Reinforcement learning for context-dependent control of emergency outbreaks of FMD

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Acknowledgements

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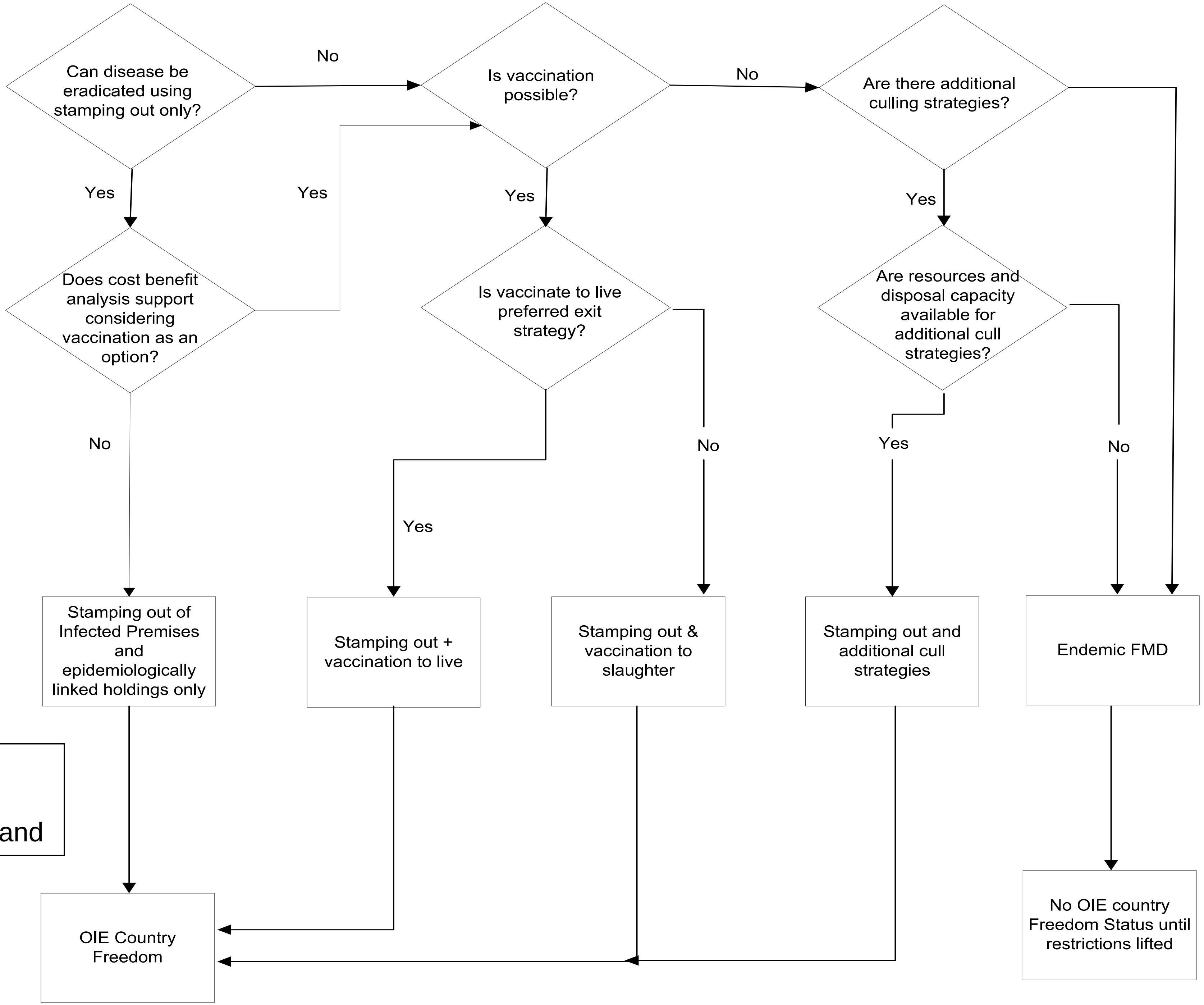
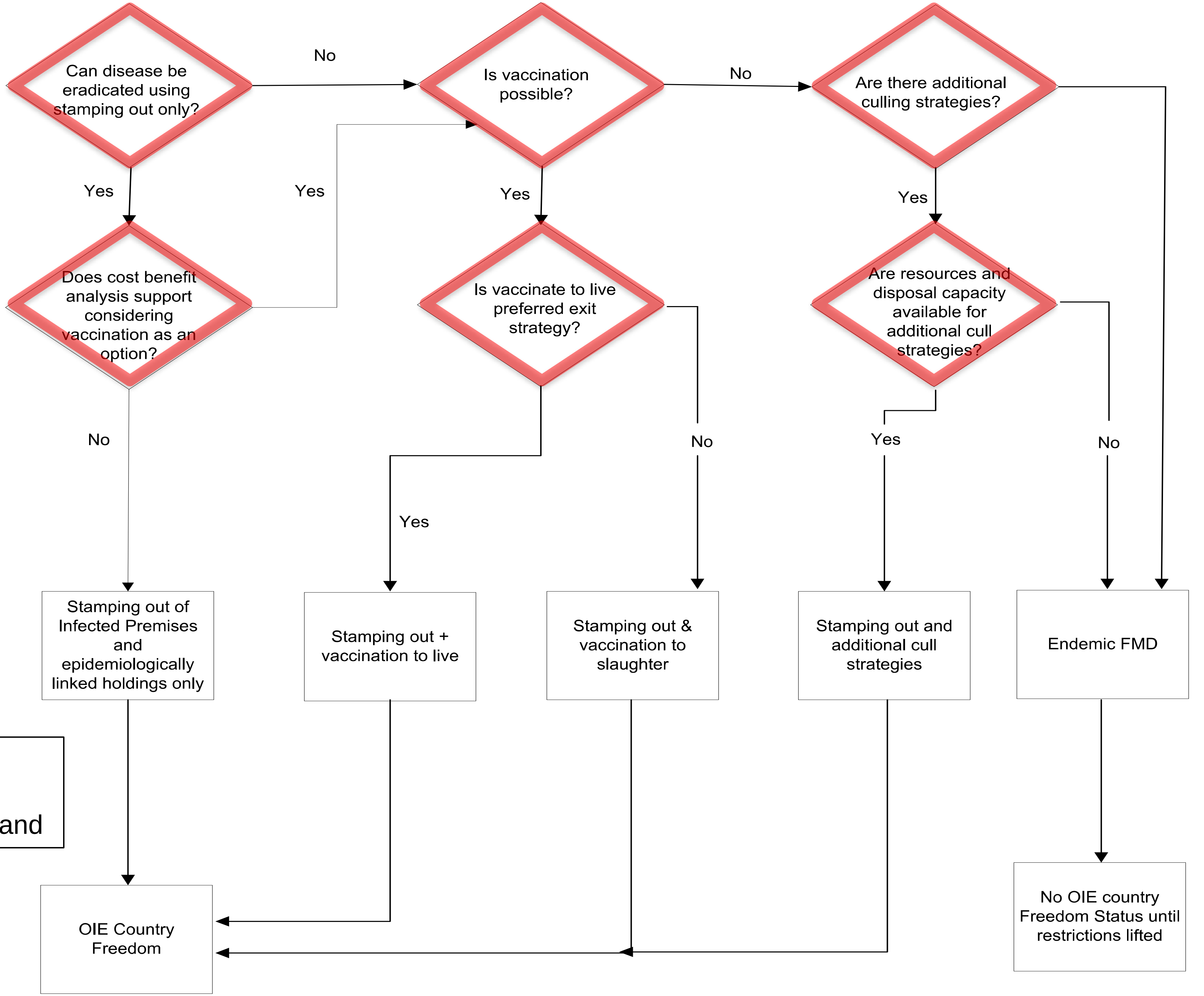
Ecology and Evolution of Infectious Disease
NSF/NIH/BBSRC 1 R01 GM105247-01

