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

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Regional Conference on Zoonotic Diseases in Eastern Africa
Naivasha, Kenya
9-12 March 2015

International Livestock Research Institute

HEALTHY FUTURES

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Outline

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- Research objective
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- Model application
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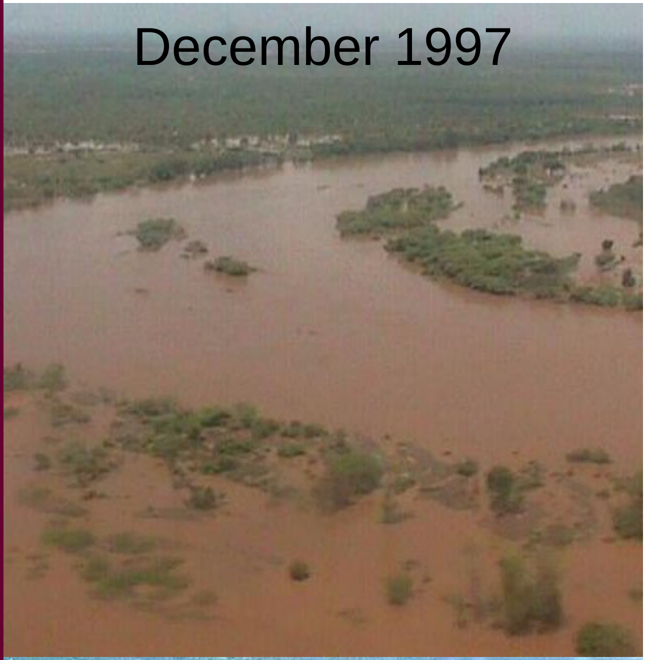
- Conclusion

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

$$Lv_{(t+1)} = Lv_{(t)} + (Eg_{brd(t)} * H_A) - (Lv_{(t)} * \mu_{A1}) - (Lv_{(t)} * E_A);$$

$$Pp_{(t+1)} = Pp_{(t)} + (Lv_{(t)} * E_A) - (Pp_{(t)} * \mu Ap) - (Pp_{(t)} * F_A);$$

$$Ad_{(t+1)} = Ad_{(t)} + (Pp_{(t)} * F_A) - (Ad_{(t)} * \mu Aa);$$

$$Eg_{brd(t+1)} = Eg_{brd(t)} + (Ad_{(t)} * S_A) * J_{A;}$$

RVF transmission model description

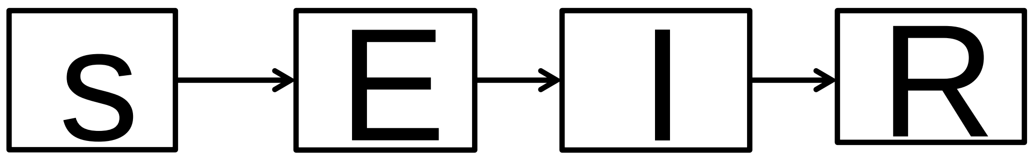
- Spatial grid cell framework

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

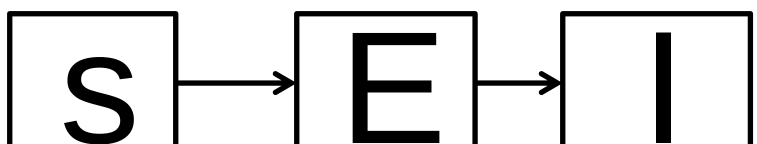
  - ✓ the locations of vector breeding sites
  - ✓ host movement patterns

