Social networks and the spread of infectious diseases

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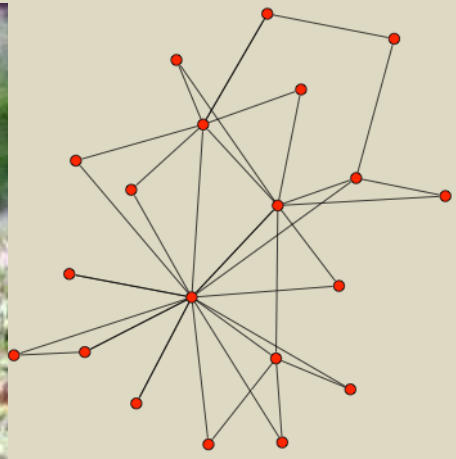
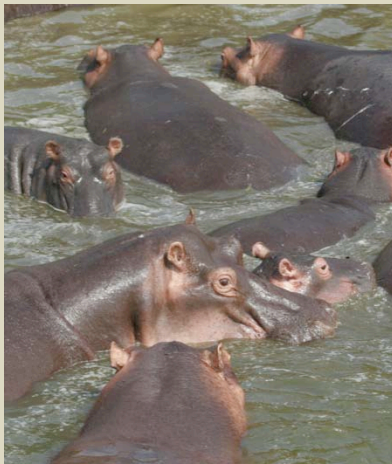
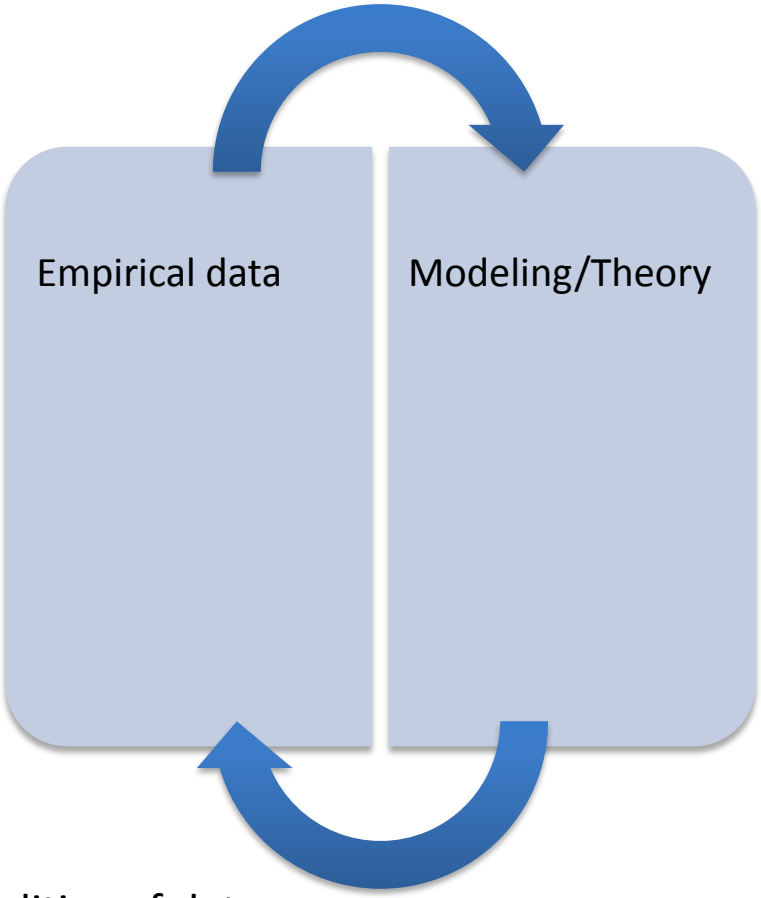
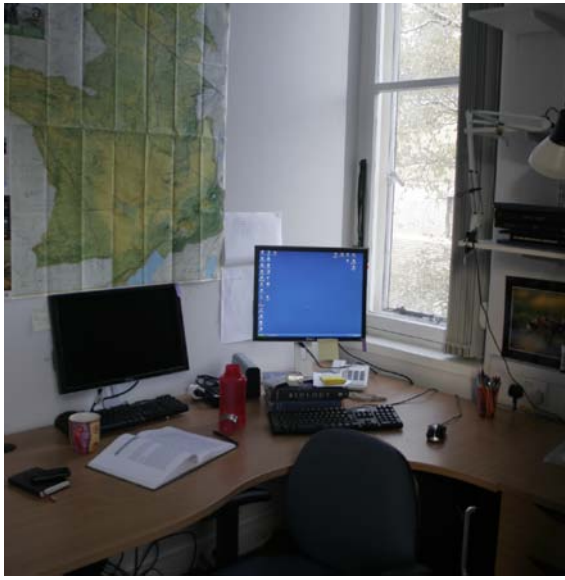



Disease ecology

Research program tools





Serengeti:
Remote conditions and realities of data

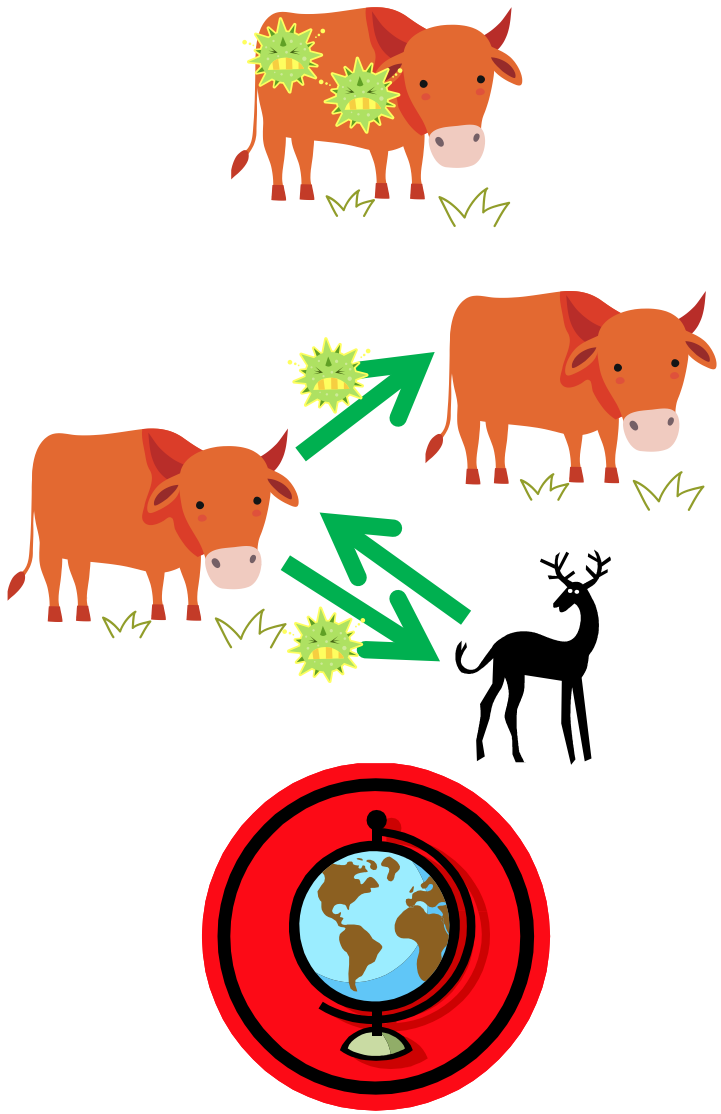
University of Glasgow:
Theoretical ecology

Scales of infectious disease models

Within host

Between hosts

Host in context of ecosystem



Networks

1. Tools to quantify contacts in wildlife
2. Social network analysis
3. Network modeling/contact network epidemiology

P.S. Rabies contacts in dogs (Hampson et al, PLoS Biology 2010)

SNA vs Network Modelling

- Social network analysis (SNA)
  - Statistical description of networks and their properties (structural, information flow)
- Network modelling/Contact networks
  - Using an existing or artificially generated network with which to describe contacts with transmission potential between individuals
  - Simulation of infection process upon that network
- Both can often use same data

Contacts and the potential transmission of close-contact infections

- Host contact network determines transmission pathways available to disease
- Different transmission modes imply different contact networks, with own particular structure

Sexual / bites	**Airborne**	**Vector**
Few contacts	Many contacts	Depends on
Infrequent	Clustering?	biology of vector

- Contact networks may change through time
  - as infection progresses
  - births, deaths, migration events
  - changes in host behaviour

How to get data on contacts in wildlife

See: Network Models: An Underutilized Tool in Wildlife Epidemiology?

