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Simulation modelling of Rift Valley fever to inform epidemic control strategies in northern Tanzania

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University of Glasgow

SEEDZ - Social, Economic and Environmental Drivers of Zoonoses in Tanzania

- Aim: examine and assess the drivers, risks and impacts of zoonotic diseases affecting cattle, sheep and goats, and impacting on people's health, livelihoods and poverty, in northern Tanzania

Sarah Cleaveland

Jo Sharp

Rowland Kao

Louise Matthews

Will de Glanville

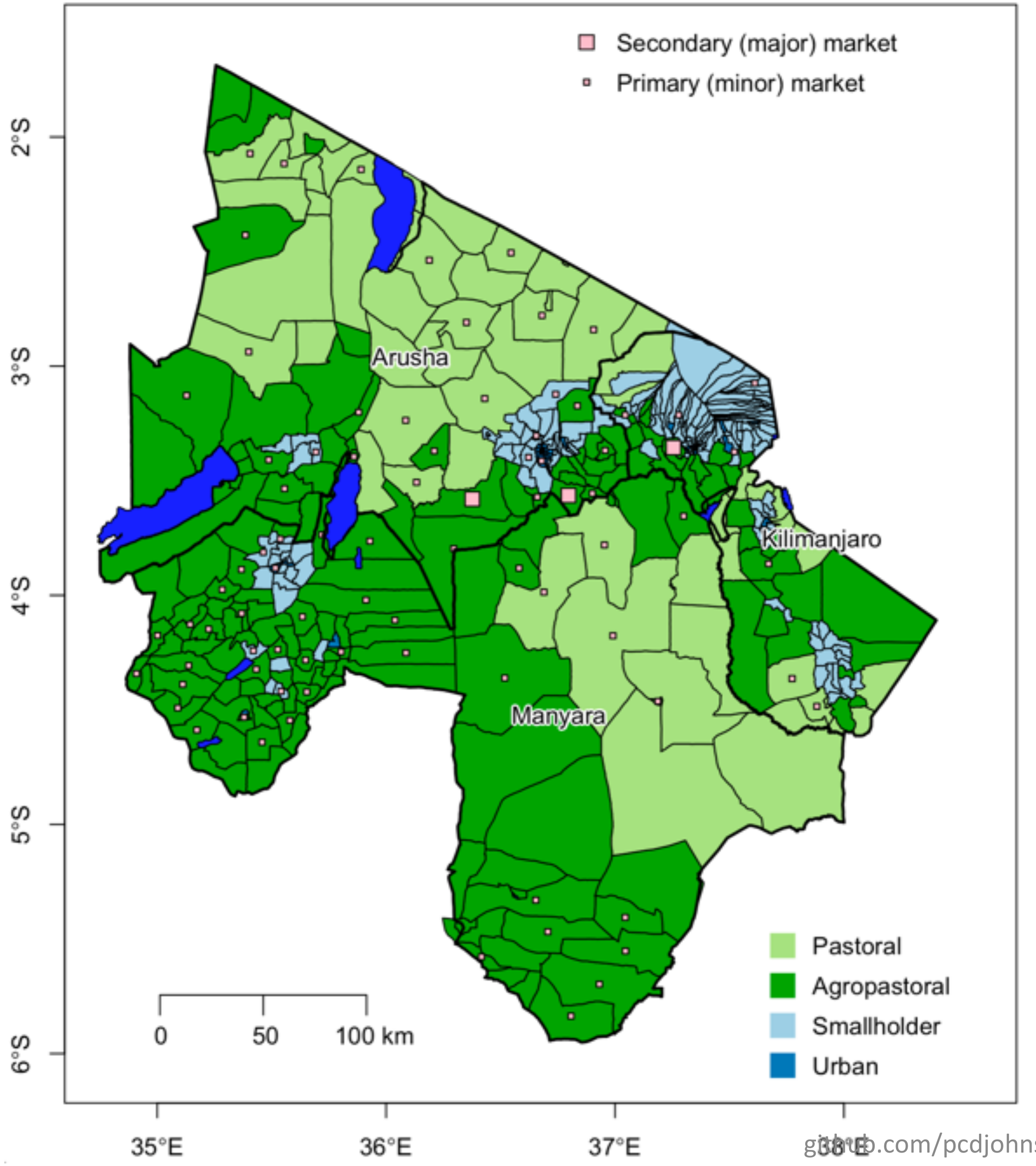
Gemma Chaters

ZELS Zoonoses & Emerging Livestock Systems

UKaid from the British people

BBSRC bioscience for the future

github.com/pcdjohnson/SEEDZ-RVF-sim



github.com/pcdjohnson/SEEDZ-RVF-sim

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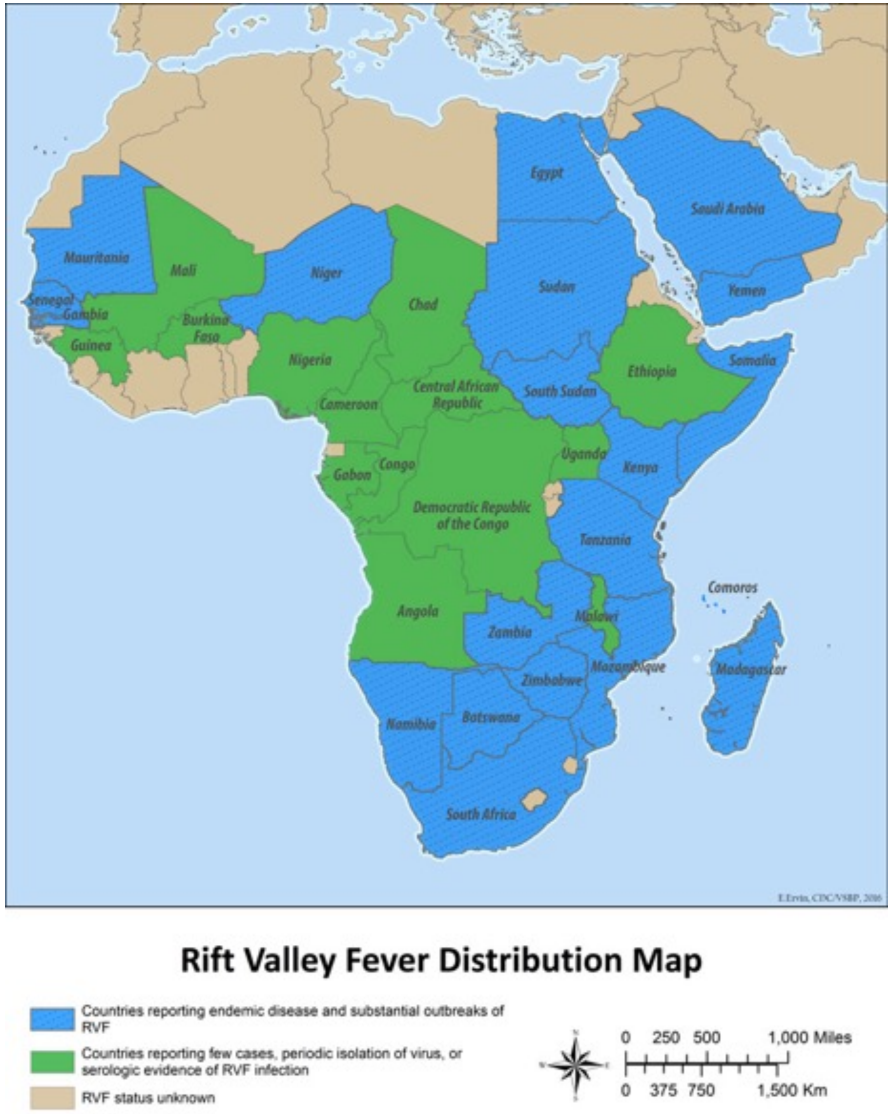
Rift Valley Fever

- Acute viral disease
- Affects cattle, sheep, goats, etc
    - Abortions
    - High mortality in young animals
    - Reduced milk and meat production
    - Indirect losses due to movement restrictions & market closures
- Affects humans
    - Eye disease, encephalitis, haemorrhage, death
- Epidemics across Africa every ~10 years
    - Linked to El Niño/Southern Oscillation



