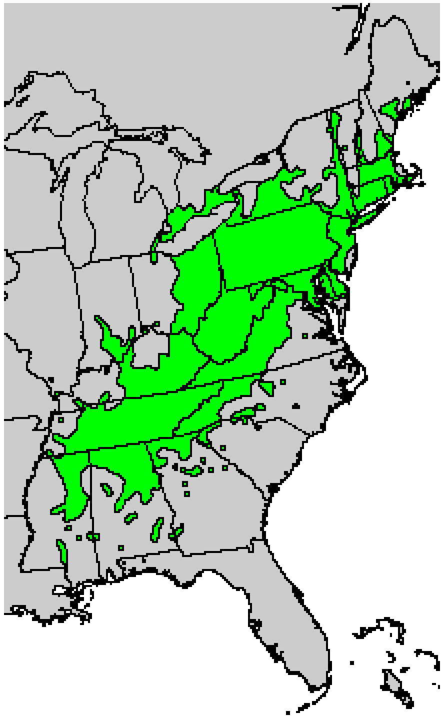
- Cycles were decreased in treated populations

- Cycle amplitude decreased with increasing application of anti-nematode drugs

- Suggests that nematode parasites shape grouse population densities

Can parasites regulate host population density?

The American Chestnut



Geographic range of *Castanea dentata* in the early 1900's

***Castanea dentata* (American chestnut)**

Can parasites regulate host population density?

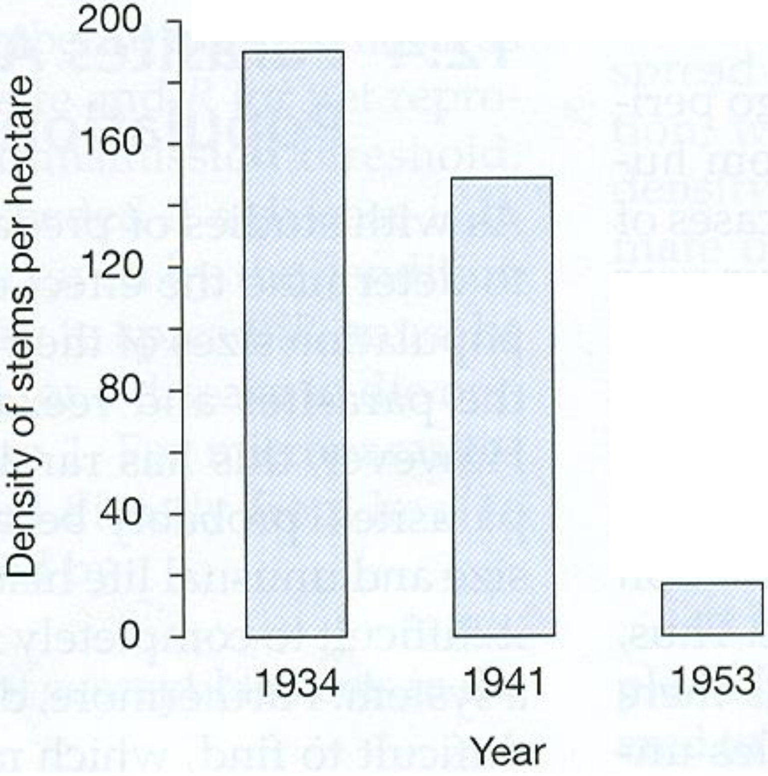
Cryphonectria parasitica
(Chestnut blight fungus)

- Parasite was introduced around 1904 from nursery stock imported from China

- Parasite is not virulent on its normal hosts

- It is, however, highly virulent on American Chestnut

Can parasites regulate host population density?