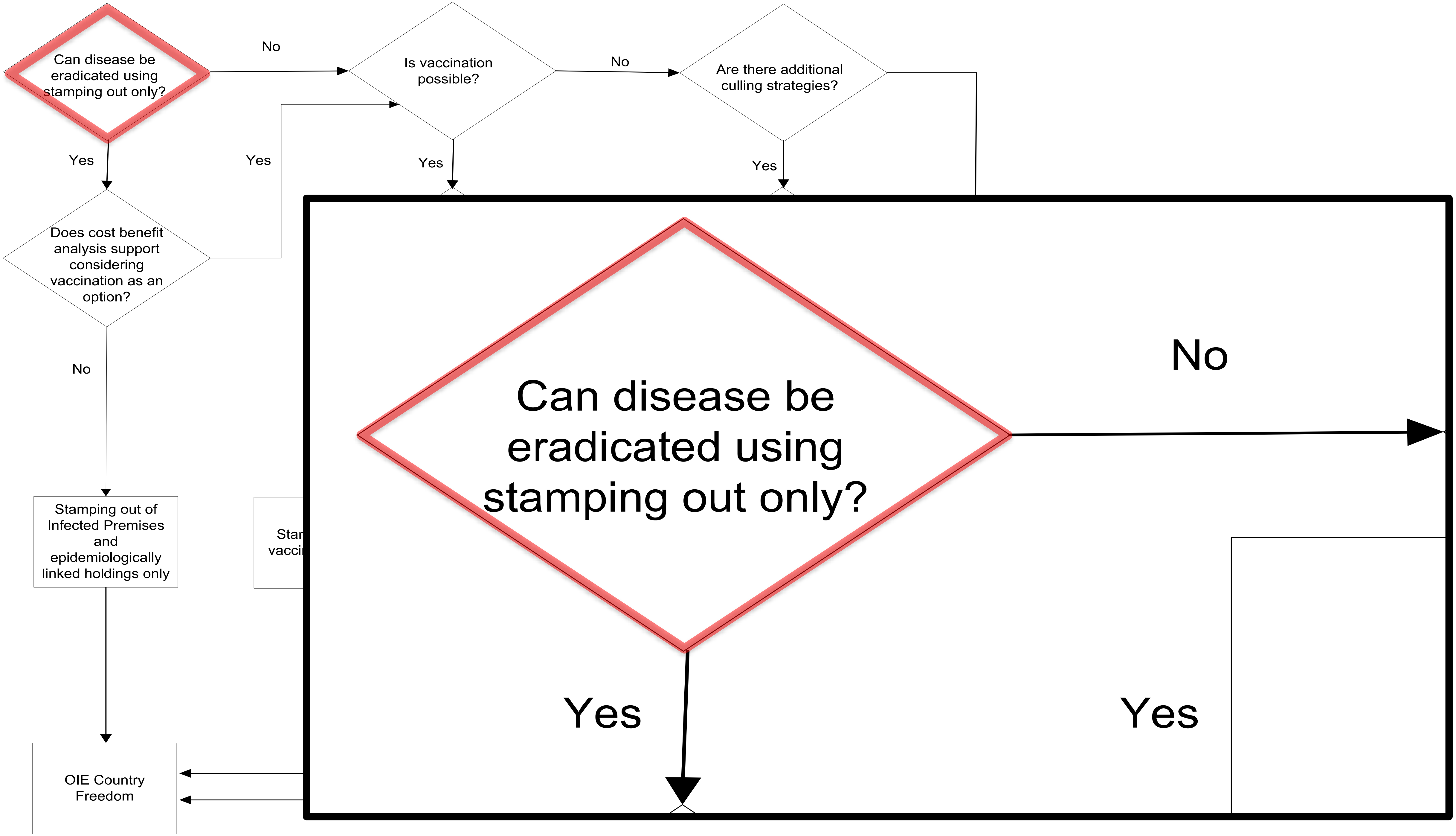


DEFRA (2017) Contingency Plan for Exotic Notifiable Diseases of Animals in England