Direct techniques

- Behavioral observations

Indirect techniques

- Biologging PIT tags/loggers (presence/absence at feeding sites)
- Biologging: proximity data loggers/collars
- Capture-mark-recapture
- Direct manipulation
- GPS recorders
- Powder marking
- Radio telemetry
- Trapping and bait marking
- Video tracking from animal's perspective
- Video trapping from fixed perspective (automated)

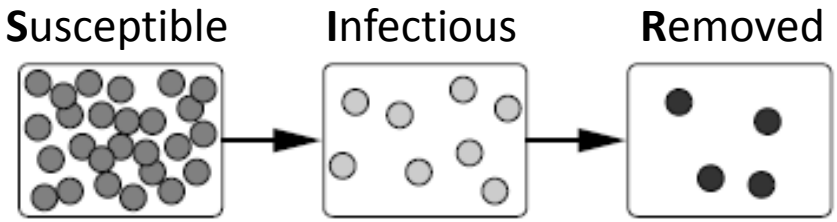
Craft & Caillaud, *Interdiscipl. Perspectives on Infectious Diseases,* 2011

Jon's personal experimentation

Example – GPS tracker logging a domestic cat

Cool data…. Neat tools
… but what's the question??

Network



ASSUME HOMOGENOUS MIXING

But behavior really matters!

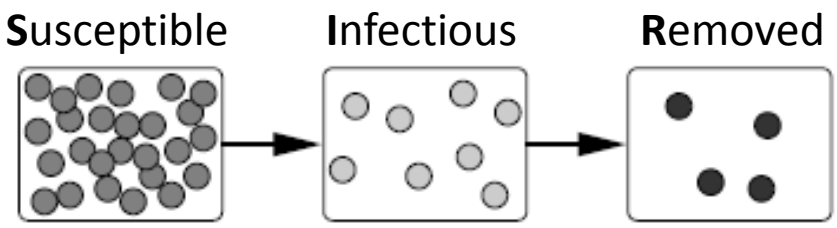
- Heterogeneous contacts
  - Spatial (cities, farms)
  - Age-structured (schools)
  - Social structure (dominance hierarchies, territoriality...)
- Superspreaders
  - Humans, e.g. SARS

(Lloyd-Smith et al., *Nature*, 2005)

  - Animals, e.g. Brushtail possums

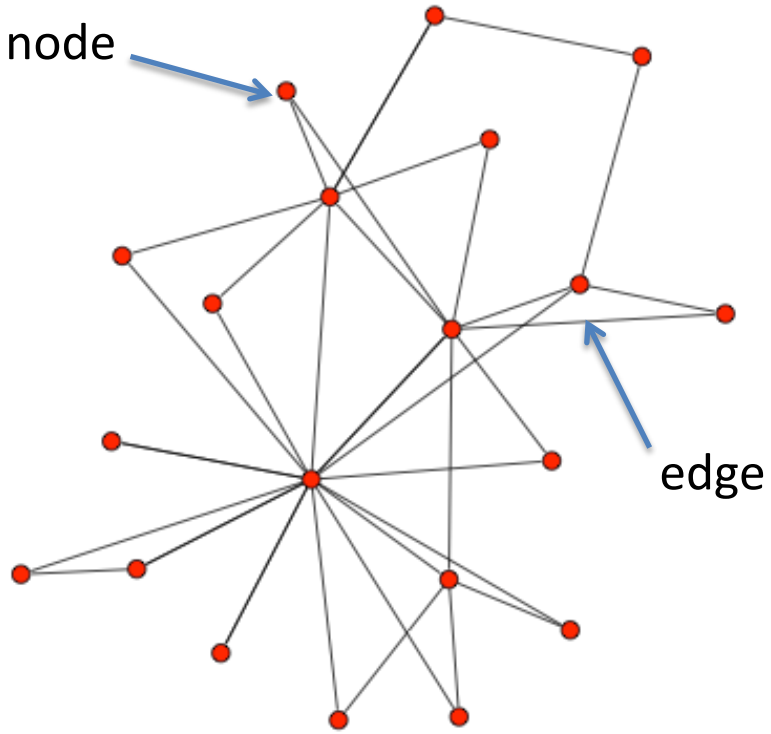
(Porphrye et al., *Vet Res* 2008)

Behavior determines contact patterns



ASSUME HOMOGENOUS MIXING

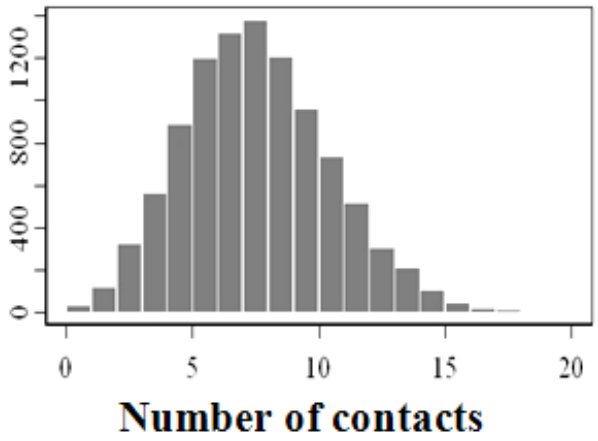
Network model



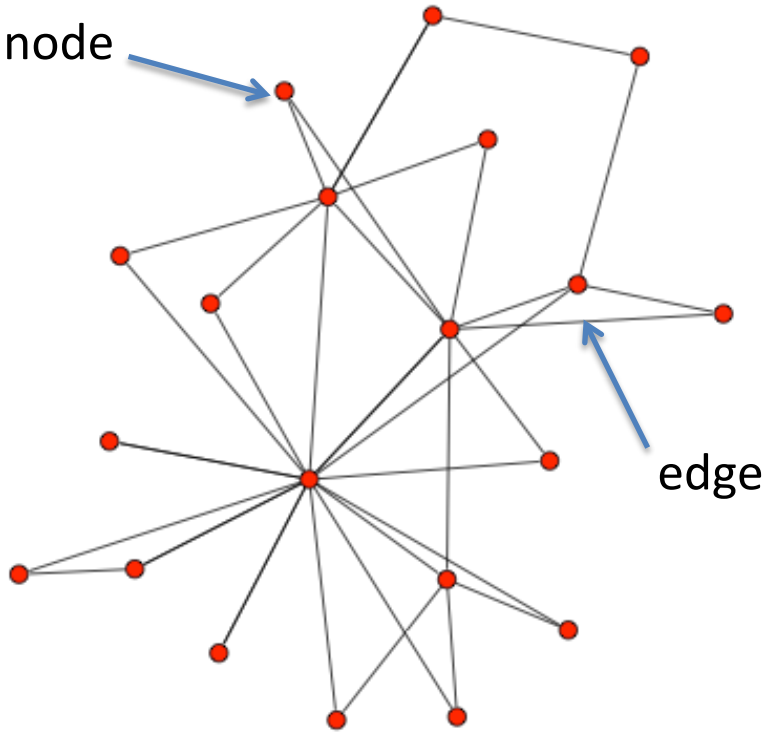
ALLOWS HETEROGENEOUS CONTACTS

Behavior determines contact patterns

Degree distribution



Network model



ALLOWS HETEROGENEOUS CONTACTS

Network analysis vs Network Modeling

- Social network analysis attempts to explore and understand the topology of a system
  - At the level of:
    - The network
    - Subgroups
    - Individuals

- Network modelling
  - "Simulates" events in a system
    - Formation and disintegration of links and/or nodes
    - Transmission and diffusion
      - Disease, ideas etc

Social network analysis

Data needed:
Who has contacted who over a defined period.

Data imported into network analysis software (Pajek, UCInet)

Calculate 'topology':
- Degree (mean and variation)
- Path length
- Clustering
- Centrality
- Betweenness

…are metrics by which to compare populations.

… affect rate of spread and final size of disease outbreak

Recommended reading

- Keeling & Eames 2005. Networks and epidemic models (review). http://www.ncbi.nlm.nih.gov/pubmed/16849187

- Danon et al 2010. Networks and the epidemiology of infectious disease. http://www.ncbi.nlm.nih.gov/pubmed/21437001

- James et al 2009. Potential banana skins in animal social network analysis. *Behav Ecol Sociobiol* 63, 989–997.

- Newman, M.E.J., 2003. The structure and function of complex networks. SIAM Rev. 45(2), 167–256.

