



Math and rabies control

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Outline

Introduction

What is rabies?

What is math?

Math and disease elimination

Patterns of spread in Africa

Statistics

Dynamical models

What species are important?

Transmission details

Other topics

Conclusions

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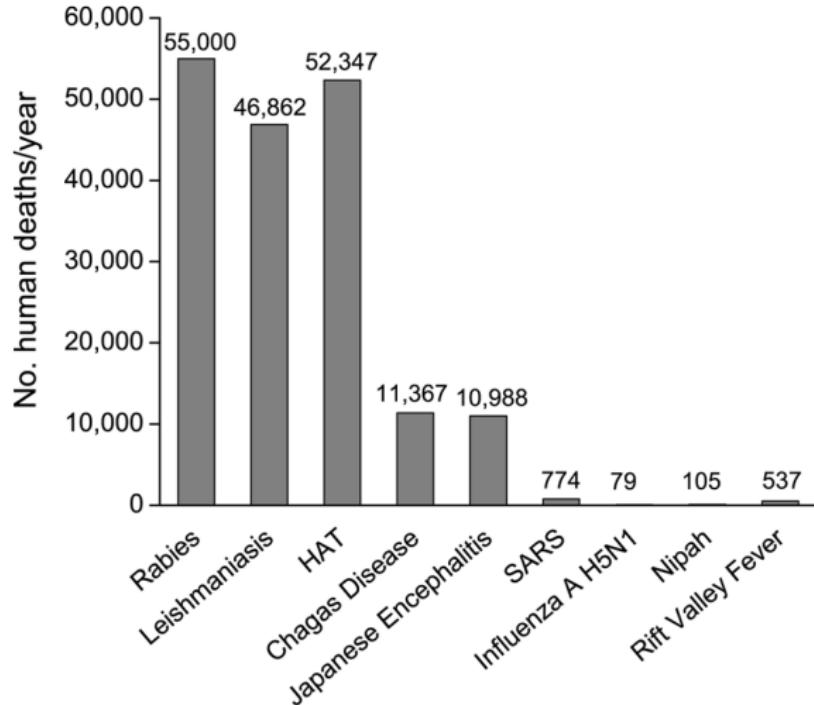
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What is rabies?

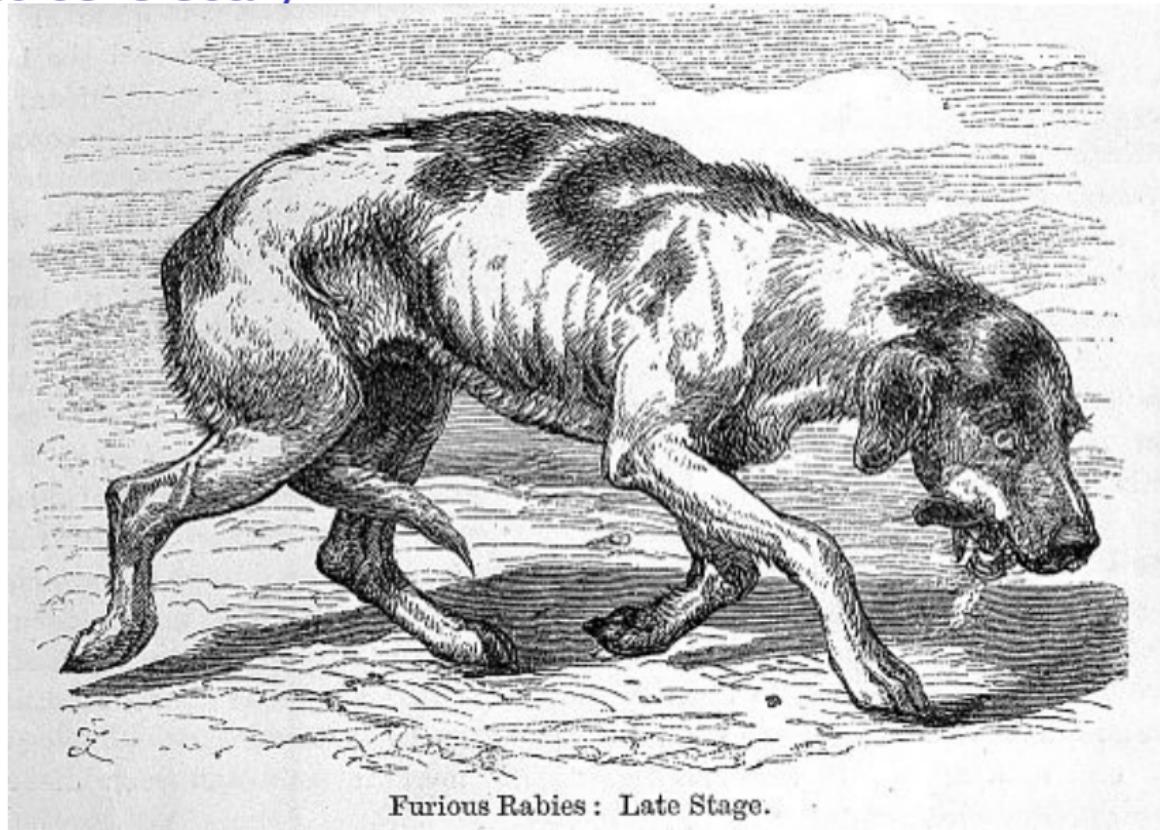
- ▶ A fatal, viral disease
- ▶ Transmitted by saliva, usually via bites

Rabies is an under-rated disease



Lembo et. al, PLoS NTDs

Rabies is scary



Furious Rabies : Late Stage.

Rabies is expensive



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Effective, economical control measures are available



Dog-mediated rabies is slated for elimination

Rabies is a major public health problem

- Fatal once symptoms appear
- One death every 15 min worldwide
- 4 out of 10 deaths are in children
- 99% human cases result from dog bites

Rabies is 100% vaccine preventable

VACCINATE TO SAVE LIVES VACCINATE TO STOP TRANSMISSION

No bites = No rabies

learn how to interact

Zero by 30
28 September - World Rabies Day

World Health Organization

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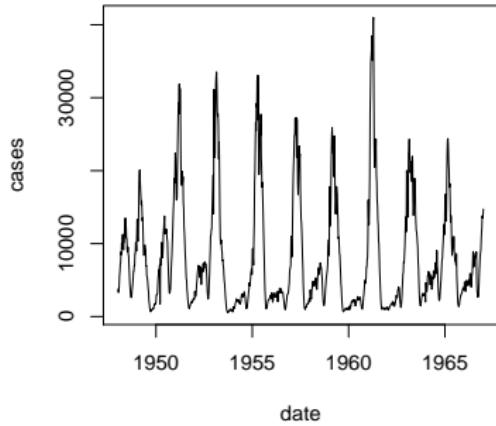
What is math?