Questions

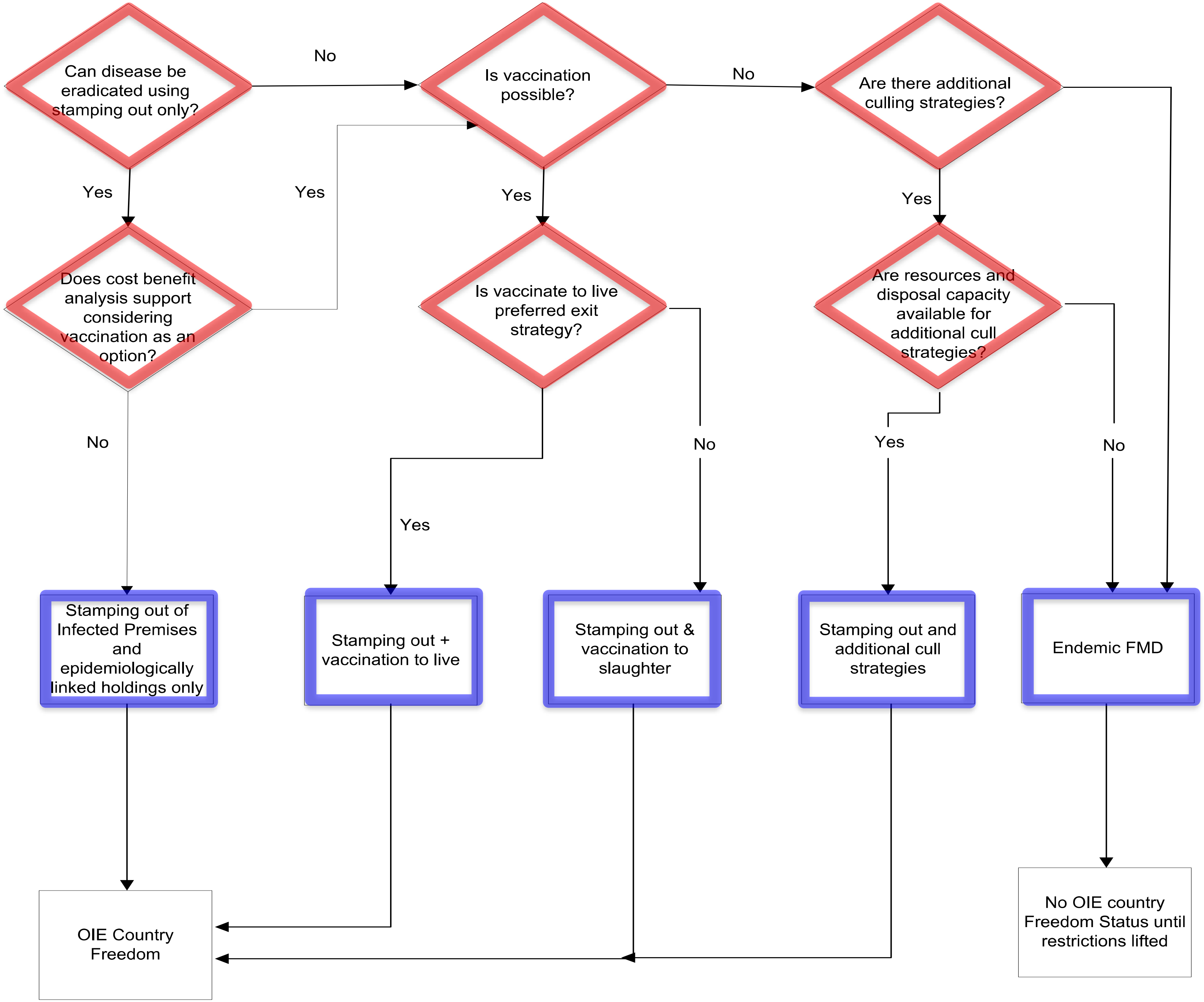


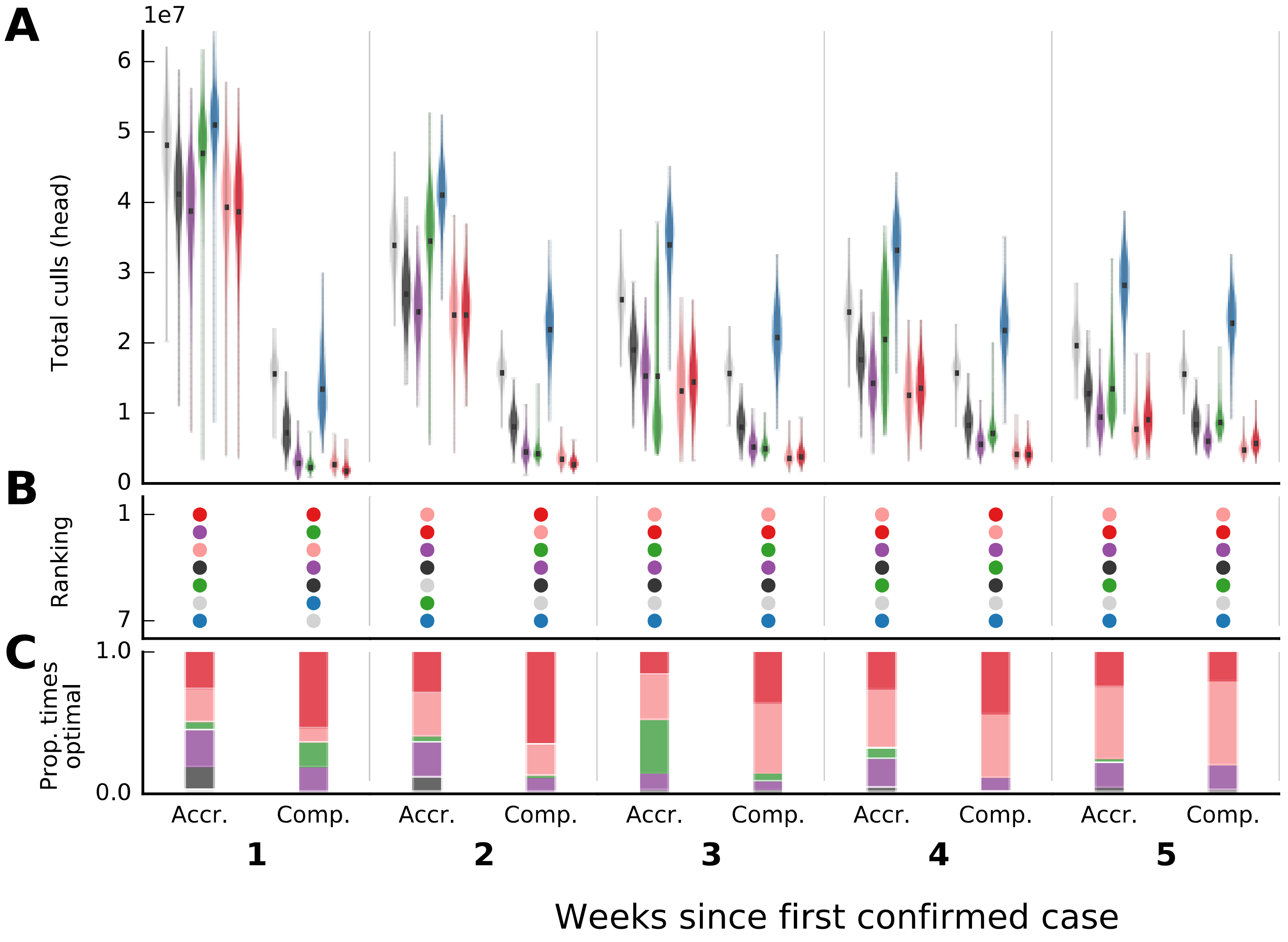
DEFRA (2017) Contingency Plan for Exotic Notifiable Diseases of Animals in England


Can disease be eradicated using stamping out only?
No
Is vaccination possible?
No
Are there additional culling strategies?
Yes
Yes
Yes
Yes
Does cost benefit analysis support considering vaccination as an option?
No
Stamping out of Infected Premises and epidemiologically linked holdings only
Star
vacci
OIE Country Freedom
Can disease be eradicated using stamping out only?
No
Yes
Yes

Questions describing the ‘state’

Recommended actions (given the state)

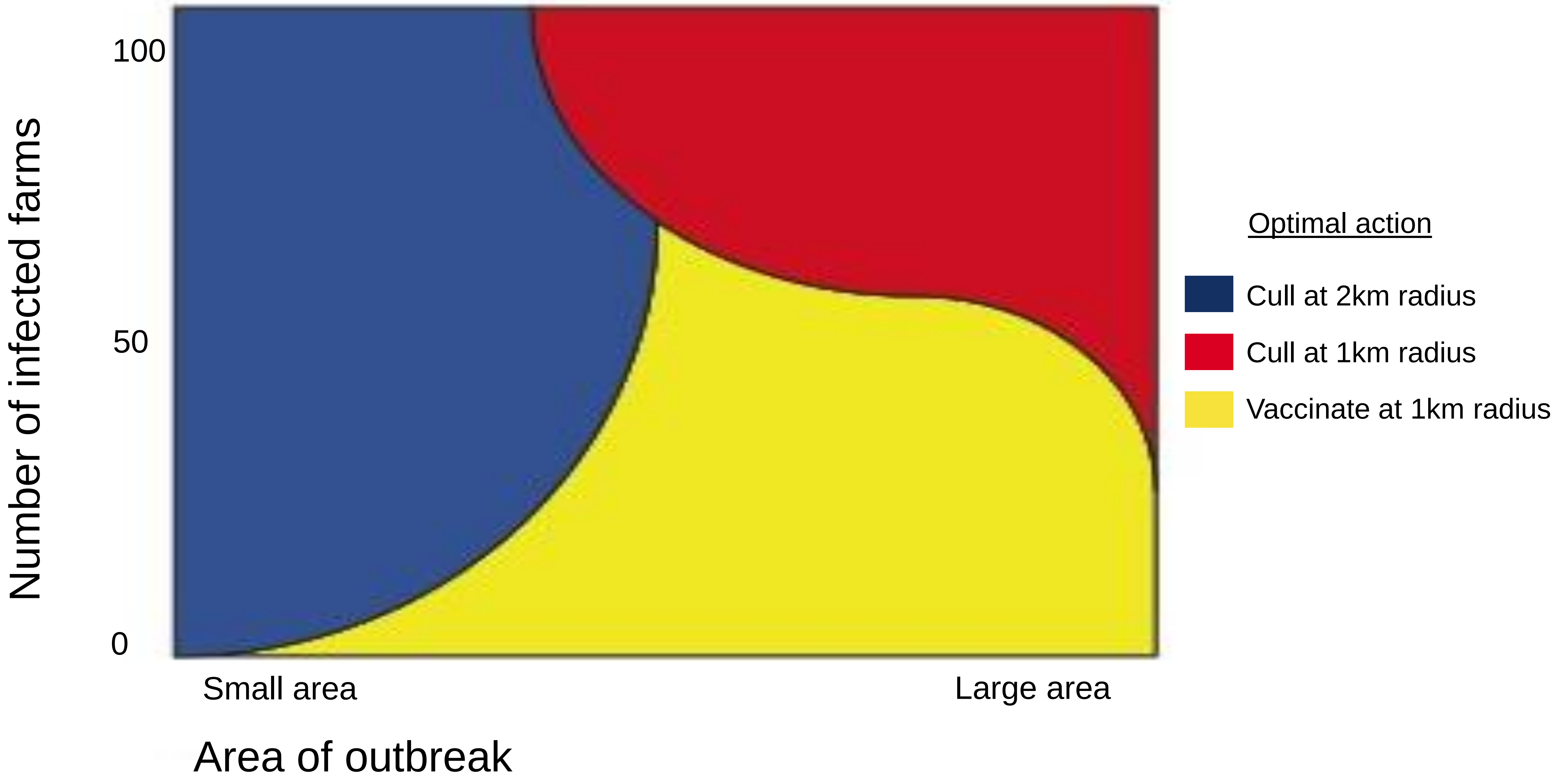




Previous work showed control choice recommendation was driven by locations of infected premises

