Assessing intervention responses against H5N1 avian influenza outbreaks in Bangladesh

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Joint work with: Thomas House[3], Madhur Dhingra[3,4], Muzaffar Osmani[5], Xiangming Xiao[6], Marius Gilbert[3], Michael Tildesley[1]

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[3] Université Libre de Bruxelles, Belgium
[4] FAO, Italy
[5] Department of Livestock Services, Bangladesh
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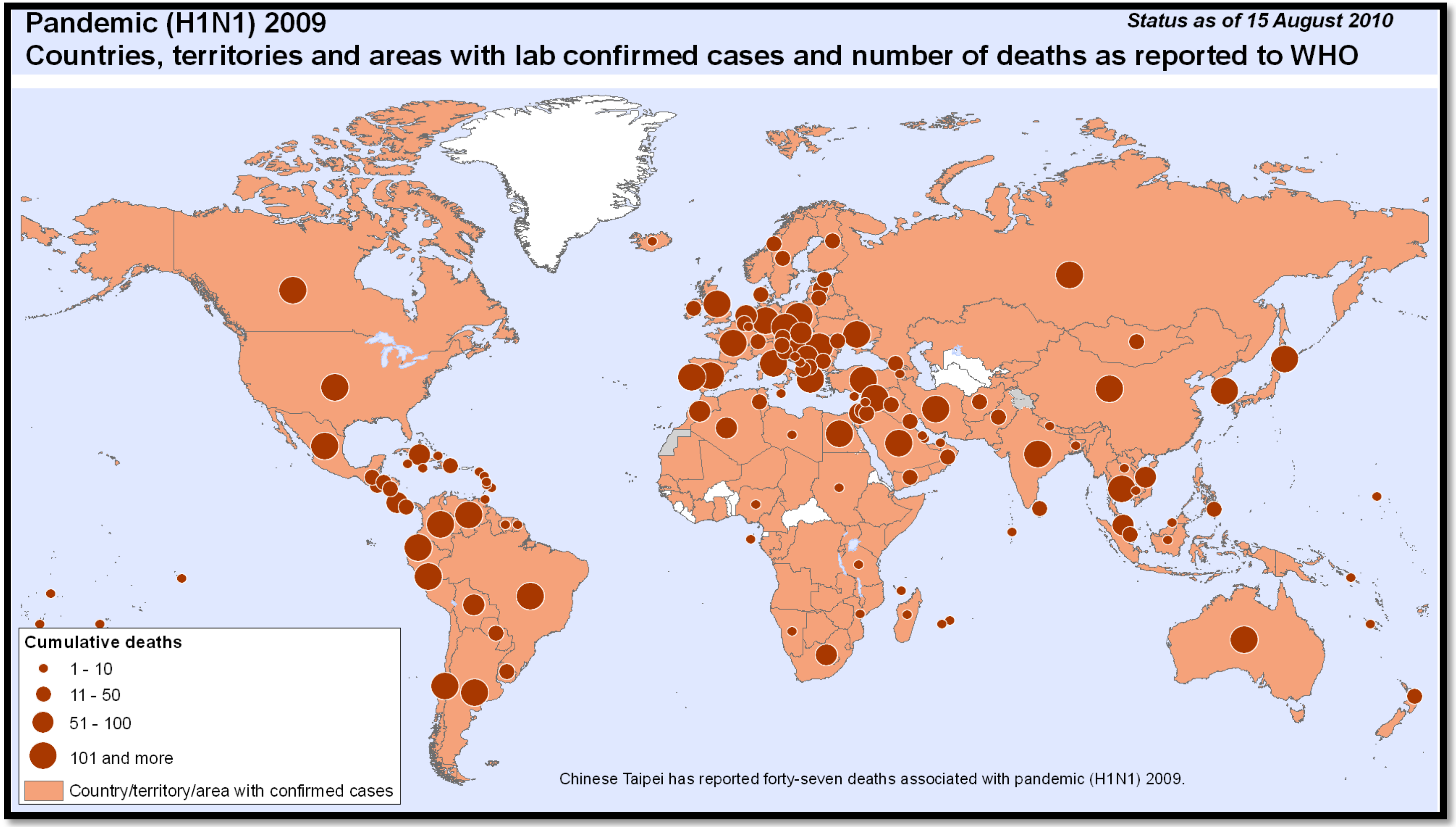
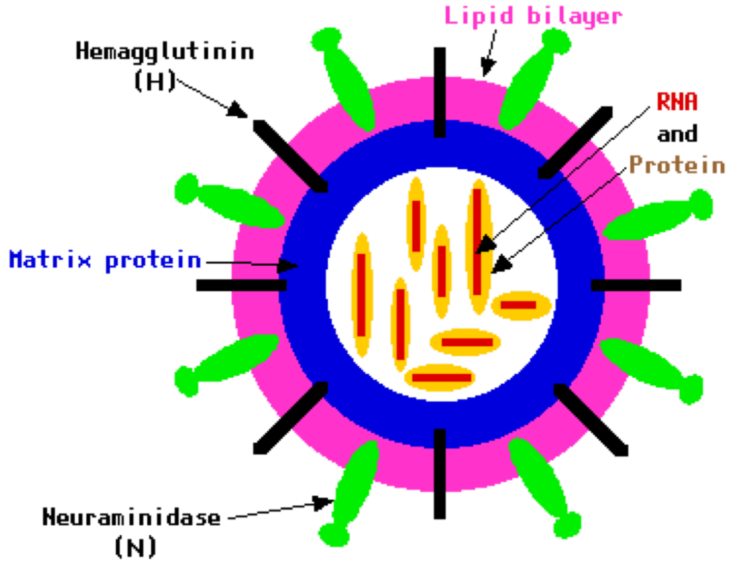
Impact of influenza pandemics

1918 flu pandemic: Infected 500 million, killed 20-40 million.



Why are influenza A viruses capable of causing global pandemics?

- There are several Influenza A virus strains, categorised into subtypes.



- Virus is notable for following dynamics:
  - **antigenic drift**
  - **antigenic shift**

