Can comparing models of measles introductions into New Zealand and Ebola virus outbreaks in West Africa lead to better control of both?

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Saving bats. Conserving ecosystems

wellcome trust

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Veterinary, Animal and Biomedical Sciences

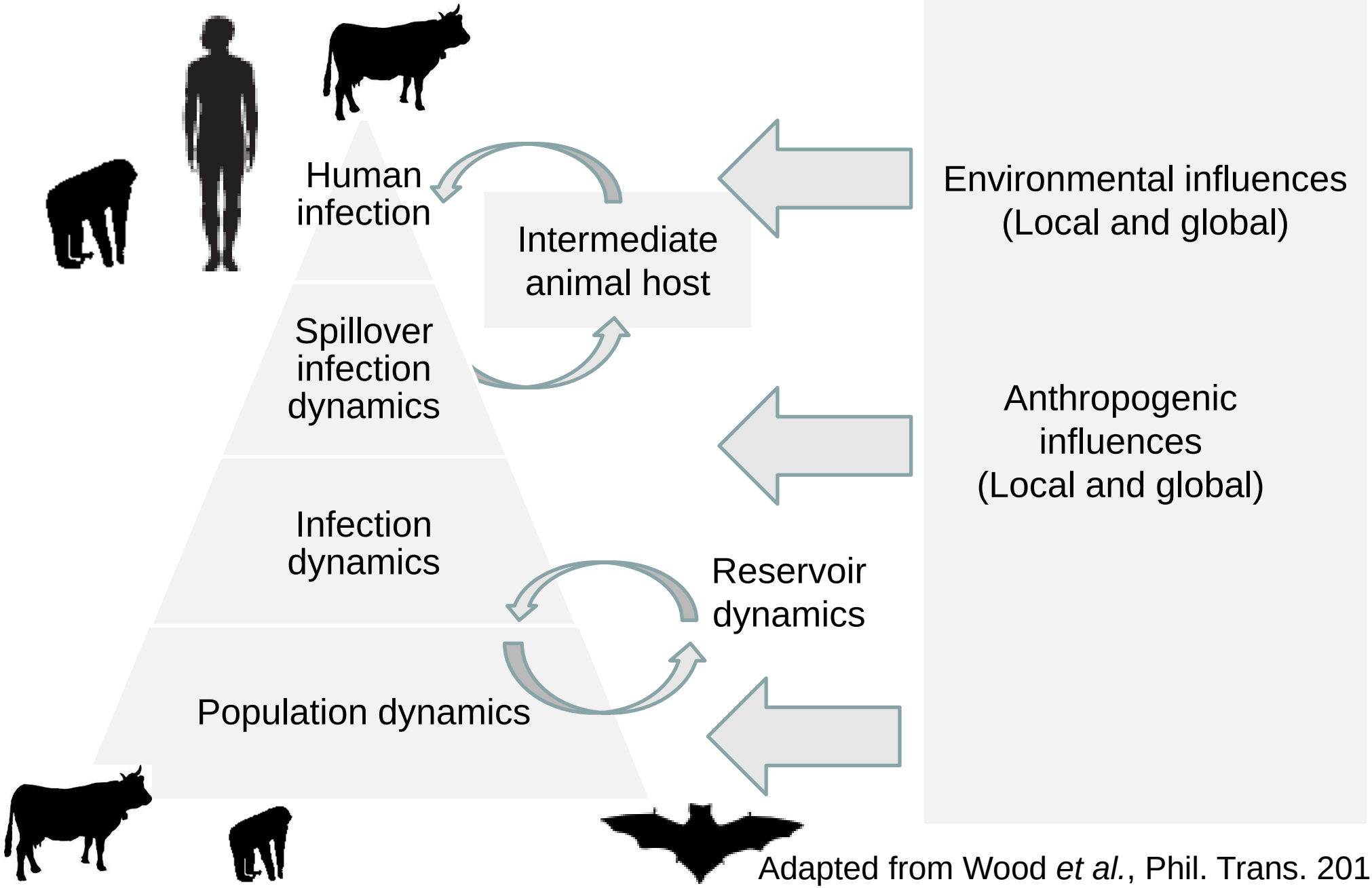
Talk outline

- A framework for (zoonotic) infection studies
- Outbreak case study 1: Ebola virus in W Africa
- Outbreak case study 2: Measles in New Zealand
- Viral phylogeny – what ‘history’ tells us

Framework

Directly transmitted infections only

Zoonotic transmission



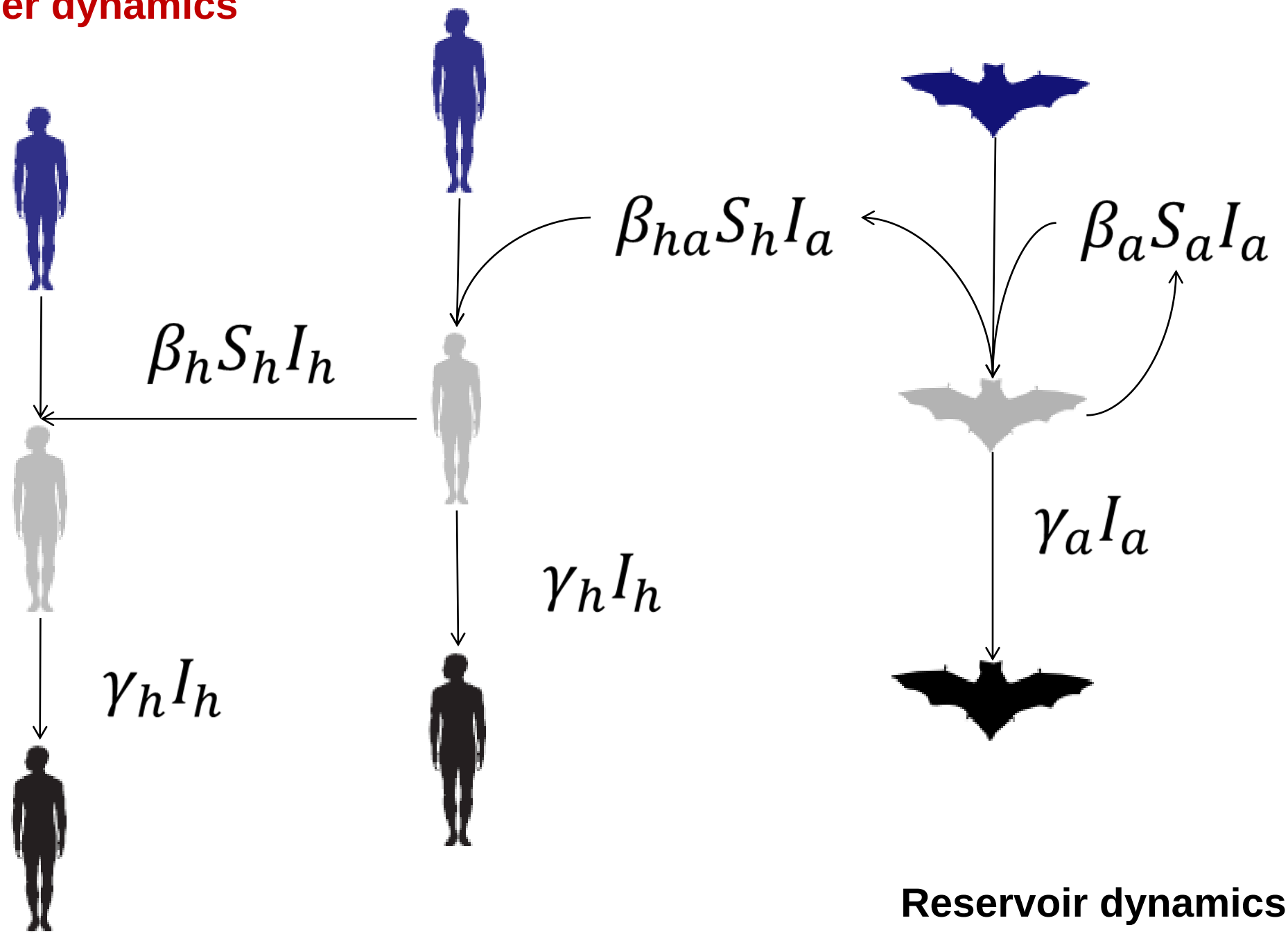
Adapted from Wood *et al.*, Phil. Trans. 2012

Terminology

- β (beta) : transmission coefficient
- γ (gamma) : recovery rate
- S : susceptible
- I : infected
- $_a$: animal
- $_h$: human

Ebolavirus transmission pathways

Spillover dynamics



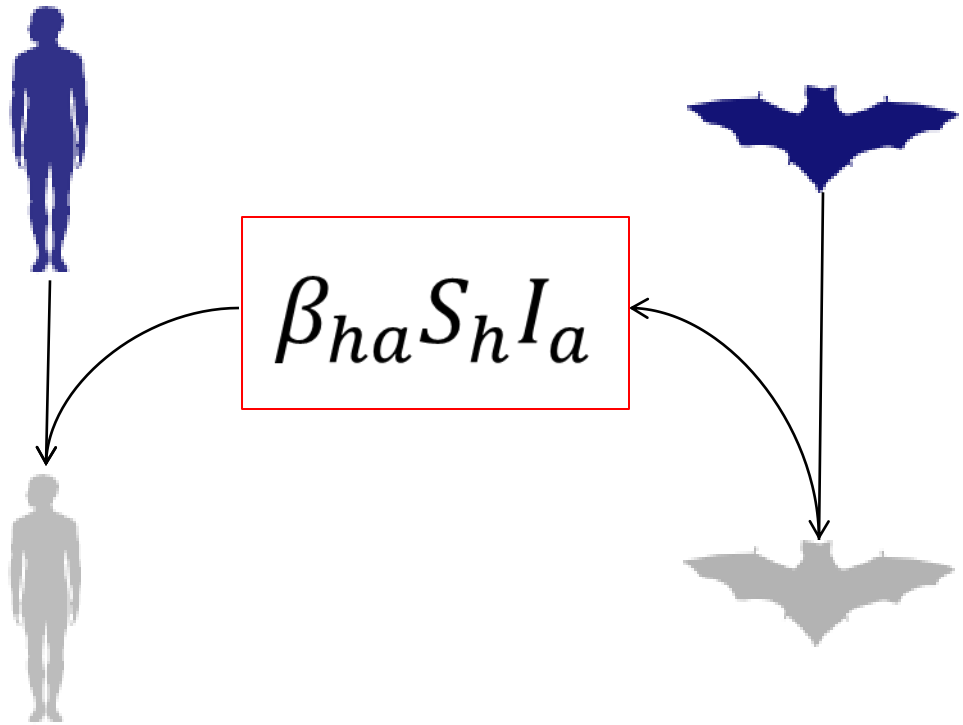
Reservoir dynamics

Ebolavirus transmission pathways

Spillover dynamics

Probability of infection

Immunity
Dose & duration of exposure
Pathogen genotype
Duration and proximity of contact
Practices (e.g. hand washing)



Contact rates

Transmission mechanism
Reservoir abundance
Spatial overlap
Human risk behaviours

Prevalence in populations

1 or more species
Host dynamics
Transmission dynamics and mechanism
Environmental and agricultural influences

Reservoir dynamics

Adapted from Lloyd-Smith *et al.*, Science, 2009

Ebola

'age ▾ Safety ▾ Tools ▾

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Ebola outbreak in Guinea: 5 things you should know

Ebola hemmorhagic fever has up to 90 per cent fatality rate

CBC News Posted: Mar 24, 2014 3:16 PM ET | Last Updated: Mar 25, 2014 9:34 AM ET

Some residents in western Uganda say they are too scared to go shopping in local markets, visit churche freely for fear of catching the Ebola virus, which has already killed 16 people. (Edward Echwalu/Reuters)

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25 March 2014 Last updated at 16:49

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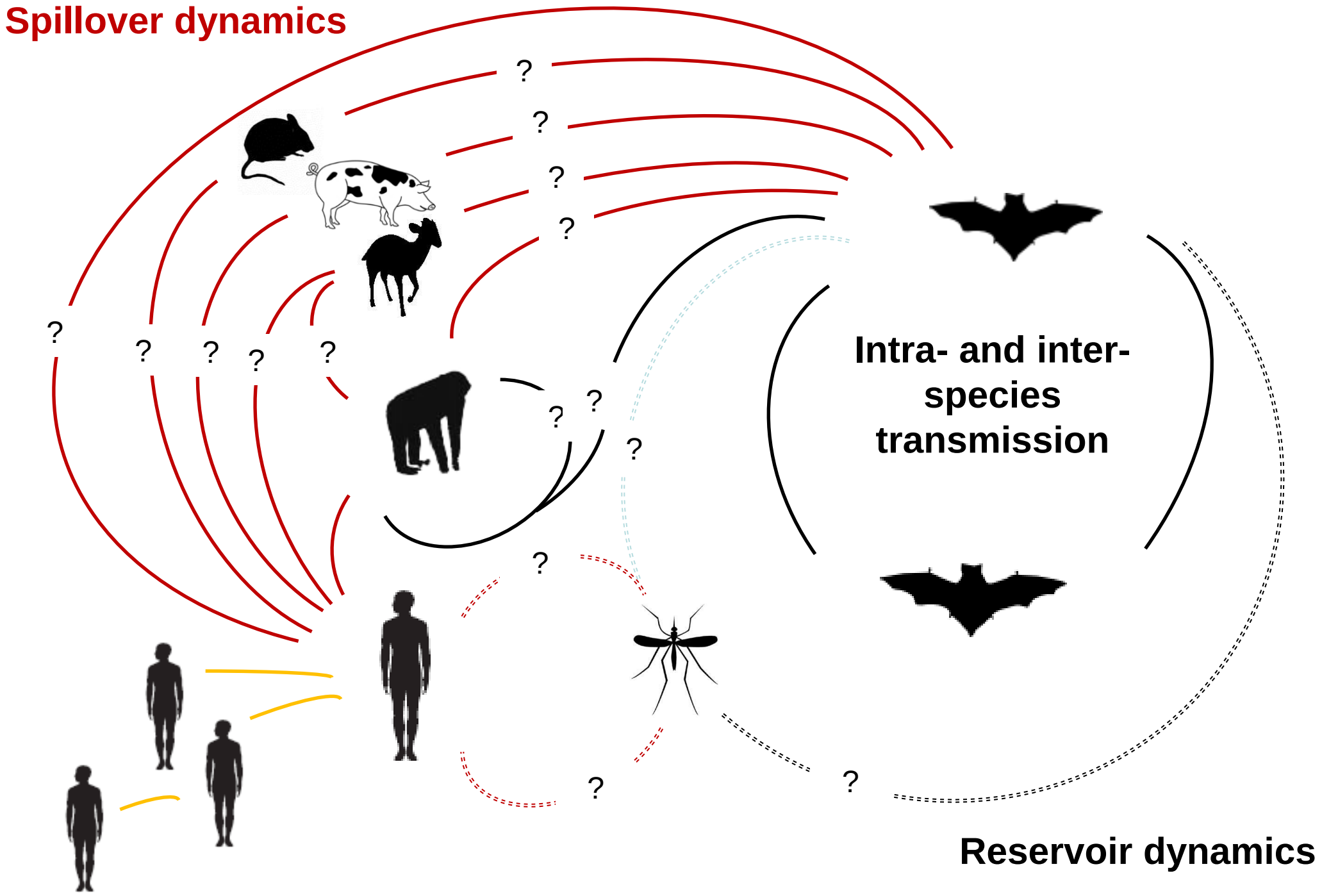
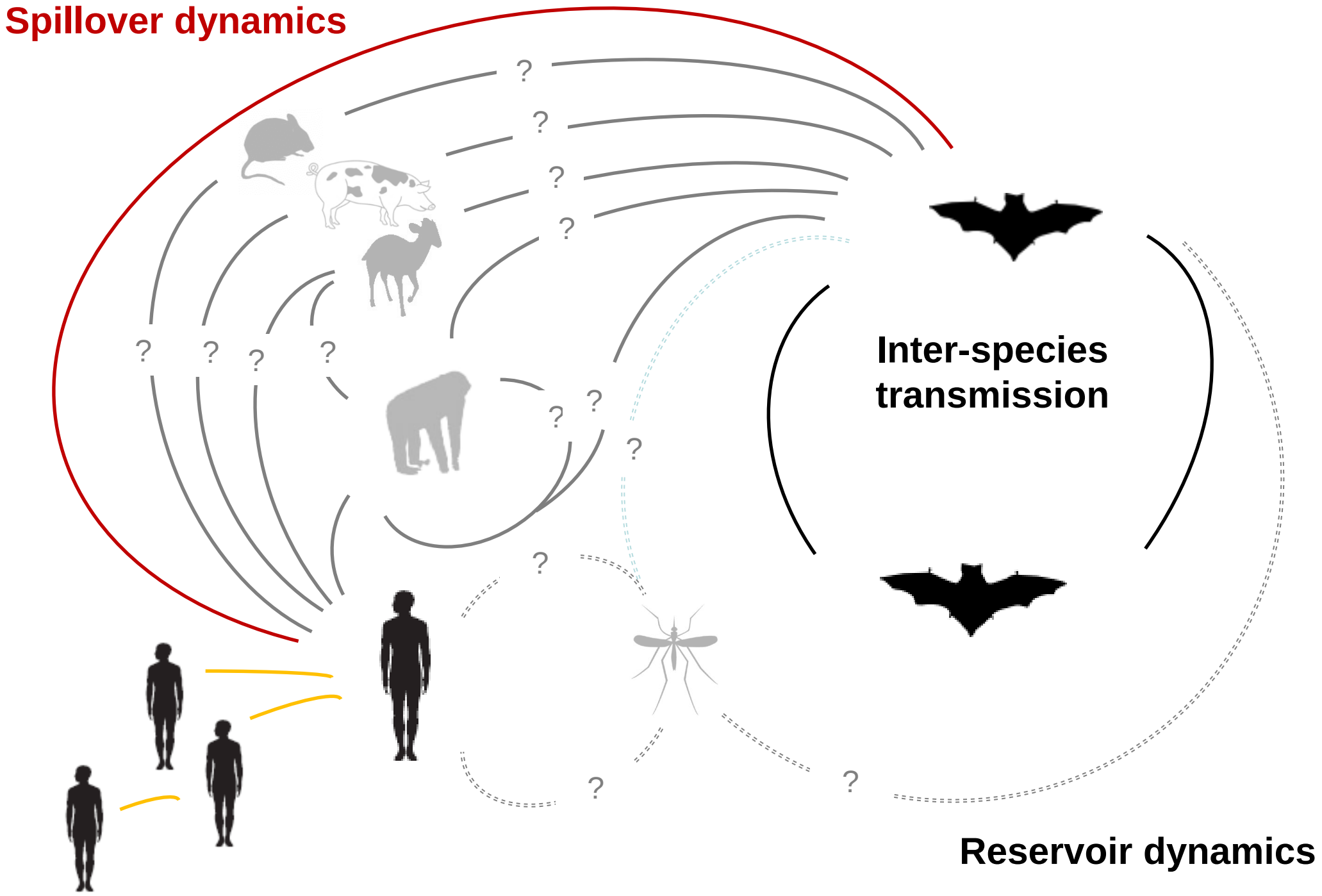
Guinea Ebola outbreak: Bat-eating banned to curb virus