- ▶ American for maths
- ▶ A well-defined framework for thinking about how assumptions relate to conclusions
- ▶ A powerful tool for helping to ask scientific questions

Dynamical modeling connects scales

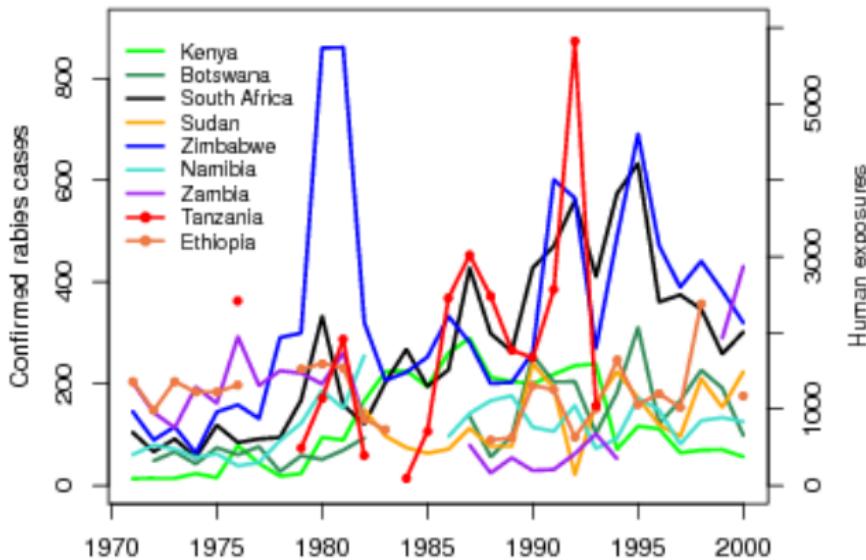


Measles reports from England and Wales



- ▶ Start with rules about how things change in short time steps
 - ▶ Usually based on *individuals*
- ▶ Calculate results over longer time periods
 - ▶ Usually about *populations*

Statistics evaluates patterns



Hampson et al., PNAS, 2007

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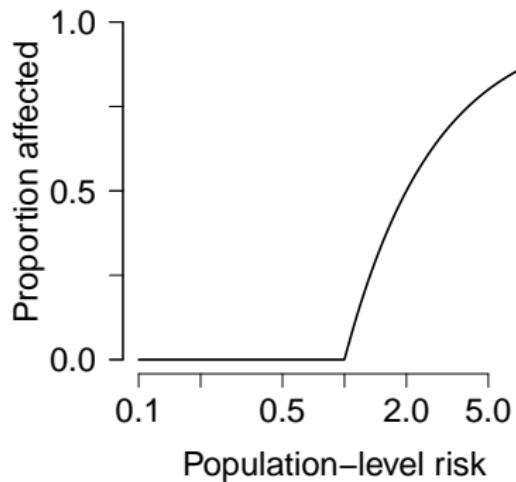


Evolution
and ecology of flu

The basic reproductive number

- ▶ \mathcal{R}_0 is the number of people who would be infected by an infectious individual *in a fully susceptible population*.
- ▶ $\mathcal{R}_0 = cpD$
 - ▶ c : Contact Rate
 - ▶ p : Probability of transmission (infectivity)
 - ▶ D : Average duration of infection
- ▶ A disease can invade a population if and only if $\mathcal{R}_0 > 1$.
- ▶ \mathcal{R} usually declines from \mathcal{R}_0 if the disease spreads (fewer people are susceptible)

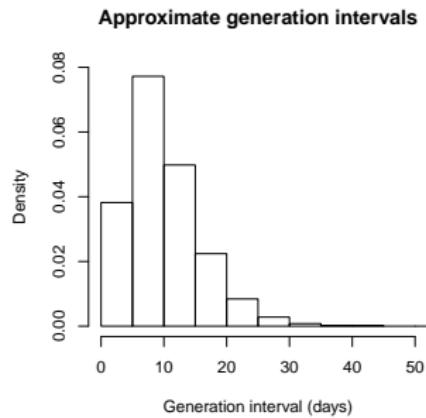
Endemic curves



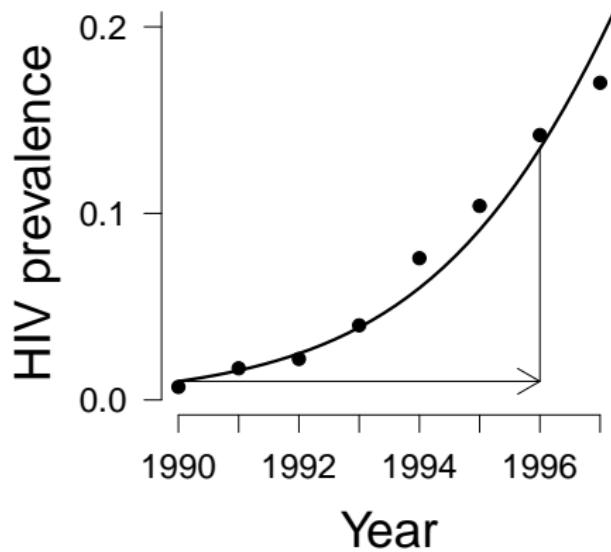
- ▶ Threshold value
- ▶ Sharp response to changes in factors underlying transmission
- ▶ Implications for control

Speed and risk

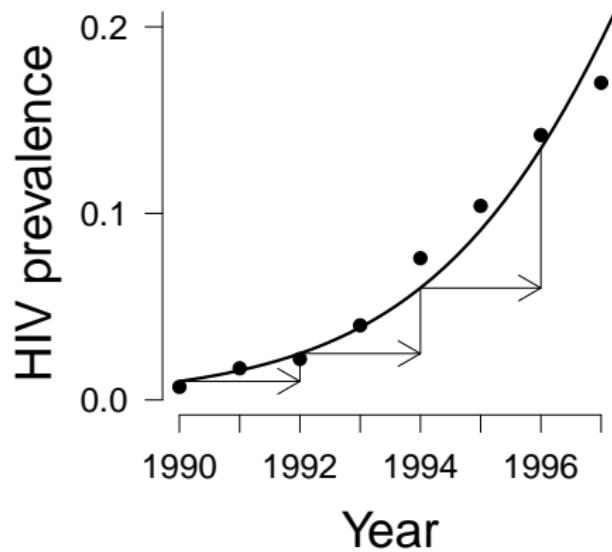
- ▶ Which is more dangerous, a fast disease, or a slow disease?
 - ▶ How are we measuring speed?
 - ▶ How are we measuring danger?
 - ▶ *What do we already know?*