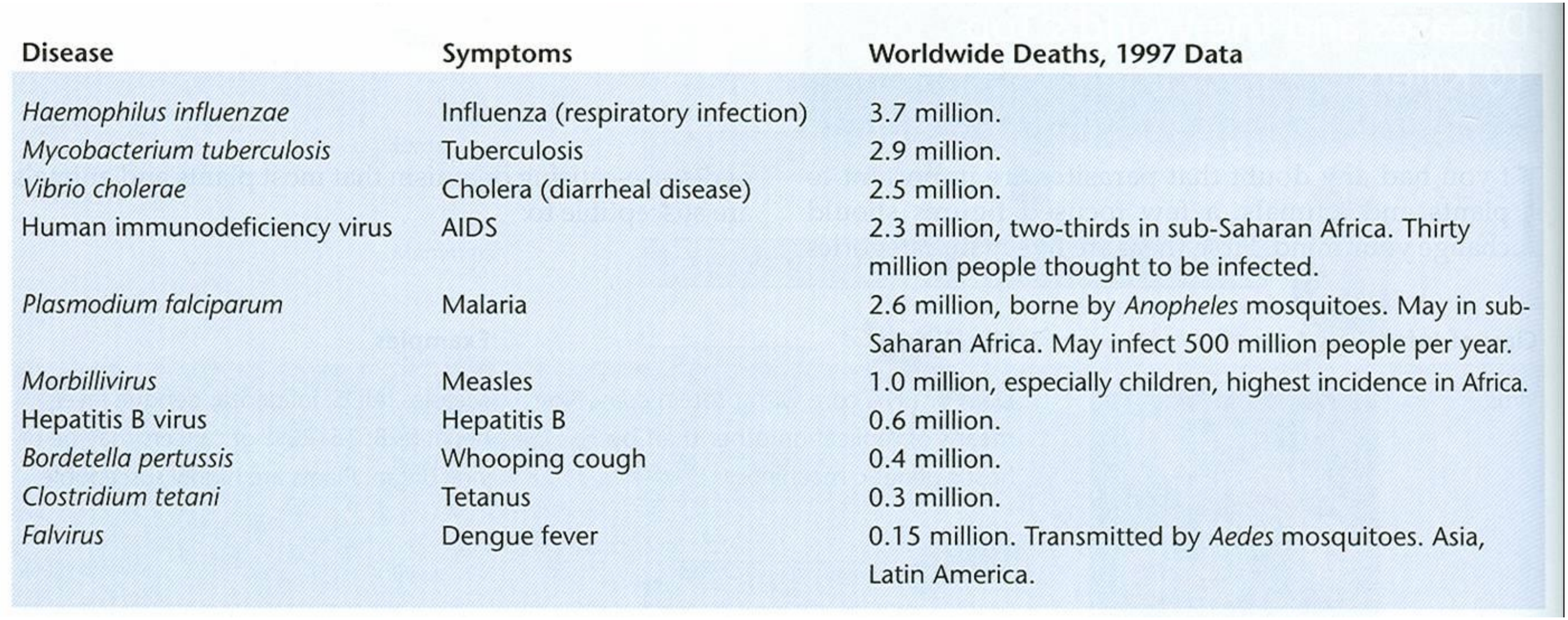
- The parasite rapidly reduced the population density of its host

- Today there are no longer any commercially viable populations of American Chestnut

- Suggests that parasites can, in some cases, virtually eradicate their host

Can parasites regulate host population density?

Human diseases



Disease	Symptoms	Worldwide Deaths, 1997 Data
Haemophilus influenzae	Influenza (respiratory infection)	3.7 million.
Mycobacterium tuberculosis	Tuberculosis	2.9 million.
Vibrio cholerae	Cholera (diarrheal disease)	2.5 million.
Human immunodeficiency virus	AIDS	2.3 million, two-thirds in sub-Saharan Africa. Thirty million people thought to be infected.
Plasmodium falciparum	Malaria	2.6 million, borne by *Anopheles* mosquitoes. May in sub-Saharan Africa. May infect 500 million people per year.
Morbillivirus	Measles	1.0 million, especially children, highest incidence in Africa.
Hepatitis B virus	Hepatitis B	0.6 million.
Bordetella pertussis	Whooping cough	0.4 million.
Clostridium tetani	Tetanus	0.3 million.
Falvirus	Dengue fever	0.15 million. Transmitted by *Aedes* mosquitoes. Asia, Latin America.