Ebolavirus transmission pathways



Olival and Hayman, 2013 Viruses

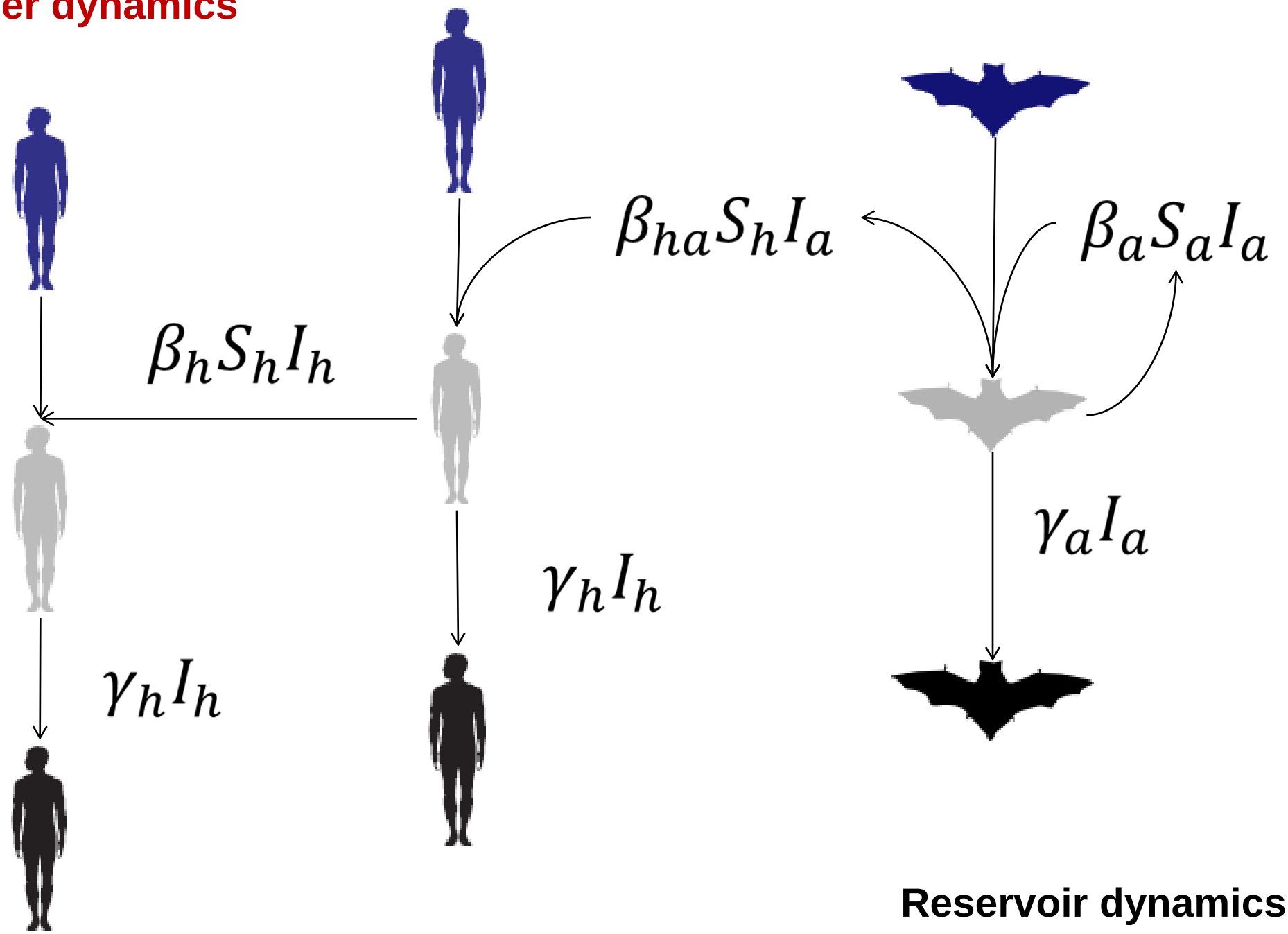
Ebolavirus transmission pathways



Olival and Hayman, 2013 Viruses

Ebolavirus transmission pathways

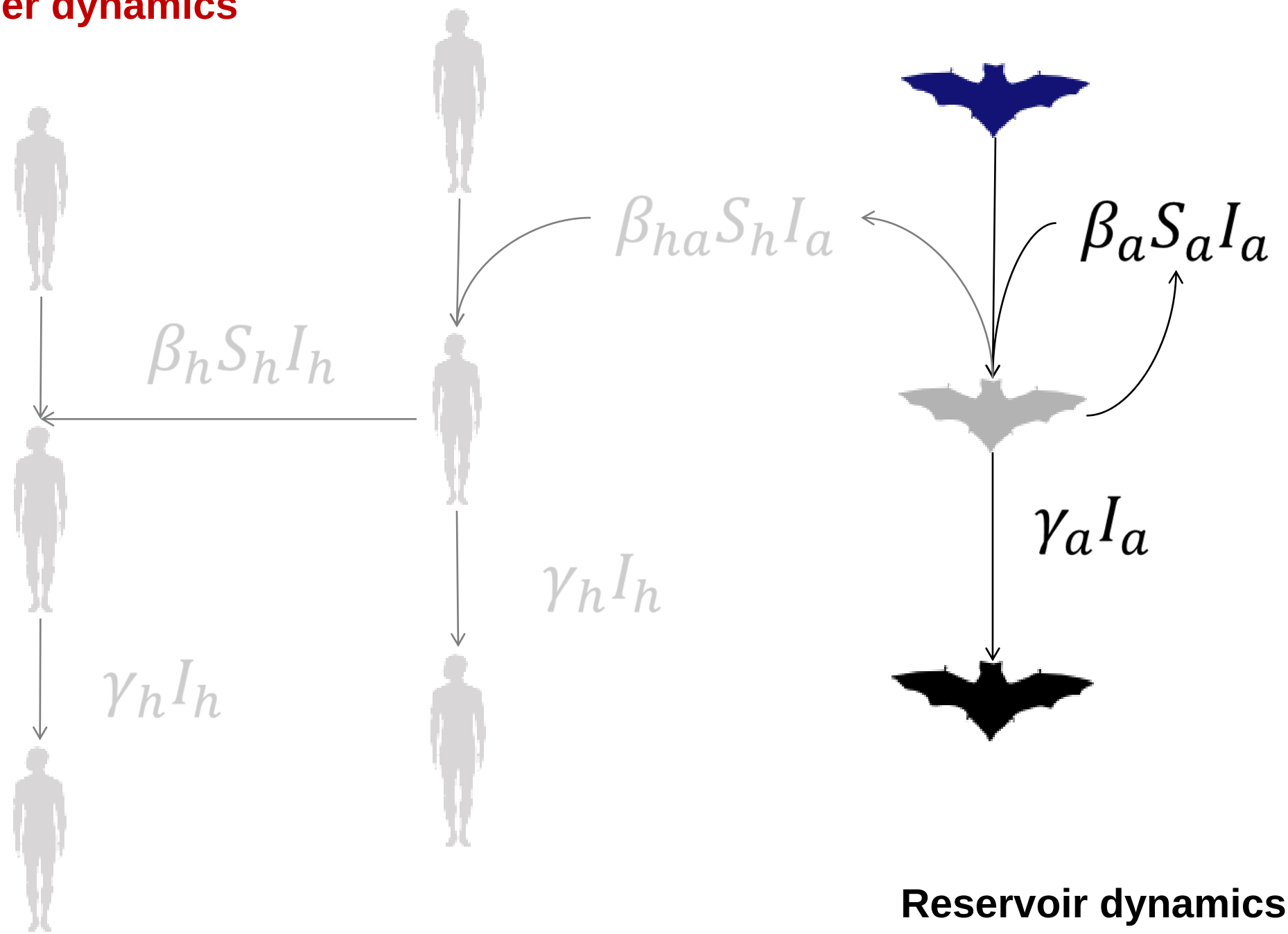
Spillover dynamics



Reservoir dynamics

Ebolavirus transmission pathways

Spillover dynamics



Reservoir dynamics

SIR compartmental models

deterministic

$$dS_j/dt = b(t)(N_a) - \beta S_j(I_j + I_a) - \delta S_j\left(\frac{N}{K}\right) - \varepsilon S_j$$

$$dS_a/dt = -\beta S_a(I_j + I_a) + \varepsilon S_j - \mu S_a\left(\frac{N}{K}\right)$$

$$dE_j/dt = \beta S_j(I_j + I_a) - \varepsilon E_j - \delta E_j\left(\frac{N}{K}\right) - \sigma E_j$$

$$dE_a/dt = \beta S_a(I_j + I_a) + \varepsilon E_j - \mu E_a\left(\frac{N}{K}\right) - \sigma E_a$$

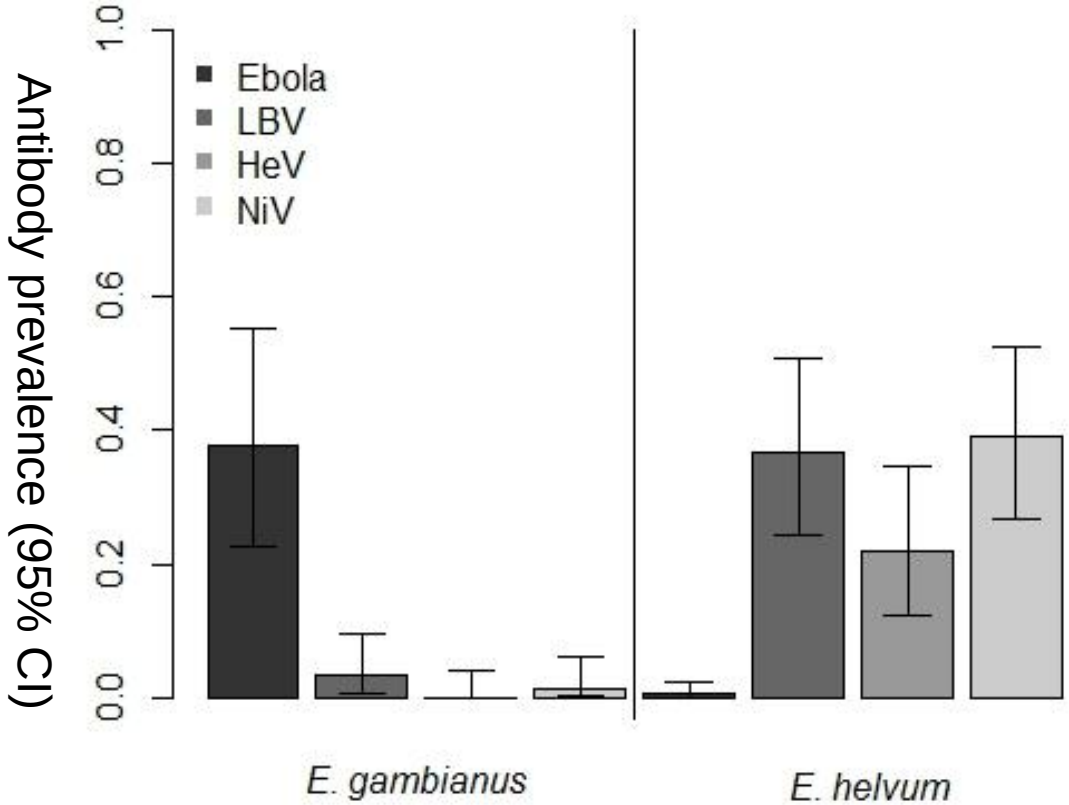
$$dI_j/dt = \sigma E_j - \tau I_j - \varepsilon I_j - \delta I_j\left(\frac{N}{K}\right)$$

stochastic

$$\left(N - \sum_{i=1}^{k} \Delta n_i, \Delta n_1, \ldots, \Delta n_k\right) \sim multinomial(N; p_0 p_1, \ldots, p_k),$$

Hayman, in revision

Not all bats are equal



Hayman *et al.*, PLoS ONE 2008; EID 2008; PLoS ONE 2010; EID 2012

Seasonality and birth pulses

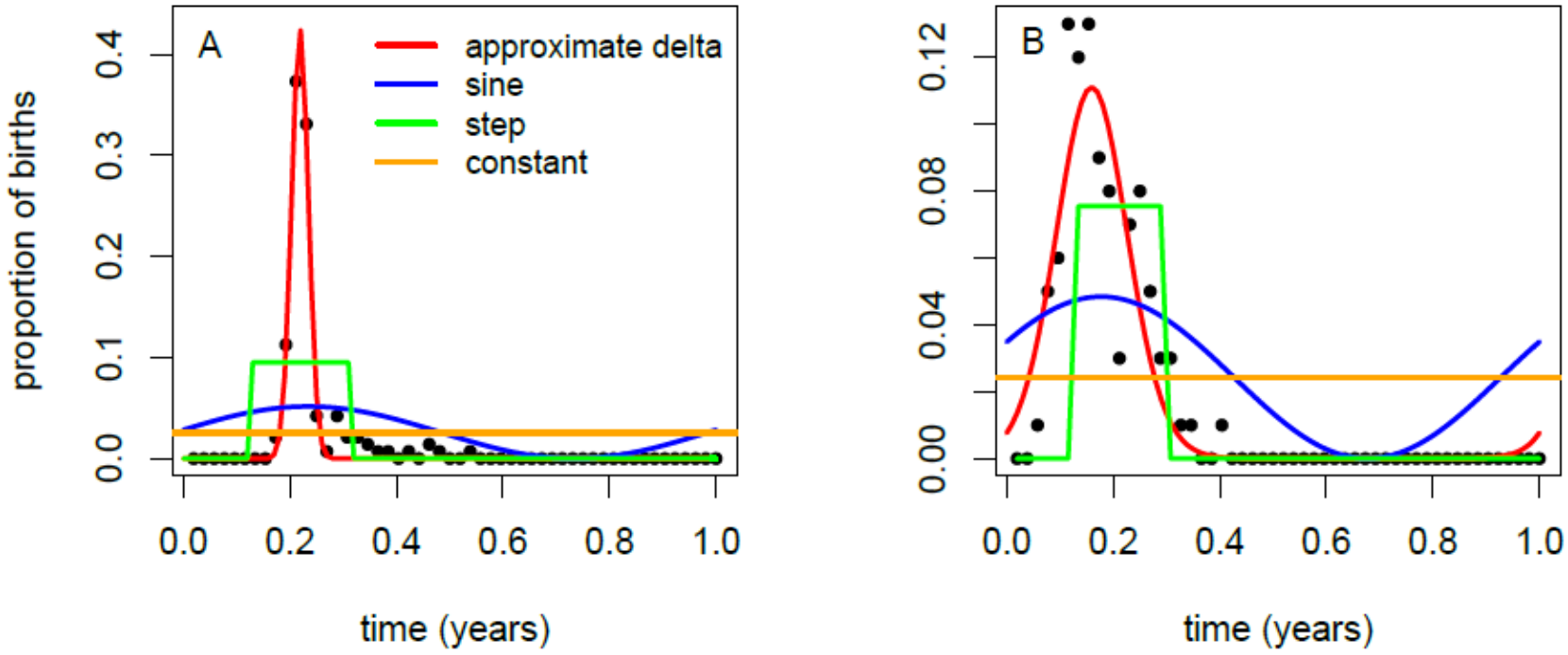
OPEN ACCESS Freely available online

PLOS | PATHOGENS

Seasonal Pulses of Marburg Virus Circulation in Juvenile *Rousettus aegyptiacus* Bats Coincide with Periods of Increased Risk of Human Infection

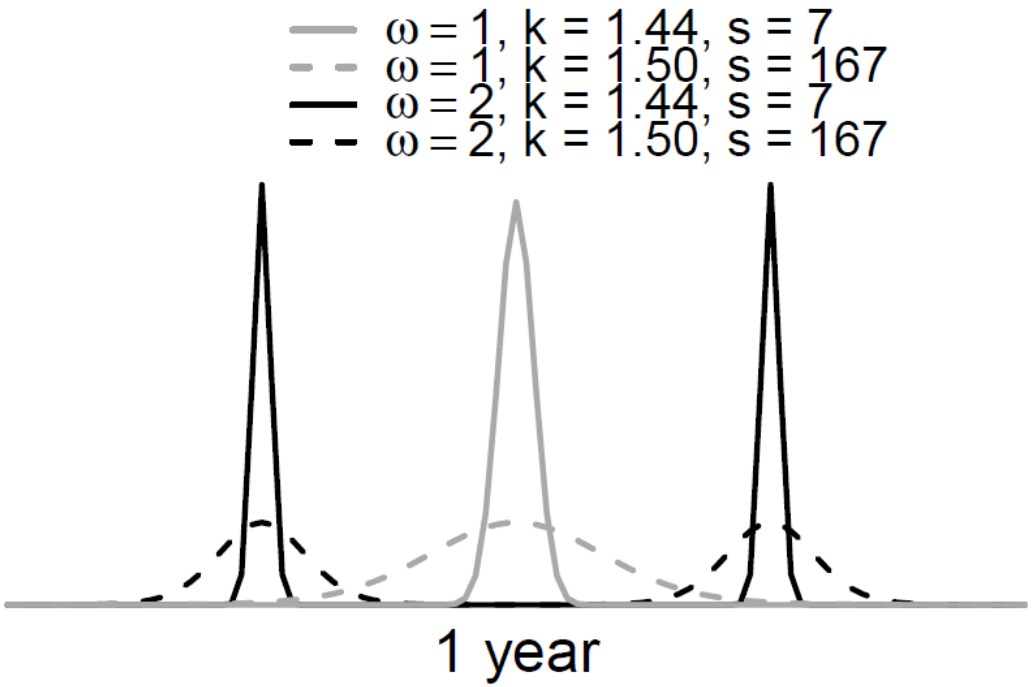
Brian R. Amman[1], Serena A. Carroll[1], Zachary D. Reed[1], Tara K. Sealy[1], Stephen Balinandi[1], Robert Swanepoel[2¤a], Alan Kemp[2], Bobbie Rae Erickson[1], James A. Comer[1], Shelley Campbell[1], Deborah L. Cannon[1], Marina L. Khristova[3], Patrick Atimnedi[4], Christopher D. Paddock[5], Rebekah J. Kent Crockett[6], Timothy D. Flietstra[1], Kelly L. Warfield[7], Robert Unfer[7], Edward Katongole-Mbidde[8], Robert Downing[9], Jordan W. Tappero[9], Sherif R. Zaki[5], Pierre E. Rollin[1], Thomas G. Ksiazek[1¤b], Stuart T. Nichol[1], Jonathan S. Towner[1*]

Seasonality and birth pulses



Peel *et al.*, Proc. Royal Soc. B, 2014

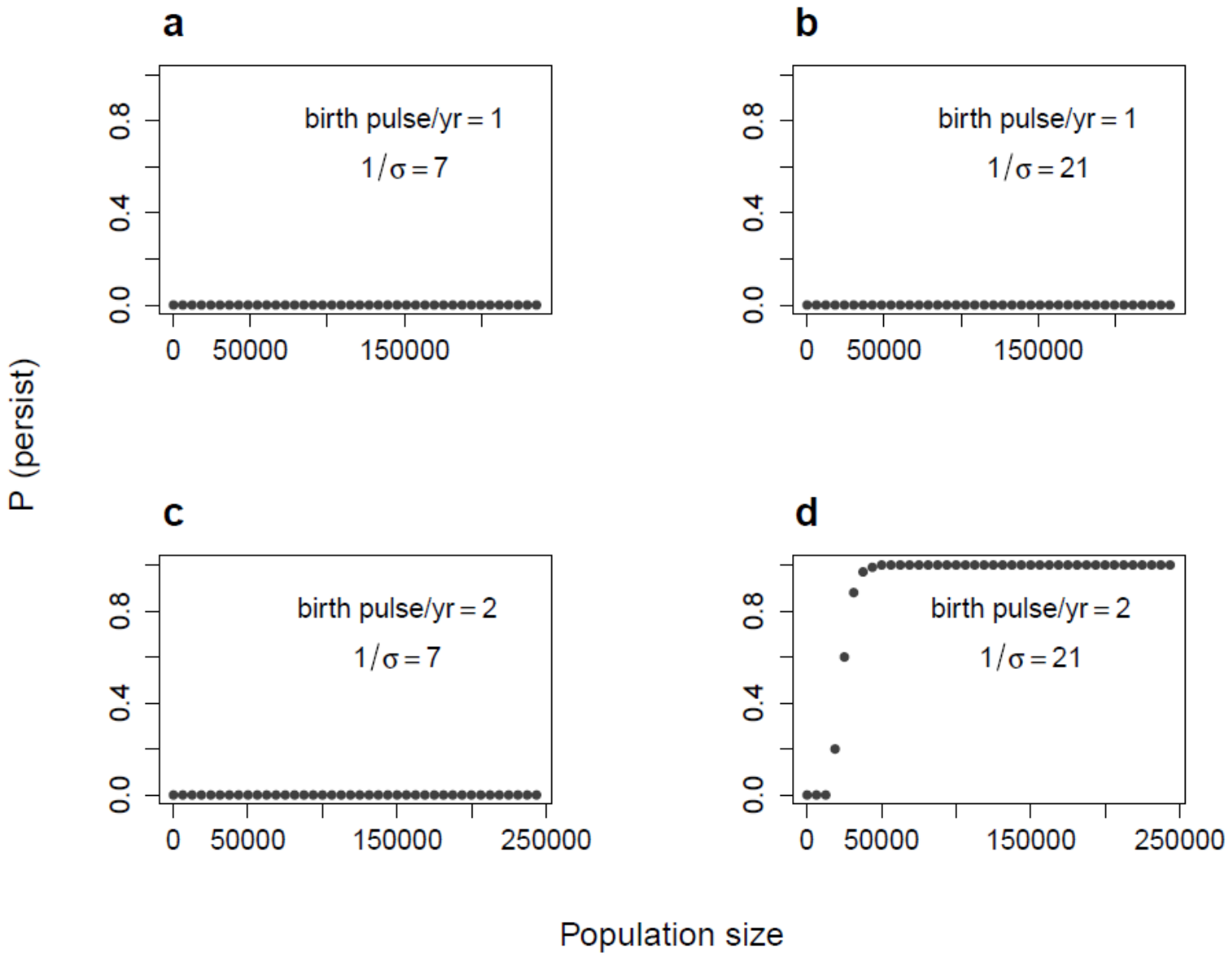
Modelling bat birth pulses



1 birth per female bat per year

Hayman, in revision

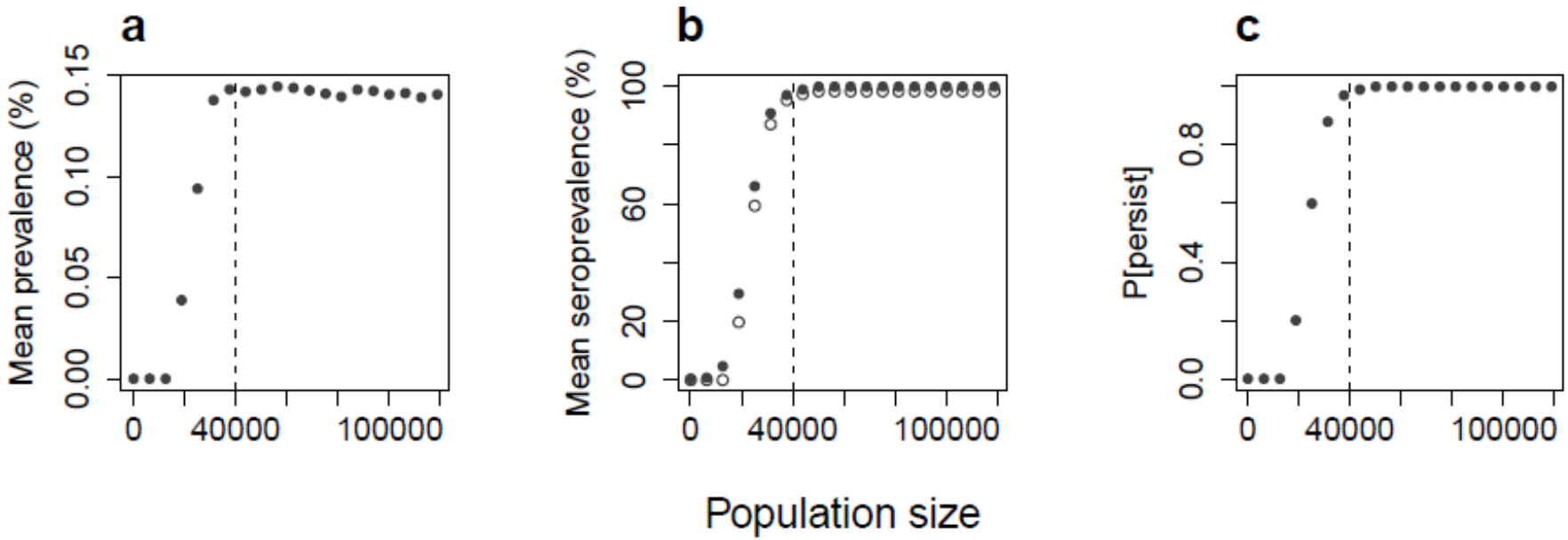
Birth pulses might matter



Hayman, in revision

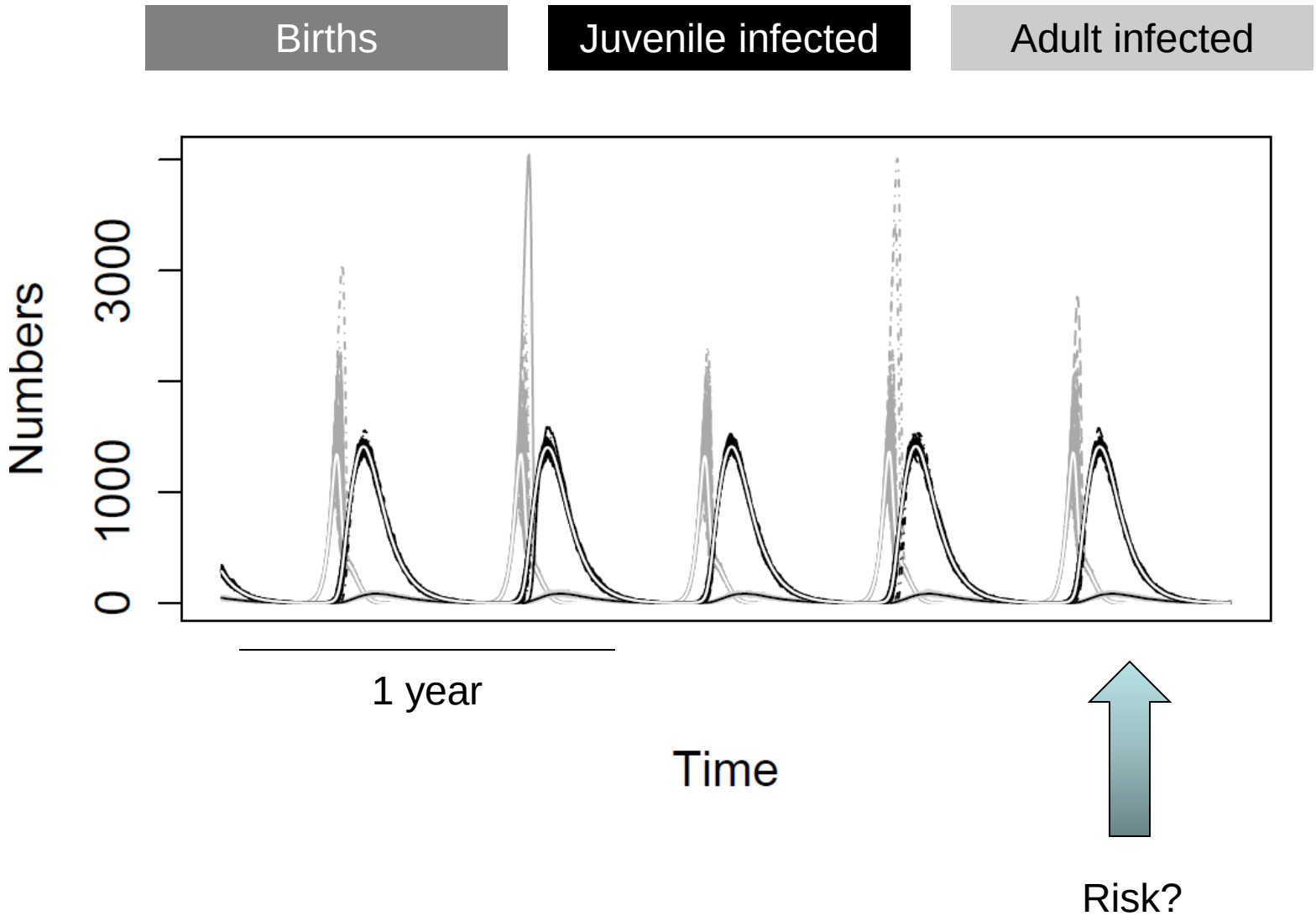
All models are wrong, but some are useful…

