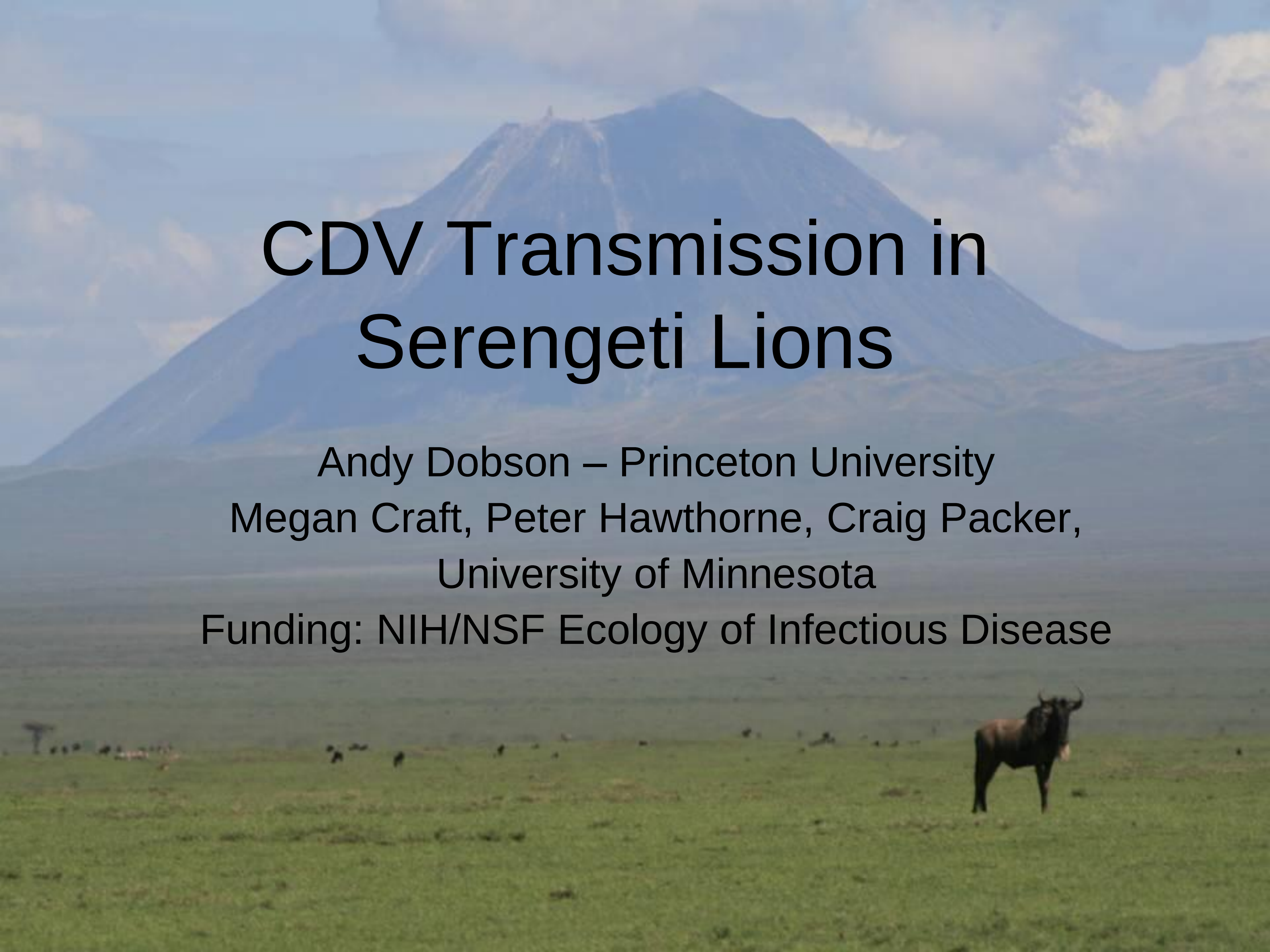
Multiple-parasites and multiple hosts:
What happens when we increase host and parasite diversity?

Andy Dobson, EEB, Princeton University – dobson@princeton.edu

Outline

- Pathogens with multiple hosts 1, CDV
  - Stochastic spatial short-term dynamics
- Hosts with multiple pathogens, CDV and CPV
  - More than SIR + SIR ….
- Pathogens with multiple hosts 2. RPV
  - Dynamics and impact
- Ecosystem level effects of pathogens

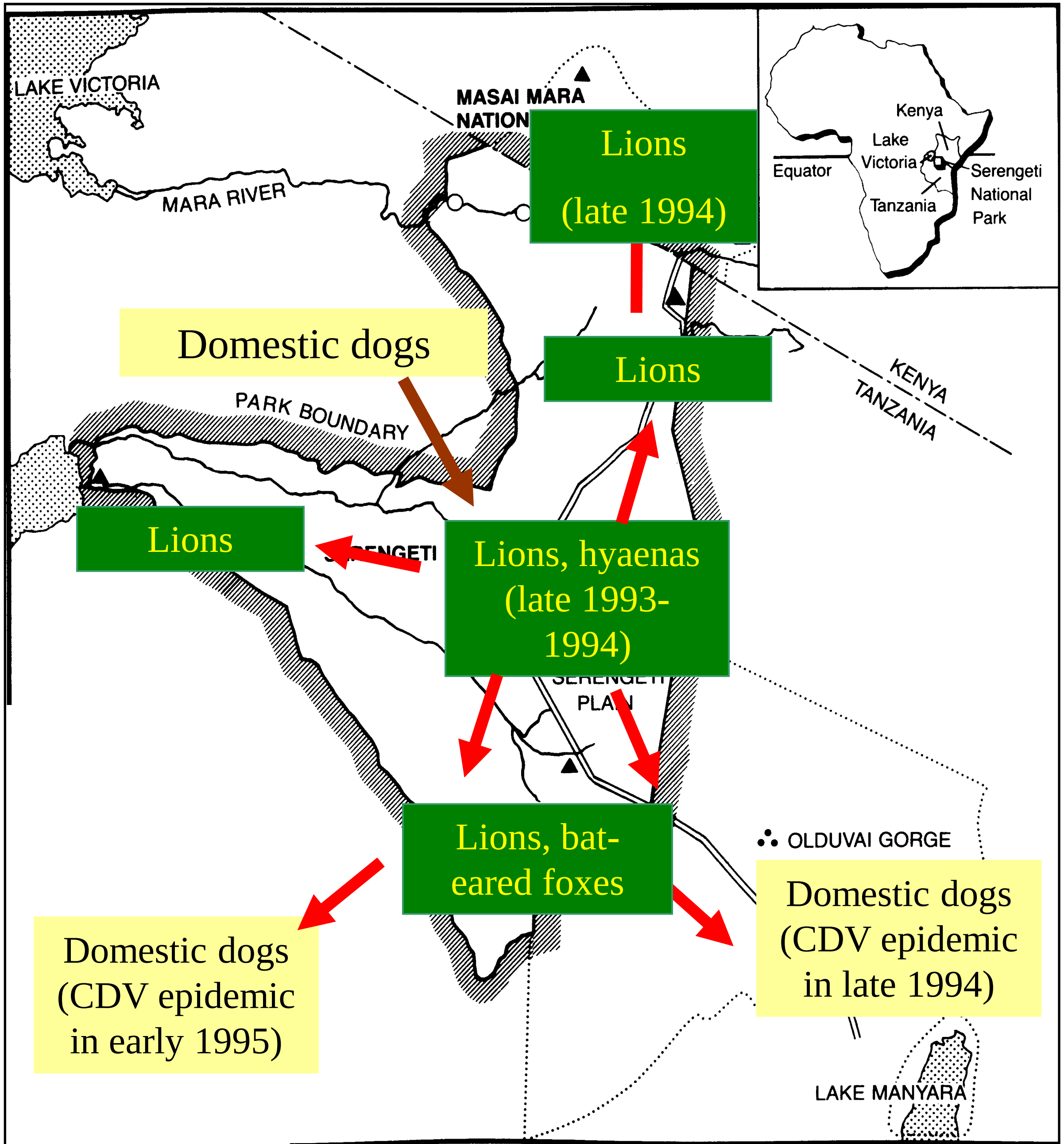


CDV Transmission in Serengeti Lions

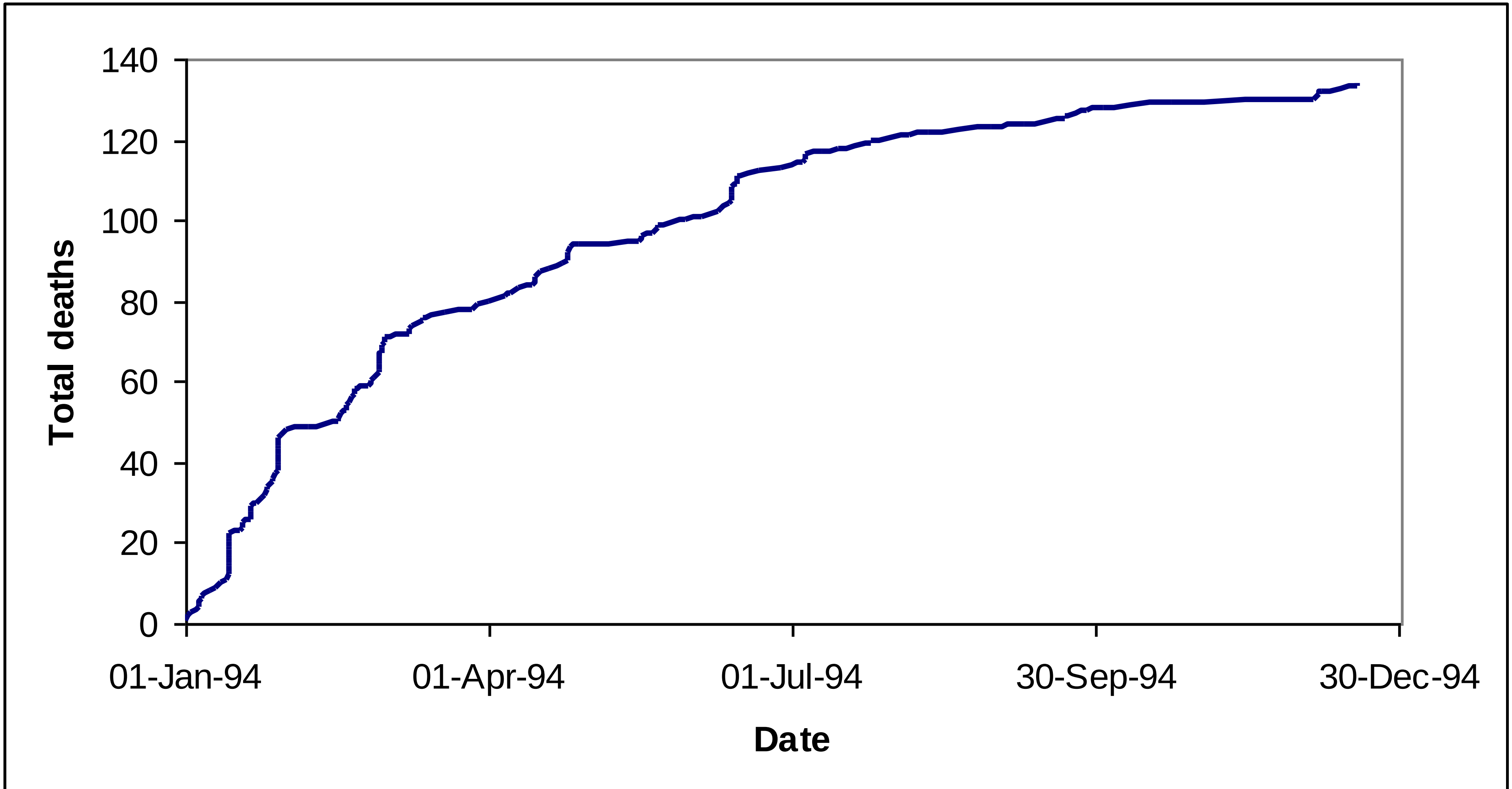
Andy Dobson – Princeton University
Megan Craft, Peter Hawthorne, Craig Packer,
University of Minnesota
Funding: NIH/NSF Ecology of Infectious Disease

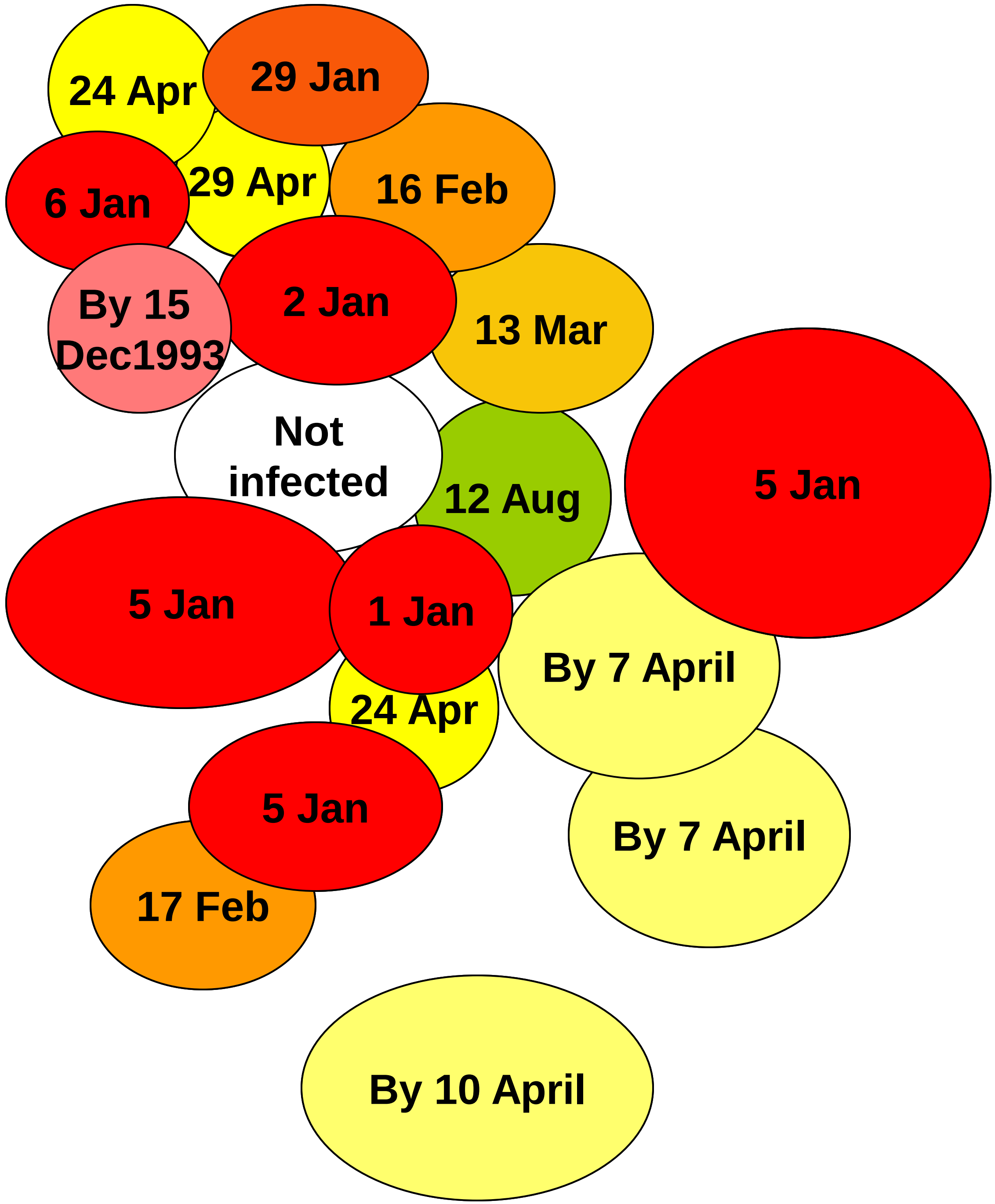
Ray & Annika Hilborn

Spread of CDV during 1994 epidemic



Serengeti 1994: Overall mortality

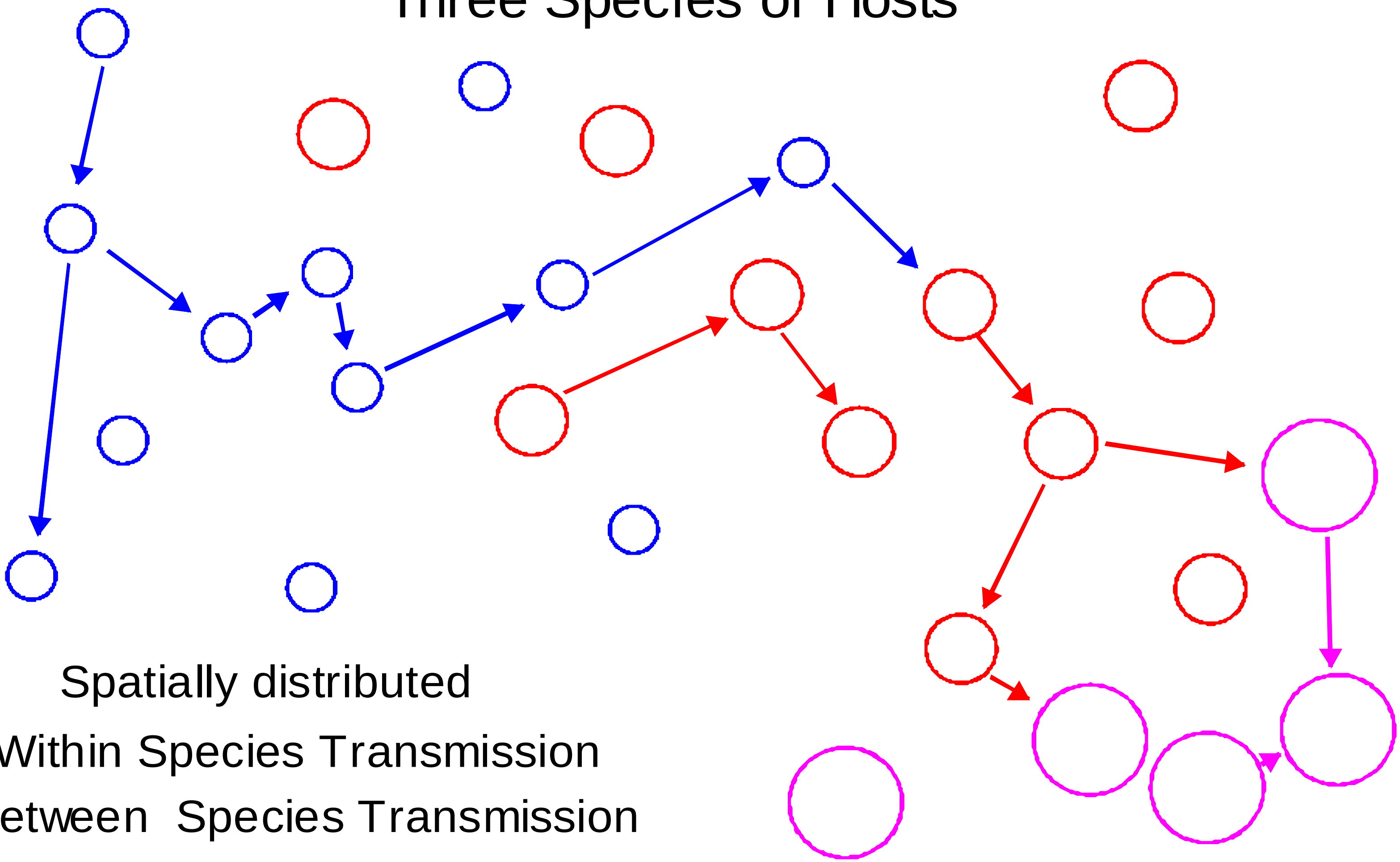




Canine Distemper Epidemic in Serengeti Lion Population (Craft, Packer et al, In prep)

A cartoon of the talk.....

Three Species of Hosts



Spatially distributed

Within Species Transmission

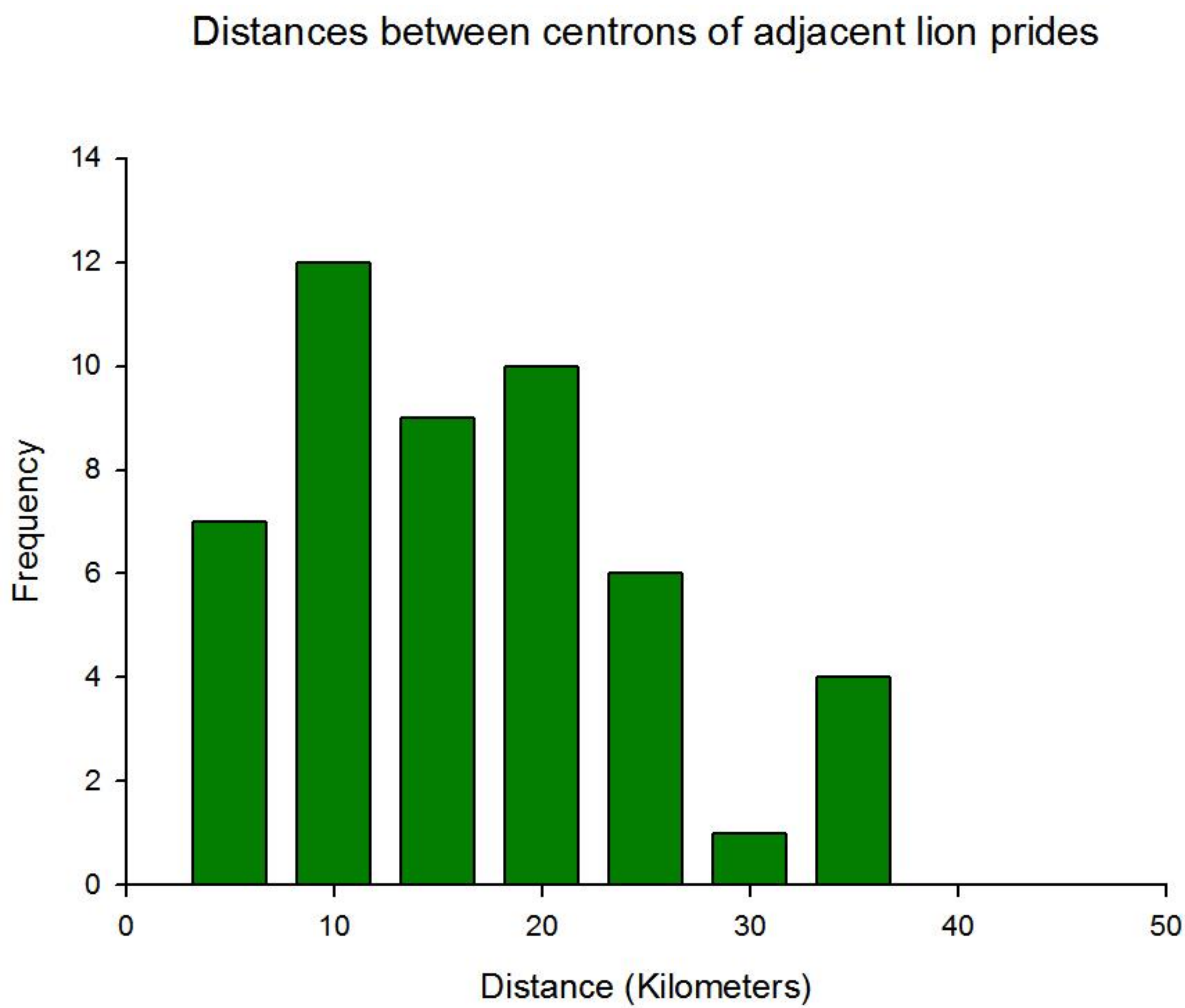
Between Species Transmission

Social, lives in big groups, commutes over large distances

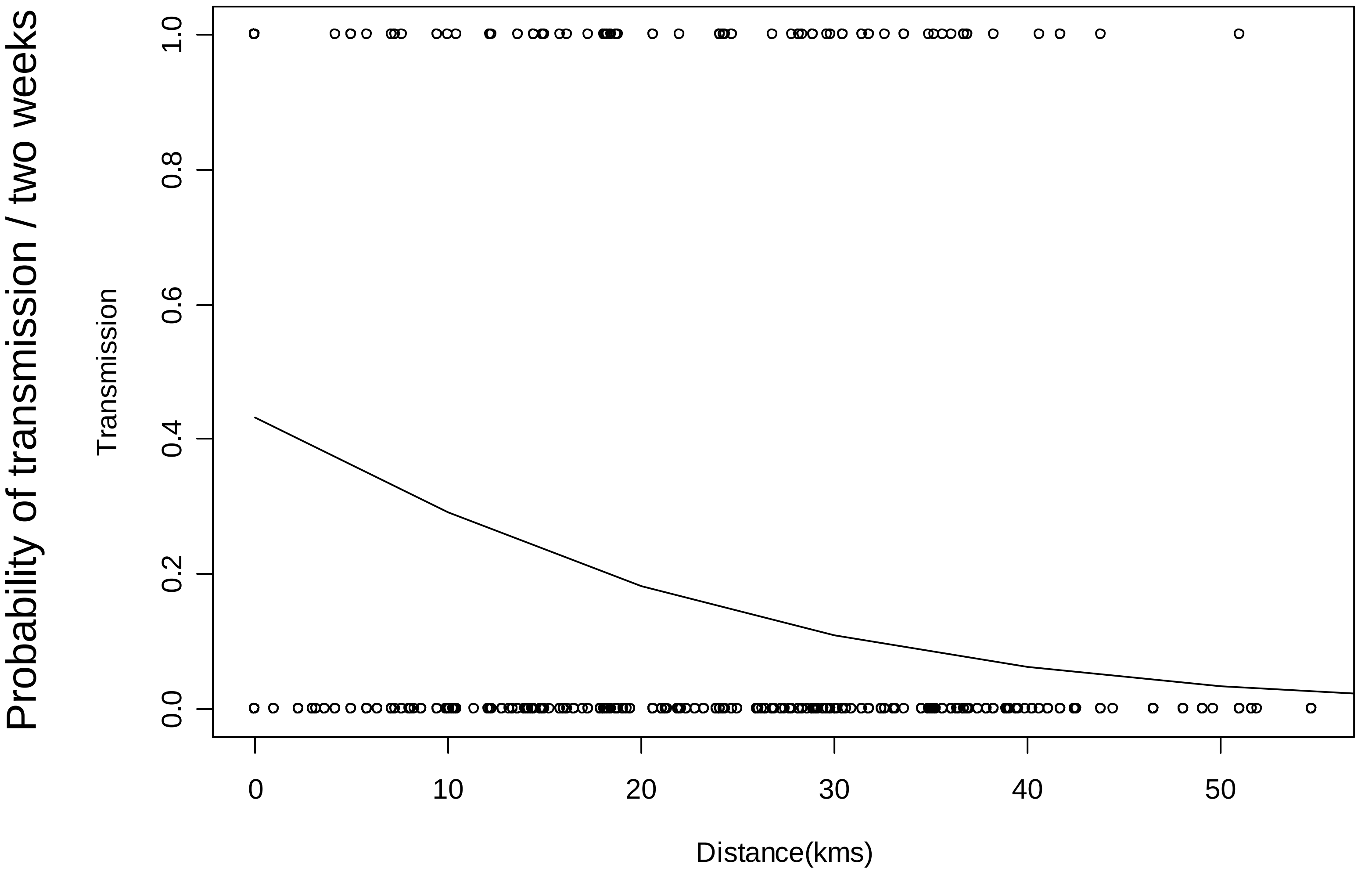
Small family groups that interact only occasionally

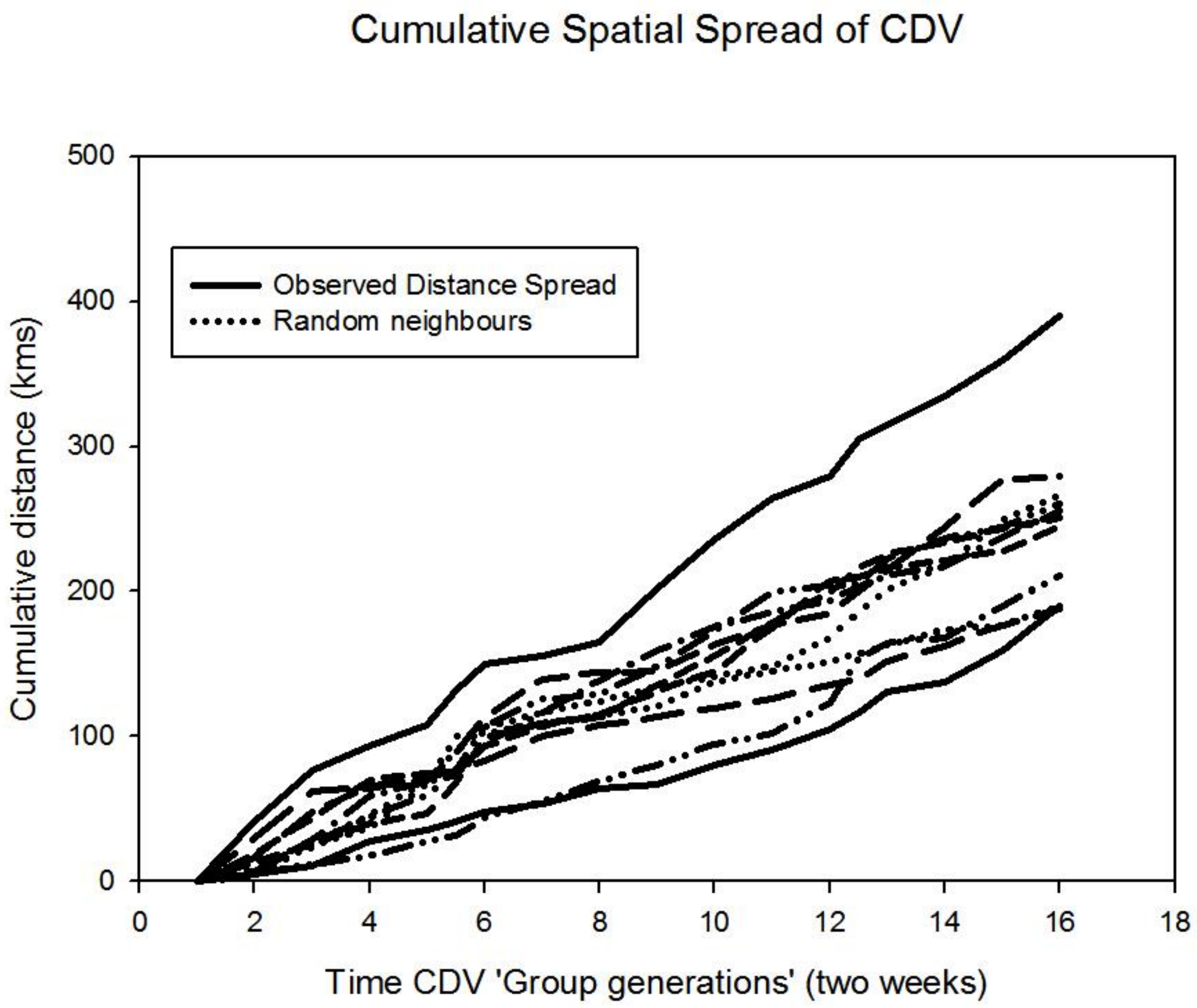
Territorial pairs with young, little between group interactions – scavenge at kills

Back to the lions…


Distances between centrons of adjacent lion prides
Frequency
0
2
4
6
8
10
12
14
0
10
20
30
40
50
Distance (Kilometers)

Transmission kernal





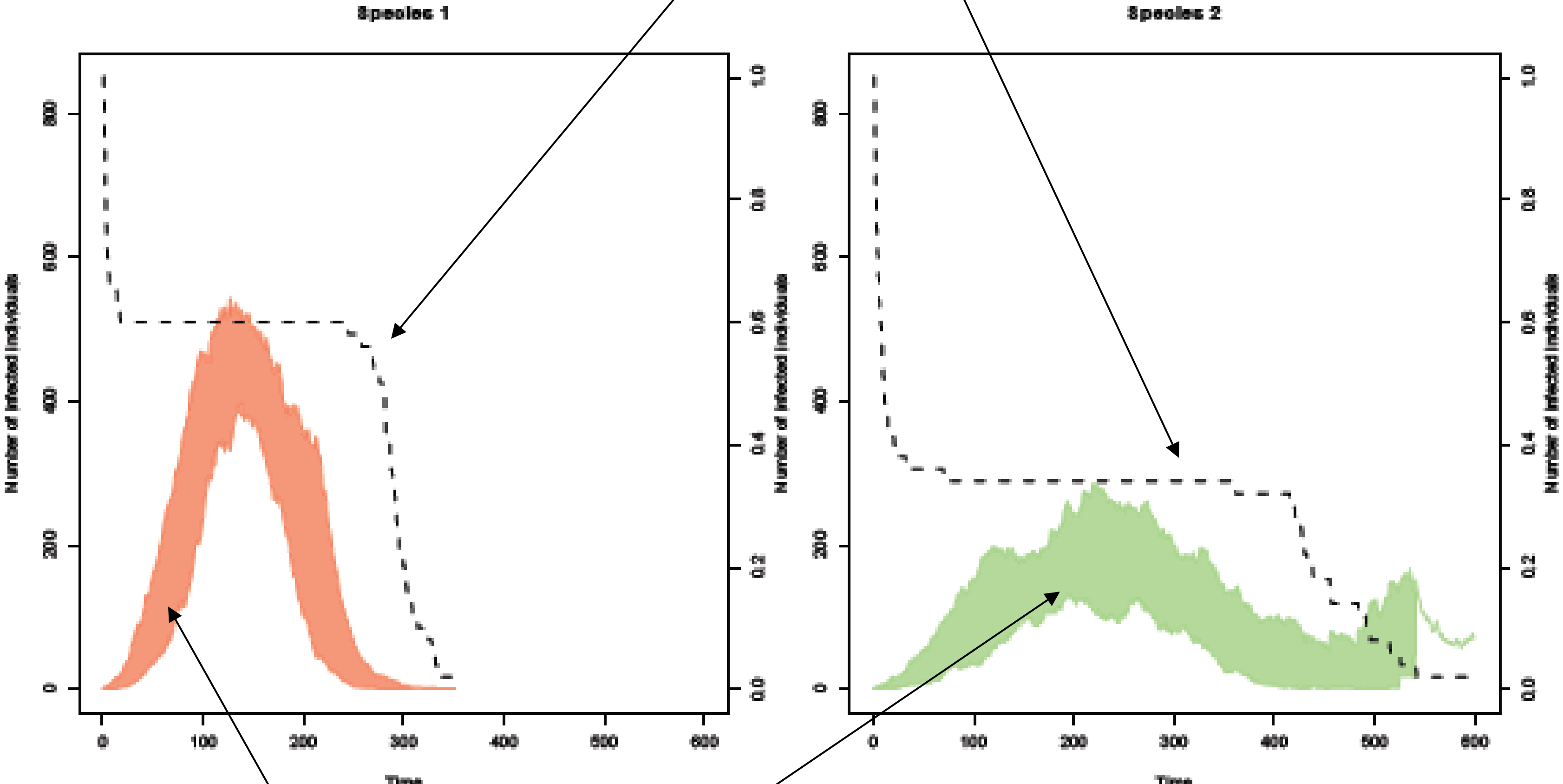
Also – only 40% of jumps between adjacent slides

Make a stochastic spatial model

- Assume the Serengeti is roughly square and contains 25x25 lion territories.
- Assume three types of hosts with different social systems defined by transmission within-in and between territories: lions, hyaenas, jackals
- Look at temporal and spatial properties of epidemic outbreaks in1,2, and 3 species.