Rift Valley Fever Distribution Map

CDC Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

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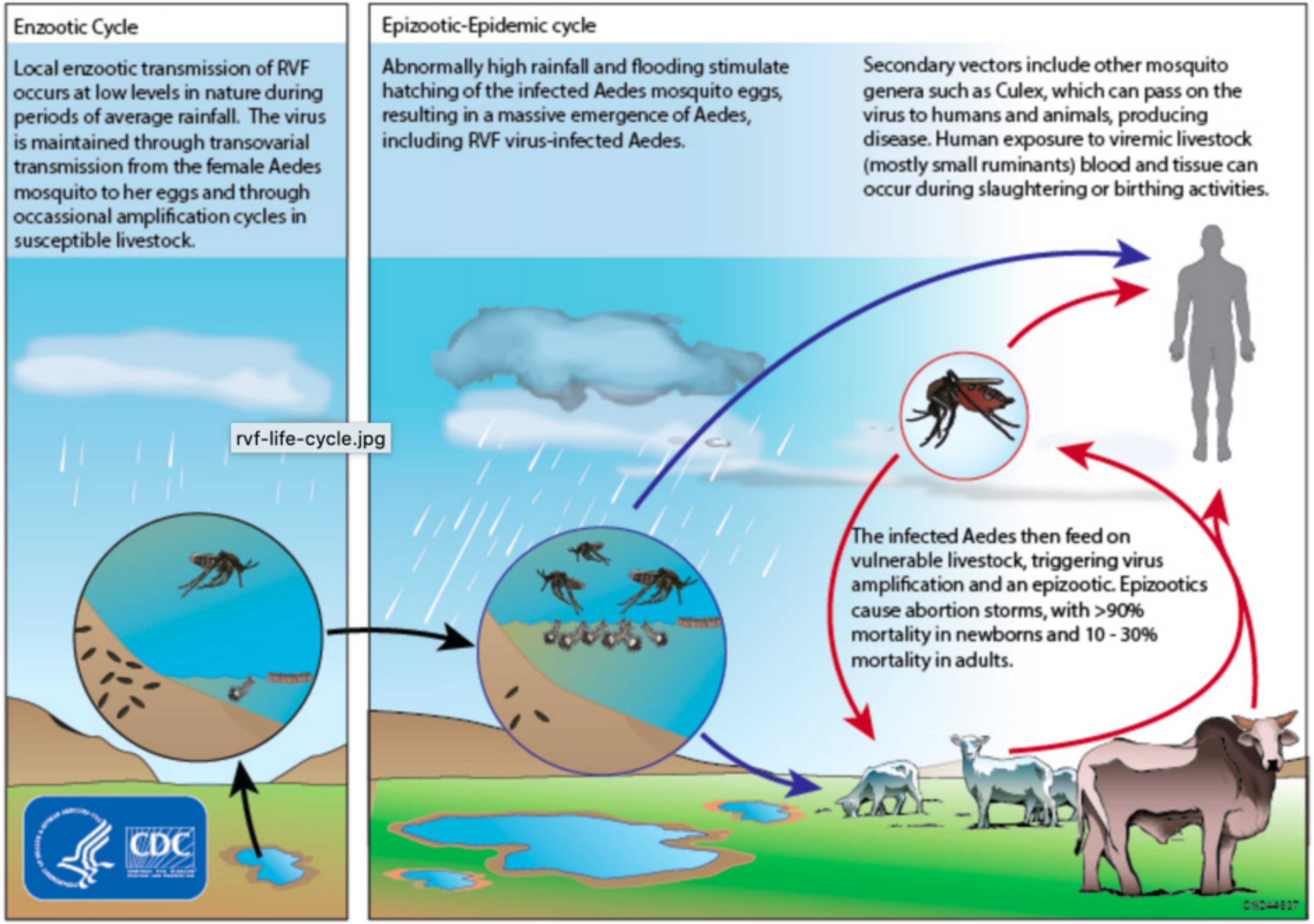
Rift Valley Fever (RVF) virus ecology



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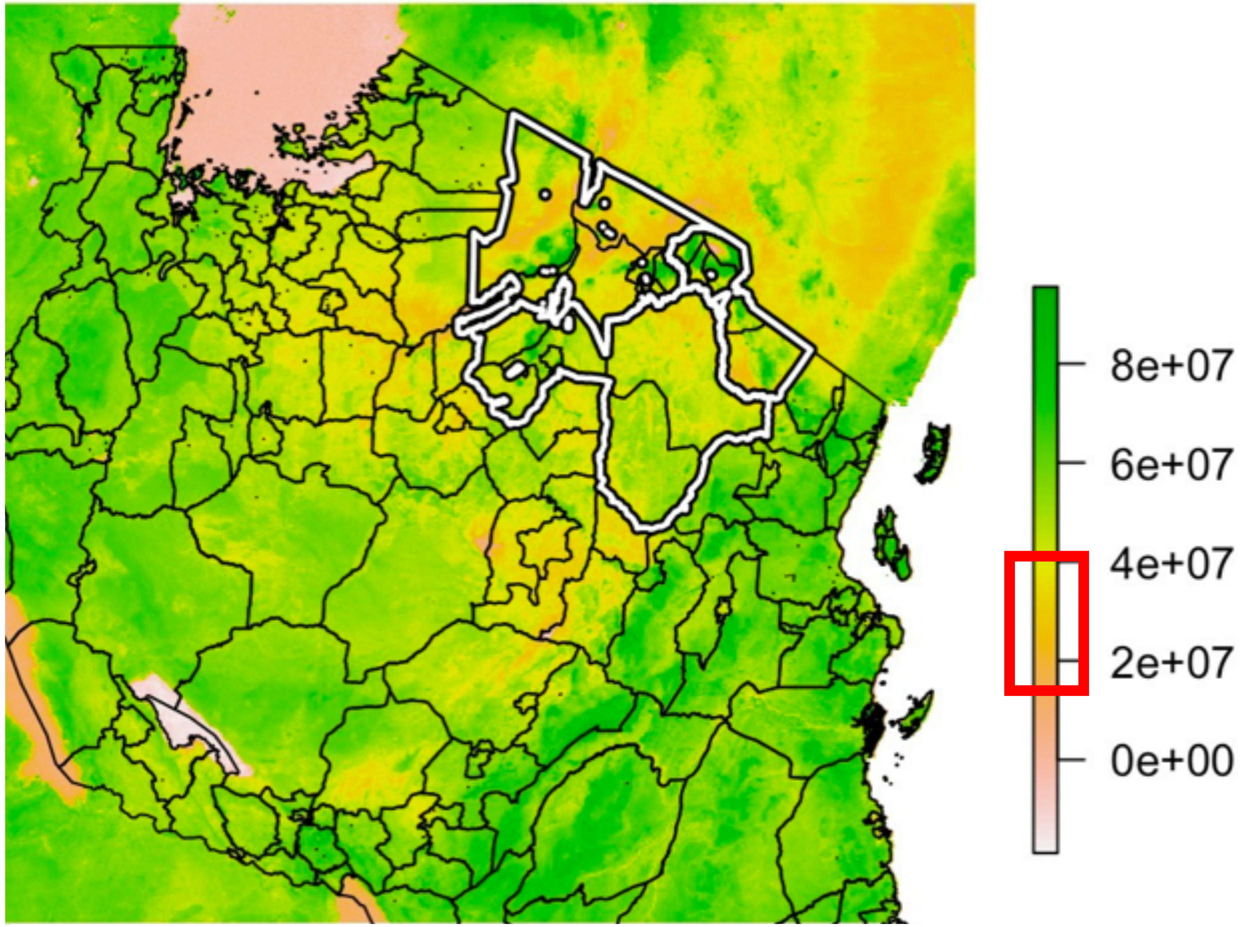
Don’t miss!

Rift Valley fever virus seroconversions humans and animals during an interepidemic period

Mindy Rostal
Tuesday 3 November
14:00 - 16:00 CET
(13:00 - 15:00 GMT)

Mean monthly NDVI Jan 2000 – Dec 2017



RVF emergence linked NDVI 0.15-0.4 (Anyamba *et al.* Photogramm. Eng. Remote Sensing 2002)

Spread of RVF by district, Jan – Jun 2007

Sindato et al. (2014) Spatial and Temporal Pattern of Rift Valley Fever Outbreaks in Tanzania; 1930 to 2007. PLoS ONE 9(2): e88897.

“Although the mechanisms of the spatial spread are not known, they are likely to include active and passive movement of infected mosquitoes and uncontrolled livestock movements within the country. ***However, data on the distribution of potential vectors and livestock movement pattern in Tanzania is scarce.”***

Sindato et al. (2014) PLoS ONE 9(2): e88897.

Question: If we had data on livestock movements, potentially combined with vector habitat suitability data, could we target interventions more efficiently, minimizing cost and disruption to trade?