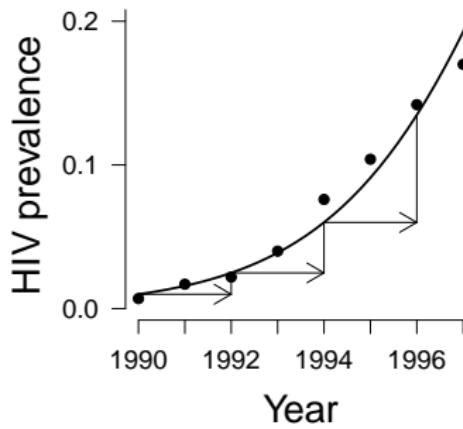
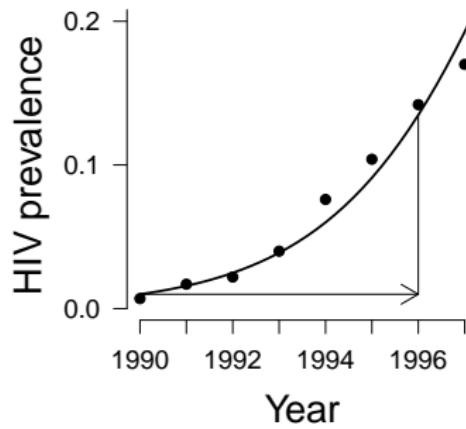
Speed and risk



Speed and risk



Speed and risk



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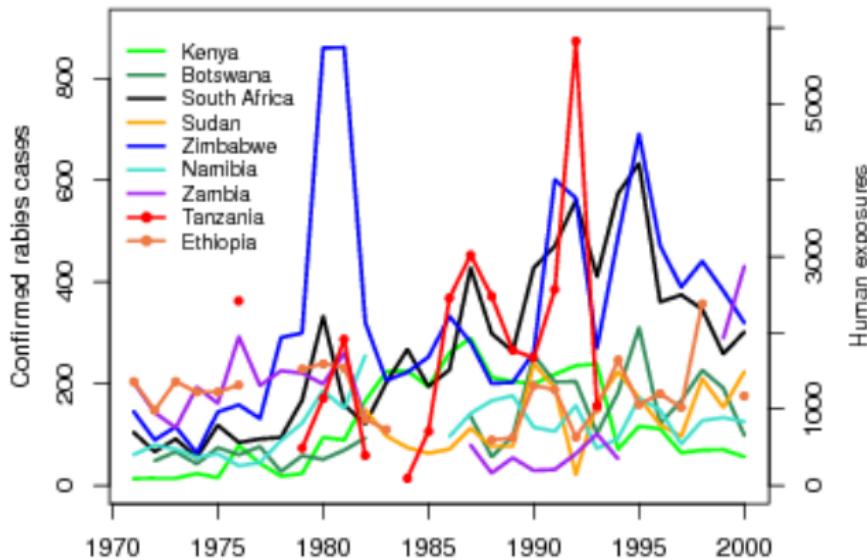
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Spatiotemporal patterns of rabies in Africa



Hampson et al., PNAS, 2007

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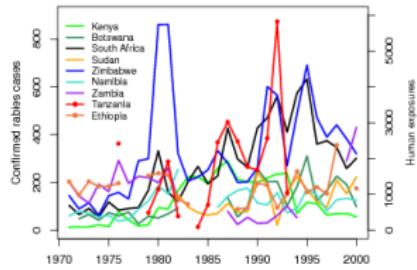
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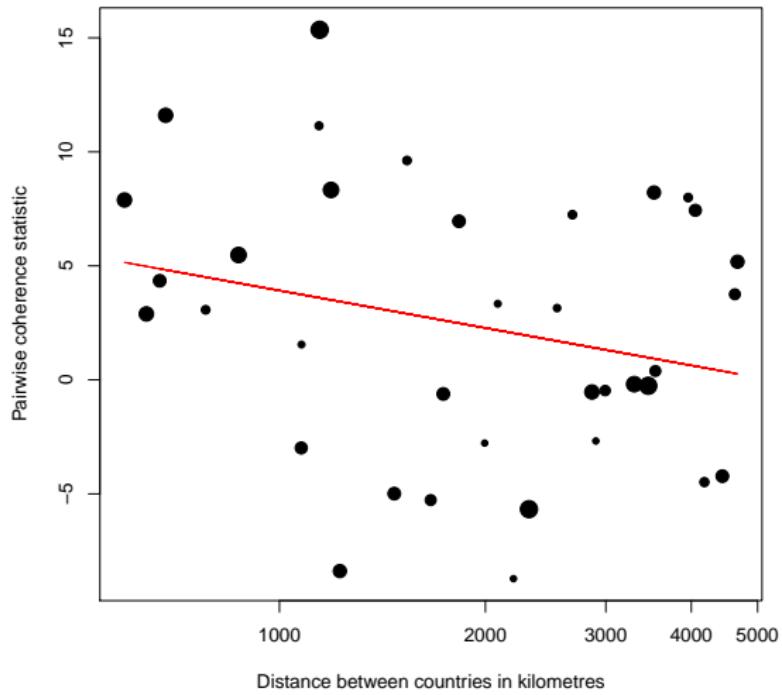
- ▶ What patterns do we see?
- ▶ How clearly do we see them?

Synchrony

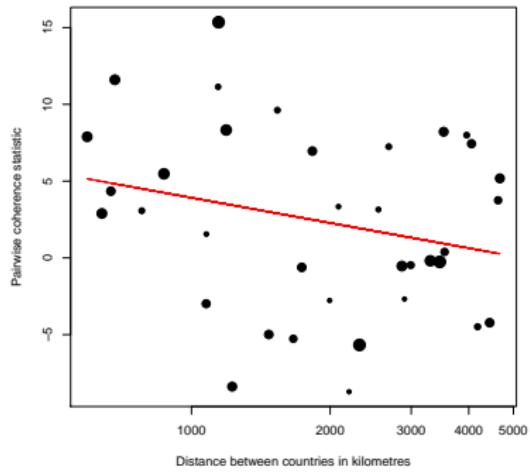


- ▶ What is a fair way to compare these to a null (unsynchronized) model?
- ▶ Randomize starting points, not each point individually