Why do some parasites cause so many more deaths than others?

From Stiling 2002

Part of the answer lies in the degree of spread

- In 1918-1919 Influenza killed more than 20 million people; more than World War I

- This strain of influenza spread rapidly around the globe becoming a pandemic

- Compare this to something like Ebola virus, which rarely manages to spread beyond a local scale before dying out (until this past year anyway!)

What determines whether an epidemic arises?

A simple mathematical model

Divide the population into three classes of individuals:

1. Susceptible
2. Infected
3. Recovered and Immune

Don’t bother to follow the actual number of parasites (microparasites)

The SIR model

So the total number of host individuals in the population, *N*, is

$N = S + I + R$

where:

***S* is the number of susceptible individuals who can potentially become infected**

***I* is the number of infected individuals who can potentially pass the parasite/disease on**

***R* is the number of resistant individuals who can no longer be infected due to immunity**

The SIR model

If we assume that individuals encounter one another at random, the number of encounters between susceptible individuals and infected individuals is equal to:

SI

If the probability that the disease is transmitted during an encounter is equal to β, the number of infected individuals at any point in time increases by an amount equal to:

βSI

If infected individuals recover (die) and become resistant (removed) at a rate γ, the number of infected individuals decreases at any point in time, by an amount equal to:

γI

The SIR model

We can now write down a series of three differential equations that describe the spread of the parasite/disease:

$$\frac{dS}{dt} = -\beta SI$$

$$\frac{dI}{dt} = \beta SI - \gamma I$$

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

The SIR model

What conditions are required for the disease/parasite to spread?

$$\frac{dS}{dt} = -\beta SI$$

$$\frac{dI}{dt} = \beta SI - \gamma I$$

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

The SIR model

The number of infected individuals must be increasing…

$$\frac{dI}{dt} = \beta SI - \gamma I > 0$$

so

$$\beta S - \gamma > 0$$

or

$$\frac{\beta S}{\gamma} > 1$$

The SIR model

How can we verbally interpret this result?

$$\frac{\beta S}{\gamma} > 1$$

βS is the number of susceptible individuals infected by each infected individual per unit time

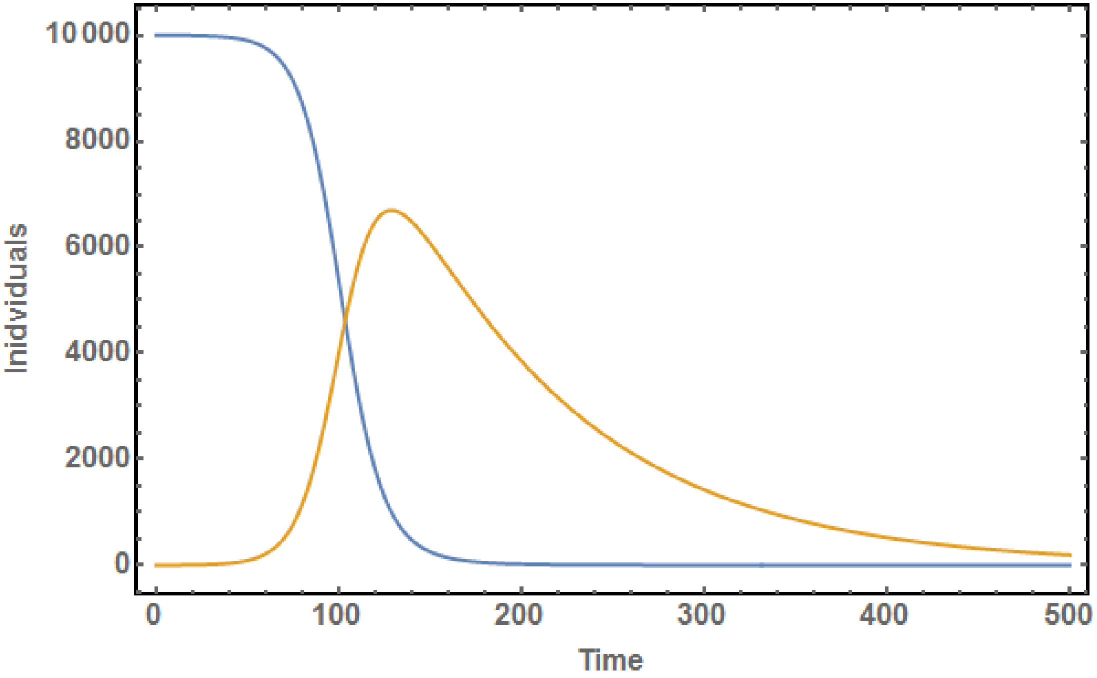
$1/\gamma$ is the average time an infected individual remains infectious