Aims

- Develop a RVF transmission simulation tool combining four components:
  - Livestock movement network simulation (based on data)
  - RVF risk map
  - RVF transmission simulation model
  - Interventions: vaccination & livestock movement restrictions

Movement data

- Movement permits
  - Access to all archived records 2009/11/13/15: ~60,000 forms
  - Each form *can* give us info on a single livestock journey
    - Date
    - Origin (where permit issued) & destination
    - Number & species moved

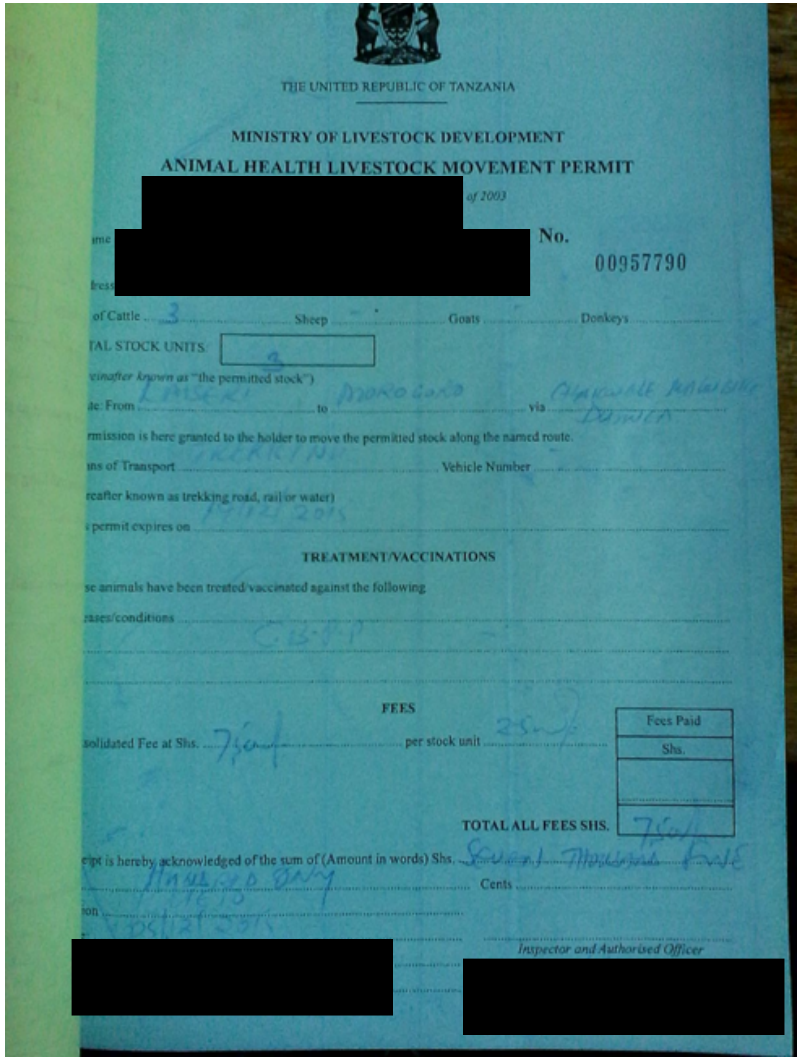
Thanks to Rigobert Tarimo, Robert Chuwa and Sambeke Kiruswa for turning 30,000 movement permits into data

Station	Cattle	Sheep	Goats	Shoats	From	To	Via	Transport	Total_fee	Date_YYYY	Date_MM	Date_DD
weruweru	1	0	0	0	weruweru	kimashuku	NA	cawtor	1000	2016	01	30
weruweru	2	0	0	0	weruweru	kimashuku	NA	NA	2000	2016	01	30
weruweru	6	0	0	0	weruweru	moshi	NA	lorry	9000	2016	01	30
weruweru	5	0	0	0	weruweru	moshi	NA	cawtor	7500	2016	01	30
weruweru	4	0	0	0	weruweru	moshi	NA	cawtor	6000	2016	01	30
weruweru	5	0	0	0	weruweru	moshi	NA	lorry	7500	2016	01	30
weruweru	7	0	0	0	weruweru	moshi	NA	cawtor	10500	2016	01	30
weruweru	3	0	0	0	weruweru	moshi	NA	cawtor	4500	2016	01	30
weruweru	3	0	0	0	weruweru	kimashuku	NA	pick up	3000	2016	01	30
weruweru	5	0	0	0	weruweru	moshi	NA	lorry	7500	2016	01	30
weruweru	5	0	0	0	weruweru	moshi	NA	lorry	7500	2016	01	30
weruweru	5	0	0	0	weruweru	kimashuku	NA	cawtor	5000	2016	01	30
weruweru	5	0	0	0	weruweru	kibosho	NA	cawtor	7500	2016	01	30
weruweru	5	0	0	0	weruweru	moshi	NA	lorry	7500	2016	02	02

github.com/pcdjohnson/SEEDZ-RVF-sim

Movement data

- Limitations of the permit data:
  - Not all movements are captured by permits
    - Permits only record *outward* journeys
    - Non-compliance is common
  - Large number of non-randomly missing permits
  - Some permits are illegible


THE UNITED REPUBLIC OF TANZANIA

MINISTRY OF LIVESTOCK DEVELOPMENT

ANIMAL HEALTH LIVESTOCK MOVEMENT PERMIT

[redacted] of 2003

No. 00957790

of Cattle 3 Sheep Goats Donkeys

TAL STOCK UNITS 3

einafter known as "the permitted stock")

te: From to via

rmission is here granted to the holder to move the permitted stock along the named route.

ns of Transport Vehicle Number

reafter known as trekking road, rail or water)

permit expires on

TREATMENT/VACCINATIONS

se animals have been treated/vaccinated against the following

eases/conditions

FEES

solidated Fee at Shs. per stock unit

Fees Paid
Shs.

TOTAL ALL FEES SHS.

eipt is hereby acknowledged of the sum of (Amount in words) Shs.

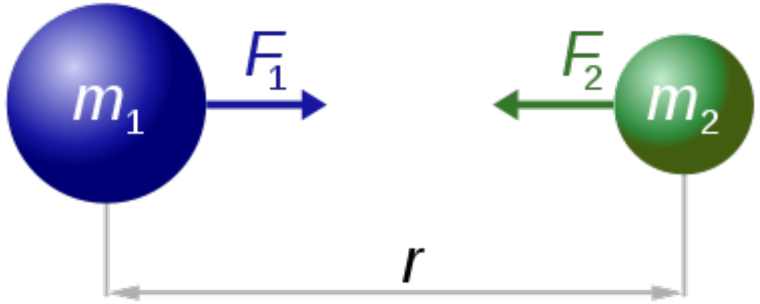
Cents

[redacted]

Inspector and Authorised Officer

[redacted]

Gravity model



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

$$G_{ij} = e^{\beta_0}\frac{{m_i}^{\beta_1}{n_j}^{\beta_2}}{{r_{ij}}^{-\beta_3}}$$