Epidemic outbreaks in viable hosts

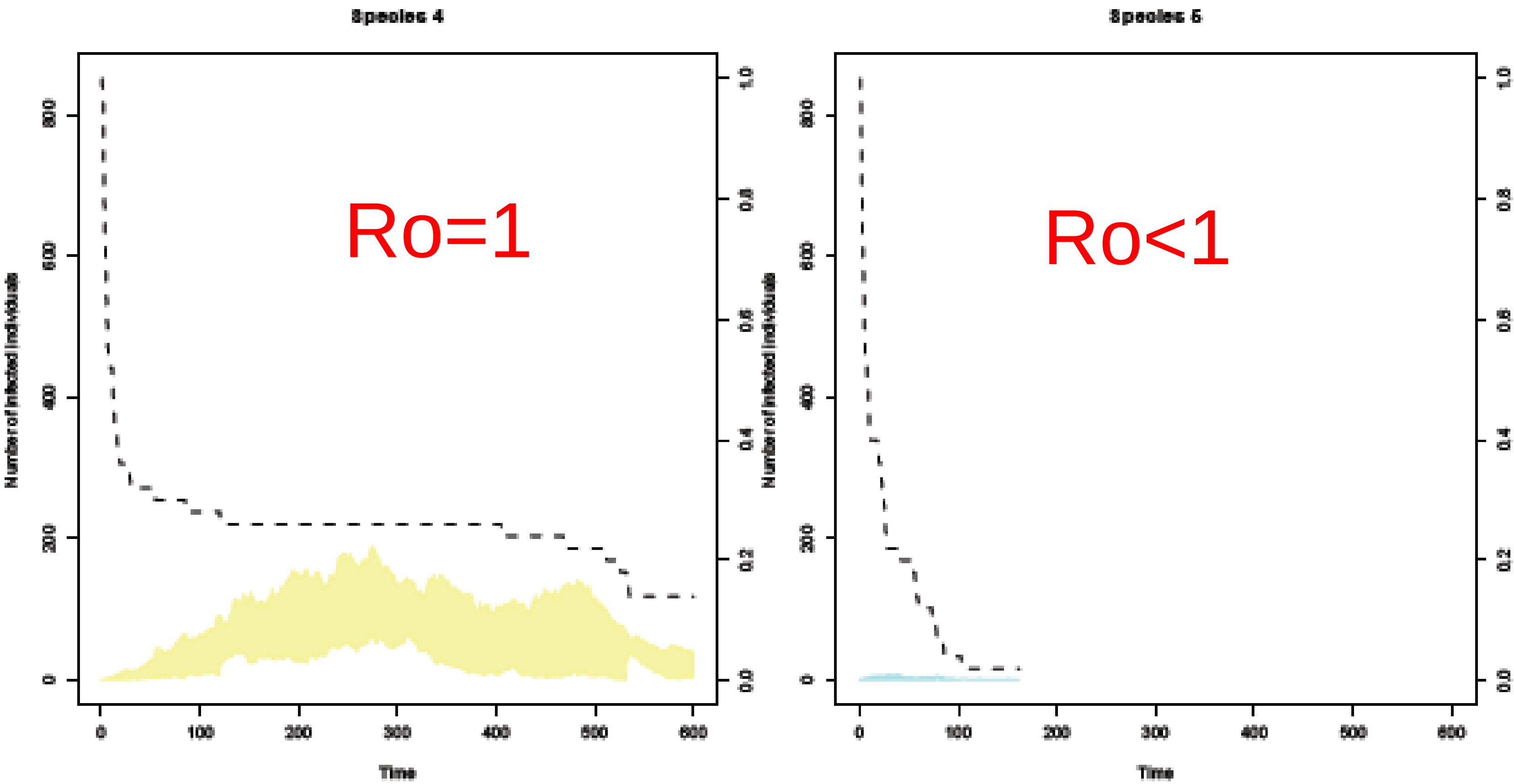
Number of patches containing an infected individual



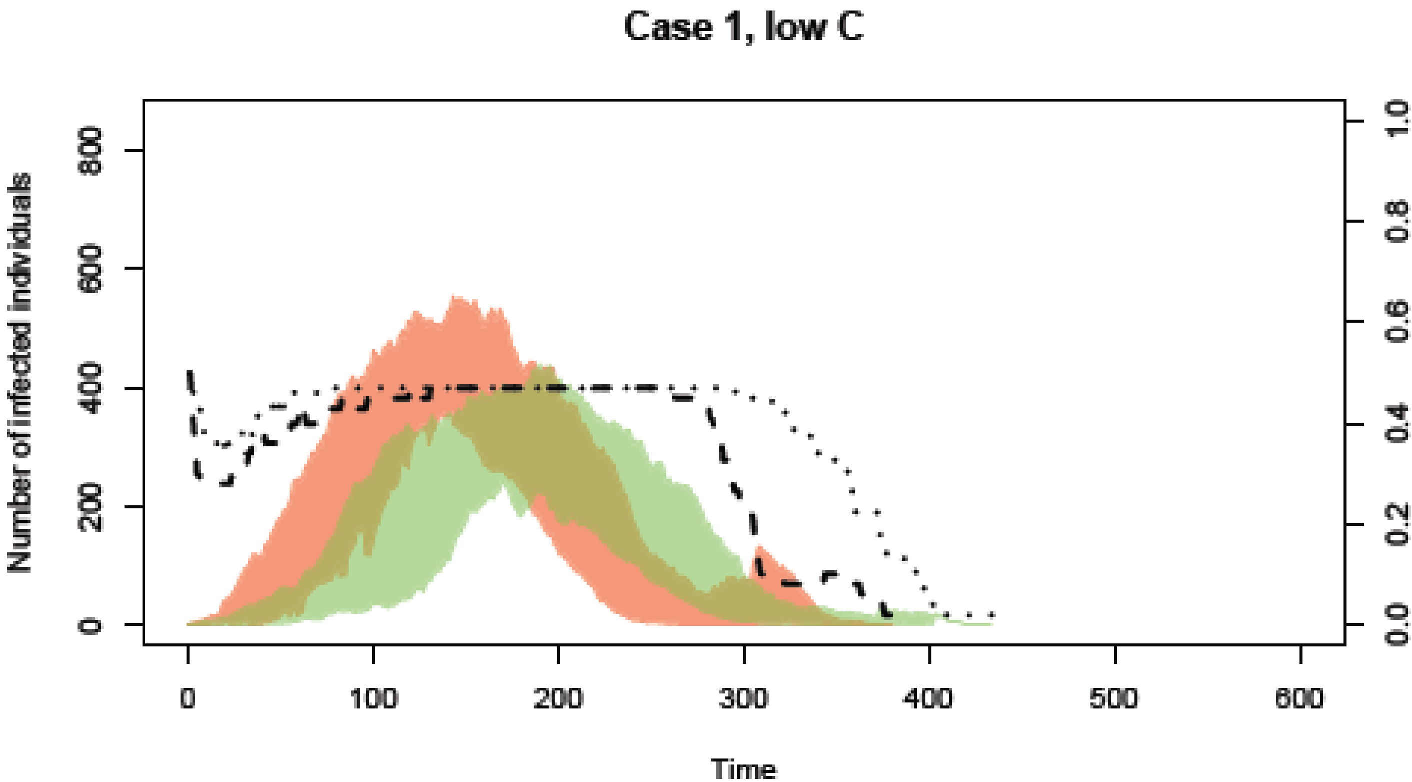
Number of individuals infected

50 replicates on 25X25 grid

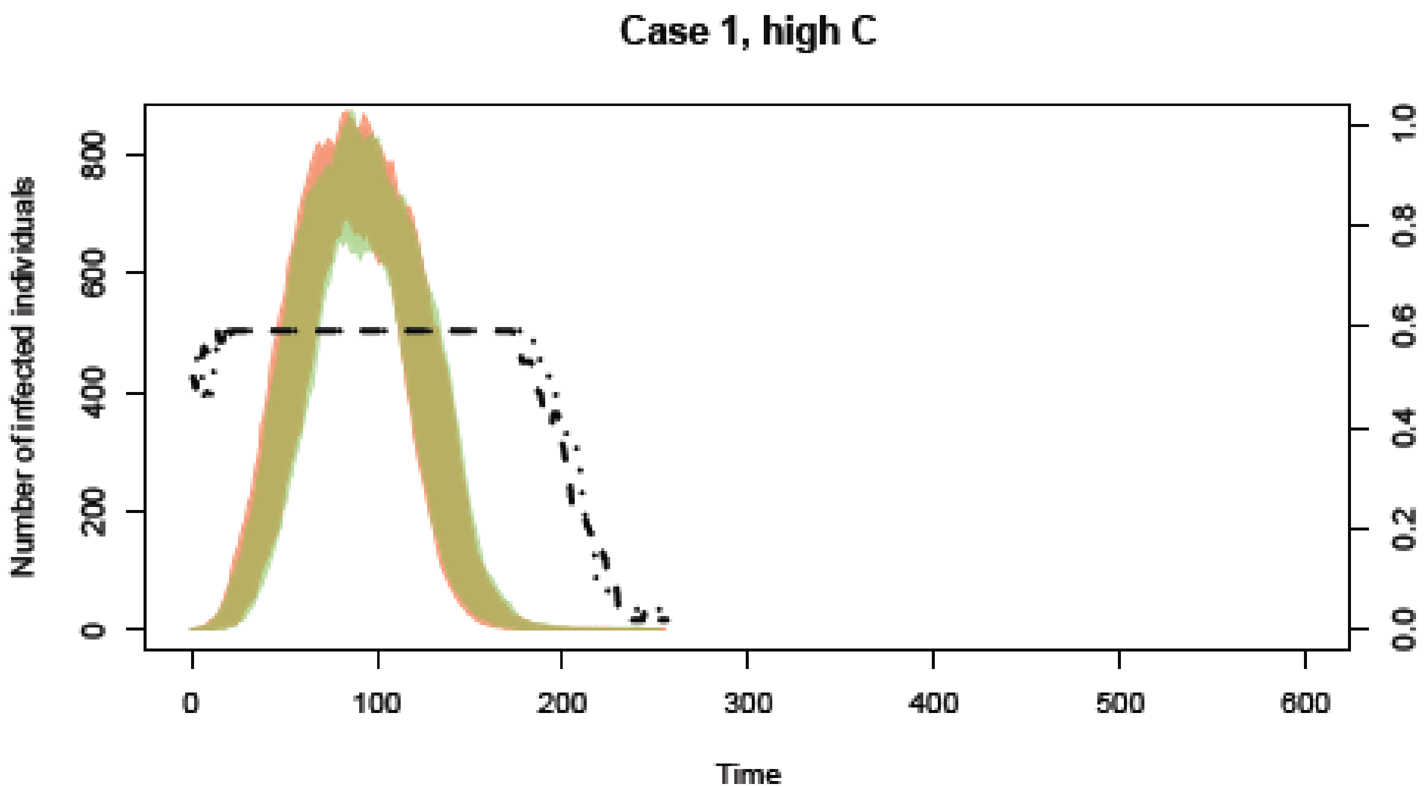
Epidemics in less viable hosts



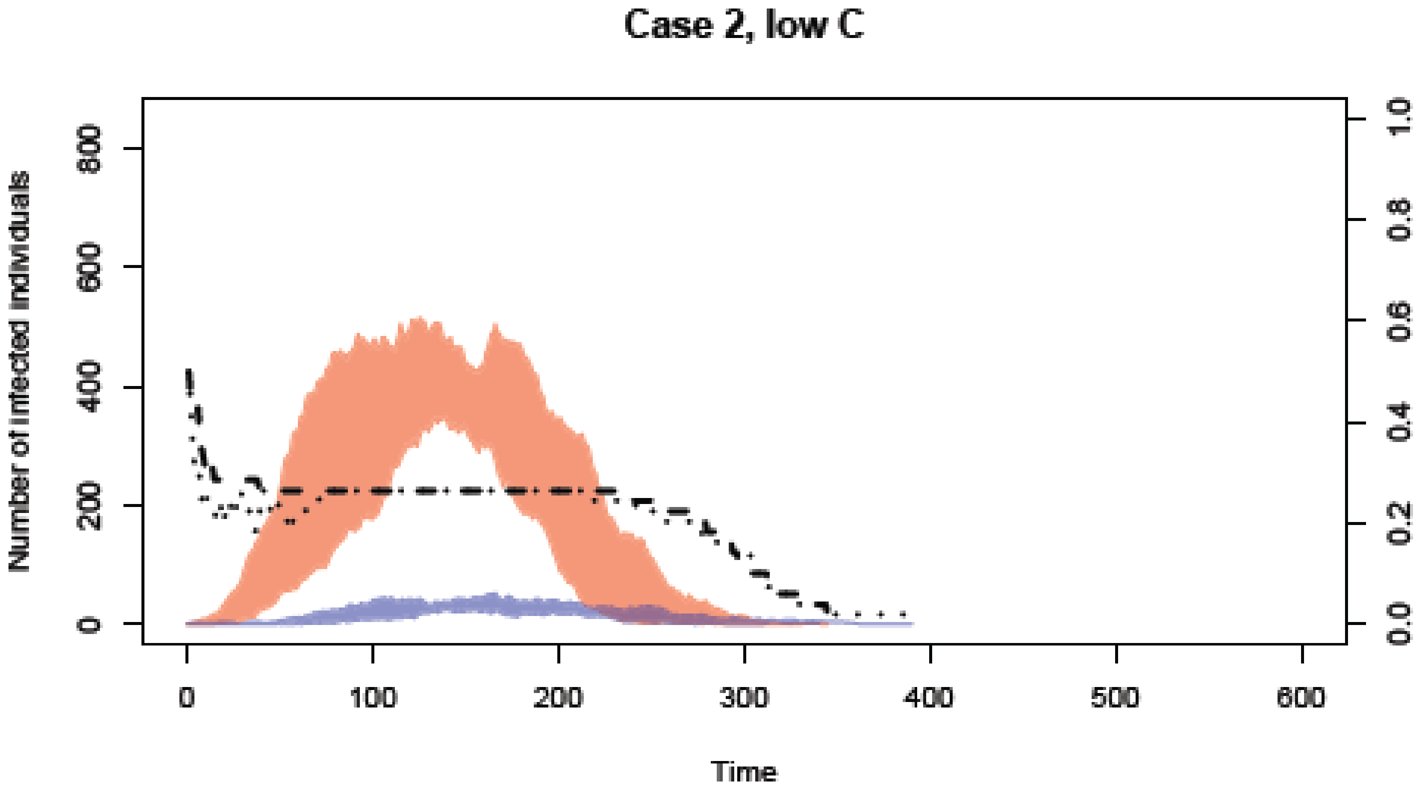
Mixed Species Epidemics
1% between species transmission



Mixed Species Epidemics
50% between species transmission

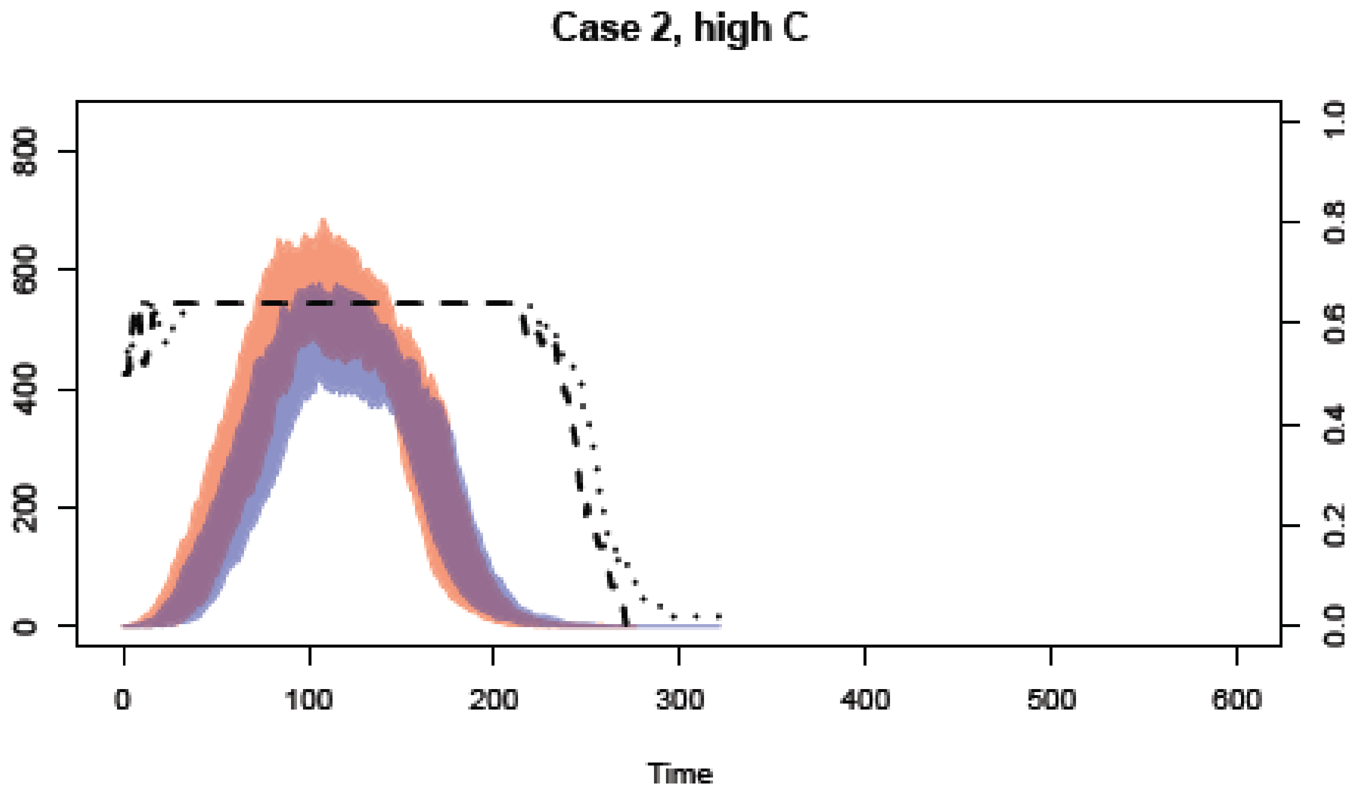


Mixed Species Epidemics
1% between species transmission



Pathogen can now persist in non-viable host

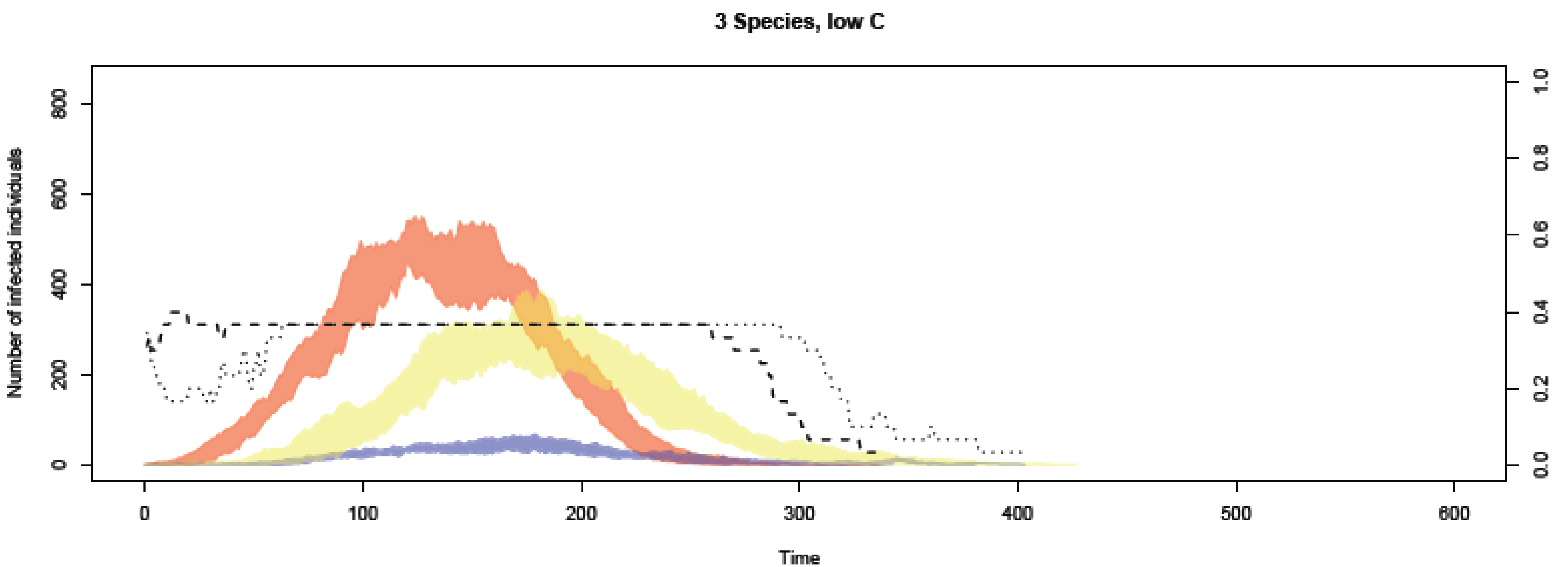
Mixed Species Epidemics
50% between species transmission



Second species can even create epidemic in non-viable species

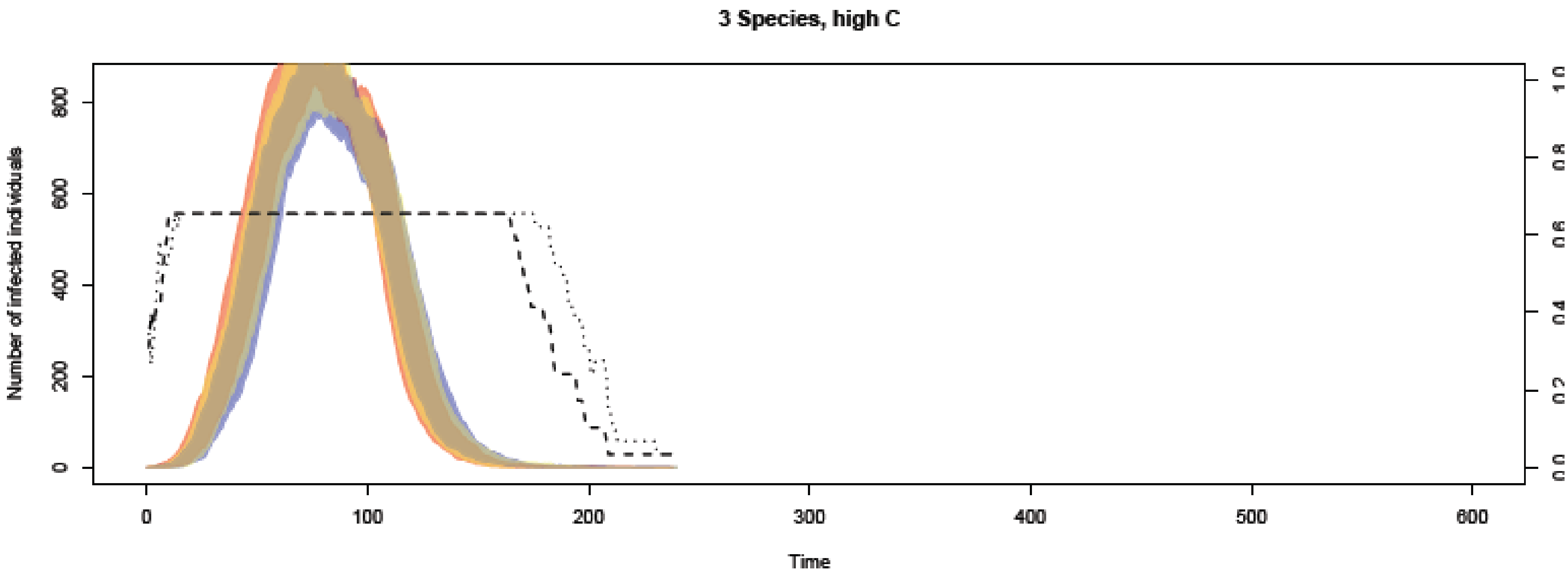
Three species epidemics….

1% between species transmission…

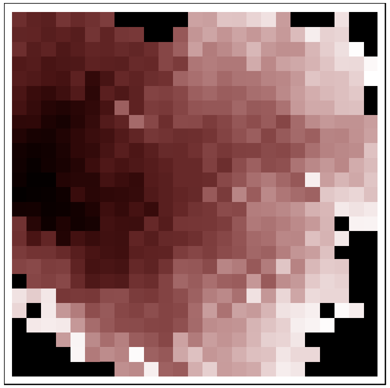


Three species epidemics….