Geographic correlations

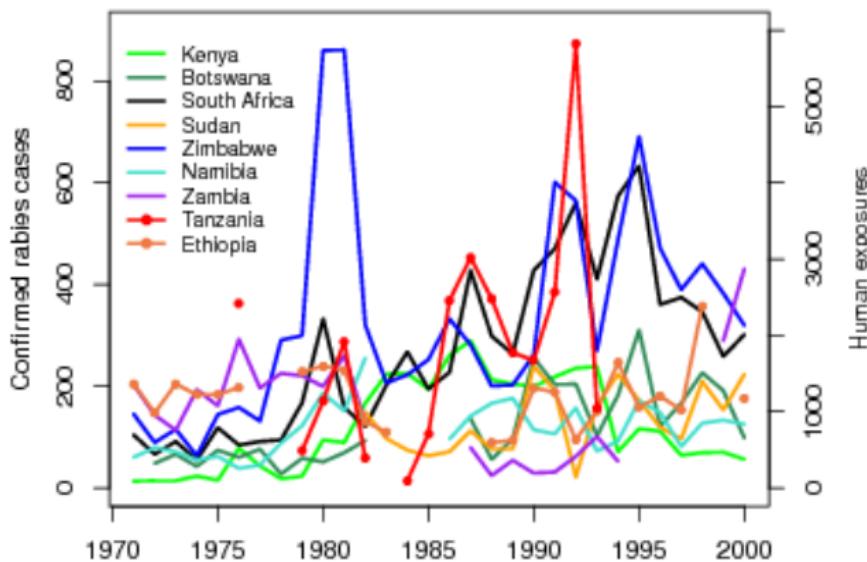


Geographic correlations

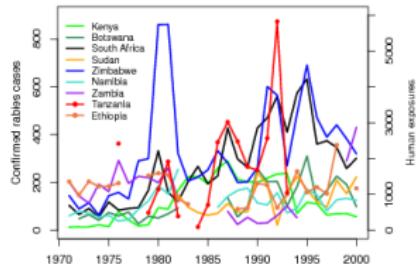


- ▶ What is a fair way to compare *these* to a null model
- ▶ Randomize one of the *country lists*, not the individual points

Periodicity



Periodicity



- ▶ What is a fair way to compare these to a null (non-periodic) model?
- ▶ Randomize *differences* rather than observations

Results

- ▶ Rabies in Africa is
 - ▶ Synchronized at a large spatial scale
 - ▶ Periodic
 - ▶ Fast (ie., cycles are faster than simple models can predict)

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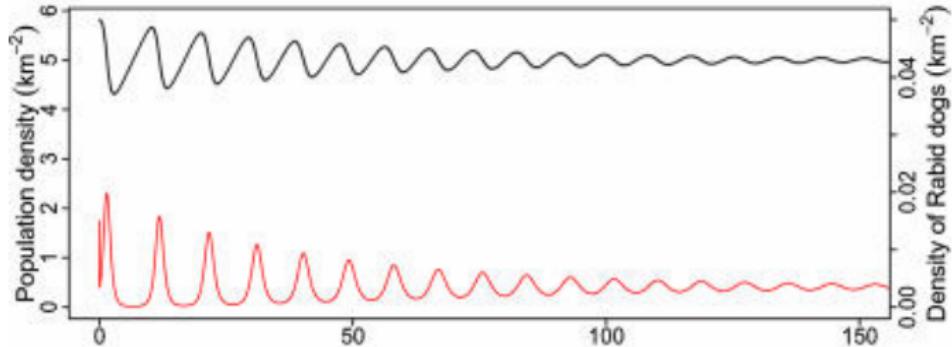
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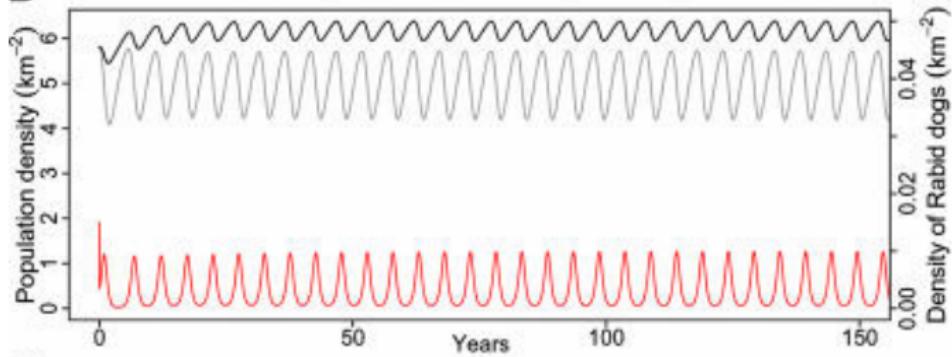
- ▶ What might explain the patterns that we see?
- ▶ Based on observations of health systems, we hypothesized that humans are *responding* to rabies outbreaks
 - ▶ Vaccination, education, awareness

Explaining fast cycles

A



B



Conclusions

- ▶ Rabies in Africa is synchronous and periodic
- ▶ Synchrony between countries may be due to border crossing
 - ▶ by rabid dogs
 - ▶ or by human ideas
 - ▶ not likely to be simply due to reporting
- ▶ Periodicity is likely driven by human responses (and their lack)
- ▶ Governments should:
 - ▶ all contribute to the effort
 - ▶ be consistent through time

