Connecting Viral Pandemics to Ecological Population Growth Models
Answer Key

PART I: 1918 Influenza

1. The R_0 in Philadelphia in 1918 was estimated to be 2.6 (Bootsma and Ferguson 2007). At the time, Philadelphia had a population of 1.7 million. Check your parameters. Set $N_0 = 1$ to indicate patient zero. Set the minimum N to zero and the maximum N to at least 1.7 million. You will also need to use R_0 to solve for *r*, and then insert the correct value.

a. Assume no one was immune and everyone had the same chance of contracting this virus. How long (*t*) would it take to infect the entire population of Philadelphia? You will need to drag the circle along the graph.
Using the equation above, if R_0 = 2.6, then r = 1.6. The entire population of Philadelphia would be infected when t equals between 8.9 and 9.

b. Remember that for a pandemic such as this, the time unit (*t*) actually represents G/T (generation time), the interval between the onset of symptoms in two consecutive generations. The G/T of the 1918 pandemic was 3.1 days, In other words, each *t* unit = 3.1 days. How many days would it take to infect the entire population of Philadelphia? Hint: Multiply your answer from question (1a) by the G/T.
If we assume t = 9 and the G/T of the 1918 pandemic as 3.1, then the following is how we would solve for the number of days:
# of days = 9 x 3.1 = 27.9 days

2. R_0 in St. Louis in 1918 was estimated to be 2.18 (Bootsma and Ferguson 2007). At the time, St. Louis had a population of 687,000. Check the proper parameters as in the question above and solve for r.

a. Assume no one was immune and everyone had the same chance of contracting this virus. How long (t) would it take to infect the entire population of St. Louis? Use the same procedure you did in the previous question.
Using the equation above, if R_0 = 2.18, then r = 1.18. The entire population of St. Louis would be infected when t equals between 11.3 and 11.4.

b. Using the G/T for the 1918 pandemic, how many days would it take to infect the entire population of St. Louis?
If we assume t = 11.4 and the G/T of the 1918 pandemic as 3.1, then the following is how we would solve for the number of days:
# of days = 11.4 x 3.1 = 35.3 days

3. Are there any differences between how long it would take for the entire population of Philadelphia to get infected compared to St. Louis? Please explain these differences.
Even though the population of Philadelphia is greater than St. Louis, the entire population of Philadelphia would be infected seven days before the entire population of St. Louis. Students may have different explanations for this. The reason is because of the differing R_0 values in each city.

4. What type of safety precautions could the two cities put in place to help with the spread of this disease? Please explain why each precaution would work.
These two cities could mandate the use of face coverings and encourage social distancing at places of businesses. The cities could also limit the number of people at indoor and outdoor gatherings. Finally, the cities could require certain businesses and schools to close.

5. The following chart shows a timeline of measures put in place by each city:

Date	Philadelphia	St. Louis
4 October 1918	Schools, churches, other public places closed (Lynch 1998)	
7 October 1918		Schools, churches, and other public places closed. Individuals diagnosed with flu were quarantined in their homes for 14 days (Kalnins 2006)
11 October 1918	Businesses voluntarily closed (Lynch 1998)	
26 October 1918	Public places allowed to open (Barry 2004)	
27 October 1918	Churches reopened (Crosby 1976)	
28 October 1918	Schools reopened (Crosby 1976)	
30 October 1918	Theaters and bars reopened (Crosby 1976)	
13 November 1918		Businesses reopened (Kalnins 2006)
14 November 1918		Schools reopened (Kalnins 2006)
28 November 1918		Ban on public gatherings was reinstated and elementary schools were closed again (Kalnins 2006)
22 December 1918		Some businesses reopened (Kalnins 2006)
2 January 1919		Elementary schools reopened (Kalnins 2006)

6. What do you think happened in each city over the course of the fall and winter of 1918?
Student answers may vary. Even though schools and churches in Philadelphia closed before those in St. Louis, businesses and schools in St. Louis did not reopen until 11/13 and 11/14, respectively. In St. Louis, elementary schools closed again on 11/28 and did not reopen until the following January. Using this information, students may state that cases in St. Louis may be less.

7. The following graph shows the death rate by pneumonia and influenza in Philadelphia compared to St. Louis during 1918. Knowing the safety measures put into place by each city, is this what you would expect? Why or why not?
Again, answers may vary. Philadelphia schools did not stay closed as long as St. Louis schools which may partially explain why there were so many more pneumonia and influenza deaths in Philadelphia. It may have also been because the R_0 in Philadelphia was slightly higher than in St. Louis. Finally, there may have been other precautions taken by each city that were not listed, such as face coverings and distancing (see question #4). This graph clearly shows that St. Louis was successful at "flattening the curve."