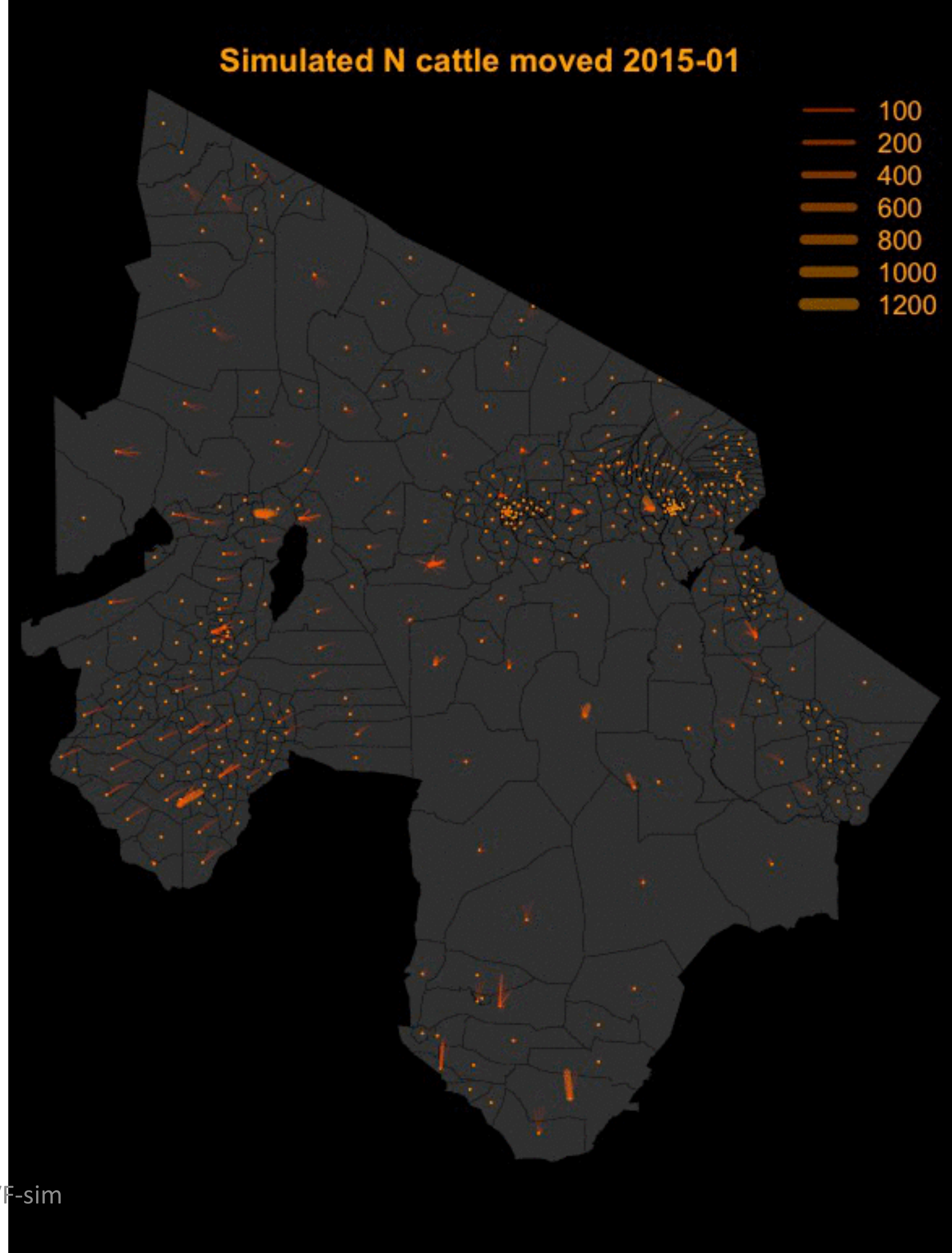
$$\log(G_{ij}) = \beta_0 + \beta_1 \log(m_i) + \beta_2 \log(n_j) + \beta_3 \log(r_{ij})$$

github.com/pcdjohnson/SEEDZ-RVF-sim

Livestock movement simulation

- Simulated from the pink slip data for 12 months in 2015
- 3.7 million cattle moving among 398 wards each month
- Cattle move between neighbouring wards as well as via markets
- Find our posters (IOHC2018) and publication (Chaters et al., Phil. Trans. B) here:

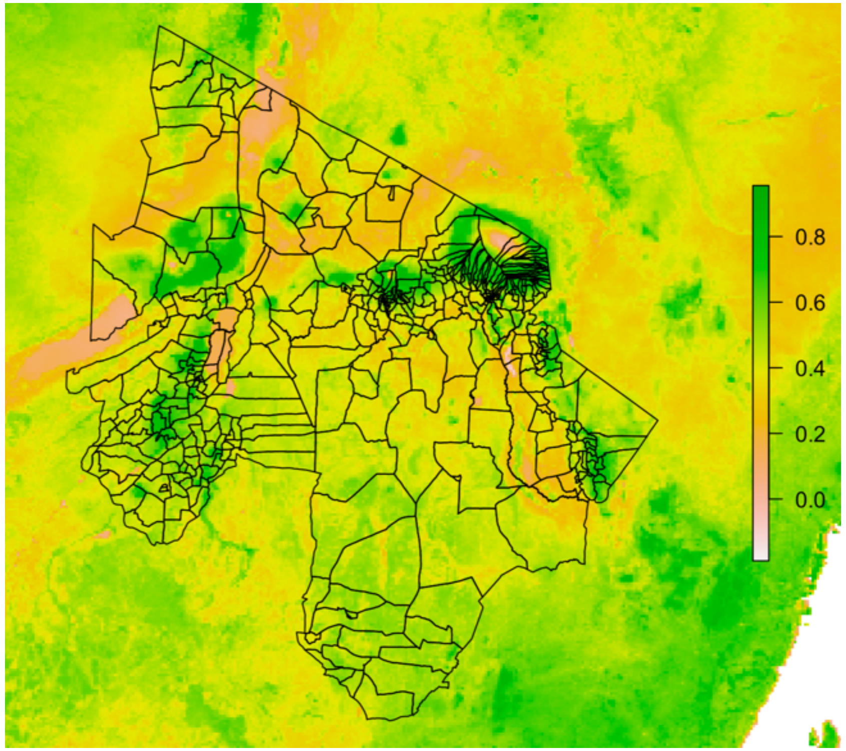
`github.com/pcdjohnson/SEEDZ-RVF-sim`

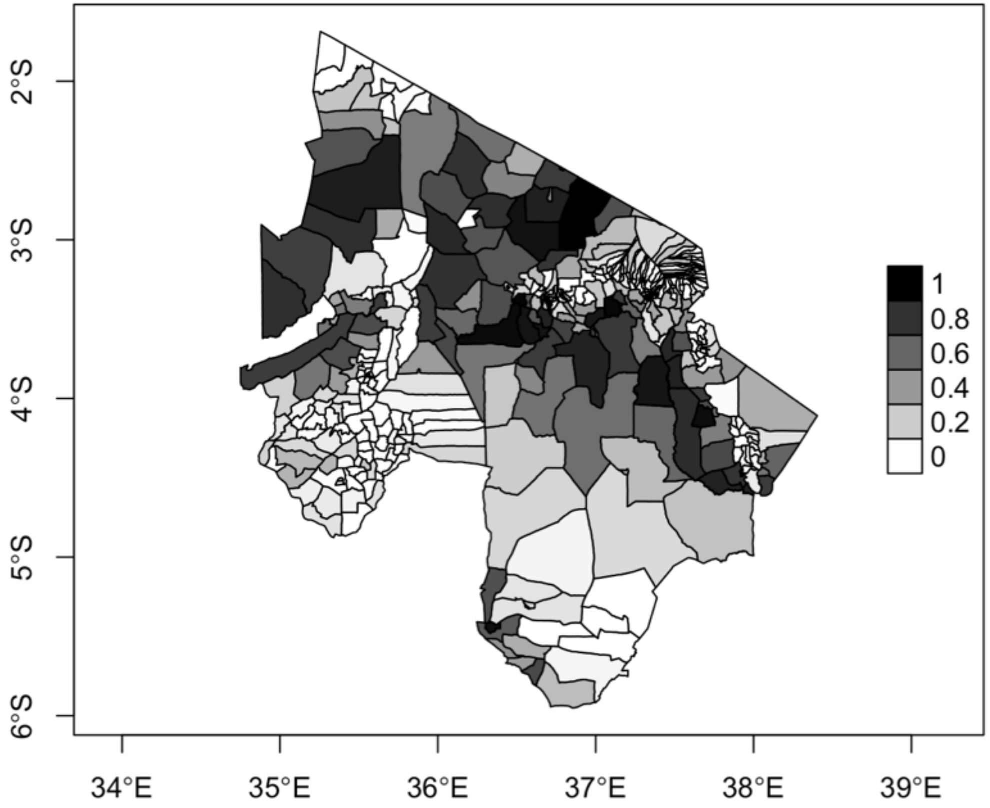


github.com/pcdjohnson/SEEDZ-RVF-sim

RVF risk map

- RVF emergence risk was linked to the proportion of each ward with NDVI 0.15-0.4 (Anyamba *et al.* Photogramm. Eng. Remote Sensing 2002)