so the quantity $\beta S/\gamma$ is simply the average number of new infections caused by each infected individual!

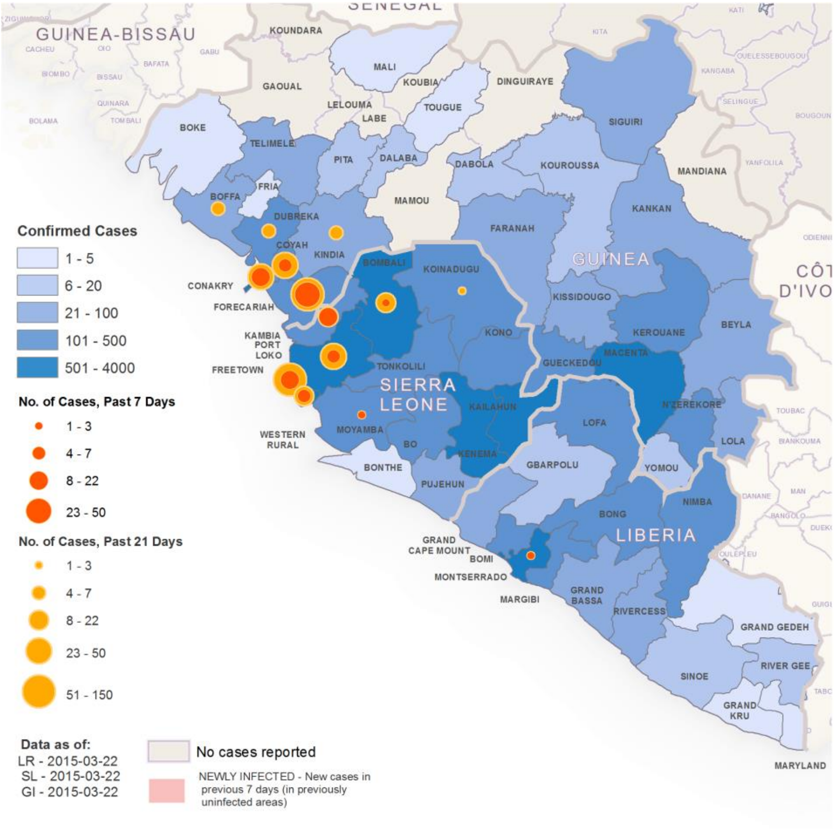
We call this number, $\beta S/\gamma$, the reproductive number of the disease and often denote it by R_0.

The SIR model

If $R_0 > 1$ an outbreak occurs



What does this look like in the real world?



http://www.nejm.org/action/showMediaPlayer?doi=10.1056%2FNEJMoa1411100&aid=NEJMoa1411100_attach_1&area=

What does this look like in the real world?