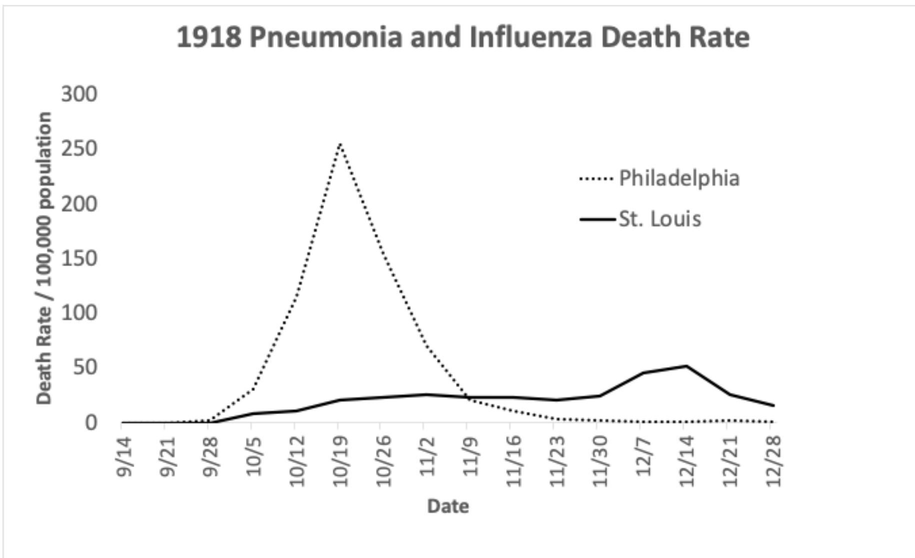

Figure 1. Death rate / 100,000 population by pneumonia and influenza in both Philadelphia and St. Louis. Figure was modified from Hatchett et al. 2007.

PART II: 2020 COVID-19

At the beginning of the 2020 pandemic, the World Health Organization estimated the R_0 of COVID-19 to be between 1.4 and 2.5 (Viceconte and Petrosillo 2020). Later studies showed the median R_0 to be anywhere from 2.79 (Liu et al. 2020) to 5.7 (Sanche et al. 2020). Remember that R_0 is not a constant number for a disease. It changes regionally and as mitigation strategies are put in place.

1.Let's assume the initial R_0 of COVID-19 to be 2.5. Measles has an R_0 of 15 while seasonal influenza has an R_0 of 1.3.

a. Create a graph showing the spread of COVID-19. How many people would be infected when t = 10?
Using an R_0 value of 2.5, we can figure out r to be 1.5. If we set N_0 = 1, r = 1.5, and t =10 in the simulator, we can see that N (number of people infected) = 3,269,017.

b. Create a graph showing the spread of measles. How many people would be infected when t = 10?
Using an R_0 value of 15, we can figure out r to be 14. If we set N_0 = 1, r = 14, and t =10 in the simulator, we can see that N (number of people infected) = 6.33×10^{60}.

c. Create a graph showing the spread of seasonal influenza. How many people would be infected when $t = 10$?
Using an R_0 value of 1.3, we can figure out r to be 0.3. If we set $N_0 = 1$, $r = 0.3$, and $t = 10$ in the simulator, we can see that N (number of people infected) = 20.

d. Which disease would you consider more contagious? Least contagious?
According to the data collected from the simulator, measles would, by far, be the most contagious and seasonal influenza the least contagious.

2. New York City, with a population of around 8.4 million, was hit extremely hard by COVID-19. R_0 in this area may have been as high as 6.4 (Ives and Buzzuto 2020). If we assume an R_0 of 6.4 with a G/T of 5.2 days, how many people would potentially be infected in 15 days once patient zero entered the city?
After setting $N_0 = 1$ and $r = 5.4$ in the simulator, we still need to solve for t. We can do the following:

$$t = 15 \text{ days}/(G/T) = 15 \text{ days}/5.2 = 2.88$$

Now, if we plug in $t = 2.88$ to the simulator, we can see that N = 6,324,807

3. Using what you have learned about R_0 and R_t, explain how it would be possible for places like New York City to get the R_t close to 1.
Distancing, face coverings, closing businesses and schools, and employing safe vaccinations would be some strategies.

4. After using this simulator to look at the impacts of varying R_0 (or R_t) values, explain why strategies like distancing, wearing masks, washing hands, and sanitizing areas are so important.
These strategies simply help prevent the spread of the virus. A virus needs a host, and by taking these precautions we can limit potential hosts.