Understanding the 2003 Outbreak of Avian Influenza in the Netherlands

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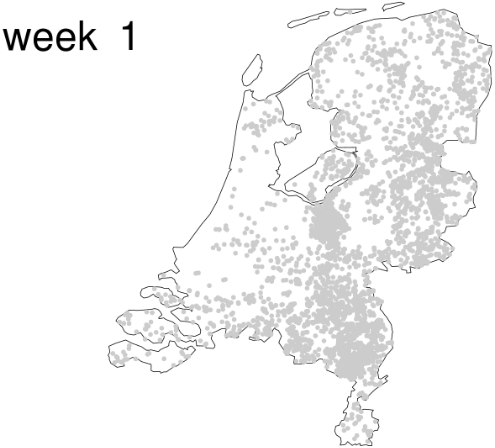
Avian Influenza



Problems and Aims

- How do we work out the probability of one farm infecting each other?
- How do we work out when the farms were infected?
- How can we use this to implement better control strategies?

Data

From the outbreak of Avian Influenza, we observe the following data:

ID	Coordinates	Status	Culling Date
1	(5.32, 18.82)	Not Infected	*NA*
2	(2.90, 15.67)	Not Infected	*NA*
3	(2.86, 17.99)	Pre-Emptively Culled	3^{rd} May
4	(4.56, 18.01)	Culled	30^{th} April
⋮	⋮	⋮	⋮

Epidemic Model

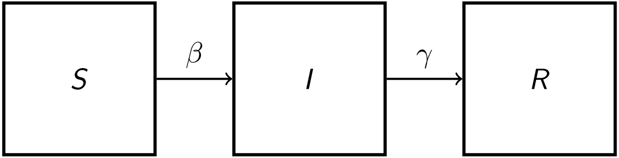


Figure: An SIR model.

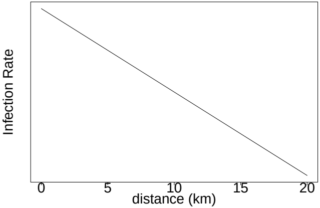
Farms are either **S**usceptible, **I**nfected or **R**emoved.

- **Infections:** Infections occur at some rate β, that tells us the probability of one farm infecting another.
- **Removals:** Individuals are infectious for on average γ days before being culled.

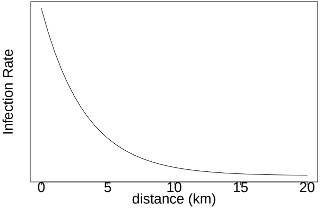
Current Methods

How can we model the probability of one farm infecting another?
We write down an equation linking the distance to the probability.

Linear:
$\beta = ad + b$

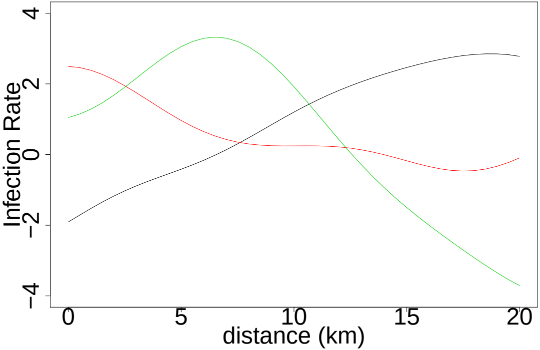


Exponential:
$\beta = ae^{d} + b$



Nonparametric Method

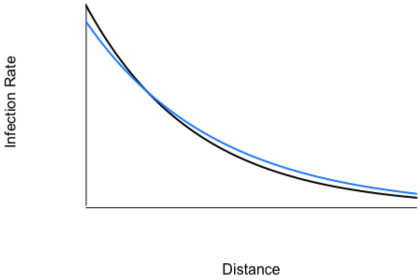
We use a method called Gaussian Processes which generates functions at random.



We still have to specify whether the function is smooth or rough, if it is periodic, and how much influence the points have on each other.