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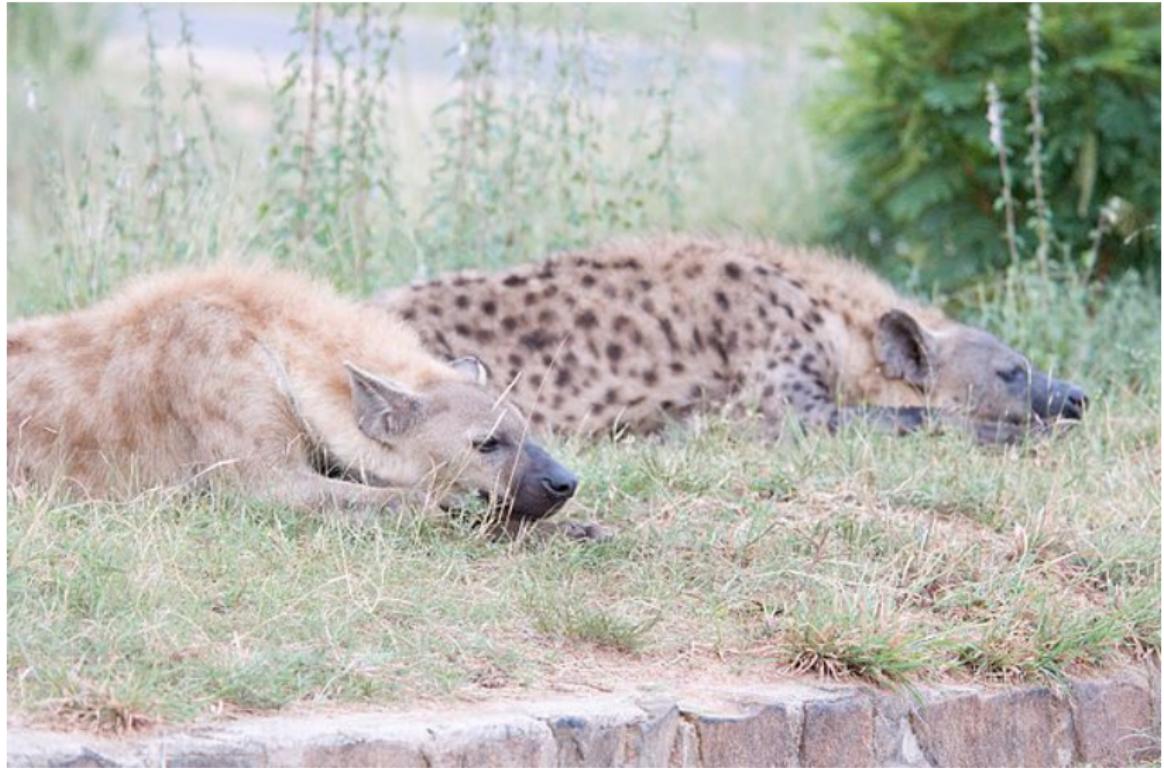
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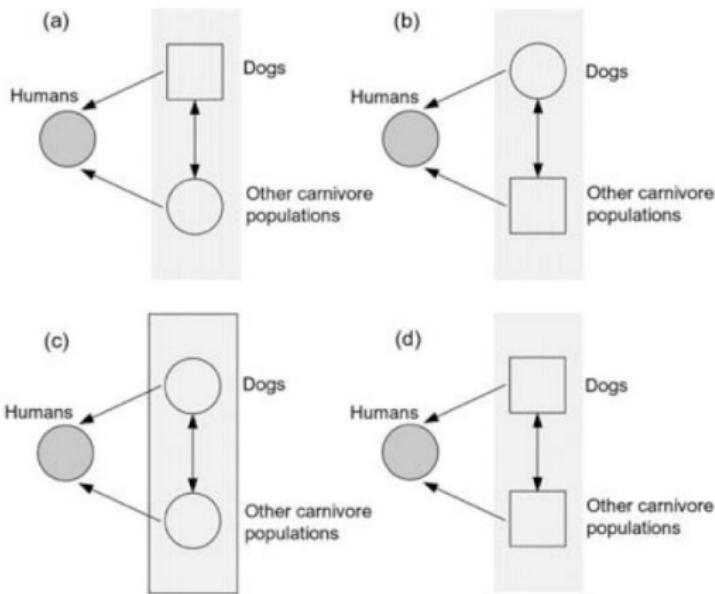
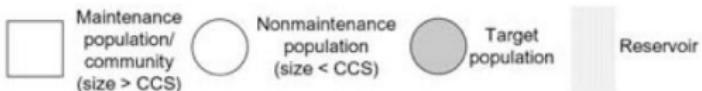
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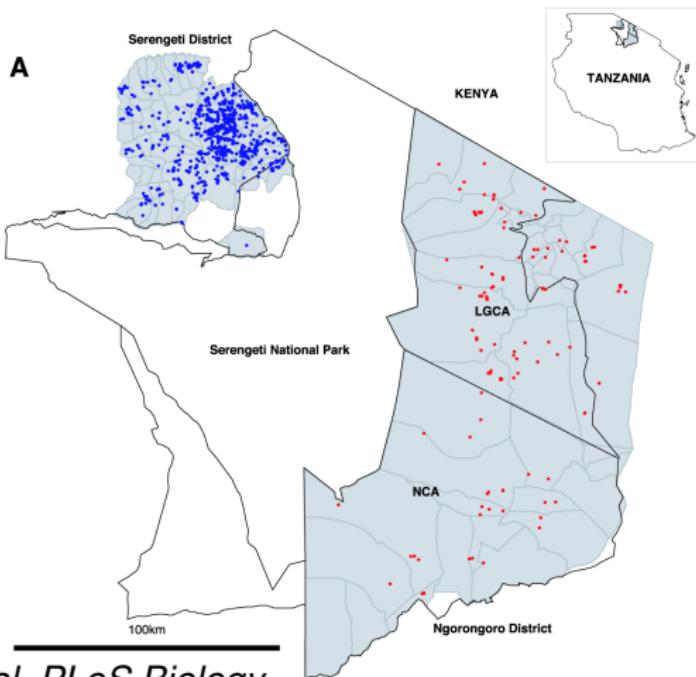
Multiple populations



Maintenance populations



NW Tanzania study



Hampson et al. PLoS Biology



Ngorongoro district



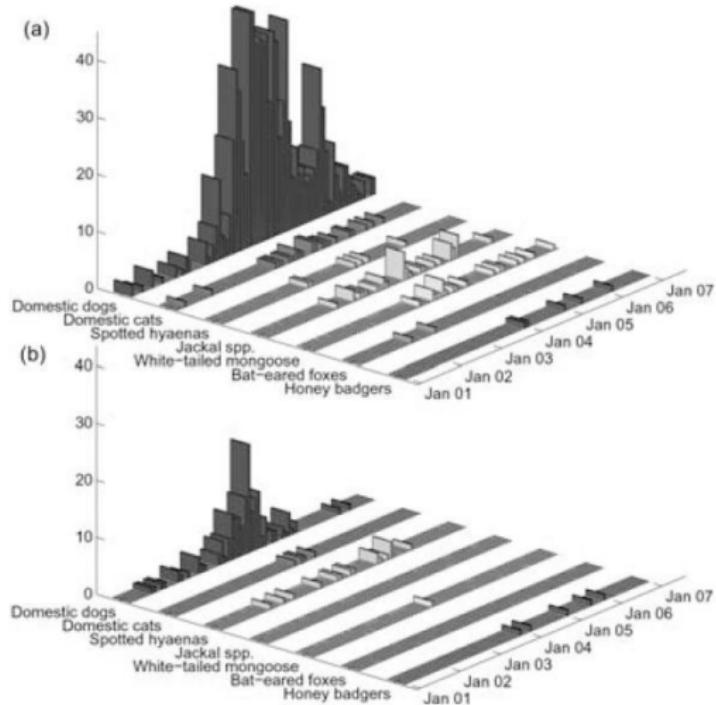
Serengeti district



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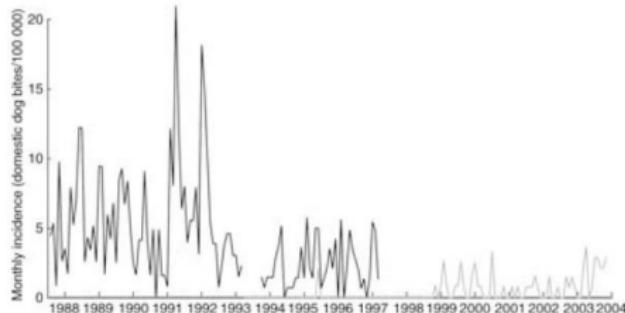
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Rabies cases identified