Figure 1: Confirmed weekly Ebola virus disease cases reported nationally and by district from Guinea

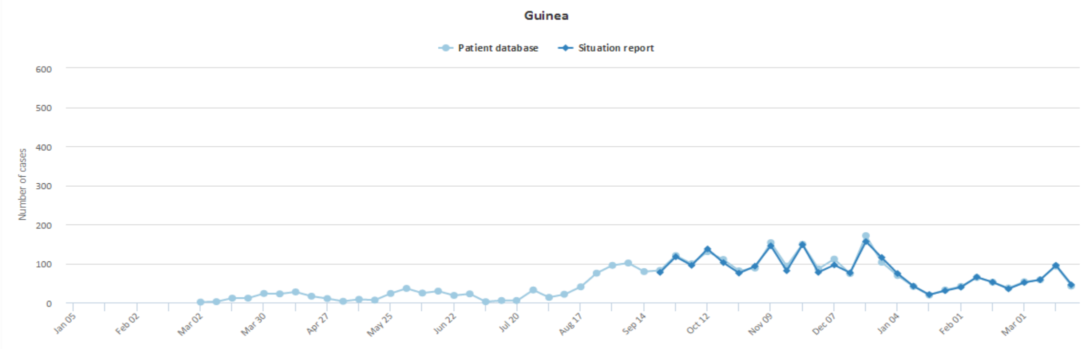


Figure 2: Confirmed weekly Ebola virus disease cases reported nationally and by district from Liberia

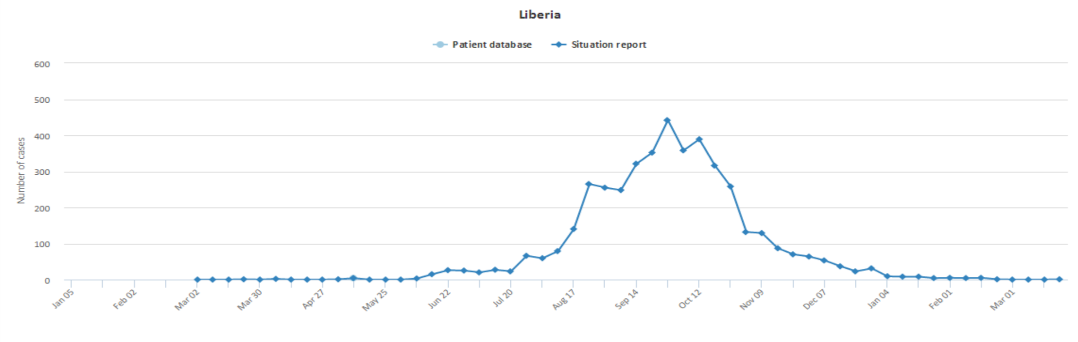
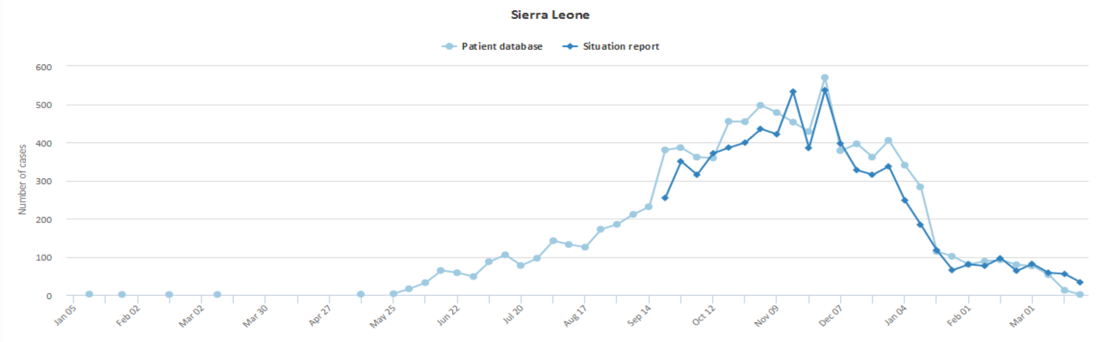


Figure 3: Confirmed weekly Ebola virus disease cases reported nationally and by district from Sierra Leone



Using the SIR model to answer key questions

1. Is there a critical threshold population density of susceptible hosts necessary for the parasite/disease to spread?

2. What proportion of a population needs to be vaccinated to prevent the spread of a disease/parasite?

Is there a threshold population size/density?

