Exploring Outbreak Prevention – Questions and answers

Part 1: Basic Outbreak Simulator

(1) In this simulation, the virus is able to reach a stable equilibrium state in the population. What features of the population allows this to happen (refer to the ppt slides)?

This simulation includes births and deaths in the population. Since individuals are born susceptible to disease, the virus can't run out of new individuals to infect. Additionally, this simulation includes waning immunity. This means that individuals can be re-infected multiple times throughout their lives.

(2) How does changing R0 impact the peak of the outbreak, it's size and when it occurs? What happens when R0 < 1, and why?

Increasing R0 makes the peak of the epidemic higher, and makes it occur sooner. When R0 < 1, there is no epidemic peak. This is because when R0 < 1 means that an infected individual will cause < 1 new infection on average so even in a fully susceptible population, the number of infected will go down not up.

(3) What about the duration of the immune period? What does it mean if the immune period=0?

Increasing the immune period doesn't have much effect on the timing of the epidemic peak, or on its size. When the immune period is short, there is an impact on the long term number of infecteds; this increases as the immune period decreases. When the immune period is 0, this means that when an individual clears the pathogen, they immediately become susceptible again. A long-term immune response is either not mounted properly, or the pathogen has advanced immune evasion strategies.

(4) Try matching the graph to some randomly simulated outbreak data by pressing the button on the left.

No answers here, just have fun!

(5) Why might it be easier to collect data on the 'R' compartment (i.e., antibody data), compared to from the 'I' compartment (i.e., detecting actual virus)?

On average, the immune period (i.e., the length of time there are detectable antibodies post infection) is longer than the infectious period (i.e., the length of time there is detectable virus during infection).

Part 2: Simulating Vaccination

(1) To start with, the rate basic reproduction number of the transmissible vaccine is set to 0. This means, it behaves the same as a traditional vaccine. Start by looking at just this traditional vaccine. When is the number of vaccinated bats the highest? Why might the number of bats vaccinated decrease over time?

The number of vaccinated bats is highest at the start of the simulation, when the vaccines are initially given to the bats.

The number of bats that are vaccinated decreases over time because the bats that have been vaccinated die due to natural causes, and new bats that are born aren't being vaccinated.

(2) Now that you've looked at the traditional vaccine, start increasing the basic reproduction number for the transmissible vaccine. Does transmission improve the percent of the population that can be vaccinated? When are the most bats vaccinated and why?

Extra: What do you think the first graph (vaccine spread over time) will look like over a longer period of time? Can you work out how to edit the code provided to run the simulation for 10 years? Hint: search for 'times' in the code and change 2 to 10.

Transmission does improve the proportion of bats that can be vaccinated with the same starting effort. The higher the vaccine R0, the more bats vaccinated. The most bats are vaccinated ~1 month after the vaccines are given to the bats, as transmission takes place in this time spreading the vaccine to more bats.

The number of vaccinated bats will reach an equilibrium if the R0 of the vaccine is >1, and remain stable. The traditional vaccine will eventually be lost from the population.

To change the graphs in the app, search for 'times'. You should find an expression that reads:

times <- seq(0, 2, by = 1/365)

This means that the model runs from time=0 to time=2 years, and gives an output at every day. To change this to running for 10 years, change the 2 to 10. Everything else should stay the same. This expression occurs several times in the code, and you will need to change all of them.

Simulating Vaccination Maths

1.

A traditional vaccine costs £2 per dose. It costs £5 to directly inject a bat with a vaccine. Currently, you have the workforce to directly give vaccine to 20% of a local bat colony, estimated to contain 250 bats. How much would this cost?

$20\%\ of\ 250\ bats = 50\ bats\ directly\ given\ vaccine.$

$Each\ injection\ costs\ £2\ for\ the\ vaccine\ and\ £5\ to\ administer.$

$(£2 + £5)\ \times\ 50\ bats = \mathbf{£350}$

What does the app predict for the reduction in disease compared to not vaccinating the bat colony under these conditions?

$Using\ the\ online\ app, using\ a\ traditional\ vaccine\ on\ 20\%\ of\ the\ population\ leads\ to\ \mathbf{10}\%$ $reduction\ in\ disease\ compared\ to\ an\ unvaccinated\ population.$

What is the cost per percent disease reduction?

$$\frac{£350}{10\%} = \mathbf{£35}$$

2.

A new type of vaccine has recently become available: a transmissible vaccine with an R_0 of 2. This vaccine costs £10 per dose to produce, and it remains £5 to directly inject a bat. If you maintain your existing rate of vaccination in the local bat colony (20%), what level of disease reduction can be achieved?

$Using\ the\ online\ app, using\ a\ transmissible\ vaccine\ with\ an\ R_0\ of\ 2\ on\ 20\%\ of\ the\ population$ $leads\ to\ \mathbf{50}\%\ reduction\ in\ disease\ compared\ to\ un\ anvaccinated\ population.$

Is this new vaccine more cost effective per % disease reduction than the traditional vaccine?