George E. P. Box FRS (18 October 1919 – 28 March 2013)



Hayman, in revision

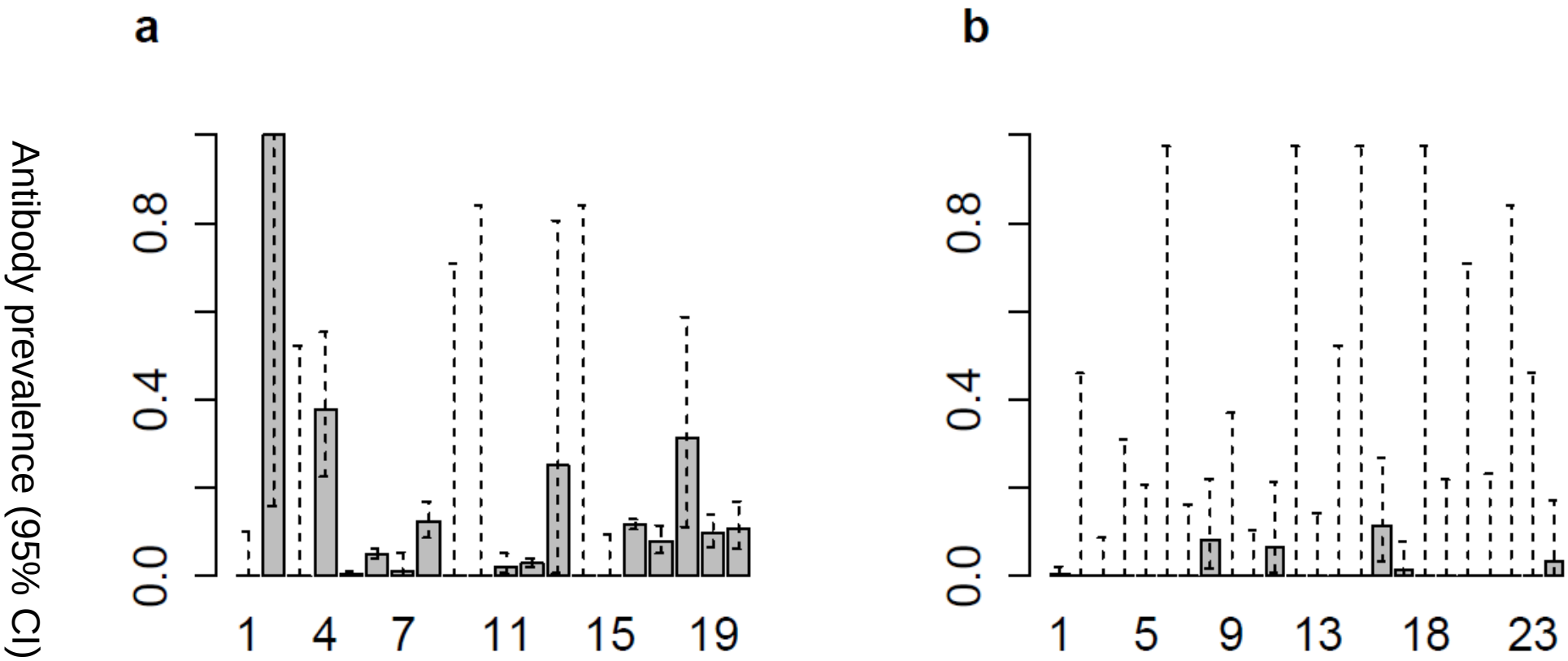
Infection dynamics when infection persists



Hayman, in revision

Data support model results

Odds ratio 4.4, 95% confidence interval 2.5-8.7



Two birth pulses

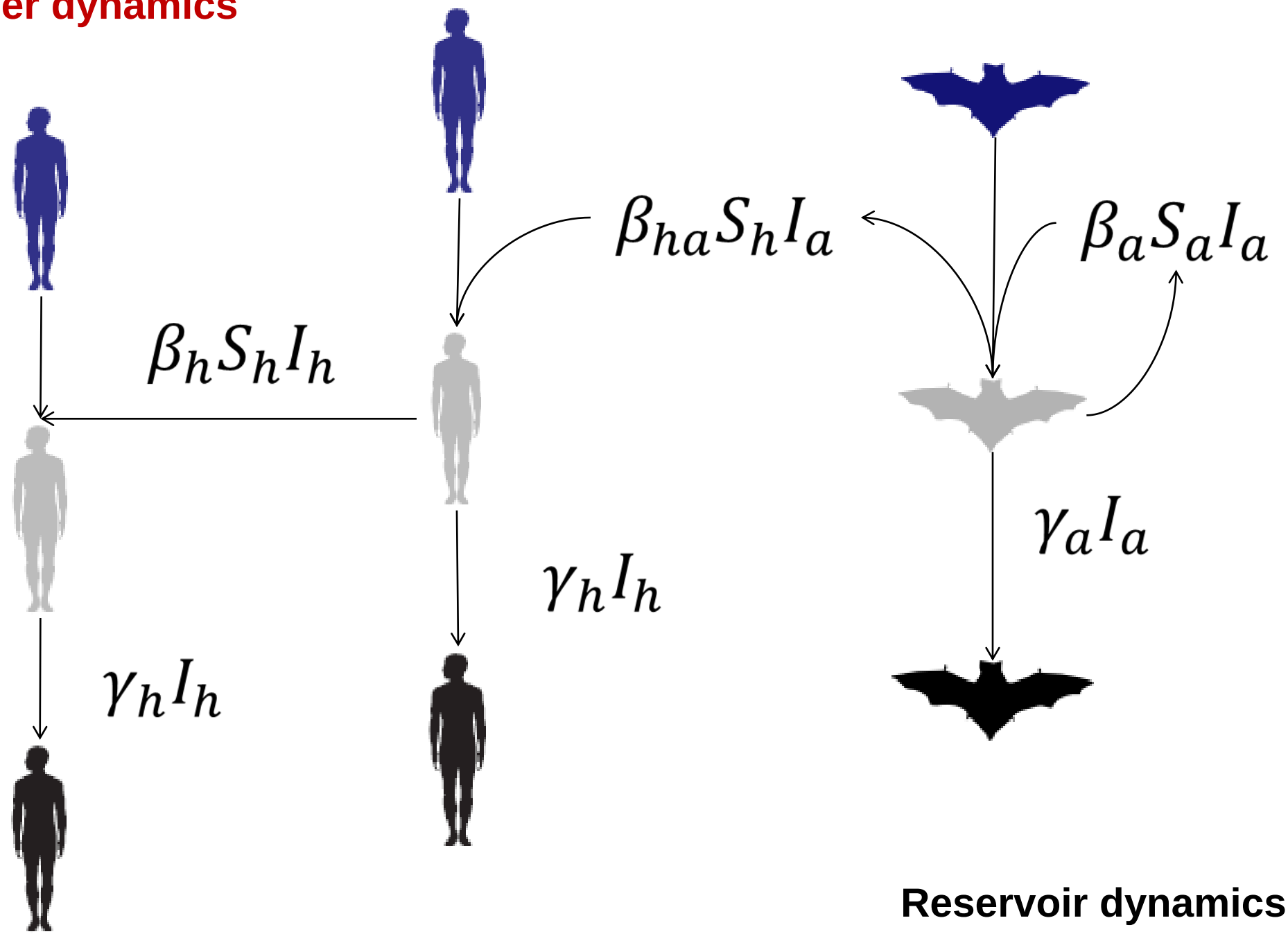
One birth pulse

Risk?