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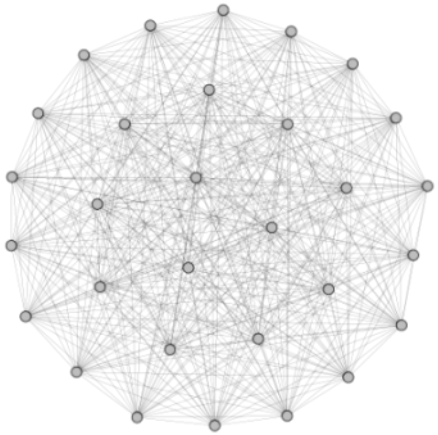
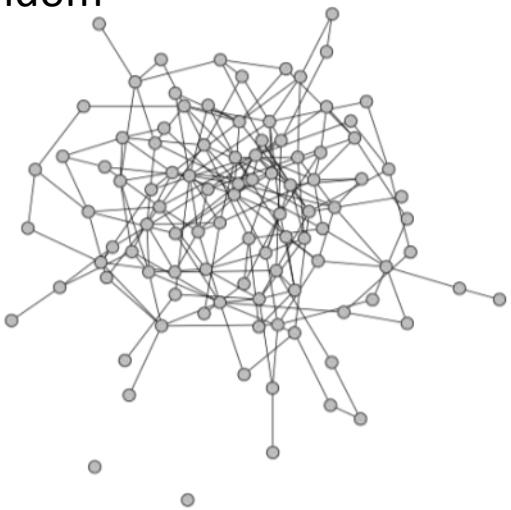
Disease impacts vary with contact structure