$20\%\ of\ 250\ bats = 50\ bats\ directly\ given\ vaccine.$

$Each\ injection\ costs\ £10\ for\ the\ vaccine\ and\ £5\ to\ administer.$

$(£10 + £5)\ \times\ 50\ bats = £750$

$$\frac{£750}{50\%} = £15\ so\ \boldsymbol{YES}, the\ transmissible\ vaccine\ is\ more\ cost\ effective\ in\ this\ case.$$

At what R_0 value is a transmissible vaccine no longer more economically viable than the traditional vaccine?

$$For\ the\ transmissible\ vaccine\ to\ be\ cheaper\ per\ \%\ disease\ reduction, it\ must\ vaccinate\ more$$
$$than \frac{total\ cost\ of\ the\ transmissible\ vaccines}{cost\ per\ \%\ reduction\ using\ the\ traditional\ vaccine} = \frac{£750}{£35} = 21.4\%.$$
$$Using\ the\ online\ app, R_0 = 1\ gives\ a\ 23\%\ reduction\ whilst\ R_0 = 0.75\ gives\ a\ 19\%\ reduction.$$
$$Therefore\ at\ \boldsymbol{R_0 < 1}\ the\ transmissible\ vaccine\ is\ no\ longer\ more\ cost\ effective\ per\ \%$$
$$disease\ reduction\ than\ the\ traditional\ vaccine.$$

3.

The local government has a new budget, and has allocated £500 to spend on wildlife vaccination. They have access to traditional vaccines and transmissible vaccines at the same prices used above. The transmissible vaccine has an R_0 of 1.5. How would you recommend they use these resources? You can vary how much of the population is vaccinated (250 bats in total), but don't exceed the budget.

$$What\ is\ the\ maximum\ number\ of\ bats\ we\ can\ vaccinate\ with\ each\ method\ for\ £500?$$
$$Traditional\ vaccine: \frac{£500}{£2 + £7} = 71\ bats$$
$$Transmissible\ vaccine: \frac{£500}{£10 + £5} = 33\ bats$$
$$What\ percent\ of\ the\ bat\ population\ is\ this?$$
$$\frac{71\ bats}{250\ bats} = 28\% \sim 27.5\%$$
$$\frac{33\ bats}{250\ bats} = 13\% \sim 12.5\%$$
$$27.5\%\ vaccination\ with\ a\ traditional\ vaccine = 14\%\ disease\ reduction$$
$$12.5\%\ vaccination\ with\ a\ transmissible\ vaccine = 29\%\ disease\ reduction$$
$$\boldsymbol{I\ would\ recommend\ using\ the\ transmissible\ vaccine}.$$

At what price per dose would you <u>not</u> recommend using this transmissible vaccine (R_0=1.5)?

$$As\ long\ as\ a\ single\ dose\ doesn't\ cost\ more\ than\ the\ budget, a\ transmissible\ vaccine\ with\ this$$
$$R_0\ will\ always\ be\ recommended\ over\ the\ traditional\ vaccine.$$

What is the lowest value of R_0 for the transmissible vaccine of this price that would be recommended for use in this population (250 bats) with this budget (£500)?

$To\ be\ recommended, the\ transmissible\ vaccine\ must\ cause\ disease\ reduction > 14\%, when\ applied\ to\ no\ more\ than\ 13\%\ of\ the\ population. When\ R_0 = 1, disease\ reduction = 17\%. When\ R_0 = 0.75, disease\ reduction = 13\%. Therefore, the\ lowest\ value\ of\ R_0\ that\ would\ allow\ the\ transmissible\ vaccine\ to\ be\ recommended, is\ 1.$

It has been a bad year for the bats, and the colony is much smaller now, at only 75 bats. With a budget of £500, and the options of a traditional vaccine or a transmissible vaccine (R_0=1.5), is your recommendation the same as it was before? Comment on how the usefulness of each vaccination method scales with bat population size.

$What\ is\ the\ maximum\ number\ of\ bats\ we\ can\ vaccinate\ with\ each\ method\ for\ £500?$

$$Traditional\ vaccine: \frac{£500}{£2 + £7} = 71\ bats$$

$$Transmissible\ vaccine: \frac{£500}{£10 + £5} = 33\ bats$$

$What\ percent\ of\ the\ bat\ population\ is\ this?$

$$\frac{71\ bats}{75\ bats} = 95\%$$

$$\frac{33\ bats}{75\ bats} = 44\% \sim 42.5\%$$

$95\%\ vaccination\ with\ a\ traditional\ vaccine = 48\%\ disease\ reduction$

$42.5\%\ vaccination\ with\ a\ transmissible\ vaccine = 44\%\ disease\ reduction$

$\boldsymbol{I\ would\ no\ longer\ recommend\ using\ the\ transmissible\ vaccine}.$

$Transmissible\ vaccines\ become\ more\ useful\ with\ larger\ population\ sizes.$

Can you think of any reason it might be better to use the transmissible vaccine even if it is slightly less cost effective than the traditional vaccine? (Hint: think safety of the people administering the vaccines.)