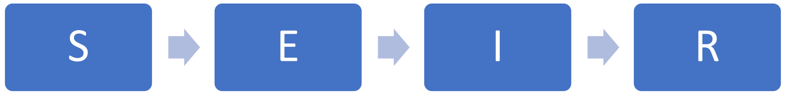




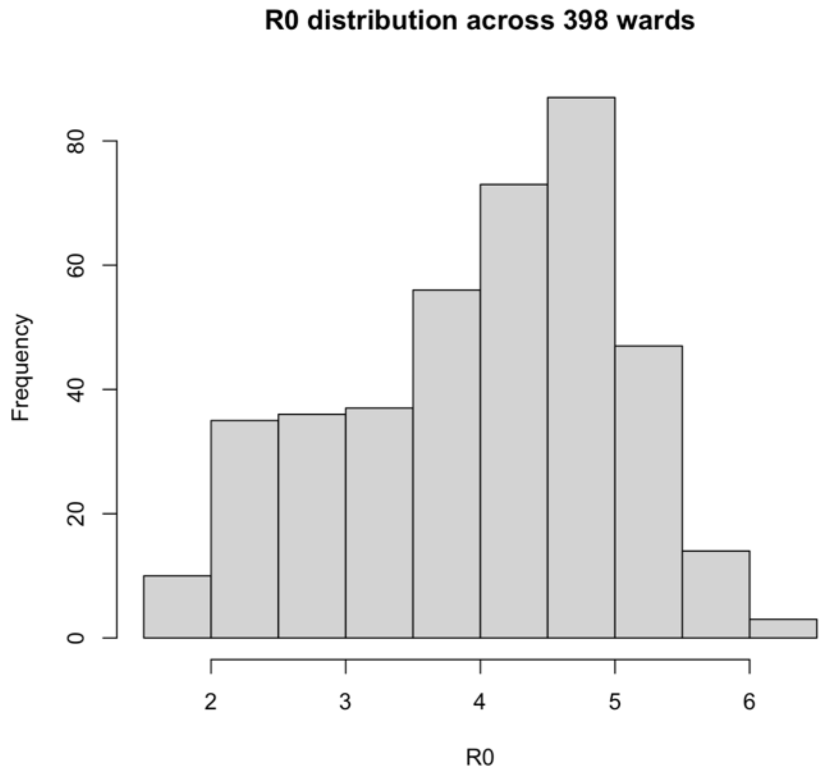
github.com/pcdjohnson/SEEDZ-RVF-sim

RVF transmission model within wards

- Stochastic SEIR model



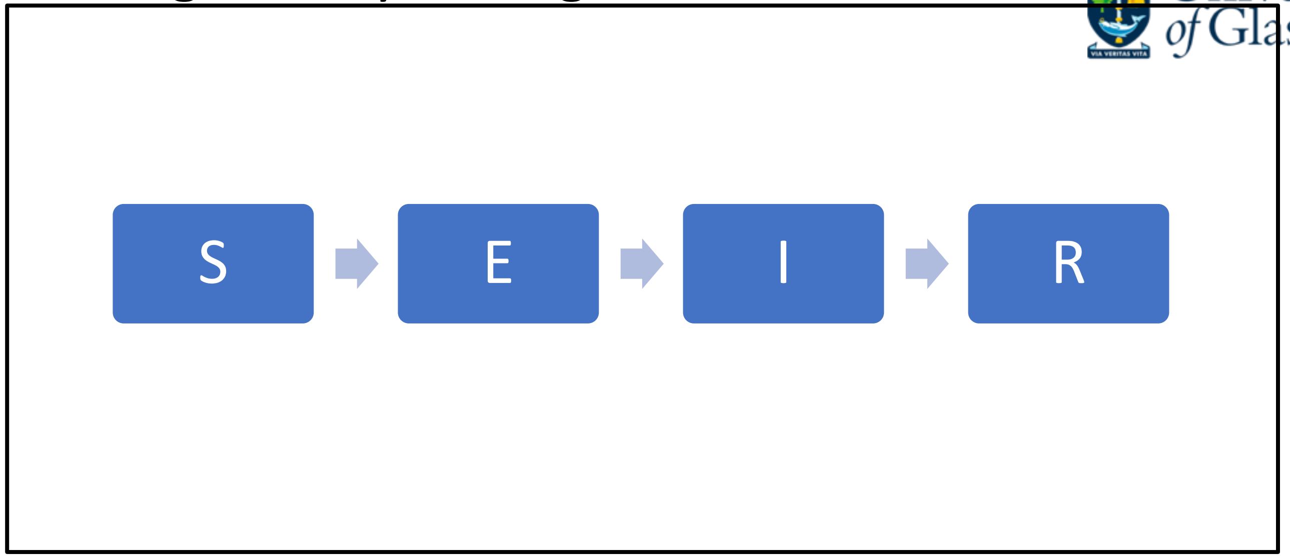
  - Based on Métras et al. (PLoS NTD 2017)
- Rate at which cattle are infected (S -> E) varies with RVF risk
  - Mean R_0 = 4, range 1-7
- Currently cattle only



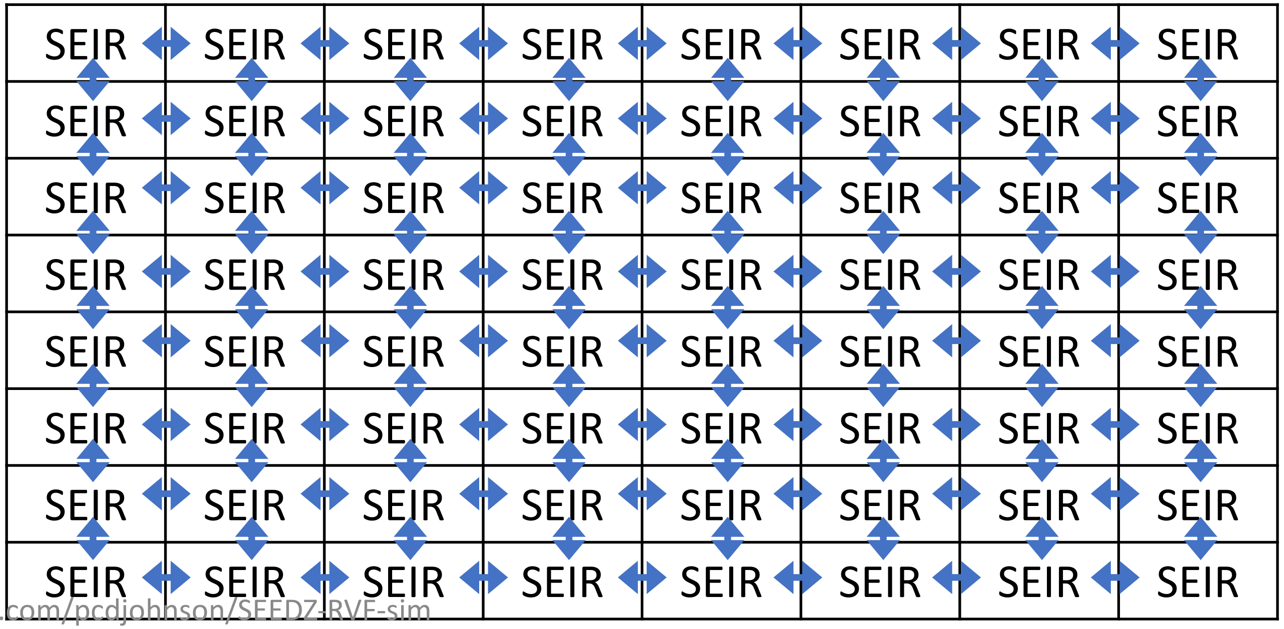
github.com/pcdjohnson/SEEDZ-RVF-sim

- Initial models: homogeneous SEIR within wards containing ~10,000 cattle (unrealistic).
- Current model is structured: ward divided into 8x8 grid running separate SEIR models, linked by coupling process.
- Movement simulation and disease model were combined using *SimInf* in *R* (Widgren et al. Vet. Res. 2016).