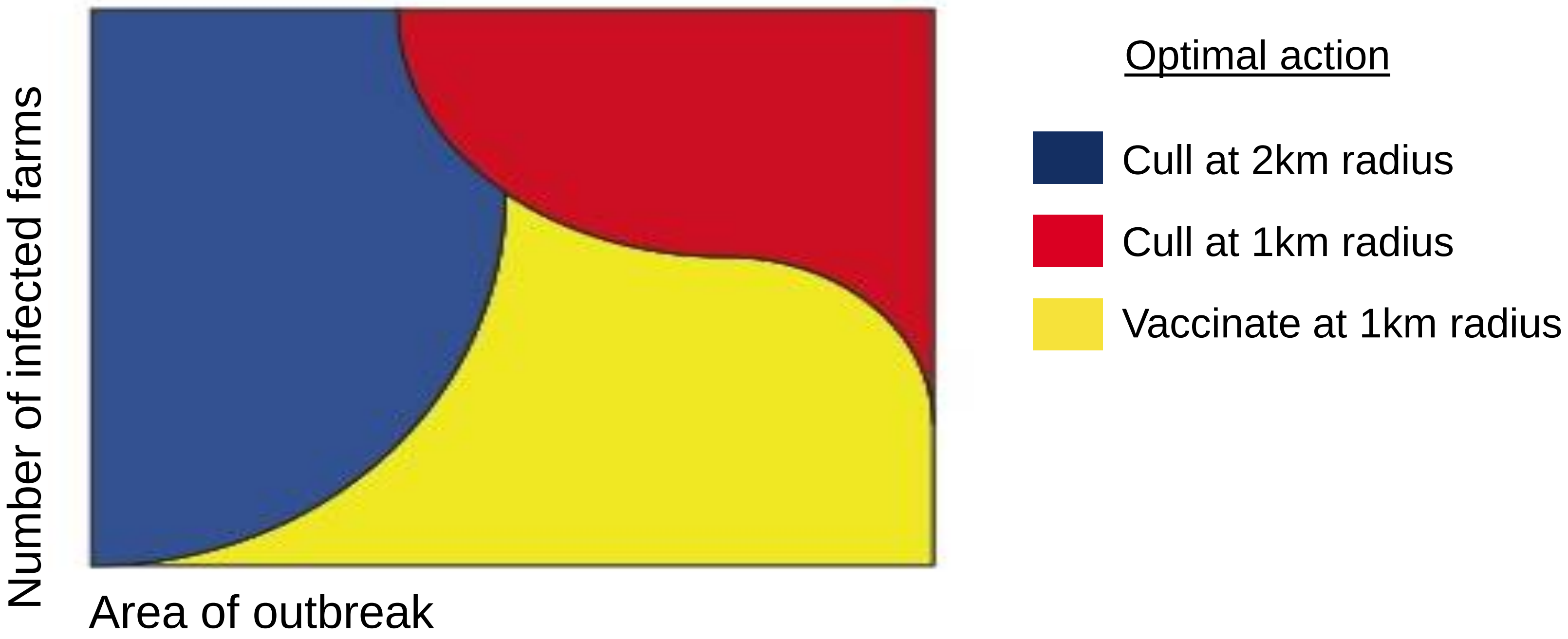
Probert et al. (2018) PLOS Comp. Biol.

How can we generate
context-dependent control policies?

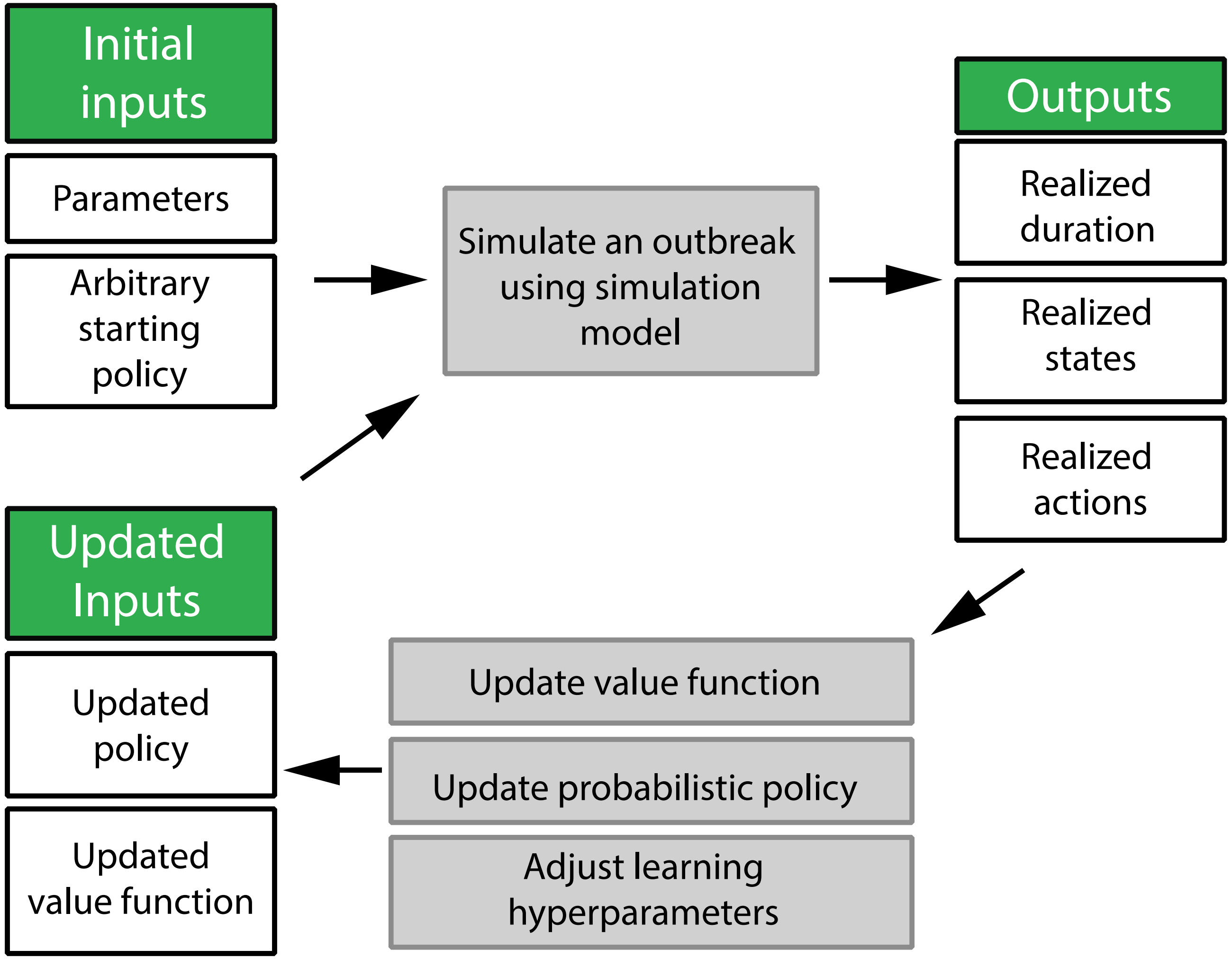

Number of infected farms
100
50
0
Small area
Large area
Area of outbreak
Optimal action
Cull at 2km radius
Cull at 1km radius
Vaccinate at 1km radius

A policy for FMD control

Policy optimises control action for the particular realisation of the outbreak (i.e. the ‘state’)