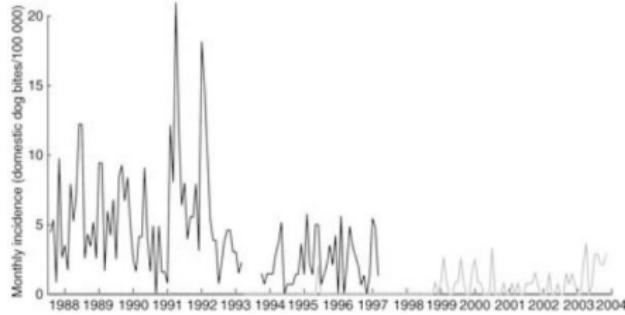
Lembo et al. 2008 J. App. Ecol.

Model fitting



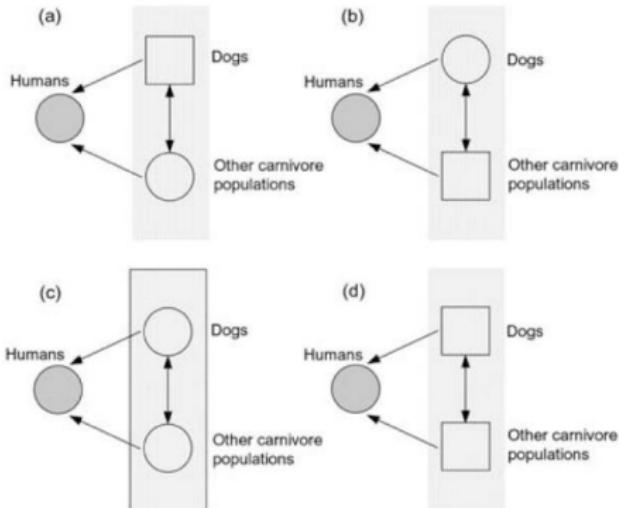
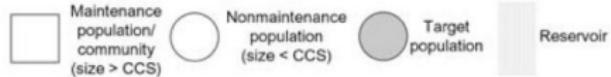
- ▶ Domestic dogs are a maintenance population
- ▶ Wild carnivores as a whole are not

Model fitting



- ▶ Some amount of intervention in dogs alone should eliminate rabies circulation in this population
- ▶ No amount of intervention in the carnivore population alone will do this

Model fitting



- ▶ Some amount of intervention in dogs alone should eliminate rabies circulation in this population
- ▶ No amount of intervention in the carnivore population alone will do this

Which species are important?

- ▶ Vaccination in domestic dogs can eliminate canine rabies strains from Serengeti and Ngorongoro districts
- ▶ Maybe from everywhere!



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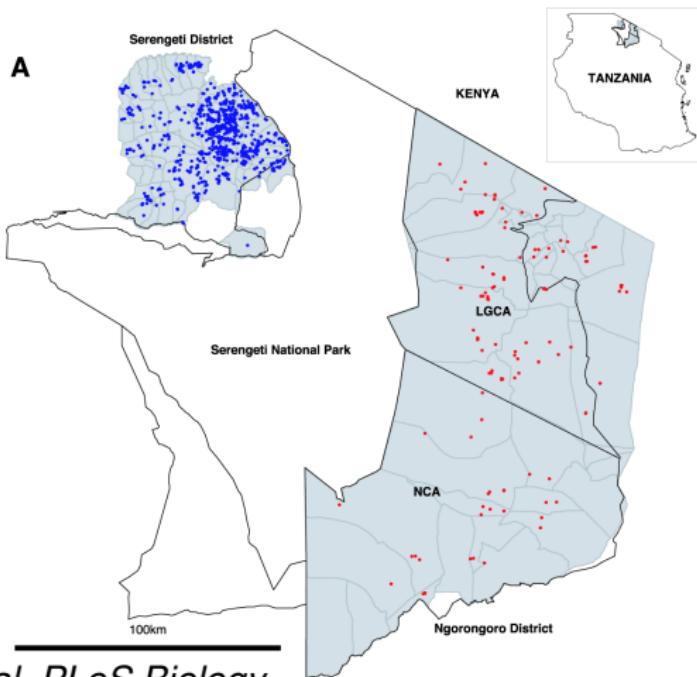
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Hampson et al. PLoS Biology

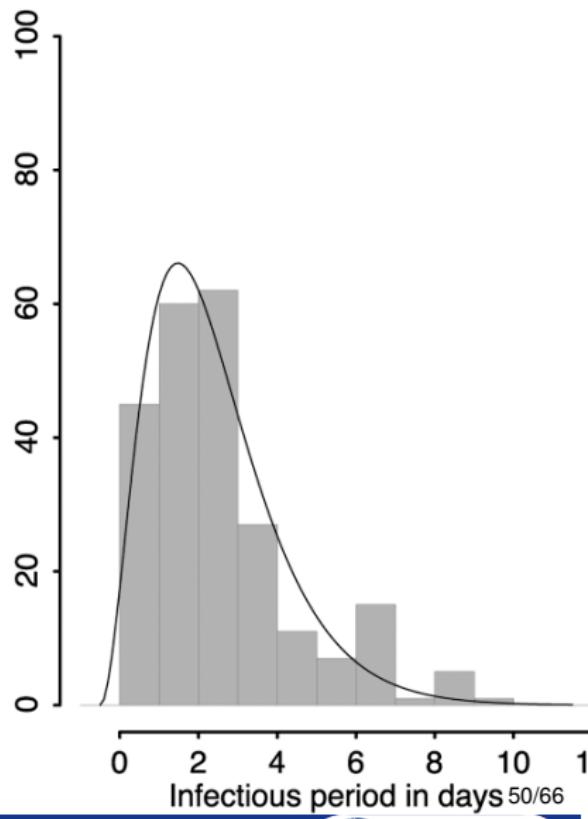
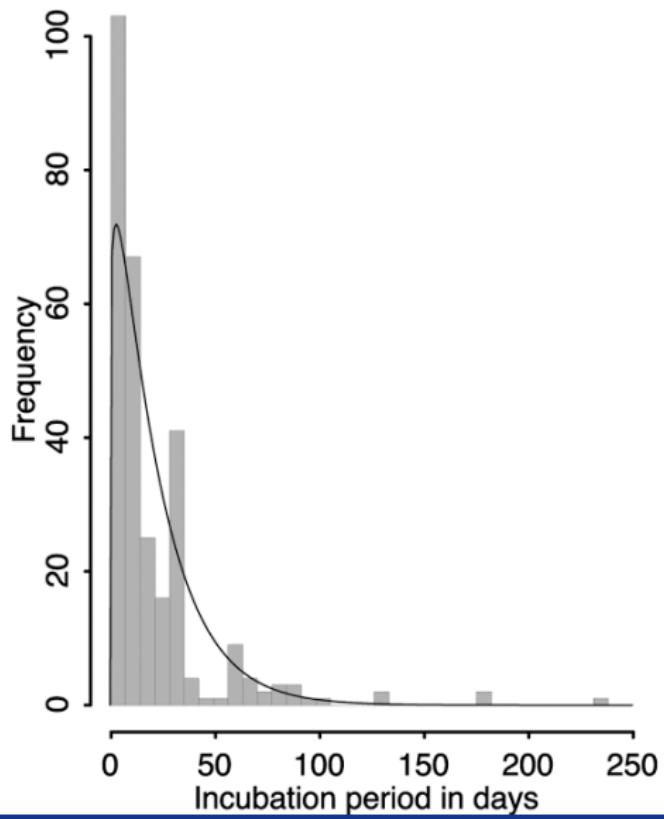