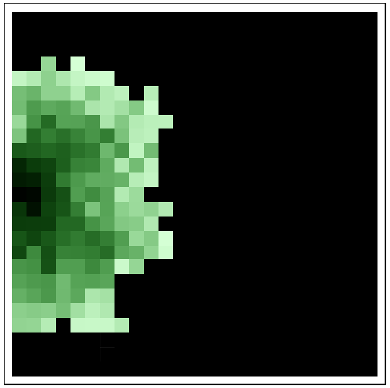
50% between species transmission…



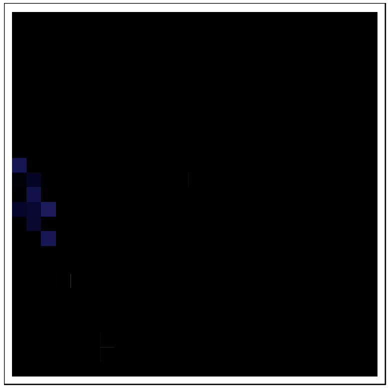
Spatial Plots: Single Species



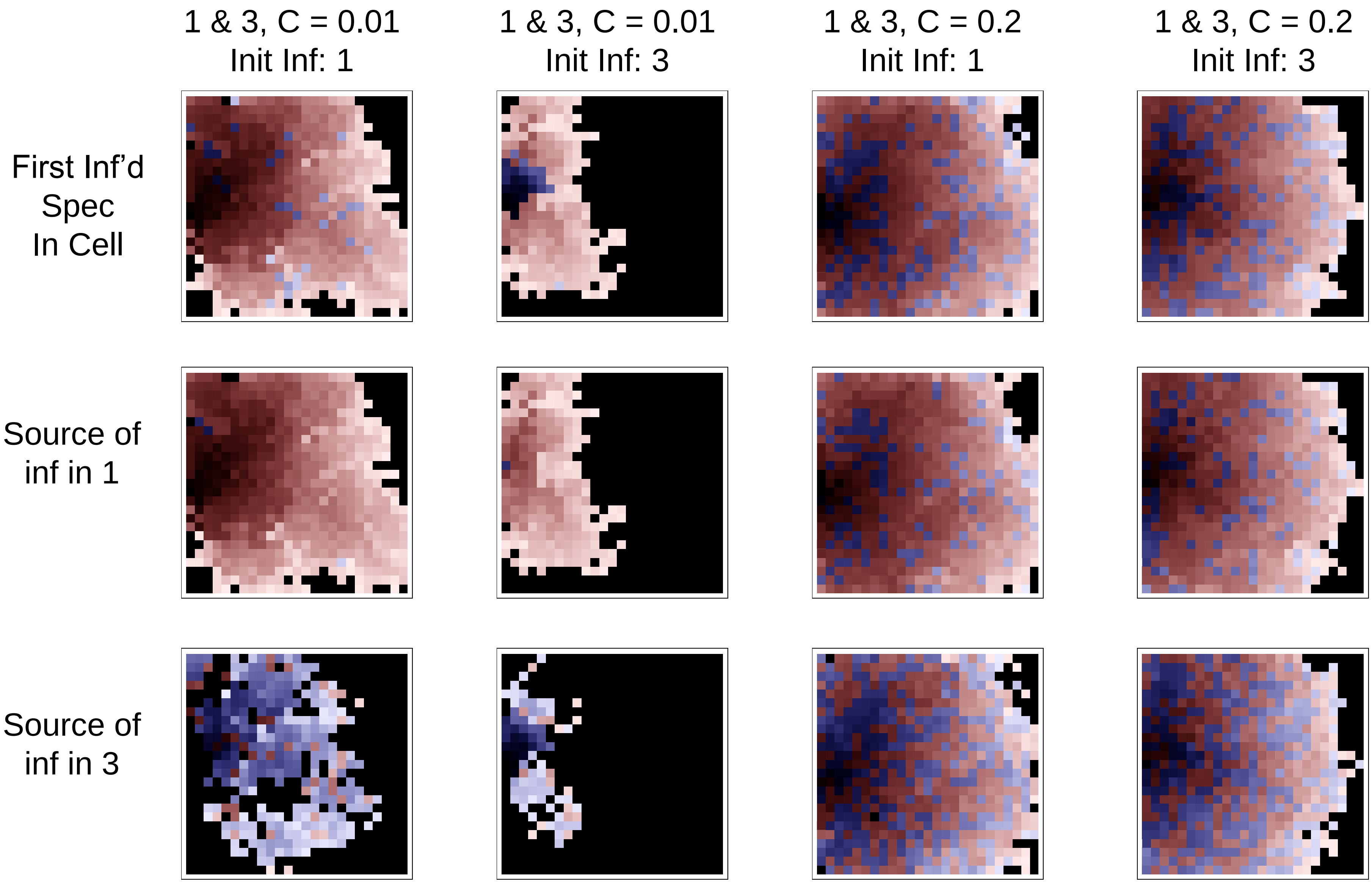
Species 1:
R_0 Local: 1.1
R_0 Neigh: 1.1

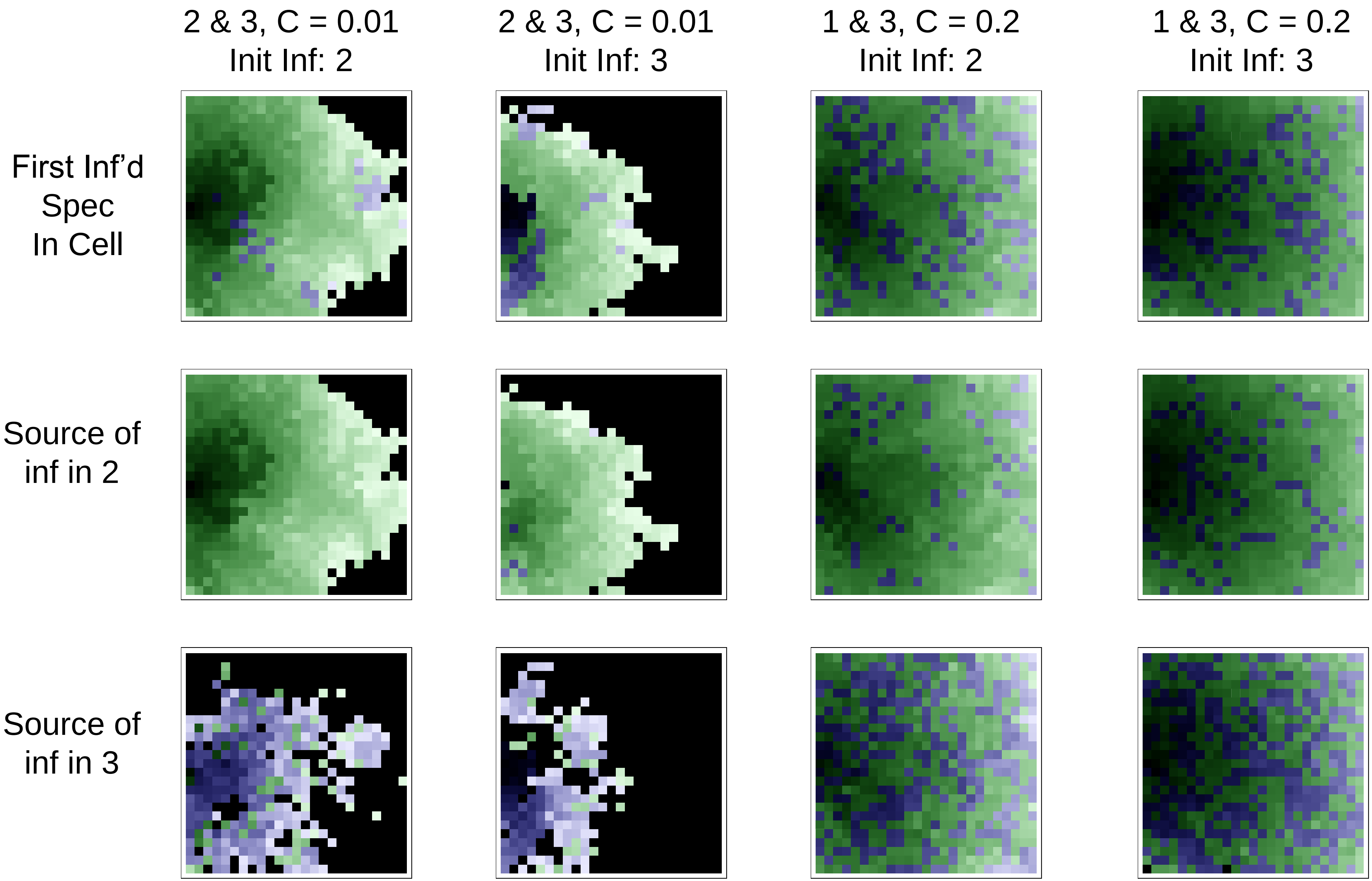


Species 2:
R_0 Local: 0.5
R_0 Neigh: 1.7



Species 3:
R_0 Local: 1.7
R_0 Neigh: 0.5


1 & 3, C = 0.01
Init Inf: 1
1 & 3, C = 0.01
Init Inf: 3
1 & 3, C = 0.2
Init Inf: 1
1 & 3, C = 0.2
Init Inf: 3
First Inf'd
Spec
In Cell
Source of
inf in 1
Source of
inf in 3


2 & 3, C = 0.01
Init Inf: 2
2 & 3, C = 0.01
Init Inf: 3
1 & 3, C = 0.2
Init Inf: 2
1 & 3, C = 0.2
Init Inf: 3
First Inf'd
Spec
In Cell
Source of
inf in 2
Source of
inf in 3

Conclusions

- The epidemic of CDV in the Serengeti lions likely involved at least two host species.
- Multi-species epidemics have dynamics that are most dependent upon rates of between species transmission
- Single species epidemics spread as waves; multi-species epidemics exhibit jumps if you only study one host species

Longer term impact of CDV

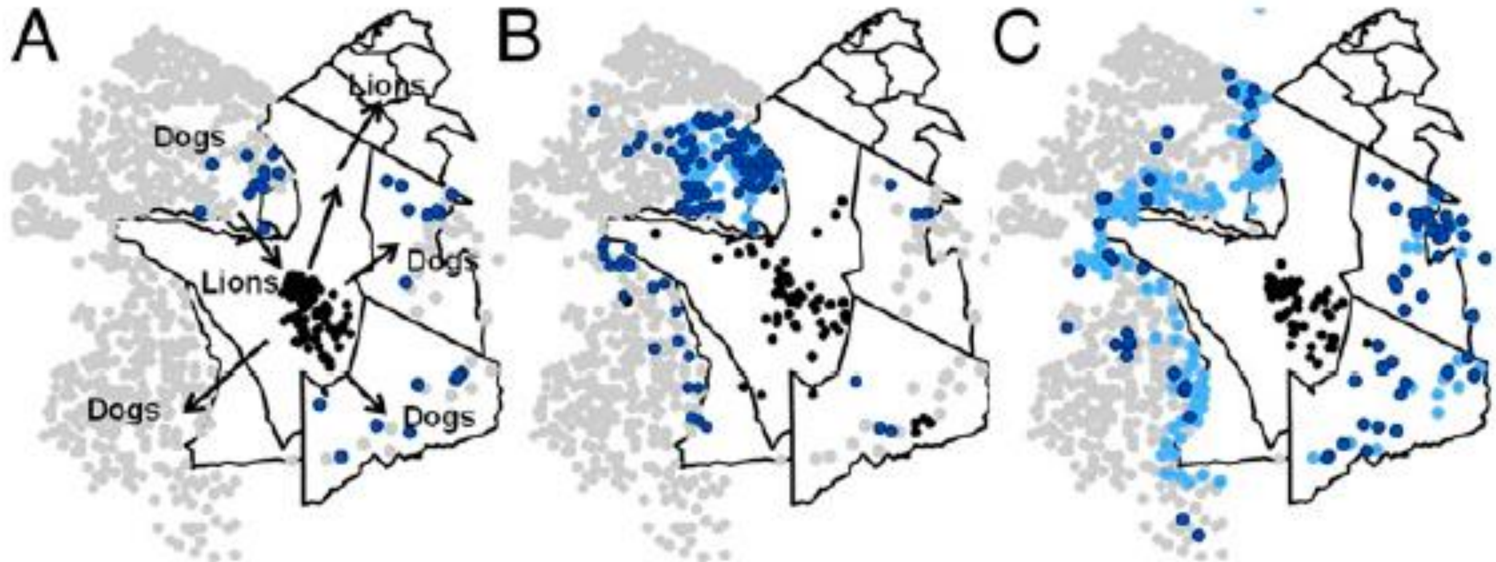


Fig. 1. Map of the Serengeti ecosystem (Tanzania). Circles represent human settlements (gray) surrounding the Serengeti National Park, villages/households from which domestic dogs were sampled (dark blue), locations where lions were sampled (black), and villages included in domestic dog vaccination campaigns that were not sampled (pale blue). (*A*) Arrows indicate the direction of the spread of CDV during the 1994 epidemic as reconstructed by Cleaveland et al. (16). (*B*) Small-scale domestic dog vaccination campaigns conducted during 1996–2002. (*C*) Expanded domestic dog vaccination program implemented during 2003–2012.

www.pnas.org/cgi/doi/10.1073/pnas.1411623112

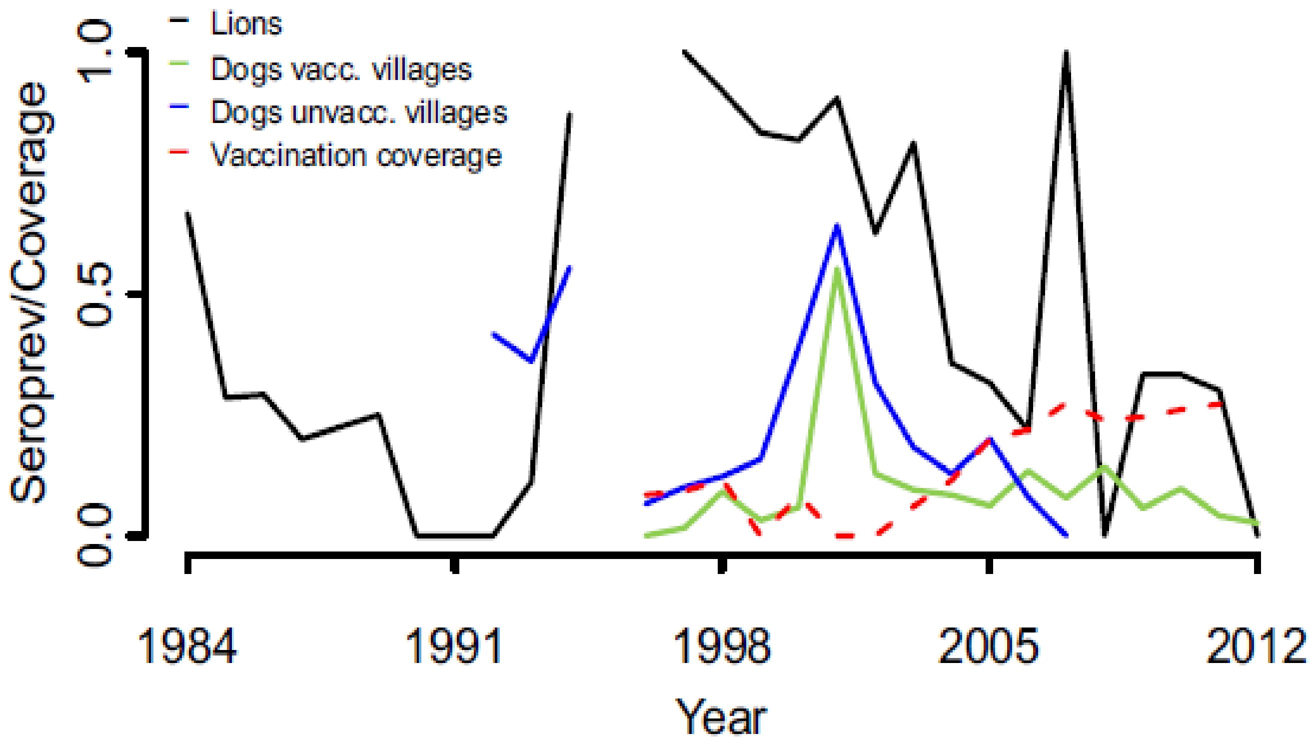


Fig. 2. Annual CDV seroprevalence in Serengeti lions (black) and in non-vaccinated dogs from vaccinated (green) and unvaccinated (blue) villages and regional vaccination coverage (red).

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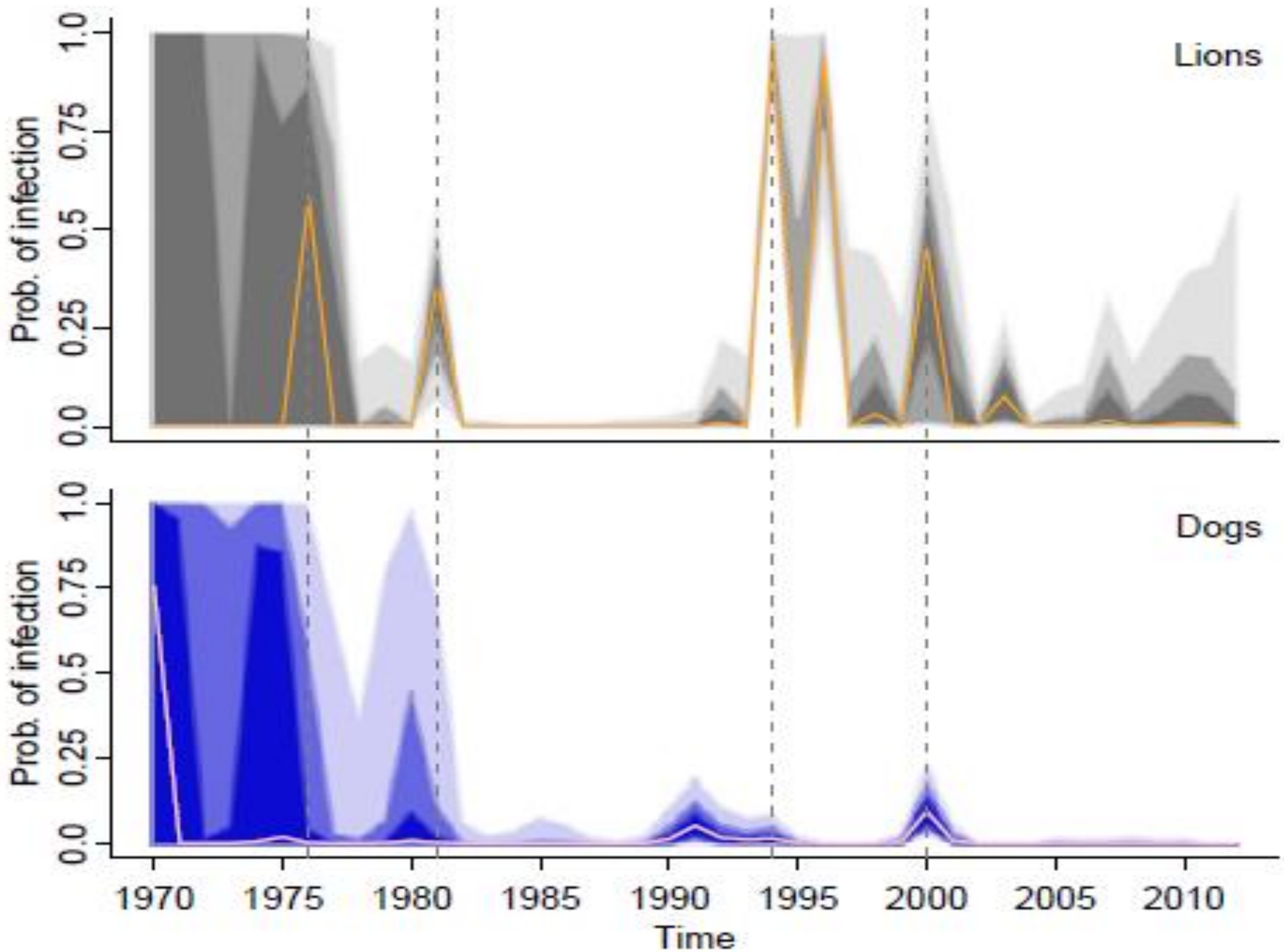
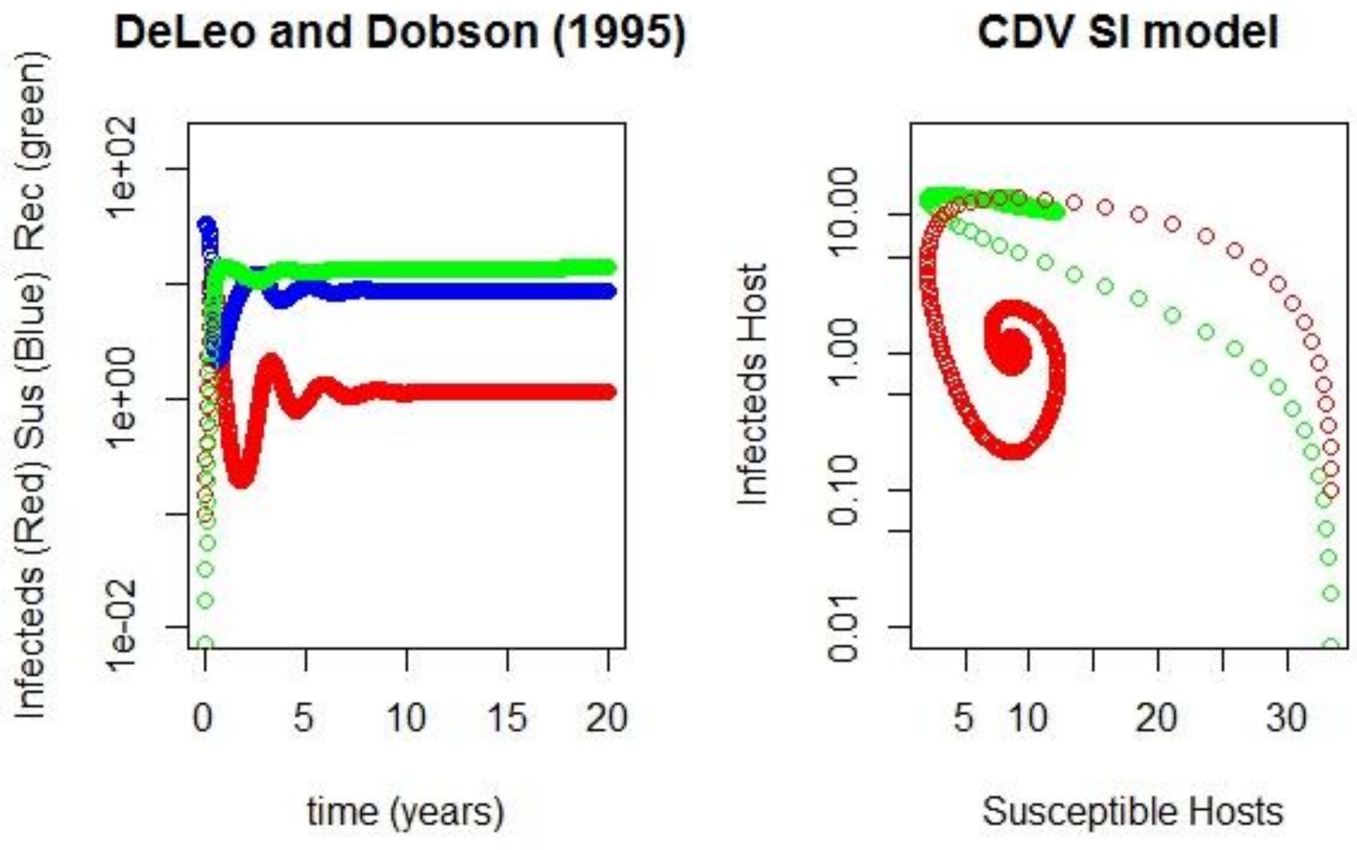


Fig. 3. State–space model estimates of the annual mode probability of CDV infection in lions (orange line, *Upper*) and dogs (pink line, *Lower*). Associated 50%, 75%, and 95% CIs are indicated by light, medium, and dark shading, respectively.

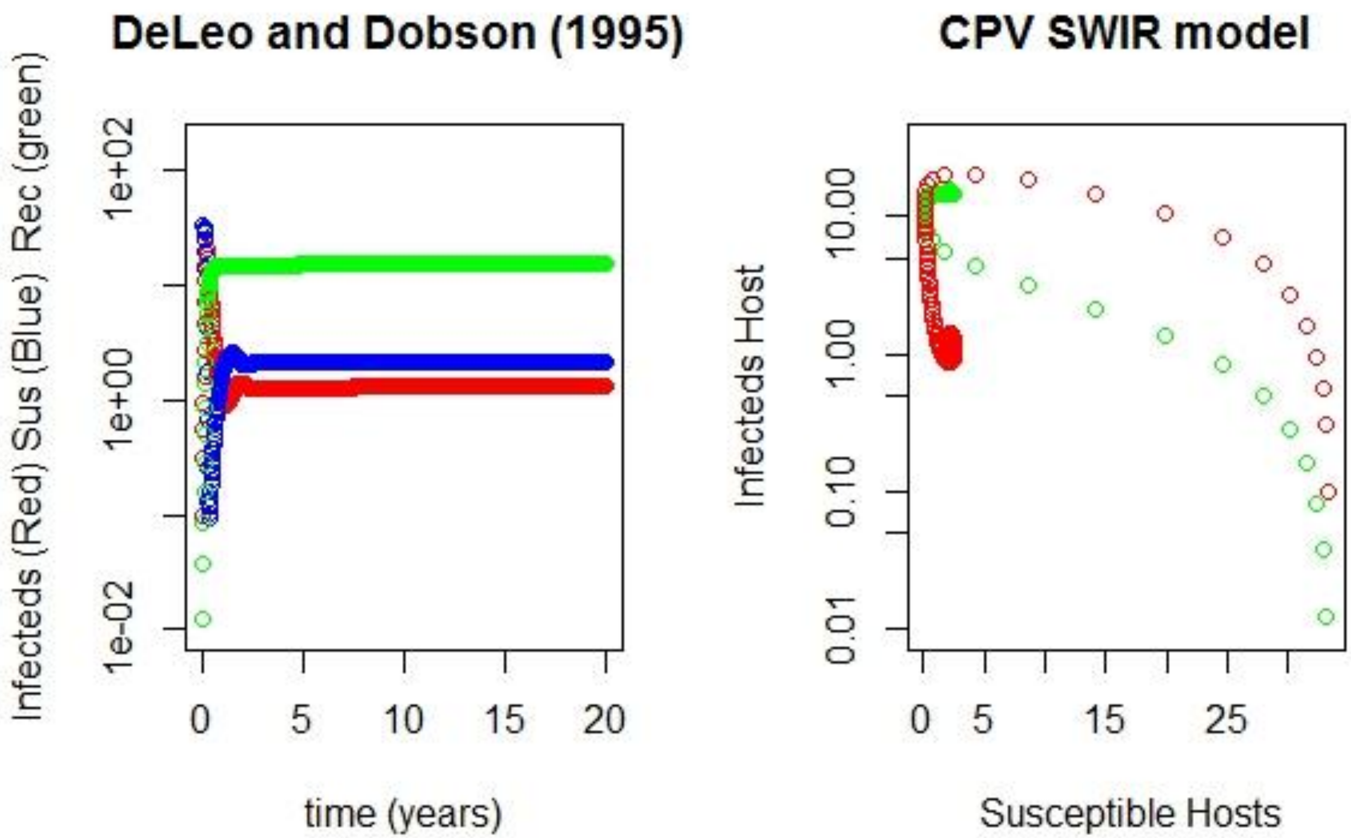
One host and two parasites

- For the last 10 to 15 years we have been vaccinating dogs against rabies, CDV, canine distemper virus and CPV, canine parvovirus.
- Focused a lot on rabies dynamics
- But what about CDV and CPV
  - CDV – direct transmission, like measles
  - CPV – free-living infective stages
  - Both create high mortality, but also high immunity