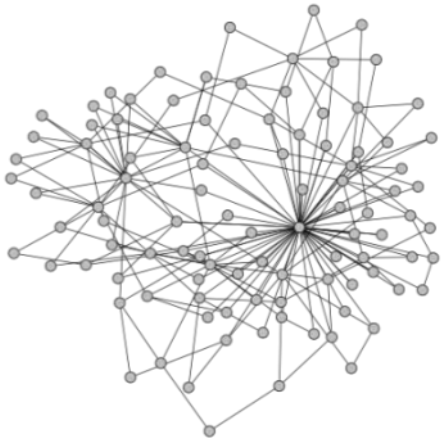
□ Homogenous

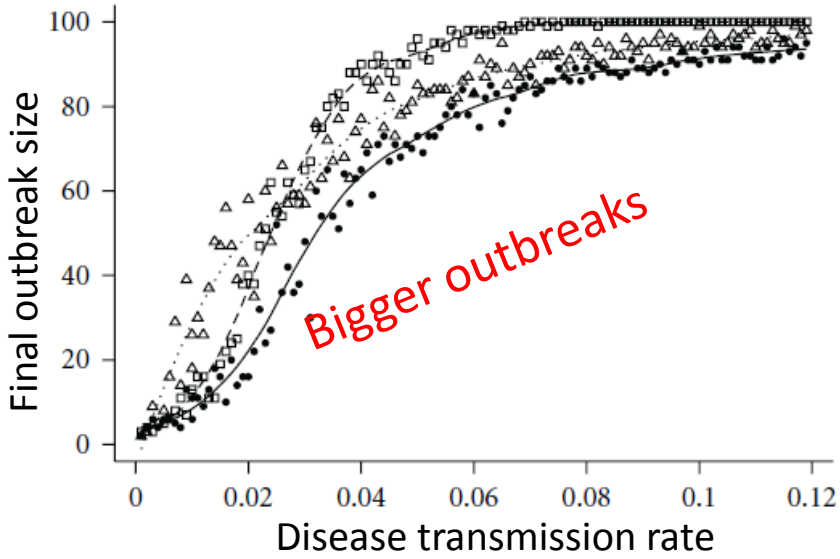


● Random



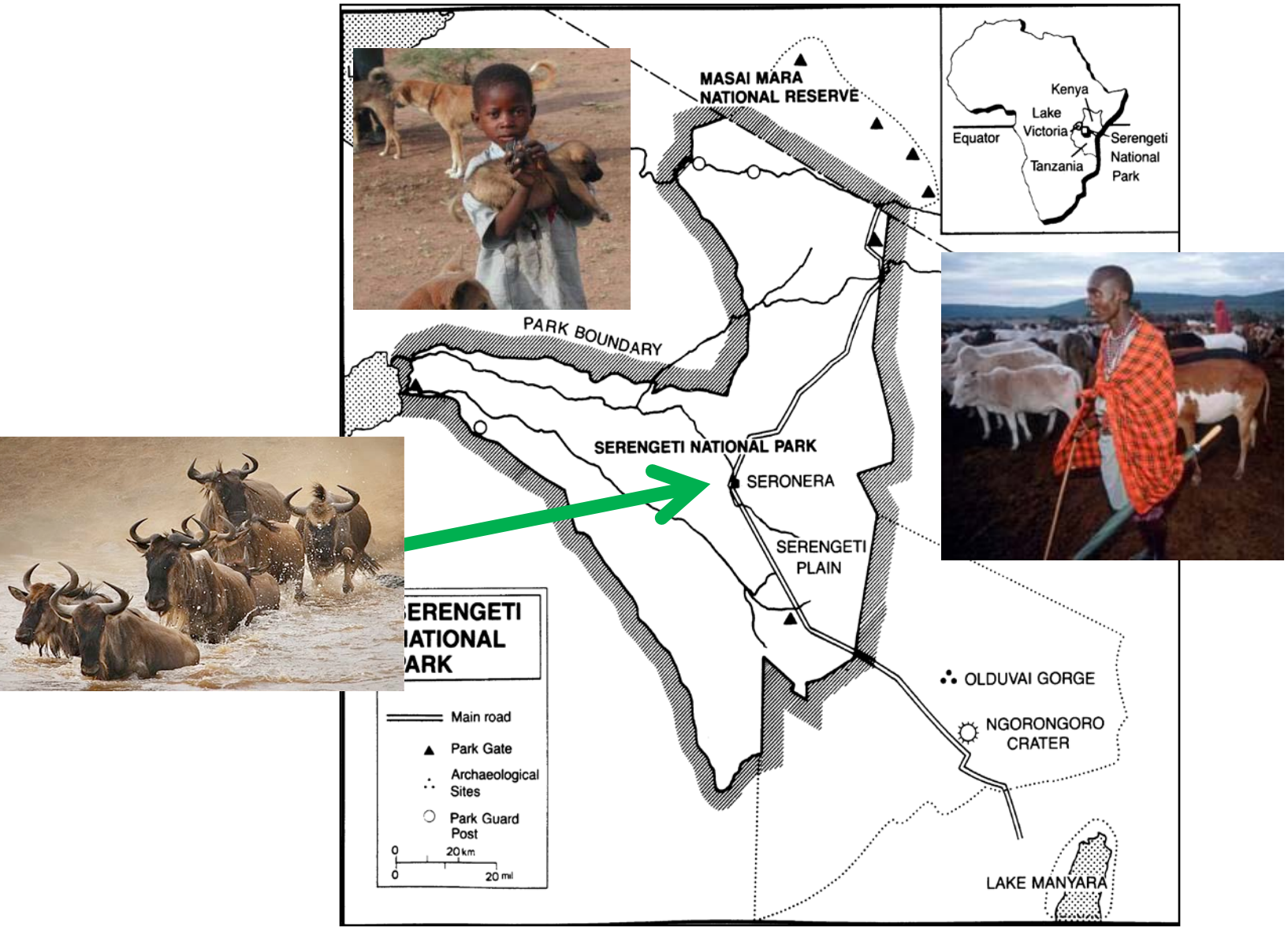
△ Superspreader





Craft & Caillaud, *Interdiscipl. Perspectives on Infectious Diseases,* 2011

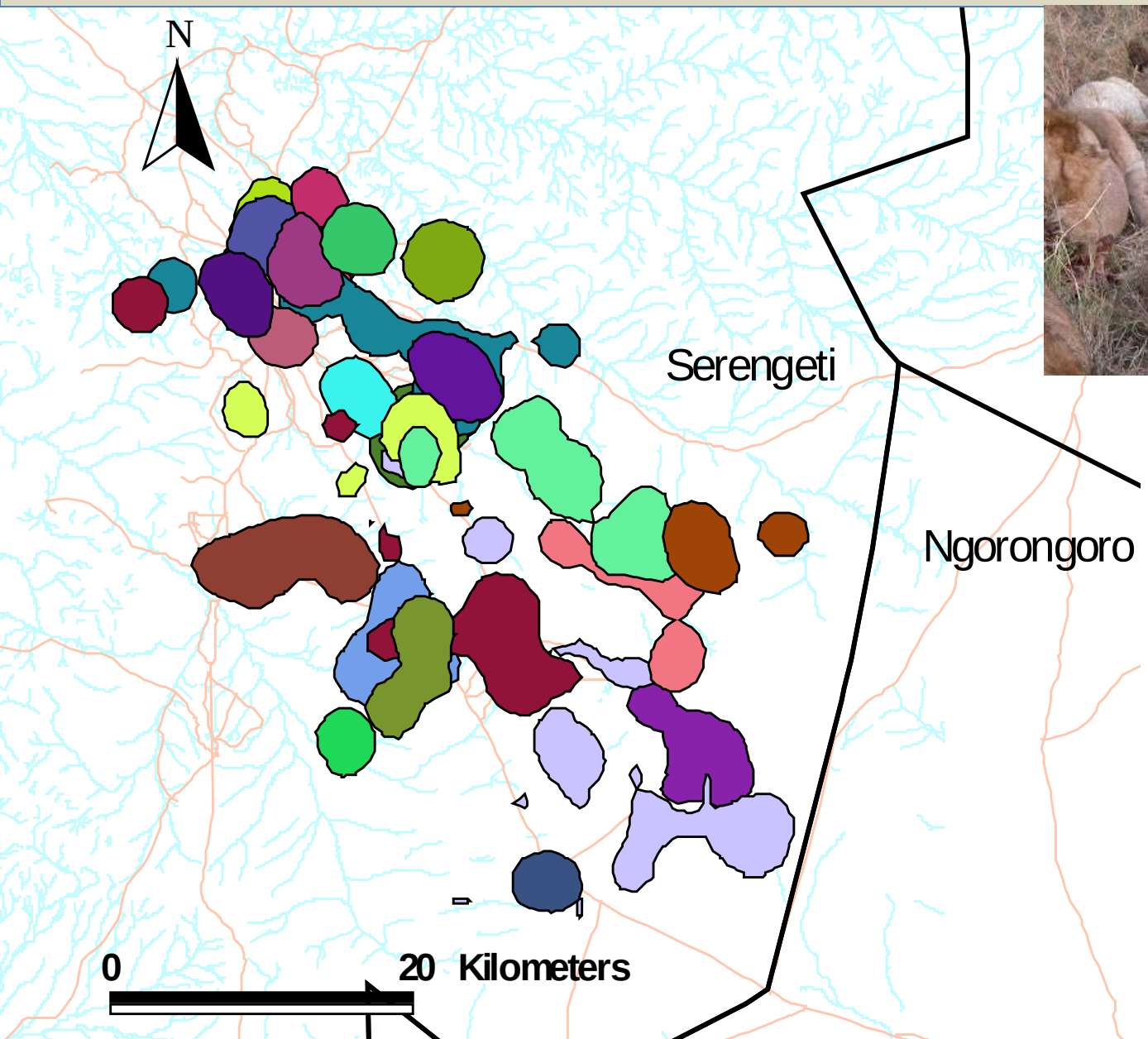
Serengeti as a model ecosystem



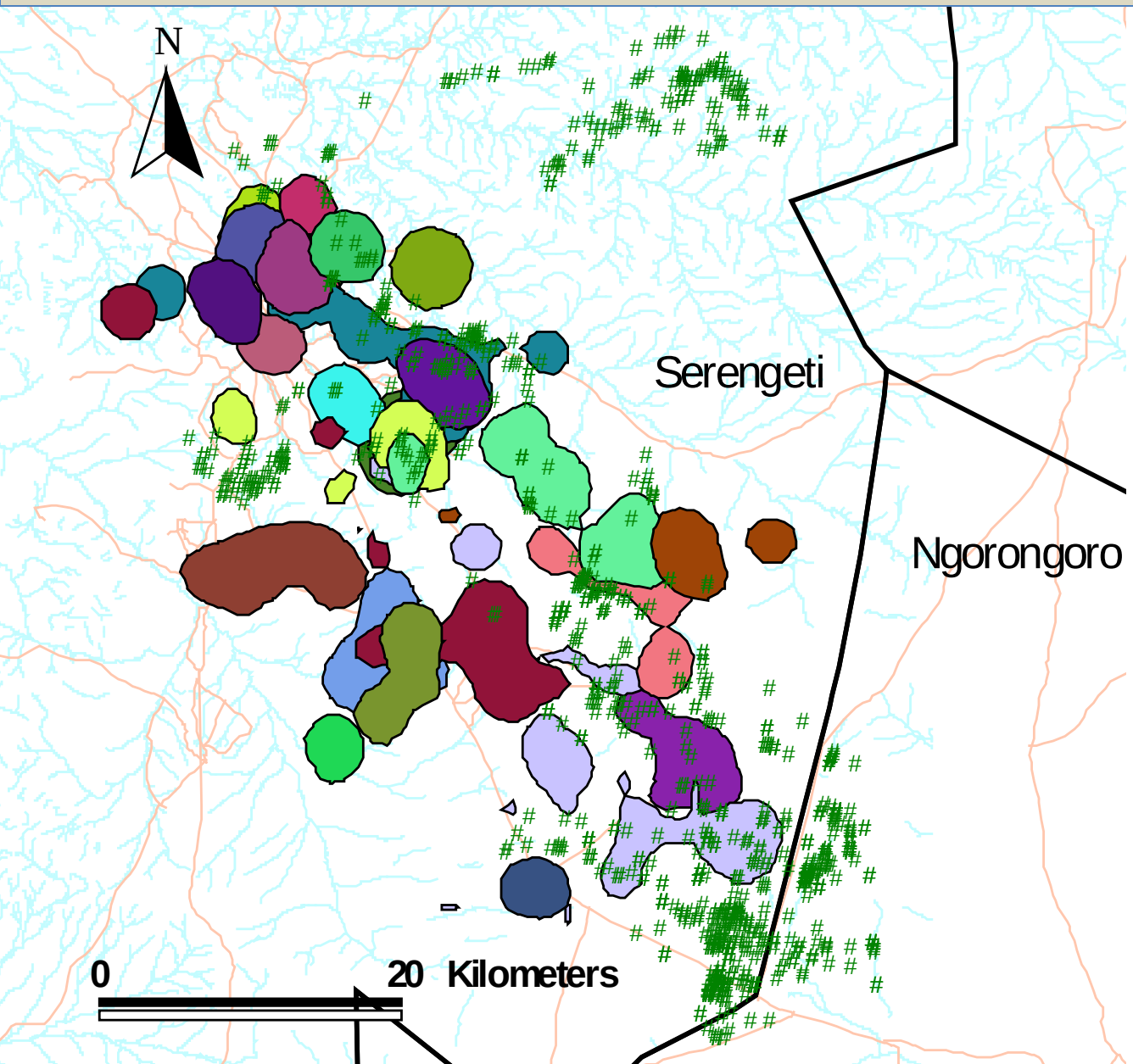
Problem: Serengeti lions dying

- ~1000 lions died from canine distemper virus
- Aerosol inhalation
- Other carnivores also infected
- How did this spread through lion population?