- Transmission module

  Individual host: Susceptible, Exposed, Infected, Recovered



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

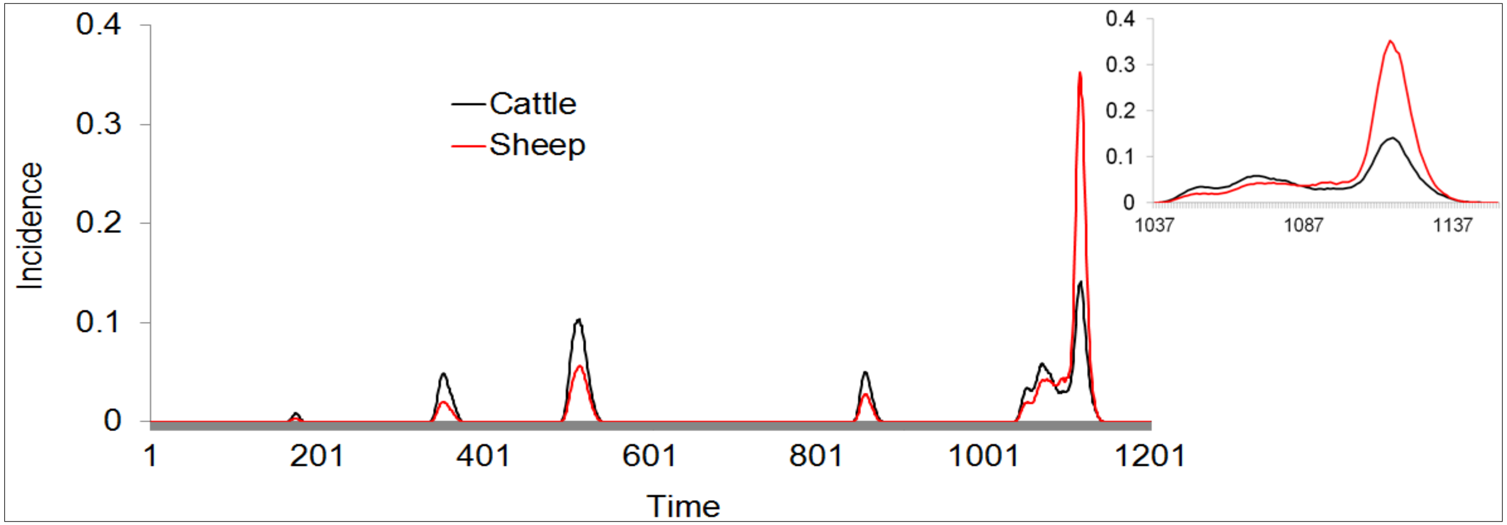


Model application

- 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%]