Contact tracing



Contact tracing can be used
to follow transmission

Time distributions

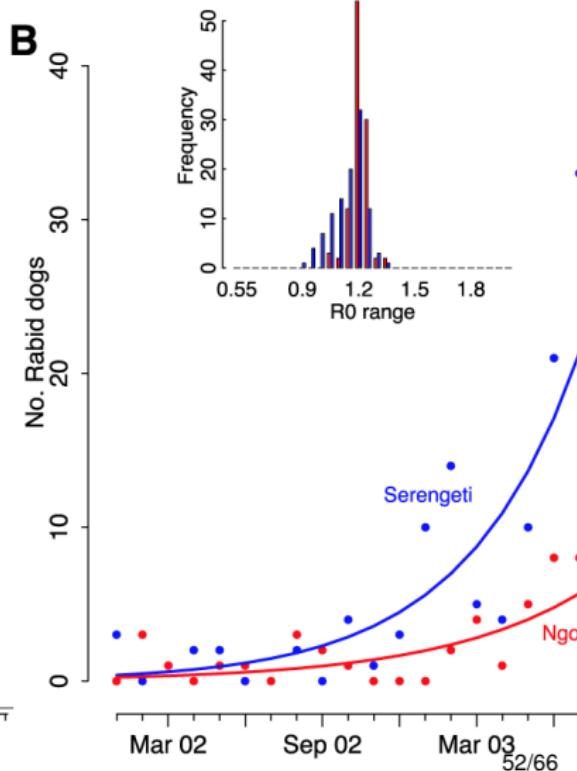
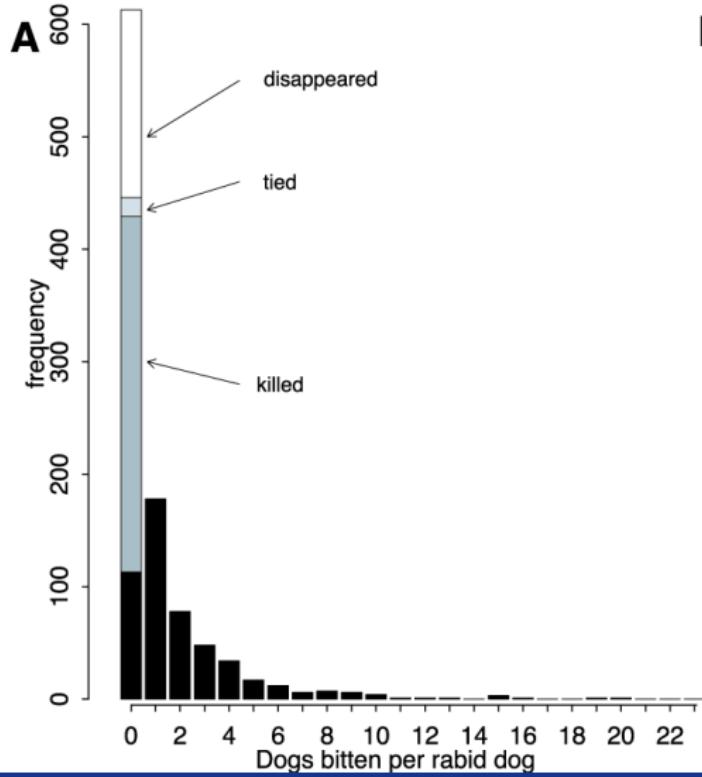


ICI3D

Estimating \mathcal{R}_0

- ▶ We estimated \mathcal{R}_0 in three ways:
 - ▶ Rate of spread compared to time distributions
 - ▶ Number of bites expected without control measures, \times probability of infection
 - ▶ Epidemic tree reconstruction (similar to reservoir paper)
- ▶ In the latter two cases we had a more than one estimate, depending on different assumptions about unobserved events