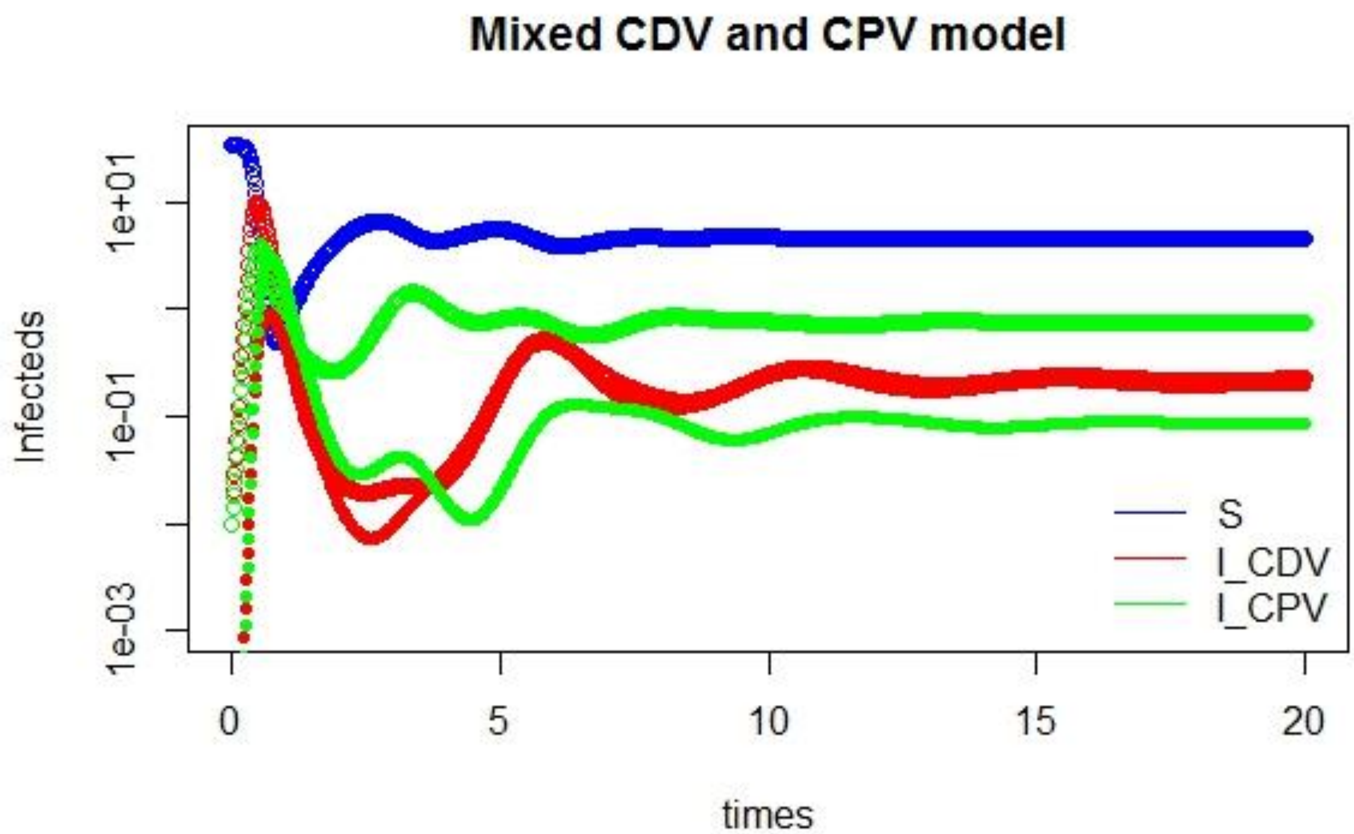
Canine distemper by itself



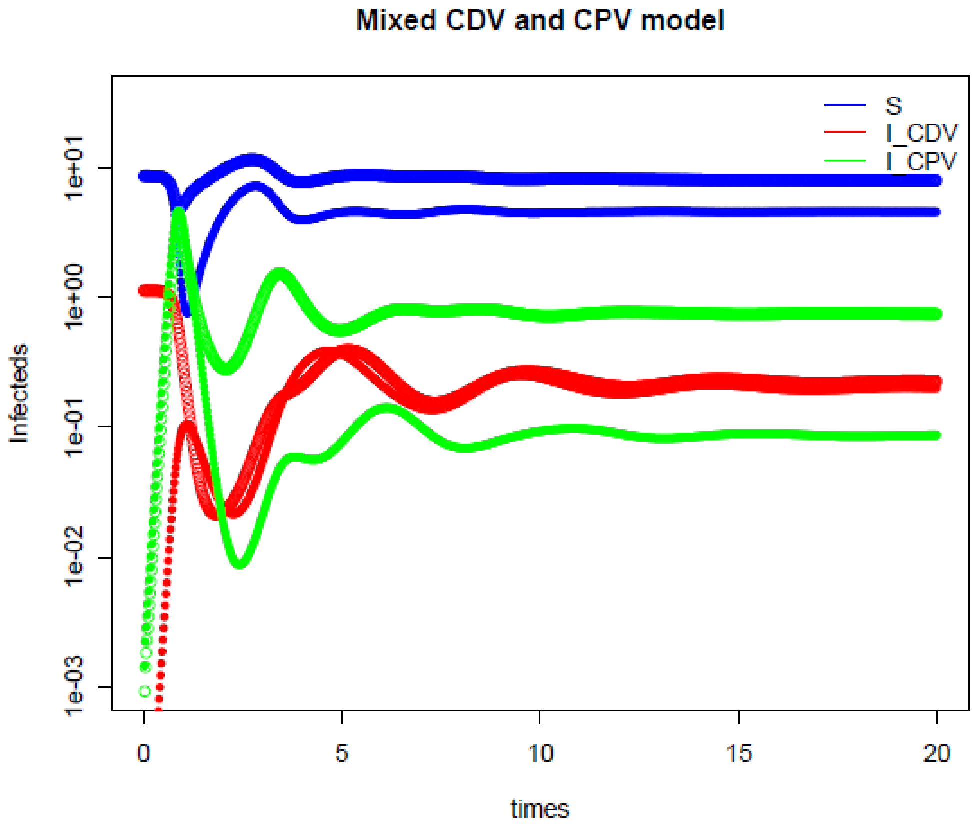
Canine parvovirus by itself

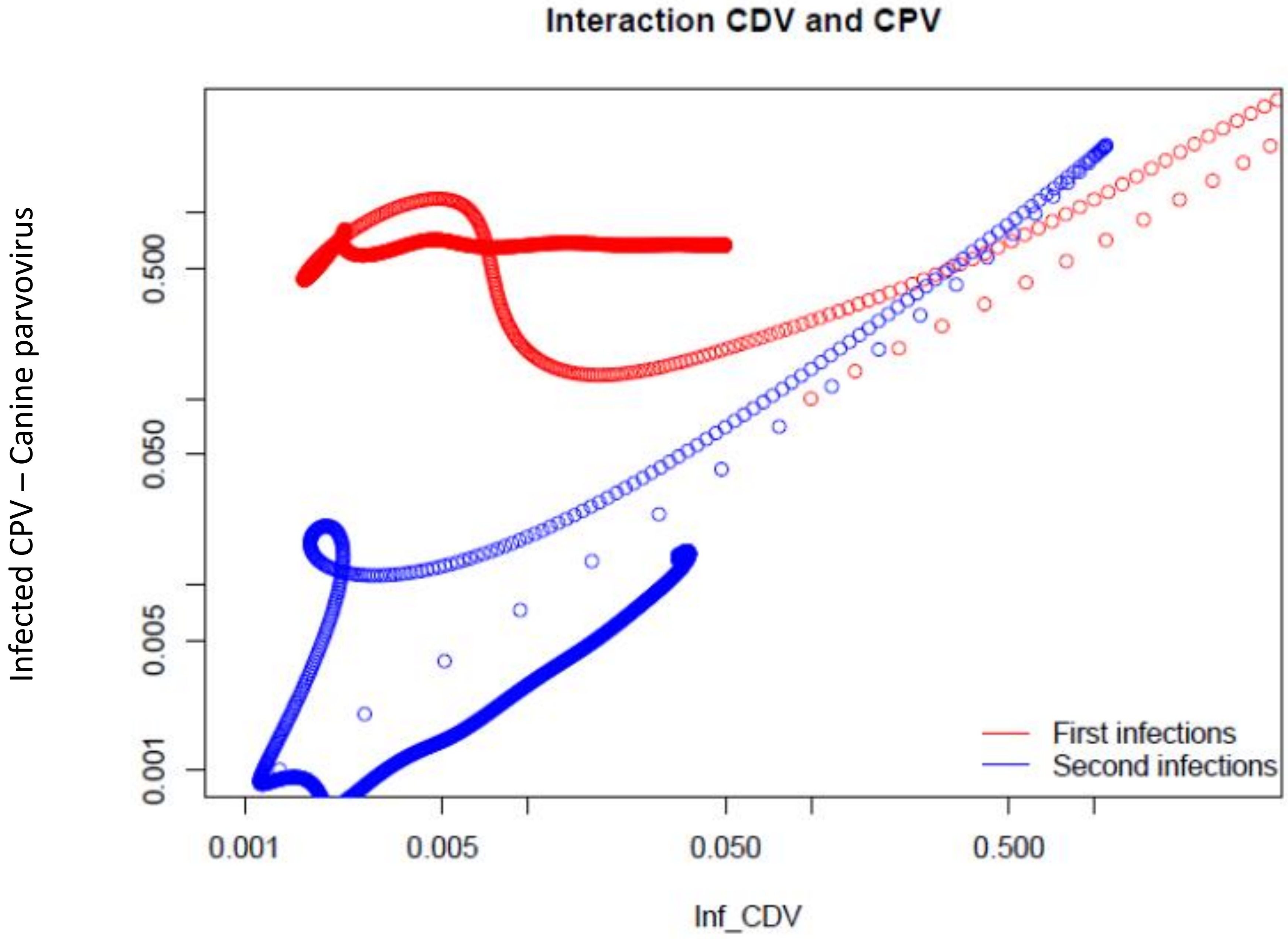


One host + two pathogens: CDV and CPV



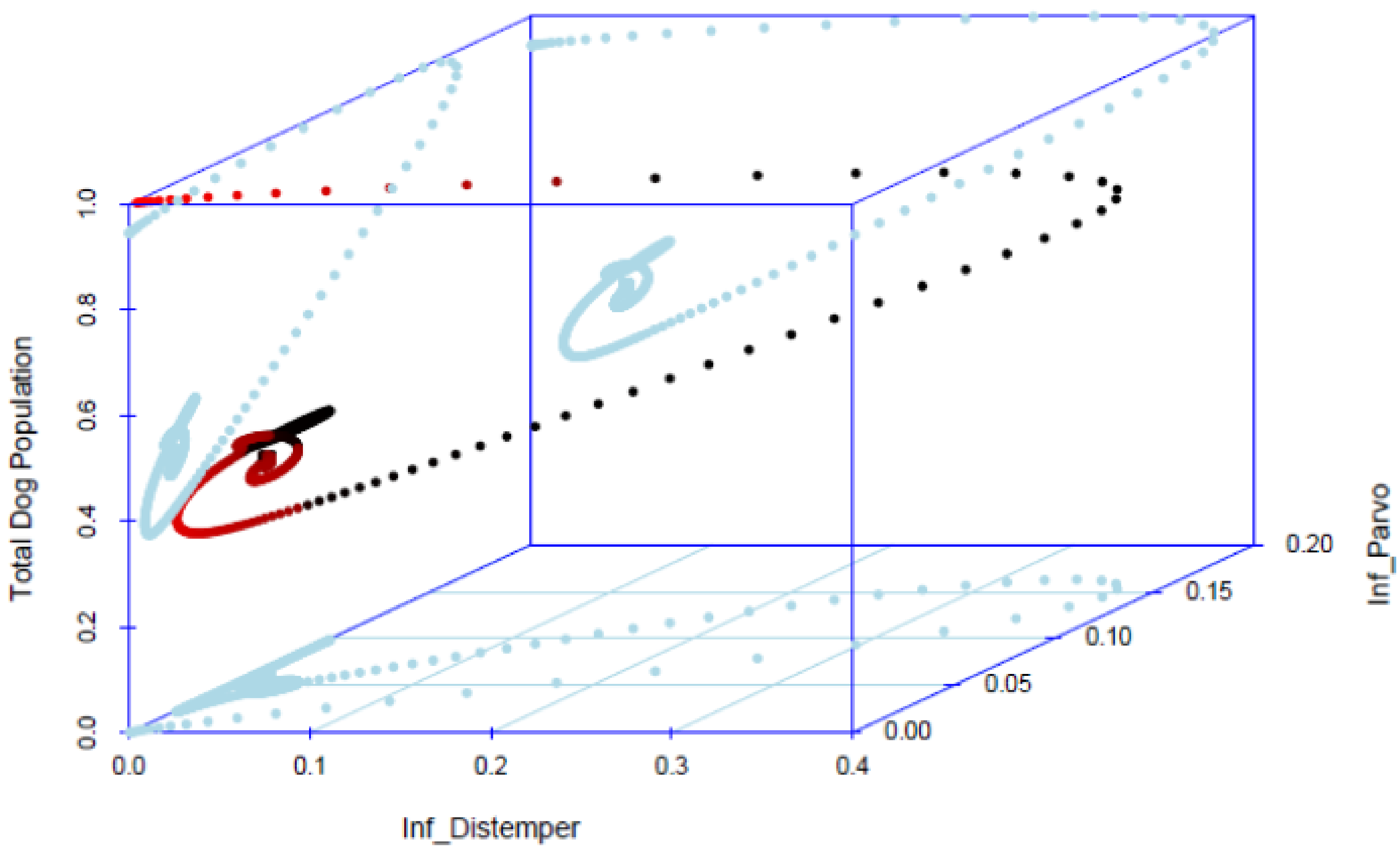
CDV present; add CPV..

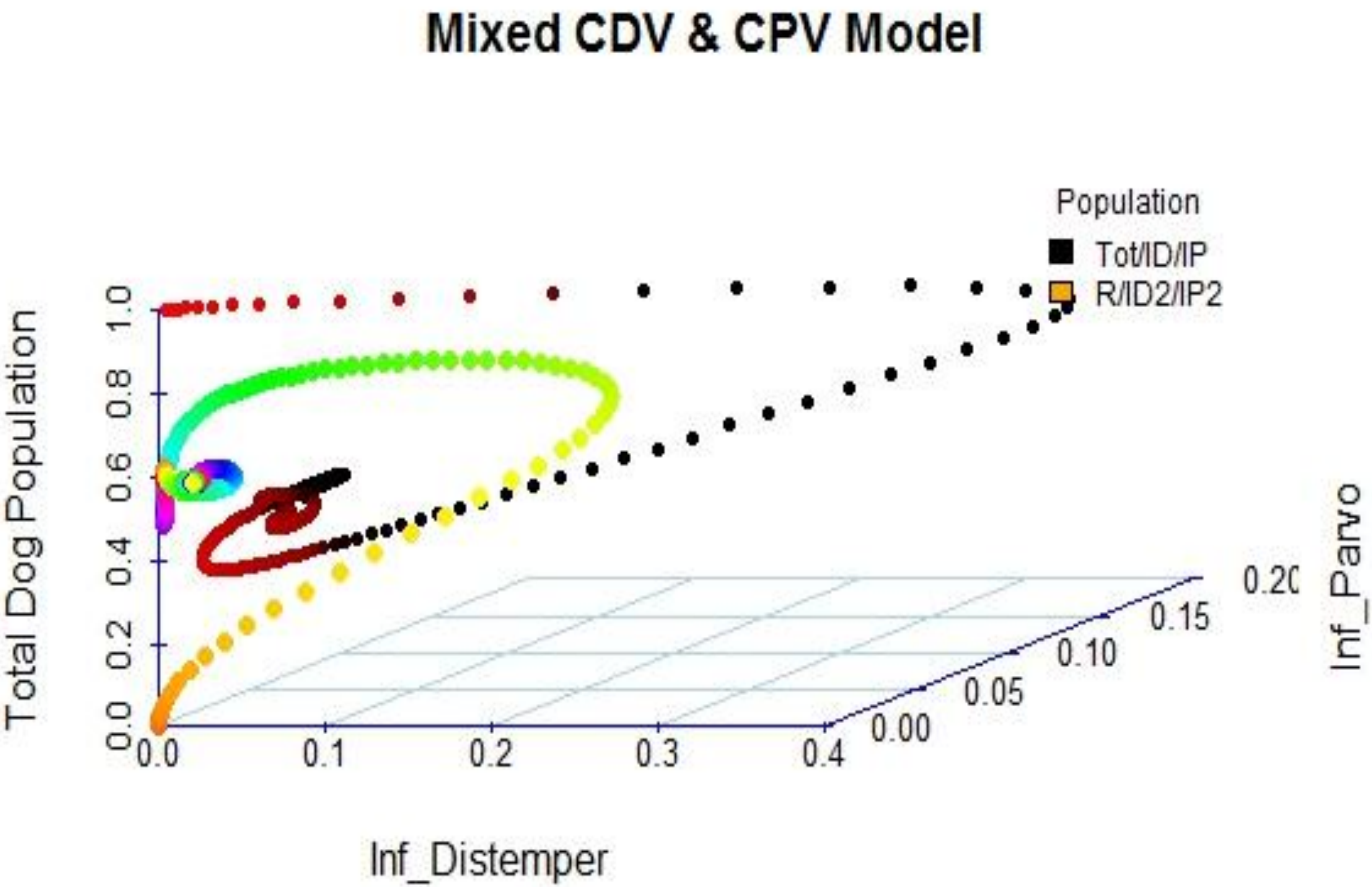




Interaction CDV and CPV
Infected CPV – Canine parvovirus
0.001
0.005
0.050
0.500
Inf_CDV
First infections
Second infections

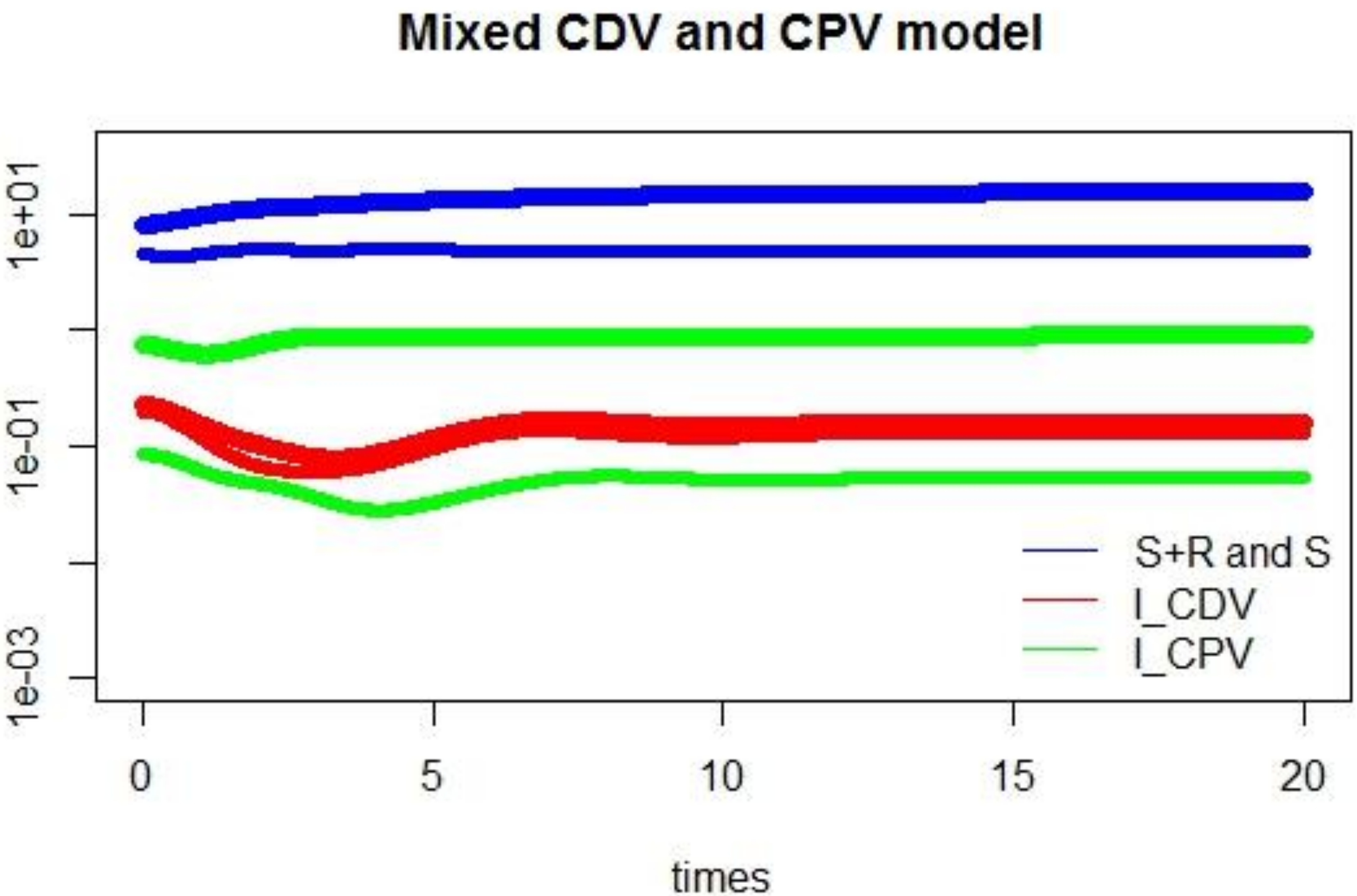
Two pathogens and a single host: CVD, CPV and Domestic dogs



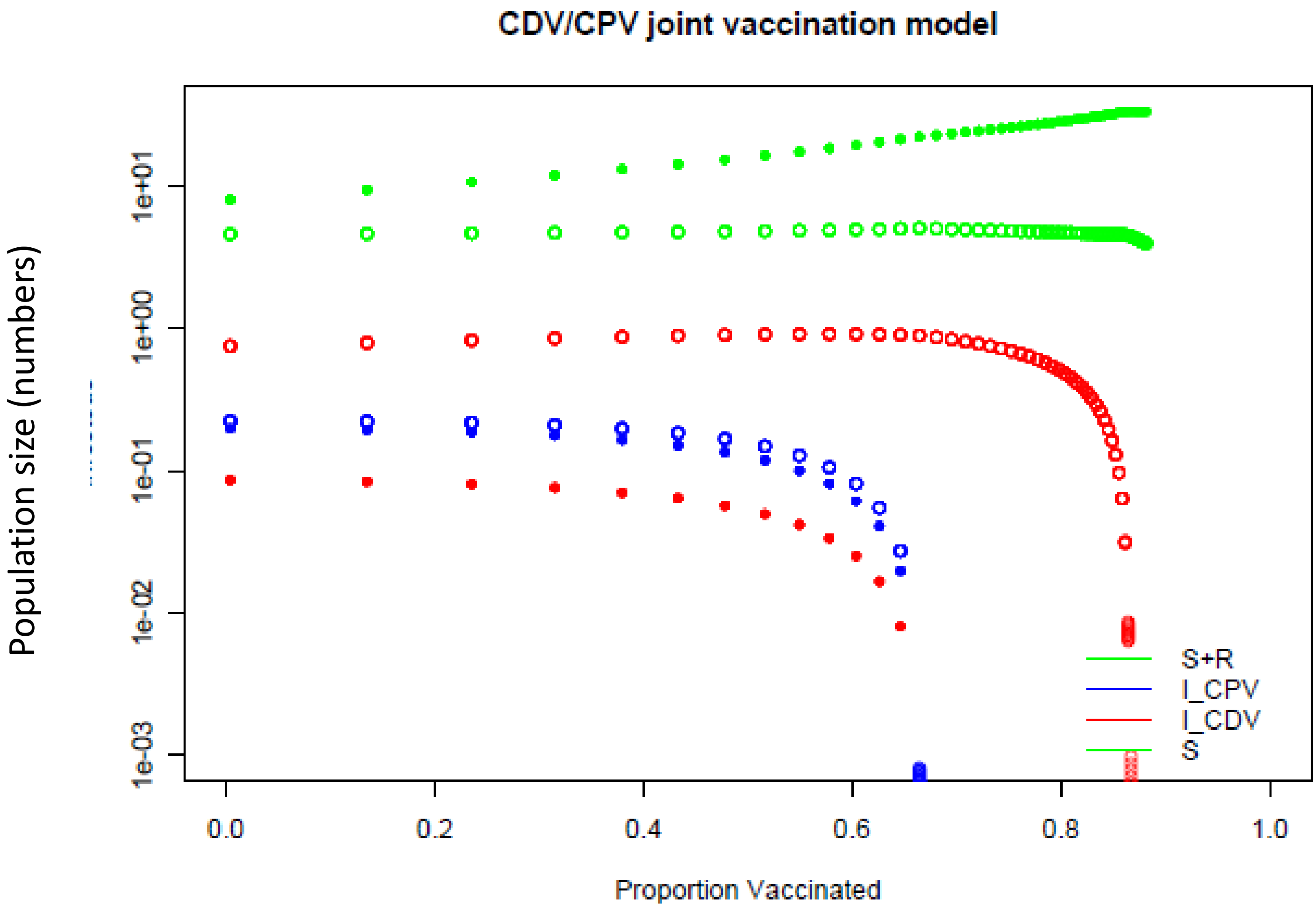


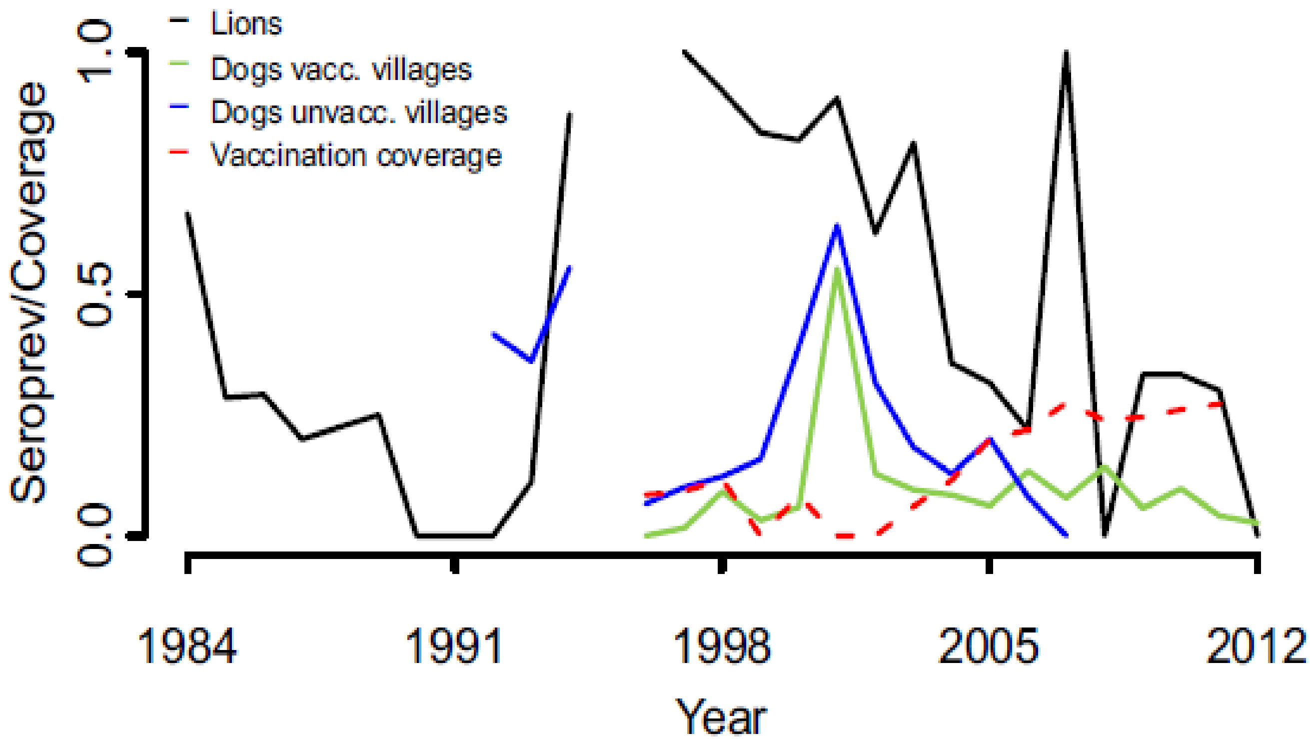
Mixed CDV & CPV Model
Population
Tot/ID/IP
R/ID2/IP2
Total Dog Population
0.0
0.2
0.4
0.6
0.8
1.0
Inf_Distemper
0.0
0.1
0.2
0.3
0.4
Inf_Parvo
0.00
0.05
0.10
0.15
0.20

25% vaccination ..?



Vaccination with two pathogens and a single host (CPV, CDV and dogs)





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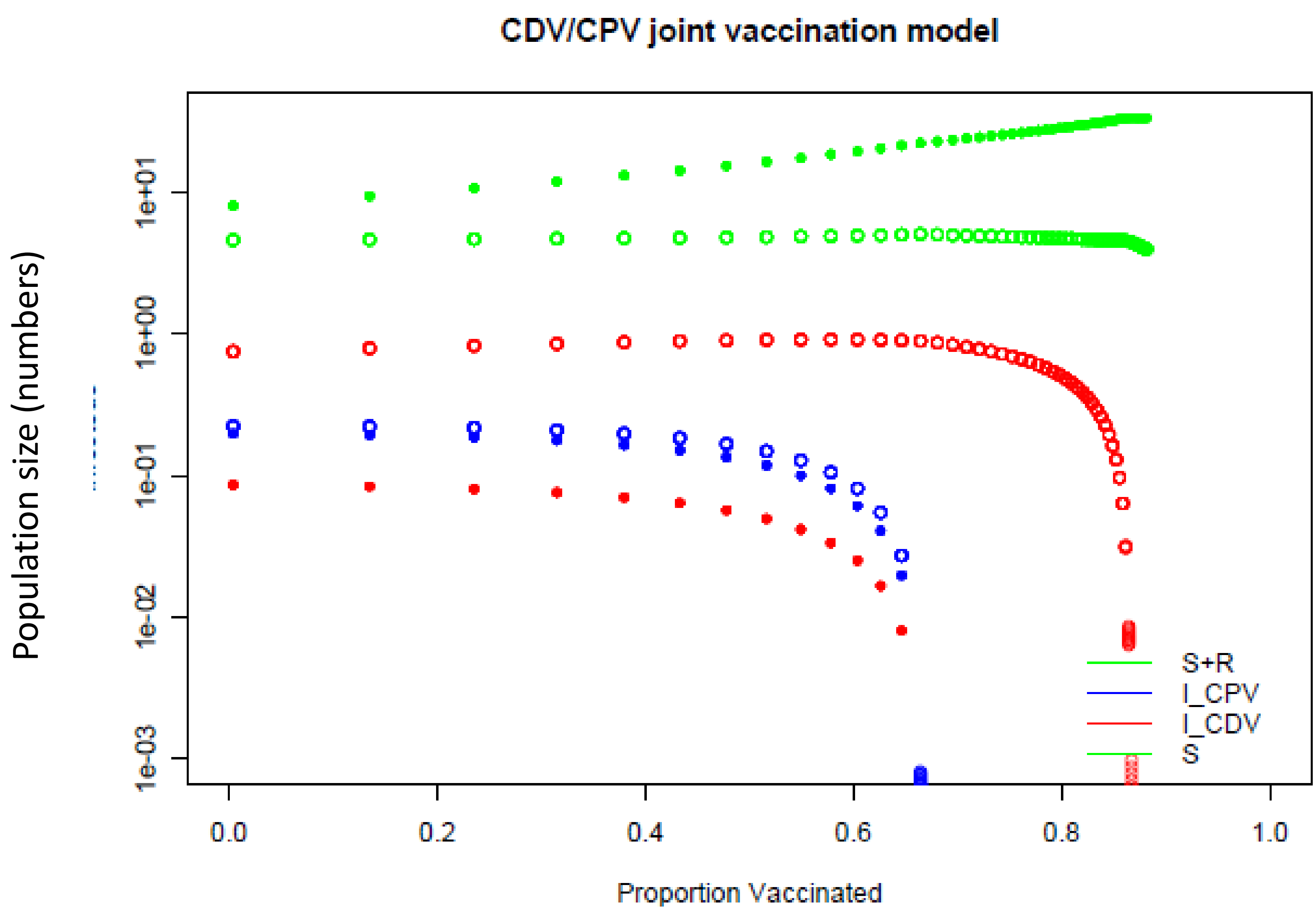
www.pnas.org/cgi/doi/10.1073/pnas.1411623112

Vaccination with two pathogens and a single host (CPV, CDV and dogs)

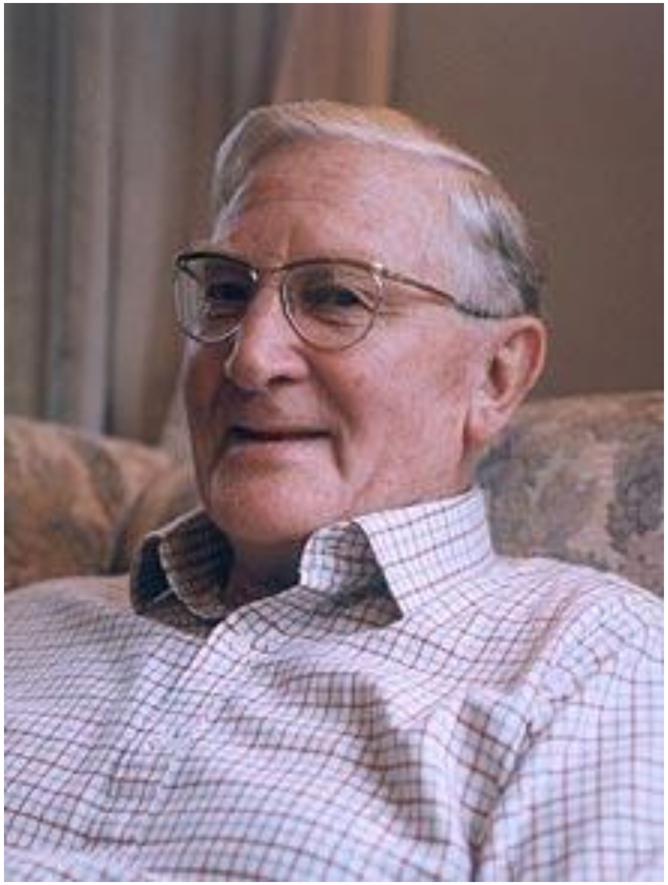


Bottom line here…

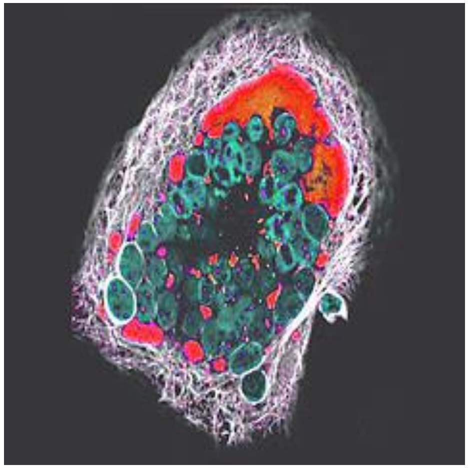
- The presence of a second pathogen (and a third, fourth, etc) will change the dynamics away from simple SIR dynamics.
- Keep this in mind when interpreting data (or fitting model) and assuming simple SIR dynamics
- Be particularly cautious when morbilliviruses are involved as 1000x more immuno-compromising than HIV!!!


Many thanks to Meggan Craft, Peter Hawthorne, Craig Packer
and Serengeti Lion Project and Serengeti Carnivore Disease Project.
Funded by NIH/NSF – Ecology of Infectious Diseases.