Lion social system (prides)



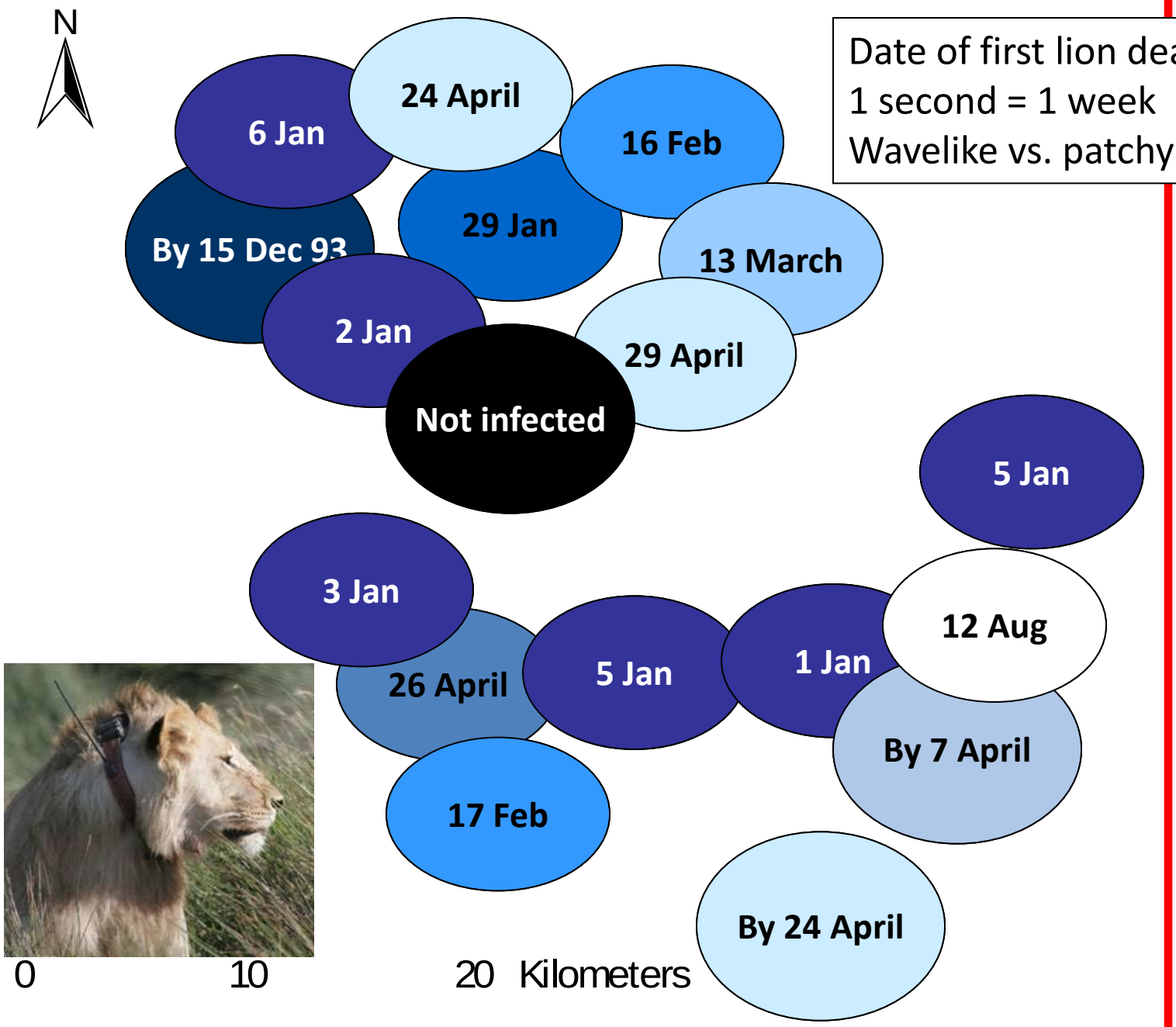
Lion social system (nomads)



Problem: Serengeti lions dying

Velocity: 100km in 35 wks

Prevalence: 94%



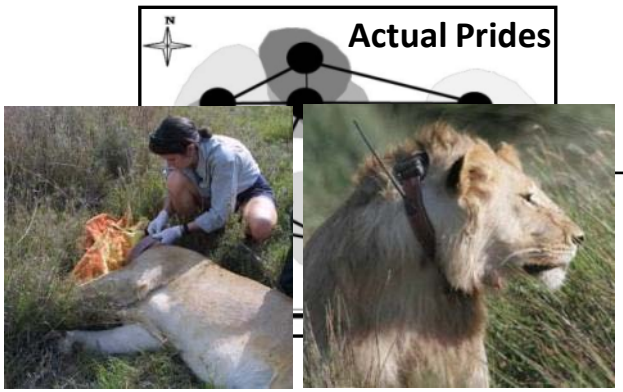
Date of first lion death/case
1 second = 1 week
Wavelike vs. patchy spread?

Ask a question- then build a model!

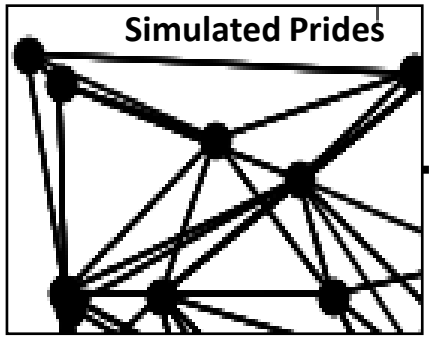
- **Are nomadic lions superspreaders?**

- **Could the 1994 CDV disease epidemic be explained by a model that includes only lions?**