Hayman, in revision

Ebolavirus transmission pathways

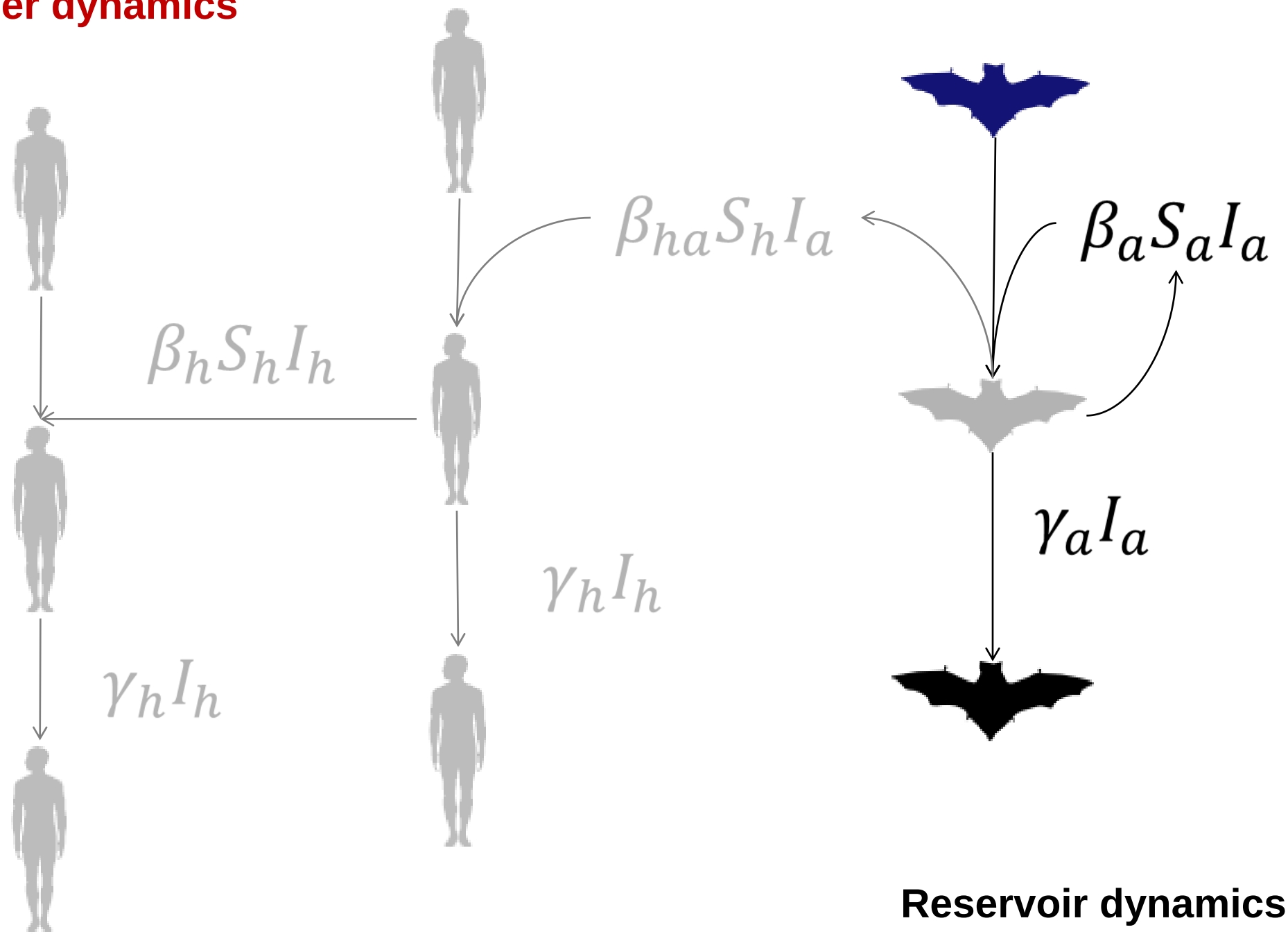
Spillover dynamics



Reservoir dynamics

Ebolavirus transmission pathways

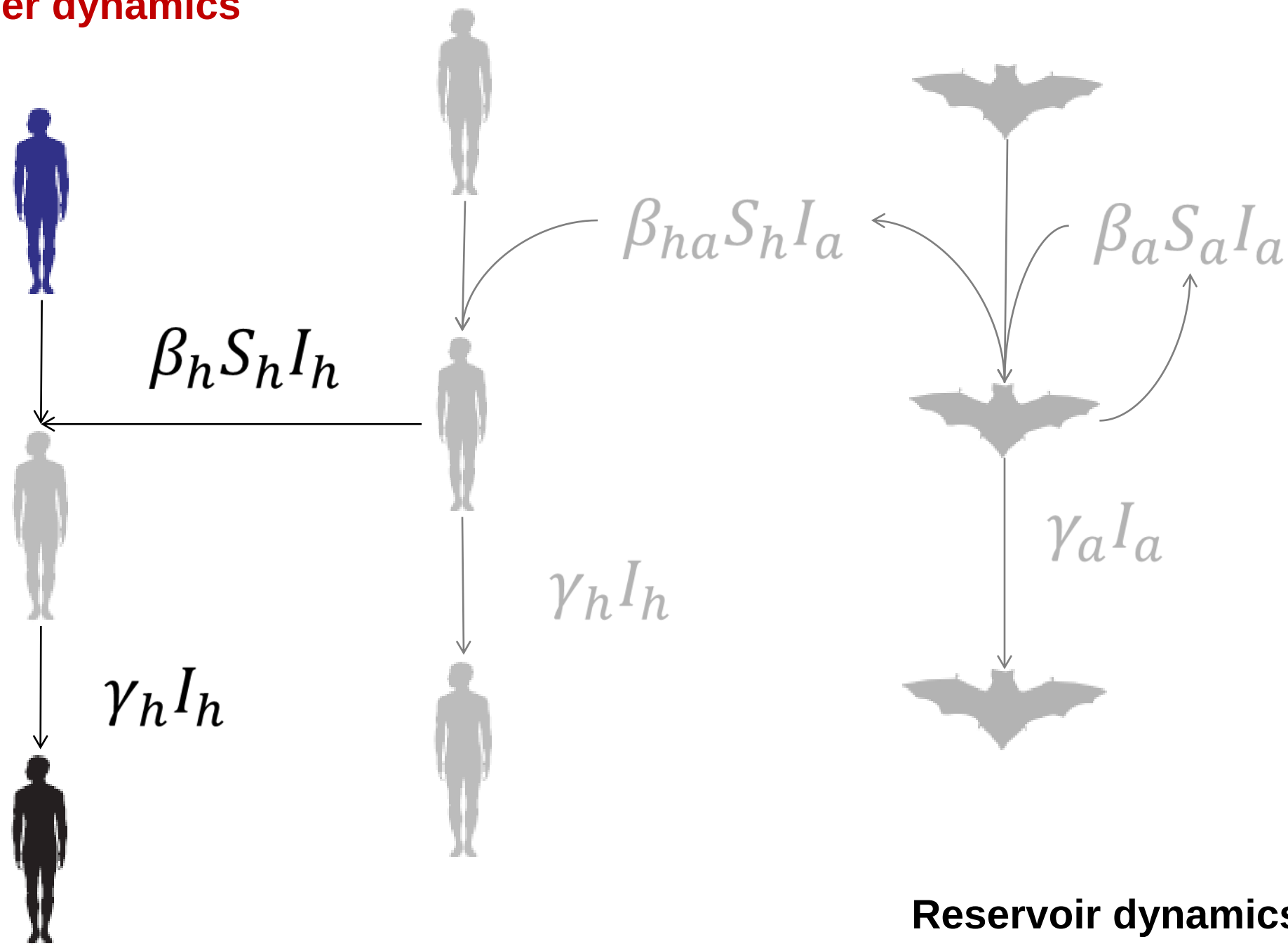
Spillover dynamics



Reservoir dynamics

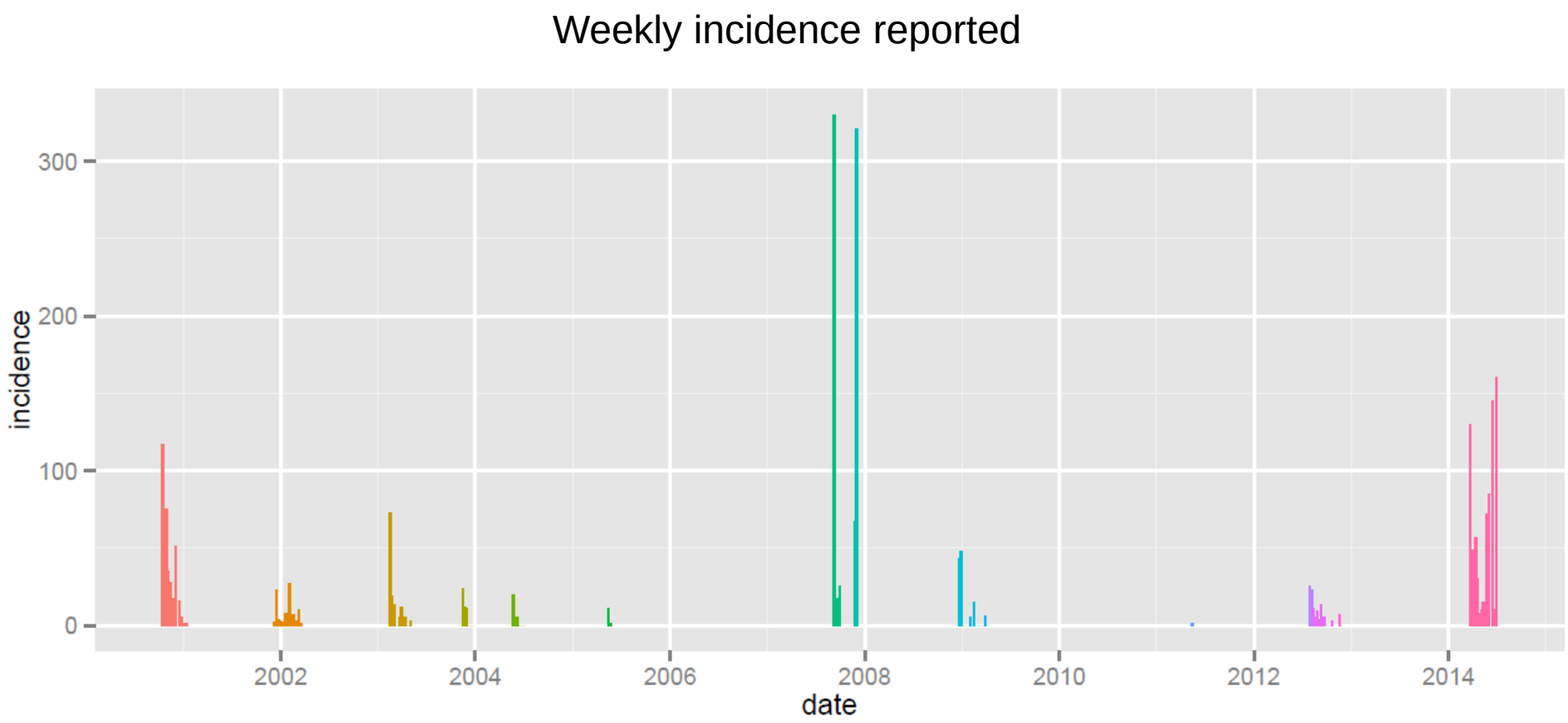
Ebolavirus transmission pathways

Spillover dynamics

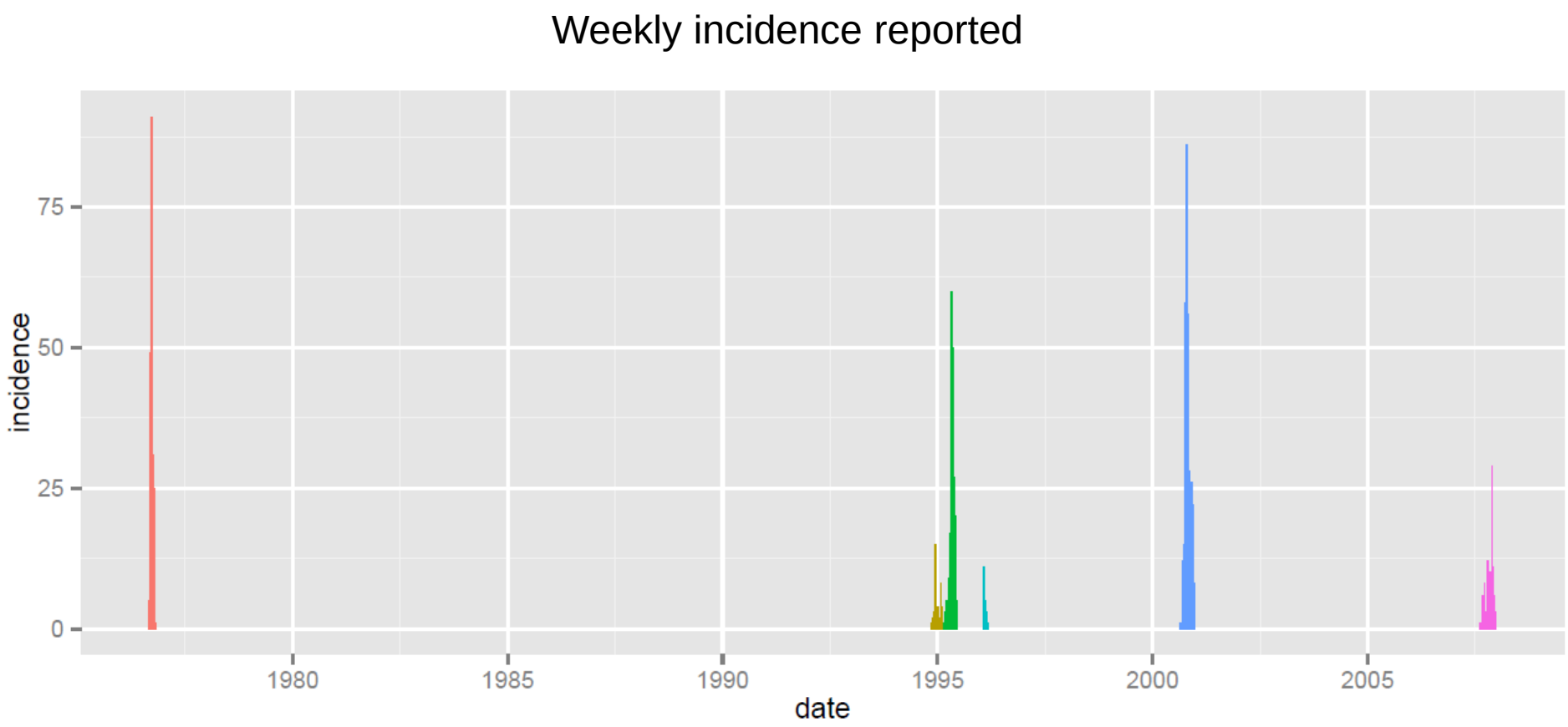


Reservoir dynamics

Ebolavirus outbreaks - WHO

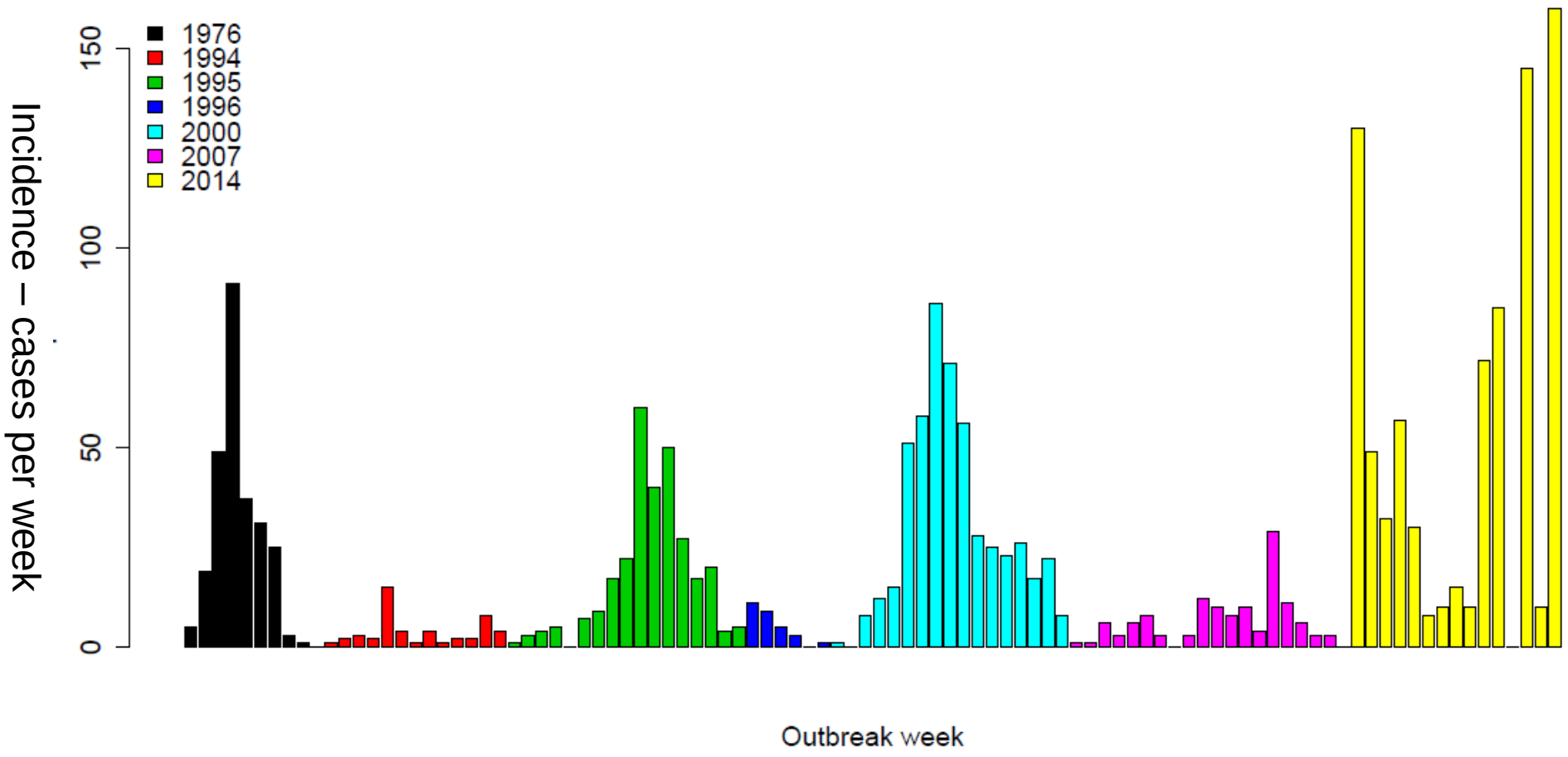


Ebolavirus outbreaks - published



WHO Bulletin 1976; MacNeil *et al.*, JID 2011; Okware *et al.*, TMIH 2002; Georges *et al.*, JID 1999; Khan *et al.*, JID 1999

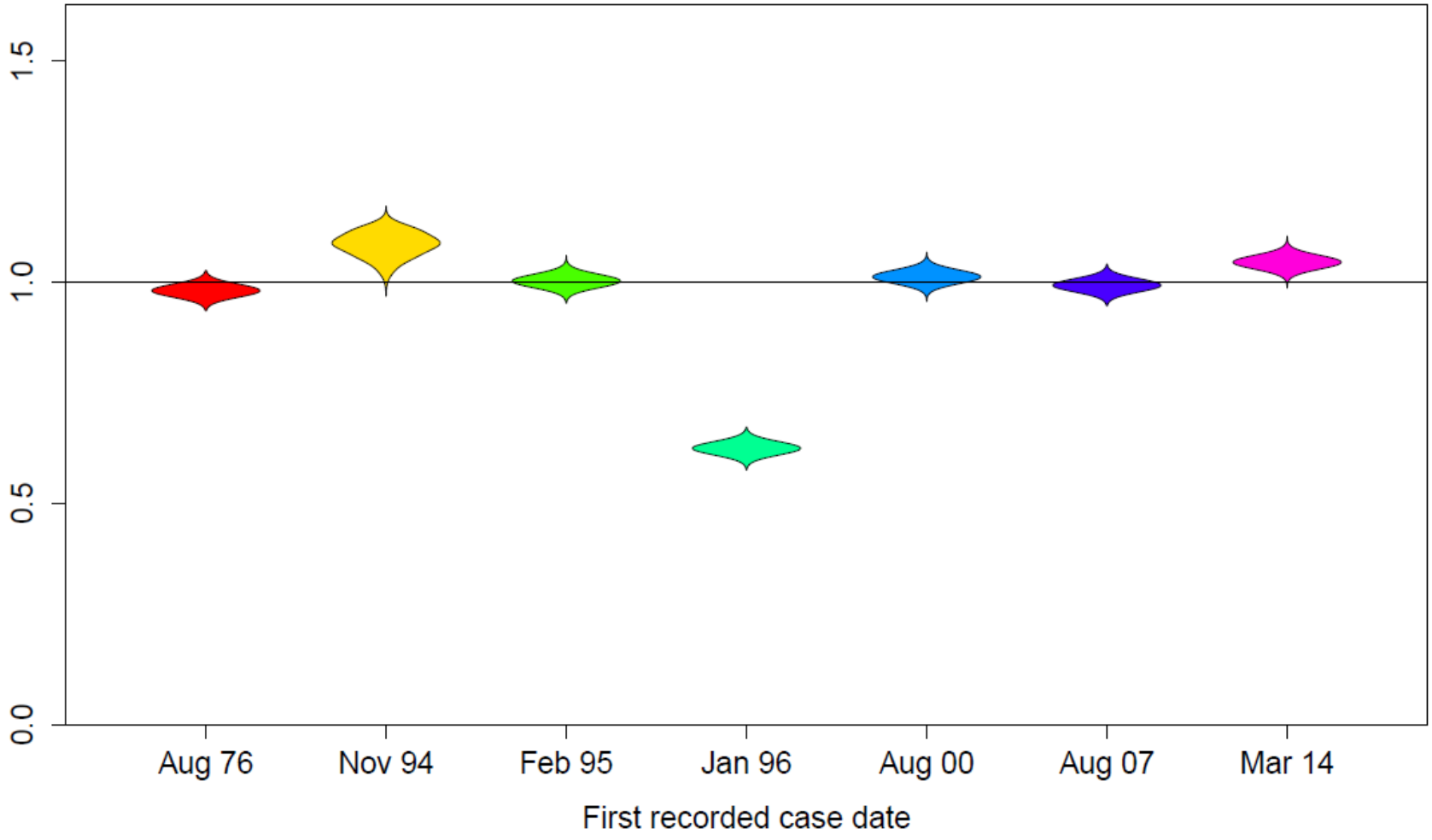
Ebolavirus outbreaks



Hayman *et al.*, unpublished

Human *ebolavirus* epidemics: R_0

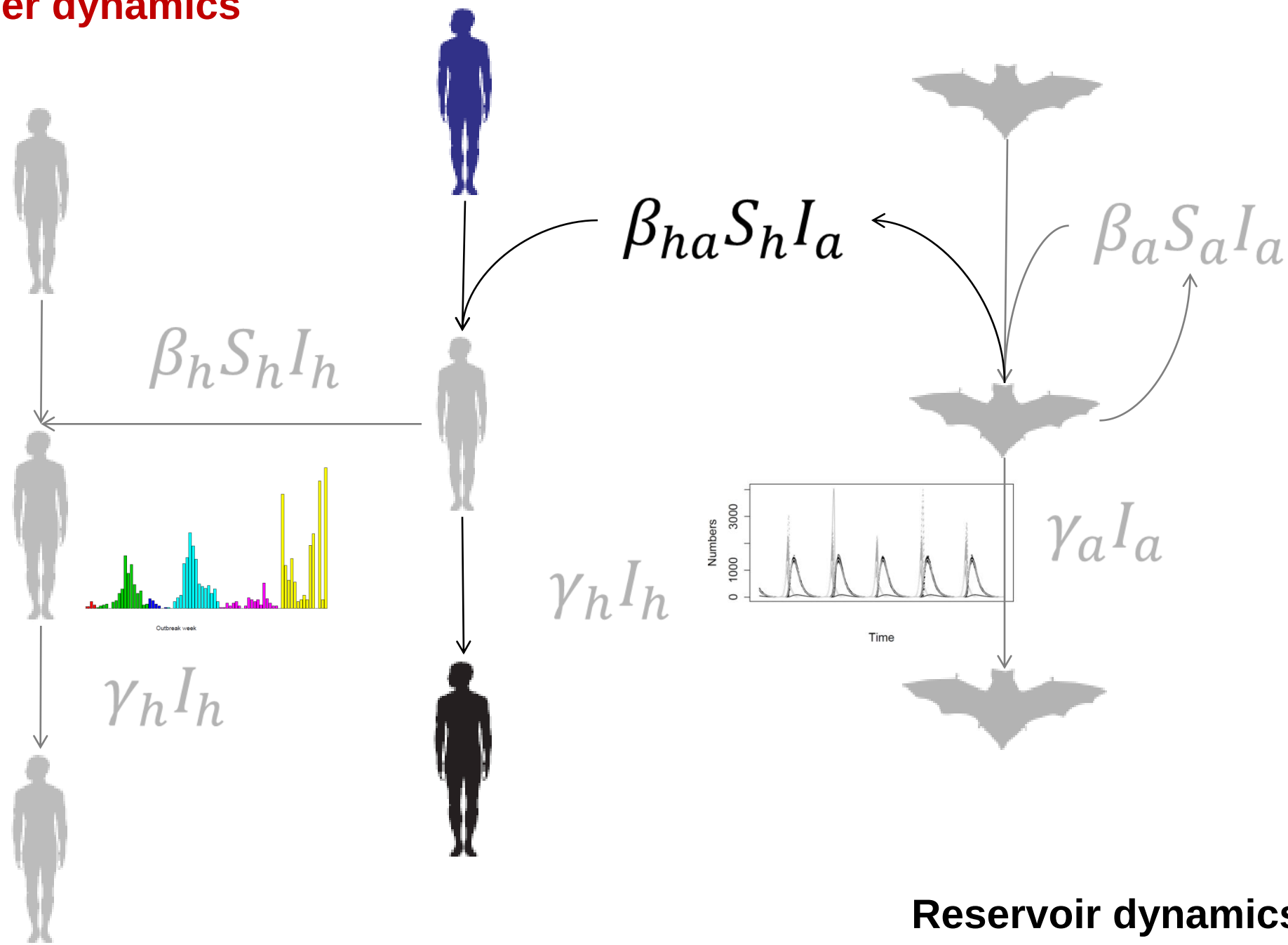
R_0 – average number of secondary cases
in a susceptible population



Hayman *et al.*, unpublished

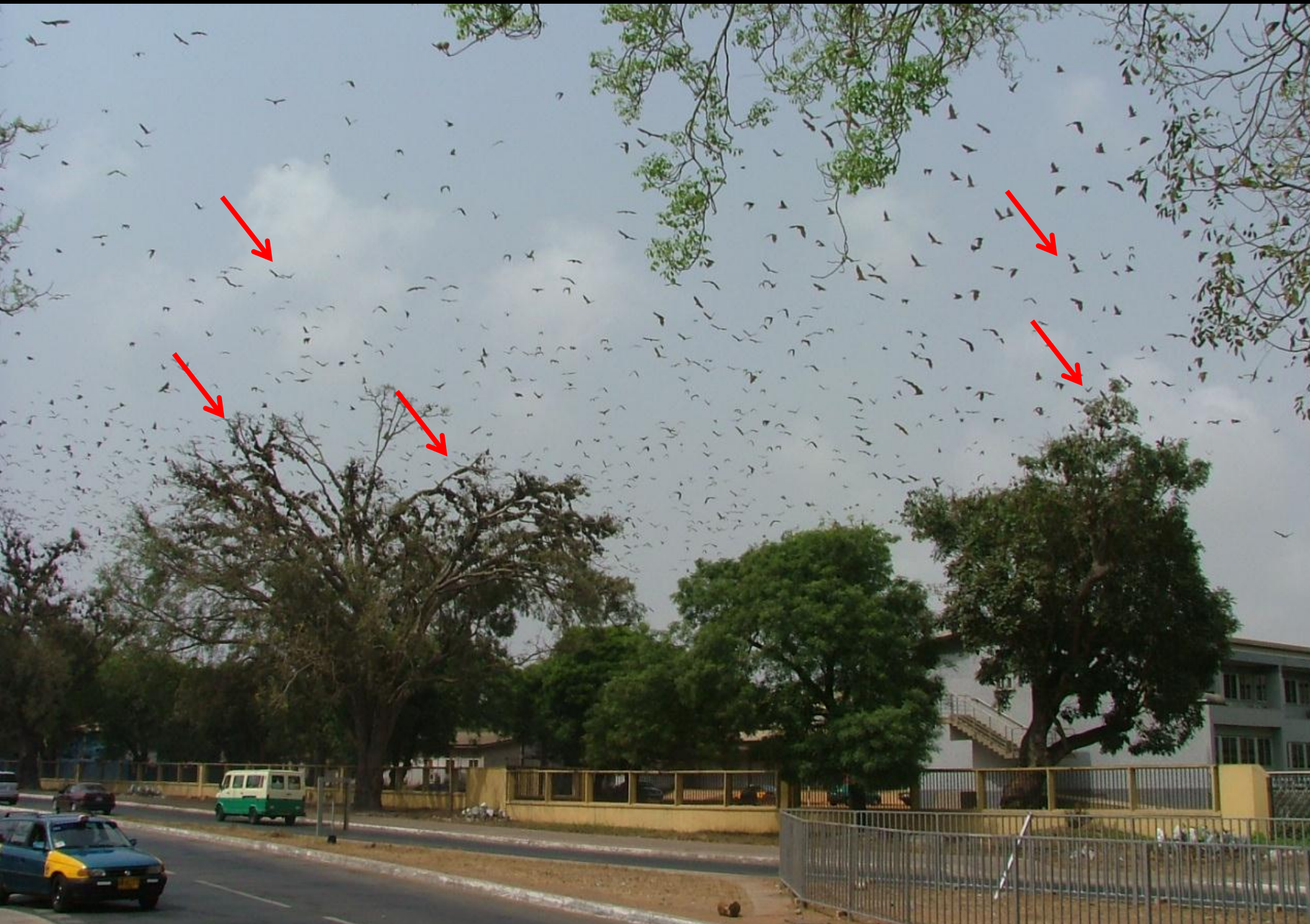
Next challenge…

Spillover dynamics



Reservoir dynamics

Ghana – ’37’ Military Hospital



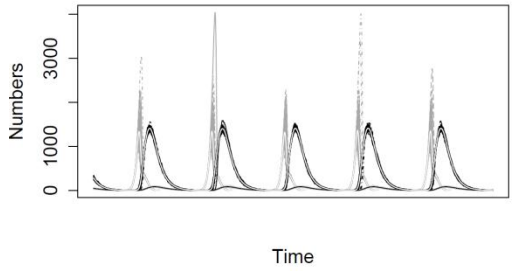
Bats as bushmeat

Fresh

Smoked

Contact rates through bushmeat

Seasonality in prevalence



Synchrony or asynchrony?

Strong seasonality in hunting

Table 2
Estimated characteristics of bat sales by the interviewed vendors in the five study sites.

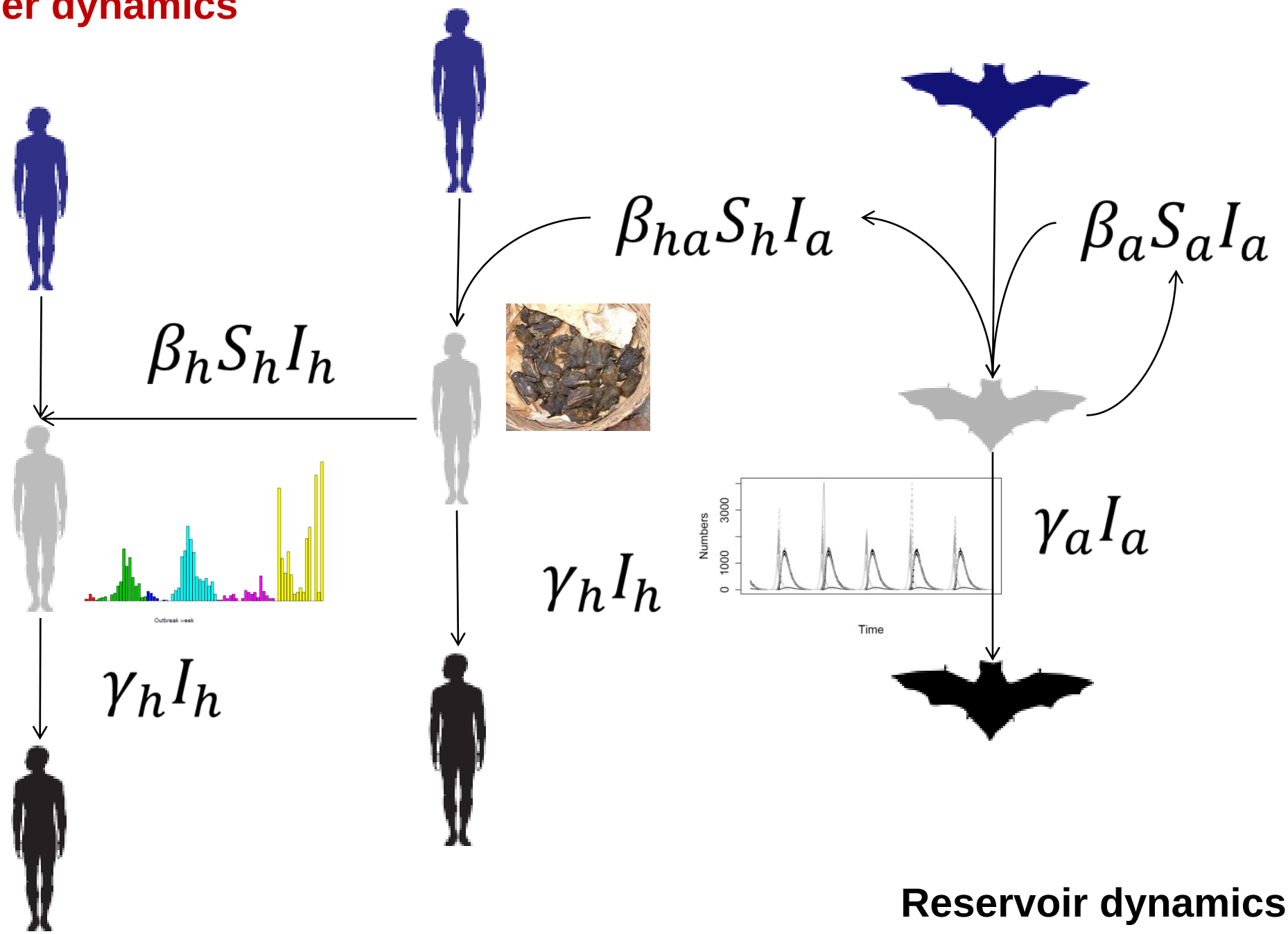
Study site	Mean number of selling days per month	Mean number of bats sold per vendor per selling day	Mean number of months selling per year	Total number of bats sold per year
Accra	16.8	72.6	4.3	38,452
Kumasi	6.25	26.3	5.5	5920
Nkawkaw	10.4	320	3	55,555
Volta	4.2	510	2	28,480
Overall	8.9	280	3.6	128,407

