



SQUIRRELPOX!

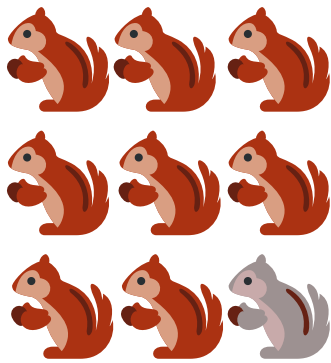
If you were a red squirrel in this exercise and you became “infected,” in a few days, you’ll start to look like **this**, and will likely die within two to three weeks. You have been infected with a fatal virus called Squirrelpox (SQPV) or parapoxvirus. This virus causes ulcers around the eyes, ears, paws, and genitals (1). Eurasian red squirrels are native to Europe, and they are being replaced by the Eastern grey squirrel, a North American species, through a process called **Disease Mediated Invasion** (2).



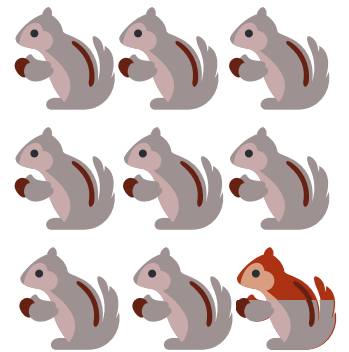
If you were an infected grey squirrel, you’re probably doing just fine. Grey squirrels are not known to show any outward signs of infection. This has led researchers to believe that they are the **reservoir hosts** of this virus (3). The first known introduction of grey squirrels to the UK in 1876 when Thomas Brocklehurst brought a pair to Henbury Park in Cheshire (4). Since then, there have been several other introductions in Europe, and the grey squirrel quickly became a problematic invasive species - causing serious declines in red squirrels.



INVASION



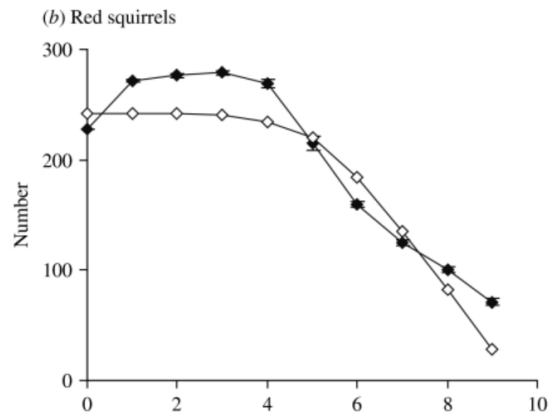
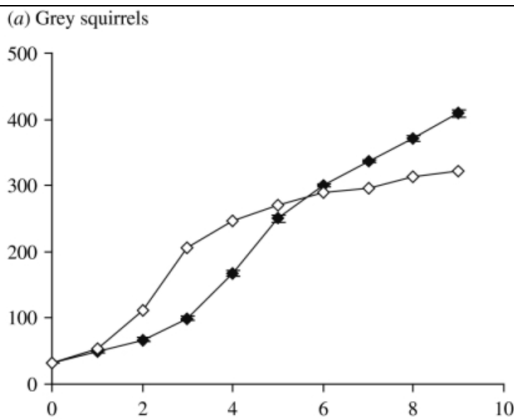
Ecologists define an **invasive species** as an introduced organism that negatively impacts its new environment. These negative impacts range from habitat destruction to species replacement. Currently, there are only 140,000 red squirrels in the UK and 2.5 million grey squirrels (5). **That's just 0.5 red squirrels for every 9 grey squirrels!**



A **Disease Mediated Invasion** occurs when an invasive species introduces a parasite or pathogen to a native species that has a higher **virulence** (more severe illness) in the native species than in the invasive species (2). When grey squirrels were introduced, they quickly took over red squirrel habitat and food sources (6,7). However the introduction of SQPV from grey squirrels has devastated red squirrel populations way more than resource competition (8). This can also be classified as an example of **apparent competition**, because these two species affect each other most by being infected by the same pathogen.