Building a network model from real data

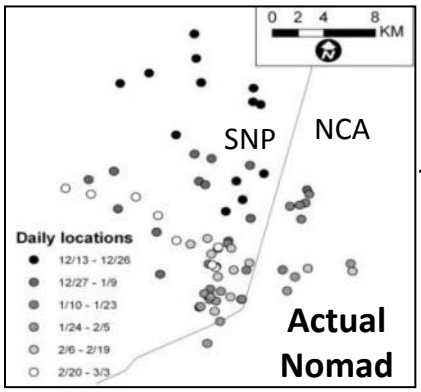


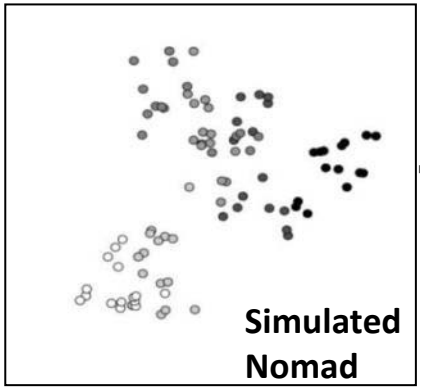
Actual Prides



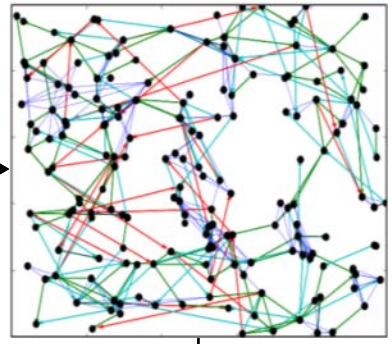
Simulated Prides

Nomads
Prides distance=1
Prides distance=2
Prides distance=3

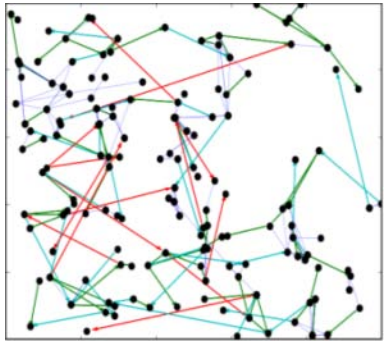




Contact Network



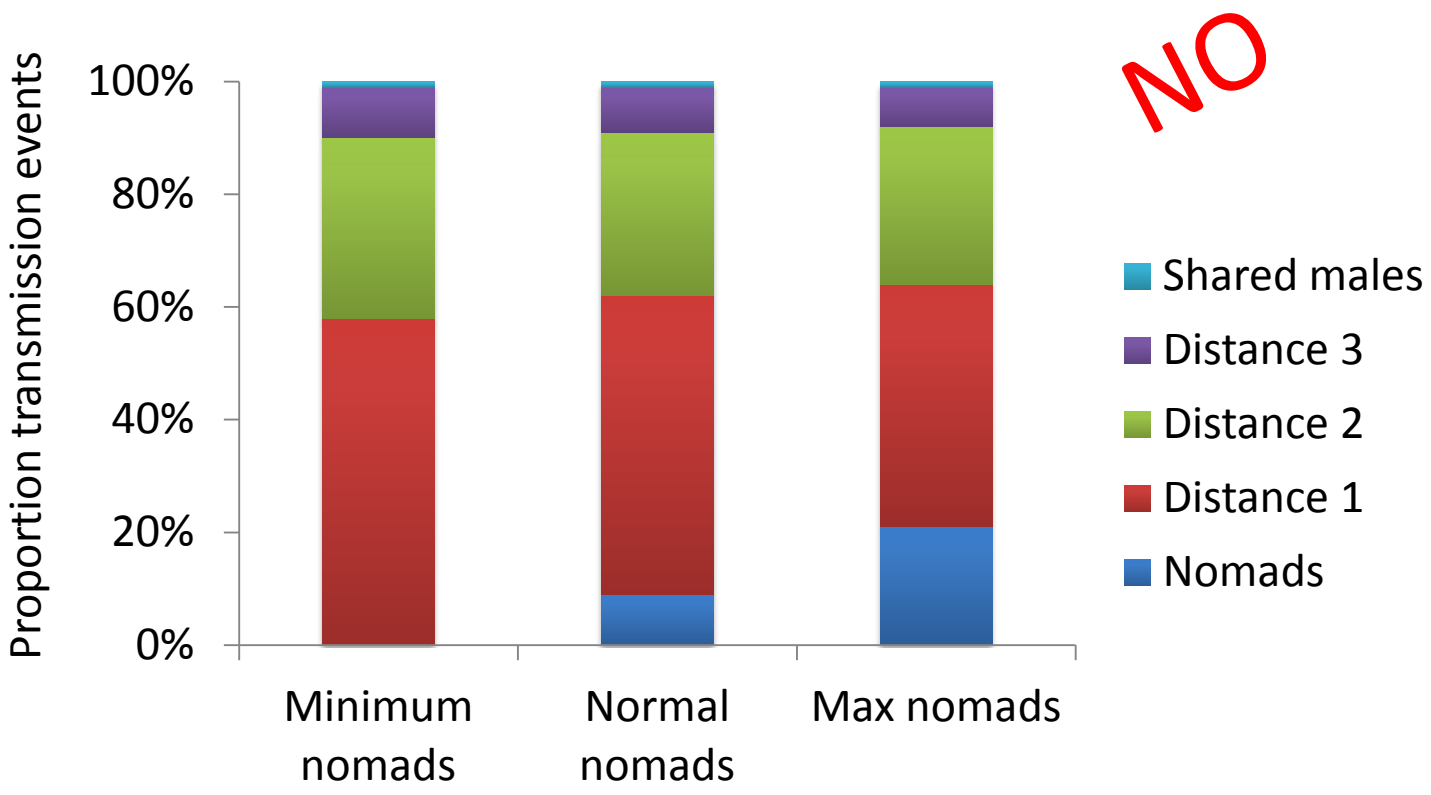
Transmission Network



Novel to use networks for wildlife studies

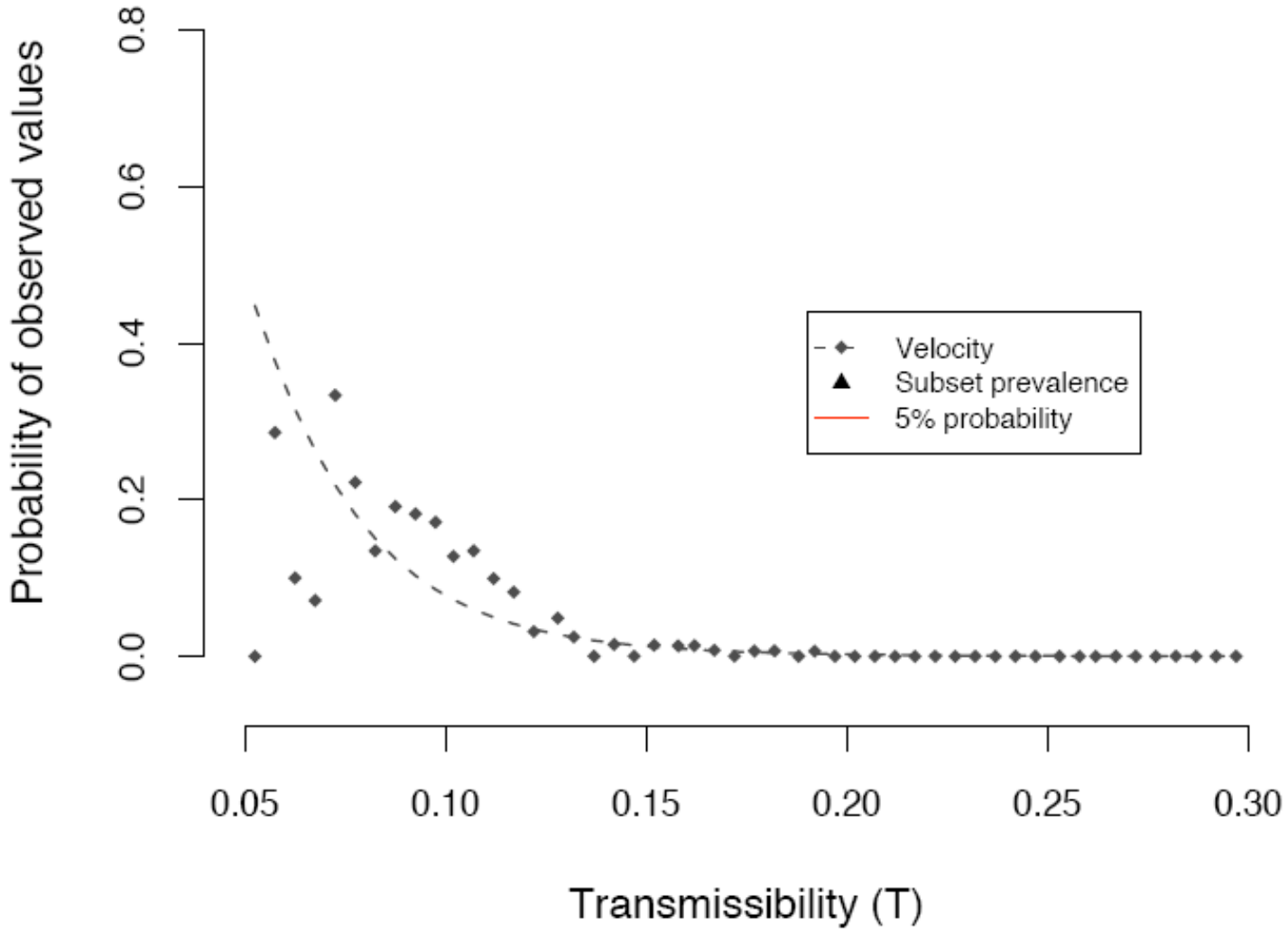
Craft et al., *J Royal Society Interface*, 2011

Results: Are nomads superspreaders?



Craft et al., *J Royal Society Interface*, 2011

Results: Could lion-lion transmission explain the 1994 outbreak?



Craft, et al., *Proceedings of the Royal Society B,* 2009

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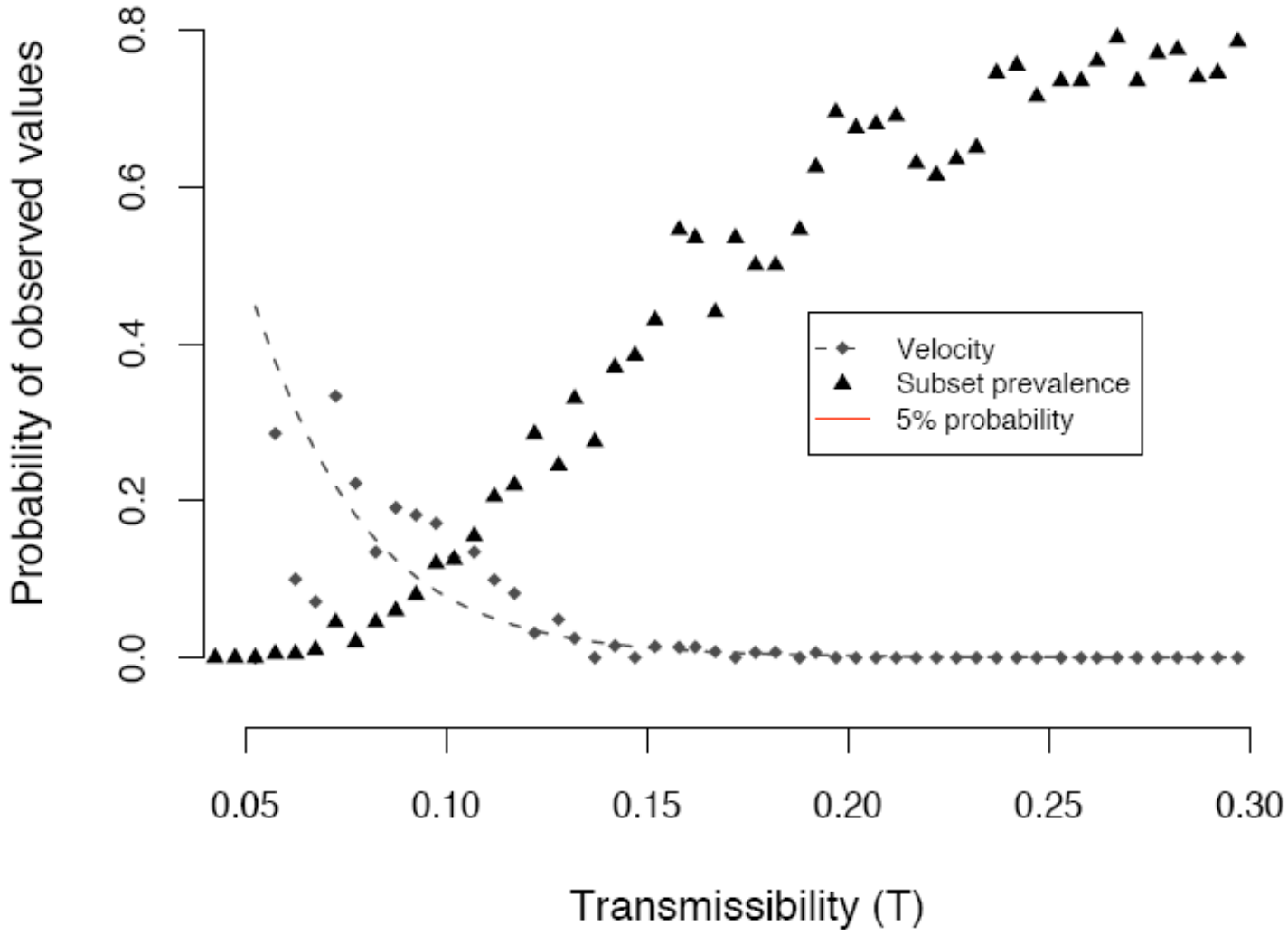