Homogenously mixing ward

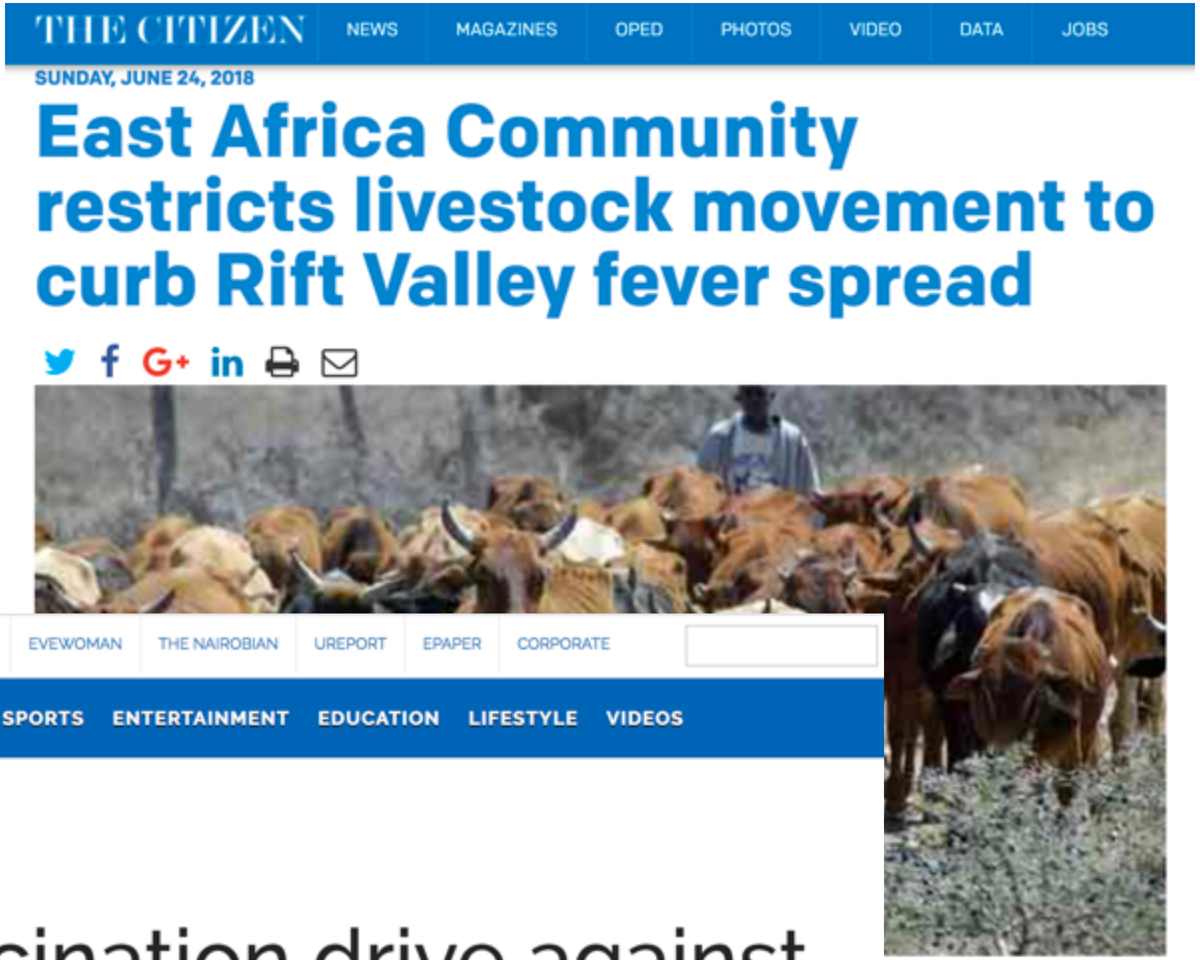


Structured ward



Interventions

- Vaccination
- Livestock movement restrictions


THE CITIZEN NEWS MAGAZINES OPED PHOTOS VIDEO DATA JOBS

SUNDAY, JUNE 24, 2018

East Africa Community restricts livestock movement to curb Rift Valley fever spread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TODAY'S PAPER

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County launches vaccination drive against Rift valley fever

By Mercy Kahenda | Published Mon, August 6th 2018 at 00:00, Updated August 5th 2018 at 20:32 GMT +3

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he county government plans to vaccinate at least 70,000 cattle against Rift Valley fever
ı Baringo South Constituency.

