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Parameter estimation for between-farm transmission of Avian Influenza, Classical Swine Fever, and Foot-and-Mouth Disease

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Abstract

- We compare between-farm transmission probabilities (in the presence of minimum intervention measures as required by EU law) estimated from recent epidemics in The Netherlands of CSF (1997/1998), FMD (2001) and HPAI (2003) [1-3].
- We use these to make a comparison of these three diseases in terms of their between-farm transmission risks and the options for control in high-risk areas by extending intervention measures with pre-emptive culling and/or emergency vaccination.
- In order to develop a rule of thumb for disease "controllability" we develop a new approach to define and estimate critical farm densities.

Spatial transmission kernel and local reproduction number

The spatial kernel p(r) describes the between-farm transmission probability in the presence of EU minimum intervention measures.

$$p(r) = 1 - \exp(-h(r)T),$$

$$h(r) = \frac{h_0}{1 + \left(\frac{r}{r_0}\right)^{\alpha}},$$

Here p(r) represents the probability that an uninfected farm will be infected by an infected farm a distance r away from it, with transmission occurring at any time over the entire infectious period T of the source farm. The "between-farm" basic reproduction number $R_{0,i}$ is defined as the expected number of secondary infections caused by one primary infection at location *i* throughout its infectious period in a naïve population of farms:

$$R_{0,i} = \sum_{j \neq i} \left(1 - \exp(-h(r_{ij})T)\right) = \sum_{i \neq j} p(r_{ij})$$

Here *j* is running over all farms in The Netherlands except farm *i*.

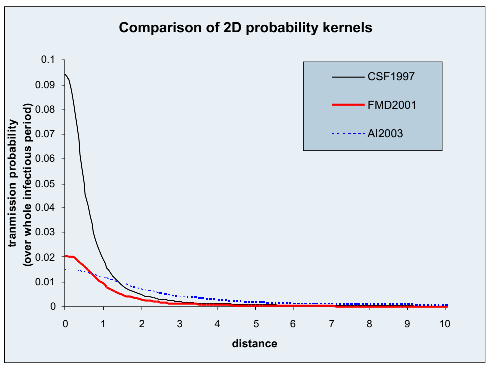

Figure 1. Comparison of transmission kernels from Refs. [1-3].

Table 1. Comparison of transmission kernel parameter estimates from Refs. [1-3].

Parameter estimates	CSF1997	FMD2001	HPAI2003
h_0	0.0032 per day	0.0019 per day	0.002 per day
	2.2	2.3	2.1
r_0	0.52 km	0.9 km	1.9 km
T	31 days	7 days	7.5 days

Critical farm density

$$\rho_c = \frac{1}{2\pi \int_0^{\infty} p(r)\, r\, dr}.$$

Because the kernel parameter is close to 2 for all three diseases, the integral in the denominator is converging only very slowly. As a result it is problematic to use the above expression for calculating the critical density. We therefore use

$$\rho_i = \rho_c R_{0,i}$$

which gives the critical density as a proportionality constant between the local density and the local reproduction number.

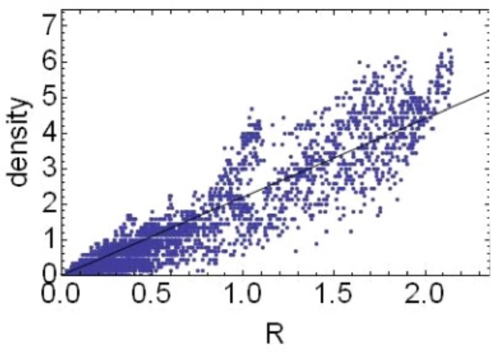

Figure 2. Estimation of the critical density for HPAI.

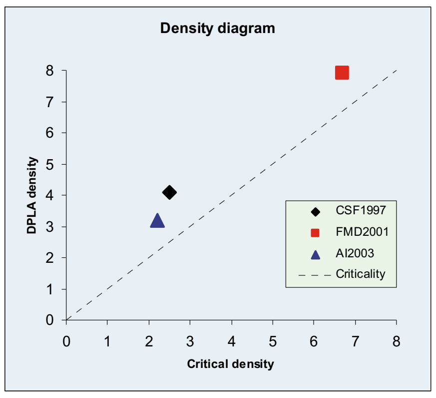

Figure 3. Density comparisons for Rule of thumb I.

Table 2. Critical farm densities for The Netherlands

Critical density	CSF	FMD	AI
Using 3x3 km squares to calculate local densities	2.5	6.7	2.2
Using 5x5 km squares to calculate local densities	2.3	6	1.9

Table 3. High-end local farm densities in the Netherlands.

Local farm density percentiles	CSF	FMD	AI
3*3 km (90%)	4.1	7.9	3.2
3*3 km (95%)	5.6	9.7	4.2

Rule of thumb I: *Farm density*
By comparing the critical farm density to high-end local farm densities, we can judge how much the clustering of farms in high-risk areas of spread complicates epidemic control.

Rule of thumb II: *Generation time versus protection delay*
If the vaccine protection delay is not smaller than the generation time, emergency ring vaccination will be unable to locally control epidemic spread; the shorter the protection delay in comparison to the generation time, the more effect can be expected from emergency vaccination.

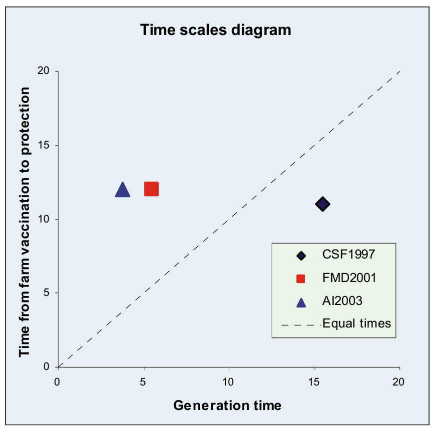

Figure 4. Time scale comparisons for Rule of thumb II.

Conclusions

- For all three diseases, there are high-risk areas in The Netherlands where the critical farm density is exceeded, and thus EU minimum intervention measures do not suffice for epidemic control. Comparing the three diseases using Rule of thumb I, we find that for HPAI the high-end farm densities exceed the critical value most.
- A further complicating factor for HPAI is that its generation time is much smaller than the vaccine protection delay, limiting the effectiveness of emergency vaccination strategies to combat epidemic spread (Rule of thumb II). For CSF, by contrast, a much longer generation time enhances the potential of emergency vaccination strategies.
- Based on the rules of thumb developed here, epidemic control using emergency (ring) vaccination strategies is expected to be least problematic for CSF and most problematic for HPAI, with FMD being intermediately difficult.

References

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