Large numbers

Kamins *et al.*, Biol. Conservation 2012

Ebolavirus transmission pathways

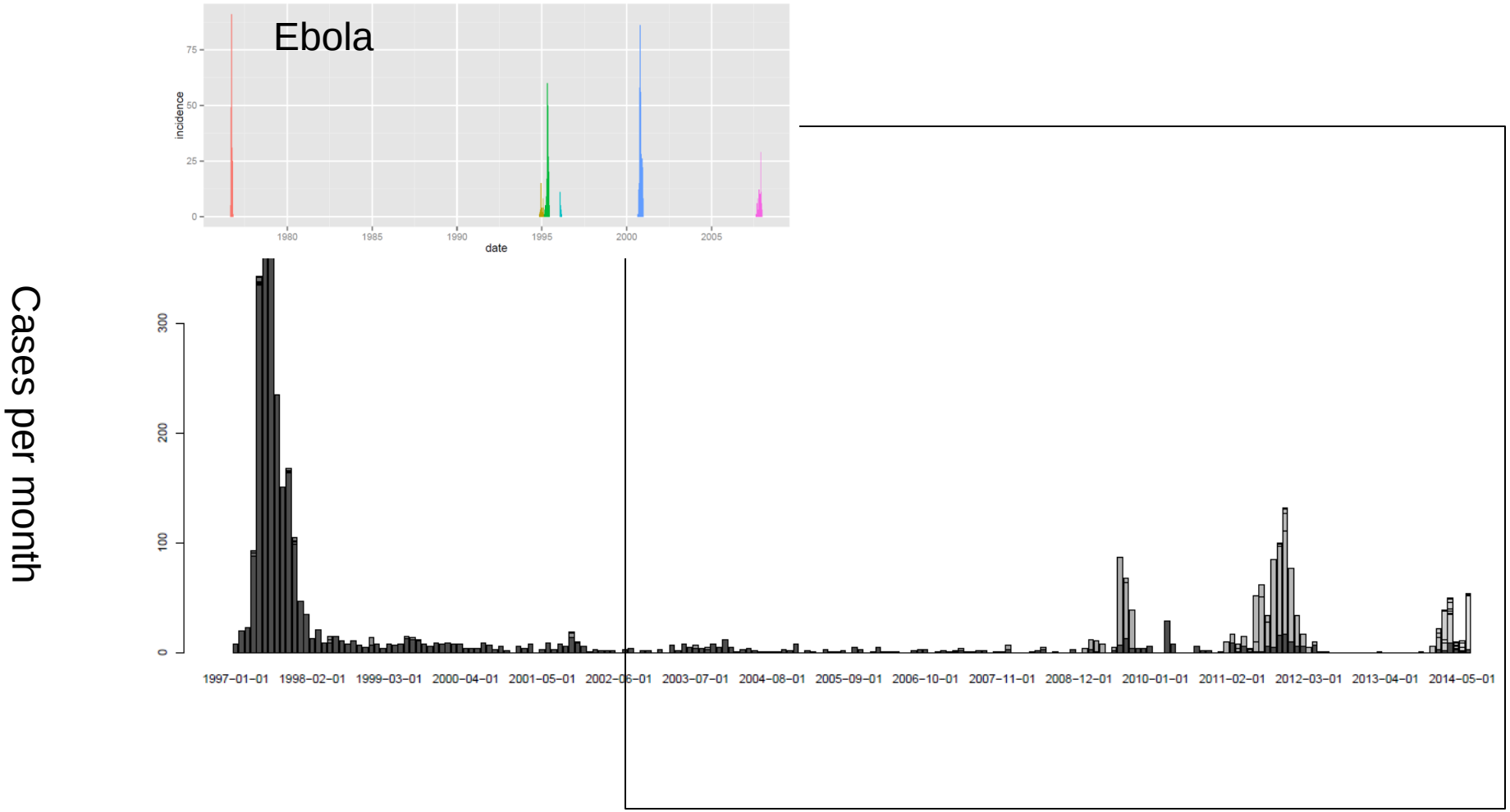
Spillover dynamics



Reservoir dynamics

Measles

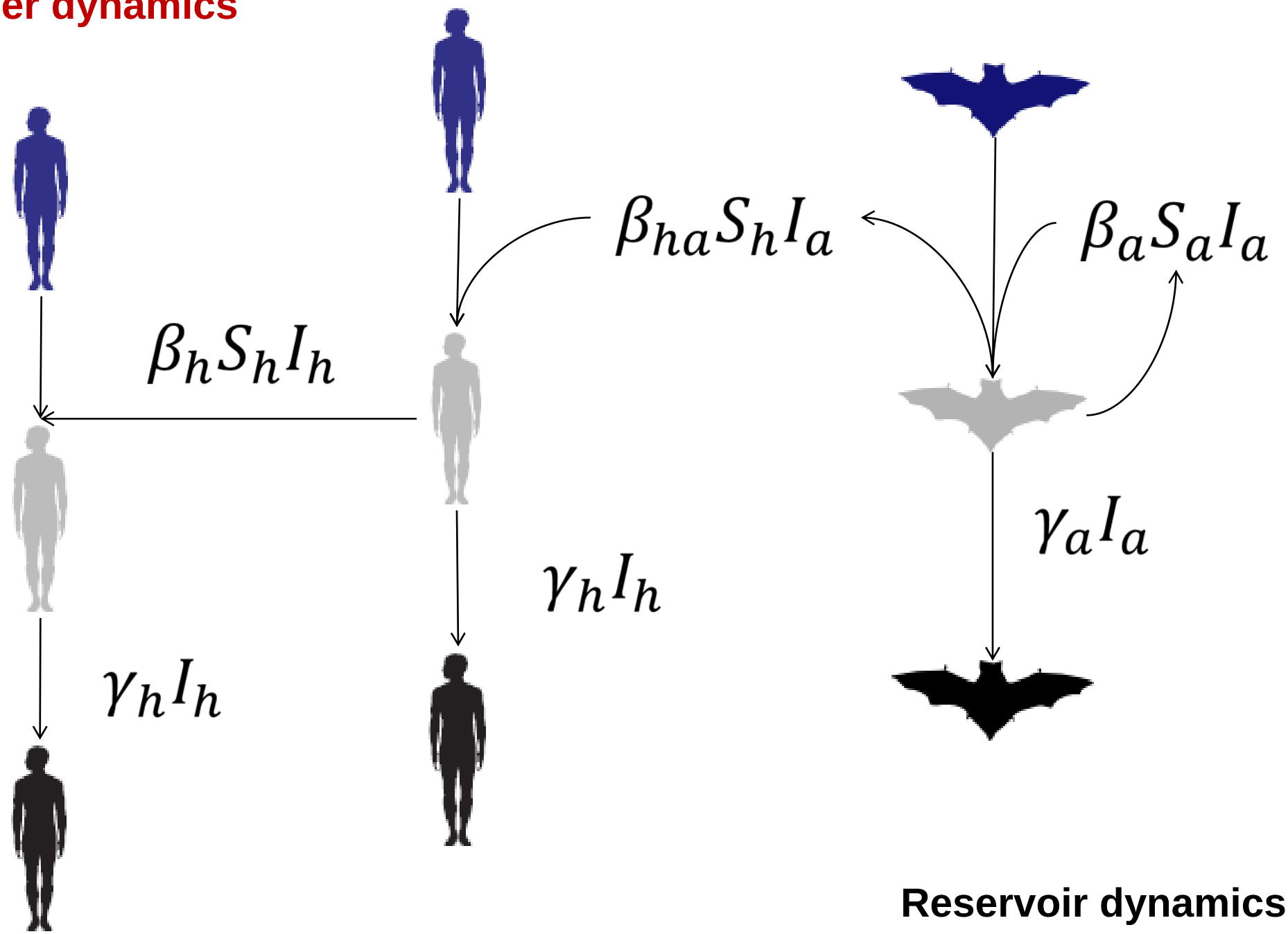
New Zealand measles incidence



Hayman *et al.*, unpublished

Ebolavirus transmission pathways

Spillover dynamics



Reservoir dynamics

Measles transmission pathways

Spillover dynamics

Probability of infection

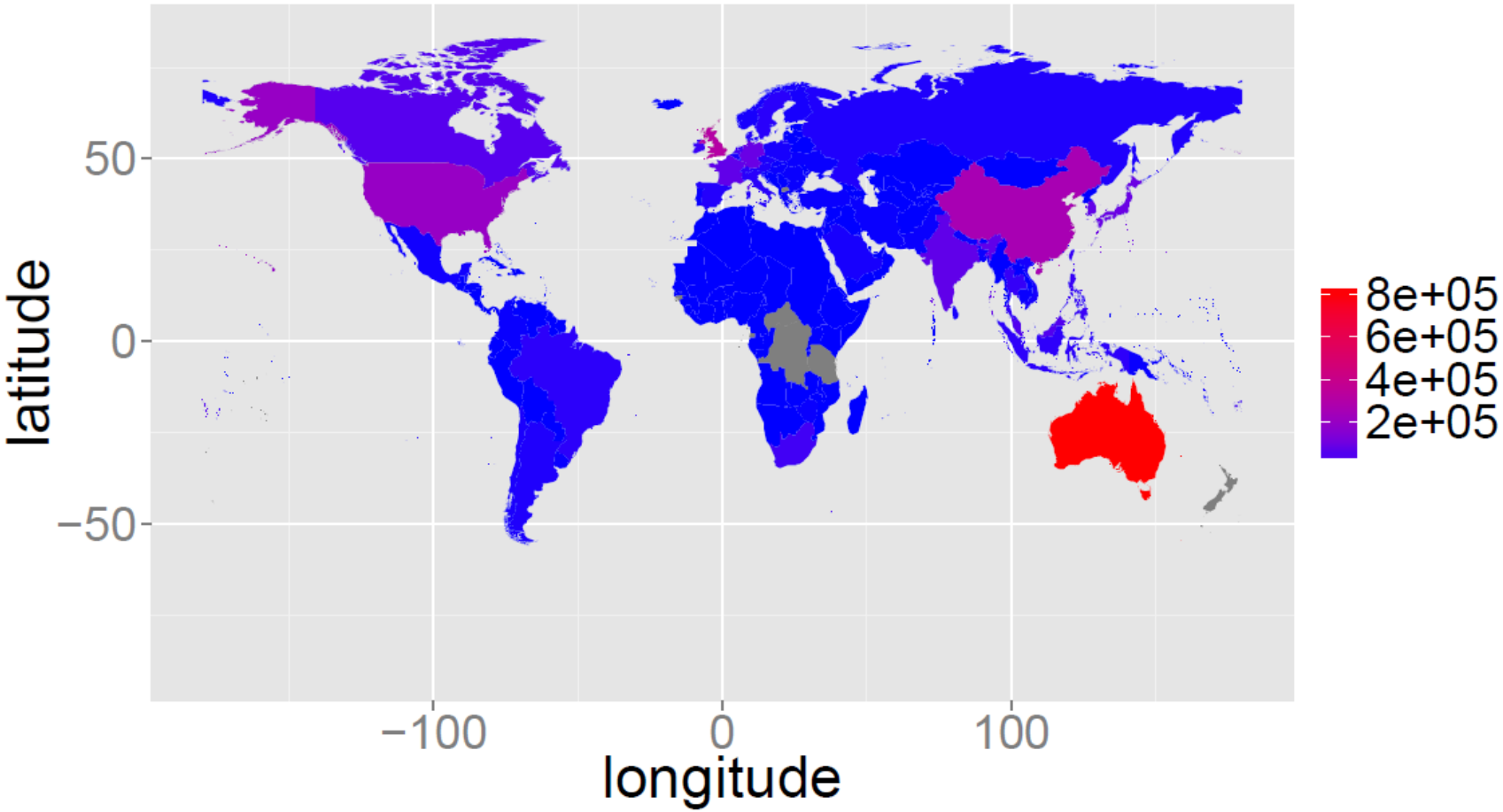
Contact rates

$$\beta_{world:NZ} S_{NZ} I_{world}$$

Prevalence in populations

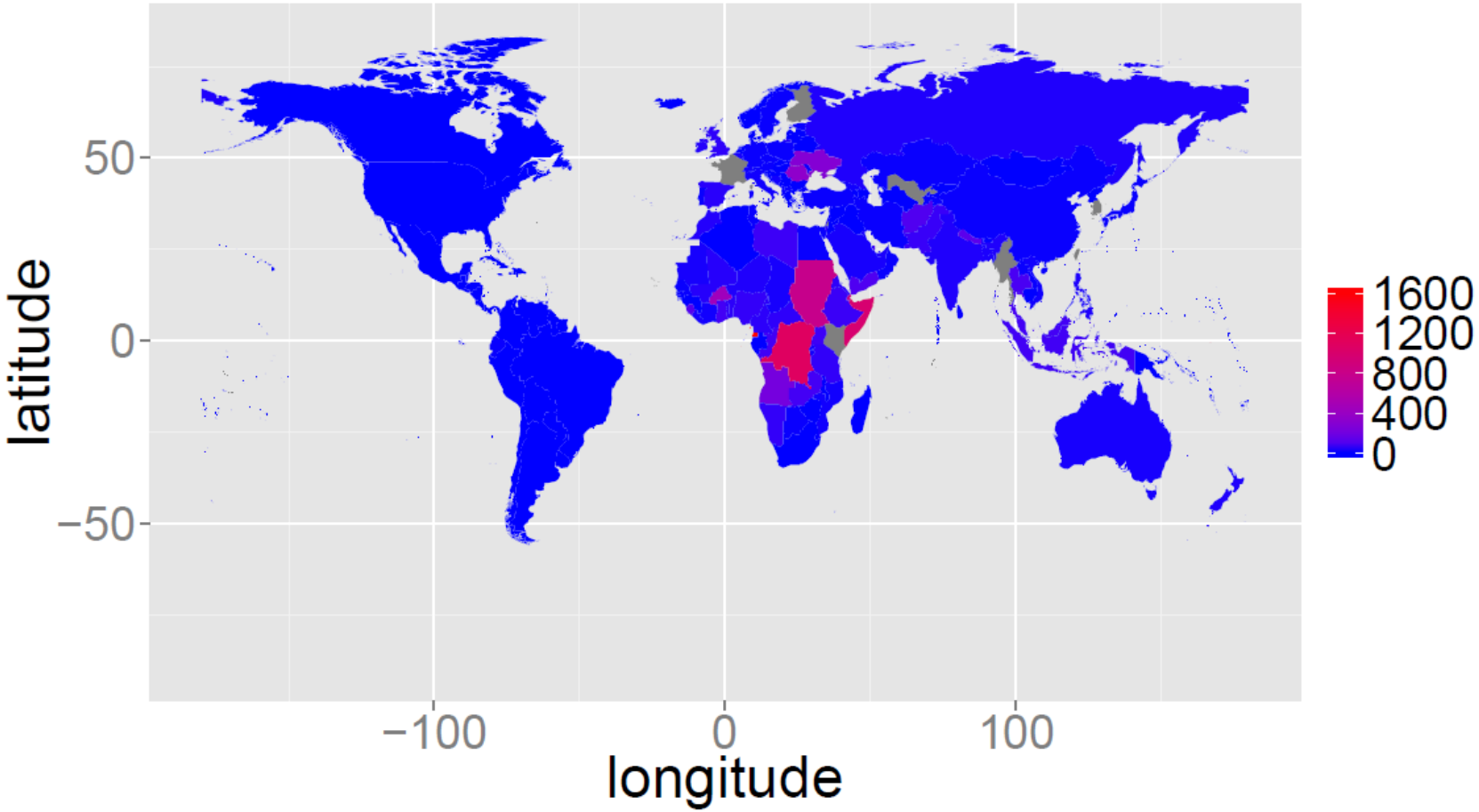
Reservoir dynamics

Immigration to New Zealand, 2012



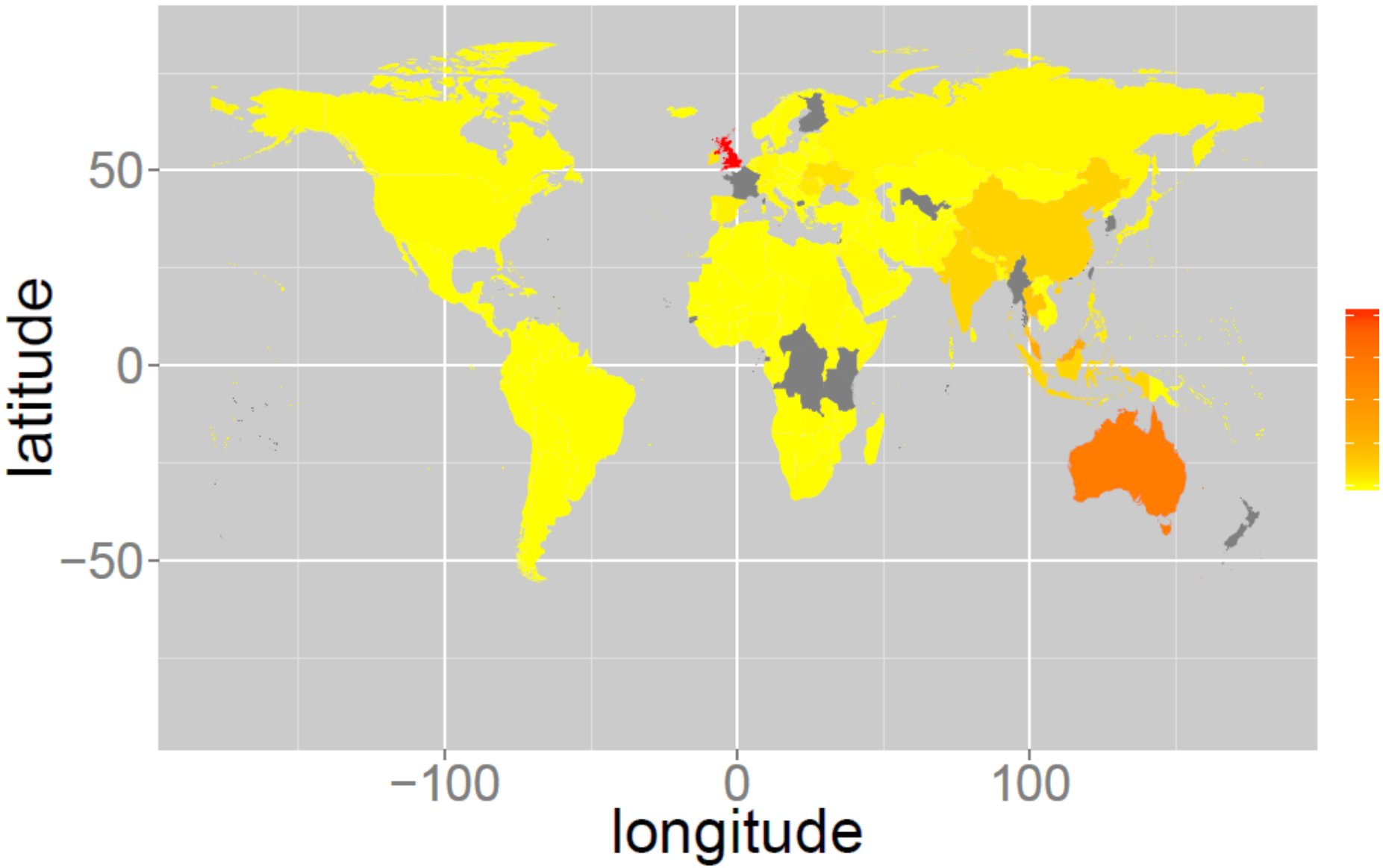
Hayman *et al.*, unpublished

Annual measles incidence per million, 2012



Hayman *et al.*, unpublished

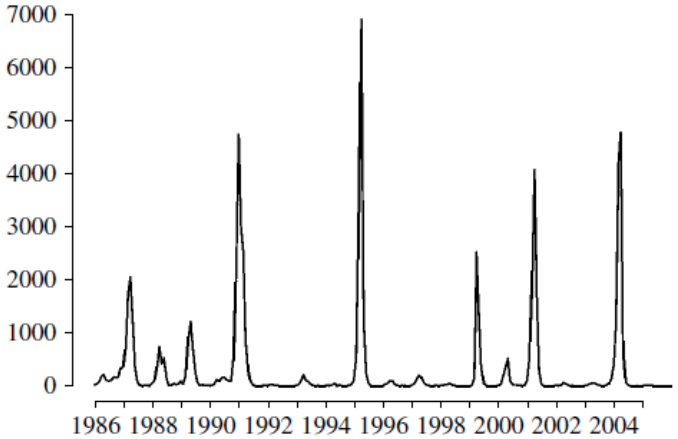
Risk of measles importation?