Antigenic shift

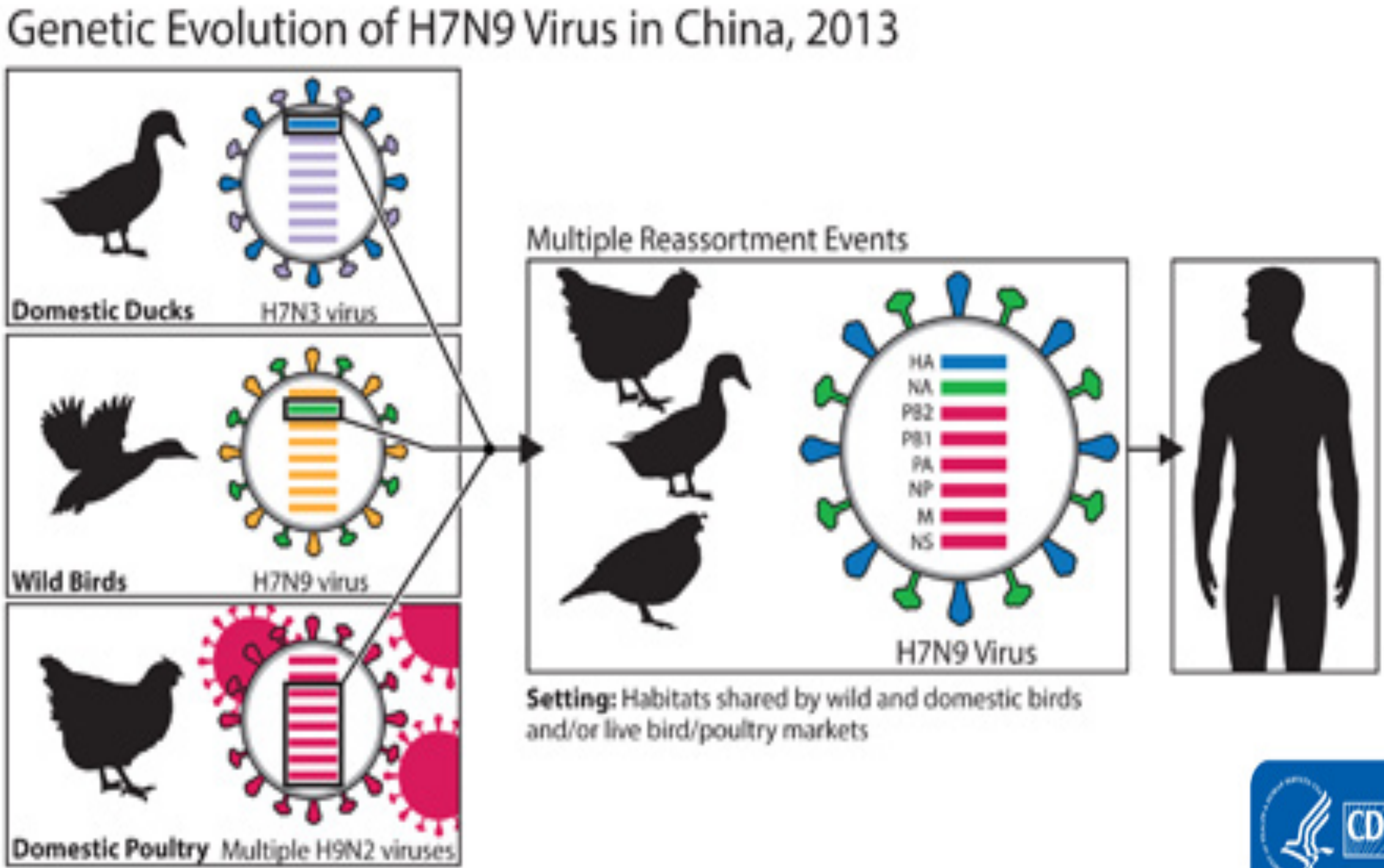
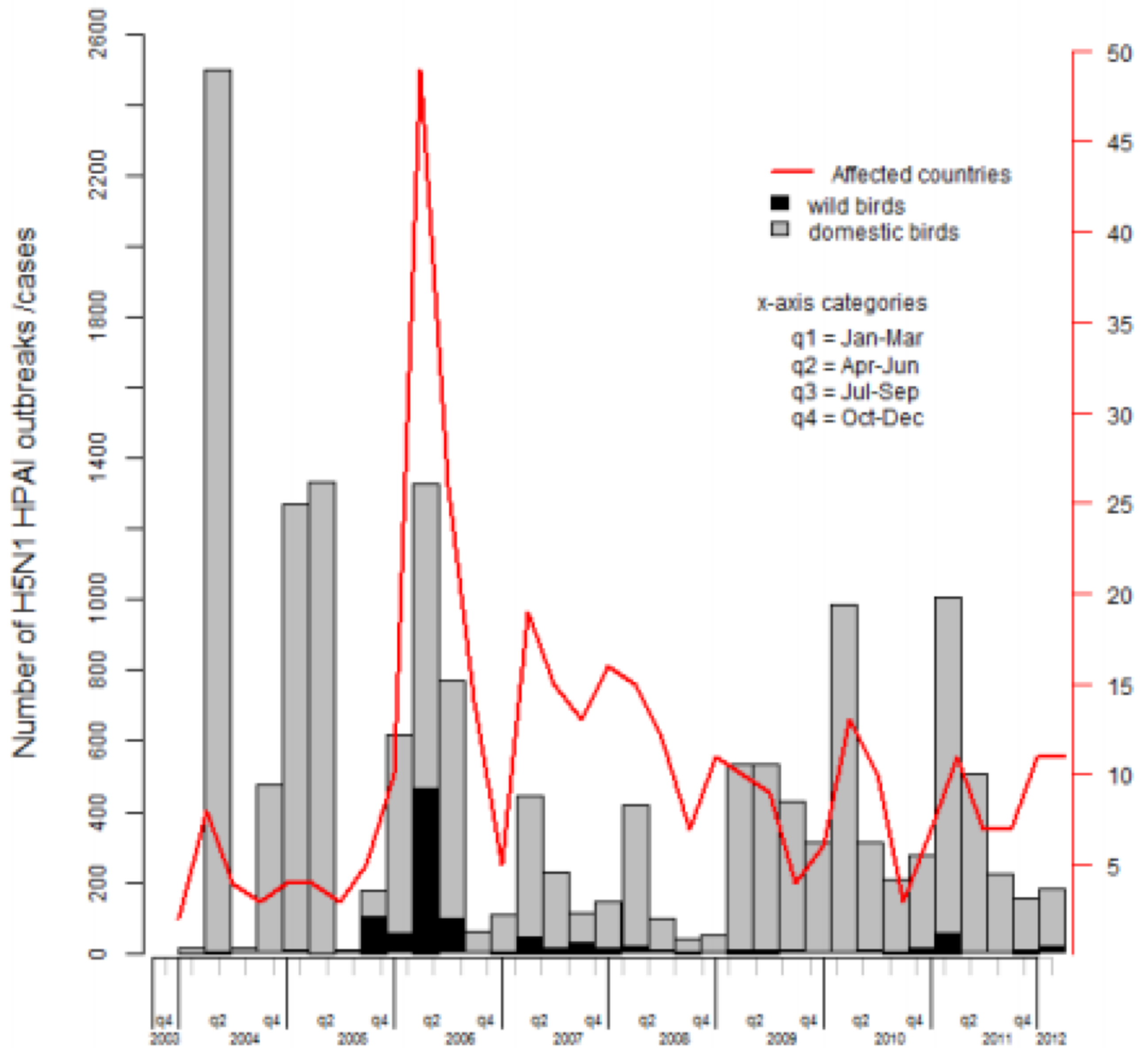
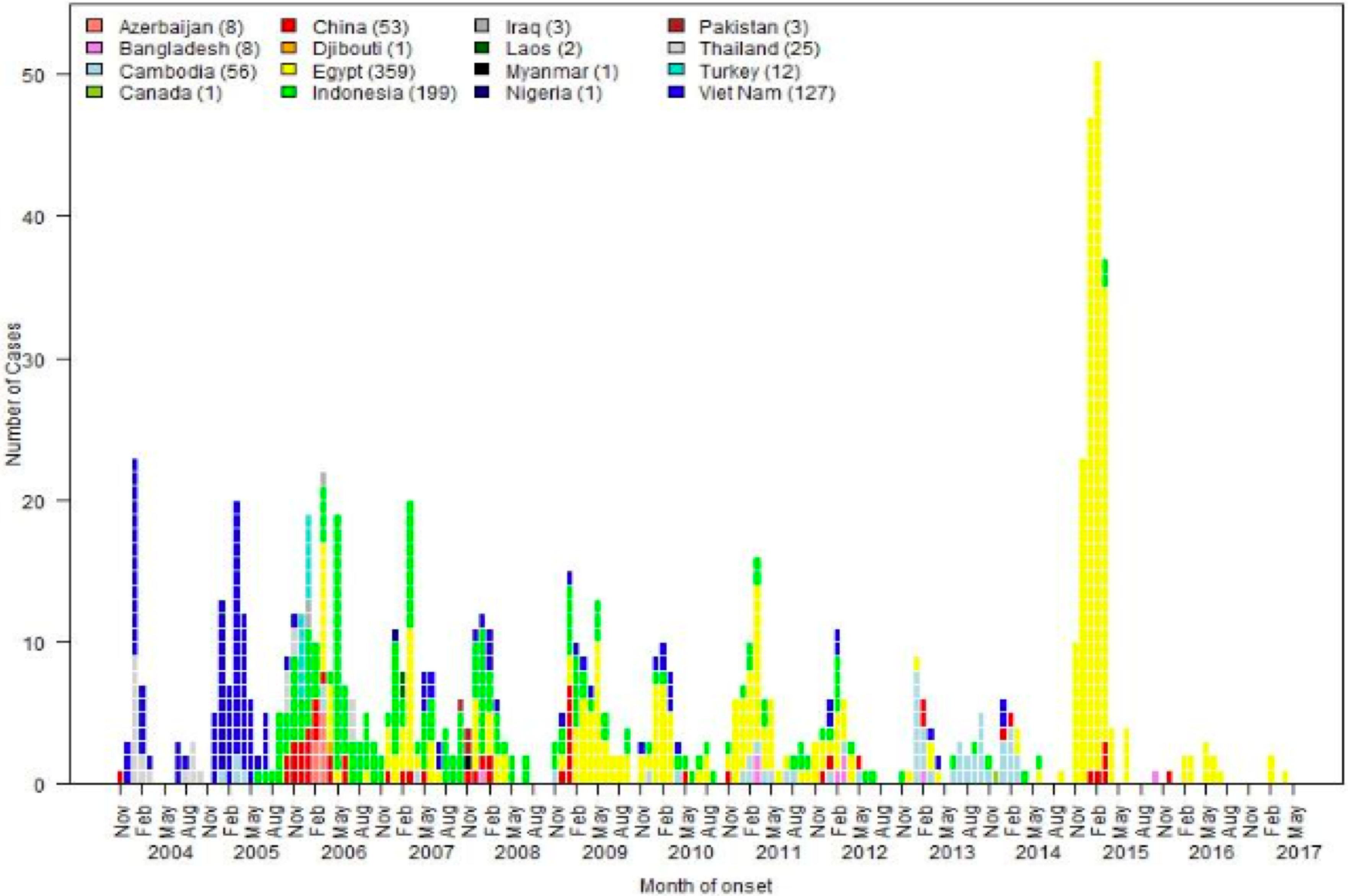


Figure 1: Epidemiological curve of H5N1 cases in poultry premises, 2003-2012.