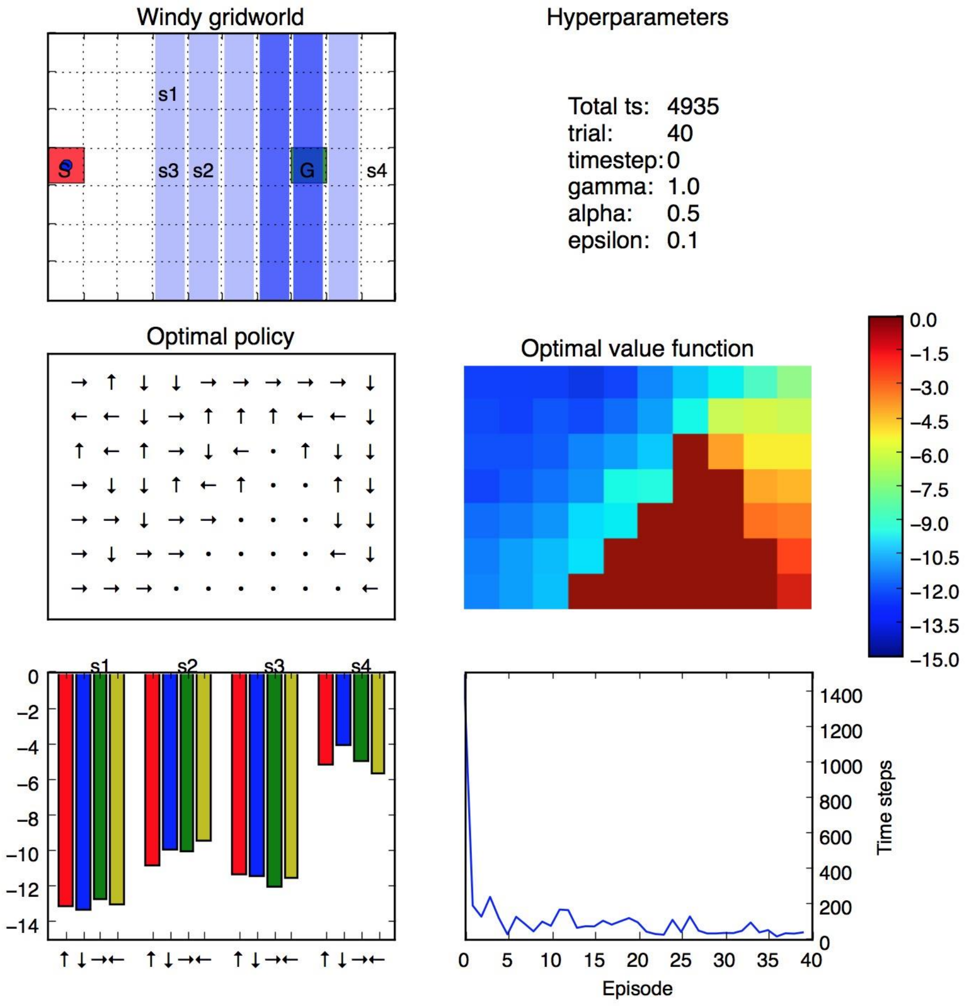


Epsilon-soft Monte Carlo control



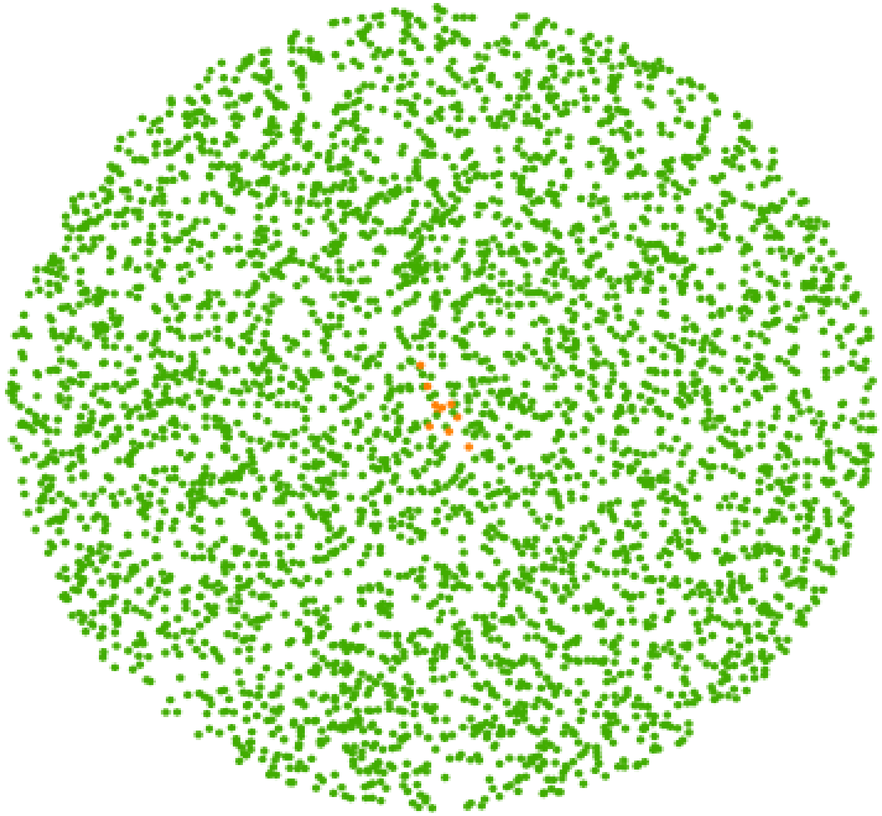
Sutton and Barto (1998) Reinforcement learning: An Introduction. MIT Press.