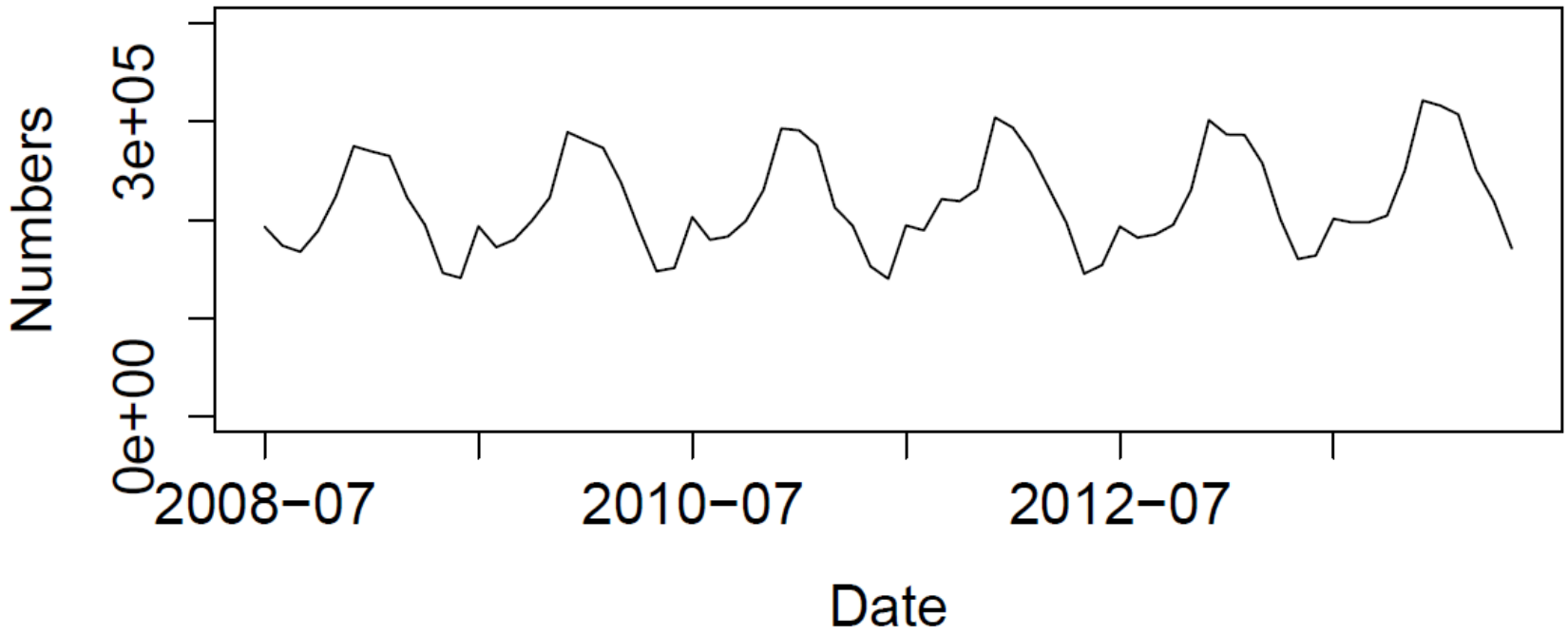
Hayman *et al.*, unpublished

Seasonality in immigration

Measles cases per month, Niger

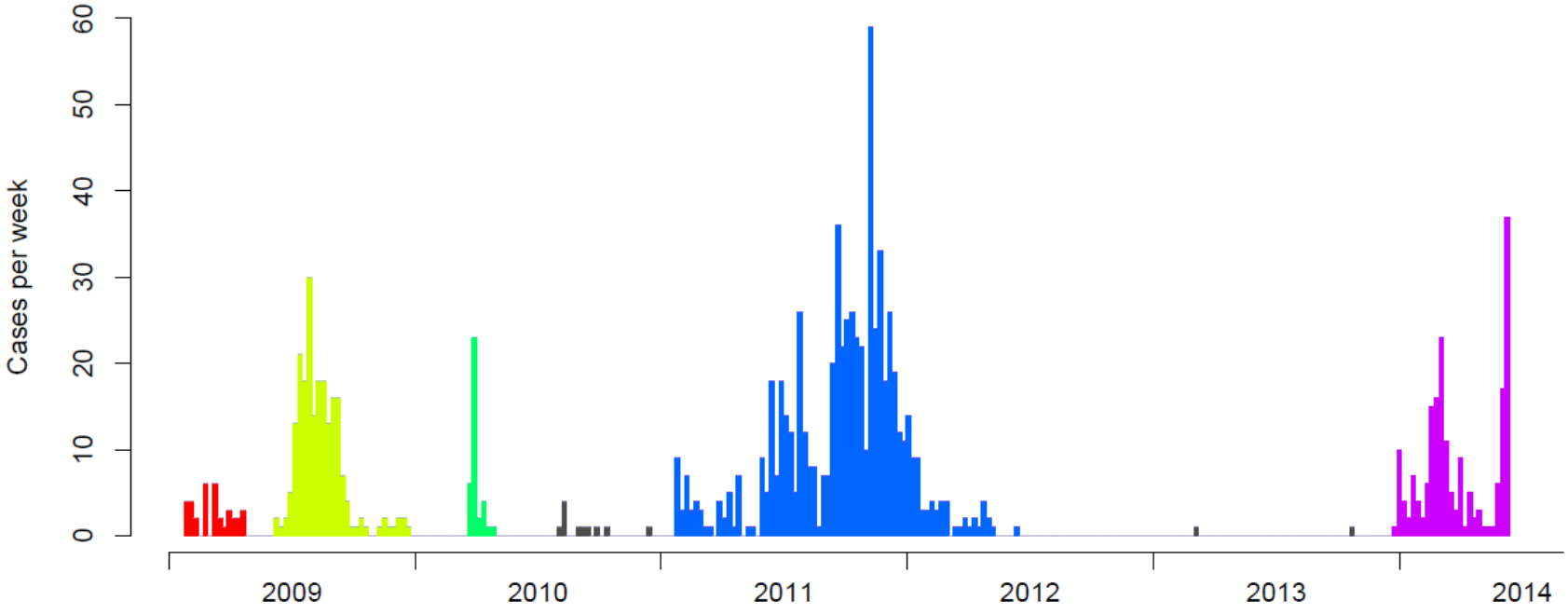


Synchrony or asynchrony?



Hayman *et al.*, unpublished; Ferrari *et al.*, E&I 2010

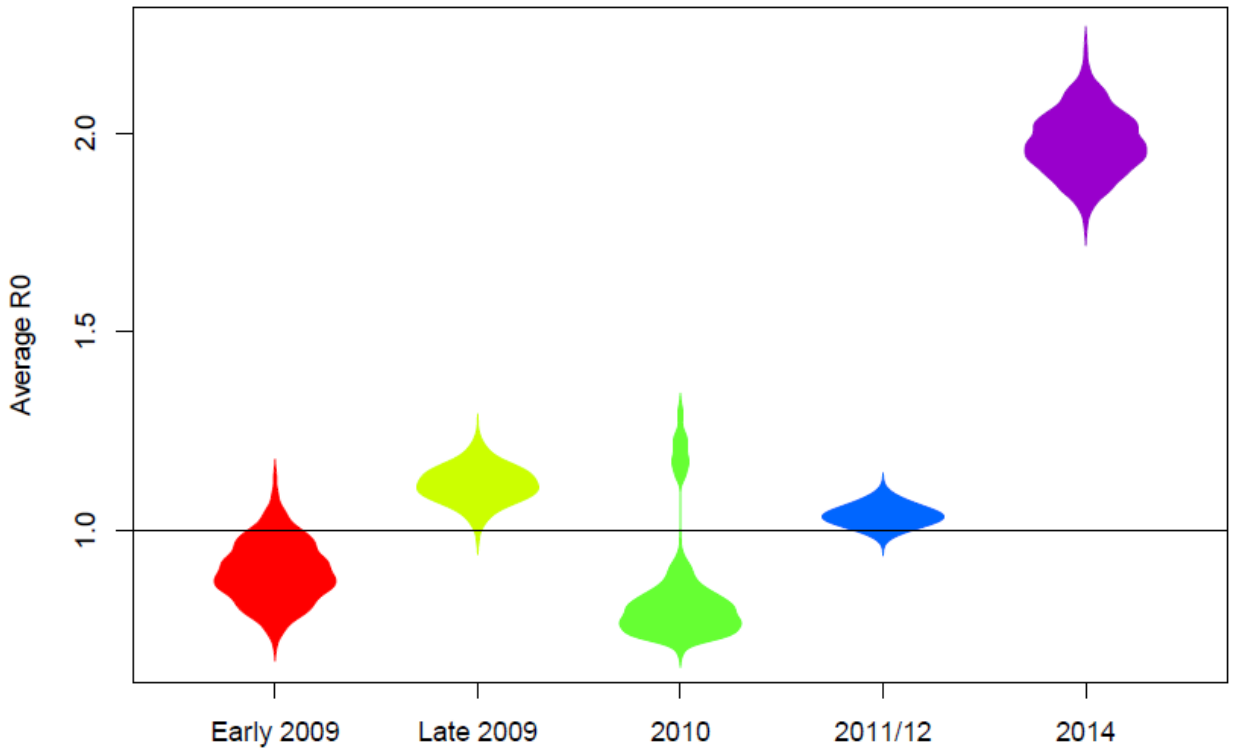
New Zealand measles incidence



Hayman *et al.*, unpublished

Human measles outbreaks: $R_{effective}$

$R_{effective}$ (R_0)– average number of secondary cases in an immune population

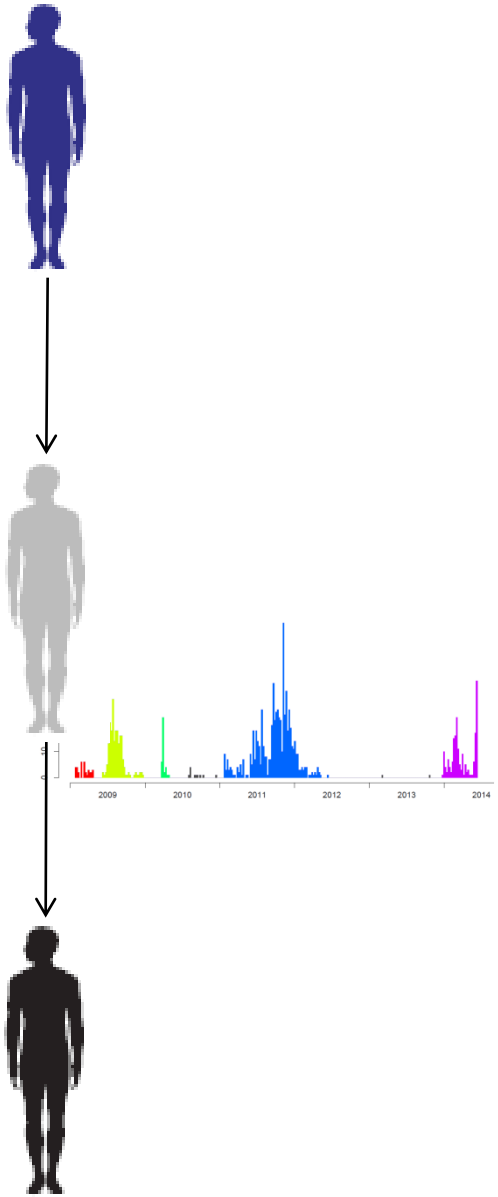


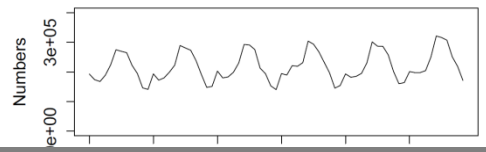
Hayman *et al.*, unpublished

Measles transmission pathways

Spillover dynamics

Probability of infection

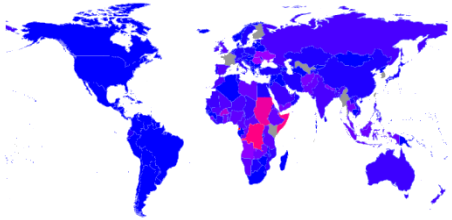




Contact rates

$$\beta_{world:NZ} S_{NZ} I_{world}$$

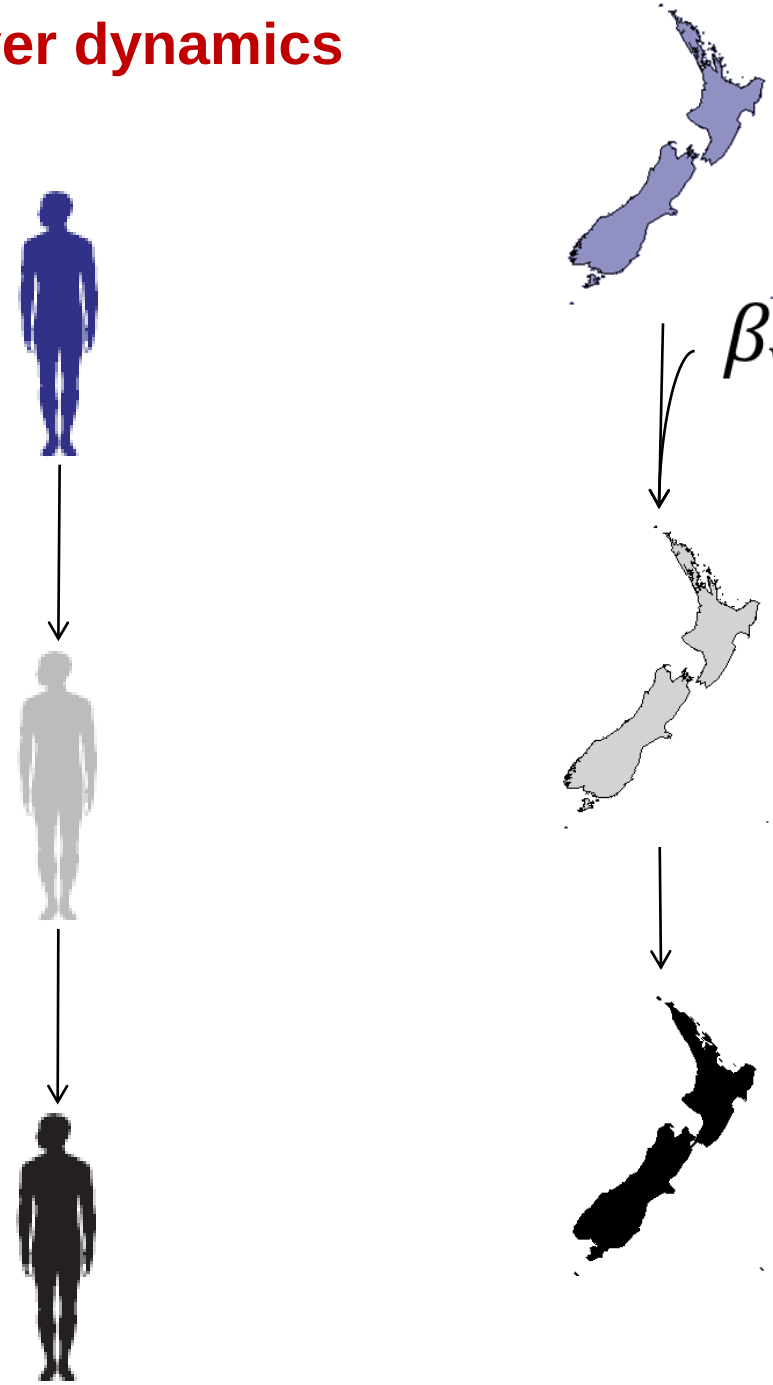
Prevalence in populations



Reservoir dynamics

Interesting framework?

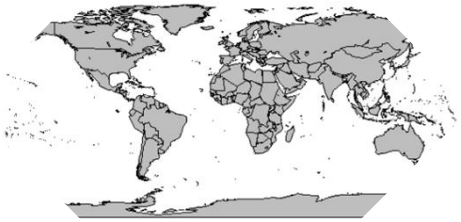
Spillover dynamics

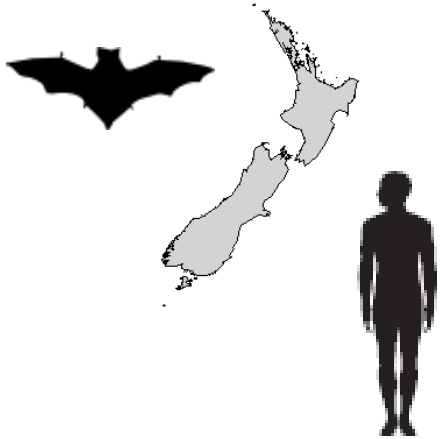


$$\beta_{world:NZ} S_{NZ} I_{world}$$

Reservoir dynamics

Comparison and summary





- Introductions into ‘naïve’ populations
- Seasonality in contact rates
- Seasonality in infection prevalence in reservoir
- *Reservoir dynamics need to be understood to understand and reduce risk*

Phylogenetics

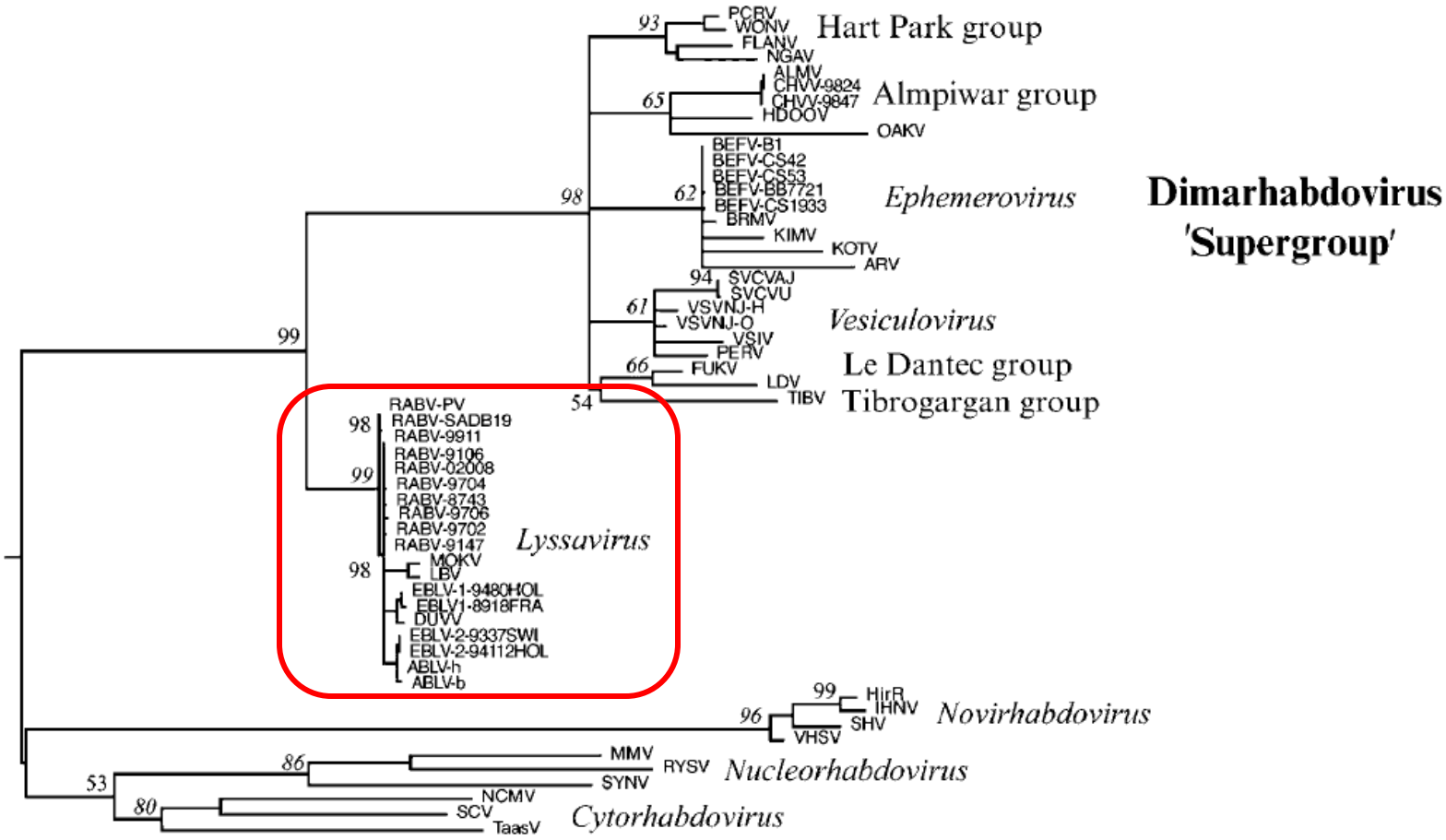
Viral phylogeny – what ‘history’ tells us

Negative sense ssRNA viruses

Mononegavirales

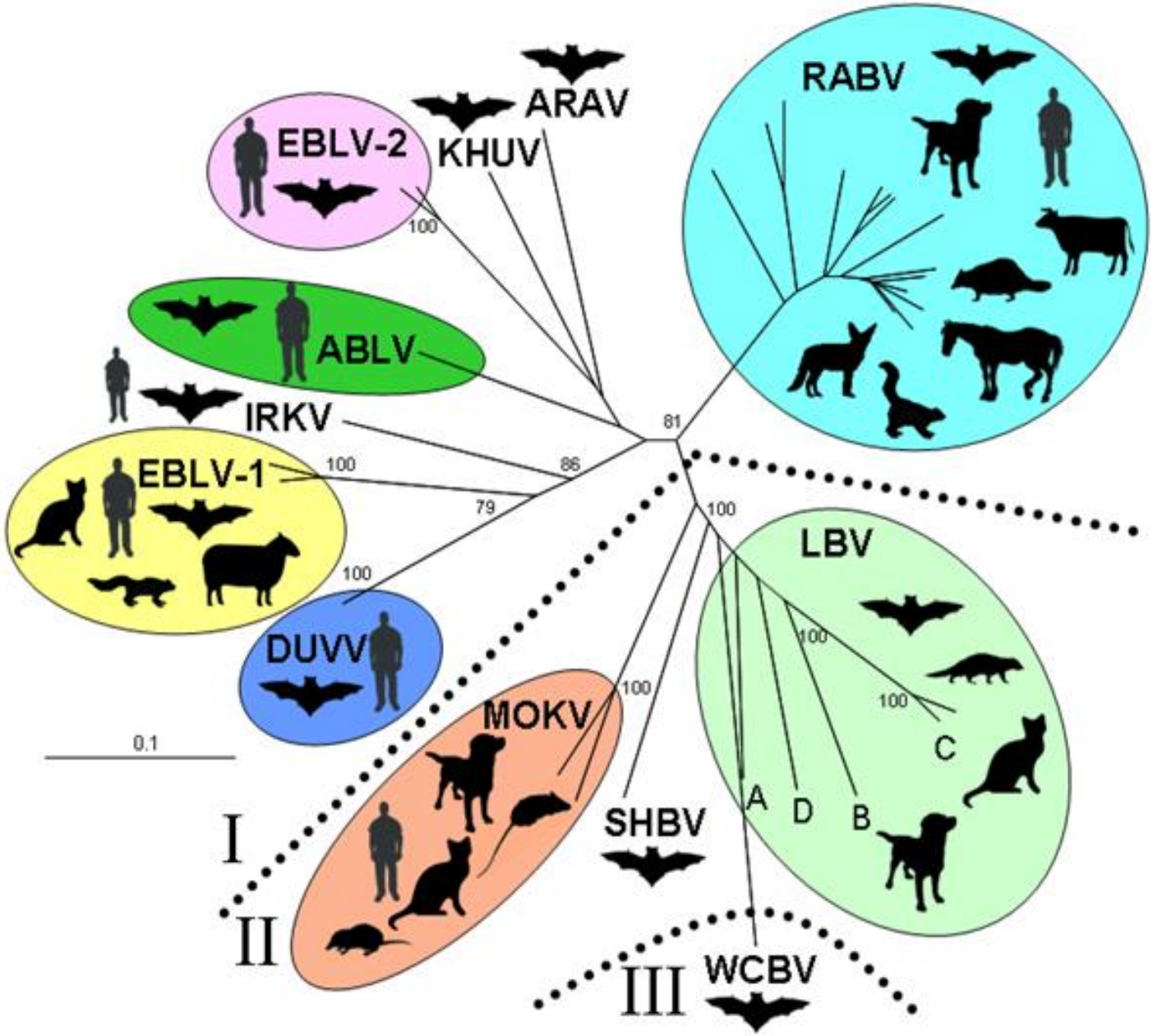
Paramyxoviridae	Rhadoviridae	Filoviridae	Bornaviridae
Rubulovirus	*Lyssavirus*	*Marburgvirus*	*Bornavirus*
Morbillivirus	*Vesiculovirus*	*Ebolavirus*	
Henipavirus	...	*Cuevavirus*	
Pneumovirinae	...		
Metapneumovirus			
...			