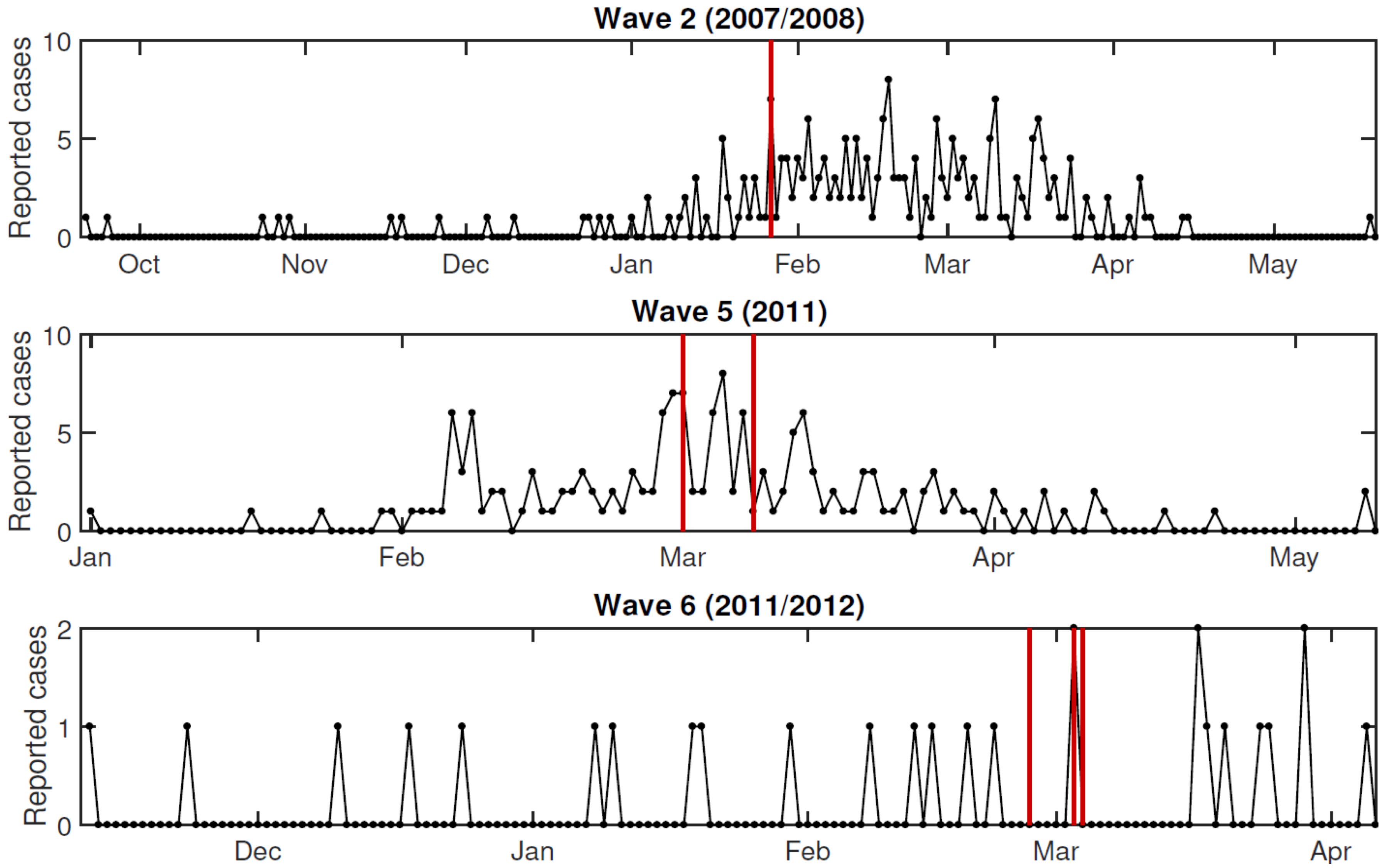
Source: FAO (2012) H5N1 HPAI Global Overview – Issue No. 31

Figure 2: Epidemiological curve of lab-confirmed avian influenza A(H5N1) cases in humans by month of onset, 2003-2017.



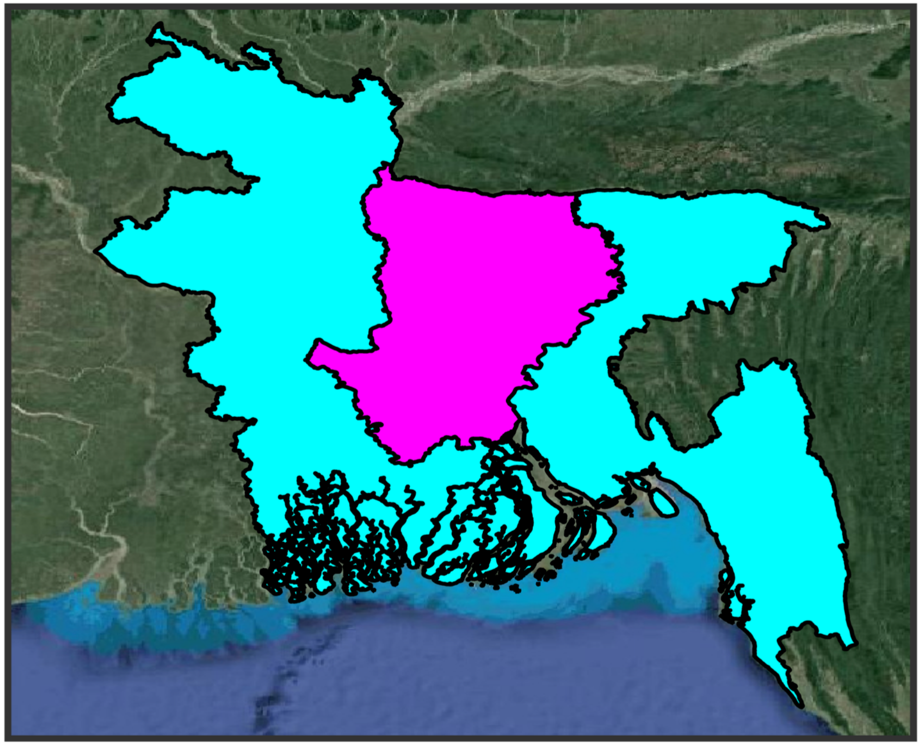
Source: WHO (2017) Monthly Risk assessment: Influenza at the human-animal interface – 16 May 2017

Figure 3: Reported H5N1 cases for poultry premises (black line) and humans (vertical red bars) in Bangladesh.



Initial model fitting

- Fit modelling framework to historical case data
  - Applied to Dhaka division (magenta shaded region)



Outline

(1) Poultry H5N1 transmission model

- Overview of the mathematical framework previously fitted to historical case data

(2) Evaluate interventions targeting poultry premises

- Ring culling
- Ring vaccination
- Active surveillance

(3) Zoonotic spillover

- Assess interventions targeting reduced transmission across the poultry-human interface

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(1) Poultry H5N1 transmission model

- Overview of the framework previously fit to historical case data

Reference:
E. M. Hill *et al.* "Modelling H5N1 in Bangladesh across spatial scales: model complexity and zoonotic transmission risk." *Epidemics* (2017).