Reinforcement learning example: Windy gridworld

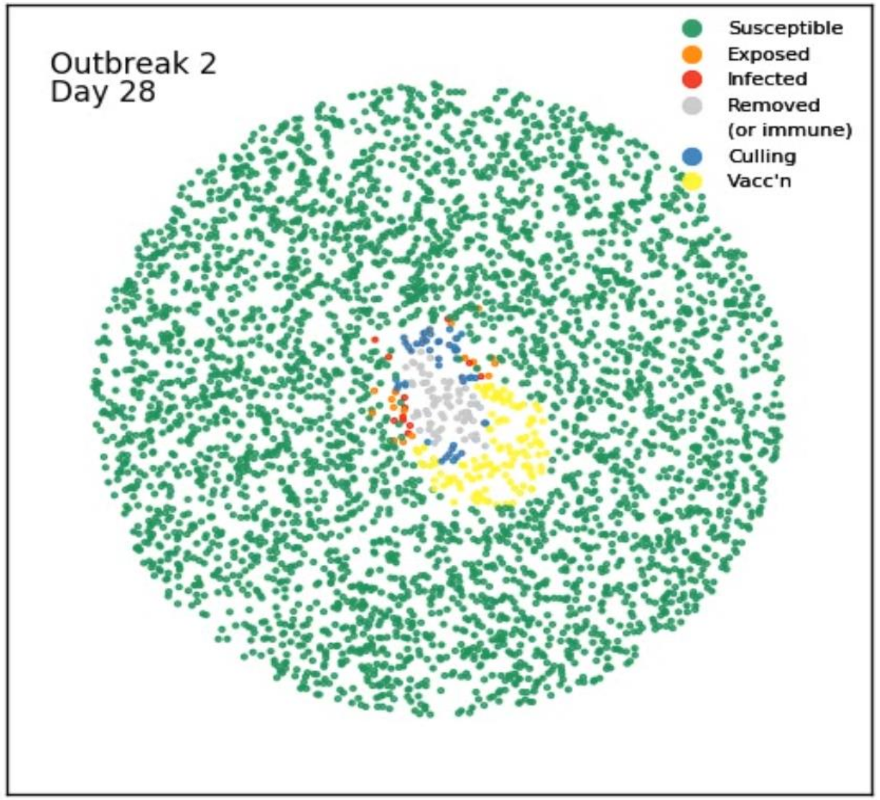


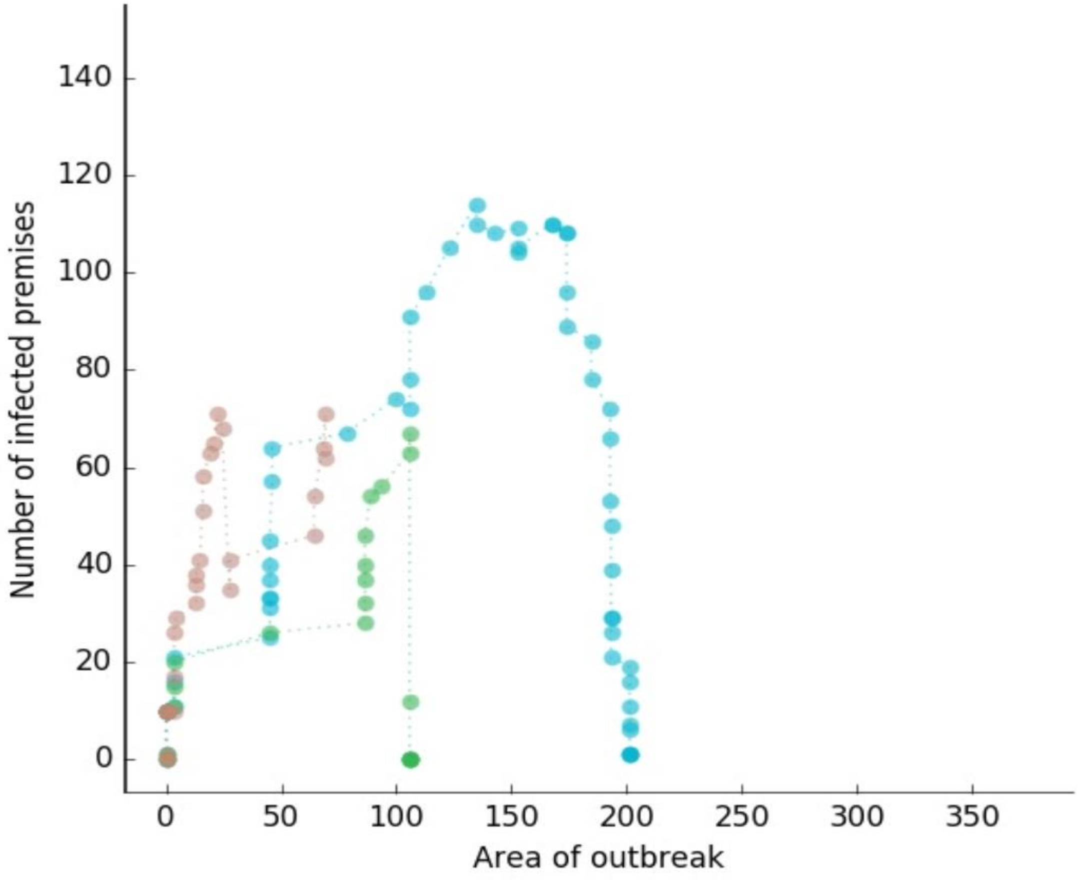
Reinforcement learning: example

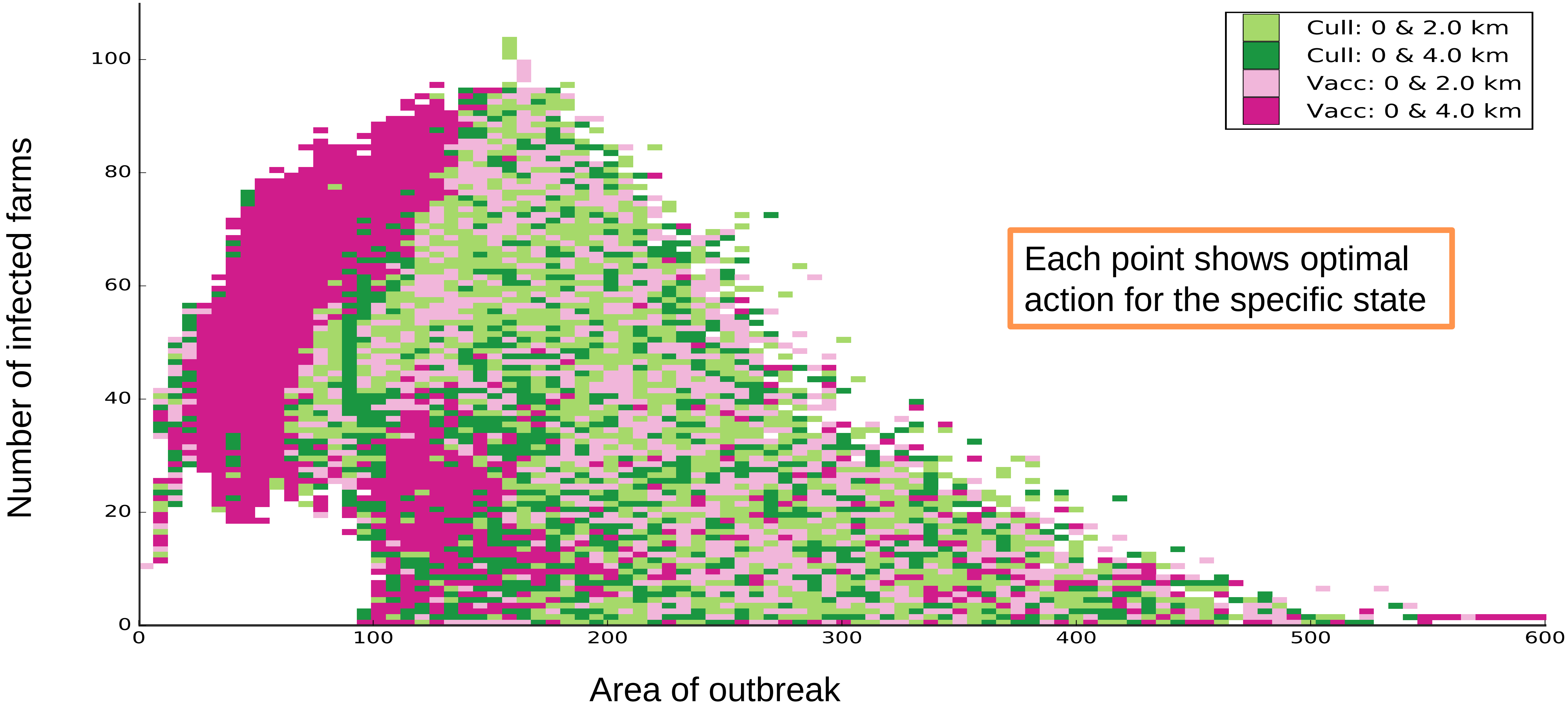
- Circular landscape of 4000 farms
- Transmission model: Tildesley et al., (2008); Keeling et al., (2001)
- States:
  - Area of outbreak
  - Number of infected premises
- Objective:
  - minimise outbreak duration
- Actions:
  - Culling at 2km or 4km rings
  - Vaccination at 2km or 4km rings
  - Change every 3 days
- Constraints:
  - Global limit on number of carcasses present
  - Delay to immunity of vaccination