Rhabdovirus phylogenetics



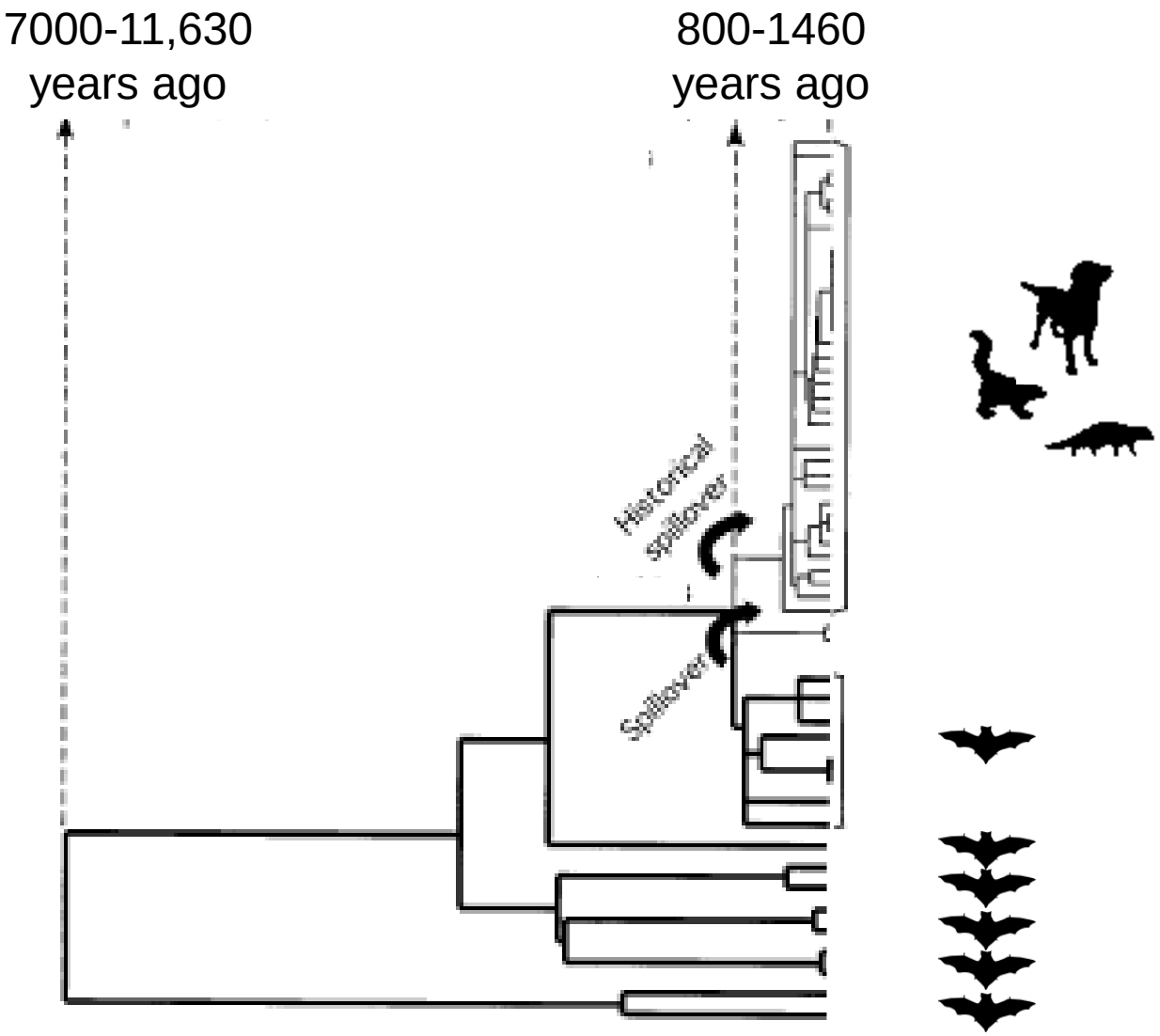
Bourhy *et al.*, JGV 2005

Lyssavirus phylogenetics



Banyard *et al.*, Adv. Virus Res., 2011

Lyssavirus phylogenetics



Badrane and Tordo, J Virol, 2001

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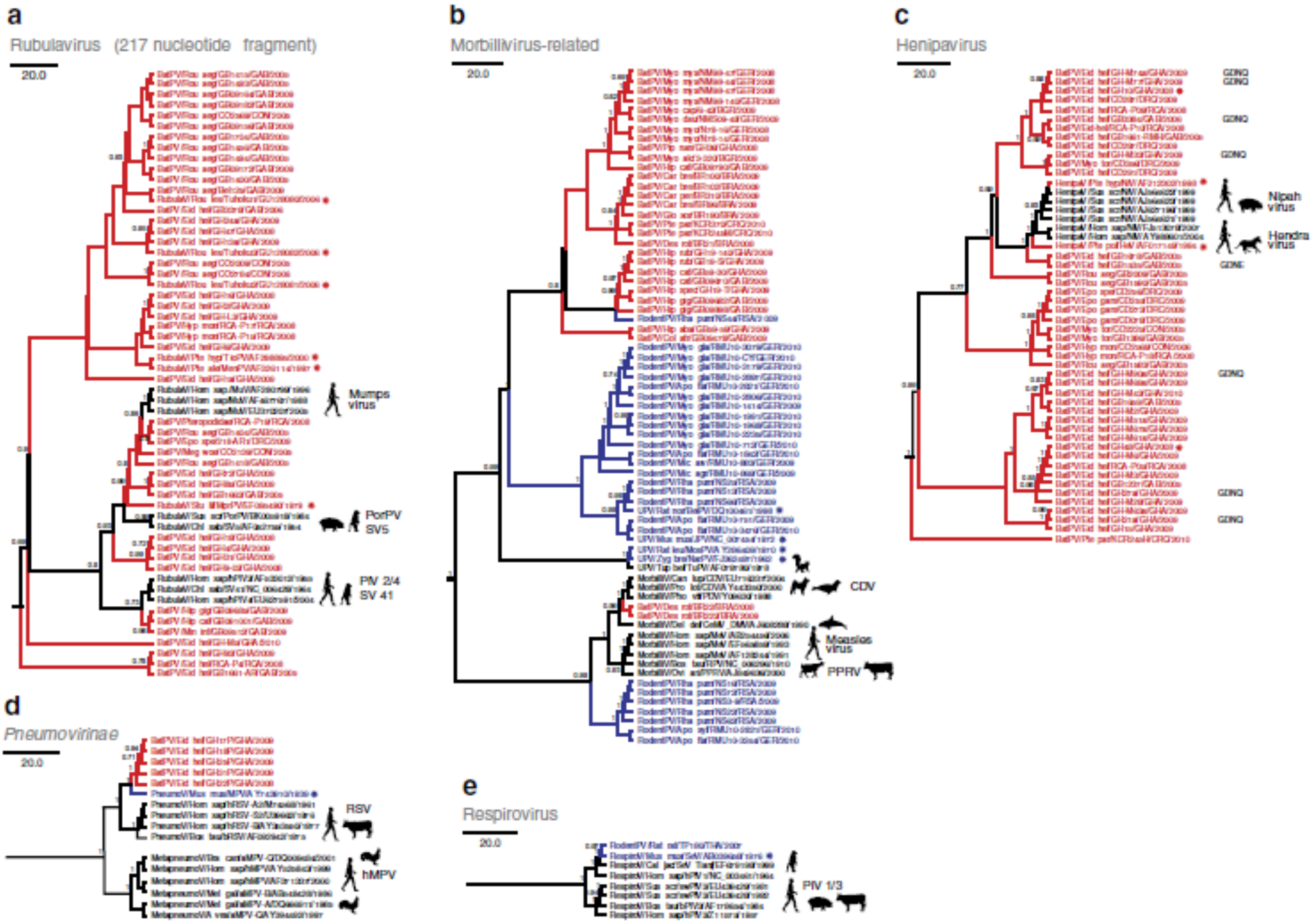
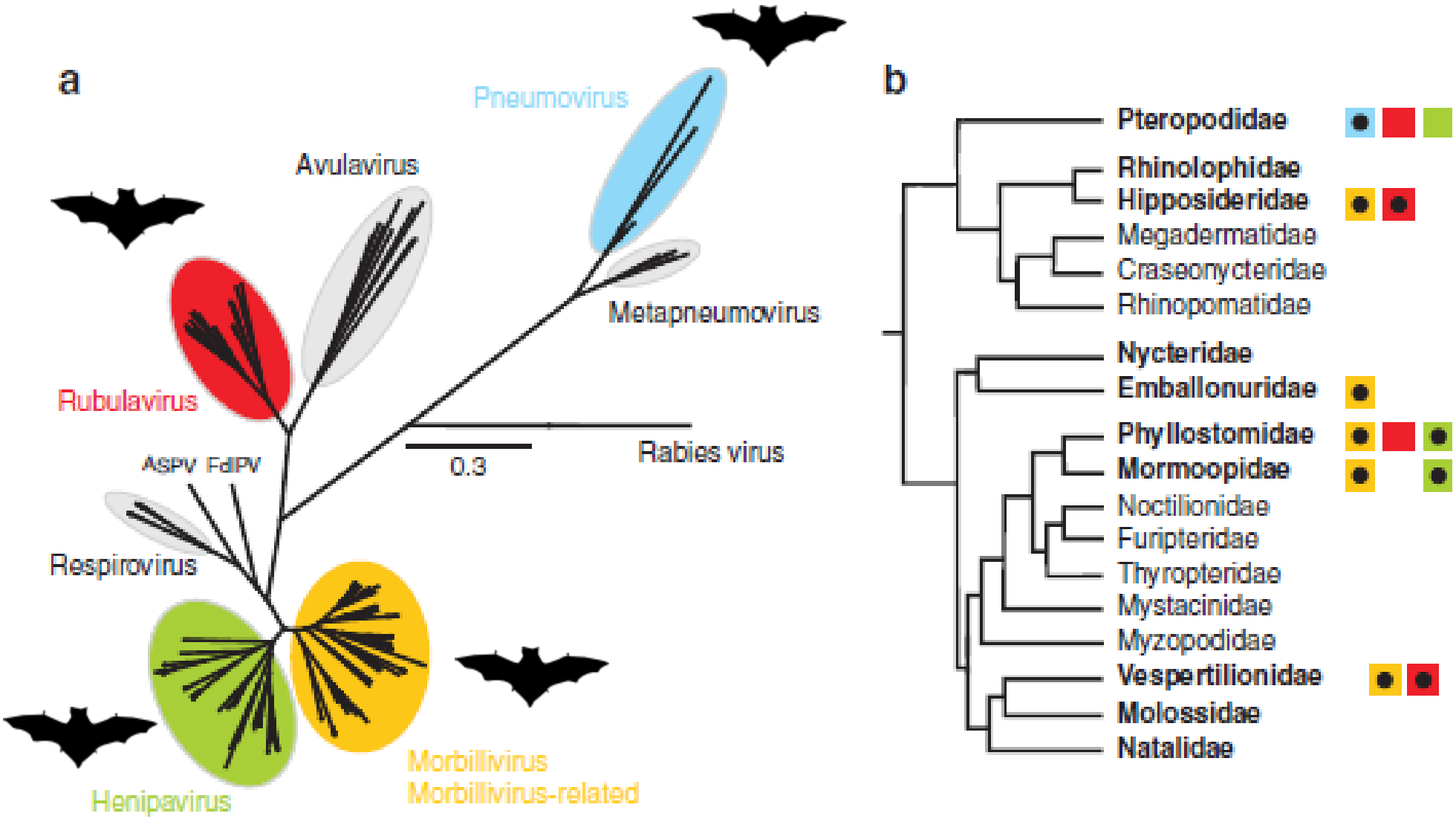


Drexler *et al.*, 2012 Nature Communications

Paramyxoviridae



Drexler *et al.*, 2012 Nature Communications

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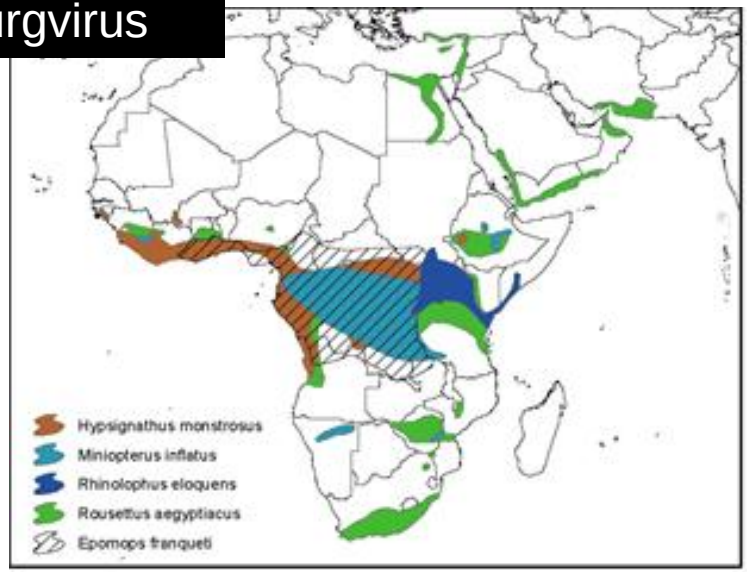
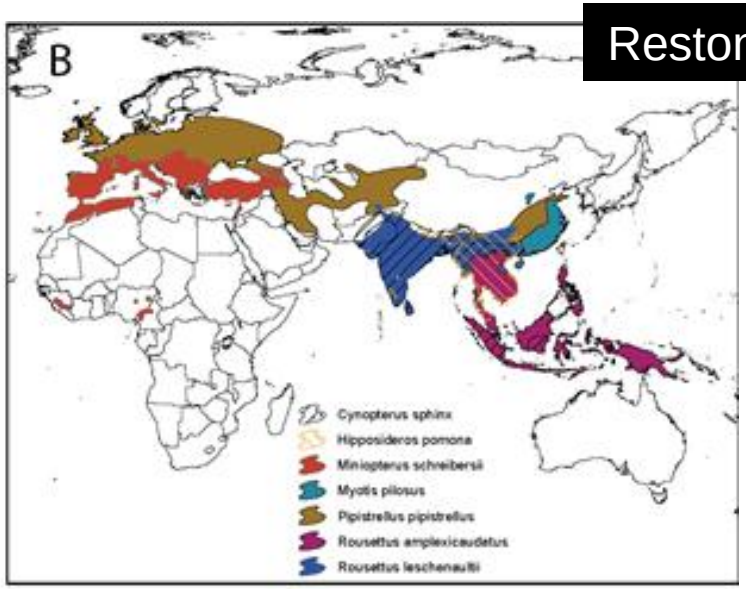
Metapneumovirus			
...			

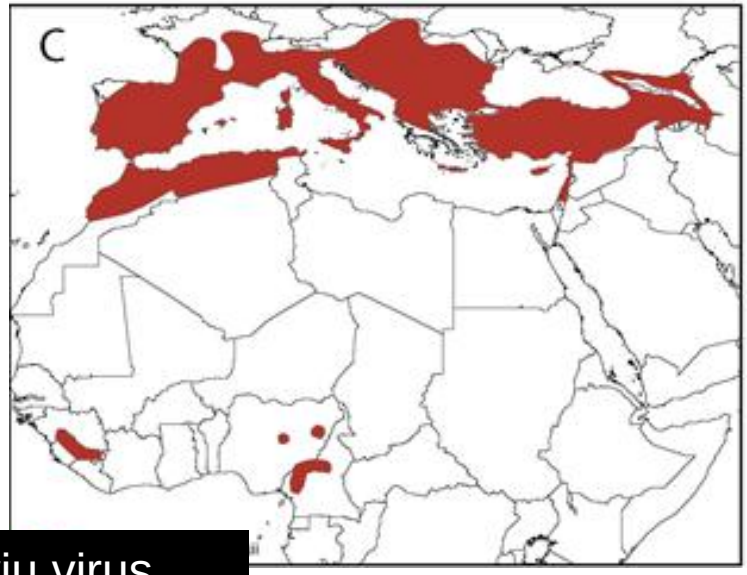
Distributions of species linked to filoviruses

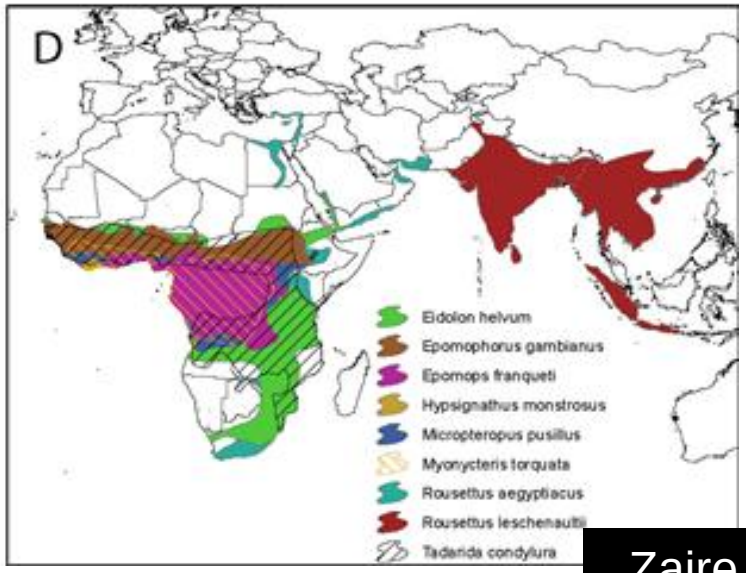
Marburgvirus



Reston ebolavirus







Lloviu virus

Zaire ebolavirus

Olival and Hayman, 2013 Viruses

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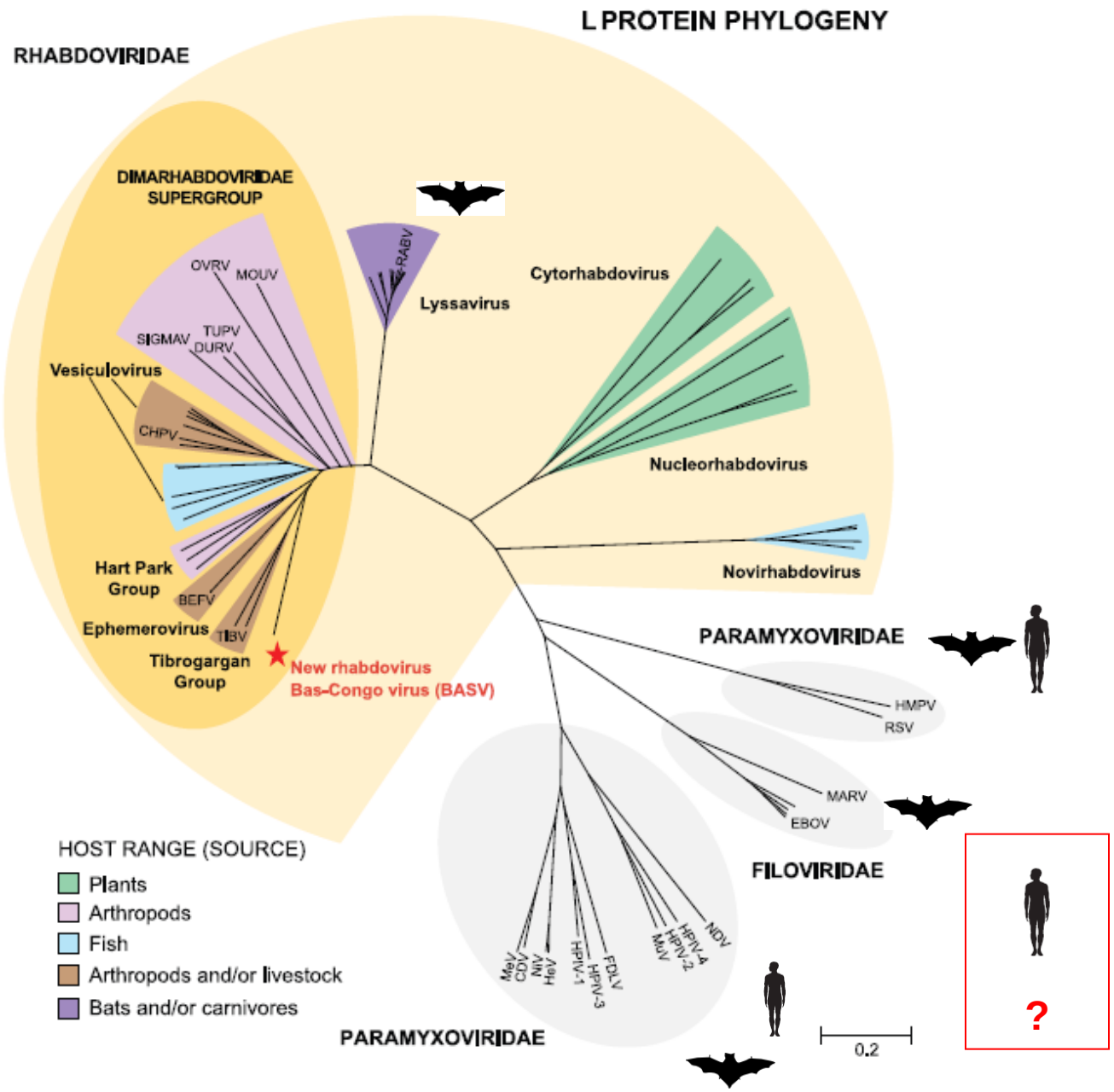
Henipavirus	...	*Cuevavirus*	
Pneumovirinae	...		
Metapneumovirus			
...			

Mononegavirales



Grard *et al.*, PLoS Pathoges, 2012

A matter of time?