Heroes and Villains



Walter Plowright



Rinderpest virus

Outline of talk

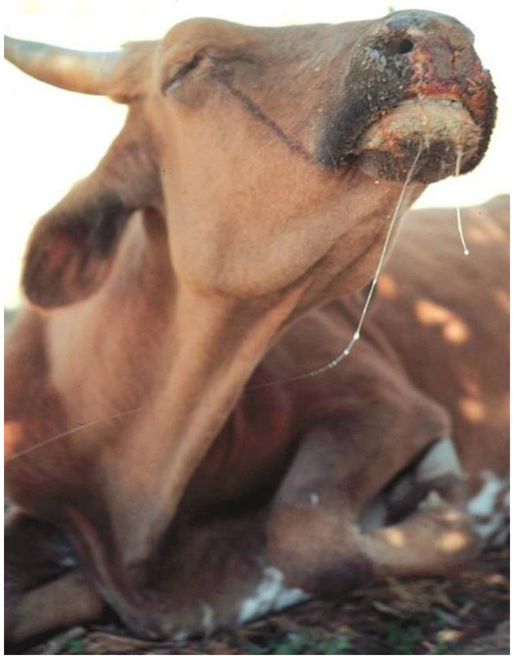
- Brief history of rinderpest and its eradication
- Consequences of eradication – ecosystem level effects
- Worries for the future

More rinderpest heroes…!

From left to right Michael Baron, Martyn Jeggo, Bill Taylor, Peter Roeder and John Anderson

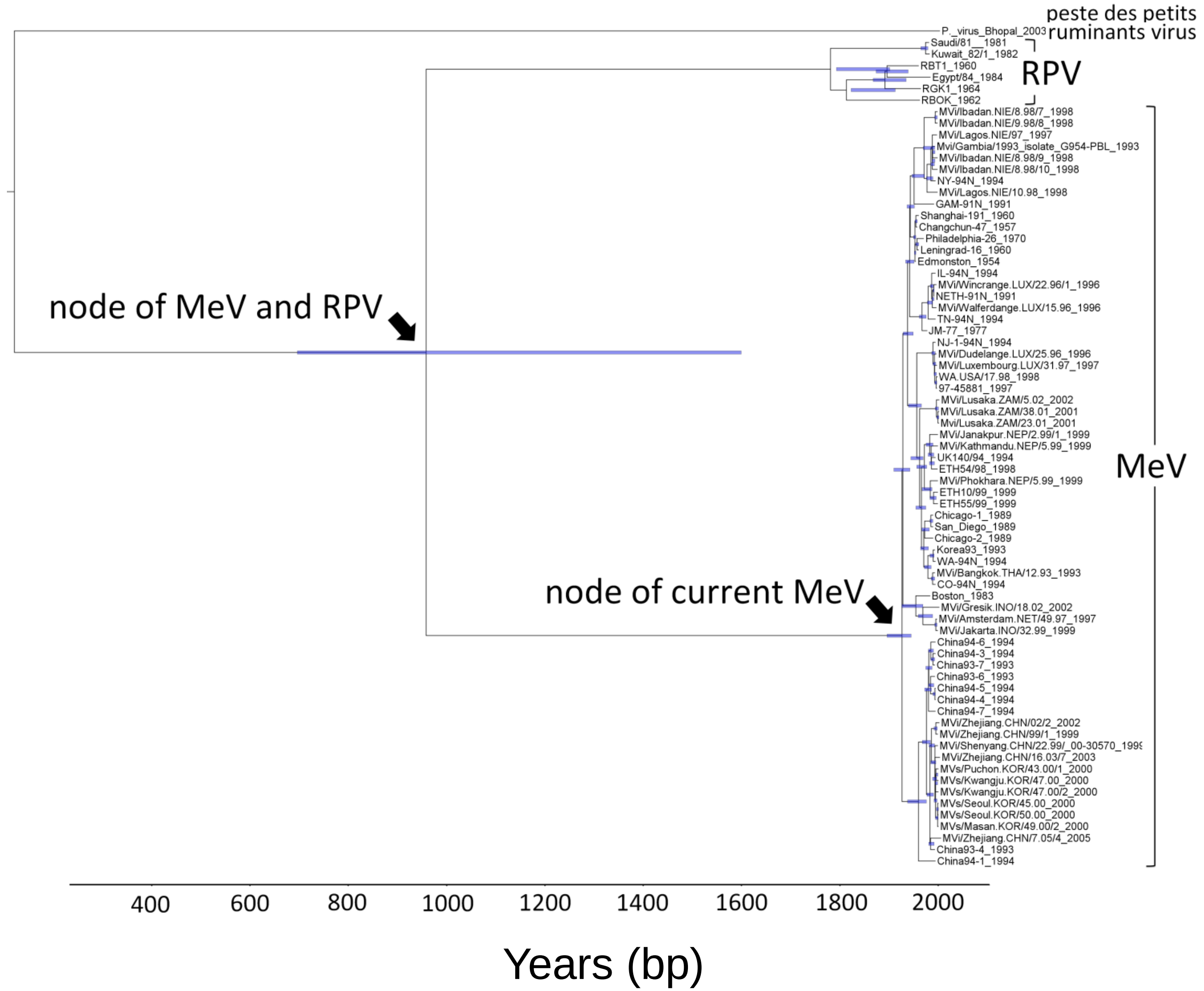
Rinderpest virus

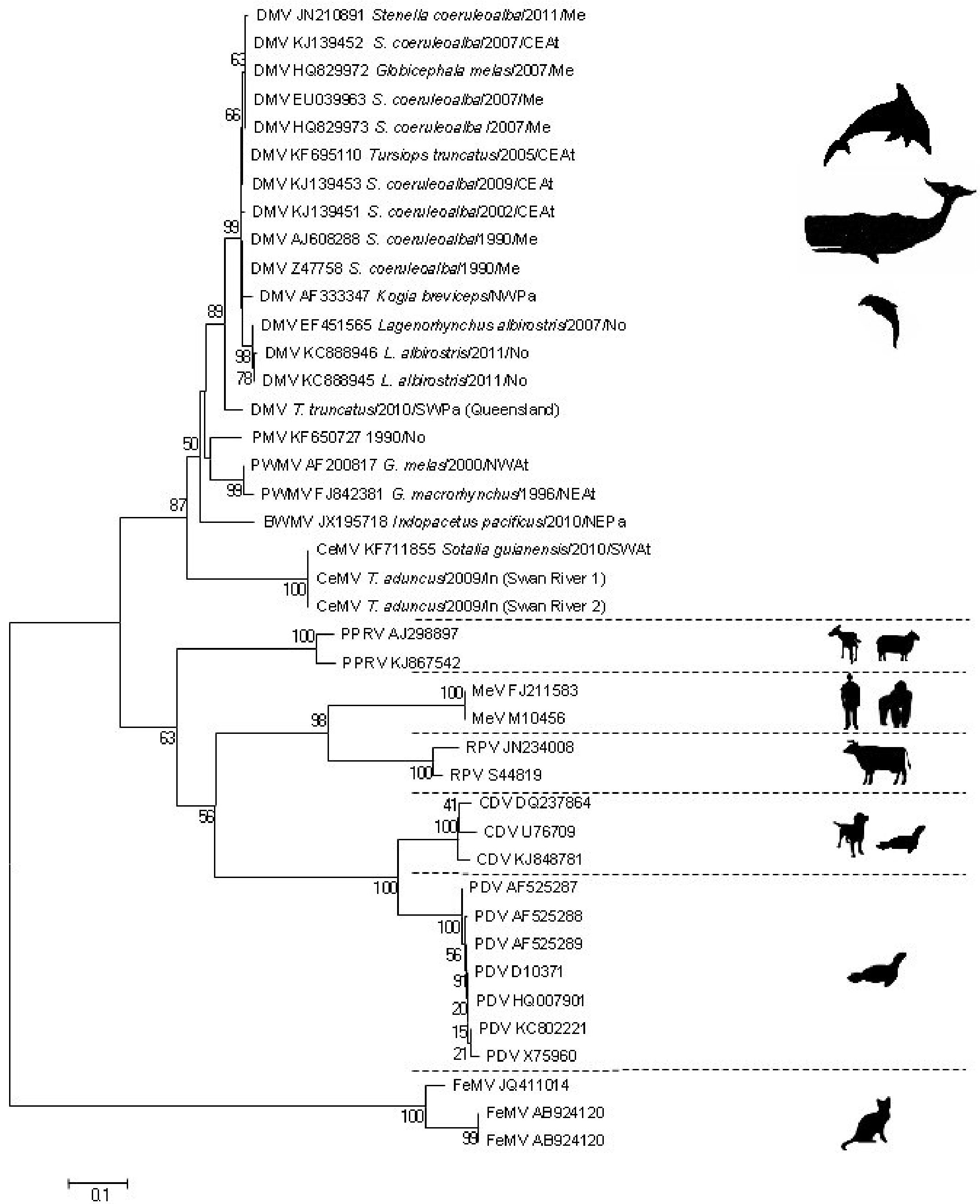
Infected cow



Split between Rinderpest and Measles

(from Furuse, Suzuki, Oshitani, Virology Journal 2010)




DMV JN210891 *Stenella coeruleoalba*/2011/Me
DMV KJ139452 *S. coeruleoalba*/2007/CEAt
DMV HQ829972 *Globicephala melas*/2007/Me
DMV EU039963 *S. coeruleoalba*/2007/Me
DMV HQ829973 *S. coeruleoalba* /2007/Me
DMV KF695110 *Tursiops truncatus*/2005/CEAt
DMV KJ139453 *S. coeruleoalba*/2009/CEAt
DMV KJ139451 *S. coeruleoalba*/2002/CEAt
DMV AJ608288 *S. coeruleoalba*/1990/Me
DMV Z47758 *S. coeruleoalba*/1990/Me
DMV AF333347 *Kogia breviceps*/NWPa
DMV EF451565 *Lagenorhynchus albirostris*/2007/No
DMV KC888946 *L. albirostris*/2011/No
DMV KC888945 *L. albirostris*/2011/No
DMV *T. truncatus*/2010/SWPa (Queensland)
PMV KF650727 1990/No
PWMV AF200817 *G. melas*/2000/NWAt
PWMV FJ842381 *G. macrorhynchus*/1996/NEAt
BWMV JX195718 *Indopacetus pacificus*/2010/NEPa
CeMV KF711855 *Sotalia guianensis*/2010/SWAt
CeMV *T. aduncus*/2009/In (Swan River 1)
CeMV *T. aduncus*/2009/In (Swan River 2)
PPRV AJ298897
PPRV KJ867542
MeV FJ211583
MeV M10456
RPV JN234008
RPV S44819
CDV DQ237864
CDV U76709
CDV KJ848781
PDV AF525287
PDV AF525288
PDV AF525289
PDV D10371
PDV HQ007901
PDV KC802221
PDV X75960
FeMV JQ411014
FeMV AB924120
FeMV AB924120
63
66
99
89
98
78
50
99
87
100
100
100
98
63
100
56
41
100
100
100
56
91
20
15
21
100
99
0.1


A
B
C
D
E
F
G

- Early diagnostics and control.

Bernardino Ramazzini had been the first to describe rinderpest, in 1712.[5] He was the principal professor of medicine at the University of Padua. He saw several similarities between rinderpest and smallpox and his views were widely accepted. Giovanni Maria Lancisi, the Pope's personal physician, recommended the slaughter of all infected and exposed animals.[6] This policy was undoubtedly the most logical approach to combat the rinderpest epizootics, but it understandably met with much resistance and was therefore applied only sparingly especially at the beginning; later in the century it would be used successfully in several countries. In others, however, the measures were seen as too drastic and costly; in addition, their strict application required a strong central authority, which was often lacking, as in the United Dutch Provinces for example.

Against this background it was not surprising that attempts were made to apply the inoculation principle to rinderpest, as it was extrapolated to measles by Francis Home a few years later.[7] Both diseases were seen as closely related to smallpox and one attack was known to provide lifelong protection. Several of the most fervent and experienced smallpox inoculators, like Pieter Camper in the Netherlands, became the most enthusiastic promotors of applying the procedure to rinderpest, especially because all attempts to cure the disease had failed; the whole range of the then known drugs used in human medicine had been tried, all to no avail.[8]

Huygelen (1997) Medical History41: 182-196

- Huygelen (1997) Medical History41: 182-196

Initial Inoculations in England and the Netherlands

The first written report of rinderpest inoculation was published as a letter signed "T.S." in the November 1754 issue of the *Gentleman's Magazine*, a journal then widely read by educated people not only in Britain, but also on the Continent. This magazine also actively supported the progress of smallpox inoculation.[9] In this context it was eager to publish letters about the applications of the principle to other diseases. The author of the letter reported that a Mr Dobson, a gentleman of Yorkshire, had inoculated his cattle and had thus preserved nine out of ten of them.[10] In the next issue of the journal, a correction appeared stating that Mr Dobson was very surprised to see his name mentioned in

connection with the procedure. The letter stated that "Mr. Dobson lives in the city of York, and is so far from having any stock of cattle, that he does not even keep a cow". The real story Dobson had heard, was as follows:

Sir William St. Quintin, of Scampton in Yorkshire, inoculated eight calves, seven of which had the distemper from the inoculation, and recovered, and were afterwards turned into a herd of infected cattle, without being infected a second time; the other case was of an old ox, which was inoculated at Malton, which had the distemper from inoculation, and recovered, and was afterwards turned into a herd of infected cattle, but did not receive the infection a second time. Mr. Dobson had the foregoing account from an eminent physician in Yorkshire, who told him the method of performing the operation, and of treating the beast in distemper, which is as follows: First bleed the beast, and from that time keep him from hay, and all dry meat, till he is quite recovered; and in order to keep his body open, give him scalded bran, or chaff. At the end of three days make an incision in the dewlap, into his wound put a piece of tow, dipped in the morbid matter discharged from the nostrils, or eyes, of an infected beast, then stitch up the wound, and let the tow remain until the symptoms of distemper appear, when the tow must be taken out; after turn the beast out to grass.[11]

In almost all later literature on rinderpest the first inoculations have been erroneously attributed to Dobson, probably because the second letter went unnoticed; in addition, most authors misspelled his name: "Dodson". Many also gave the incorrect date of 1744 instead

Huygelen (1997) Medical History41: 182-196

Spread of Rinderpest in Africa 1889-1897 (after Mack 1970).

Introduced into Horn of Africa – most likely by Italian Army laying siege to Gordon in Khartoum.

Easier and faster to transport cattle by steamboat – so Sahara no longer provided a barrier to cattle movement.

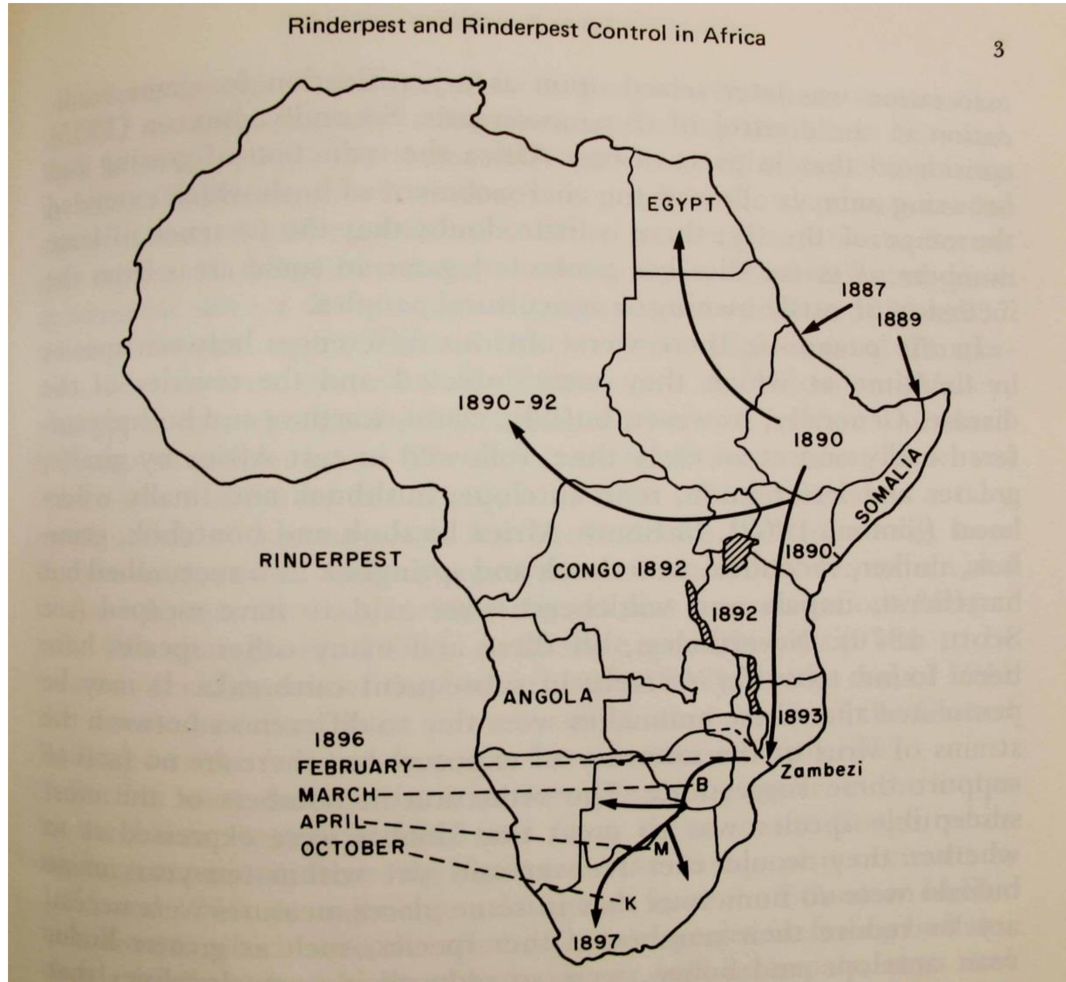


FIG. 1. The course of the great rinderpest panzootic in Africa, 1889–1897. From Mack (1970), with acknowledgements to the author and *Tropical Animal Health and Production.*

Oxen were main power of transport and agriculture in South Africa in 19th Century

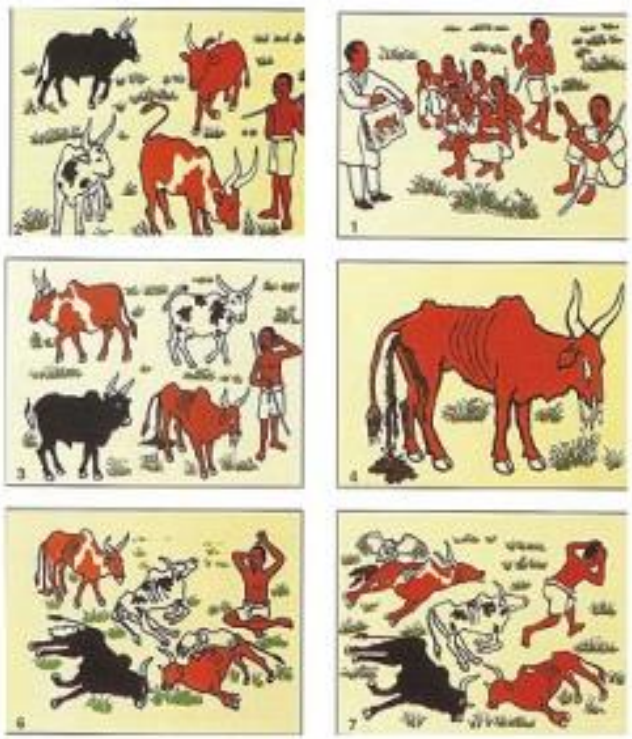
Around 2.5 million cattle died of rinderpest in South Africa in 1890’s (Mack 1970)

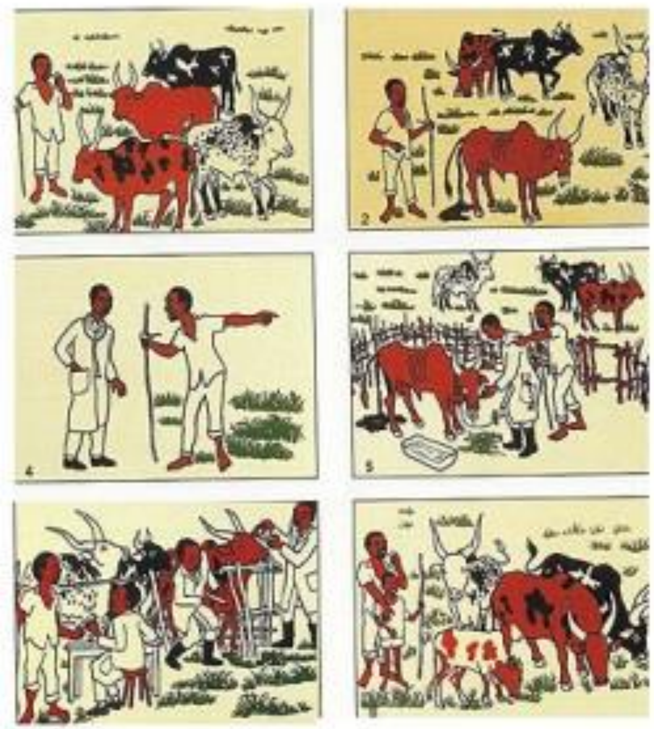
Walter Plowright

Walter Plowright, CMG, FRS[1], FRCVS (born 20 July 1923, Holbeach, Lincolnshire – 19 February 2010 London[2]) was an English veterinary scientist who devoted his career to the eradication of the cattle plague rinderpest. Dr Plowright received the 1999 World Food Prize for his development of tissue culture rinderpest vaccine (TCRV), the key element in the quest to eliminate rinderpest.[3] Rinderpest became the first animal disease to be eliminated worldwide

Rinderpest eradication programmes:

Education





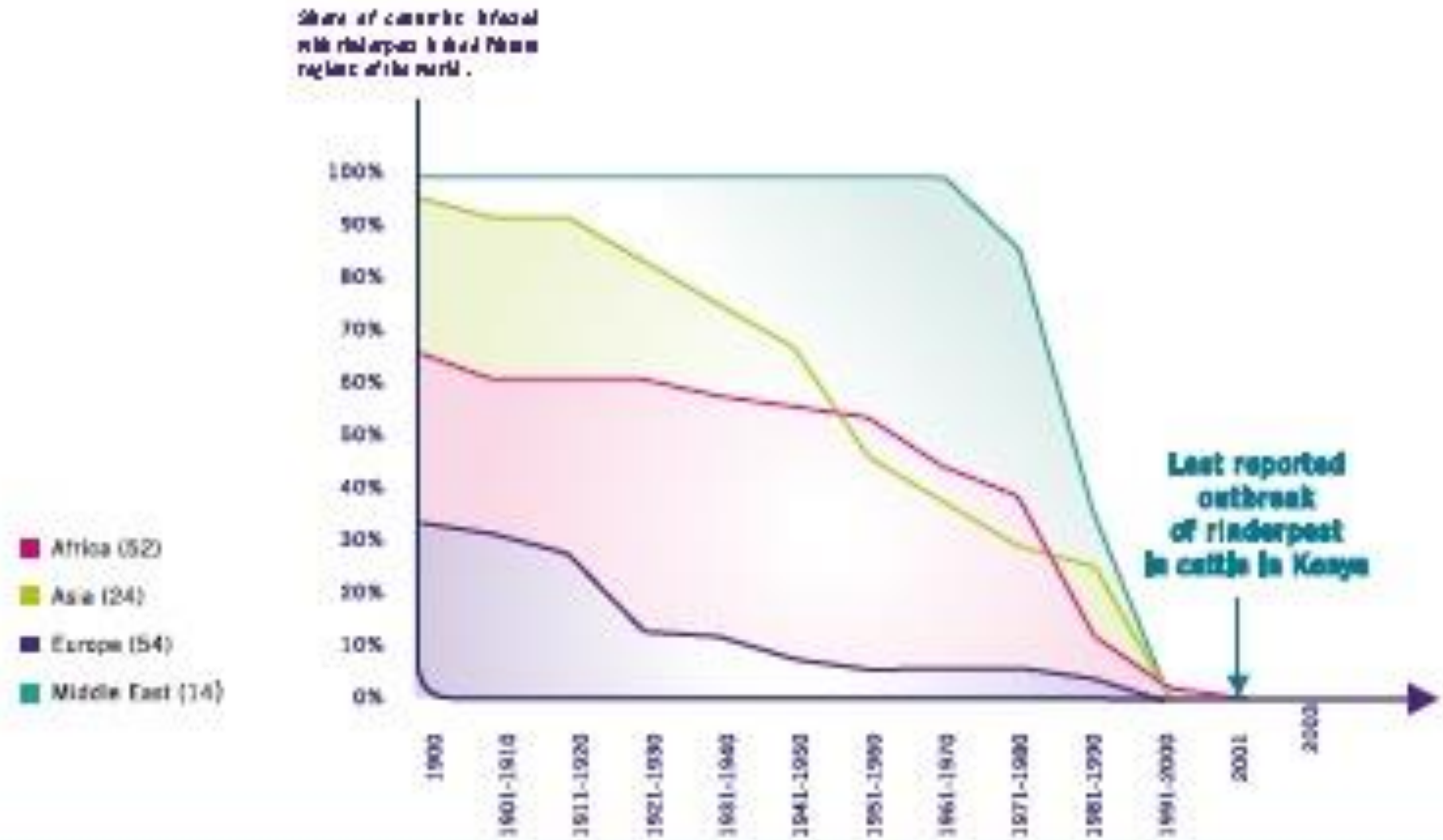
Disease of the 3Ds : discharge, diarrhoea and death

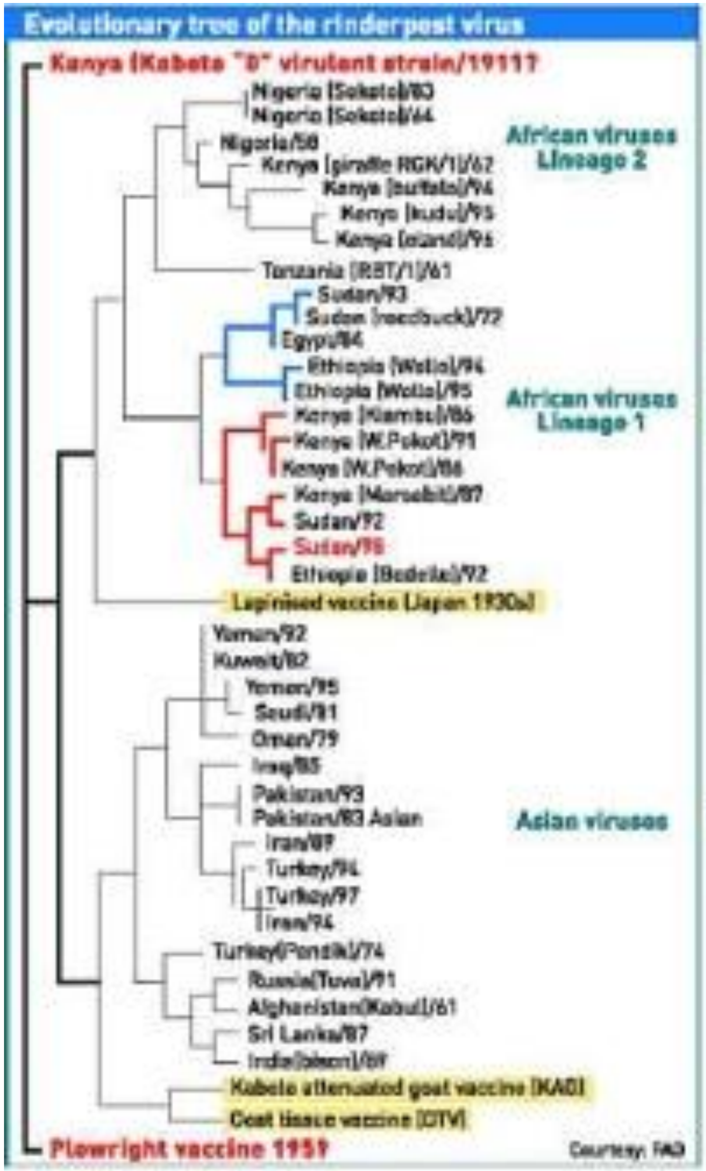
Pan-African Rinderpest Campaigns
Attempted to rid Africa of rinderpest;
But constant leaking on of infections
From middle east and Pakistan

Need to go for global campaign

ERADICATING RINDERPEST : moments in time

Reported outbreaks of rinderpest steadily declined over the last 100 years.