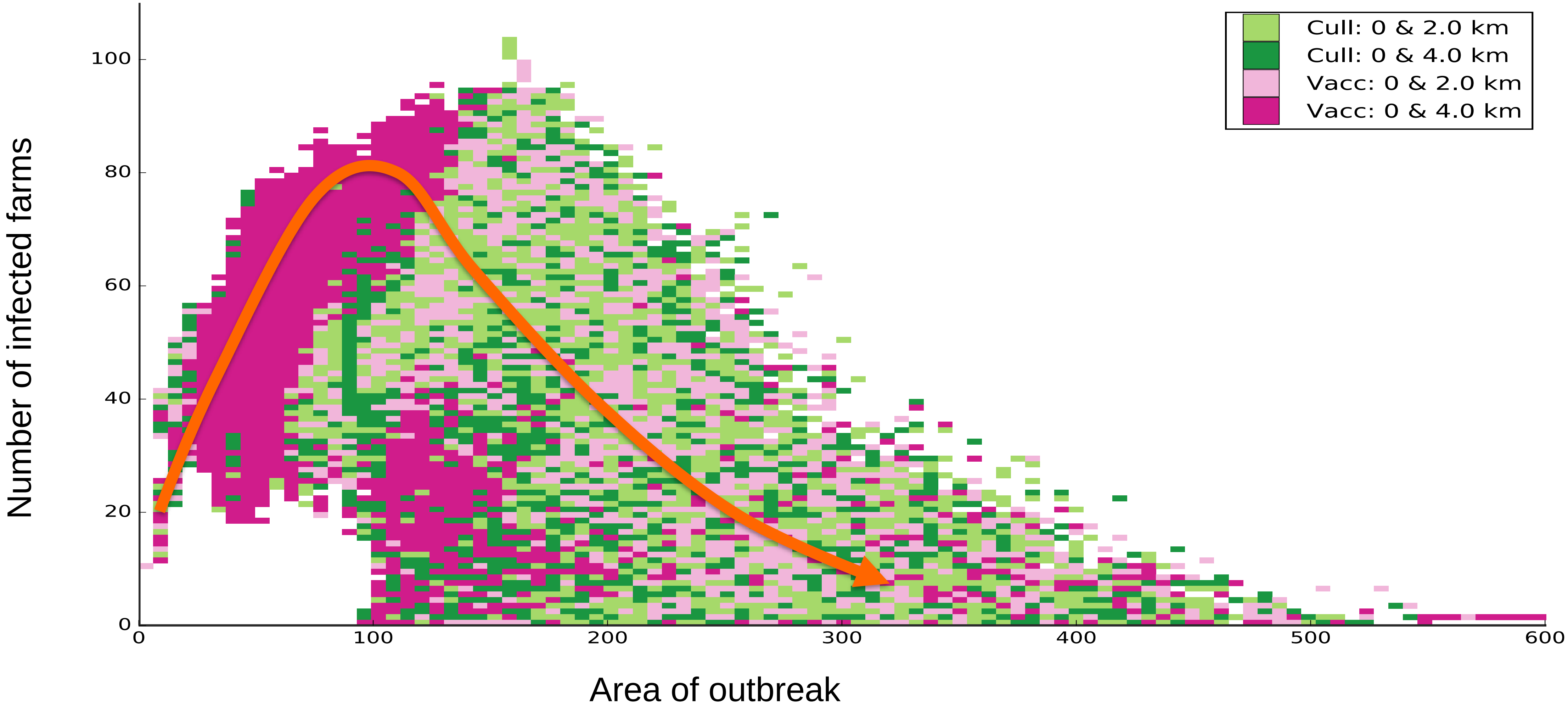
‘Policy space’ in the context of an outbreak



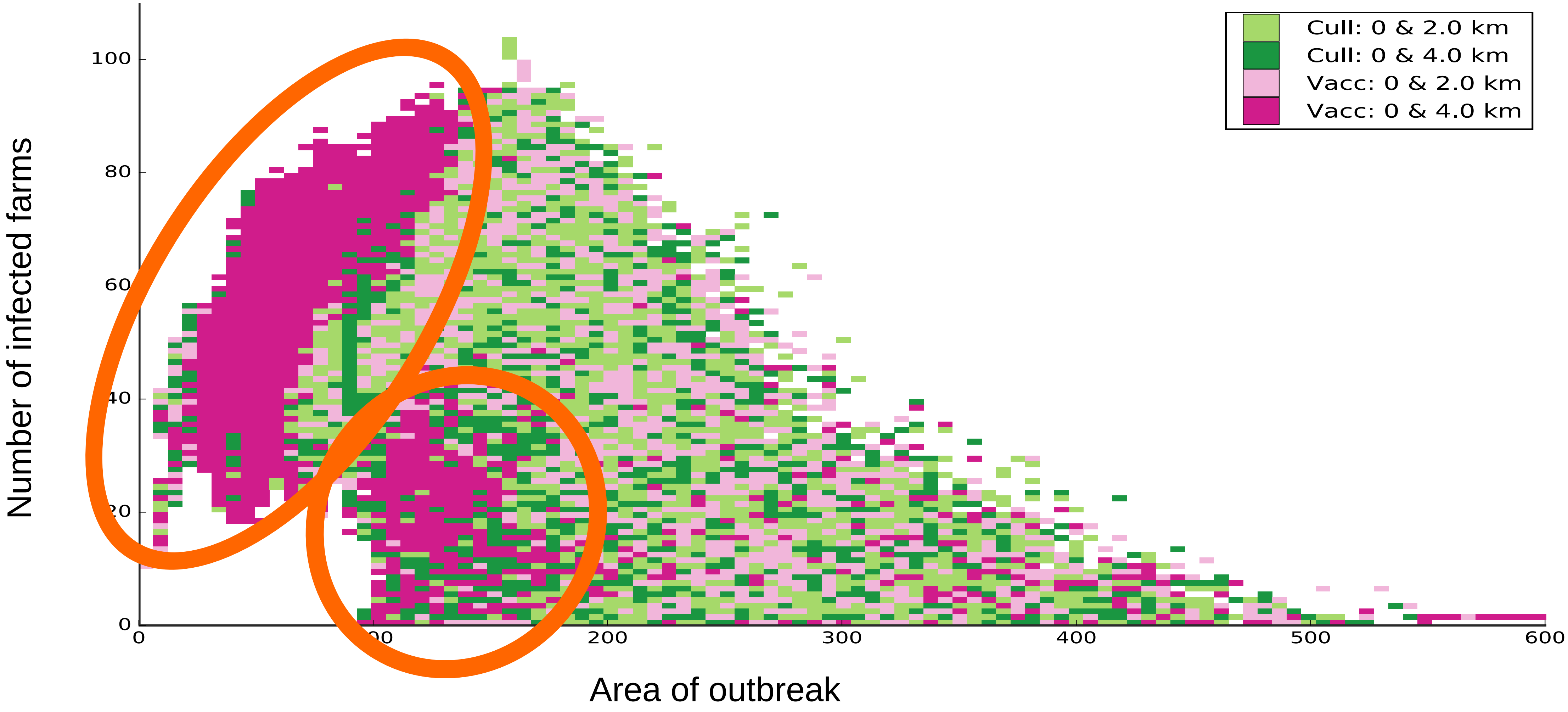




Each point shows optimal action for the specific state

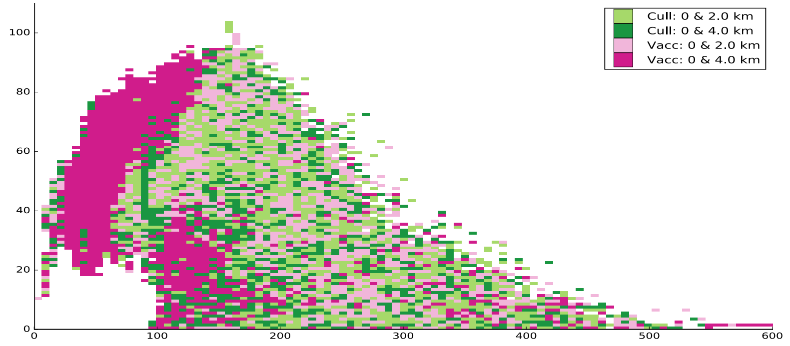

Cull: 0 & 2.0 km
Cull: 0 & 4.0 km
Vacc: 0 & 2.0 km
Vacc: 0 & 4.0 km
Number of infected farms
Area of outbreak
0
20
40
60
80
100
0
100
200
300
400
500
600

Early in the outbreak large scale vaccination is optimal but above a threshold size it is better to use small scale culling/vax