Negative sense ssRNA viruses

Mononegavirales

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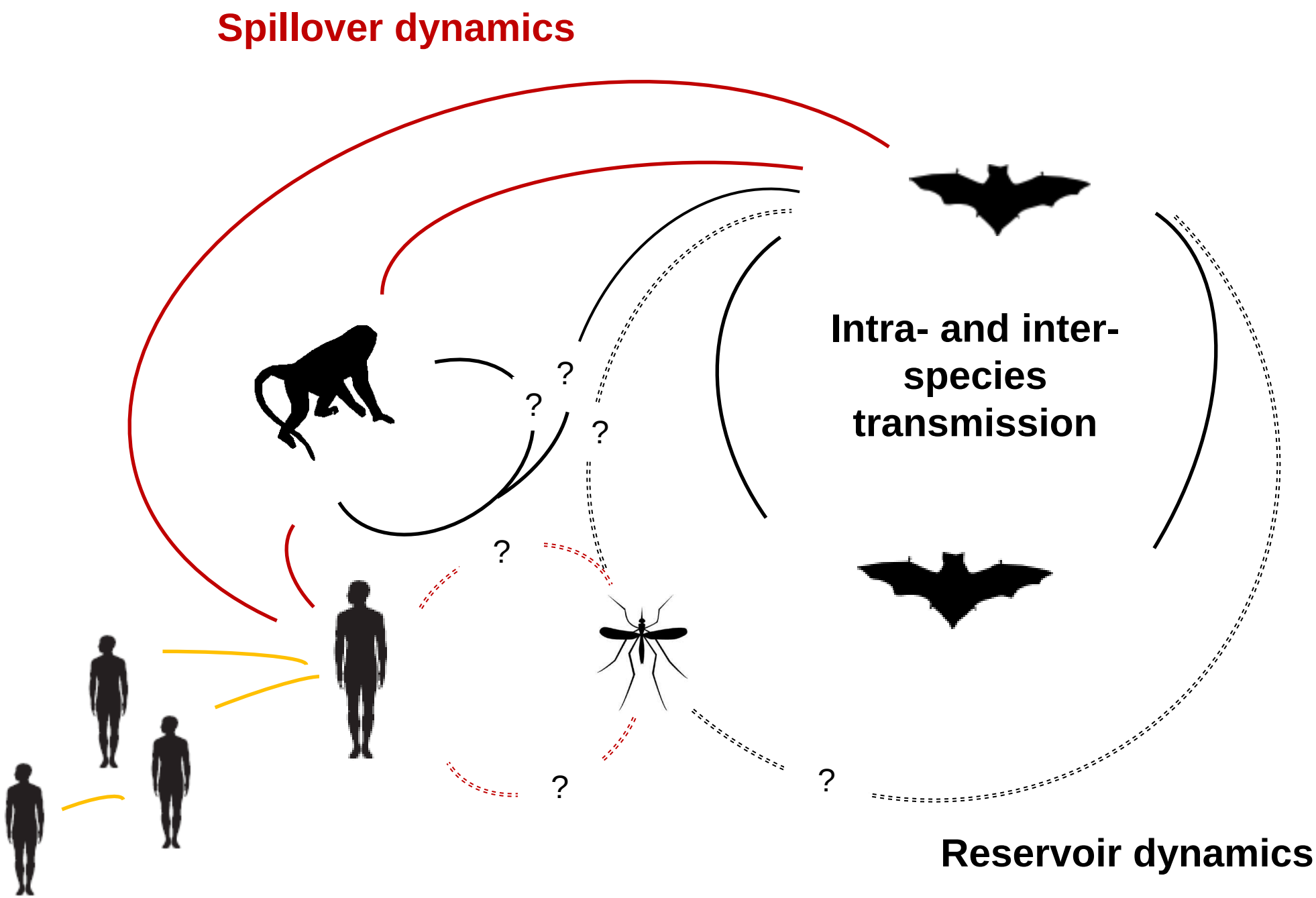
Henipavirus	***…***	***Cuevavirus***	
Pneumovirinae	***…***		
Metapneumovirus			
…			

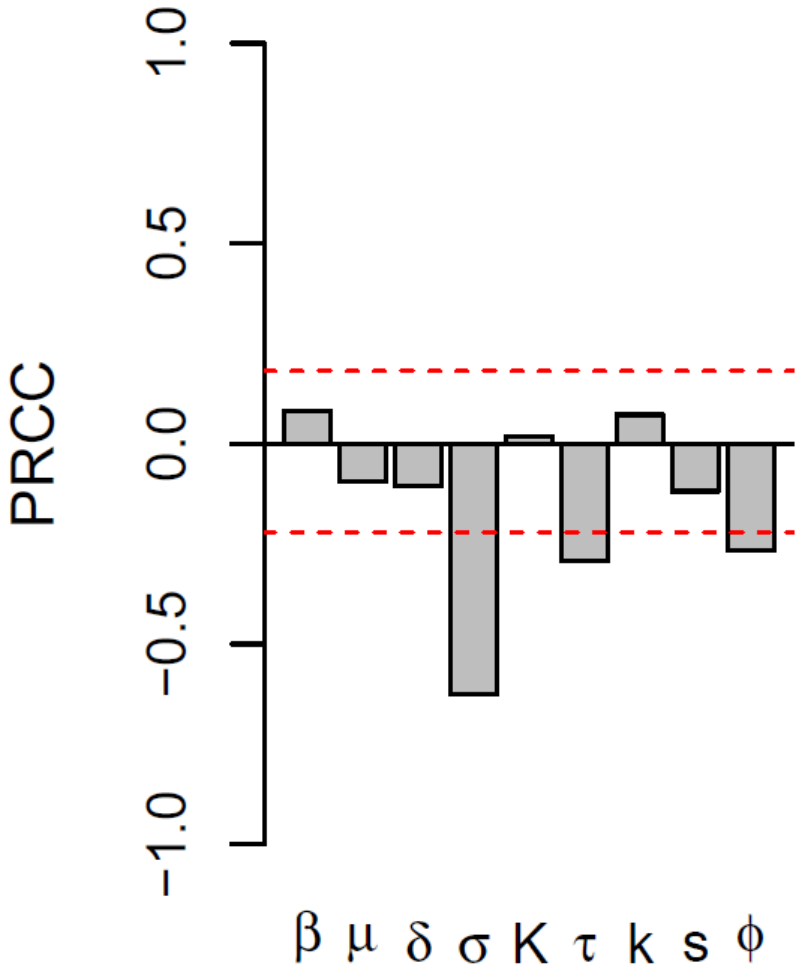
Questions

Marburgvirus transmission pathways



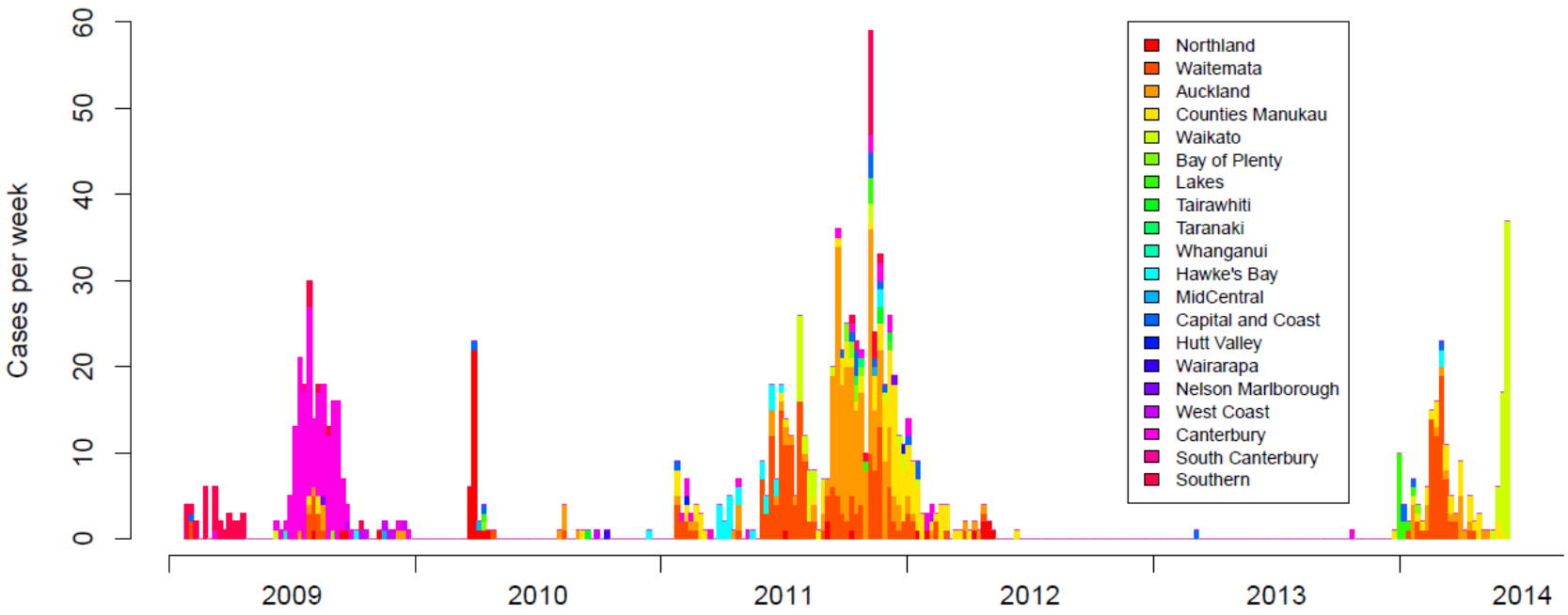
Olival and Hayman, 2013 Viruses

Sensitivity analyses



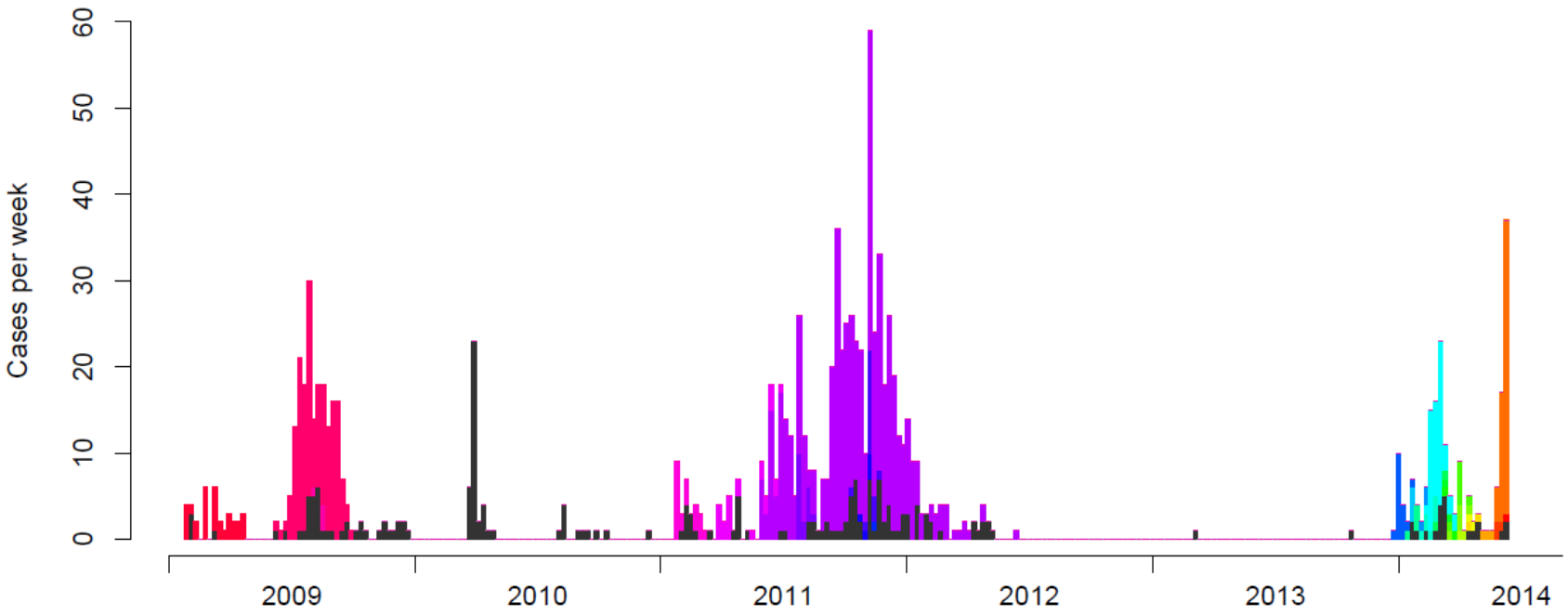
Hayman *et al.*, unpublished

New Zealand measles incidence



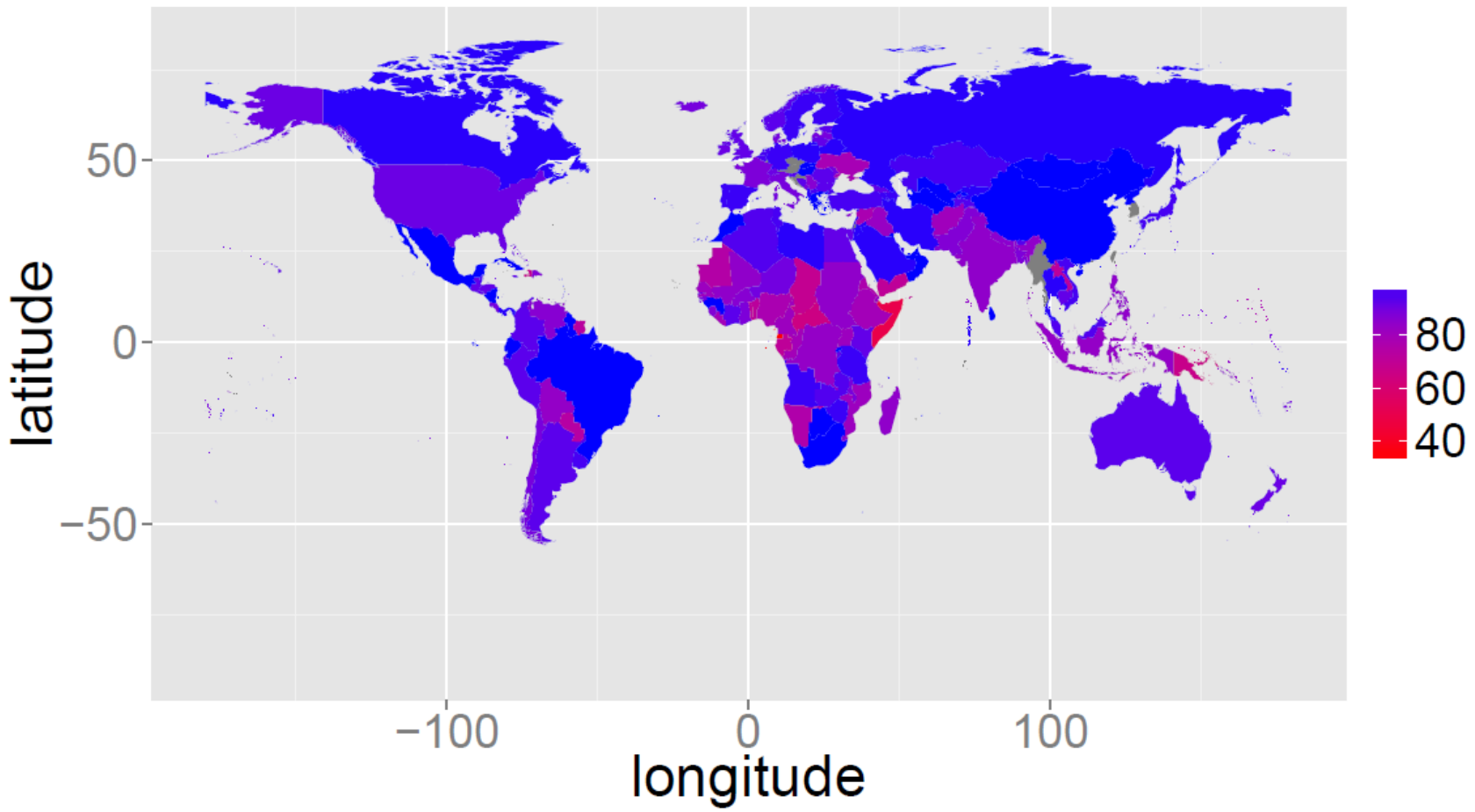
Hayman *et al.*, unpublished

New Zealand measles incidence



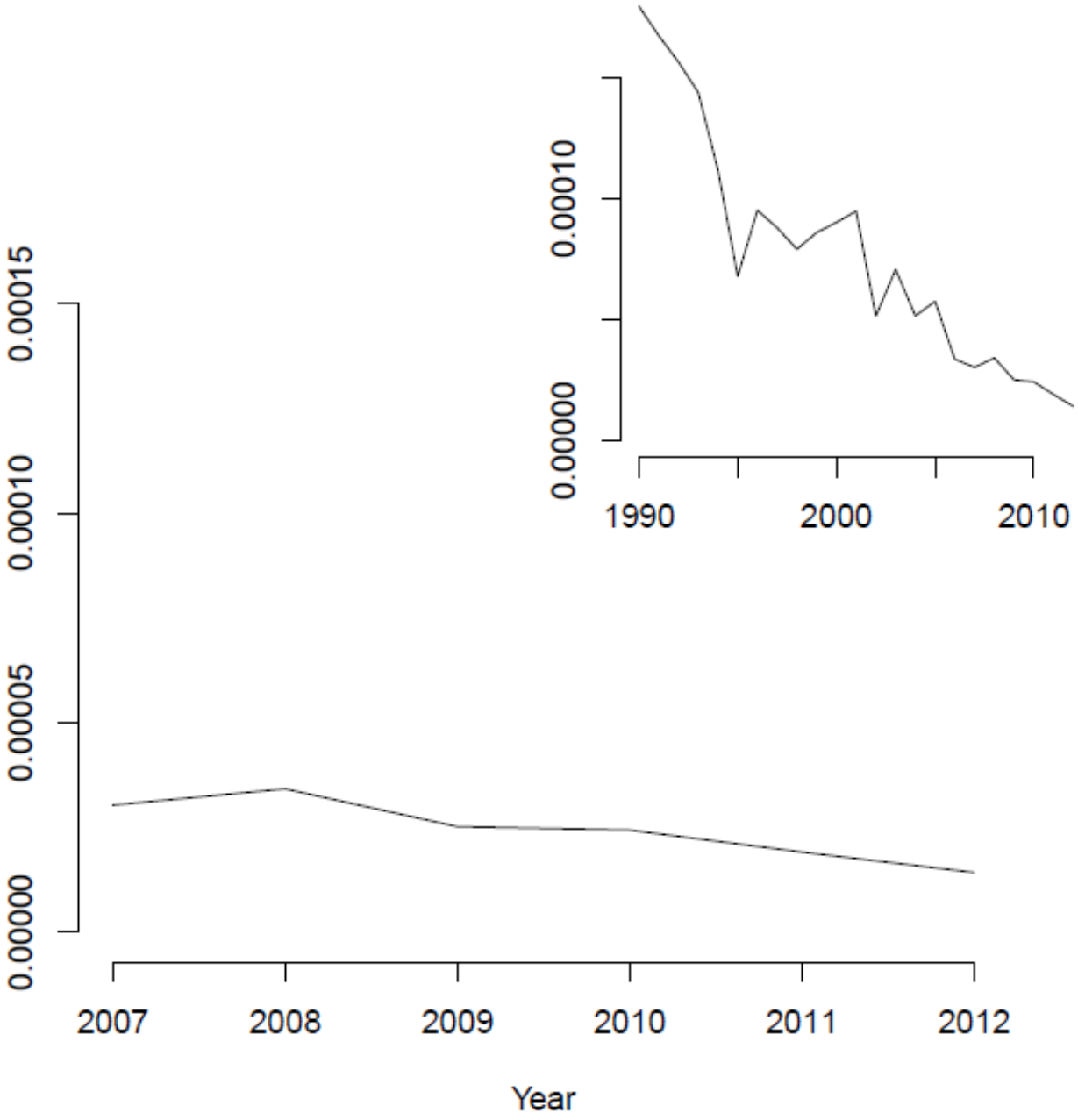
Hayman *et al.*, unpublished

Measles vaccination coverage (%), 2012

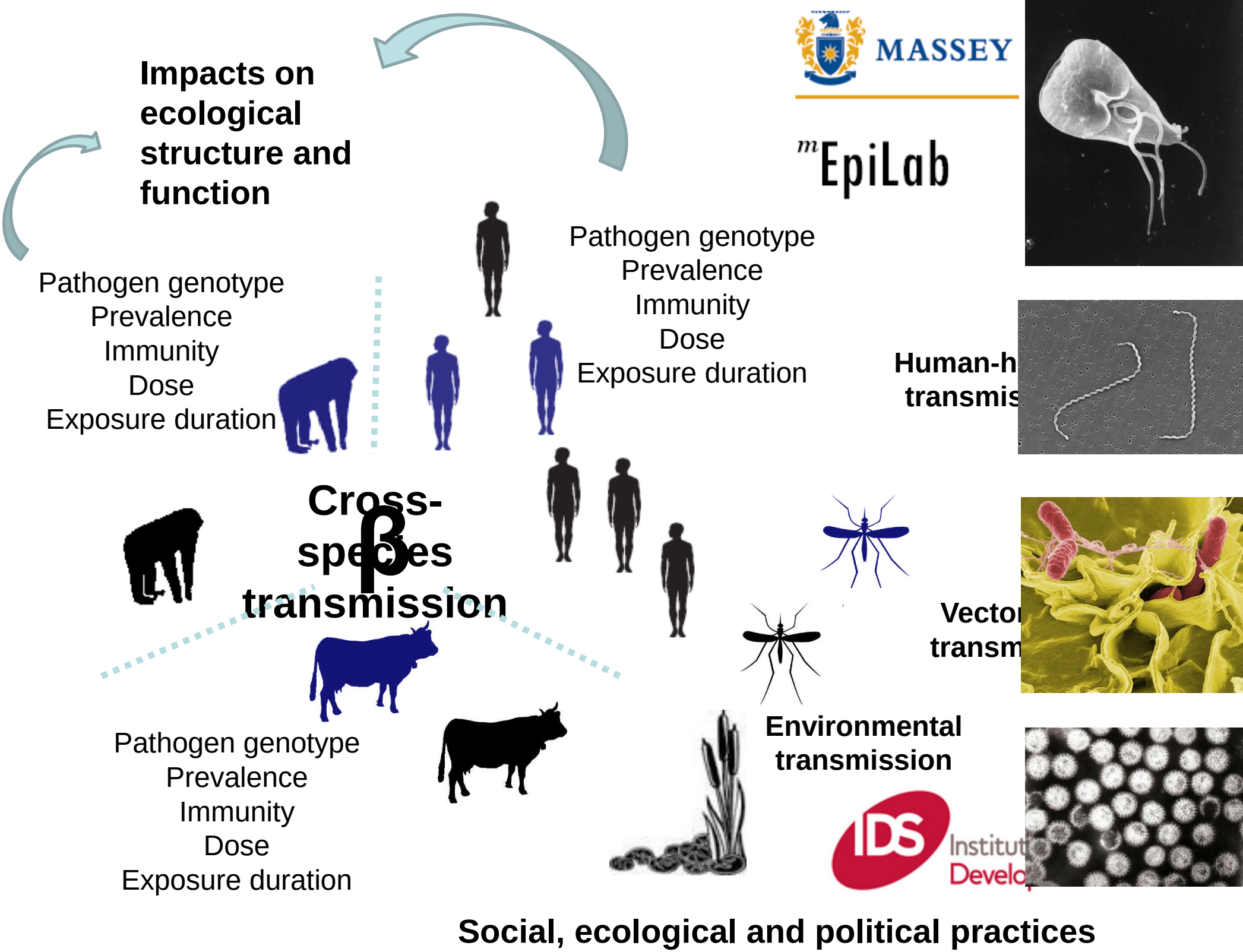


Hayman *et al.*, unpublished

Global trend in annual measles incidence



Hayman *et al.*, unpublished


Impacts on ecological structure and function
Pathogen genotype
Prevalence
Immunity
Dose
Exposure duration
Pathogen genotype
Prevalence
Immunity
Dose
Exposure duration
Cross-species transmission
β
Pathogen genotype
Prevalence
Immunity
Dose
Exposure duration
Environmental transmission
Social, ecological and political practices