$$\frac{\beta S}{\gamma} > 1$$

At the beginning of any potential epidemic, all individuals within the host population are likely to be susceptible, so we can rewrite this equation as:

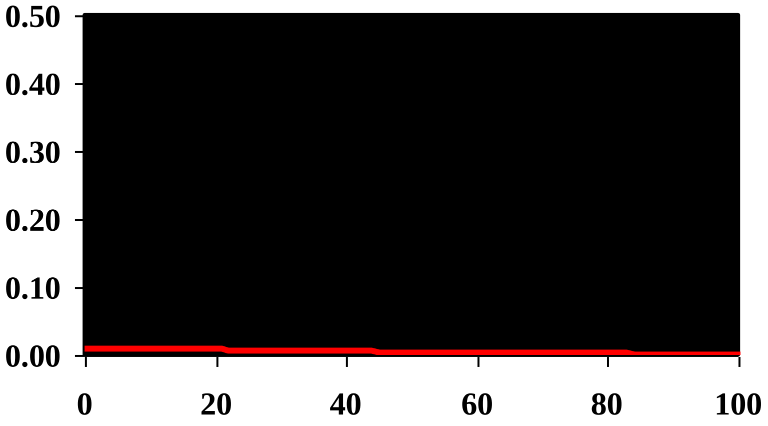
$$\frac{\beta N}{\gamma} > 1$$

Since β and γ are considered fixed, there is a *minimum population size* required for the spread of a parasite or disease:

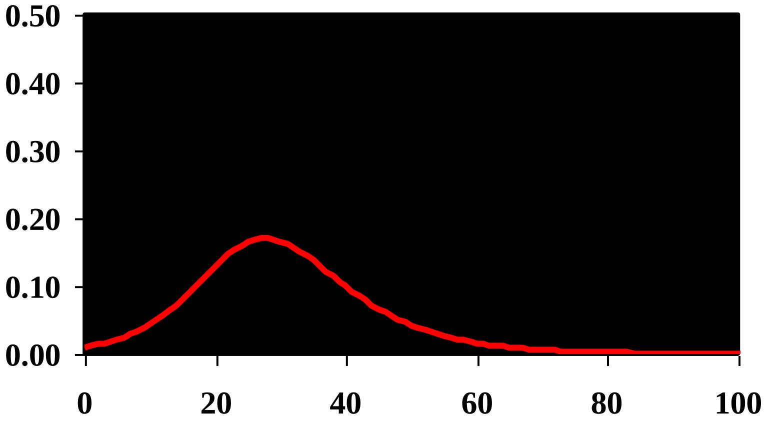
$$N_{crit} = \frac{\gamma}{\beta}$$

Is there a threshold population size/density?

$$N_{crit} = \frac{\gamma}{\beta}$$



$$N < \frac{\gamma}{\beta}$$



$$N > \frac{\gamma}{\beta}$$

Is there a threshold population size/density?

$$N < \frac{\gamma}{\beta}$$

In previous outbreaks within equatorial Africa, Ebola was largely confined to remote rural areas, with just a few scattered cases detected in cities.

$$N > \frac{\gamma}{\beta}$$

In contrast, the outbreak of 2014 occurred within West Africa and cities – including the capitals of all three countries – have been epicentres of intense virus transmission. The West African outbreaks demonstrated how swiftly the virus could move once it reached urban settings and densely populated slums.

2014 WHO Report on the Ebola outbreak

What proportion of a population needs to be vaccinated?

For a disease/parasite to spread there must be a critical number of susceptible host individuals:

$$N_{crit} = \frac{\gamma}{\beta}$$

So to prevent an epidemic, we need to vaccinate enough individuals so that the # of susceptible individuals is below this critical value:

$$p_V = \frac{N_{total} - N_{crit}}{N_{total}} = \frac{N_{total} - \gamma/\beta}{N_{total}} = 1 - \frac{\gamma/\beta}{N_{total}} = 1 - \frac{\gamma}{N\beta} = 1 - \frac{1}{R_0}$$