Evolutionary tree of the rinderpest virus
Kenya (Kabete "O" virulent strain/1911)
Nigeria (Sokoto)/83
Nigeria (Sokoto)/64
Nigeria/58
Kenya (giraffe RGK/1)/62
Kenya (buffalo)/94
Kenya (kudu)/95
Kenya (eland)/96
Tanzania (RBT/1)/61
Sudan/93
Sudan (reedbuck)/72
Egypt/84
Ethiopia (Wollo)/94
Ethiopia (Wollo)/95
Kenya (Kiambu)/86
Kenya (W.Pokot)/91
Kenya (W.Pokot)/86
Kenya (Marsabit)/87
Sudan/72
Sudan/98
Ethiopia (Bedelle)/72
African viruses Lineage 2
African viruses Lineage 1
Lapinised vaccine (Japan 1930s)
Yemen/92
Kuwait/82
Yemen/95
Saudi/81
Oman/79
Iraq/85
Pakistan/93
Pakistan/83 Asian
Iran/89
Turkey/94
Turkey/97
Iran/94
Asian viruses
Turkey(Pendik)/74
Russia(Tuva)/91
Afghanistan(Kabul)/61
Sri Lanka/87
India(bison)/89
Kabete attenuated goat vaccine (KAG)
Goat tissue vaccine (GTV)
Plowright vaccine 1959
Courtesy: FAO


Global rinderpest situation as of November 2009
Recognition obtained
Recognition not obtained yet
Global rinderpest situation as of October 2010
Global rinderpest situation as of June 2011
Courtesy: FAO

Rinderpest eradication in India

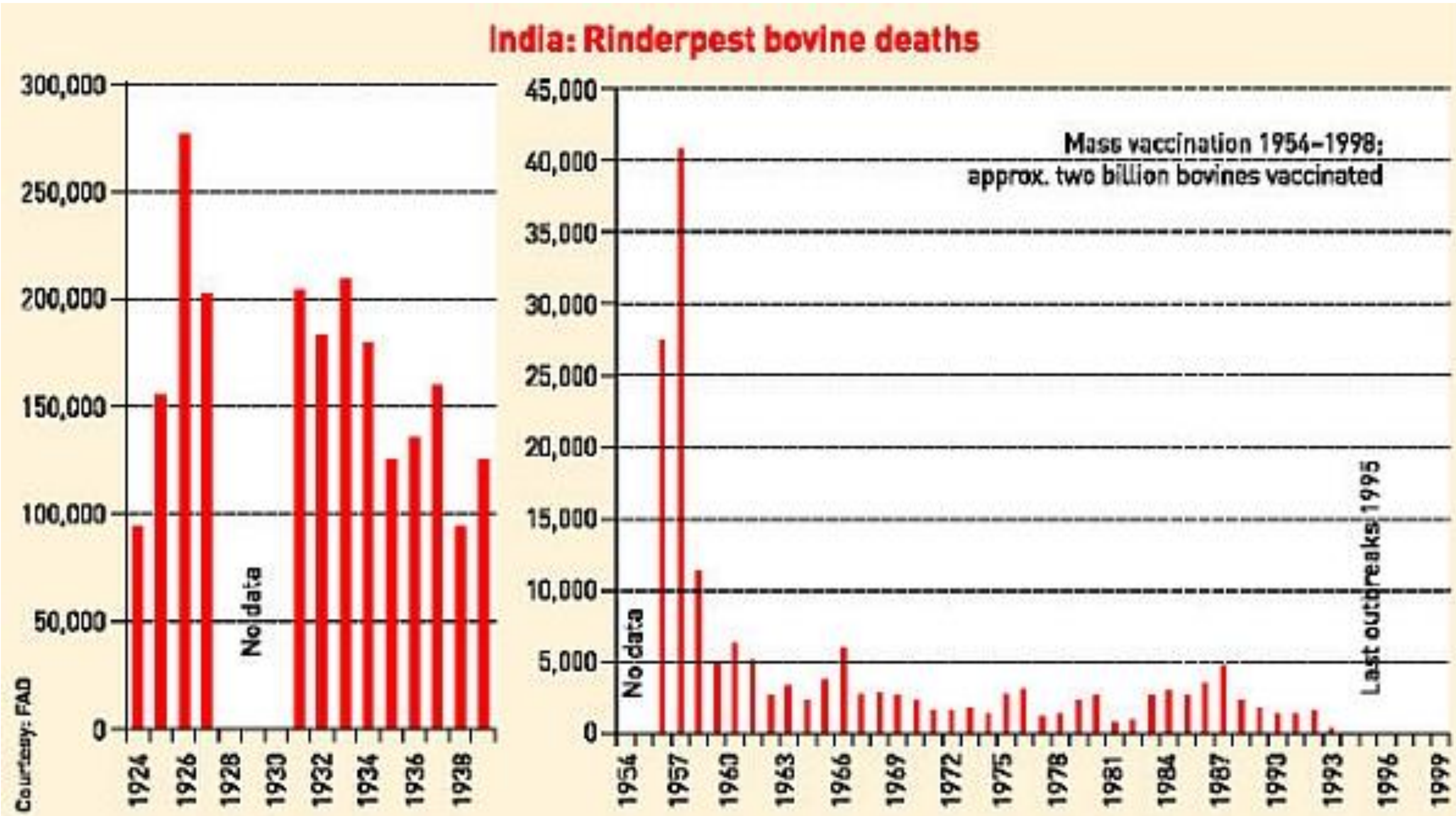
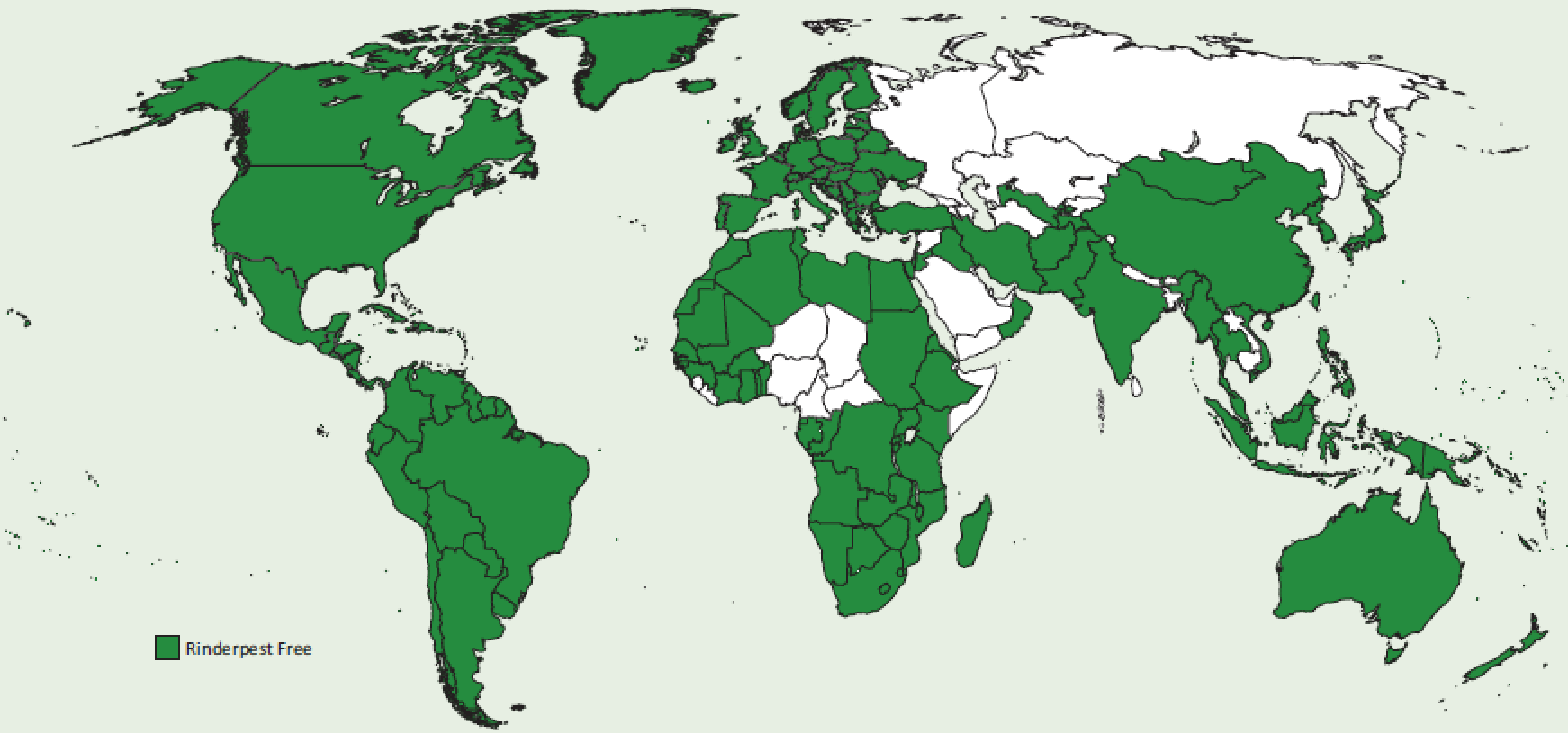


Figure 16.1—Exports of beef products from Pakistan, 1992–2006

Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database. Rome.

Figure 16.2— Status of accreditation of rinderpest freedom, 2009



Source: World Organization for Animal Health. 2009. www.oie.int/eng/status/Rinderpest/en_RP_free.htm.

- Crucial importance of community-based animal health workers.

Community-based animal health workers were specifically used to combat rinderpest in South Sudan, the Afar region of Ethiopia, Karamoja in Uganda, and Turkana in Kenya, as part of the Pan African Rinderpest Campaign. The effort, directed by the Organization of African Unity/Interafrican Bureau for Animal Resources and implemented in partnership with various nongovernmental organizations working on the ground, quickly achieved dramatic results.

In South Sudan, where armed conflict had disrupted cold chains and brought vaccination efforts to a standstill by 1992, a community animal health worker program using the new vaccine succeeded in vaccinating over 4.3 million cattle between 1993 and 1995; as a result confirmed outbreaks of rinderpest decreased from 11 in 1993 to only one in 1998.[b] In Ethiopia's Afar region, where government teams had been unable to contain the disease through a 15-year campaign dating back to the late-1970s, community animal health workers succeeded in vaccinating 73,000 cattle in just one season in 1994. Because of this success there were no further cases of rinderpest after 1995; the reservoir of infection had been effectively removed.

Prepared by: Andy Catley, Tim Leyland, and Peter Roeder

---

a. Leyland, T. 1996. The case for a community-based approach with reference to southern Sudan. In *The world without rinderpest*, FAO (Food and Agricultural Organization of the United Nations) Animal Production and Health Paper 129. Rome: FAO.

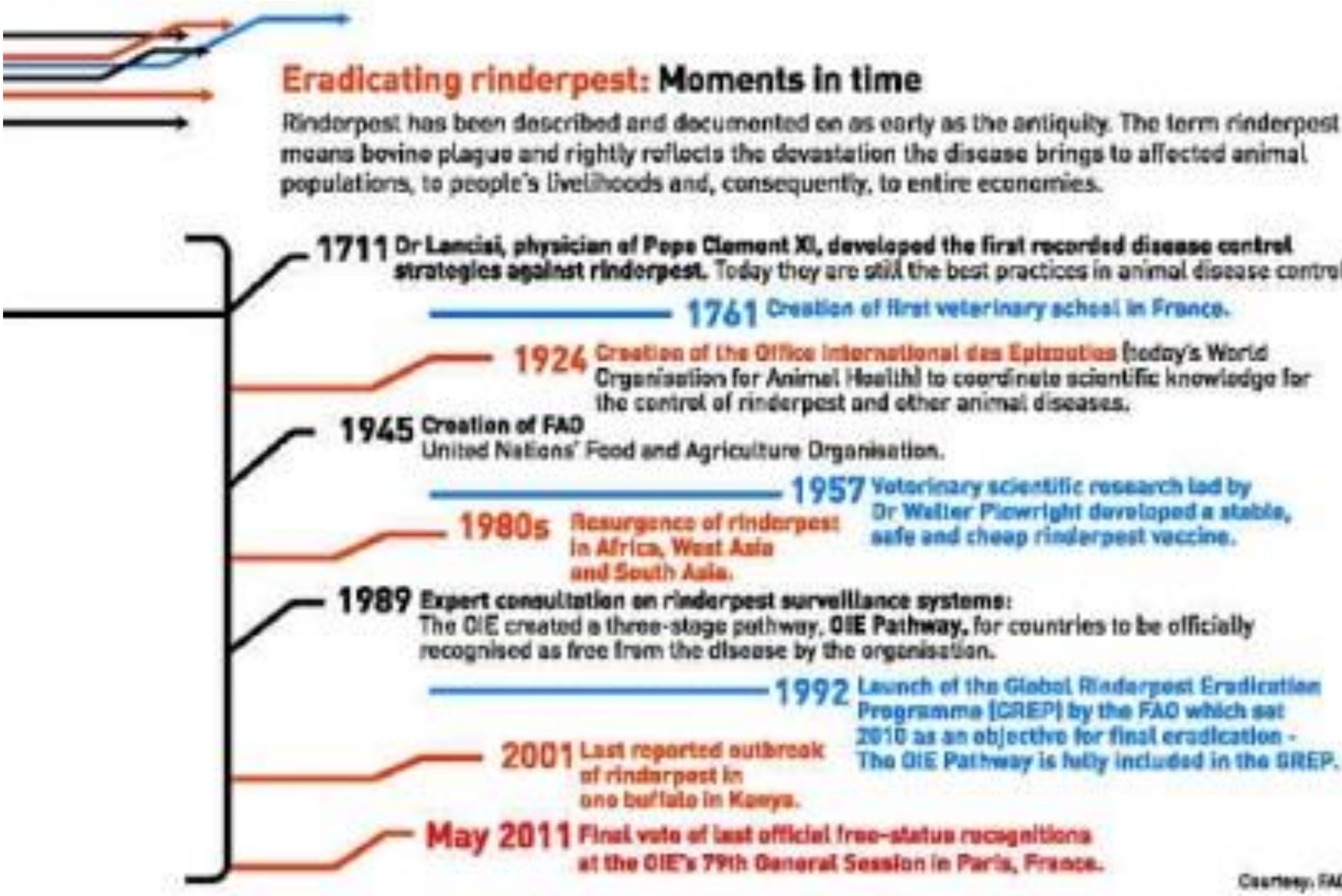
b. Catley, A., T. Leyland, and S. Bishop. 2008. Policies, practice and participation in protracted crises: The case of livestock interventions in South Sudan. In *Beyond relief: Food security in protracted crises*, ed. L. Alinovi, G. Hemrich, and L. Russo. Rugby, England: Practical Action Publishing and Rome: FAO; Leyland 1996.

Walter Plowright receives World Food Prize for pioneering work on rinderpest vaccine

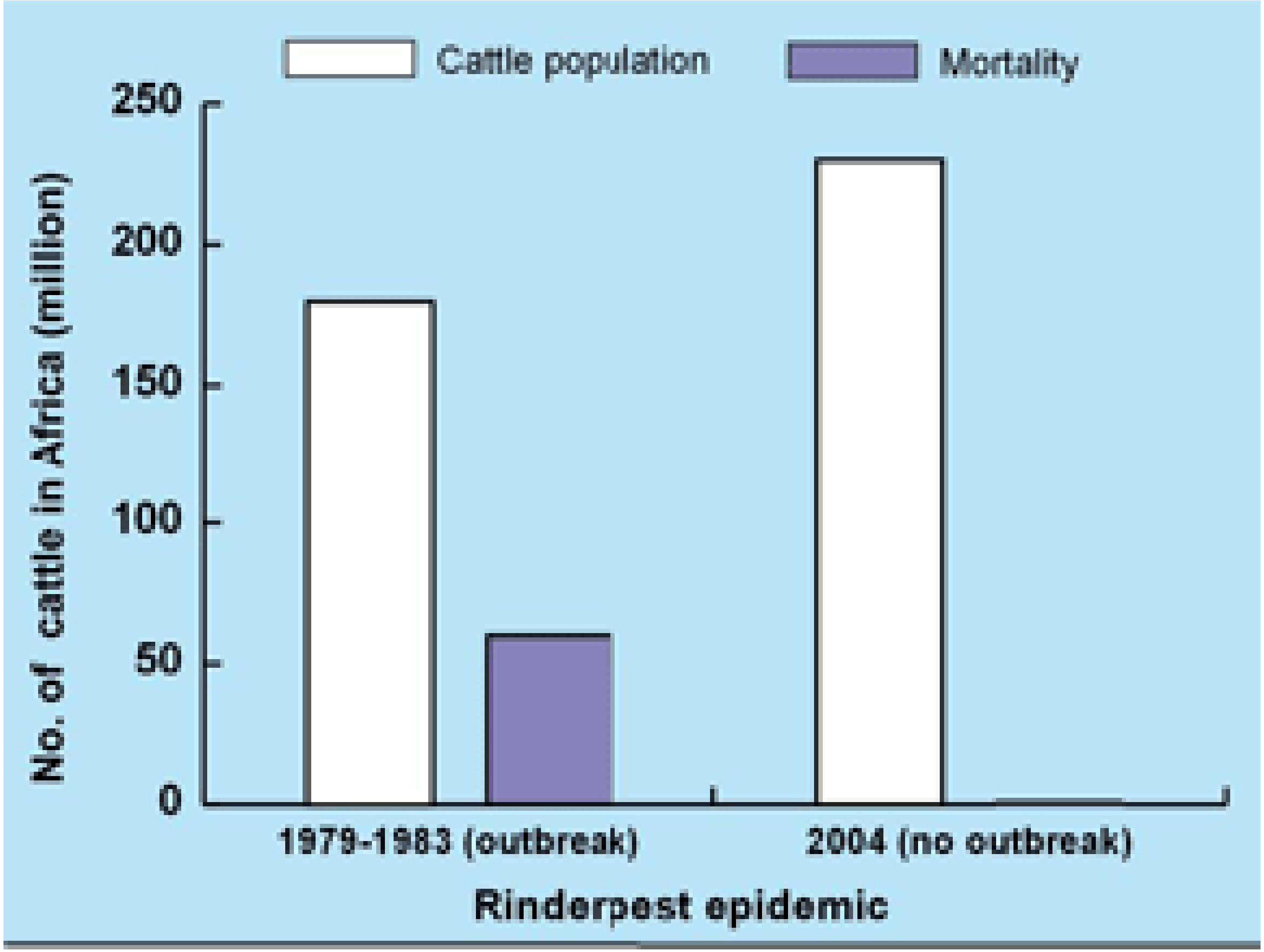
More rinderpest heroes…!

From left to right Michael Baron, Martyn Jeggo, Bill Taylor, Peter Roeder and John Anderson

Time line for eradication of rinderpest



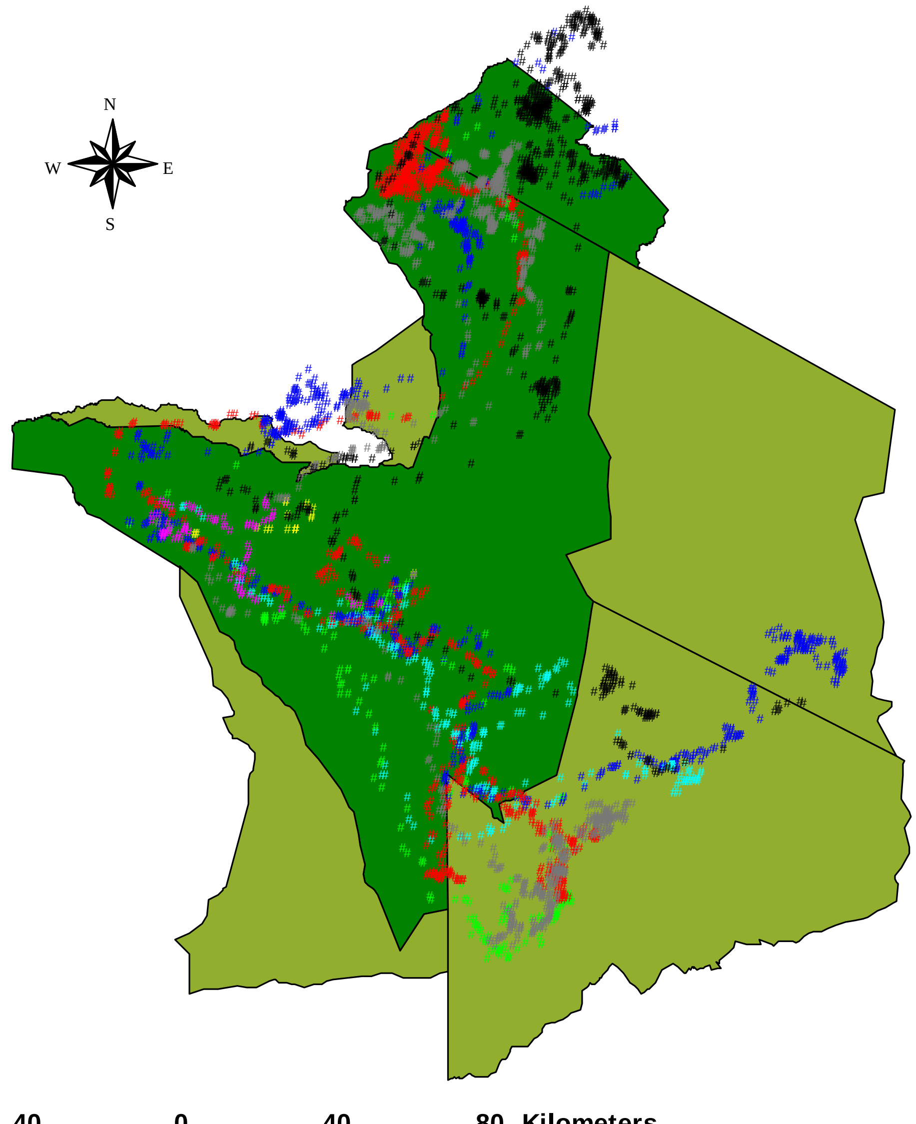
Consequences of rinderpest control in Africa



Statistics showing numbers of animals and incidence of rinderpest outbreak

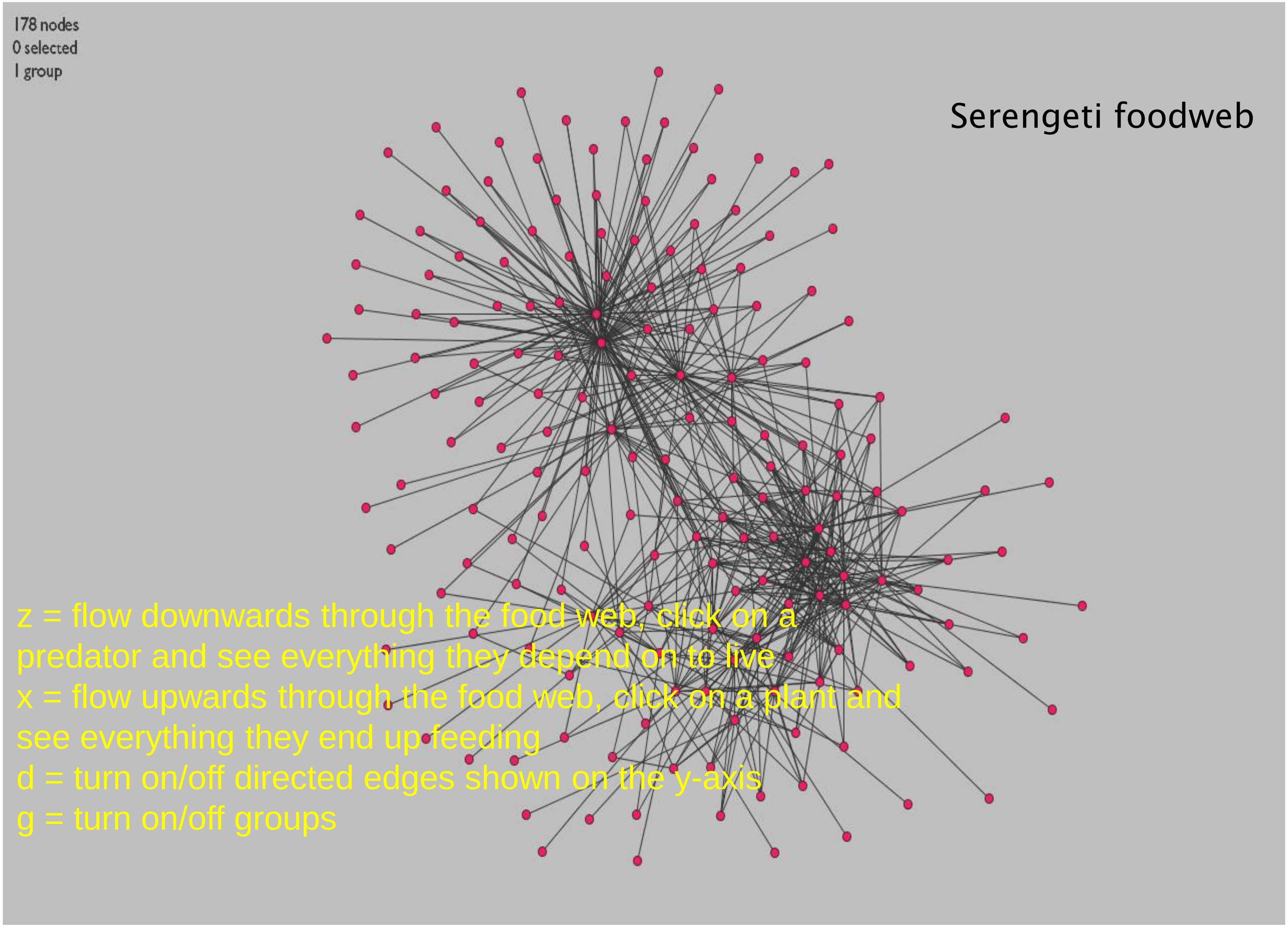
Serengeti National Park

- Established as National Park in 1951, formally gazetted 1959
- Currently 14,763 km^2
- Defined by the movements of migratory wildebeest
- Diversity of habitats – short-grass plains, woodlands and riverine forests



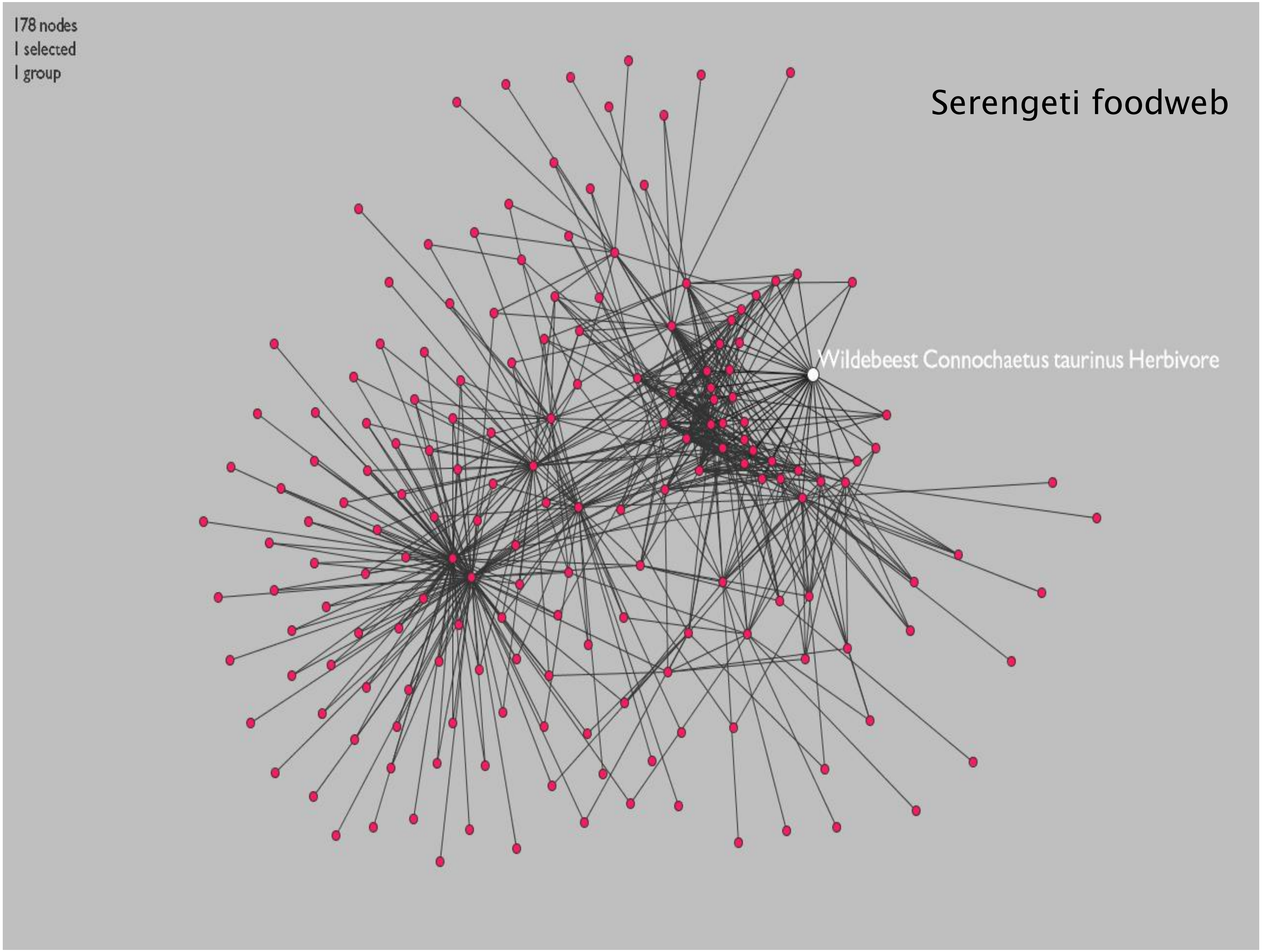
SERENGETI ECOSYSTEM

Photo from Felix Bonner, FZS



Work with Ed Baskerville, Trevor Bedford, Stefano Allesina and Mercedes Pascual

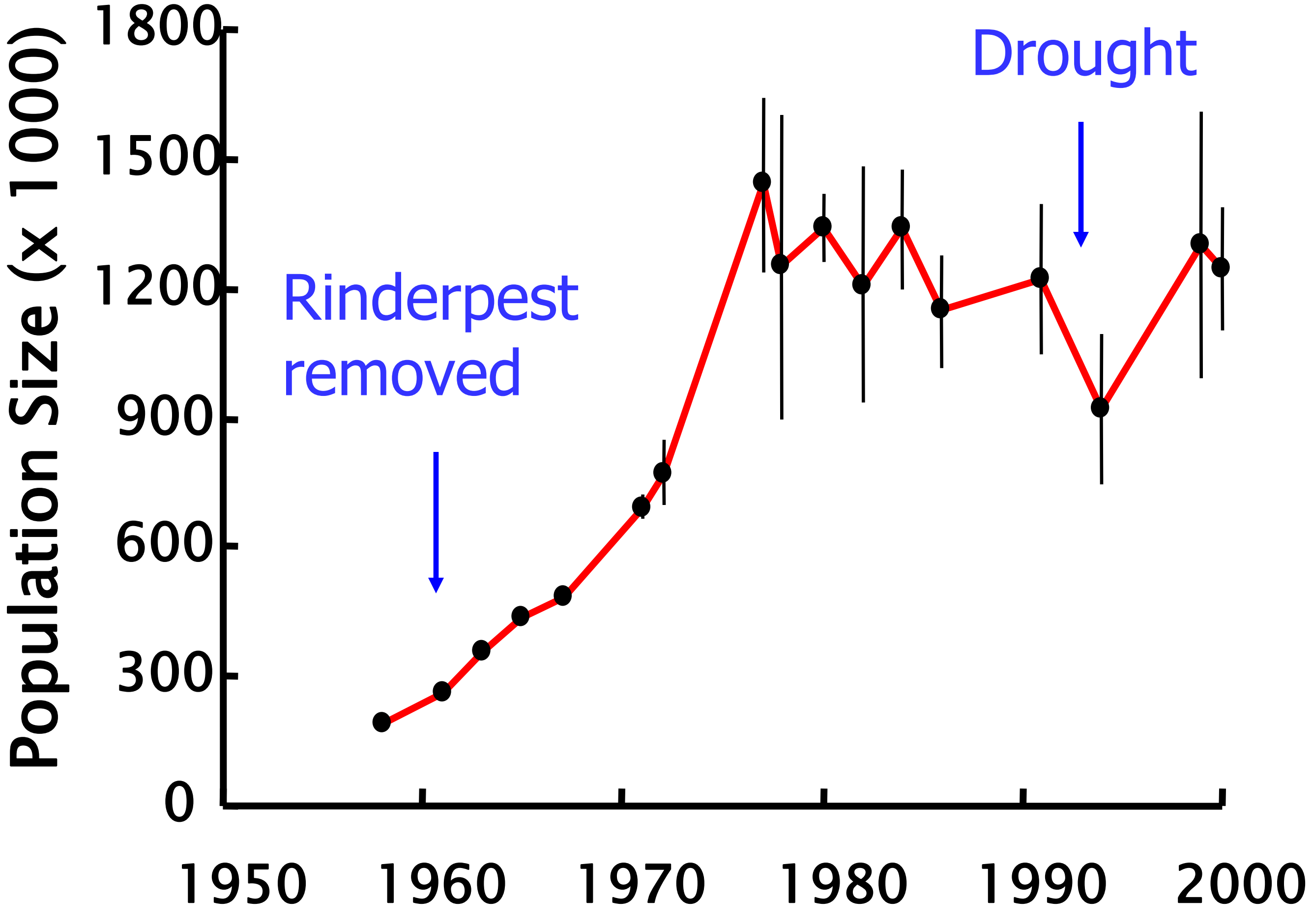
Serengeti foodweb



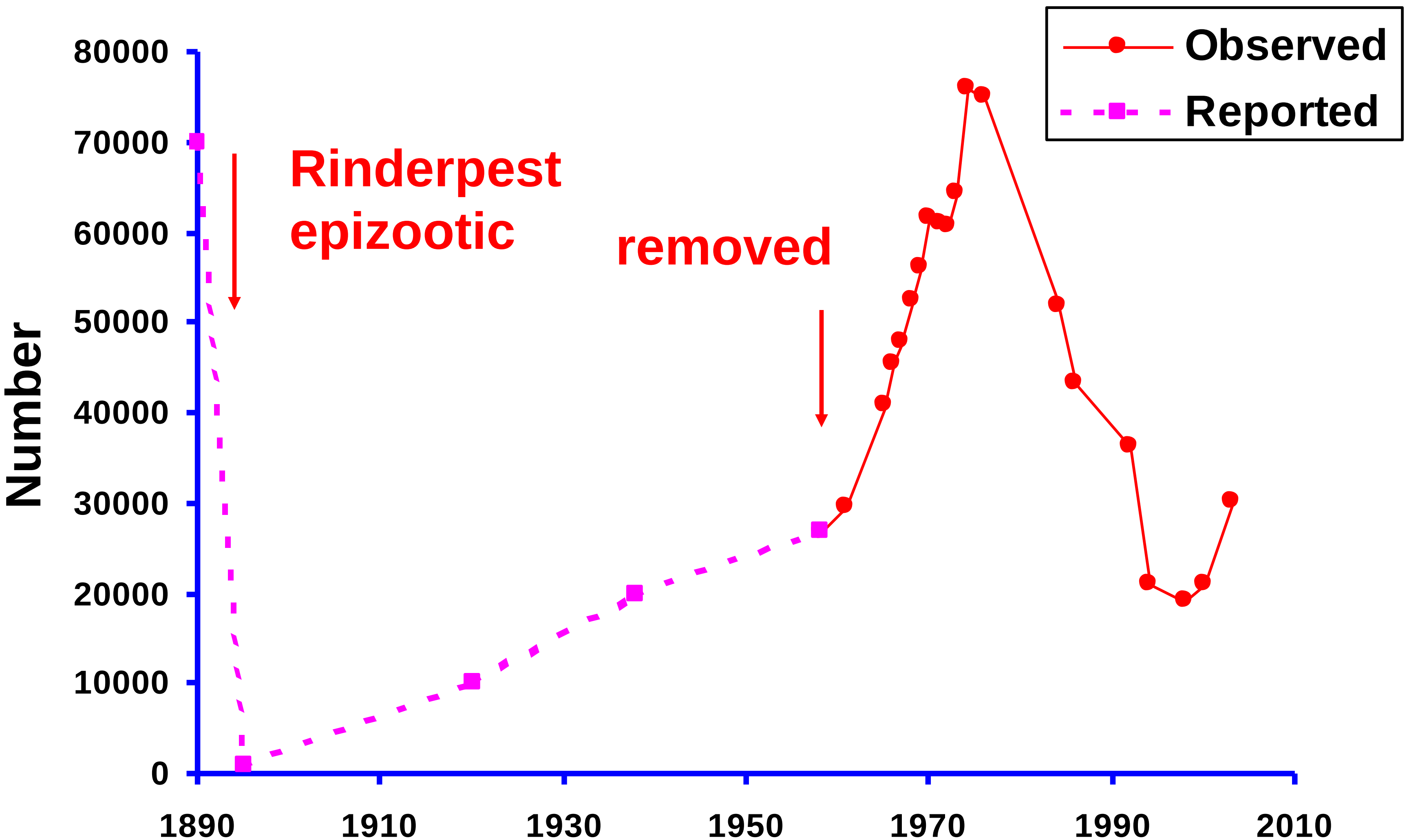
The Great Rinderpest

- The Epizootic of 1889
- Ethiopia to Cape by 1896
- Die-off of cattle and other ruminants 95%
- These include African buffalo
- Wildebeest yearling disease present up to 1963