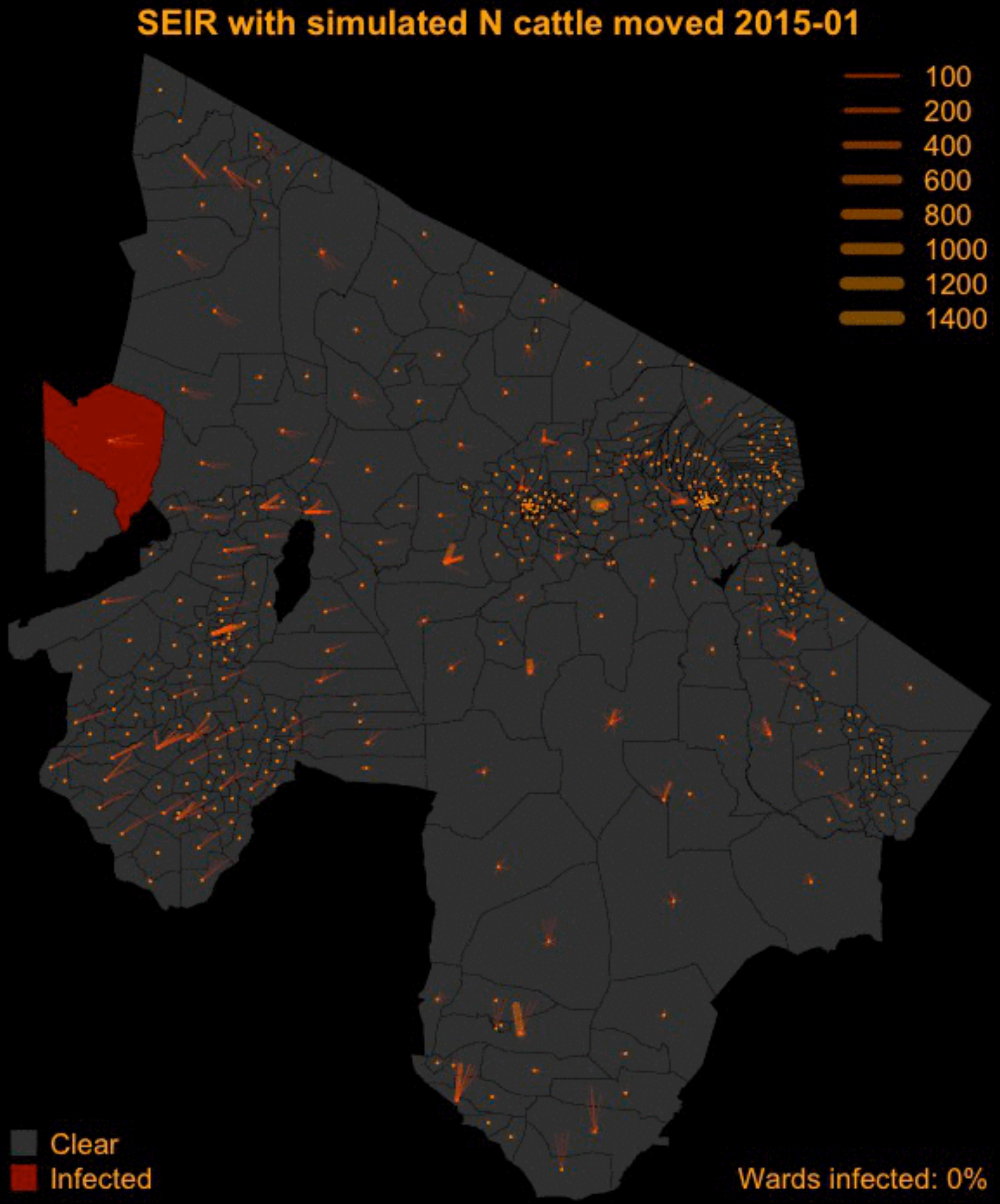
LATEST NEWS

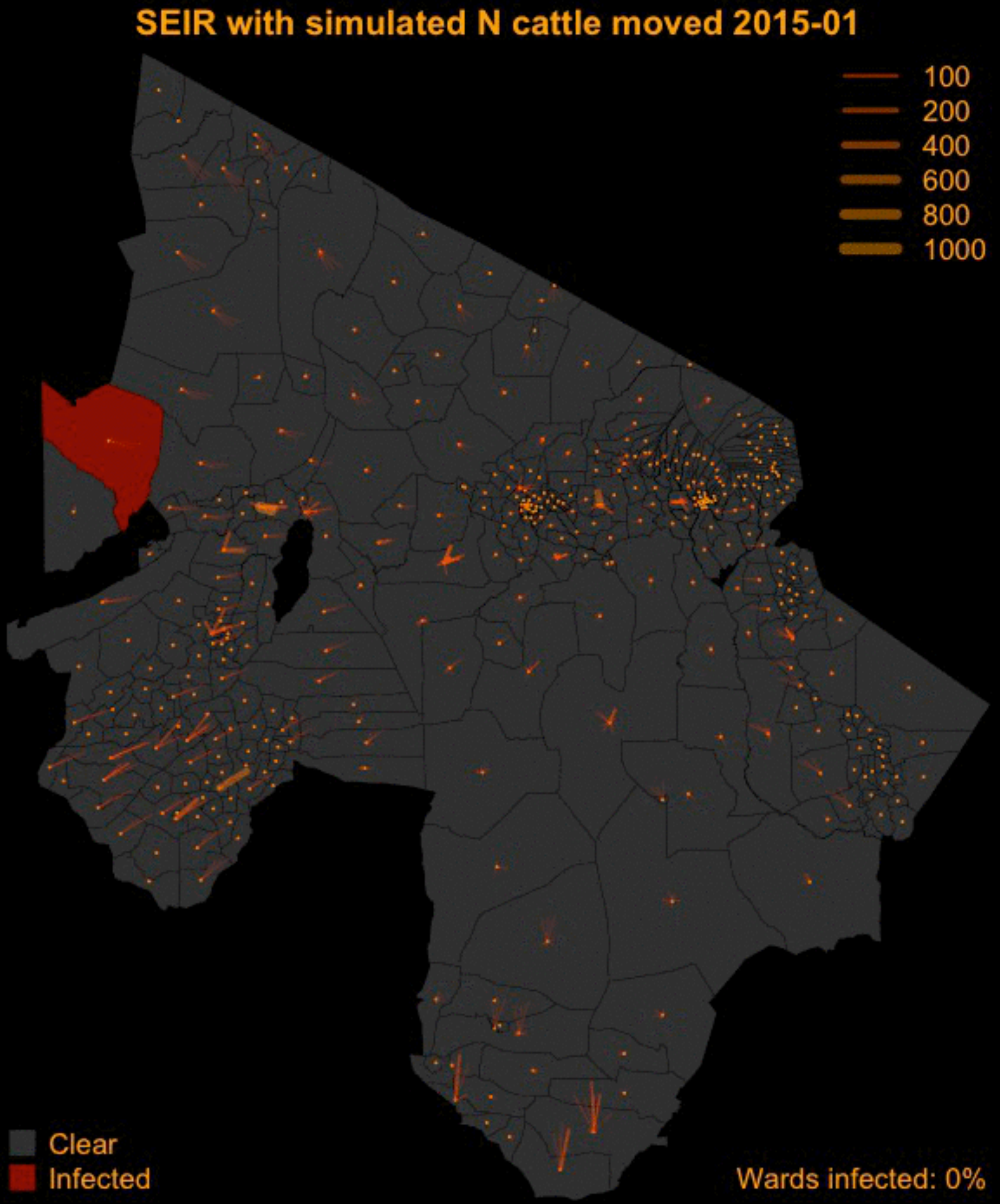
Interventions: vaccination scenarios

- Preventative, not responsive
- Unlimited resource scenario
  - All 398 wards at 70% coverage (2.6 million doses/3.7 million cattle)
- Limited resource scenario: enough doses for 10% coverage
  - All 398 wards at 10% coverage (370,000 doses)
  - 20 wards at 70% coverage, chosen
    - At random
    - Using network measures (degree centrality)
    - Using RVF risk score (1 - NDVI)
    - Network + RVF risk

Interventions: movement ban scenarios

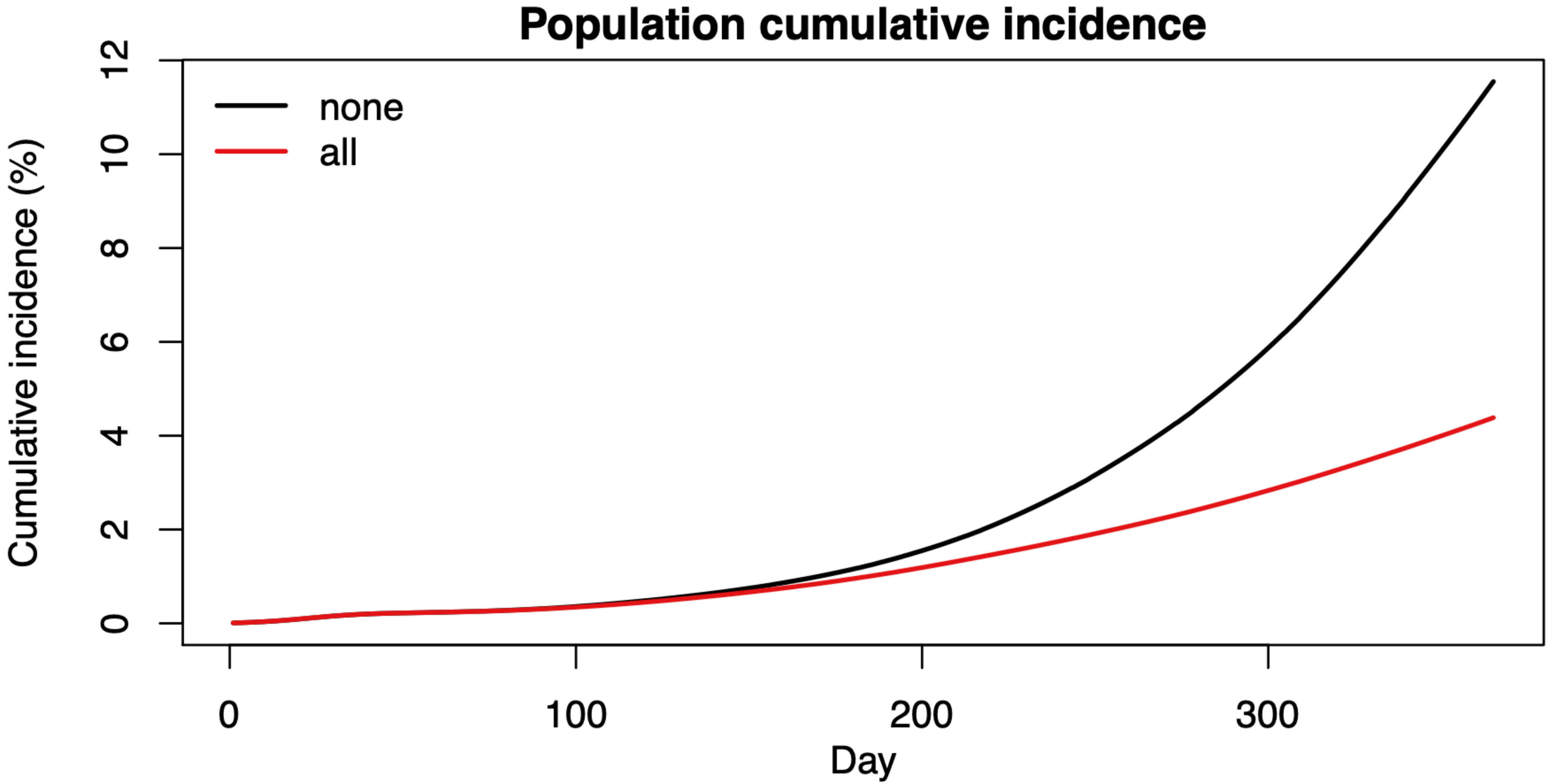
- Responsive: occurs after the epidemic has been detected
- Only affects the market network – local movements unaffected
- Total ban scenario
  - All 111 markets
- Limited ban scenario
  - 20 markets, chosen
    - At random
    - Using network measures (degree centrality)
    - Using RVF risk score (1 - NDVI)
    - Network + RVF risk