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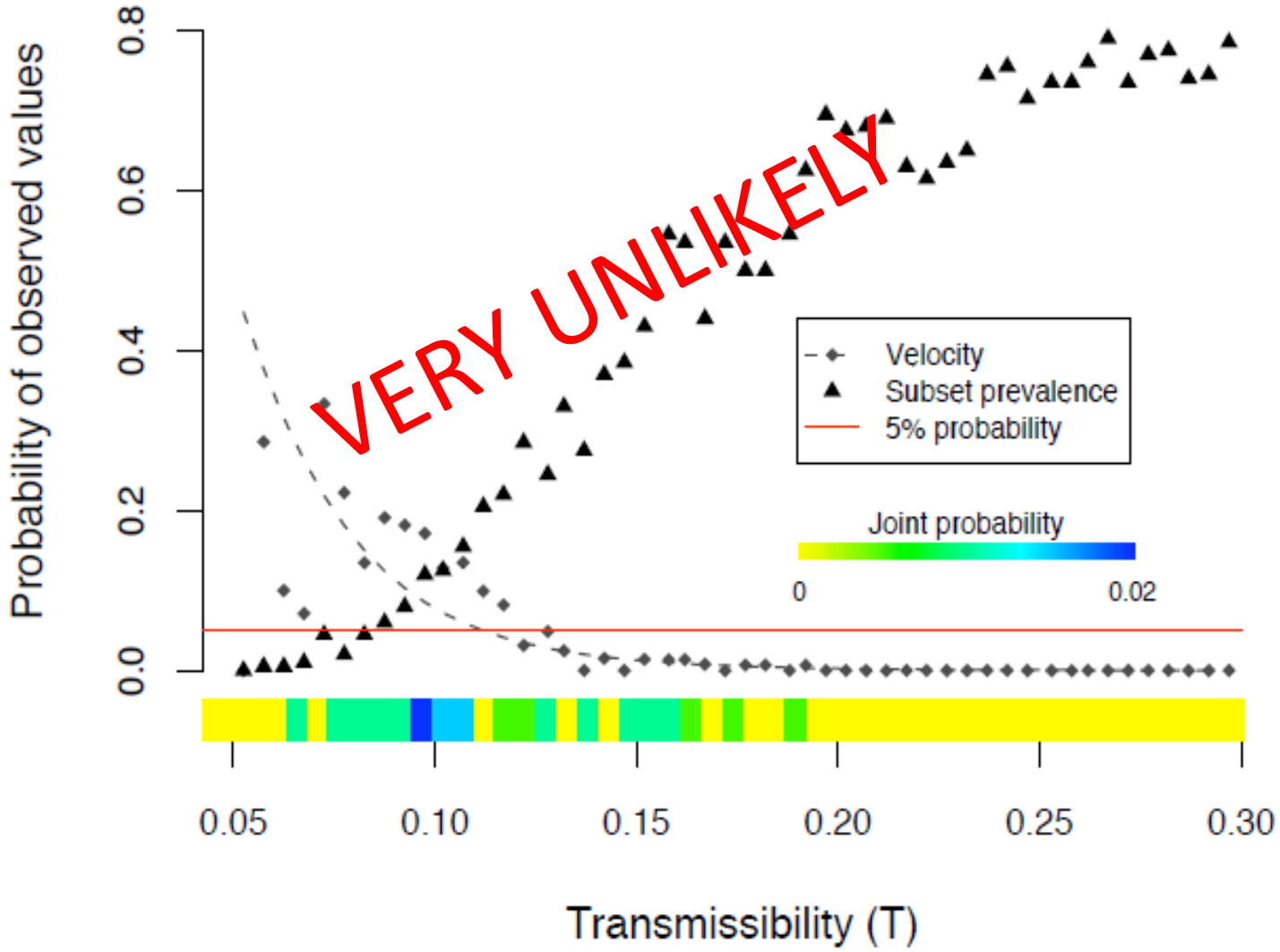
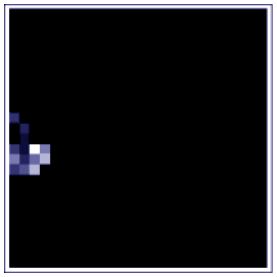
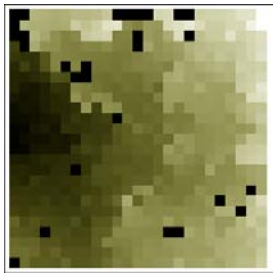


Craft, et al., *Proceedings of the Royal Society B,* 2009

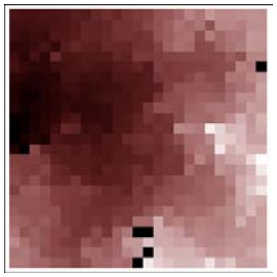
Are wild carnivores essential to emulate the spread of CDV in lions in 1994?