(2) Interventions targeting poultry

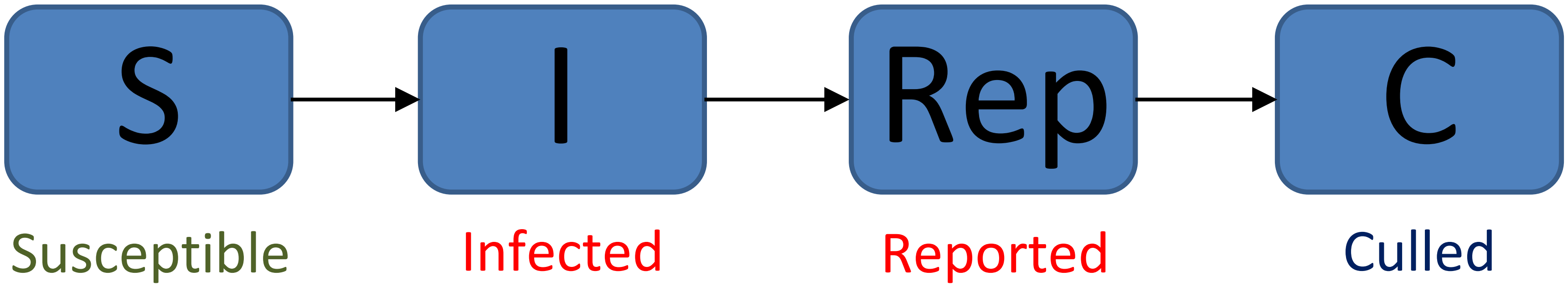
- Ring culling; Ring vaccination; Active surveillance

(3) Zoonotic spillover

- Interventions targeting reduced transmission across the poultry-human interface

Poultry Model Assumptions

- Epidemiological unit – premises



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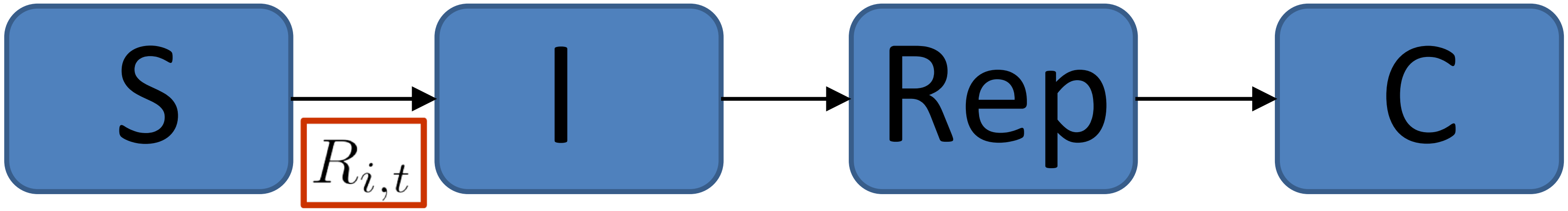

- Force of infection

$$R_{i,t} = \left(\sum_{j \in \text{infectious on day t}} N_{c,i}^{p} \times t_c N_{c,j}^{q} \times K(d_{ij}) \right) + \epsilon$$

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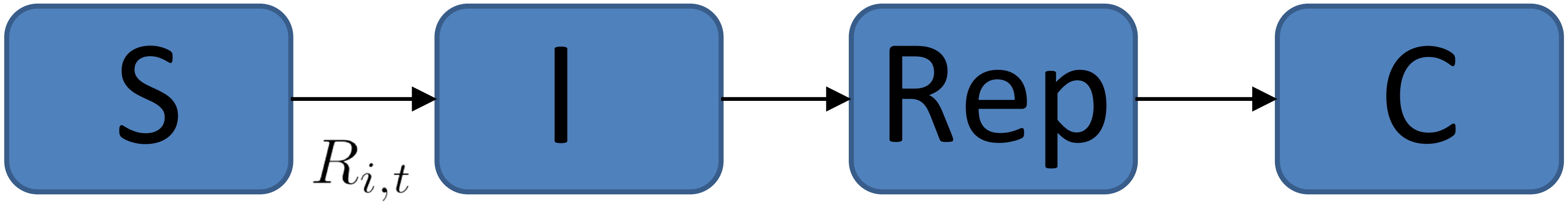

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Flock size on susceptible premises i

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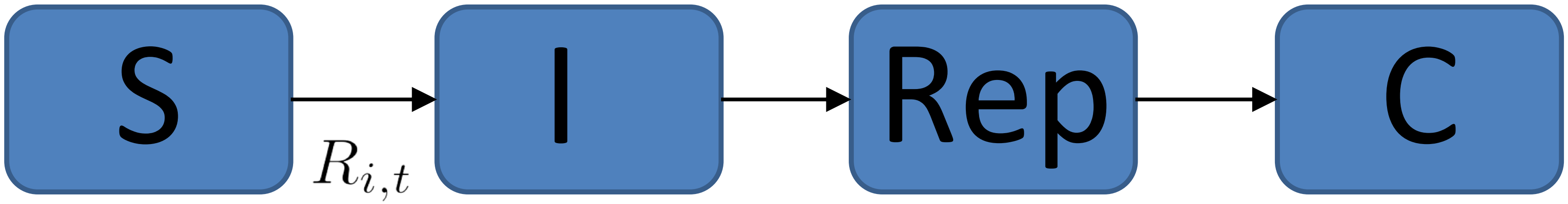

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Flock size on infectious premises j

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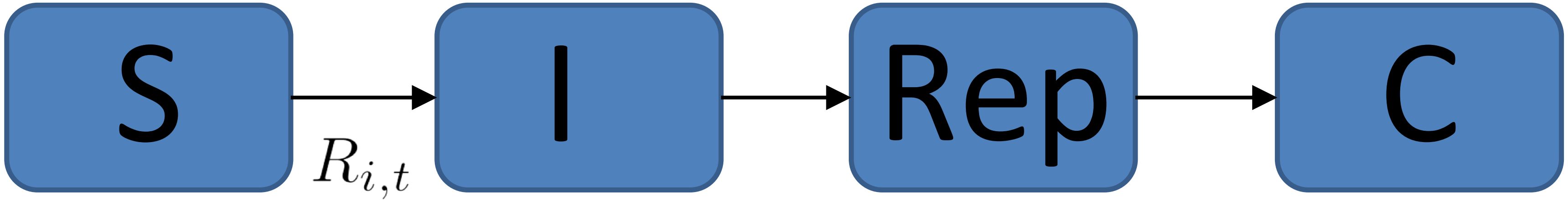

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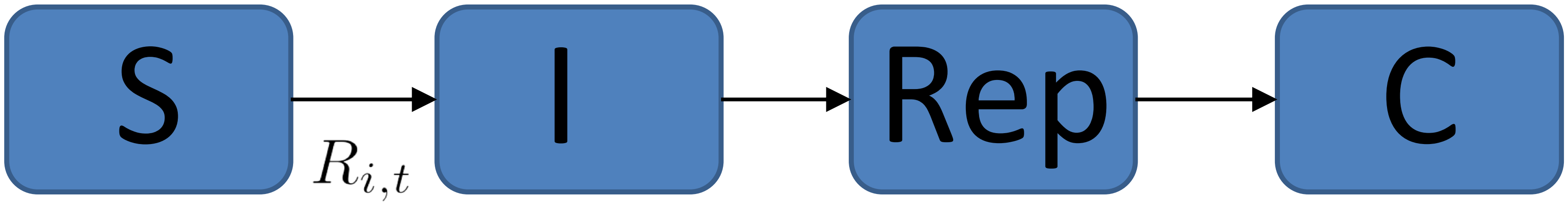
Distance between premises i & j

Poultry Model Assumptions

- Epidemiological unit – premises



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External factors

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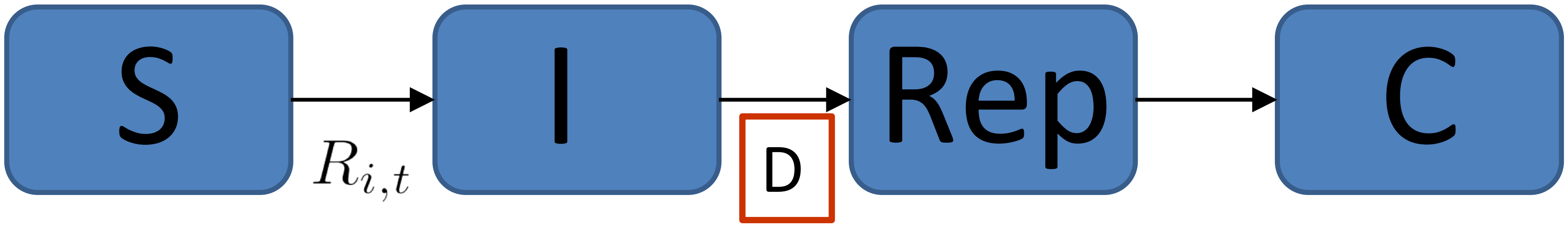

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- Notification delay
  - D = 7 days