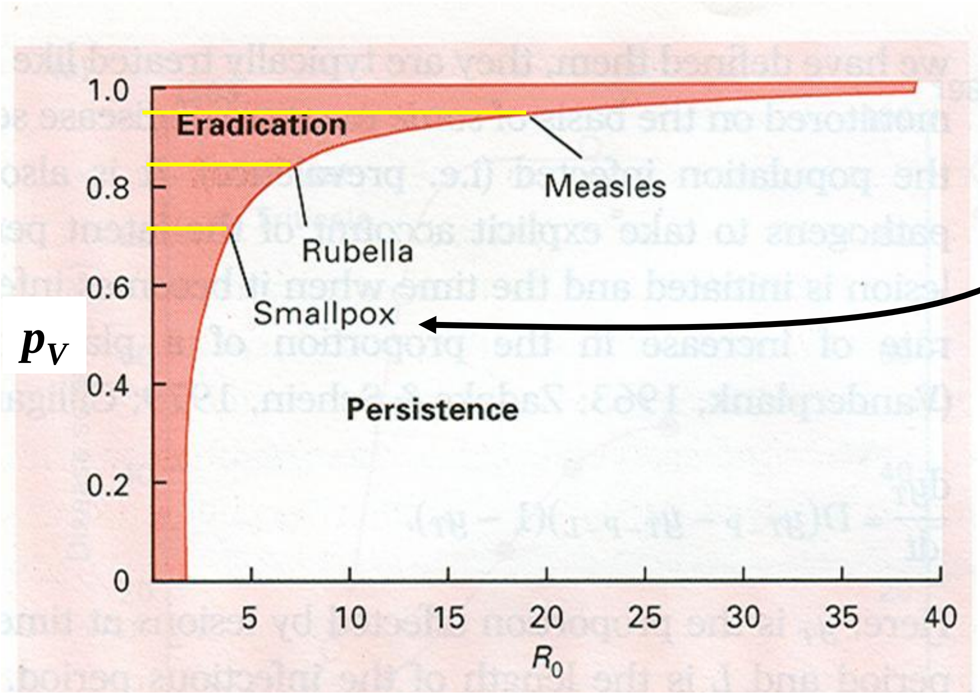
An epidemic can be prevented without vaccinating the entire population!

Where p_V is the proportion of the population that must be vaccinated

What proportion of a population needs to be vaccinated?

$$p_V = 1 - \frac{1}{R_0}$$

This is the only disease listed that has been successfully eradicated through vaccination!



Summary of parasites

- Parasites are generally highly specialized, using only one or two host species

- Parasites can be very effective regulators of host population density

- There is a minimum host population size required for the spread of a parasite/disease

- The entire host population need not be immunized to prevent the spread of a parasite or disease

Practice Problem: Applying the SIR model

Imagine that an emerging infectious disease has been identified in the human population of the United States. Scientists from the CDC have studied this viral disease intensively during its first several weeks and determined that $\beta = .24$ and $\gamma = .12$. They have also determined that the entire human population is likely to be initially susceptible to this disease. Use this information to answer the following questions:

A. Derive a general mathematical expression for the minimum population size that will lead to an epidemic, starting from the standard SIR model which assumes that the rate of change in the density of infected individuals per unit time is: $\frac{dI}{dt} = \beta SI - \gamma I$.

B. What would the minimum human population density have to be for this emerging infectious disease to lead to an epidemic?

C. Now assume that the human population density is actually .98. Would this disease now lead to an epidemic? Why?

D. Assume again that the density of the human population is .98. What proportion of the population would need to be vaccinated to prevent an epidemic?

Practice Problem

Year	Wolf Growth Rate	Wolf Inbreeding Coefficient
2002	2.02	0.09
2003	1.65	0.109
2004	1.38	0.136
2005	0.99	0.161
2006	0.83	0.173
2007	0.71	0.233
2008	1.19	0.261
2009	0.97	0.285
2010	0.94	0.309
2011	0.95	0.332

Data from the Isle Royale Wolf Project: http://www.isleroyalewolf.org/