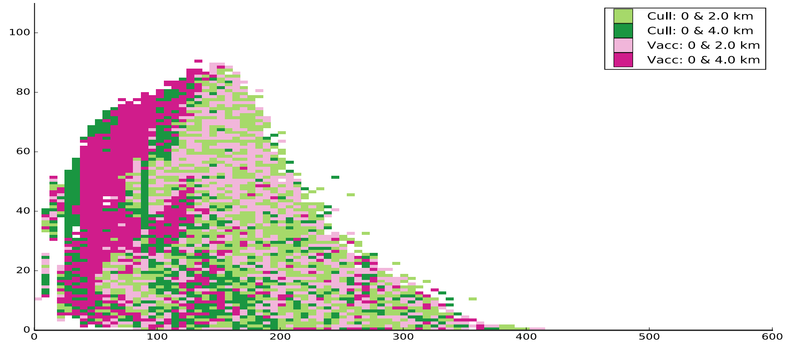


Carcass constraint

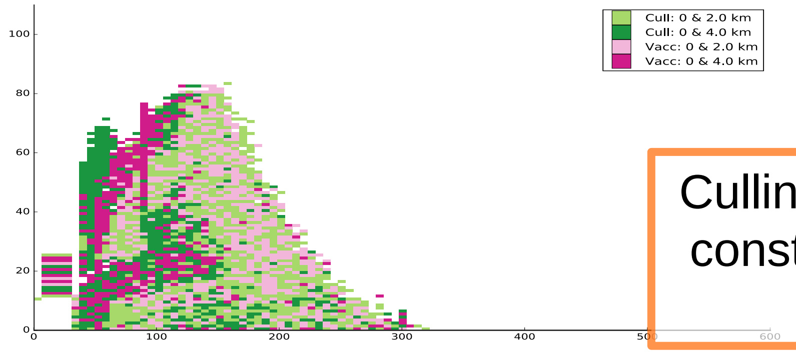
10,000



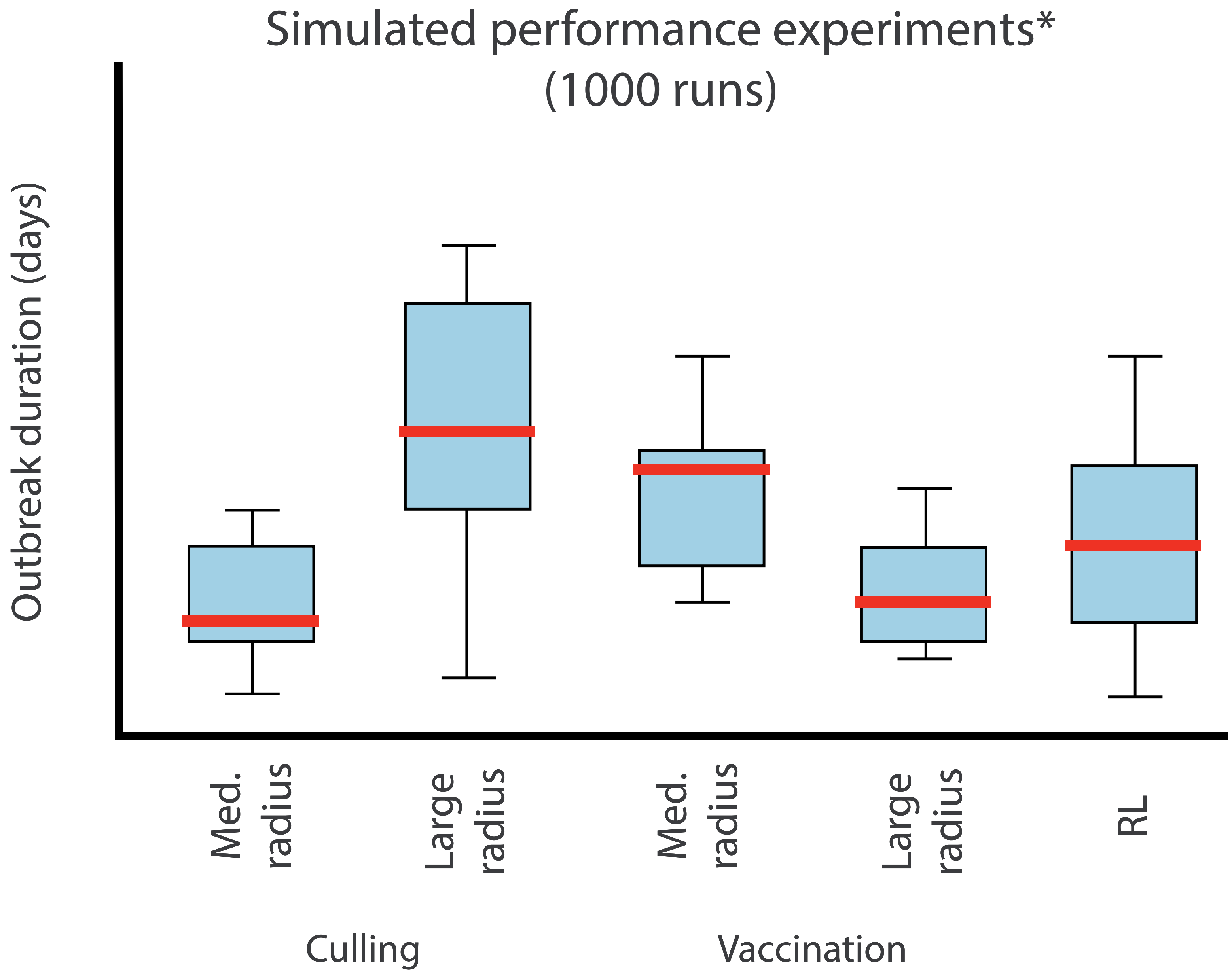
20,000



40,000



Culling becomes optimal as constraint on carcasses is increased


Simulated performance experiments*
(1000 runs)
Outbreak duration (days)
Med. radius
Large radius
Med. radius
Large radius
RL
Culling
Vaccination

Summary

RL generates state-dependent control policies that capitalise upon wealth of existing computer simulation models.

Allows search for non-intuitive control strategies.

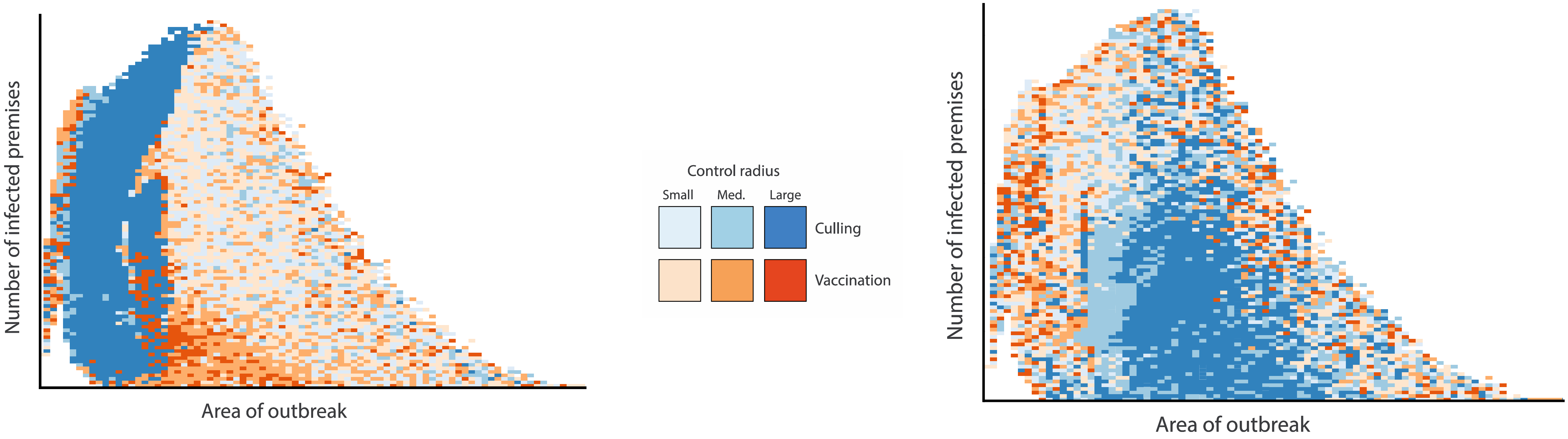
(i.e. we aren't required to think of all possible interventions *a prior*)

Highlights concordance in control policies across stakeholders.

Using a small number of states allows AI to augment human decision-making, not replace it.

Policy for minimising outbreak duration

Policy for minimising livestock culled



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Thanks

Photo: Devon show