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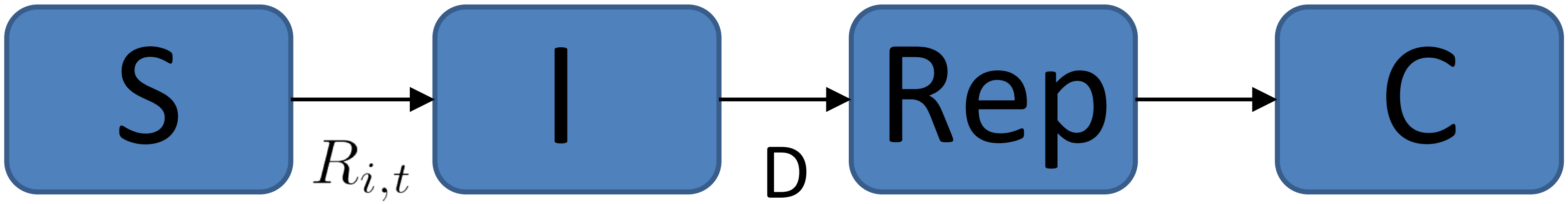

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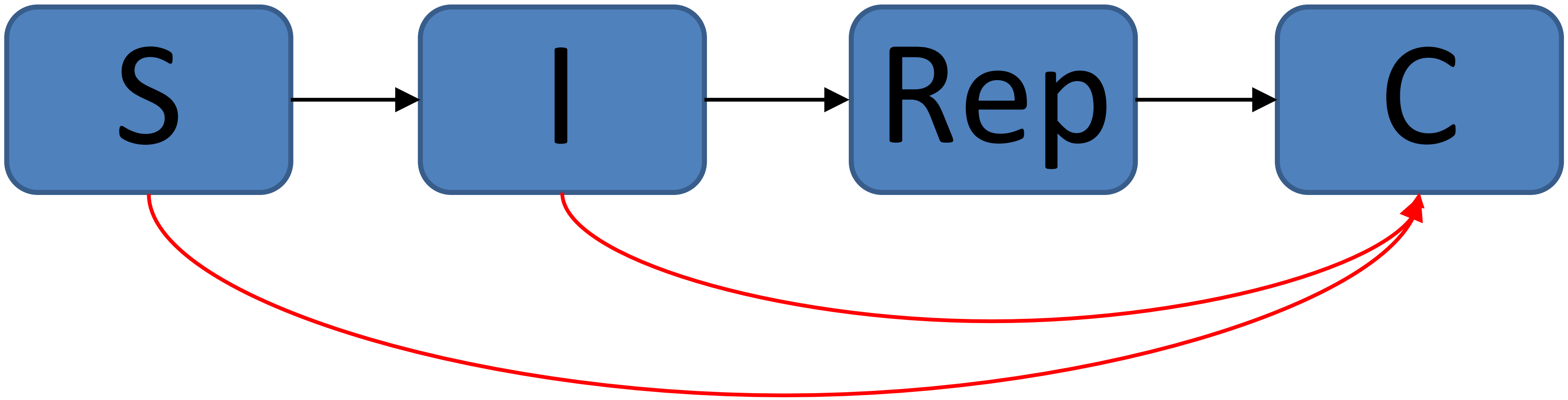
Ring culling strategies

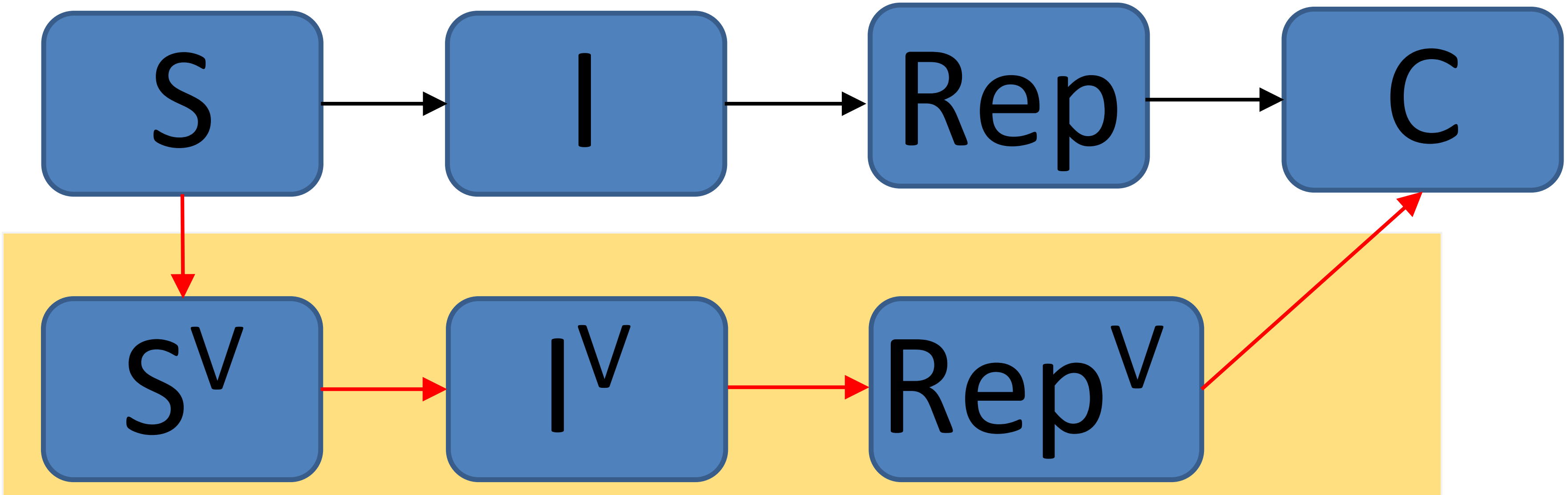
- **Baseline strategy:** Culling of reported premises only.



- **Additional:** All premises within a specified distance of each location with confirmed infection are listed for culling.
- **Ring radii:** 1-10km (1km increments)
- **Prioritisation:** Outside-to-centre

Ring vaccination strategies

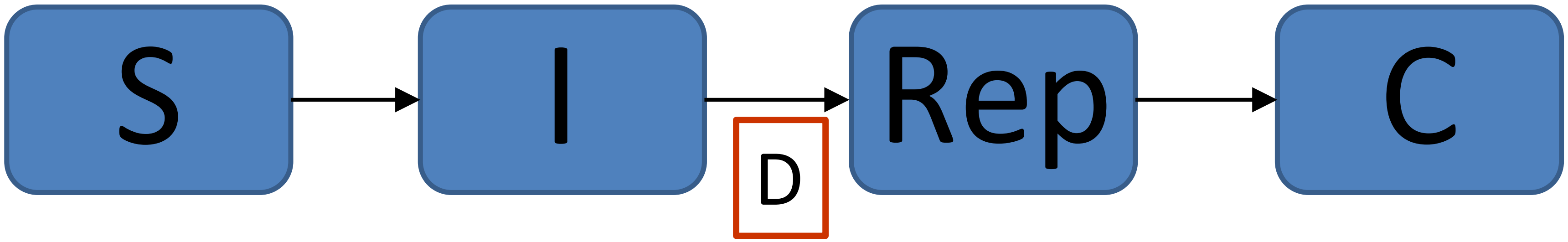
- All premises within a specified distance of each location with confirmed infection are listed for vaccination.



- **Effectiveness delay:** 7 days
- **Efficacy:** 70% of flock protected/unable to transmit infection

Active surveillance strategies

- Modifies notification delay



- **Premises undergoing active surveillance:** D = 2 days
- **Four prioritisation schemes analysed**
  - ‘Reactive’: (I) by distance; (II) by population.
  - ‘Proactive’: (III) by population; (IV) by density.

Control under uncertainty

- Investigate sensitivity to following considerations via simulations of previously fitted model framework.

TRANSMISSION DYNAMIC CHARACTERISTICS

WHAT IS THE SPECIFIC CONTROL OBJECTIVE?