Evaluating Plausible Functions

1. We take our current function (black).
2. We generate a new random function and scale it.
3. We add it on to our current function to make our new function (blue).
4. We compare the likelihood of our current function with the likelihood of our new function.
5. We accept or reject the new function based on this ratio.



$$\frac{\text{new likelihood}}{\text{current likelihood}} = \frac{20\%}{40\%} = 50\%$$

We have a 50% chance of accepting the blue function.

Estimating Infection Dates

We do not observe when the farms were infected, how can we estimate these?

- We have some information from farmers, but not necessarily reliable.
- We use the same method as the infection probability.
- We suggest new times, and see if they are more or less likely than our current guesses.
- This takes a long time as the neighbouring farms will have similar infection times.
- At the same time, we can estimate the value of γ the average number of days a farm is infectious for.

Simulation Study

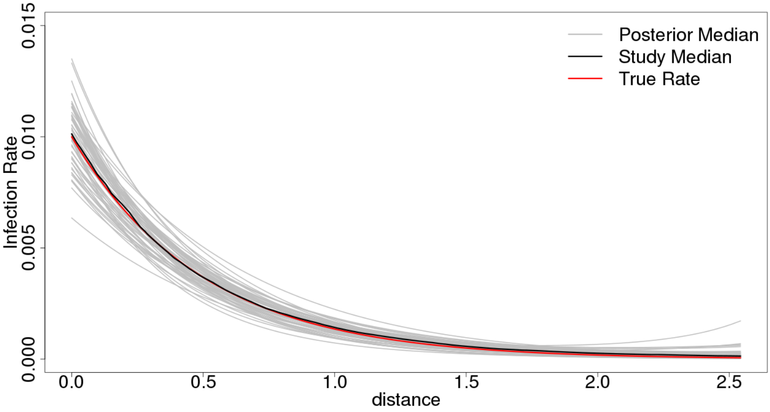


Figure: 250 simulated outbreaks of Avian Influenza with the best estimates of the infection rate.

Avian Influenza Results

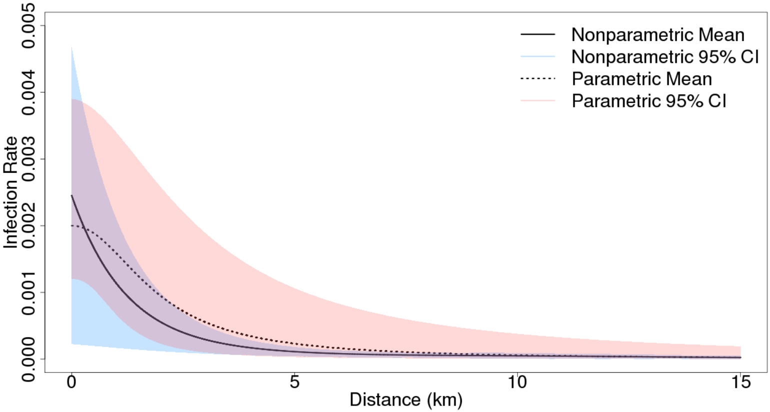


Figure: The parametric and nonparametric results for the Avian Influenza data.

Culling Strategies

Can we use this to help us these results to improve future responses to Avian Influenza?

We assume the once a farm is identified as infected, we cull all farms within *r* km.

Radius (km)	Small	Medium	Large	Cost (€million)
0	1 in 6	2 in 6	3 in 6	35
1	11 in 20	8 in 20	1 in 20	0.98
2	11 in 20	9 in 20	$<$ 1 in 1000	3.5
5	11 in 20	9 in 20	$<$ 1 in 1000	19

Table: The probabilities of different outbreak sizes, and cost to the government, based on different culling strategies.

Conclusion

- We can model the spread of infectious diseases on farms, such as Avian Influenza.
- We can do this without writing down any formulas for the probability of different farms infecting each other.
- We can also estimate when each farm was infected and for how long.
- We can use this to work out optimal control strategies.