Rift Valley fever: Influence of herd immunity patterns on transmission dynamics

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Outline

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- Model application
- Key findings & interpretation
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Background

- Rift Valley fever virus (RVFV) transmission elevated following excessive persistent rainfall and flooding.

- Average inter-epizootic interval in Kenya = 3.6 yrs. (1–7 yrs.)

- Hypothesis: Herd immunity plays an important role in modifying the length of these intervals
Research objective

- To evaluate the relationship between herd immunity and RVFV transmission dynamics
- Evaluation – based on a transmission dynamics simulation model
RVF transmission model description

Host module

✓ A 2-host model – cattle and sheep – based upon:
✓ Age-structured population dynamics – individual-based – characteristics and behaviour tracked for each host

Vector module

✓ A 2-vector model – *Aedes* and *Culex* spp.
✓ Population-based – Life stages modelled using difference equations
✓ Population dynamics – driven by satellite-based rain using probability functions

\[
L_{v(t+1)} = L_{v(t)} + (E_{g_{brd(t)}} * H_A) - (L_{v(t)} * \mu_{A}) - (L_{v(t)} * E_{A});
\]

\[
P_{p(t+1)} = P_{p(t)} + (L_{v(t)} * E_{A}) - (P_{p(t)} * \mu_{Ap}) - (P_{p(t)} * F_{A});
\]

\[
A_{d(t+1)} = A_{d(t)} + (P_{p(t)} * F_{A}) - (A_{d(t)} * \mu_{Aa});
\]

\[
E_{g_{brd(t+1)}} = E_{g_{brd(t)}} + (A_{d(t)} * S_{A}) * J_{A};
\]
RVF transmission model description

Spatial grid cell framework

representation of spatial heterogeneities in the model through the variation of:

✓ the locations of vector breeding sites
✓ host movement patterns

Transmission module

Individual host: Susceptible, Exposed, Infected, Recovered

Vector (population-based): Susceptible, Exposed, Infected
Model application

- Variations in vectors’ population growth and data periods

- Simulations implemented for 1200 days that cover the data period to predict 2006-07 outbreak

- Transmissions are subsequently shut. Simulations then run for five years to assess the post-outbreak evolution of herd immunity dynamics.

- C++: 1000 simulations for each scenario
Key predictions (1)

- The model reproduces the temporal course of 2006-07 RVF outbreak
- Plus seasonal transmissions that are dependent on amount of rain
Key predictions (2)

- The model predicts a high herd immunity level at the end of that outbreak:

  Sheep: 94% [range 65%, 99%]
  Cattle: 89% [range 81%, 96%]

- Over time, after the outbreak, immunity wanes. Five years later, declines to:

  Sheep: 0.3% [range 0.07%, 0.5%]
  Cattle: 6% [range 4%, 8%]

- This period falls within the reported range of inter-epizootic period in Kenya and appears to depend on species.
Key predictions (2)

A box-and-whisker plot: evolution of herd immunity dynamics during the post-outbreak period

The serial numbers denote time in years following the outbreak.
Key predictions (3)

Can herd immunity dynamics modify the length of inter-epizootic intervals?

- Separate model analyses – assessing impact of control options

- Predicted full-blown outbreak prevention window
  - Average 317 days in sheep
  - Average 723 days in cattle
Interpretation

- Rate of decline in herd immunity higher in sheep than in cattle
- Likely due to the greater population turnover
- Inter-annual transmissions might be responsible for sustaining herd immunity over time
- Predictions suggest that host diversity can influence the temporal pattern of a multi-host epizootic
Conclusion

- Findings provide a better understanding of immunity patterns critical in refining existing control strategies

- Strategies aimed at boosting herd immunity during the inter-epizootic period

- Findings provide huge potential for use in evaluation of cost-effectiveness of vaccination campaigns
Acknowledgements

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