CAPACITY CONSTRAINTS

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Outline of tested capacities

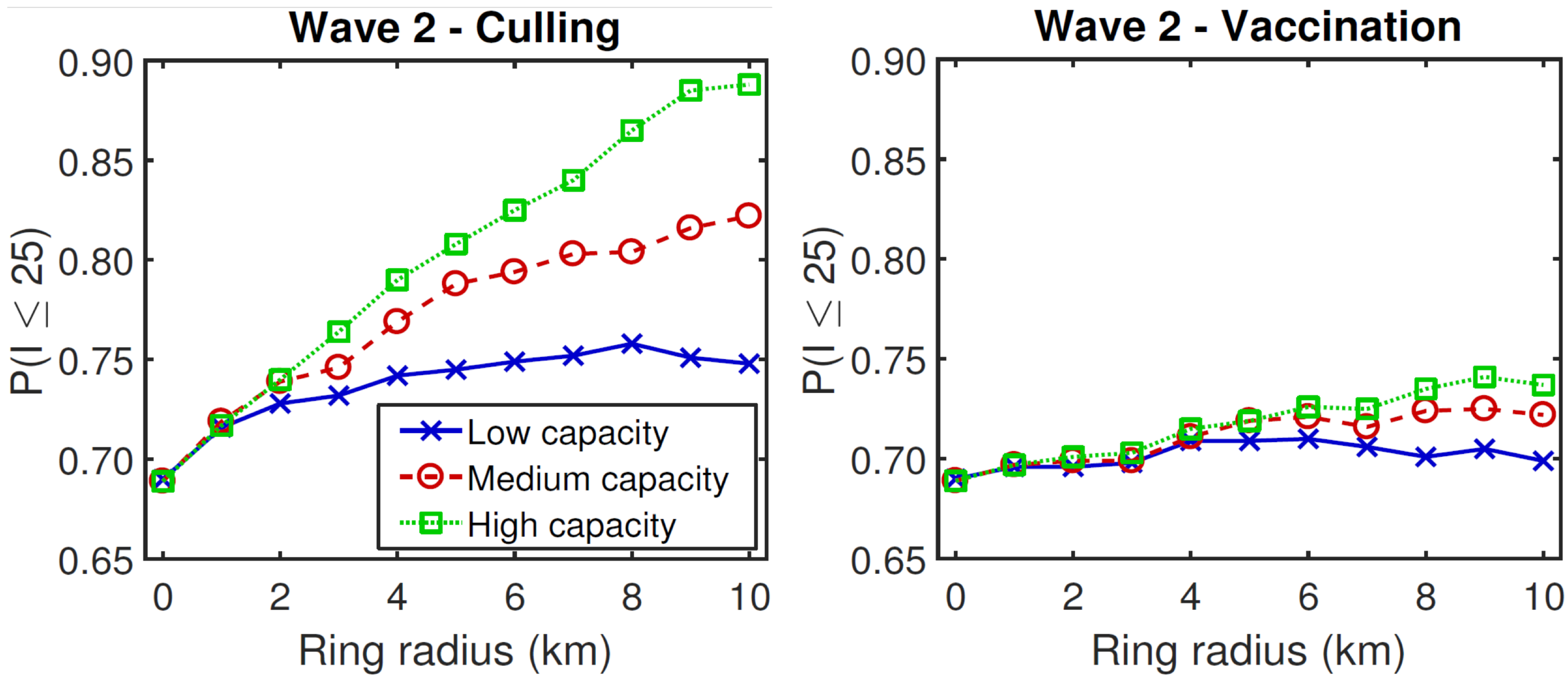
Culling/vaccination (daily limits):

	Birds	Premises
Low	20,000	20
Medium	50,000	50
High	100,000	100

Active surveillance:

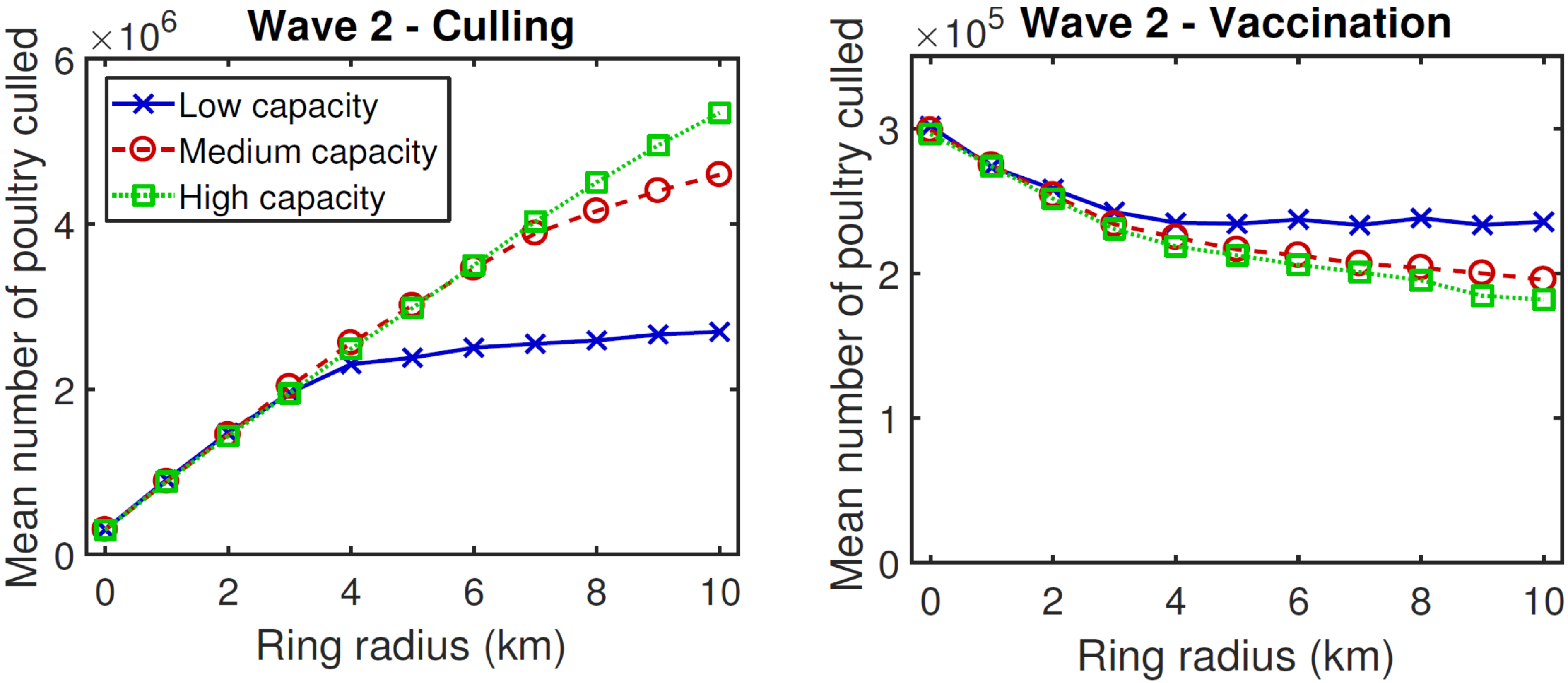
	Reactive scheme coverage (per outbreak)	Proactive scheme coverage
Low	25	5%
Medium	50	10%
High	100	25%

Figure 4A: Predicted probability of outbreak size being 25 premises or less, under different ring culling/vaccination radii.



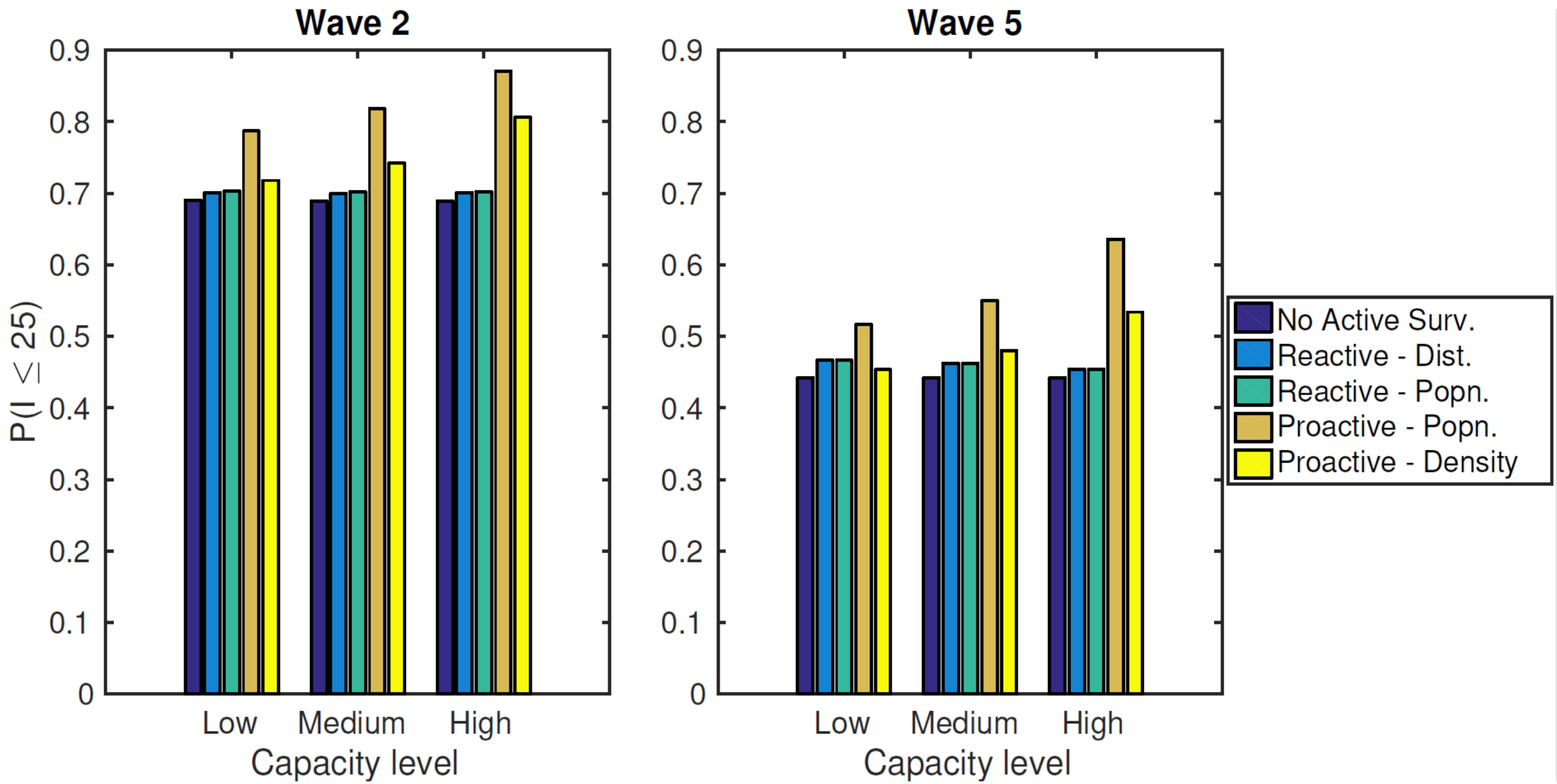
- ➢ For this control objective, culling outperforms vaccination.