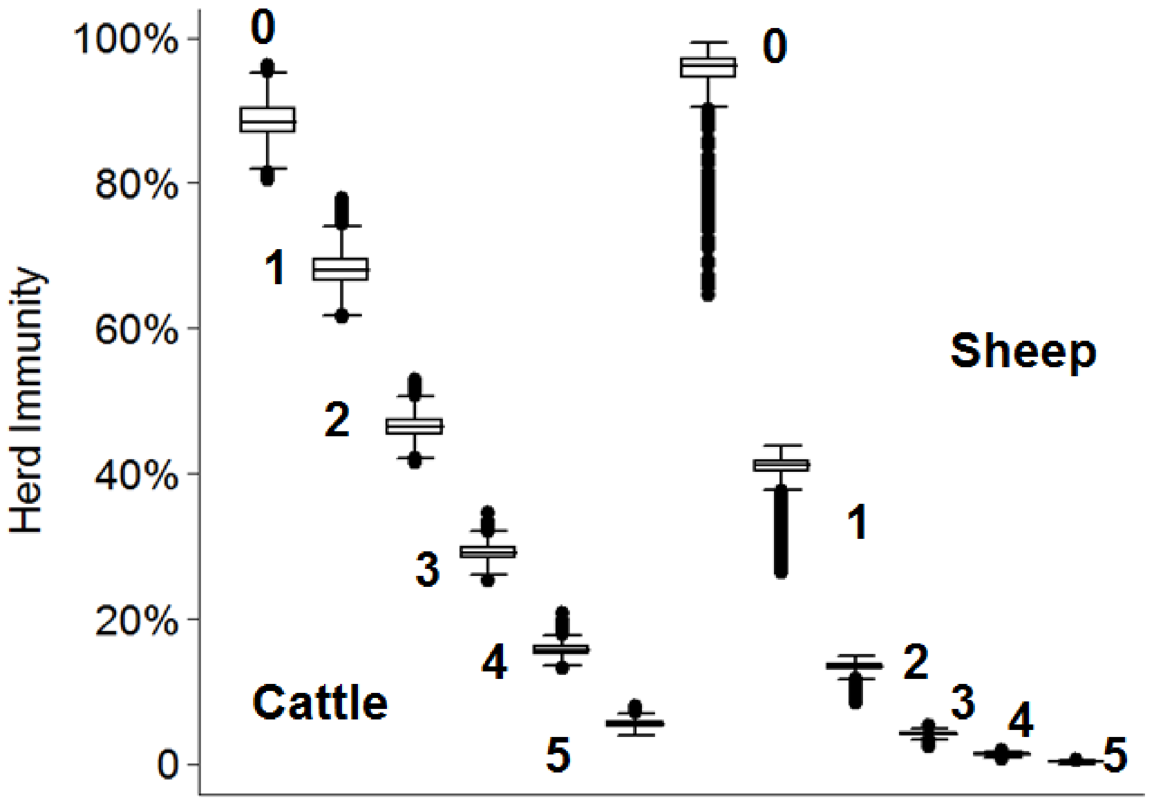
- Over time, after the outbreak, immunity wanes. Five years later, declines to:

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)

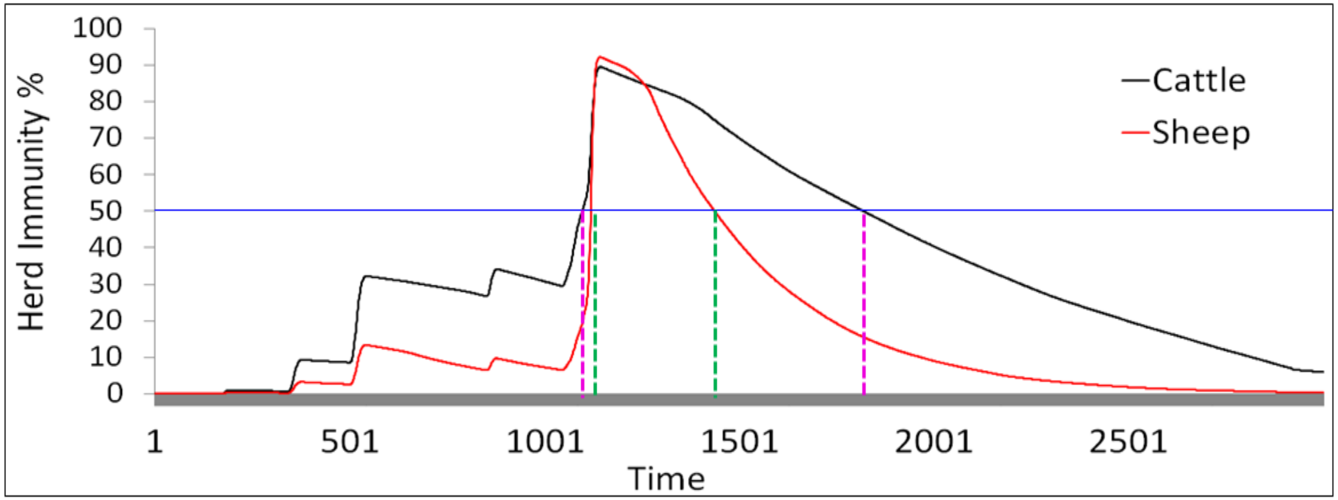
A box-and-whisker plot : evolution of herd immunity dynamics during the post-outbreak period



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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