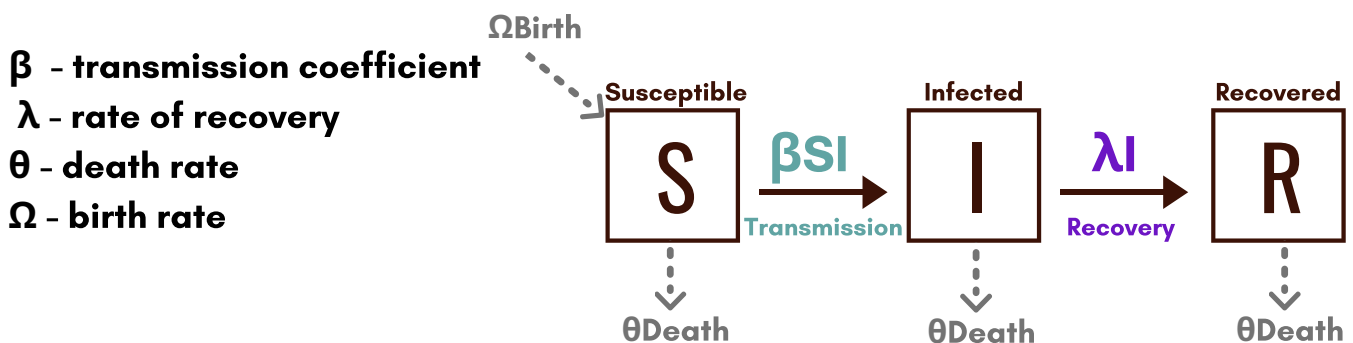
Researchers in the UK created an **individual-based model** (a model that simulates populations or communities by assigning individuals unique traits) to simulate population and disease dynamics amongst grey squirrels and red squirrels between 1993 and 2002 (8). Here they show the number of quadrants in Cumbria that were predicted (solid diamonds) and observed (clear diamonds) to be occupied by grey (a) or red squirrels (b). These researchers estimated that areas where there are known SQPV infections experience a decline in red squirrel populations **17-25 times faster** than areas where there are no SQPV infections (8).



Rushton et al., 2006

The basics of pathogen transmission

In order to understand how grey squirrels took over the UK, we first need to know some of the basics of pathogen transmission. Epidemiologists and ecologists create models of transmission by building upon a framework called a **compartmental** or **mechanistic** model. Known as the **SIR** (Susceptible, Infected, Recovered) **model**, this mechanistic model of transmission tracks the progression of a pathogen within an individual (cell to cell), a population (host to host), or across metapopulations by categorizing each entity by their infection status at a given time. These statuses include, but aren't limited to: Susceptible, Infected, and Recovered; and the sum of the individuals of each status is equal to N , the population. SIR compartmental models are typically illustrated as shown below.





A system of calculus equations is used to describe an individual's change in status over time. The equations are modified by transmission parameters such as the transmission coefficient (β), the rate of recovery (λ), and population processes such as the death (θ) and birth (Ω) rate.

$$N = S + I + R$$

Total Population = # Susceptible + # Infected + # Recovered

$$\frac{ds}{dt} = \Omega N - \beta SI - \theta S$$

Change in # Susceptible over time = Birth of new Susceptibles - # of Newly infected - Death of Susceptibles

$$\frac{di}{dt} = \beta SI - \lambda I - \theta I$$

Change in # Infected over time = # of Newly infected - # of Newly Recovered - Death of Infectives