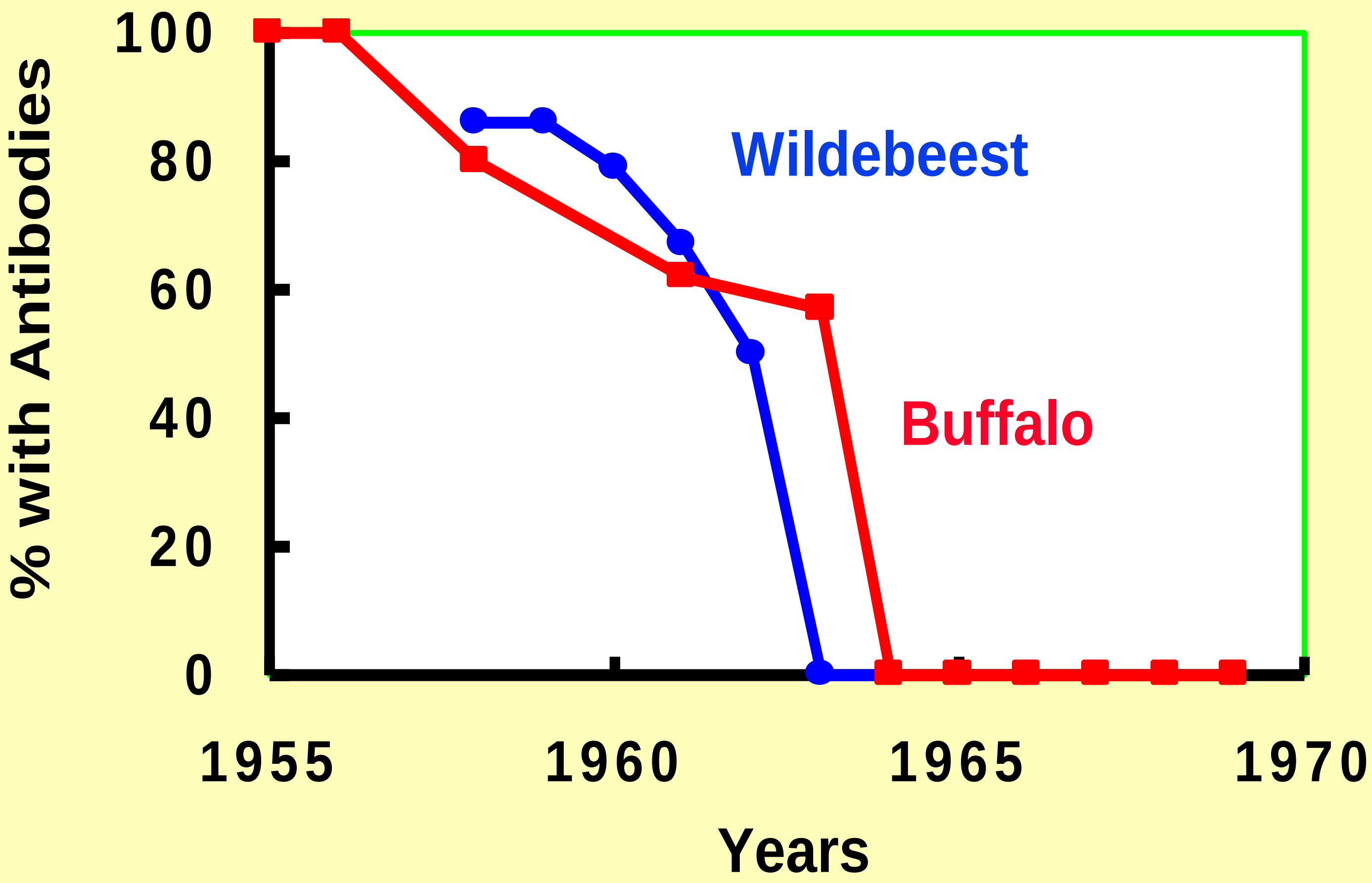
Serengeti Wildebeest Population



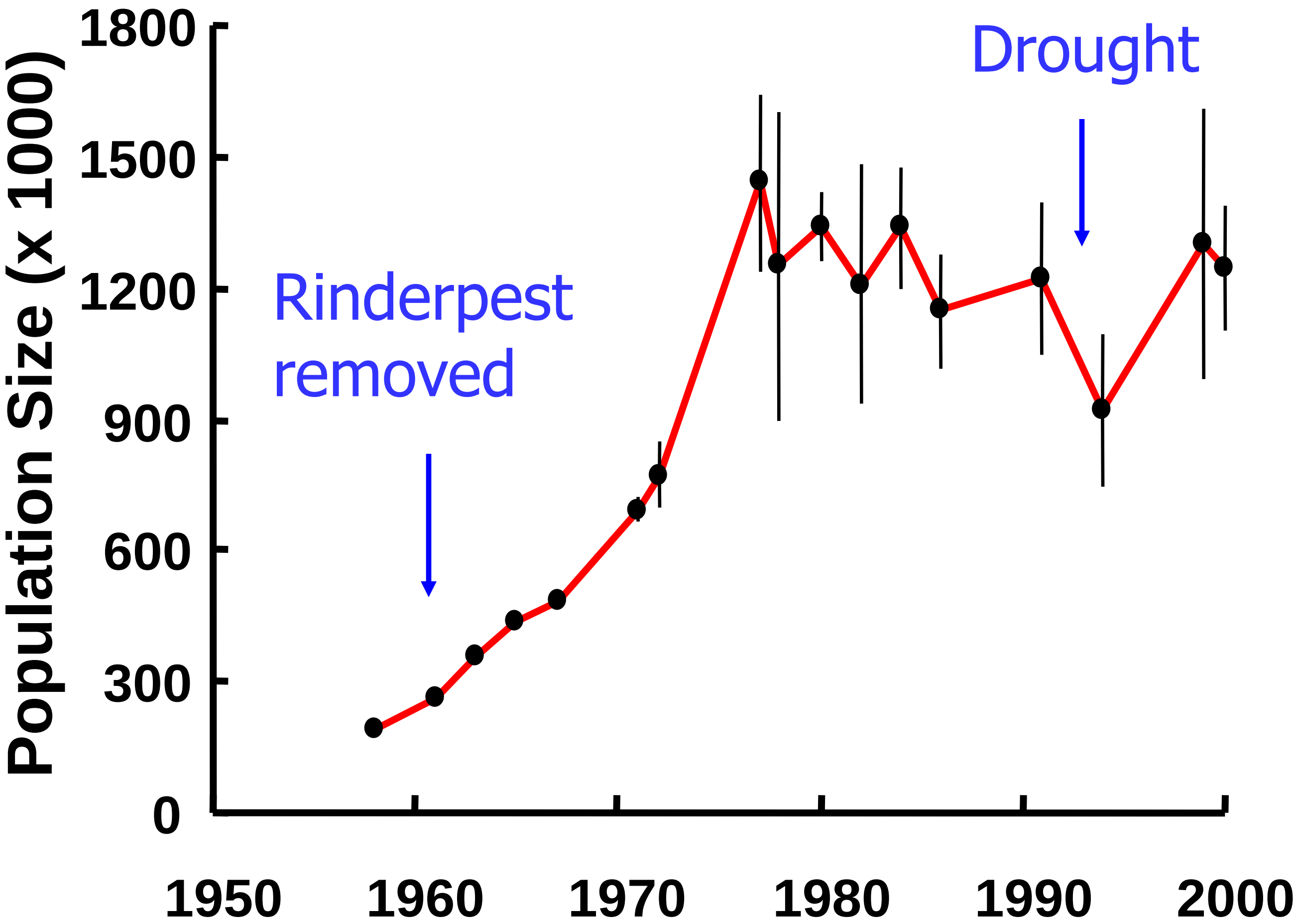
Buffalo long-term change 1890-2003



Incidence of Rinderpest in Serengeti

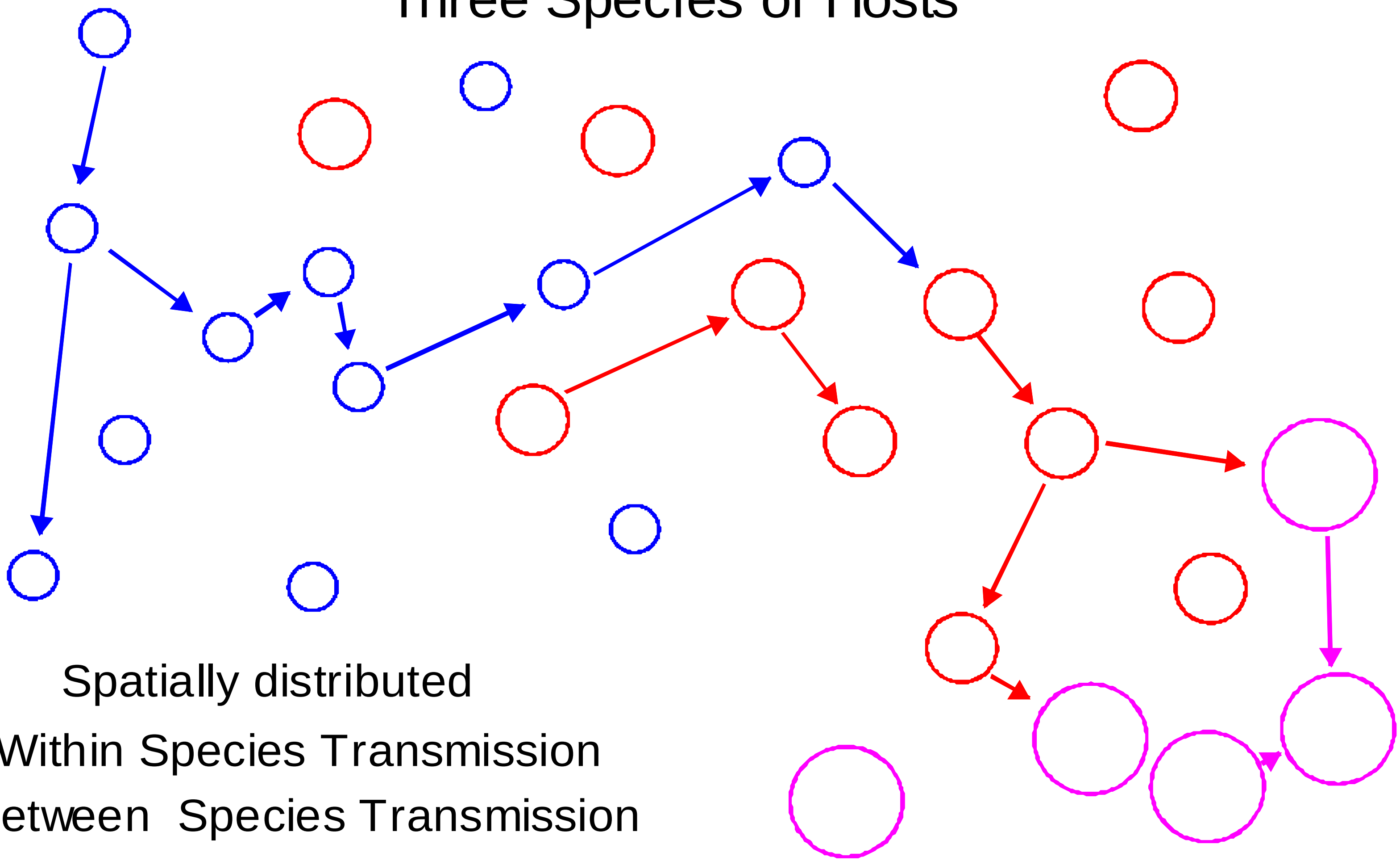


Serengeti Wildebeest Population



A cartoon of the talk.....

Three Species of Hosts



Spatially distributed

Within Species Transmission

Between Species Transmission

Rinderpest – Serengeti

Basic model structure..

Susceptibles

Allometric scaling of all birth and death rates

$$dS_i/dt = (b_i - d_i - \Delta_i(S_i + I_i))S_i - (\beta_{ii} I_i + \sum \beta_{ij} I_i) S / (\sum_{j=1,n} N_n)^c$$

Within

Between

Infecteds

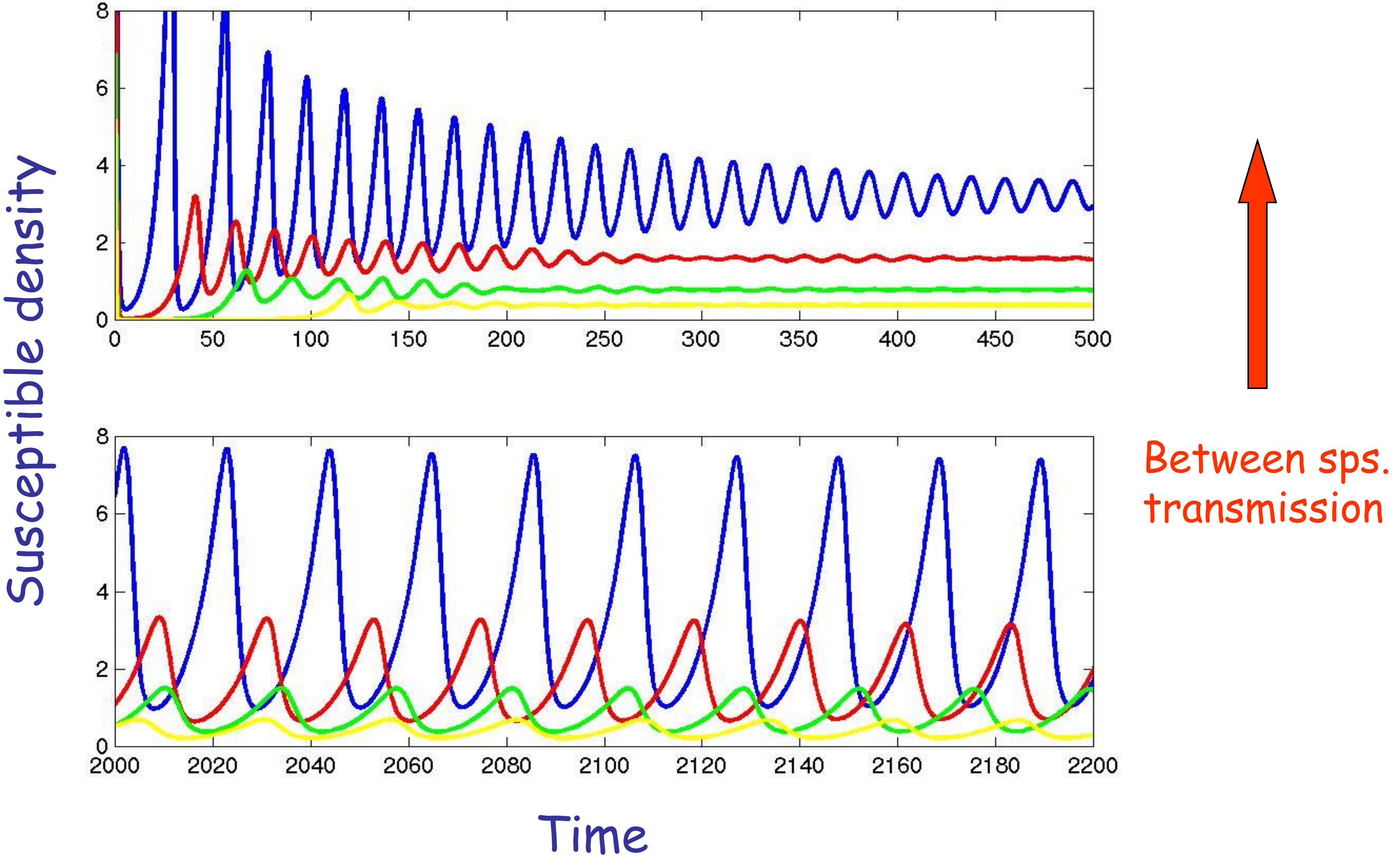
$$dI_i / dt = (\beta_{ii} I_i + \sum \beta_{ij} I_i) S / (\sum_{j=1,n} N_n)^c - d_i(1 + \alpha_i) I_i$$

Scale virulence
as a proportion
of life expectancy

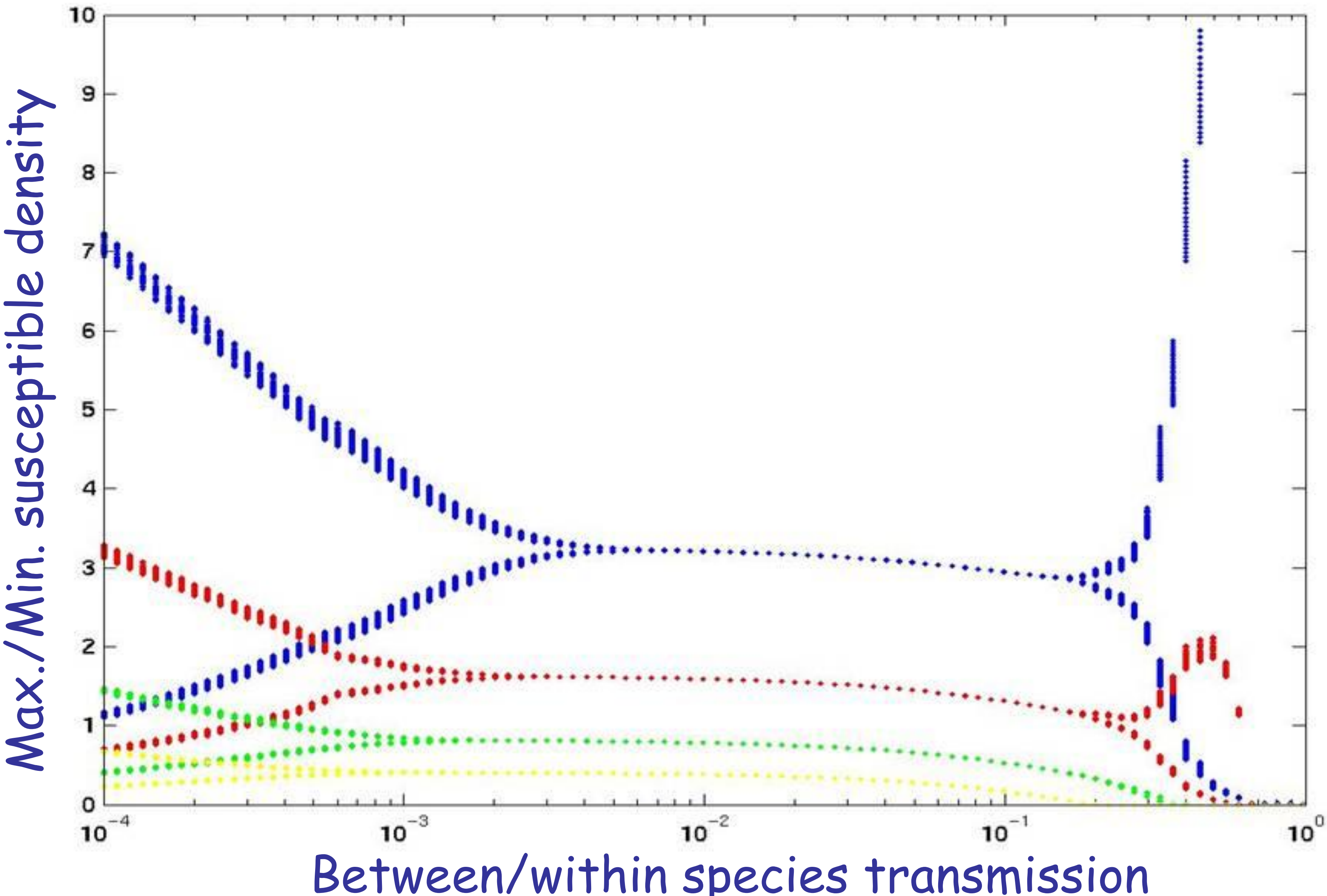
Between species transmission

$$\beta_{ij} = c\sqrt{\beta_{ii}\beta_{jj}}$$

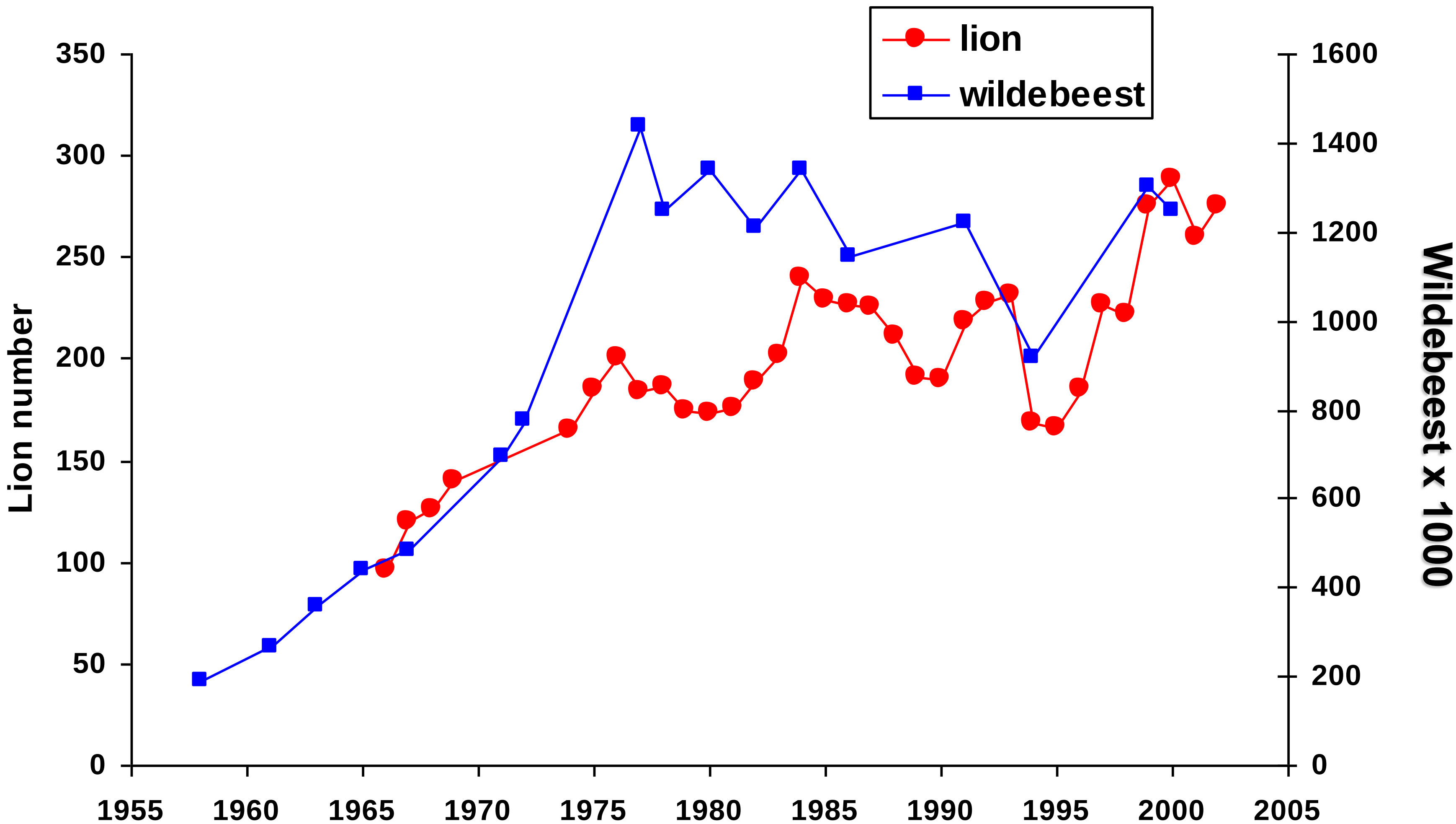
Buffering: dynamics in DD case



Buffering: dynamics in DD case



Serengeti woodland lion numbers



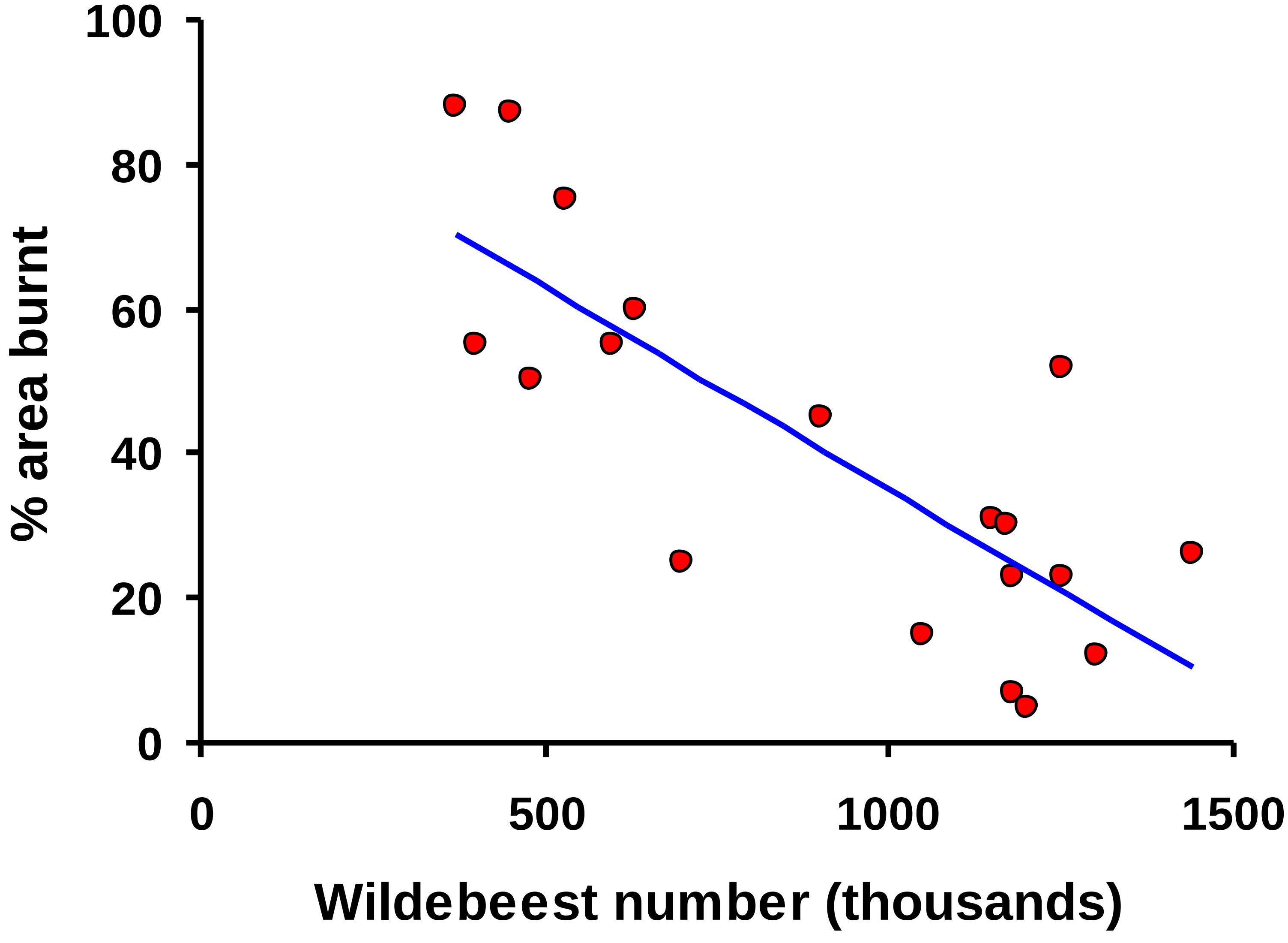
Lion data from C. Packer

Grass fires prevent regeneration below 2 m height

Repeated burning prevents regeneration and produces a distorted age structure of old trees

Wildebeest grazing reduces grass fuel and area burnt

Increase in wildebeest causes decrease in burning



Serengeti as Carbon sink…

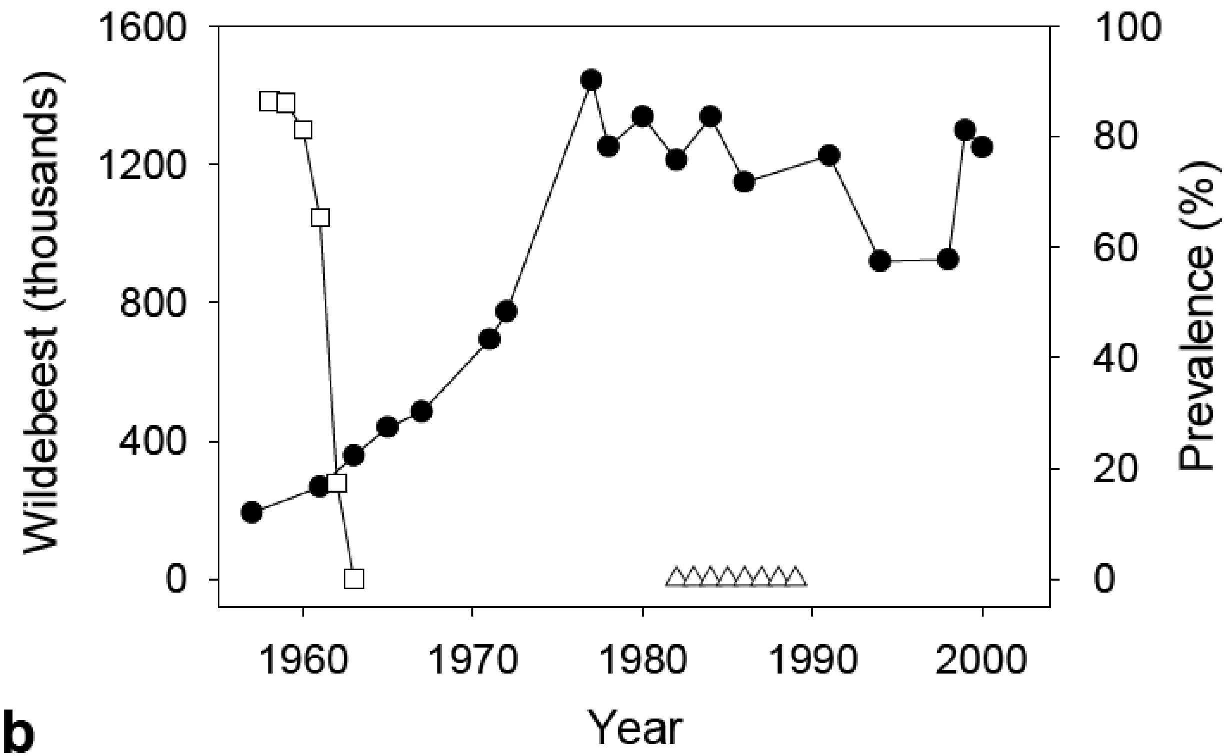
- The 2.5 million wildebeest, zebra and gazelles remove at least 50% of the 100-200 g/m^2 of plant material each year.