Estimating \mathcal{R}_0

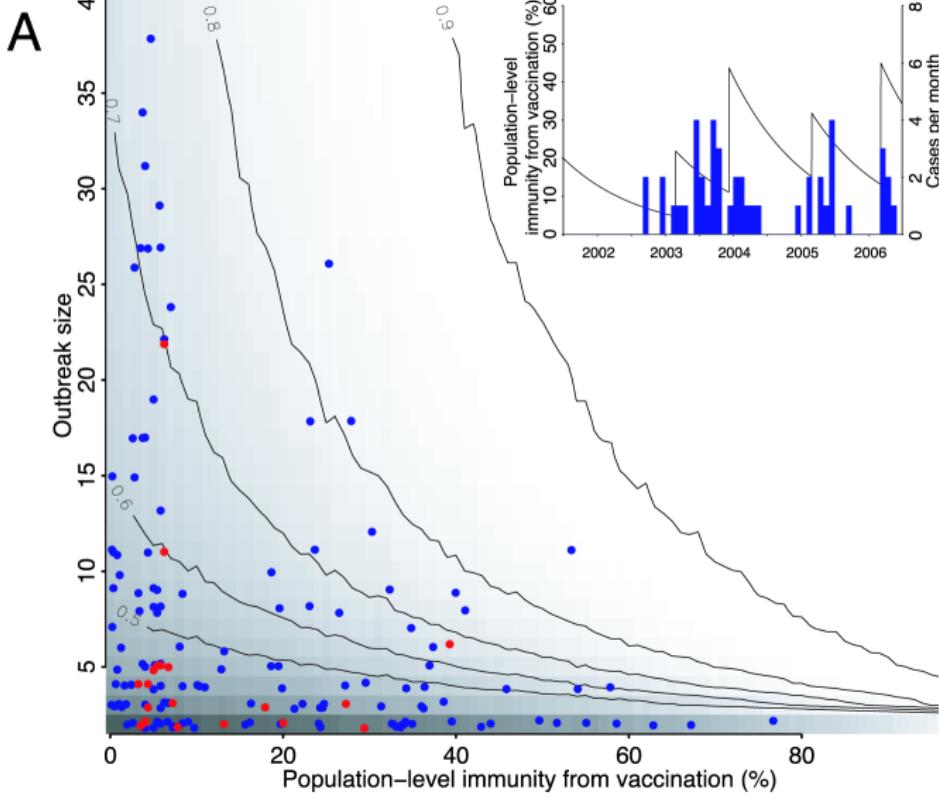


Vaccination campaigns

This can be achieved at ~\$1 per dog



Vaccination and outbreaks



Conclusions

- ▶ Low \mathcal{R}_0 means that elimination of canine rabies and thus the public health threat of rabies is possible in this area
 - ▶ This implies that it should be possible in most or all areas of the world – it would be nice to know which
- ▶ Short dog lifespans make elimination harder; co-ordinated, consistent effort is required

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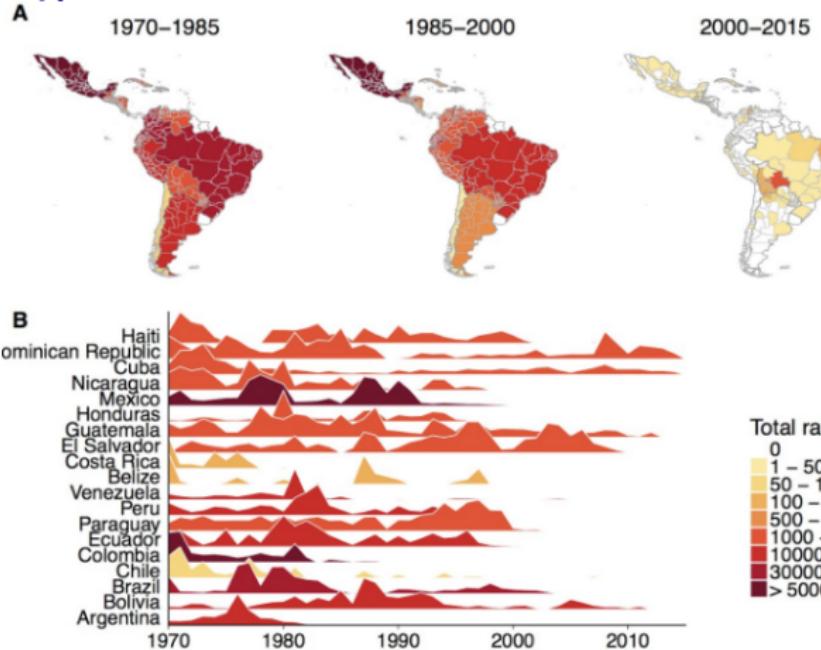
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Other topics

- ▶ Math is a wonderful tool!



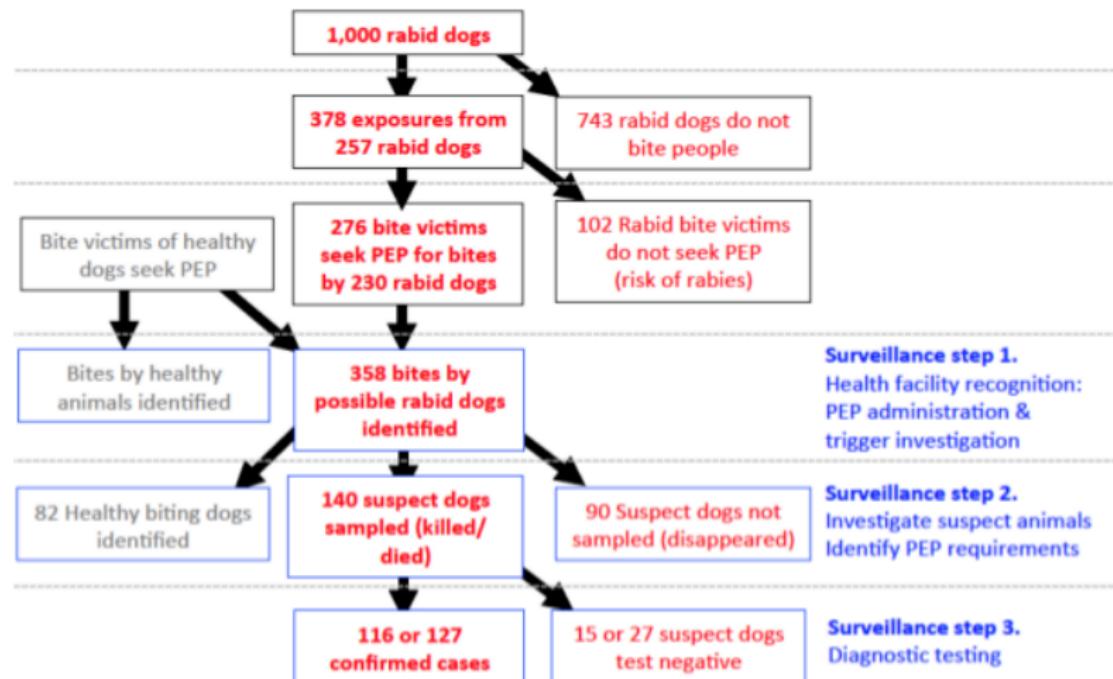
Learning from Latin America



Harris . . . Hampson, in prep
► Patterns of rabies decline

Verifying elimination

Hampson et al <https://www.biorxiv.org/content/early/2016/12/31/096883>



Demography



- ▶ How long do dogs live? How does this effect vaccination campaigns? What would be the effect of sterilization?

How does human vaccination fit in?



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Get it right



- ▶ Measure twice, cut once
- ▶ Calculate twice, implement policy once
- ▶ Dynamic models and statistics are our measuring devices

Get it done



Photo by @matthewmuturi

Mass vaccination of domestic dogs should lead to:

- ▶ elimination of canine rabies
- ▶ decrease of 100× or more in rabid bites and deaths

Thanks

- ▶ Public and workshop participants
- ▶ AIMS
- ▶ Katie Hampson, Glasgow group and other co-authors
- ▶ Thumbi Mwangi
- ▶ ...



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