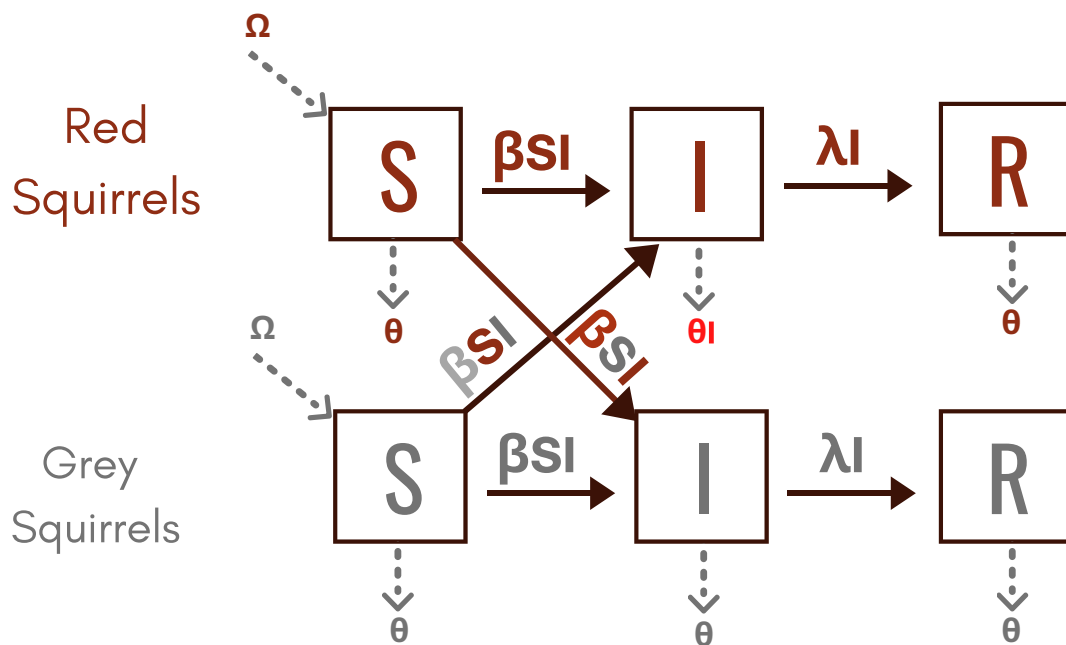
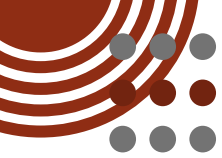
$$\frac{dR}{dt} = \lambda I - \theta R$$

Change in # Susceptible over time = # of Newly Recovered - Death of Recovered

These equations are typically plotted to visualize the course of an epidemic. At the beginning of the time series in this plot, we can see that the population is entirely susceptible, with the exception of one infected individual that kicks off this epidemic. The number of susceptible (red) declines as the number of infected (green) rise, and soon after, the infected individuals begin to recover (blue).



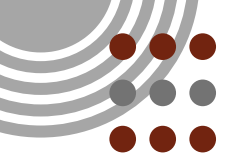
Pathogen transmission dynamics become a little tricky when two species are involved, as the effect of each species on the other must be considered in order to accurately illustrate an epidemic. Though this isn't the exact dynamics between red and grey squirrels, here's what the compartmental model might look like.



In this compartmental model, βSI indicates that an infected grey squirrel transmits the virus to a susceptible red squirrel, and βSI indicates the opposite - in which an infected red squirrel transmits the virus to a susceptible grey squirrel. θI is the death rate for infected red squirrels. This value is distinguished from the death rates of susceptible and recovered red squirrels because infected red squirrels are likely to die at a much higher rate.

DISCUSSION QUESTIONS

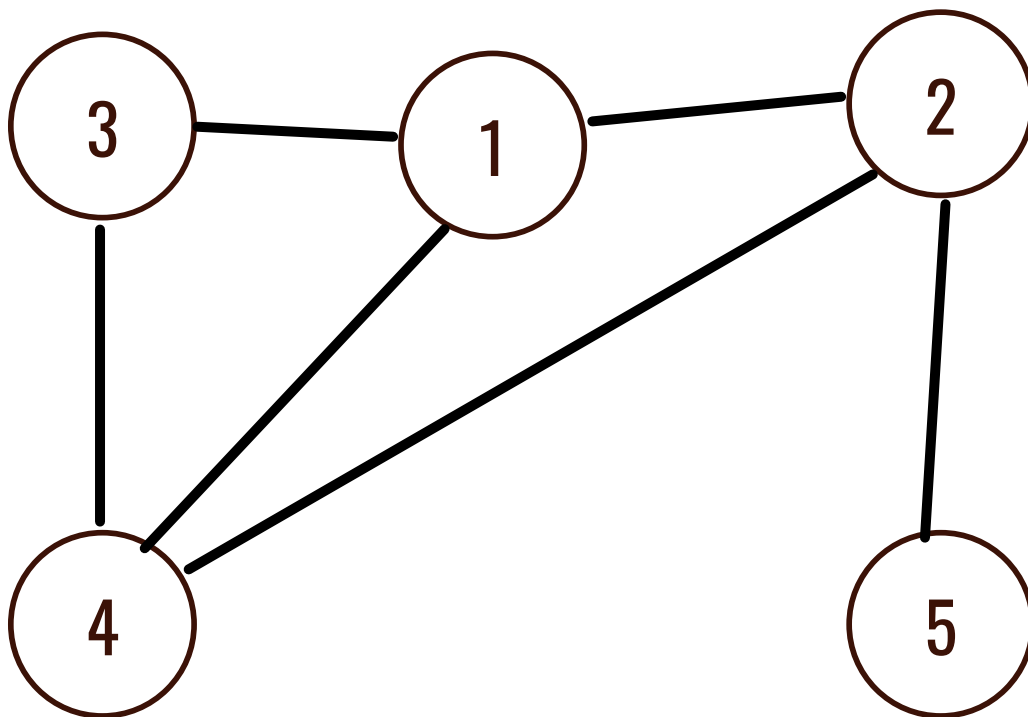
1. What is the difference between red and grey squirrels? How does this affect disease transmission?
2. Discuss differences in virulence of Squirrel Pox (red squirrels die, grey squirrels are unaffected) and how that might affect inter- (between) and intra- (within) species transmission.
3. What has the exercise taught you about competition and invasive species?
4. Can you think of any similar examples in Georgia or in general?