Figure 4B: Mean number of poultry culled, under different ring culling/vaccination radii.



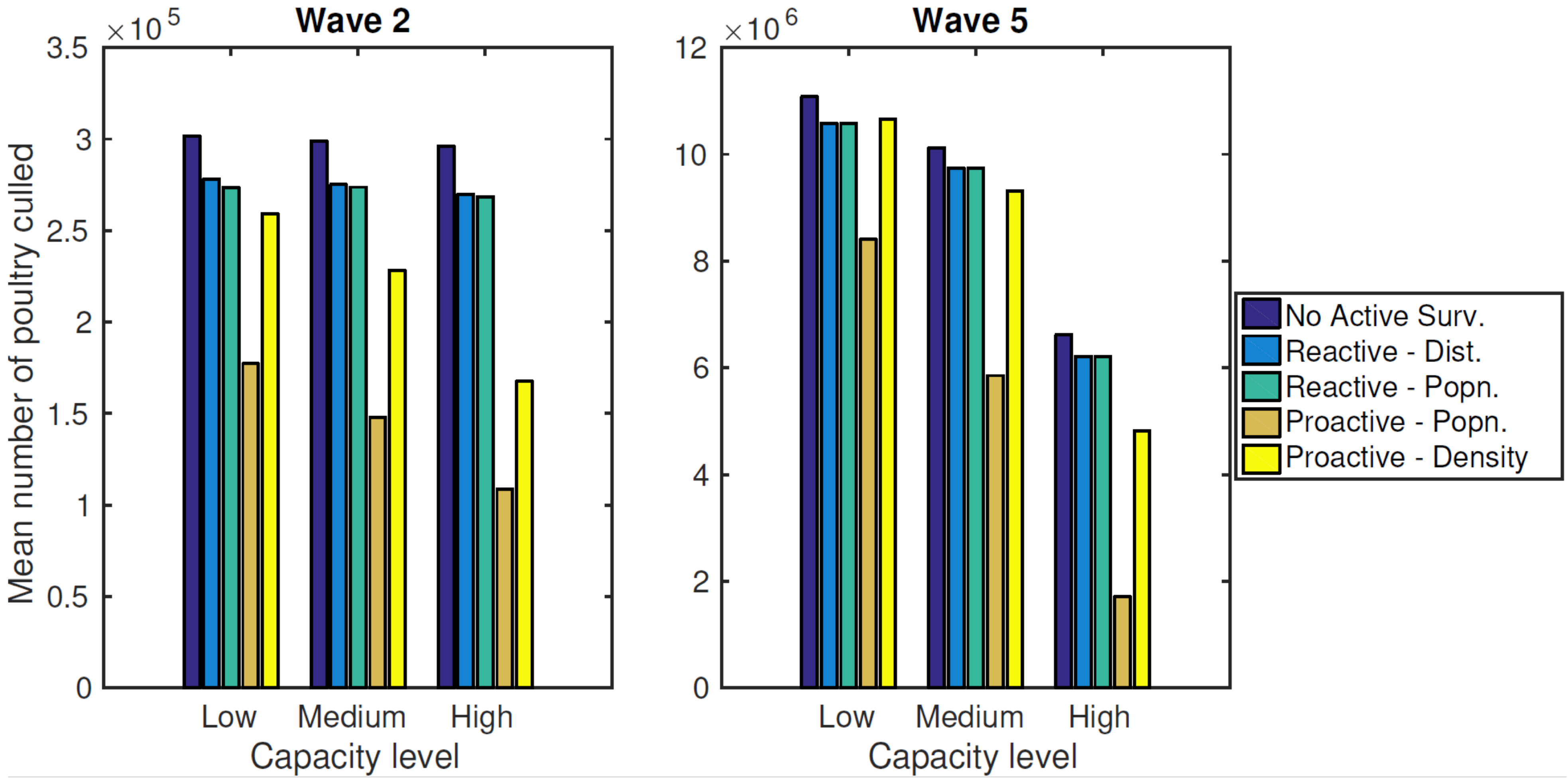
- Disparities across capacity constraints appear from 3km and above.

Figure 5A: Surveillance strategy performance – **outbreak duration** objective



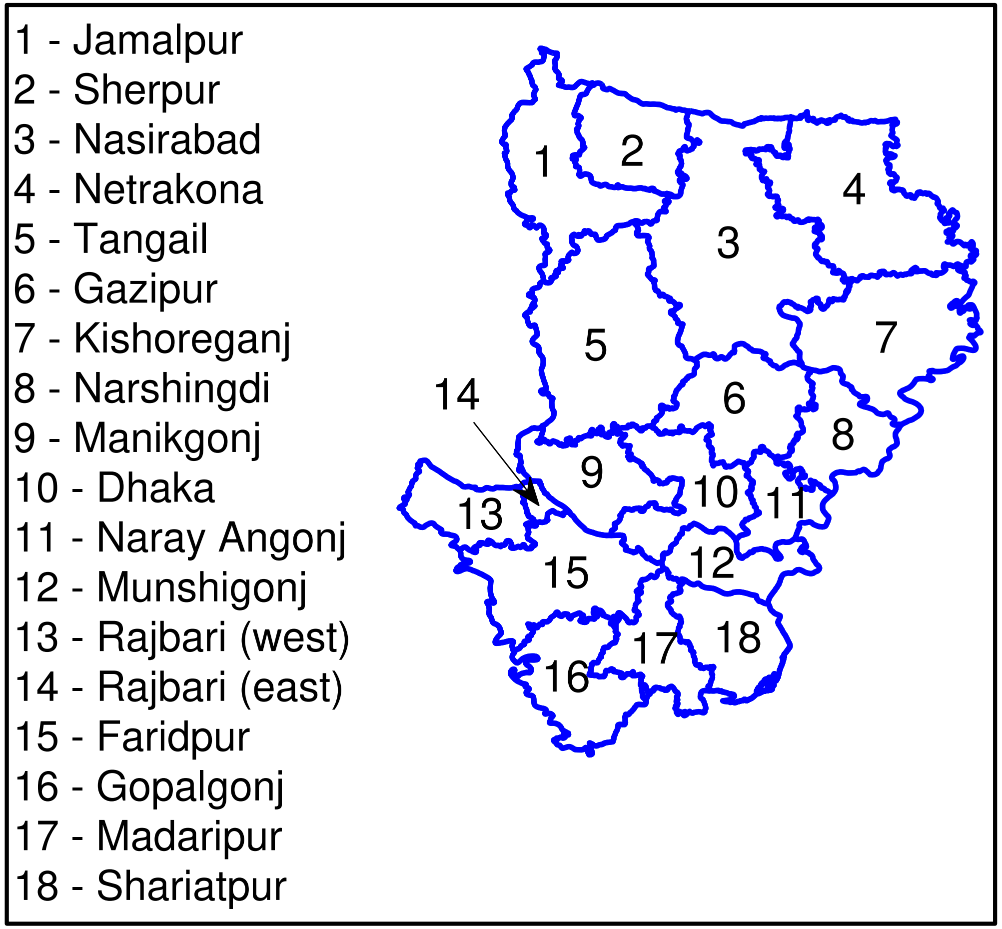
- ‘Proactive by population’ the best performing strategy.

