Epidemics: emergence, elimination, seasonality

In an SIR epidemic model, an infectious disease spreads through a population where each individual is either susceptible, infective or recovered. The population is represented by a network (graph) of contacts, where the vertices correspond to individuals and the edges correspond to potential infectious contacts. Different individuals have different patterns of activity, leading to different numbers of contacts. The degree of a vertex is the number of contacts of the corresponding individual. The basic reproductive ratio is the key quantity for such a model, calculated from the model parameters such as the transmission rate, recovery rate, and the average number of contacts of an individual. It is the average number of secondary cases resulting from one case of a disease and determines the speed of epidemic progression in the early stages.

Emergence of new diseases and elimination of existing diseases is a key public health issue. In an SIR epidemic model and other types of mathematical models of epidemics, such phenomena involve the process of infections and recoveries passing through a critical threshold where the basic reproductive ratio is 1. For example, a pathogen mutation can increase the transmission rate and make a previously ‘subcritical’ disease (i.e. not infectious enough to cause a large outbreak) into a ‘supercritical’ one, where a large outbreak may occur. A closely related issue is seasonality of certain diseases (e.g. malaria), and how the basic reproductive ratio increases above 1 at certain times of the year, and then decreases below 1 during others. Various interventions (e.g. mosquito spraying in the context of malaria or dengue fever) can also affect the basic reproductive ratio in similar ways.

This project will explore mathematical models of disease emergence, elimination and seasonality. Some possible directions of research include the following:

1) Extending the framework of [JLW2015] to vector-borne diseases such as malaria and to time dependent transmission rates. In addition to theoretical results about the probability and size of a large outbreak, we would want to fit the predictions to data from actual malaria outbreaks.

2) Extending the work of [G2015] to study the probability of a large outbreak with seasonality and various interventions. Previous work on seasonality in mosquito-borne diseases (e.g. [B2007]) has focused on a time-varying mosquito birth rate and how it affects the basic reproductive ratio. A time-varying death rate could also be considered (due to e.g. temperature changes or house spraying), and whether its effect on the basic reproductive ratio is different from a changing birth rate.

3) Compare the effects of varying mosquito birth and death rates as studied in 2) with predictions that could be obtained via analytical methods in 1).

This project would be supervised jointly by Jamie Griffin and Malwina Luczak.

References