TRANSMISSION NETWORK

Using your classroom data, build a social network to track transmission! Create a table as shown below. Every time you shook hands with someone count that as a 1, and leave the cell blank or add a 0 for everyone you didn't encounter. Draw a circle to represent each classmate, then draw lines between those who came in contact with each other. If you recorded the time that you had an encounter, try to replicate the course of the epidemic by tracking the infection from the first infected classmates to the last.

	Person 1	Person 2	Person 3	Person 4	Person 5
Person 1		1	1	1	
Person 2	1				
Person 3				1	
Person 4		1			
Person 5		1			





RESOURCES

Image Sources

A Red squirrel (*Sciurus vulgaris*) suffering from squirrelpox. – Credit: Sarah McNeil
Eastern Grey Squirrel – This is a file from the Wikimedia Commons.

References

1. Tompkins, D.M., Sainsbury, A.W., Nettleton, P., Buxton, D., Gurnell, J., (2001), Parapoxvirus causes a deleterious disease in red squirrels associated with UK population decline. *Proc R Soc Lond*, 269 529-533
<https://www.jstor.org/stable/3067988>
 2. Strauss, A., White, A. and Boots, M. (2012), Invading with biological weapons: the importance of disease-mediated invasions. *Funct Ecol*, 26: 1249-1261.
<https://doi.org/10.1111/1365-2435.12011>
 3. Sainsbury, A. W., Nettleton, P., Gilray, J. & Gurnell, J. 2000 Grey squirrels have high seroprevalence to a parapoxvirus associated with deaths in red squirrels. *Anim. Conserv.* 3, 229-233 <https://doi.org/10.1111/j.1469-1795.2000.tb00107.x>
 4. Bosch, S. and Lurz, P.W.W. (2015), Grauhörnchen vs. Eichhörnchen. *Biologie in unserer Zeit*, 45: 254-260. <https://doi.org/10.1002/biuz.201510572>
 5. "Red Squirrels." The Wildlife Trusts, www.wildlifetrusts.org/saving-species/red-squirrels.
 6. Bertolino, S., di Montezemolo, N.C., Preatoni, D.G. et al. A grey future for Europe: *Sciurus carolinensis* is replacing native red squirrels in Italy. *Biol Invasions* 16, 53-62 (2014). <https://doi.org/10.1007/s10530-013-0502-3>
 7. Wauters L, Tosi G, Gurnell J. A review of the competitive effects of alien grey squirrels on behaviour, activity and habitat use of red squirrels in mixed, deciduous woodland in Italy. *Hystrix, the Italian Journal of Mammalogy*. 2005;16(1). doi:10.4404/hystrix-16.1-4340.
 8. Rushton SP, Lurz PW, Gurnell J, Nettleton P, Bruemmer C, Shirley MD, Sainsbury AW. Disease threats posed by alien species: the role of a poxvirus in the decline of the native red squirrel in Britain. *Epidemiol Infect.* 2006 Jun;134(3):521-33. doi: 10.1017/S0950268805005303.
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