Figure 5B: Surveillance strategy performance – **minimising poultry culled** objective



- ‘Proactive by population’ the best performing strategy.

Transmission dynamics – Absence of external factors

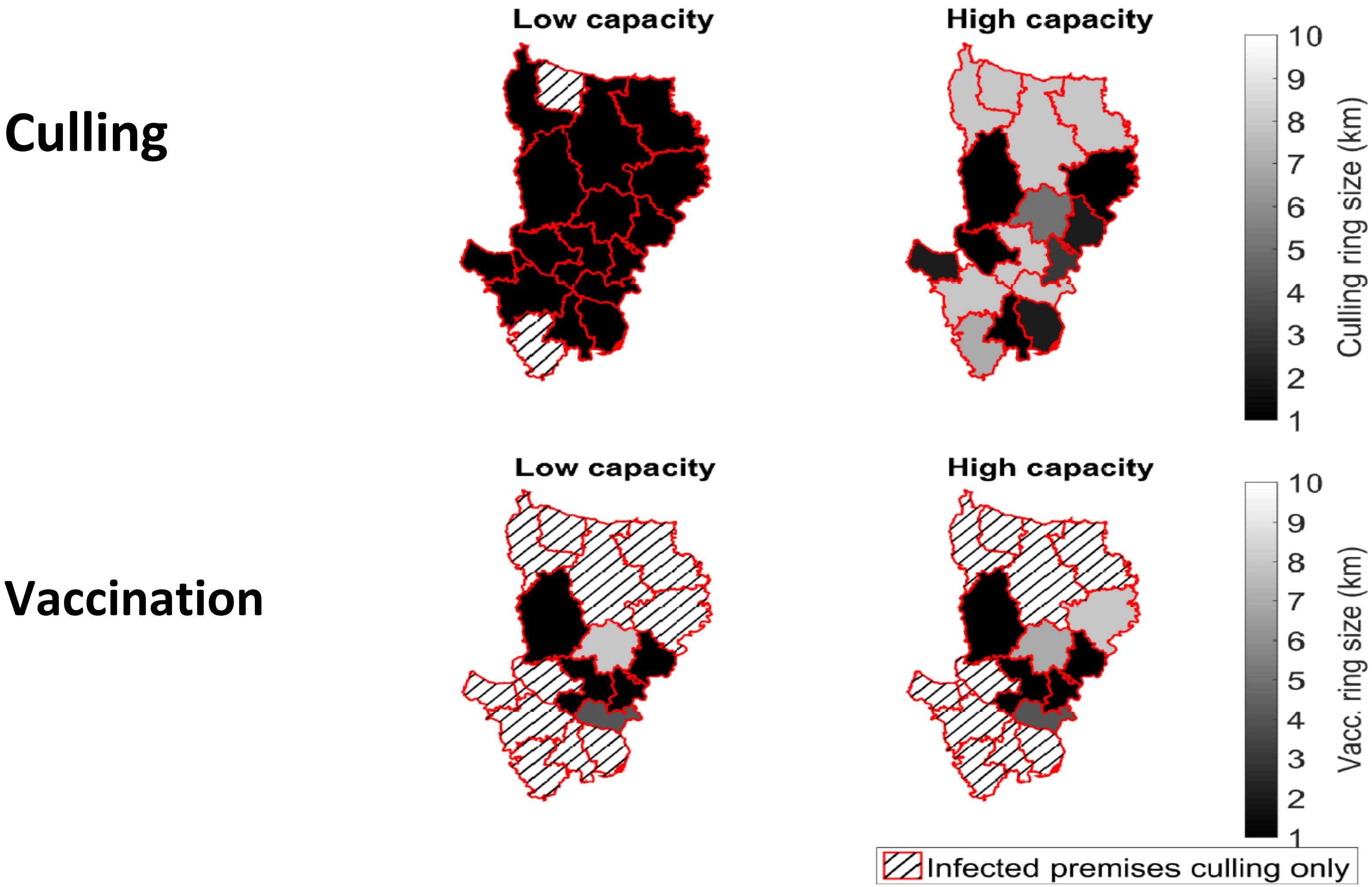


- Does the division-level strategy alter based on the district the outbreak originated from?
- Revised force of infection:

$$R_{i,t} = \left(\sum_{j \in \text{infectious on day t}} N^p_{c,i} \times t_c N^q_{c,j} \times K(d_{ij}) \right)$$

- Specific control objectives:
  - Outbreak duration
  - Probability of a widespread outbreak

Figure 6: Surveillance strategy performance – **wave 5 model, widespread outbreak** objective



- ➢ Policy of infected premises culling alone can be the most suitable.

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Zoonotic spillover interventions

Non-spatial model

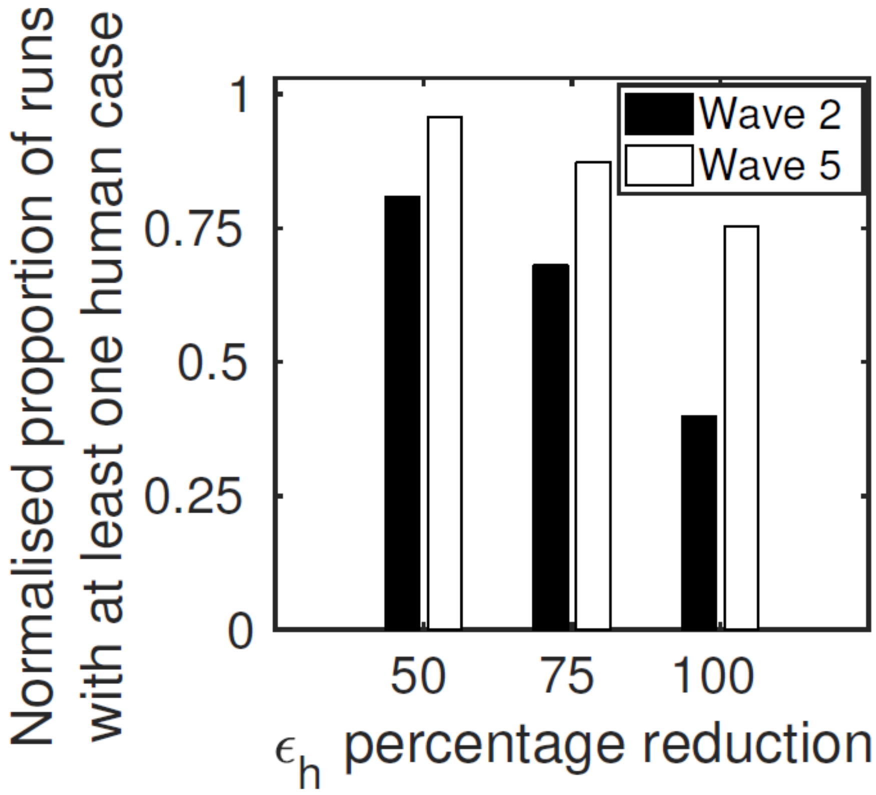
- Assume human case occurrence is a Poisson process.

Infection Rate: $\lambda(t) = \beta I_b(t) + \epsilon_h$

➢ Separate set of human targeted measures.

➢ Captured by scaling ϵ_h (50%, 75%, 100% reduction)

Figure 8: Zoonotic spillover intervention performance



- Under wave 2 type outbreak dynamics, potential for vast cuts in spillover transmission risk.

Summary of findings

Evaluation of interventions targeting poultry premises

- Reactive culling and vaccination impact **highly dependent** upon epidemiological characteristics, control objectives and capacities.
- Proactive surveillance schemes **significantly outperform** reactive surveillance procedures.

Zoonotic spillover

- Enforcement of control measures not directly applied to poultry flocks themselves can **severely diminish** the risk of spillover transmission.

Acknowledgements

- Bangladesh Department of Livestock services (DLS)
- FAO-ECTAD (Emergency Centre for Transboundary Animal Diseases)

EPSRC

Engineering and Physical Sciences Research Council

centre for complexity science

For further details:

EM Hill et al. (2018*)* The impact of surveillance and control on highly pathogenic influenza outbreaks in poultry in Dhaka division, Bangladesh. *bioRxiv.* doi: 10.1101/193177.

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