- The poop and beetles return this to the soil
- Fire suppression allows woodland to recover, trees are carbon…

- How much C does this store 50?, 100?, 200? 500? $Mg/km^2/year$??

Rinderpest and wildebeest…

a



b

Plus – series of annual photographs of tree and grass cover since 1960's…

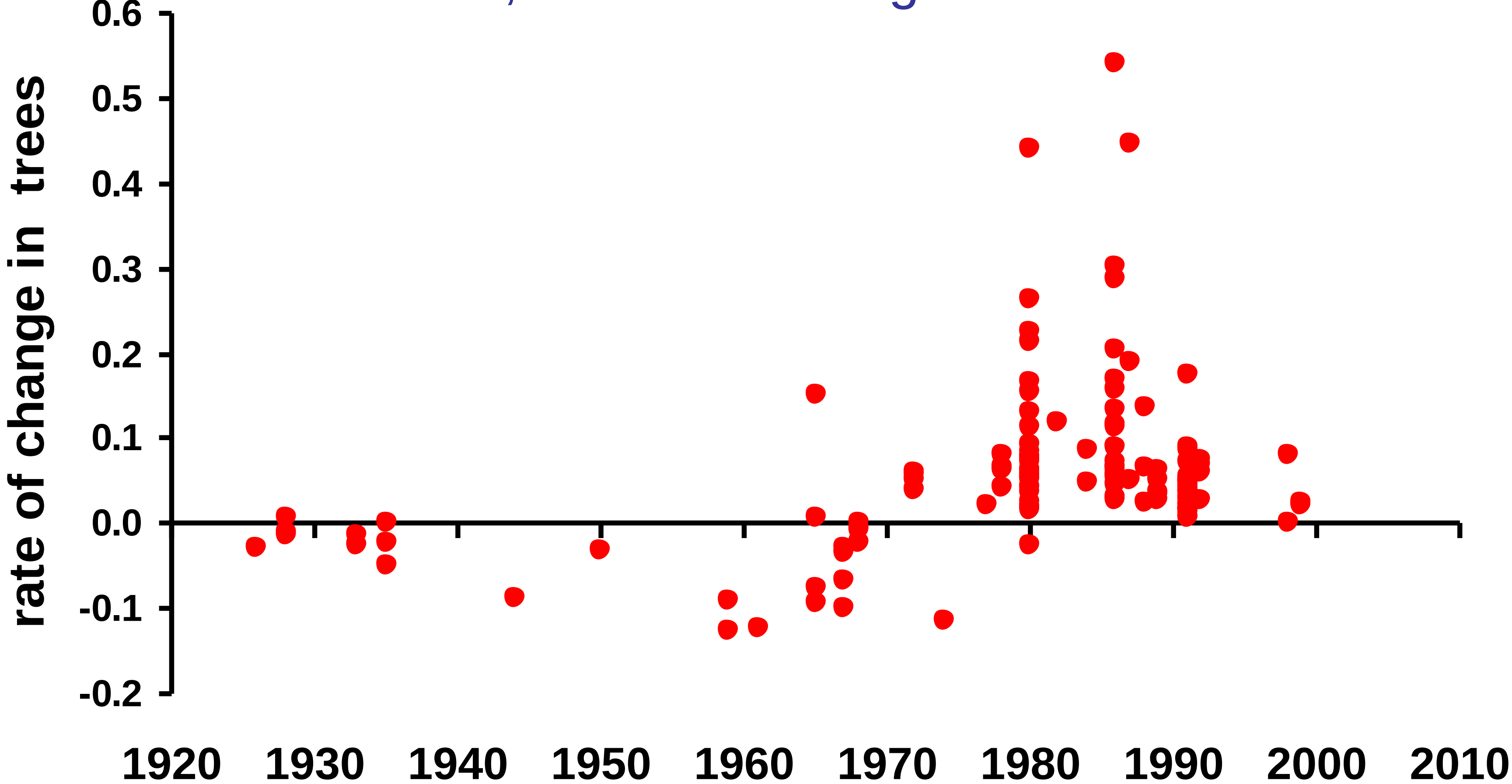
1980

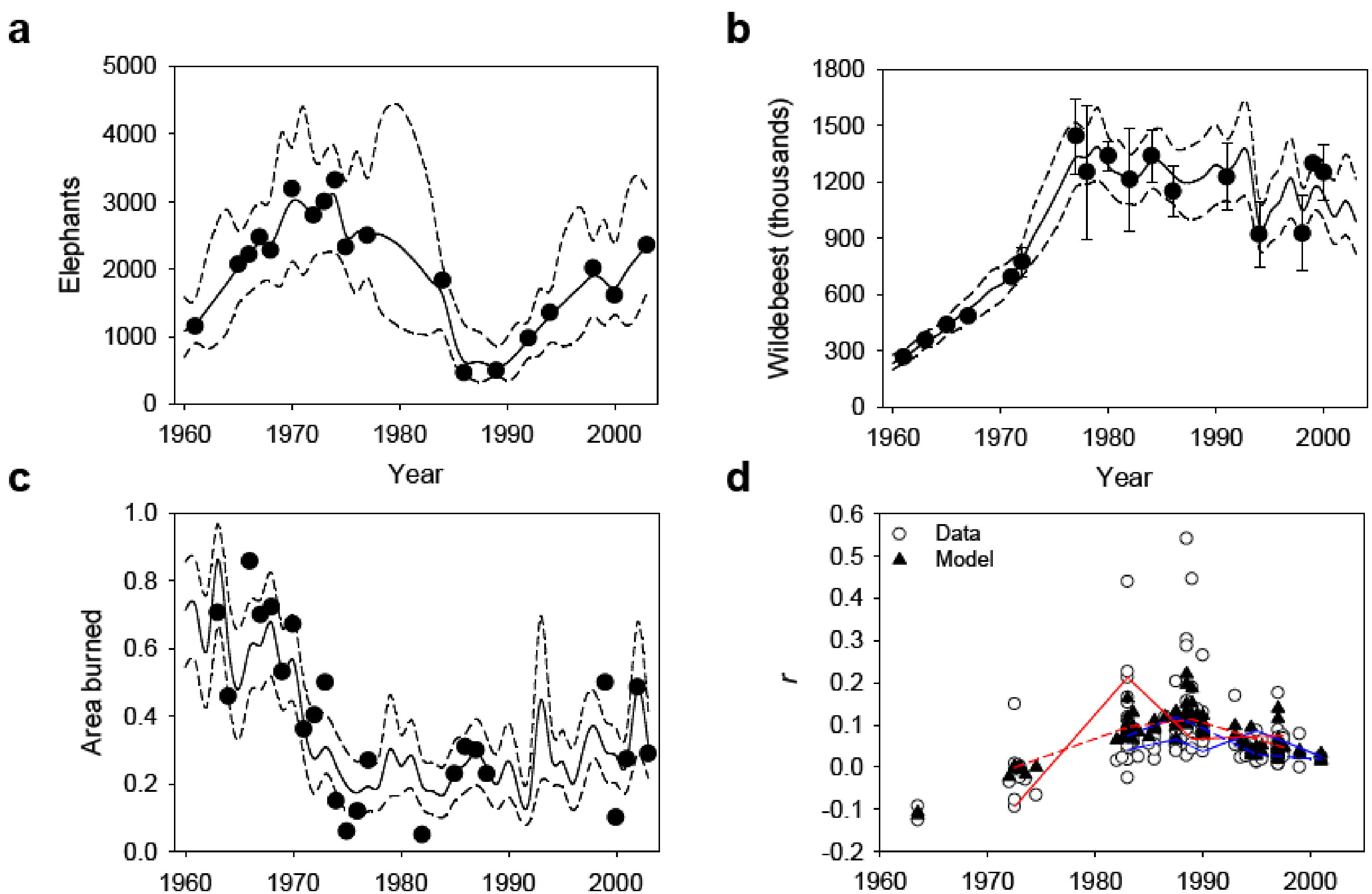
1986

1991

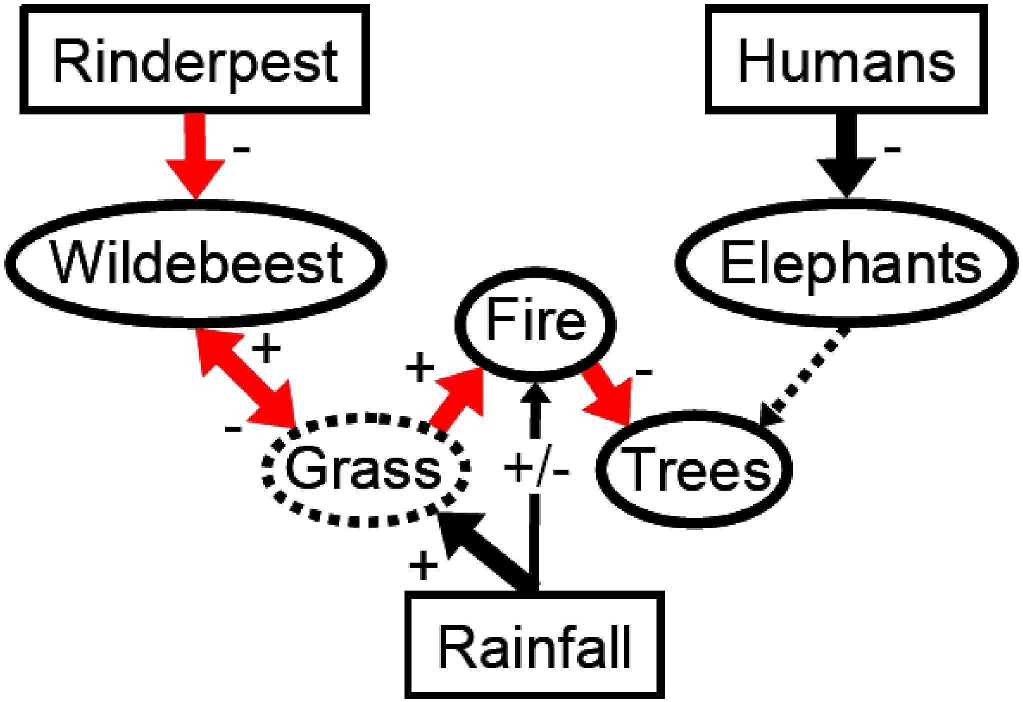
SERENGETI TREE DENSITY

Instantaneous rate of change in tree density negative 1920s-1960s, then increases rapidly in 1980s, 1990s following wildebeest



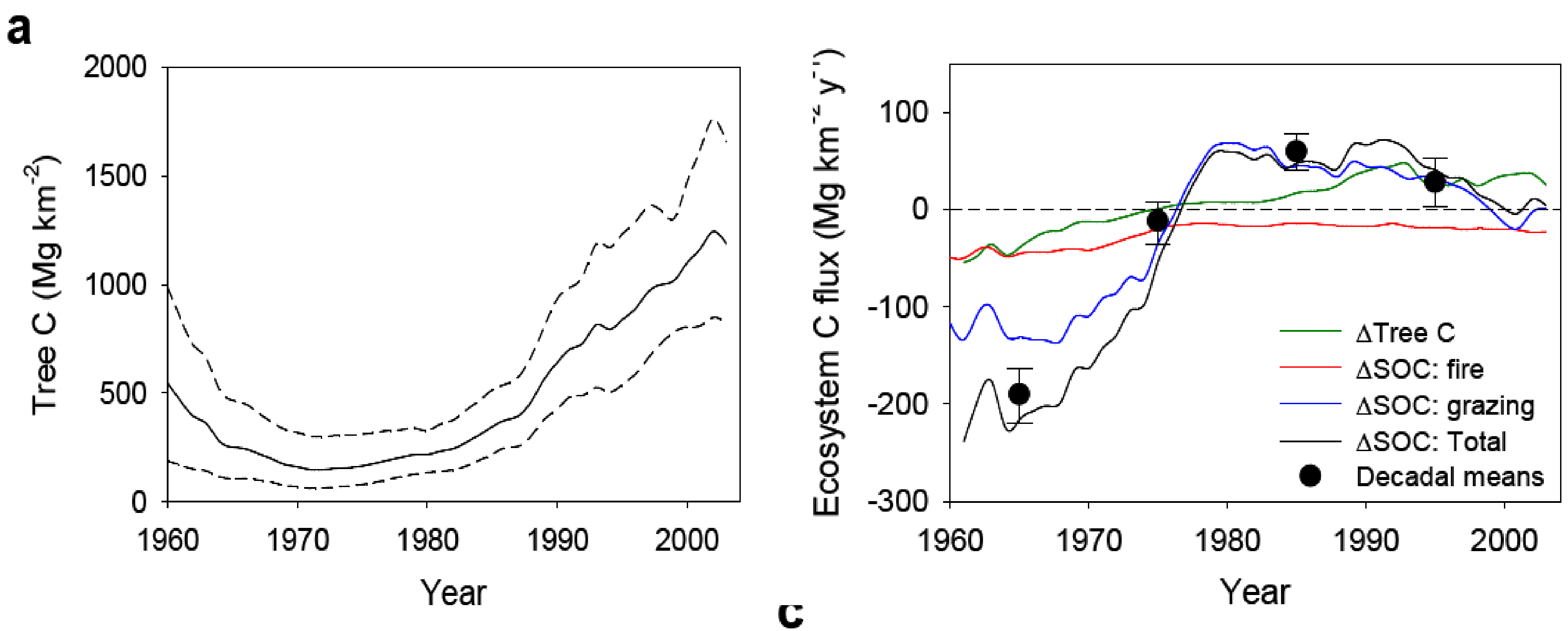


State-space model fits to the data for the best model. **a**, Elephants, **b**, Wildebeest, and **c**, Proportion of SNP burned. Shown are observations (●), posterior means of estimated true values (solid line), and 95% credible intervals for the posterior distributions (shaded area). Standard errors for the observed values are shown for the wildebeest data. **d**, Annualized rates of tree cover change (*r*), centred on the midpoints of each time span (e.g., a value of *r* based on photos taken in 1980 and 1990 is centred on 1985). Correlations among points (corresponding to photo sites) are not shown for legibility, except for two sites: (blue and red solid lines = data; dashed lines = model fit).



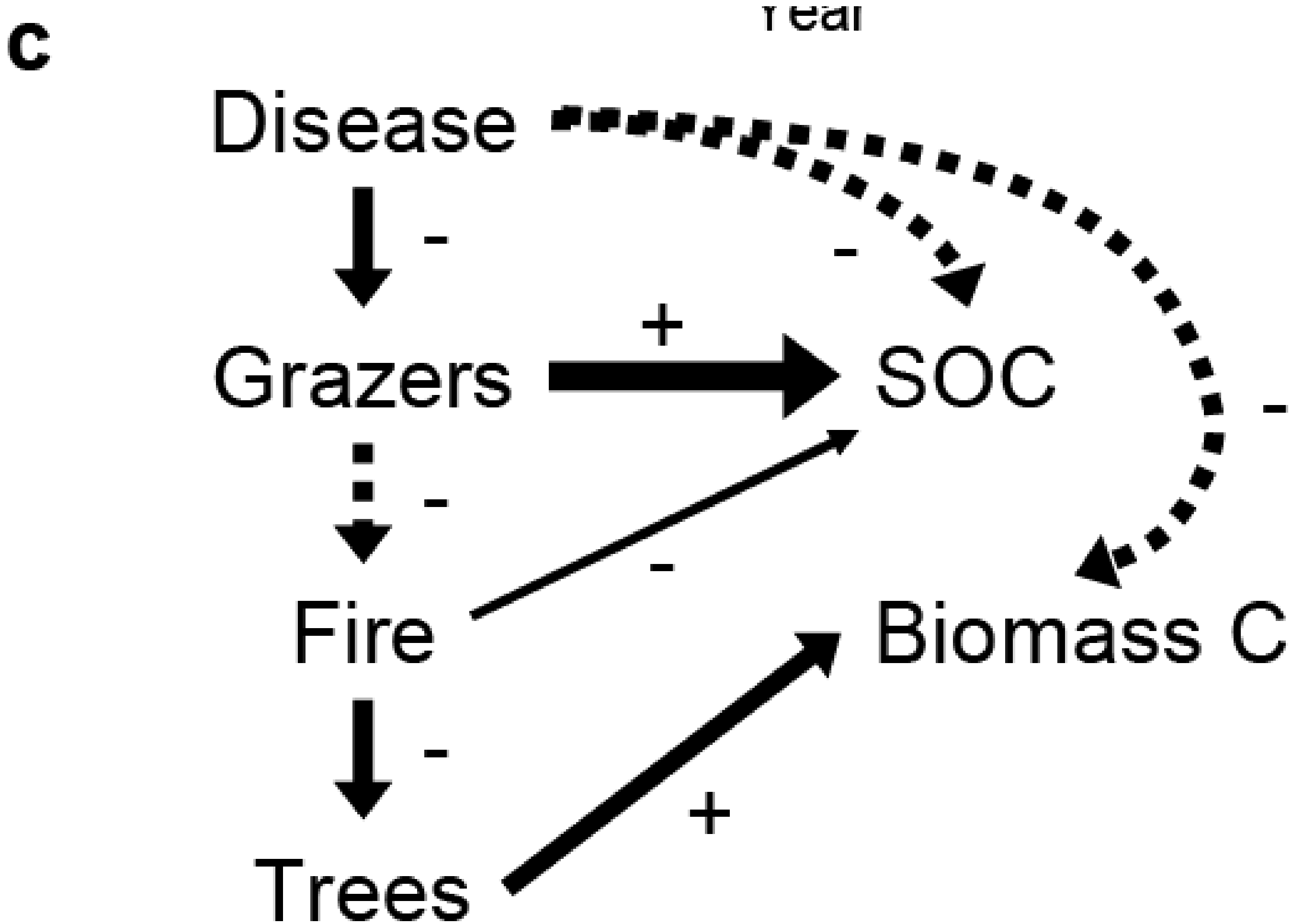
Inferred causal relationships driving tree dynamics in the Serengeti.
The dominant effects are shown with thick arrows.
Highlighted in red is a four-step pathway of causality linking rinderpest
with tree population dynamics.
The grass compartment, as an unobserved variable, is shown in dotted outline.

Carbon stored in Serengeti trees



Simulated shifts in ecosystem C balance. a, Simulated trajectory of woody biomass C in the Serengeti ecosystem between 1960-2003; **b**, Simulated changes (as 5-year moving averages) in ecosystem C balance (total, tree biomass C, and SOC changes driven by fire and grazing) and annualized decadal net changes in total ecosystem C balance (means ± 95 CIs); the temporary shift from net sink to source predicted by our simulation in 2000 was driven by drought and the resulting overgrazing.

Holdo et al, in press



Inferred causal pathways linking disease with ecosystem C flux as a result of a trophic cascade (solid line=direct effects and dashed line=indirect effects).
(Holdo et al, in press)

Carbon stored in Serengeti soils

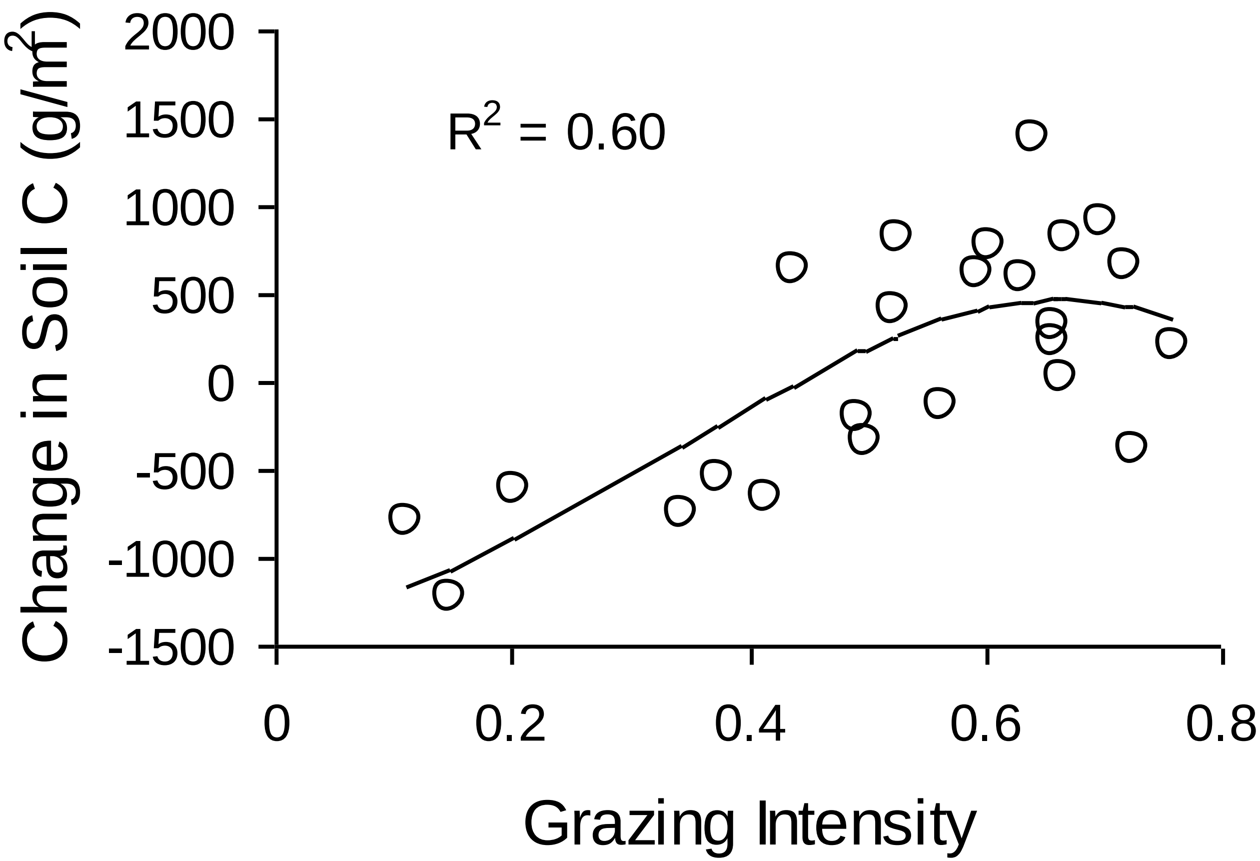


Fig. 1. Mean (±SE) difference in SOC estimated to a depth of 40 cm among paired fenced and unfenced plots across eight sites in Serengeti National Park as a function of the mean grazing intensity (proportion of production consumed) for each set of paired plots (Ritchie et al, in press).

SOC in Serengeti Soil and Wood

- Our simulations of C fluxes suggest that the changes in wildebeest population density, fire prevalence, and tree cover that have occurred over the past half-century have had important effects on the stocks of both woody biomass and of soil C that determine the total C stocks in the Serengeti ecosystem (Fig. 3). At present, the Serengeti constitutes a net C sink, removing on the order of 40-70 Mg C km-2 y-1 from the atmosphere in woodland habitat (Fig. 3b). Across 25,000 km2 of mostly protected woodland habitat across the entire ecosystem, this is equivalent to 10^6 Mg C y-1 (Holdo et al, in press)

- **Expected greater methane production from higher herbivore densities was too low to cancel the potential CO2 offset from increased grazing from wildlife conservation and a moderation of fire frequency, which in the Serengeti could offset the equivalent of 400-600 Mg.km-2.yr-1 of CO2.**

- Mg – Megagrams – 10^6 – grams / square kilometer / year

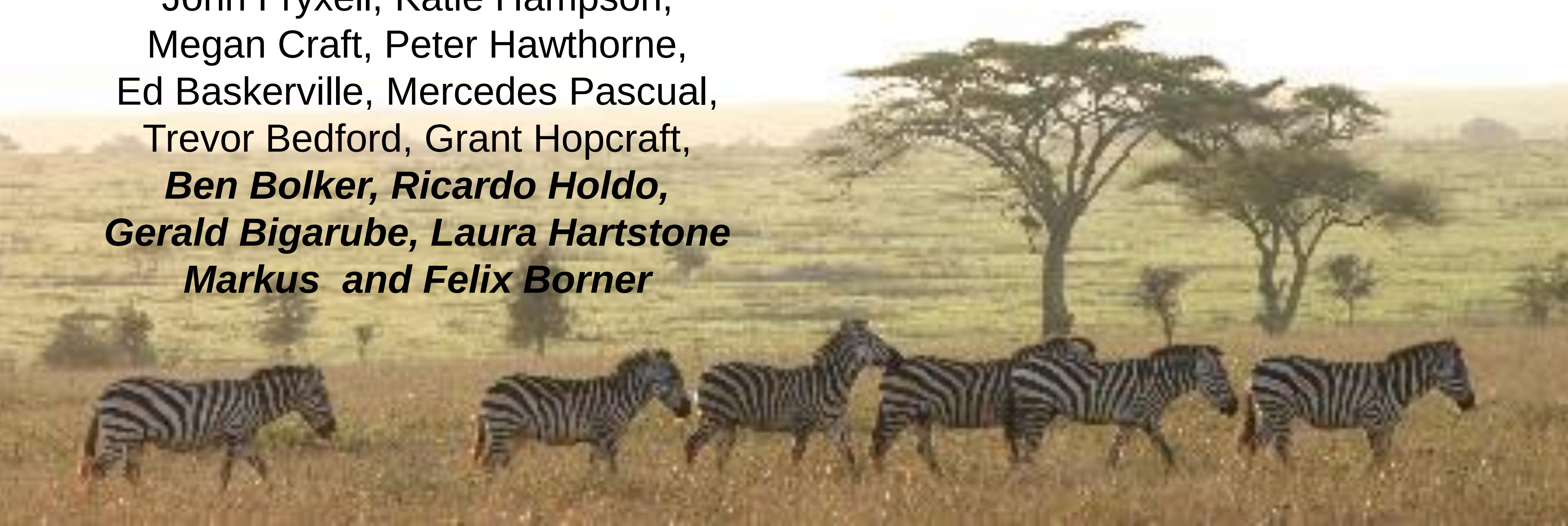
Value of carbon stored

- 200-400 Mg/km^2 is worth
- = \$2000-\$4000 / km^2 / year
- Serengeti NP + surrounding ecosystem = 12,700 + 29,000 km^2 = 40,000km2
- Net annual value = \$80 to \$160 million!

- Need to set up deal with airlines to retrieve significant amount of this.

Serengeti Multihost Pathogens and Ecosystem Consequences of Roads and Parasites

Based on Work in Collaboration with
Tony Sinclair, Simon Nduma,
Craig Packer, Sarah Cleaveland,
Mark Ritchie, Han Olff, Ray Hilborn,
John Fryxell, Katie Hampson,
Megan Craft, Peter Hawthorne,
Ed Baskerville, Mercedes Pascual,
Trevor Bedford, Grant Hopcraft,
Ben Bolker, Ricardo Holdo,
Gerald Bigarube, Laura Hartstone
Markus and Felix Borner



Walter Plowright

Walter Plowright, CMG, FRS[1], FRCVS (born 20 July 1923, Holbeach, Lincolnshire – 19 February 2010 London[2]) was an English veterinary scientist who devoted his career to the eradication of the cattle plague rinderpest. Dr Plowright received the 1999 World Food Prize for his development of tissue culture rinderpest vaccine (TCRV), the key element in the quest to eliminate rinderpest.[3] Rinderpest became the first animal disease to be eliminated worldwide

Worries for the future..

Pestes des petites ruminants, PdPRv

Disease of goats and gazelles

Cross-immunity to Rinderpest (distemper) – increasingly significantly in Africa..


Thank you!