github.com/pcdjohnson/SEEDZ-RVF-sim

Results



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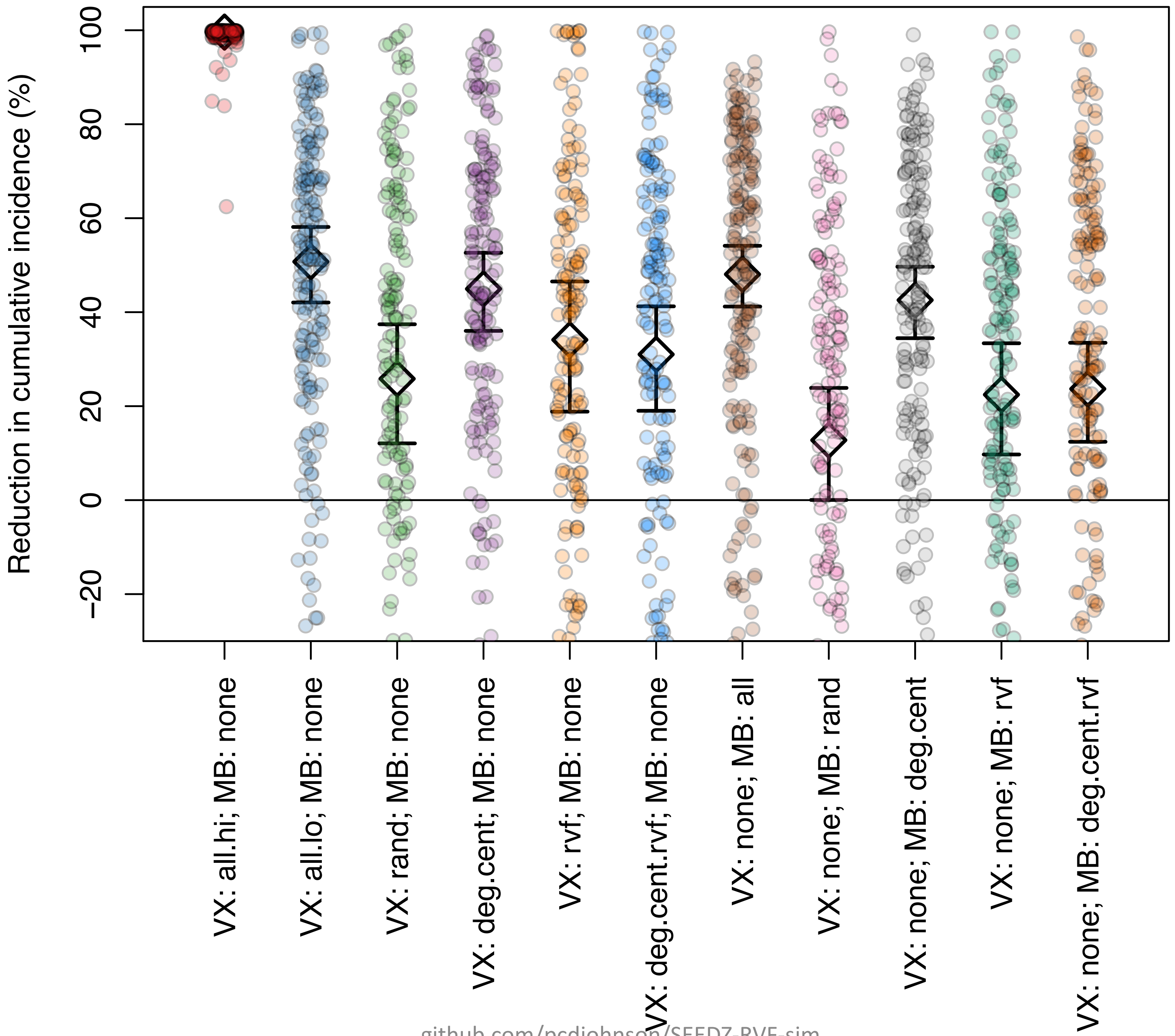
Results



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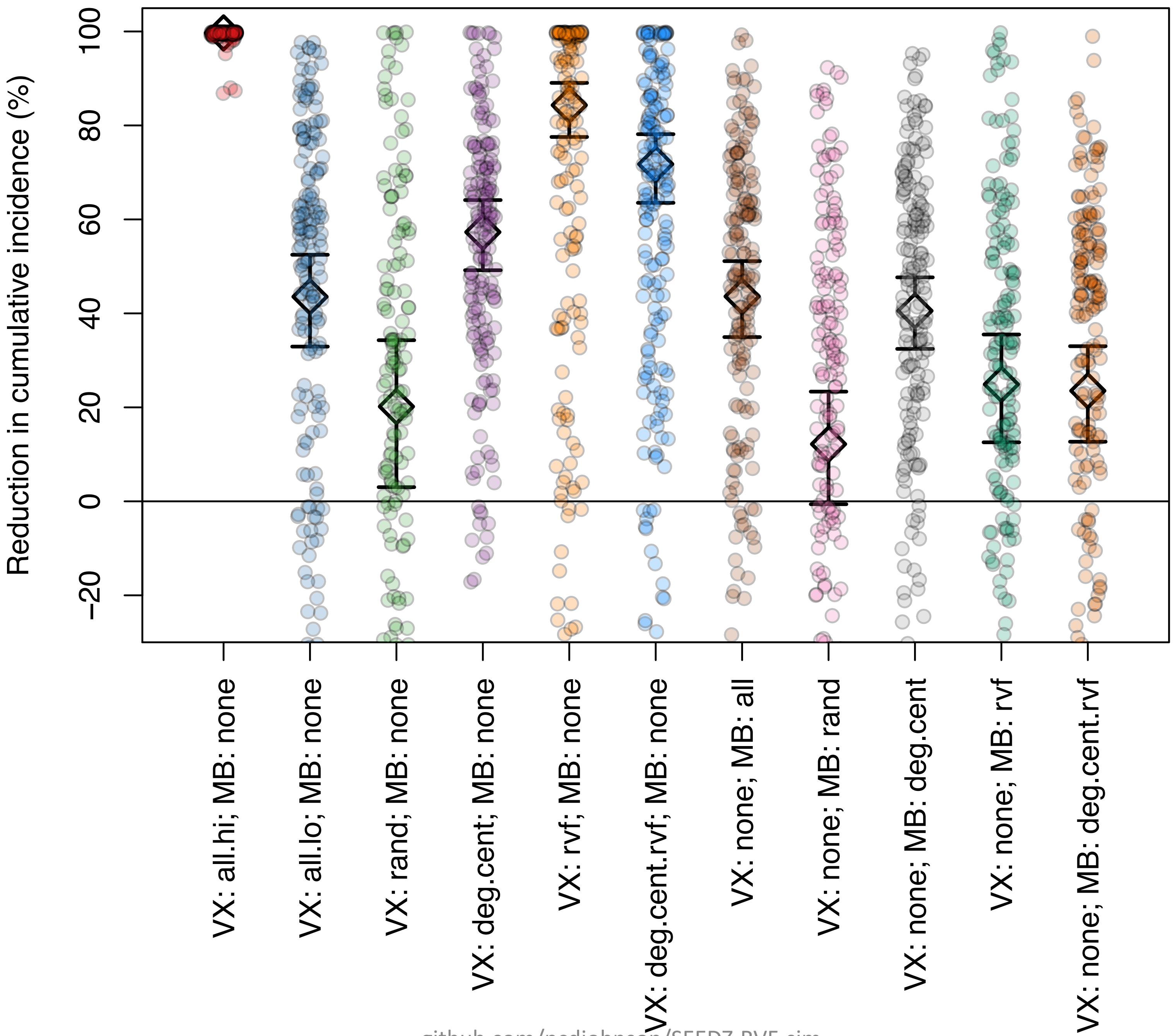
Results



github.com/pcdjohnson/SEEDZ-RVF-sim

RVF vaccination strategies: conclusions

Vaccination plan	Targeting	Reduction in cumulative incidence	
		Choose seed ward randomly	Choose seed ward from RVF risk top 20
70% coverage in 398 wards	-	100%	100%
10% coverage in 398 wards	-	51%	44%
70% coverage in 20 wards	Random	26%	20%
70% coverage in 20 wards	Network	45%	57%
70% coverage in 20 wards	RVF risk	34%	84%
70% coverage in 20 wards	Network + RVF risk	31%	72%

- *Using network information target vaccination reduces incidence*
- *Adding information from the risk map:*
  - *Doesn't improve targeting if the epidemic is seeded randomly*
  - *Does improve targeting if the epidemic is seeded according to RVF emergence risk*

github.com/pcdjohnson/SEEDZ-RVF-sim

Movement ban strategies: conclusions

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Movement ban plan	**Targeting**	**Reduction in cumulative incidence**	
		Choose seed ward randomly	Choose seed ward from RVF risk top 20
All 111 markets	-	48%	44%
20 markets	Random	13%	12%
20 markets	Network	43%	41%
20 markets	RVF risk	22%	25%
20 markets	Network + RVF risk	24%	24%

- *Using network information helps to target movement ban*
- *Adding information from the risk map doesn't improve targeting*

Limitations

- So many assumptions…
  - Lack of data on local (non-market movements)
  - Relationship between habitat and risk
  - …?
- Currently only includes cattle – we will add sheep and goats
- Lacks seasonal effect on RVF risk – this can also be added
- Non-compliance with movement restrictions

General conclusions

- Network information has the potential to inform RVF control
- Simulation tool could be adapted to
  - Other diseases with different transmission rates (e.g. brucellosis, Q fever, FMDV)
  - Wider range of interventions, e.g. surveillance
  - Predicting response to long-term change e.g.
    - Climate (rainfall pattern)
    - Species composition (from cattle to sheep & goats)
    - Land use & ownership
    - Urbanisation

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QUANTITATIVE RESEARCH & ONE HEALTH

IN THE INSTITUTE OF BIODIVERSITY, ANIMAL HEALTH & COMPARATIVE MEDICINE (IBAHCM)

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