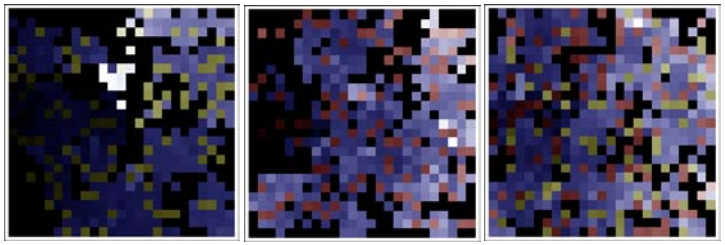
Lion



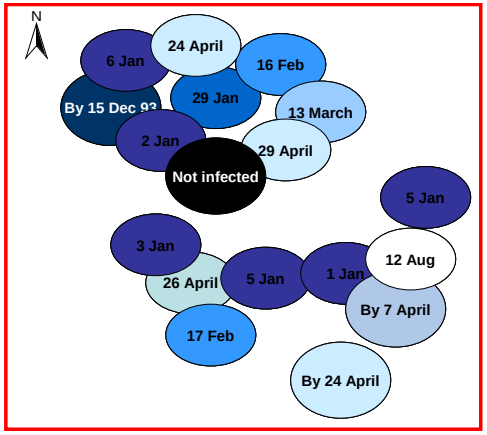
Jackal



Hyena



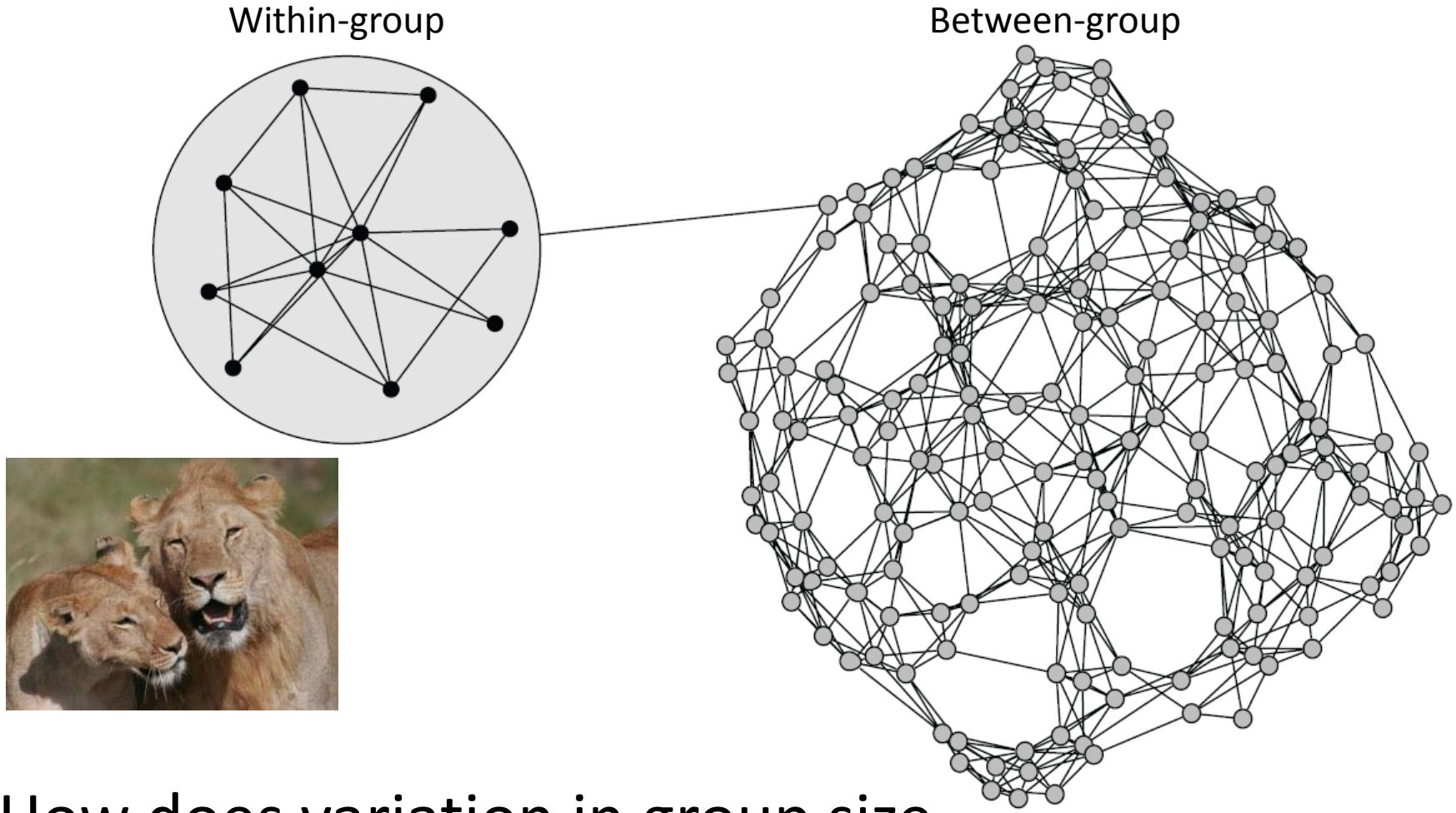
L+J L+H L+J +H



Result: Can get patchy and extensive spatial spread with multiple hosts with different social structure!

Craft et al, *Journal of Animal Ecology*, 2008

Current work: Nested networks



How does variation in group size affect disease dynamics?

Caillaud, Craft et al., in prep for *Epidemics*

CDV: Conclusions

- Lions likely spread diseases neighbor-to-neighbor

  (Implications for control?)
- Multiple wild hosts needed to replicate 1994 fatal outbreak.

Final thoughts on networks

Issues:

- How to sample a network (edge effects)
- Diseases like rabies change behavior (contact networks normally collected on healthy individuals)
- Networks are realistic; but data-intensive
- ‘Contacts’ do not equal transmission

Are there other ways to measure transmission/interaction without contact networks?

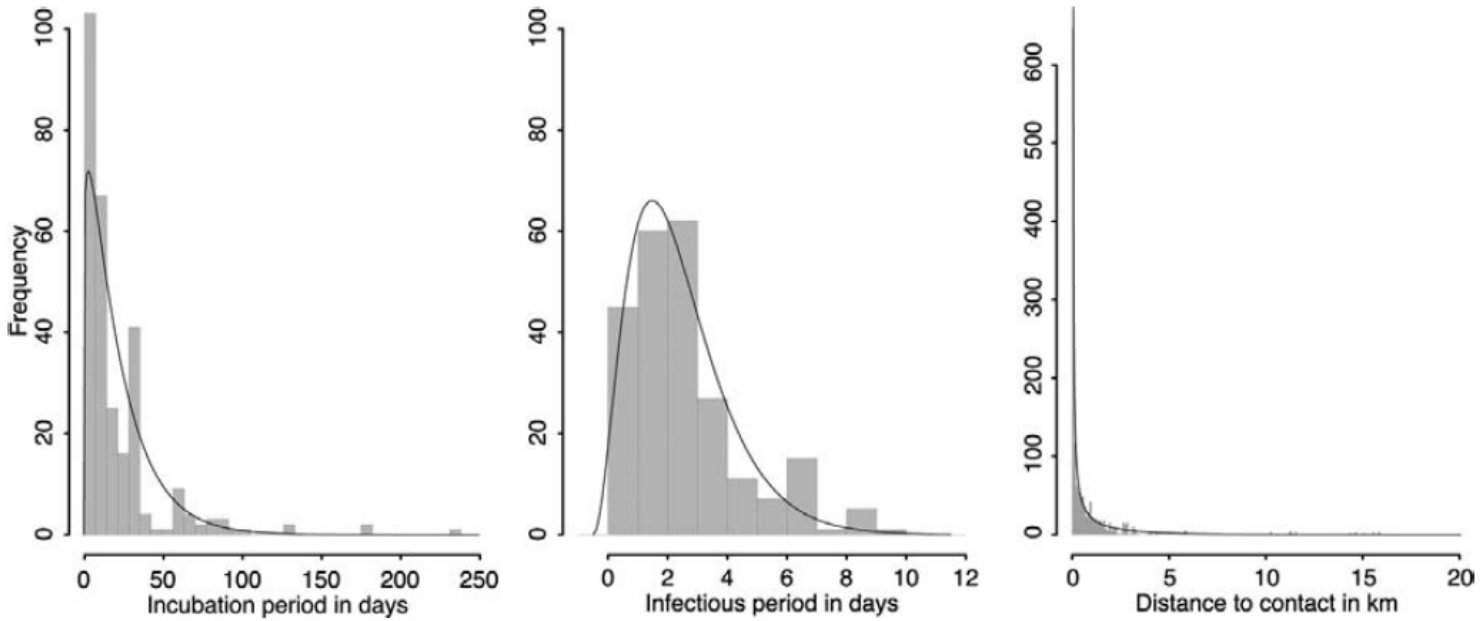
Rabies in domestic dogs

OPEN ACCESS Freely available online

PLOS BIOLOGY

Transmission Dynamics and Prospects for the Elimination of Canine Rabies

Katie Hampson[1,2*], Jonathan Dushoff[3], Sarah Cleaveland[4,5], Daniel T Haydon[5], Magai Kaare[6†], Craig Packer[7], Andy Dobson[1]



Rabies in domestic dogs

Table 1. Epidemiological Parameter Estimates

Parameter	Estimate (95% CIs)	*n*
Incubation period	22.3 d (20.0–25.0)	288
Infectious period	3.1 d (2.9–3.4)	234
Mean generation interval $\bar{t}_{ij}$	24.9 d (23.7–26.2)	*
Mean transmission distance $\bar{d}_{ij}$	0.88 km (0.83–0.92)	1397
$P_{\text{rabies|bite}}$	0.49 (0.45–0.52)	699
$R_{0\ \text{(bites * Prabies|bite)}}$	1.05 (0.96–1.14)	511
$R_{0\ \text{secondary cases}}$	1.14 (1.03–1.25)	506
Time series regression: $R_{0\text{Serengeti}}$	1.19 (1.12–1.41)	—
Time series regression: $R_{0\text{Ngorongoro}}$	1.14 (0.94–1.32)	—
Tree reconstruction: $R_{0\text{Serengeti}}$	1.06 (1.04–1.10)	—
Tree reconstruction: $R_{0\text{Ngorongoro}}$	1.32 (1.26–1.42)	—

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- **University of Texas**
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- **Princeton University**
  - **Andy Dobson**
- **University of Michigan**
  - **Erik Volz**